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25 October 2001

Mr. Clay Hiles
Executive Director, Hudson River Foundation
40 West 20th Street, 9th Floor
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Dear Mr. Hiles:

Enclosed please find a white paper entitled *PCBs in the Upper Hudson River: The Science Behind the Dredging Controversy*. This paper was written by a group of scientists and engineers knowledgeable about the environmental behaviors and risks of PCBs and about sediment transport and dredging. In writing this paper, our goal was to identify and highlight those technical issues which are key to the PCB debate in the Hudson River and for which considerable scientific consensus can be reached. As a group, we critically examined the science underlying the controversy, deduced the relevant principles, and drew conclusions based on the available science. We conclude that the levels of PCBs in the Hudson are likely causing increased risks to humans and to wildlife, that a significant amount of the PCBs in the Upper Hudson River sediments are being released and transported downstream, and that suitable dredging technology exists to permanently remove considerable quantities of PCBs from the environment. We recognize that the proposed remediation will be expensive, will result in local short-term disruptions, and will reduce but not eliminate the risks posed by PCBs in the Hudson.

This white paper specifically addresses whether active remediation is necessary and whether dredging technology exists to reduce the risk of PCBs in the Hudson. Although we conclude that the answers to both questions are yes, we emphasize that designing and executing this complex dredging operation remains to be done. We see many potential management difficulties as the remediation moves forward, and serious consideration needs to be made about the management and oversight of any remediation operation. The Hudson River Foundation should continue to facilitate open discussion of the technical aspects of any remediation of the Hudson River.

On behalf of my co-authors, I thank the Hudson River Foundation for providing us the opportunity to write this paper.

With best wishes,

Joel E. Baker
Professor

PCBs in the Upper Hudson River:

The Science Behind the Dredging Controversy

A White Paper Prepared for the Hudson River Foundation by:

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25 October 2001

Introduction

From the latter 1940's until 1977, the General Electric Corporation (GE) discharged an estimated 200,000 to 1.3 million pounds[1] of polychlorinated biphenyls (PCBs) into the Hudson River from two electrical capacitor manufacturing plants at Hudson Falls and Fort Edward, NY (Figure 1). In 1977, under a settlement agreement with the New York State Department of Environmental Conservation, GE stopped direct discharges of PCBs to the river, although leakage of PCBs from the factory sites to the river continues to this day. PCBs used at the GE plants were oily liquids containing dozens of distinct PCB compounds. Most of these components are persistent in the environment, attach strongly to soils and river sediments, and readily accumulate in fish, wildlife, and humans[2]. These properties, combined with the large discharges of PCBs from the GE plants over 50+ years, have led to elevated levels of PCBs in the water, sediments, and biota of the Upper Hudson River (defined here as the stretch upstream of the Troy lock and dam). Levels of PCBs in the Hudson

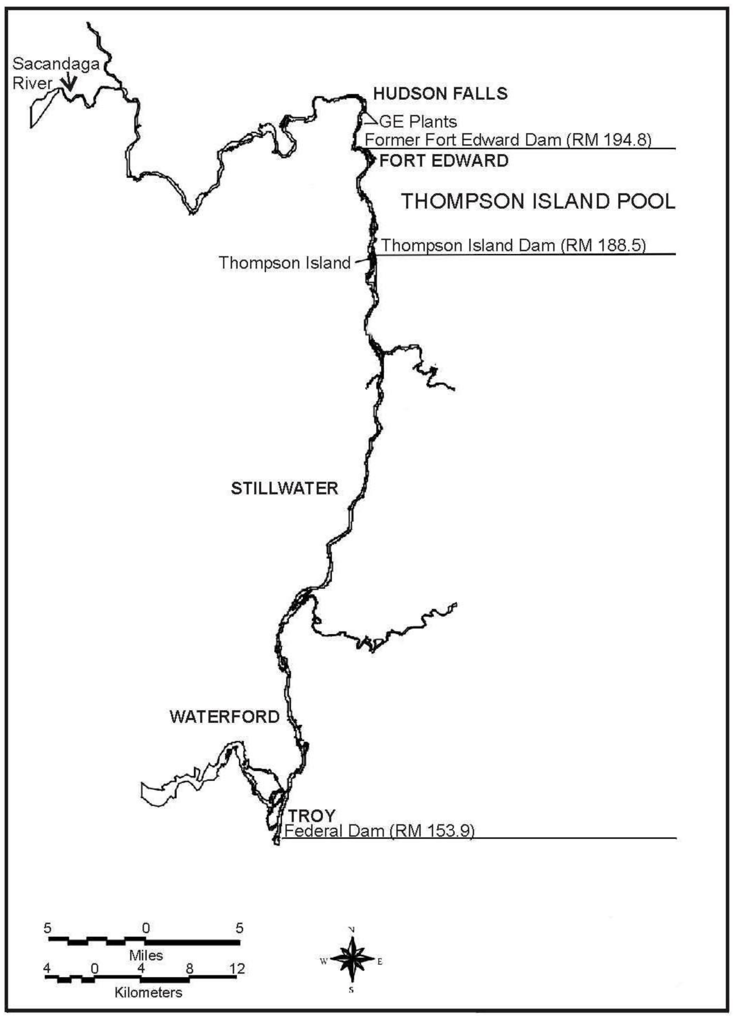

Figure 1. The Upper Hudson River

River ecosystem are among the highest in the United States.

PCB contamination in the Hudson River is a management problem for the public because it has likely increased human health risks (primarily from consumption of fish), increased ecological risks to fish and fish-eating birds and mammals, and caused losses of river use and the resulting economic impacts (catch and release only fishery; advisories on fish consumption; restrictions on navigational dredging limiting access to the Champlain canal; restrictions on and the increased costs of dredging; and commercial fishery closure). PCB levels found in the Upper Hudson between Hudson Falls and the Federal Dam at Troy exceed numerous risk-based guidelines[1], and PCB transport over the Federal Dam is a major source of contamination affecting the lower tidal river and estuary[3]. Consequently, the U.S. federal government is compelled to address the problem of PCBs in the Upper Hudson River.

Public awareness of PCBs in the Upper Hudson River dates back to the early 1970's. In 1976, the New York State Department of Environmental Conservation banned all fishing from Hudson Falls to the Federal Dam and commercial fishing for striped bass in the lower Hudson.[4] Investigations of the sources and impacts of PCB contamination were conducted, and in 1984, the U.S. Environmental Protection Agency (EPA) designated the lower 200 miles of the Hudson River a "Superfund" site[1]. It is among the largest Superfund sites in the country. Under federal law, listing a Superfund site sets in motion a series of policy and management steps to evaluate the extent of the problem, identify the parties responsible for the contamination, design and implement clean-up and restoration, and assess economic damages. In 1984, EPA selected an interim 'No Action' remedy for the contaminated sediments because the agency believed that the feasibility and effectiveness of sediment remediation technologies was too uncertain[1]. In 1995, the NYS Department of

Environmental Conservation replaced the ban on all fishing in the Upper Hudson River with a "catch-and-release" program, but the ban on commercial fishing for striped bass in the Lower Hudson River remains in effect.[4] In December 2000, EPA published its 'Superfund Proposed Plan' for the Upper Hudson River[1], in which it recommended that 2.65 million cubic yards of contaminated sediments, containing over 100,000 pounds of PCBs, be dredged from the Upper Hudson River. In August, 2001, EPA Administrator Whitman announced that EPA would continue to pursue that cleanup plan[5].

During the twenty-five years since PCB contamination in the Hudson River was first brought to the public's attention, a large number of studies have been conducted to determine the sources, movements, ultimate fates, and effects of PCBs in the system. Studies of PCB contamination have generally resulted in high quality data, with excellent measurements of PCB concentrations in Hudson River water, sediments, and fish[6]. These data, along with complementary analyses and modeling studies, have provided us with a detailed description of PCB distributions in the Hudson River and a good understanding of many key aspects of PCB fate and transport under present conditions. Although these studies have been extensive, one could still argue that our understanding of the science behind the PCB problem is not complete and that further studies are necessary to add to our knowledge and to help reduce the uncertainty surrounding the issue. However, after two decades of study, there is likely to be a point of diminishing returns and there are costs in further delaying the decision. In the case of the Hudson River, as with any policy debate centering on a technically-complex issue, decisions must be made based upon the preponderance of the data, knowing full well that our ability to predict the consequences of our actions is not perfect.

The fact that our scientific understanding of PCBs in the Hudson River is not perfect has led to a vigorous debate as to the nature of the PCB problem and to the most effective course of remediation. Such a debate, which is critical to resolving complex technical issues, has allowed all sides of the PCB problem to be explored in detail and has played a critical role in advancing the state of the science. Controversy, however, still surrounds the interpretation of technical information on PCB fate and effects, and on the effectiveness of dredging technologies. Nevertheless, we believe that PCBs in the Upper Hudson River have been extensively studied and debated, and informed decisions can be made now.

This report has been written by a panel of independent experts convened by the Hudson River Foundation[7]. Our charge was to critically examine the science underlying the controversy, deduce the relevant principles, and draw conclusions based on the available science. Volumes have been written about PCBs in the Hudson River, ranging from exhaustive scientific and technical reports to numerous articles in the popular press. While we have reviewed much of this information, our objective here is not to comprehensively summarize all of this material. Rather, we wish to convey those aspects of the problem for which we believe the science and engineering are clear. We take a "weight-of-evidence" approach to reach our findings based on our considerable collective expertise and experience. We believe these findings are supported by the available scientific information and are consistent with underlying scientific principles.

The role of science in public policy is not to make decisions *per se*, but to provide clear interpretations of existing information relevant to key issues, and to project possible consequences of societal actions. After reviewing the science of the issue, we conclude that the decision whether and how to clean up the PCBs in the Upper Hudson River hinges on four key questions:

1. Are the current levels of PCBs in the Upper Hudson River causing harm to the residents and environment of the Upper and Lower Hudson River?

2. Are the PCBs in the Upper Hudson River sediments an important continuing source of contamination to the Lower Hudson under average flow conditions?

3. What are the chances that a large quantity of the PCBs currently buried in the sediments of the Upper Hudson River will be released sometime in the future under extreme weather conditions?

4. Can active remediation be implemented in such a way that it provides a net long-term benefit to the Hudson River?

Each of these key questions is addressed below.

Key Question 1. Are the current levels of PCBs in the Upper Hudson River causing harm to the residents and environment of the Upper and Lower Hudson River?

Findings ***PCB levels in Hudson River fish far exceed those believed[8] to impact the health of people who consume fish.***

Concentrations of PCBs in fish and wildlife exceed levels believed[8] to cause harm.

Effects of PCBs on People. The effects of PCBs on individual humans and on human populations have been studied extensively over the past 30 years[9]. As a result of this research, PCBs have been labeled "probable human carcinogens" by the EPA, and are also suspected of inducing developmental and learning disorders, impairing human immune systems, and causing low birth weights[8]. Production of these chemicals has been banned internationally under terms of the United Nations' recent treaty on Persistent Organic Pollutants[10].

It is very difficult to prove that exposure to an environmental contaminant harms people, as evidenced by debates over tobacco smoke and asbestos. Risks usually have to be judged in terms of probabilities. The science of risk assessment has matured considerably since the National Academy of Sciences endorsed it in 1983[11]. Risk assessment has been widely adopted within the public health profession. The risk to people exposed to PCBs in the fish they eat depends upon the amount of fish they consume, the PCB concentrations in those fish, and their vulnerability to PCB-induced diseases. Only the first two of these factors can be controlled.

To determine the "safe" level of PCB exposure for a human population, environmental epidemiologists first decide what level of risk is "acceptable." The U.S. Food and Drug Administration has set the acceptable PCB level in fish sold for human consumption in interstate commerce at 2 parts per million (ppm, or milligram PCB per kilogram of edible fish tissue on a wet weight basis). This guidance, now 17 years old, was based on the average amount of fish consumed by the American public and the known PCB effects on humans at the time. Since the FDA guidance level was set, the average U.S. diet has changed to include more fish[12]. Also, our understanding of the subtle impacts of PCBs on humans, including non-cancer effects such as developmental impairment has greatly improved[9]. More recent human health risk assessments of PCBs suggest that the FDA guidance level does not protect recreational fishers, certain ethnic groups, and coastal dwellers who consume more fish than the average U.S. resident. Non-cancer threats of PCBs, especially to children and women of child-bearing age, have led some coastal states to set more stringent PCB guidelines[13]. Although the EPA provides some advice on how the states should evaluate PCB risks and set guidelines[14], each individual state currently sets its own PCB

Table 1. The Great Lakes Protocol Risk-Based PCB Advisory	
PCB Concentration in Edible Fish Tissue	Advisory
Less than 0.05 ppm	Unlimited consumption, no advisory
0.06 - 0.2 ppm	Restrict intake to one fish serving per week
0.21 - 1.0 ppm	Restrict intake to one fish serving per month
1.1 - 1.9 ppm	Restrict intake to one fish serving every 2 months
Greater than 2 ppm	Do not eat

advisory level. Many coastal states are following the Great Lakes Protocol, a risk-based approach for setting PCB advisory levels developed by a consortium of eight Great Lakes states (Table 1)[15]. While the public health advisories produced by individual states vary somewhat, in general they are very close to the Great Lakes Protocol.

In the Upper Hudson River, mean PCB levels in edible fillets of fish commonly caught in recreational fisheries range from 2 to 41 ppm (Table 2)[16]. These levels exceed by more then ten-fold the most recent risk-based levels developed to protect human health by coastal and Great Lakes states.

Table 2. Comparing PCB levels in Upper Hudson River Fish to those from Other Coastal Waters

	Mean PCB Concentration, ppm
Hudson River[16]	
Thompson Island Pool	7 - 29
Stillwater Reach	1.6 - 41
Waterford Reach	3 - 19
Below Federal Dam	1.1 - 11
Great Lakes[17]	0.4 - 1.9
Delaware Bay[18]	0.4 - 0.7
Chesapeake Bay[19]	0.05 - 1.0

Even below the Federal Dam at Troy, PCB levels in fish are up to five times the Great Lakes criterion for no consumption. The closure of the striped bass fishery in the Lower Hudson River due to PCB contamination has resulted in a significant economic impact. Since the consumption advisory program in New York State is linked to the licensing program for recreational fishing, advisories are only provided in non-tidal waters above the Federal Dam where licenses are required. Some local residents have probably consumed enough Hudson River fish to affect their health. Possible effects, however, have not yet been quantified in any comprehensive epidemiological studies.

Effects on Fish and Wildlife. PCBs are persistent bioaccumulating compounds that cause a wide range of biological dysfunction in exposed biota. A substantial body of literature describes the results of laboratory and field investigations on the consequences of PCB exposure to a variety of animals (invertebrates, fish, reptiles, birds and mammals).[21] Some of the more common effects seen

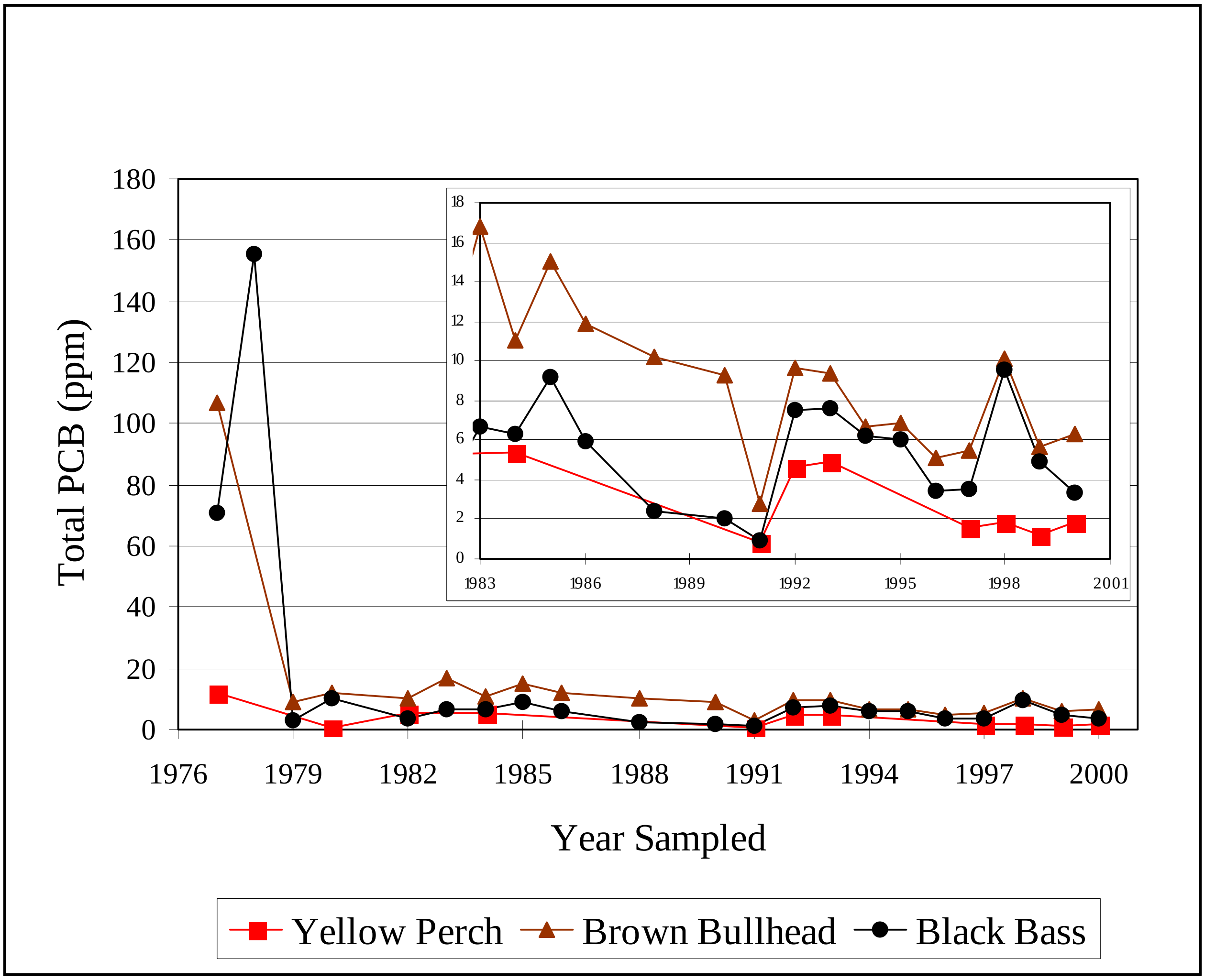

Figure 2. PCB levels in fish (wet weight basis) from the Upper Hudson long-term trends site (Stillwater/Coveville). Recent year-to-year variation is most clearly seen in the inset. [Figure supplied by Ron Sloan of the New York State Department of Environmental Conservation (NYSDEC), based on data from NYSDEC (2001)[20].]

after animals have been exposed to PCBs include reproductive dysfunction (including feminization of males), impaired development, reduced growth, immunotoxicity, induction of histological changes, and alterations in biochemical processes, including induction of enzyme synthesis as well as inhibition of enzyme activities.

A substantial issue to be considered in the Hudson River decision-making process is whether current exposures of animals to PCBs pose ecological risks. The most recent data show that many species sampled in and adjacent to the Upper Hudson River continue to have substantial body burdens of PCBs.[22] The most comprehensive Hudson River PCB data set, compiled by the New York State Department of Environmental Conservation[23], is for fish, with the majority of the analyses conducted on fish fillets. Concentrations in fillets are relevant to human fish consumption, but they may underestimate those in whole fish bodies, which tend to be consumed almost entirely by fish and wildlife predators. For several species in the Upper Hudson, average fillet PCB concentrations range from 1.6 ppm to 41 ppm PCBs (Table 2) [16, 23]. For the same species in the Lower Hudson within 11 miles of the Federal Dam, concentrations range from 1.1 ppm to 11 ppm. PCB concentrations vary greatly within each species, and PCB levels in individual fish have exceeded these mean values by several fold. In recent years, maximum PCB concentrations in fillets from individual Hudson River fish have been found to be as high as 480 ppm in common carp, 290 ppm in white sucker, 160 ppm in American eel, 150 ppm in largemouth bass, 50 ppm in red-breasted sunfish, 42 ppm in walleye, 39 ppm in smallmouth bass, 37 ppm in brown bullhead, 30 ppm in yellow perch, and 27 ppm in black crappie.[22] In the lower Hudson River, recent maximum concentrations of 77 ppm in shortnose sturgeon liver, 42 ppm in Atlantic sturgeon gonad, and 31 ppm in striped bass fillet have been documented.[22] Fewer data are available for wildlife species other than fish, but several bird and mammal species sampled near the Hudson River also exhibit increased levels of PCBs in their tissues.[24]

For Upper Hudson River fish, PCB concentrations declined substantially between the 1970's and 1980's and experienced an increase in the early 1990's due to the Allen Mill event (the collapse of a wooden gate structure adjacent to the riverbank at the GE Hudson Falls plant site that resulted in a release of PCBs). The most recent data show considerable year-to-year variability and less obvious declining trends (Figure 2).[20] Comparing these tissue burdens of PCBs with published guidelines demonstrates that the current levels of exposure of fish and wildlife in the upper Hudson River drainage basin are high enough to cause concern for environmental effects. To protect piscivorous wildlife in the Great Lakes, a guideline for total PCB loads in fish of approximately 0.1 ppm was recommended by the International Joint Commission.[25]

Some of the strongest evidence of adverse PCB consequences to fish-eating animals has been documented for mink and otter, two mammals that are especially sensitive to PCBs.[26] When mink eat fish containing PCB levels comparable to those recently and historically reported in the Upper Hudson fish, they experience impaired reproduction, reduced offspring (kit) survival, and reduced kit body weight. Results of three long-term studies in which PCB-contaminated fish were fed to mink allowed development of a dose-response curve relating the rate of PCB ingestion (milligram of PCB ingested per kg body weight per day, mg/kg-day) to a decline in fecundity.[26] That analysis suggests that a daily dose of 0.69 mg PCB/kg-day (corresponding to approximately 5 ppm PCBs wet weight in their food) will result in greater than a 99% decline in mink reproductive fecundity, while approximately 0.1 and 0.025 mg/kg-day (equivalent to ca. 0.7 and 0.2 ppm) will result in 50% and 10% declines in mink reproduction, respectively.[26] PCBs levels in Hudson River fish exceed levels demonstrated to cause reproductive impairment in mink. Moreover, recent analyses of PCBs in the livers of mink and otter collected from the Upper Hudson River valley showed levels in some individuals that exceed values reported to cause negative impacts.[23,27]

Thus our current knowledge strongly suggests that the health of some sensitive mammalian species, such as mink and otter, may be seriously impaired along the Upper Hudson River. EPA considers otter to be at slightly greater risk than mink, because otter diets have higher proportions of fish, and the agency has designated whole body fish concentrations of 0.03-0.3 ppm (mg/kg) total PCBs (approximately corresponding to 0.012-0.12 mg/kg total PCBs in fish fillets) as the upper limit for protection of otter.[28] Fish concentration goals designed to protect mink and otter should afford protection to the other less sensitive species that inhabit the Hudson River ecosystem. A corollary to this is that the less sensitive species should recover sooner in response to decreasing PCB levels in the Hudson River than the more sensitive species.

Besides being a source of PCB contamination to consumers, fish themselves are vulnerable to these chemicals. Recommended levels for protecting fish from exposure to PCBs range from a median threshold value of 1.1 ppm total PCBs in whole body [29] to 25-70 ppm in adult fish liver,[30] and 5-125 ppm in the body of fish larvae. Current levels of PCB contamination in Upper Hudson River fish often exceed those associated with health effects on fish and wildlife. Because PCBs have such wide-ranging effects on the health of biota, and are so persistent once exposure occurs, it is very likely that current levels of contamination are causing injury to species that depend on the Upper Hudson River ecosystem.

Key Question 2. Are the PCBs in the Upper Hudson River sediments an important continuing source of contamination to the lower Hudson under average flow conditions?

Findings ***PCBs leaking from the GE plant sites and remobilized from the sediments continue to add PCBs to the Hudson River and to the food chain.***

In recent years, contaminated sediments have become the dominant source of PCBs to the river. As a result of source controls being implemented at the plant site, contaminated sediments are expected to serve as the dominant source of PCBs to the river for years to come.

Analyses conducted to date by both GE and EPA using relatively coarse-scale numerical models[31] lack the required fine-scale spatial resolution in the sediment transport model and use of an overly simplistic PCB distribution and bioaccumulation model. These deficiencies limit the ability of either model to accurately project future PCB levels in the Upper Hudson River, with or without active remediation. More sophisticated field evaluations and models would greatly improve efforts to define and monitor the remediation of the Hudson River.

The current releases of PCBs from the GE facilities are substantially less than those during active operation of the plants. GE has spent and will continue to spend considerable amounts of money to stem the flow of PCBs from their properties. Nonetheless, given the large amount of PCB contamination on these sites, and their immediate proximity to the Hudson, a small but significant amount of PCBs is expected to continue to enter the river from the GE sites for many years. Based on the amount of PCB in the river near the GE facilities, this small amount of leakage is presently estimated to be no more than 3 ounces per day (or 30 kilograms per year, see below), whereas the average PCB releases from the facilities were 2,700 to 16,000 kilograms per year between the 1940's and 1977.[1] In addition to this recognized leakage of PCBs from the plant sites, PCBs that were previously discharged from the plants and now reside in river sediments downstream from the plants are being released into the river's waters. PCBs may be released from the sediments during resuspension by currents and by diffusion and mixing of PCBs.

To estimate the relative importance of these two sources of PCBs to the Upper Hudson River, we examined monitoring data collected by GE[32] at two locations downstream of their facilities (Figure 3). The first site is at Rogers Island downstream of GE's Fort Edward plant (Figure 1). Here PCB concentrations are (relatively) low and quite constant. By multiplying the PCB concentration in the river by the river's flow rate at Fort Edward, we estimate that about 30 kilograms of PCBs per year were moving down the river at this point in the late 1990's.[33] In contrast, PCB concentrations

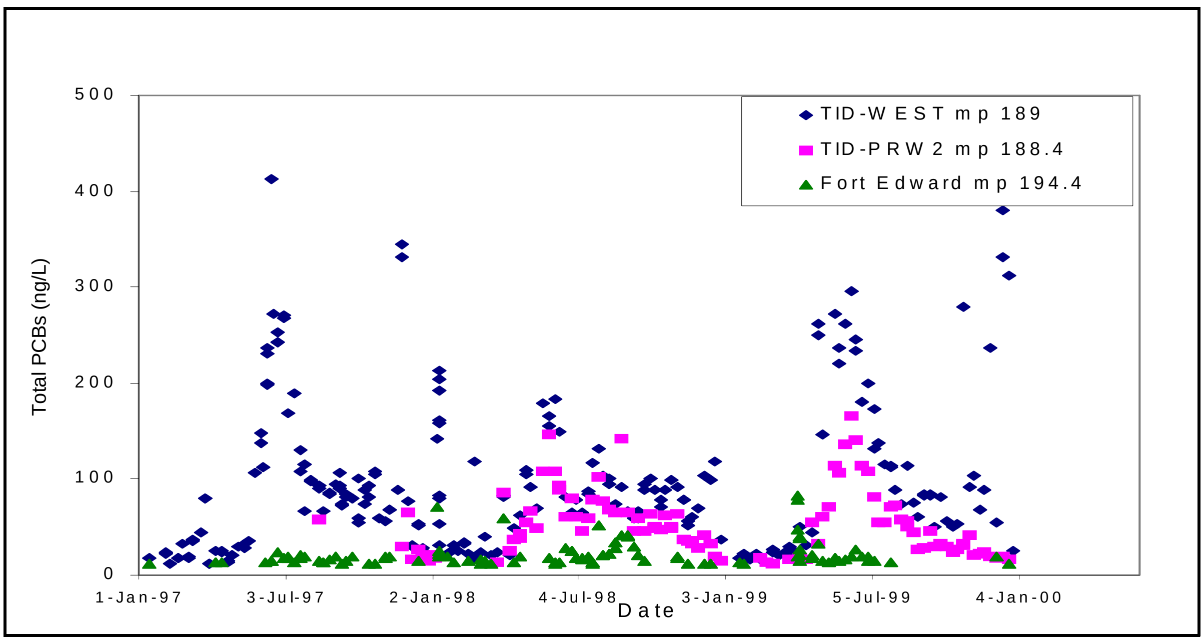

Figure 3. PCB concentrations in weekly water sample collections at the upstream (▲) and downstream (■,◆) ends of the Thompson Island Pool in 1997 through 1999. Increased levels at the downstream end indicate that the contaminated sediments in the Thompson Island Pool are the major current source of PCBs to the Upper Hudson River water column, contributing on the order of 180 kg/y. [Plot prepared by Jennifer Tatten as part of RPI (2001) based on data from General Electric Company as reported in the database supplied by GE to NYSDEC.[32]]

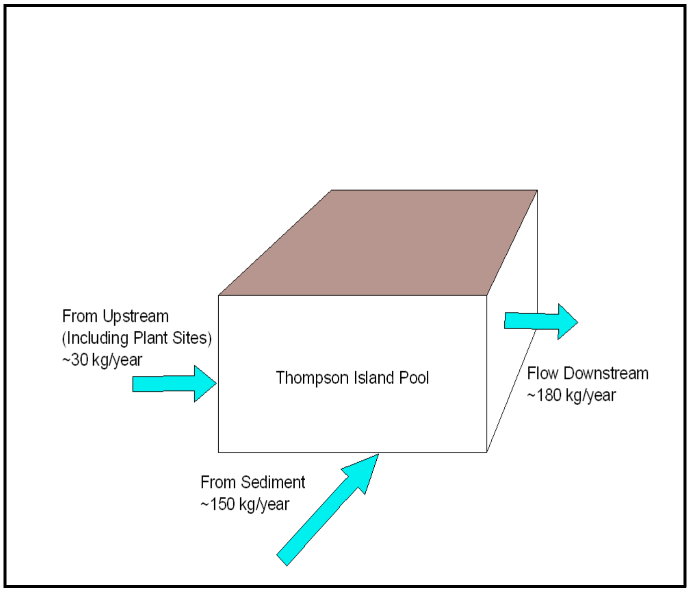

Figure 4. Approximate mass balance for PCB fluxes in the Thompson Island Pool for 1998, based on data shown in Figure 3.

in the waters passing over the Thompson Island Dam six miles downstream were much higher and more variable than at the upstream site (Figure 3). These higher PCB concentrations, multiplied by the river flow, yield an estimate of 180 kilograms of PCBs per year passing over the Thompson Island Dam. We conclude, therefore, that about 150 kilograms of PCBs per year enter the river as it moves through the Thompson Island Pool (Figure 4). The only plausible source of these PCBs is release from the Thompson Island Pool sediments. These sediments are highly contaminated with PCBs that can be released into the water column under a variety of flow conditions and there are no other likely significant PCB sources to this stretch of the river. It is important to note that these releases have occurred during relatively typical flow conditions.

These observations are consistent with our understanding of PCB behavior in rivers. Measurements of PCBs in the river indicate that the release of PCBs from sediments in the Upper Hudson River, including those below the Thompson Island Pool, is currently occurring and that this release is the dominant source of PCBs to the Hudson River downstream from the GE facilities at Hudson Falls and Fort Edward. GE has asserted that this current on-going PCB supply is transient, resulting from the contamination of near surface sediments in the Thompson Island Pool (and, presumably, a number of other spots downstream) by the Allen Mill gate failure (1991) and more recent releases from the plant sites. Both the GE and EPA models indicate that the Thompson Island Pool is a region of net deposition and GE maintains that its ongoing program to control releases from the plant sites will lead to burial by relatively clean materials in short order, isolating these sediments and associated PCBs from the overlying water column.[34]. As a result, the company says, dredging of contaminated sediments would be counterproductive, invasive and expensive because it could expose deeply buried, highly PCB-contaminated sediment layers and increase downstream transport of contaminated sediments. If this were the case, monitored natural attenuation of PCB impacts by allowing new sediments to bury the contaminated sediments within the Thompson Island Pool and elsewhere would clearly be the preferred course.

If the Thompson Island Pool were a quiescent area of net deposition, one would expect that the sediments would accumulate in a rather orderly fashion, layer by layer, forming a stable, stratified deposit in which the deeper, older sediments and their associated contaminant burden would be efficiently isolated from the surface layers and the overlying waters. Transport and material exchange would be confined to the immediate surface layers even during the extreme flow events. This idealized description of sediment accumulation, however, is not consistent with the bulk of the available data. While there are a few sediment cores that show orderly and progressive deposition as evidenced by radionuclide dating, there are many more showing a disturbed and irregular sediment column in which the record of sediment accumulation cannot be readily deciphered.[35] In contrast to the well-ordered cores, these irregular distributions of properties provide clear indication that significant areas of the sediment deposit resident within the Thompson Island Pool are subject to time-variant disturbance involving vertical distances similar in magnitude to the observed depths of contaminant burial. When viewed collectively (rather than selectively), these disparate field data indicate that the Thompson Island Pool sediment deposit is not an ordered, stratified mass with near horizontal uniformity in sediment properties, but rather is more accurately described as a spatially heterogeneous "patchwork quilt." In this deposit, sediment characteristics and the associated PCB concentrations display significant spatial variability. These variations affect the ability of the sediment to be moved by bottom currents under average ambient flows as well as the aperiodic high energy storm event. As a result, a given flow condition might find some areas of the pool experiencing net deposition while other areas erode. A change in flow state could significantly alter the locations of deposition and erosion and might change the pool from net depositional to net erosional or *vice versa*.

We believe that the heterogeneous nature of the Thompson Island Pool sediment deposit in space and time makes it impossible to specify the "age" of the PCBs being added to the water passing by. Whether the PCBs being added to the water at present are simply remnants of those introduced by the Allen Mill gate failure or contaminants introduced much earlier and subsequently remobilized by physical and biological processes, or some combination of these two sources, cannot be accurately determined from the field data alone. Nonetheless, we conclude that under the prevailing average flow conditions the sediments of the Thompson Island Pool are a continuing source of PCBs to the overlying waters.

Having concluded that PCB release from the sediments of the Upper Hudson River is the dominant <u>current</u> source of these contaminants to the water column and food web, the next question is how long this condition will persist in the river. Will PCBs continue to bleed from the sediments indefinitely, or will natural processes gradually sequester the PCBs within the river's sediments? If all of the PCBs in the Thompson Island Pool sediments (approximately 15,000 kg)[1] were available to be reintroduced back into the river and the rate of release continued at the present level (150 kg/year), there would be sufficient PCB in the sediment to support release for 100 years. This approximation is not realistic, however, as some of the 15,000 kg are undoubtedly trapped within the sediments, and one would not expect the release rate to remain constant in the face of declining PCB inventories in the sediments. To refine this estimate requires a coherent understanding of the movements of water, sediments and PCBs in the river, as well as addressing the difficult problem of quantifying remobilization of sediment. Predicting the future consequences of environmental actions is quite difficult, especially in a dynamic river system that has already been altered through the construction of locks and dams, reservoirs, canals, and dredged channels. Numerical models are tools used to estimate how PCB levels in the Hudson River sediments, water, and biota will change in the future, with and without active remediation. If the main motivation for active remediation is to reduce PCB levels in the future, our ability to design and evaluate the effectiveness of proposed remediation depends almost entirely on the accuracy of such models.

Both GE and EPA have developed numerical models that describe PCB transport in the Upper Hudson River.[31] While these two models share many similarities, there are also some key differences related to the extent of PCB release from the sediments. The two models predict similar levels of PCBs in the Upper Hudson River during the next several decades.[36] Both models predict slowly declining PCB levels in the Upper Hudson River over the next several decades as the system continues to respond to the gradual depletion of PCBs in the 'active' layer of sediment. In other words, the results of the models are driven by the underlying assumption that the sediments are a source of PCBs to the river water, but that the magnitude of this source will gradually decrease over the next several decades. This decrease results from the continued burial of PCBs by ongoing deposition of clean "new" sediment and from the release into the overlying water. Neither model predicts that the PCB levels will approach zero within the next 65+ years, reflecting both the likely continual chronic release of PCBs from upstream and the inherently slow response time of the system. As discussed above, it is not clear to us that the Thompson Island Pool is net depositional. Therefore, we question whether on-going burial will significantly deplete PCBs in the surface sediment as fast as predicted by these models.

Because the long-term recovery of the river from PCBs depends explicitly on the amount of PCBs in the river sediments and the rate at which these PCBs are removed from the active surface sediment, our ability to assess the future course of PCB levels in the Hudson River, with or without active remediation, depends upon our ability to model sediment transport processes. This is a challenging exercise because the sediment transport regime with the upper river is highly dynamic and is significantly variable in space and time. River sediments are constantly being reworked and those which settle in one location are often later resuspended and displaced. A fraction of these materials may accumulate within the Thompson Island Pool, while others move downstream. The extent of this "trapping" of sediments within any stretch of river is difficult to estimate. The retention efficiency of the Thompson Island Pool (*i.e.*, the fraction of the solids entering the pool which remain in the pool for long times) is believed to be low, and the associated sedimentation rates are low (on the average of a few tenths of a centimeter per year, averaged over the entire pool).[37] Temporal variations in sediment transport and accumulation result in a heterogeneous sediment deposit whose characteristics vary significantly over small vertical and horizontal distances. As a result, the bottom throughout the upper river is a complex mosaic of fine sands, silts, clays, wood chips and other organics formed by the combination of constantly changing currents and sediment supplies. Predicting sediment and PCB transport within such a system requires the use of a numerical model with sufficient spatial resolution to accurately represent this heterogeneity . Unfortunately, the models used by both the EPA and GE employ relatively coarse spatial segmentation that effectively masks the heterogeneity of the river bottom. Only the GE model attempts to address the complexities associated with the transport of sediments of mixed composition. This approach, although commendable, is essentially untested, leaving its accuracy open to question.

In addition, we feel that the numerical models used by both EPA and GE to describe PCB transport and accumulation in biota are too simplistic in their chemical descriptions. Although a large amount of high quality measurements of PCB components were made in the Hudson River, the models treat the complex and variable mixture of PCB components as a single ‘chemical’ (called Tri+ PCB, equal in concentration to the sum of all PCB components in the Hudson with three or more chlorines). The behavior of the PCB mixture varies markedly depending on the properties of the individual PCB components, especially as a function of the number of chlorines. The PCB composition changes with space and time in the Hudson. We are concerned that extrapolating a PCB model into the future that has been calibrated primarily on data collected over a relatively short period in which the PCB composition has not varied markedly introduces important uncertainties into the projections of long-term recovery. Based on our knowledge of PCB behavior, we believe that the recovery time of the more highly chlorinated PCB congeners (those that accumulate most in the food web) could be longer than that projected by the models.

Both the EPA and GE models appear to reasonably match previous field measurements. One should not conclude from this general agreement, however, that the underlying processes are correctly modeled. As noted above, we are concerned that the lack of fine-scale spatial resolution in the sediment transport model and the use of an overly simplistic PCB distribution and bioaccumulation model limits the ability of either model to accurately project future PCB levels in the Upper Hudson River, with or without active remediation. More sophisticated field evaluations and models would greatly improve the efforts to define and monitor the remediation of the Hudson River.

Key Question 3. What are the chances that the PCBs currently buried in the Upper Hudson River will be released sometime in the future under extreme weather conditions?

Findings ***The extent of remobilization of "buried" PCB-contaminated sediments during episodic high flow events (e.g., 100-year or 200-year floods) may have been underestimated and remains a concern.***

Based on current releases of PCBs from sediments and potential remobilization of "buried" PCBs during episodic events, we do not see monitored natural attenuation as a sufficient remedy.

As if modeling sediment and PCB movements in the dynamic Upper Hudson River was not difficult enough, the modeling of extreme weather events, such as a 100- or 200-year flood, is particularly challenging. Models are calibrated with available data, which typically do not include extreme events and often do not include flood periods. The spatial patterns of sediment erosion and deposition vary as functions of river flow. It is quite likely that an extreme event such as a 100-year storm will occur in the Upper Hudson River during the recovery period. Whereas a 100-year storm is an event that occurs, on average, every one hundred years, there is a 10% probability of a 100-year storm occurring in the next 10 years, a 25% probability in the next 30 years, and a 40% probability within the next 50 years. A question central to the PCB issue in the Upper Hudson is the depth of remobilization of sediments under different flow conditions. More energy in the river in the form of water currents can cause a deeper disturbance of the sediments and a greater release of the associated PCBs to the water column. To assess the potential impact of high flow events, both GE and EPA modeled the bottom current velocities under a high flow of 47,000 cubic feet per second.[31] The two models predict substantially different amounts of non-cohesive sediment remobilization in the Thompson Island Pool, with the EPA model predicting as much as 13 cm eroded (averaged over the pool)[38] *versus* 0.14 cm from the GE model.[39] This important discrepancy underscores the difficulty in using hydrodynamic and sediment transport models to estimate sediment remobilization during extreme events in the Upper Hudson River.

We are also concerned that the flows used to model the impact of extreme events do not adequately account for high flows from the Sacandaga Reservoir, which drains to the Hudson upstream from the GE plants. Since the Sacandaga River was dammed in 1930, one storm (May 1983) was large enough to cause water to spill over the dam and raised flows in the Sacandaga River above 12,000 cubic feet per second,[40] which is 50% higher than the worst-case Sacandaga River flows used in the sediment transport modeling. In addition, the operation of the Sacandaga dam has recently changed. Relicensing agreements between Orion Power and surrounding communities on the Sacandaga Reservoir and along the downstream Hudson River dictate that Orion Power will keep the reservoir at higher levels both during summer and winter months.[41] The new agreement signals a shift in management practices away from one favoring flood control, towards one favoring recreational uses of the reservoir and river. This loss in reservoir capacity decreases the dam's ability to hold back precipitation during extreme events, and increases the likelihood of flows through the Upper Hudson River that have not been experienced since the dam was constructed 70 years ago.

Neither the GE nor the EPA model adequately explains the observed current PCB releases from the Thompson Island Pool. We believe this is partly due to the coarse spatial and temporal resolution of those models and their corresponding inability to properly represent small-scale and ongoing redistribution of sediments within the pool. As we mentioned previously, both GE and EPA maintain that the Thompson Island Pool is net depositional, without any supporting geophysical evidence. The overall result of their modeling is that less than 20% of the total reservoir of PCBs in the Thompson Island Pool will be released over the next 30 years without dredging, with the remainder buried indefinitely.[37] Due to shortcomings of the modeling with respect to the ongoing redistribution of sediments under low to moderate flows and large-scale changes under extreme flood events, we believe the eventual release of PCBs from the Thompson Island Pool could be much greater than the 20% of the current PCB reservoir predicted by the models. We believe that both GE and EPA have likely underestimated the magnitude and probability of PCB release from the sediments and subsequent transport downstream.

Key Question 4. Can active remediation be implemented in such a way that it provides a net long-term benefit to the Hudson River?

Findings ***In other locations, active remediation of contaminated sediments resulted in lower contaminant levels and risk in wildlife. While the most sensitive species will continue to be impacted for decades, other less sensitive species will benefit sooner from declining PCB levels resulting from active remediation.***

With the best dredging techniques, only a very small fraction of PCBs are released to the water, likely less than 2% of the total PCBs dredged. In the Thompson Island Pool, this short-term release is comparable to the rate at which PCBs are currently being released from the sediments. Thus, with properly designed and executed techniques, dredging may result in no more than a doubling of the present day PCB flux during the project period.

Effectively managing the dredged materials stream is critical to the success of the active remediation.

Dredging with appropriate techniques is technically feasible, but requires rigorous oversight to minimize contaminant dispersion and community disruption.

There will be short-term impact of the dredging operations on local communities

and habitats but, properly managed, these impacts need be no greater than those of other large construction activities (road/bridge construction, navigation dredging, lock and dam repair and maintenance).

The estimated average concentration of PCBs in surface sediment in Thompson Island Pool is approximately 40 ppm, with maximum concentrations reaching 2,000 ppm.[1] Elsewhere, concentrations of this magnitude and less required or led to remedial actions under state and federal laws. For example, sediment remediation in Commencement Bay near Tacoma, Washington is proposed to reduce the PCB level to 0.45 ppm, although the National Oceanic and Atmospheric Administration and the Department of Interior, the federal stewards of natural resources, have requested a lower target of 0.2 ppm in the interests of chinook salmon and fish-eating birds.[42] Target PCB concentrations have been set at 1 ppm for cleanup of the Housatonic River (Connecticut--Massachusetts), the St. Lawrence and Raquette rivers (New York), the Kalamazoo River (Michigan), and the Delaware River (New Jersey–Pennsylvania); at 0.5 ppm for the Sheboygan River and harbor (Wisconsin); and at 0.25 ppm for the Fox River (Wisconsin).[43]

Although active PCB remediations have not always been successful due to design and operational problems[44], there are other examples where biological benefits have followed active remediation. We note that whether a specific remediation is deemed 'successful' depends upon the criteria established for that project. Short-term degradation resulting from the dredging activity can mask eventual benefits, and one must recognize that judging the 'success' or 'failure' of a remediation will likely require a long-term view. Examples where biological benefits followed active remediation include Sweden's Lake Järnsjön, where after two years PCB concentrations in 1-year-old Eurasian perch in the lake and 50 miles downstream were half those before dredging.[45]

Removal of PCB-contaminated soils and near shore sediments along the Upper Hudson River at Queensbury, New York (upstream from the two GE plants) led to significant declines of PCBs in yellow perch except near a remnant hot spot.[46]

Active remediation has relieved stress from other contaminants as well. Marsh and open-water sediments along the Lower Hudson River at Cold Spring were badly polluted with heavy metals (mainly cadmium but also cobalt and nickel). These sediments were excavated or dredged. The marsh area was covered with an absorptive clay fabric liner and clean fill and then replanted. Subsequently, five years of monitoring showed notable decreases of cadmium in the bodies of local plants, birds, invertebrates, and test fish.[47]

Similar finding have been reported for sediments contaminated with polycyclic aromatic hydrocarbons (PAHs), a class of synthetic organic compounds that are toxic to animals. Brown bullheads living over PAH-contaminated sediments in the Black River, Ohio, had high prevalences of liver tumors. Dredging of the sediments brought a temporary increase in tumors among resident bullheads, but bullheads spawned after the dredging had no tumors 4 years later.[48] The age class structure of the bullhead population improved, and the benefit of dredging was greater than that observed after onshore source control of the PAHs.[49] Similarly, liver tumors in English sole at a PAH Superfund site in Eagle Harbor of Puget Sound, Washington, decreased 15-fold over the six years after the site was capped with cleaner sediments.[50] Eleven years of monitoring before this remediation had shown no evidence of natural PAH attenuation in either the sediments or the fish.[48]

These case studies indicate that active remediation of contaminated sediments can more effectively reduce toxic pollution in most aquatic systems than natural dissipation of the pollutants. In addition to reducing surface contaminant concentrations, dredging will greatly reduce the reservoir of buried contaminants that could be remobilized during an extreme event. Lessening the risk of event-driven release of PCBs is one of the most valuable long-term benefits of dredging. Our professional opinion is that removal of contaminated sediments from the Upper Hudson River will accelerate recovery of the river.

Dredging will bring problems, of course. Some contaminants inevitably will be released when dredging disturbs the sediments. Previously buried muds with high PCB concentrations might be encountered and disturbed. Aquatic habitats will be disrupted in and downstream from dredging areas. Management of waste sediments will be a large and challenging operation. Nearby human communities will be bothered by noise, lights, odors, and temporary closures of roads and navigation channels. We believe these problems are less serious than commonly perceived and can be minimized.

Dredging technology has greatly improved in the past decade.[2] An ability to "surgically" dredge has developed in response to demand for such technology around the world, and firms specializing in remediation dredging (as distinct from navigation dredging) now exist. As with any engineering project, success or failure of Hudson River dredging will depend equally on the quality of the project design *and* the rigor and responsiveness of the project's oversight. Both factors can be encouraged and facilitated by performance-based contracting, but it will be very important to carefully specify the expected outcomes of dredging in terms of contaminant removal. Detailed site assessments will be needed before dredging begins to refine our knowledge of the current spatial distributions of sediments and contaminants in PCB hot spots. The collection and analysis of high spatial resolution data detailing sediment and PCB distributions through the project area will allow managers to select the best removal technology (for example, hydraulic versus mechanical dredging), access points, and waste management procedures. Such information also is needed for accurately estimating overall project costs.

Any disturbance of contaminated sediments can release both particle-associated and dissolved PCBs. Operations must be designed to minimize these releases. In a well-documented study in the Fox River, Wisconsin[51], the release of particulate and dissolved contaminants was 2% of the total weight of PCB's removed. No particular attempt was made to optimize PCB confinement in this project. We believe that substantial improvements can be realized and that ultimate losses will be less than 2%. However, even at the 2% loss level, the additional release and downstream transport of PCBs would amount to 180 kilograms per year under the proposed EPA alternative[52], an amount comparable to the current annual release from the Thompson Island Pool sediments. In this "worst case," the total amount of PCBs released into the Upper Hudson with dredging could be doubled, relative to not dredging, over the duration of the project period.

Dredging will temporarily destroy habitat in several ways besides changing the substrate: local flows will be altered and submerged aquatic vegetation and marginal wetlands will be lost. However, aquatic vegetation will readily recolonize disturbed areas from upriver sources once dredging is finished. Wetlands can be restored by established techniques with full consideration of the concerns raised recently by the National Research Council[53] regarding implementation, monitoring, and selection of success criteria. Fish undoubtedly will be driven from areas of dredging because of bottom disruptions, turbidity, and noise. The stress of displacement and of crowding on established populations elsewhere may increase fish mortality for a period of time. However, fish and aquatic invertebrates typically recolonize abandoned areas rapidly after disturbances have ended. Scheduling of operations to avoid known periods of spawning and migration will be important nonetheless.

Management of waste sediments can greatly disturb adjacent human communities if it is not carefully designed and implemented.[2] The plan as presented calls for the wastes to be ultimately transported to an out-of-state Hazardous Waste Landfill[1], but operational aspects must be considered. These include the de-watering facility, waste transfer stations, and transport of waste from the dredging site to the processing site by pipeline, barge, or rail. The de-watering facility consists of a settling basin and a filter press to remove interstitial water from dredged sediments. Residual waters will be treated to remove PCBs and returned to the river. Dried sediments may be moved directly or barged to a transfer station for out-of-state rail transport and disposal. If these operations are sited and managed to minimize the number of times sediment is handled, community impacts will be lower than otherwise. Efforts to reduce these impacts will benefit from early and continuing consultation with community representatives.

No data indicate that dredging operations themselves will directly affect public health. Despite claims to the contrary[54], construction projects similar in magnitude to and larger than the proposed Hudson River dredging occur regularly in densely populated areas and are accommodated by the affected communities. Although the entire proposed dredging operation along the upper Hudson will take several years, particular communities will be affected for much shorter times. Economic impacts can be offset by care in planning and scheduling and, when unavoidable, financial compensation. Lighting and noise intrusions often can be reduced below expectations. Continuous operations (night and day, seven days per week) are most efficient and therefore preferred from an operational standpoint, but more accommodating schedules might be adopted in areas of high population density. Innovation and a willingness to compromise will be needed by all.

Conclusions.

Based on our evaluation of the current levels of PCBs in the Upper Hudson River relative to a wide variety of benchmarks, we conclude that PCBs are very likely causing harm to the environment and are sufficiently high to pose risks to human health. PCB levels in the upper river have declined since the discharges from the GE facilities were curtailed, and will continue to decrease over the next century even without active remediation. However, the large quantity of PCBs residing in the sediments of the Upper Hudson River are not permanently sequestered, but rather are currently leaking back into the water, comprising the largest single source of PCBs to the river. Based on our review of field data and models, we believe that both EPA and GE have likely underestimated both the potential magnitude of PCB release from these sediments under typical conditions and the probability of large releases during extreme weather conditions. For these reasons, we believe active remediation such as the planned dredging is beneficial, as it takes advantage of the present opportunity to permanently remove this large quantity of PCBs from the environment. We recognize that cleaning up the PCBs that had been discharged into the Hudson over the past 50+ years will be expensive and will take many years. The technology exists to dredge, treat, and dispose of the contaminated sediments. Successful dredging, which will require careful planning and diligent execution, will accelerate the recovery of the Upper Hudson River and substantially reduce the risks to the Lower Hudson. The issue of PCBs in the Hudson River has been studied and debated for a generation. We conclude that the risks are real, the problem will not solve itself, and that the proposed remediation (with monitoring) is feasible, appropriate, and prudent.

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