Technical Report No. 27

Cumberland Bay PCB Study

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for
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3. (A) *GIS Management Plan for the Lake Champlain Basin Program.* Vermont Center for Geographic Information, Inc., and Associates in Rural Development. March, 1993.

   (B) *Handbook of GIS Standards and Procedures for the Lake Champlain Basin Program.* Vermont Center for Geographic Information, Inc. March, 1993.

   (C) *GIS Data Inventory for the Lake Champlain Basin Program.* Vermont Center for Geographic Information, Inc. March, 1993.

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   Lake Champlain Sediment Toxics Assessment Program. An Assessment of Sediment - Associated Contaminants in Lake Champlain - Phase 1. Executive Summary. Alan McIntosh, Editor, UVM School of Natural Resources. February 1994.

6. *(A) Lake Champlain Nonpoint Source Pollution Assessment.* Lenore Budd, Associates in Rural Development Inc. and Donald Meals, UVM School of Natural Resources. February 1994.

   (B) Lake Champlain Nonpoint Source Pollution Assessment. Appendices A-J. Lenore Budd, Associates in Rural Development Inc. and Donald Meals, UVM School of Natural Resources. February 1994.

7. *Internal Phosphorus Loading Studies of St. Albans Bay. Executive Summary.* VT Dept of Environmental Conservation. March 1994.

   (A) *Dynamic Mass Balance Model of Internal Phosphorus Loading in St. Albans Bay, Lake Champlain.* Eric Smeltzer, Neil Kamman, Karen Hyde and John C. Drake. March 1994.

   (B) *History of Phosphorus Loading to St. Albans Bay, 1850 - 1990.* Karen Hyde, Neil Kamman and Eric Smeltzer. March 1994.

   (C) *Assessment of Sediment Phosphorus Distribution and Long-Term Recycling in St. Albans Bay, Lake Champlain.* Scott Martin, Youngstown State University. March 1994.

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10. *Population Biology and Management of Lake Champlain Walleye.* Kathleen L. Newbrough, Donna L. Parrish, and Matthew G. Mitro, Fish & Wildlife Research Unit, University of Vermont. June 1994.

11. (A) *Report on Institutional Arrangements for Watershed Management of the Lake Champlain Basin. Executive Summary.* Yellow Wood Associates, Inc. January 1995.

    (B) *Report on Institutional Arrangements for Watershed Management of the Lake Champlain Basin.* Yellow Wood Associates, Inc. January 1995.

    (C) *Report on Institutional Arrangements for Watershed Management of the Lake Champlain Basin. Appendices.* Yellow Wood Associates, Inc. January 1995.

12. (A) *Preliminary Economic Analysis of the Draft Plan for the Lake Champlain Basin Program. Executive Summary.* Holmes & Associates and Anthony Artuso. March 1995

    (B) *Preliminary Economic Analysis of the Draft Plan for the Lake Champlain Basin Program.* Holmes & Associates and Anthony Artuso. March 1995

13. *Patterns of Harvest and Consumption of Lake Champlain Fish and Angler Awareness of Health Advisories.* Nancy A. Connelly and Barbara A. Knuth. September 1995.

14. (A) *Preliminary Economic Analysis of the Draft Plan for the Lake Champlain Basin Program. Executive Summary - Part 2.* Holmes & Associates and Anthony Artuso. November 1995

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17. (A) *Executive Summary. Economic Analysis of the Draft Final Plan for the Lake Champlain Management Conference.* Holmes & Associates and Anthony Artuso. July 1996

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18. *Catalog of Digital Spatial Data for the Lake Champlain Basin .* Vermont Center for Geographic Information, Inc. September 1996.

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23. (A) *Lake Champlain Sediment Toxics Assessment Program. An Assessment of Sediment - Associated Contaminants in Lake Champlain - Phase 11. Executive Summary.* Alan McIntosh, Mary Watzin and Erik Brown, UVM School of Natural Resources. October 1997

    (B) Lake Champlain Sediment Toxics Assessment Program. An Assessment of Sediment - Associated Contaminants in Lake Champlain - Phase 11. Alan McIntosh, Mary Watzin and Erik Brown, UVM School of Natural Resources. October 1997

24. *Development of Land Cover/Land Use Geographic Information System Data Layer for the Lake Champlain Basin and Vermont Northern Forest Lands Project Areas.* Dr. Thomas Millette. October 1997

25. *Urban Nonpoint Pollution Source Assessment of the Greater Burlington Area.* Urban Stormwater Characterization Project. James Pease, VT Dept. of Environmental Conservation. December 1997

26. *Long-Term Water Quality and Biological Monitoring project for Lake Champlain.* Cumulative Report for Project Years 1992- 1996.

27. *Cumberland Bay PCB Study.* Clifford W Callinan, NY State Dept. of Environmental Conservation; Lyn McIlroy, Ph.D., SUNY Plattsburgh; and Robert D. Fuller, PhD., SUNY Plattsburgh. July 1998

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Excerpts: letter from Commodore Thomas MacDonough to Hon. William Jones, Secretary of the Navy.

U.S. Ship Saratoga, off Plattsburg,
September 11th, 1814.

SIR,

The Almighty has been pleased to grant us a signal victory on Lake Champlain ....

I have the honour to be etc.
T. MACDONOUGH.

Executive Summary

In 1992, researchers from the University of Vermont and the United States Geological Survey investigating contamination levels in the bottom sediments of Lake Champlain and its drainage basin, discovered significant levels of polychlorinated biphenyls (PCBs) adjacent to the Department of Transportation's Barge Dock (a.k.a. Wilcox Dock) in Cumberland Bay. Follow up investigation led to designation of the site as a Class 2 hazardous waste site (NYSDEC Site # 5100017). The waste site is estimated to cover 34 acres (14 hectares) with an approximate sludge volume of 90,000 - 95,000 cubic yards (69,000 - 73,000 cubic meters) (Rust, 1995). The site is presently scheduled for remediation in 1999, and will involve hydraulic dredging and off-site disposal.

This study is designed to assess the transport and fate of PCB contamination within the bay. The primary objectives of the Study include: (1) development and calibration of a PCB mass balance screening model for the bay; and (2) estimation of the PCB flux from the bay to the main lake.

The Study included extensive monitoring of the bay, the Saranac River, and a portion of the main lake adjacent to the bay. Study elements included water column monitoring for PCBs and surrogate parameters, collection of sediment cores, and deployment of sediment traps.

Sediment core results indicate that PCB contamination within the bay increased substantially (approximately 5 fold) in the early to middle 1960s, suggesting that the PCB contamination present at the Wilcox Dock site was discharged during the same time frame. Thus, contamination at the Wilcox Dock site has been subject to scour and transport for over 30 years. Results from this study, as well as findings from beach cleanup activities around the bay, indicate significant migration of PCB contamination from the Wilcox Dock site. Water column sampling within the bay depicts a clear PCB gradient aligned approximately north to south. Water column PCB concentrations ranged on average from 3.65 ng/l in the northwest corner of the bay to 0.287 ng/l just outside the bay within the main lake.

While there are indications of PCB contamination entering the bay from the Saranac River, the primary source of PCB contamination to the bay is the Wilcox Dock hazardous waste site. Contaminant patterns and the PCB concentration gradient within the bay clearly support this conclusion. The flux of PCBs across the mouth of the bay is estimated at 4.0 kg/year.

The principal recommendations of this study are as follows: (1) it is imperative that the Wilcox Dock Site be remediated as soon as possible; (2) monitoring and modeling efforts within the bay should be continued during and following remediation to assure conditions within the bay improve sufficiently, and to provide verification of model predictive capability; and (3) a basin-wide PCB study and mass balance model should be developed within the Lake Champlain Basin to determine the transport and fate of PCBs within the basin, and to identify possible additional sources of PCBs to the basin.

I. Introduction

Setting

Perhaps best known for its role in the War of 1812, Cumberland Bay was the site of what some consider to be the decisive battle of the war. The Battle of Plattsburgh began on the morning of September 11, 1814, at the mouth of Cumberland Bay (Hill, 1977). It involved nearly 30 vessels and over 1700 men (Hill, 1977).

Cumberland Bay is located on the western (New York) side of Lake Champlain, at approximately 44°42'30" north latitude and 73°25'30" west longitude. Orientation of the bay is along an axis running from the north-northwest to the south-southeast with the mouth at the south-southeast end of the embayment. The bay is bounded by Cumberland Head to the east and the City of Plattsburgh to the west. Tributary flow to the bay is dominated by the Saranac River, which enters the Bay from the west. Additional tributary flow comes from Dead Creek (also known as Scomotion Creak) which enters from the north-west end of the bay.

The principal municipality adjacent to Cumberland Bay is the City of Plattsburgh. Situated on the western shore of Cumberland Bay, the population of Plattsburgh was 21,255 as of 1990 (www.census.gov, 1997). Count Charles de Fredenburgh, a former captain in the British army, first surveyed Land in the Plattsburgh area in the 1760's. In 1769 he was granted 30,000 acres of land on the west side of Lake Champlain (Sargent, et al., 1964). The Town of Plattsburgh was first recognized on April 4, 1785 (Sargent, et al., 1964). As of 1964 the City of Plattsburgh encompassed approximately 48 square miles, or roughly the same amount of area originally granted Count Charles de Fredenburgh nearly 200 years earlier (Sargent, et al., 1964). The bay and the City of Plattsburgh are located within Clinton County. The county has an area of 1,049 square miles (Hope Farm Press & Bookshop Internet , 1997) and the population, as of 1990, was 85,969 (www.census.gov, 1997).

Since its inception in the late 1700s, the industrial base of the Plattsburgh area has revolved around the natural resources of the area. The earliest industrial activities focused on the abundance of rich farmland, forests, and water power (Sargent, et al., 1964). Drawn to the Saranac River for power and transportation most early industry in the area located adjacent to river. The first dam on the Saranac River was constructed at Bridge Street in the late 1700s, and was used to power a sawmill and gristmill (Everest, 1985). Several additional industries followed including a fulling mill, dye-house, and forge. Industrial development increased further in the second half of the 19th century driven primarily by lumbering and iron mining.

The wood products industry began shortly after settlement of the area. The rudiments of the industry began with the sale of potash in the late 1700s. In 1846 the State of New York declared the Saranac River a public highway which accelerated lumbering activities in the Adirondack interior (Everest, 1985). Designation of the Saranac as a public highway enabled lumber companies to float logs downstream to the mills. The magnitude of the operation was enormous, in May of 1886, 25,000,000 board feet of logs were floated down the Saranac River to the mills. Sawmills located adjacent to the river in Redford, Cadyville, and Plattsburgh, would dump their sawdust and wood scraps into the river which ultimately came to rest in Cumberland Bay. Concern about industrial discharge to the Saranac River and Cumberland Bay goes back a century or more. In earlier years, concern focused primarily on the physical (navigational) problems associated with the waste materials, however, chemical impairments were also articulated. In an 1876 op-ed piece from the Plattsburgh Republican entitled "Shall Cumberland Bay be Converted into a Sawdust Swamp" a resident describes the bay as "covered with depths of drifting, rotting, sawdust, thrown up by the waves in their efforts to rid their waters of the foul impurity." The author goes on to state "the steamer Vermont finds it very difficult to pass the east end of the railroad wharf when coming to her dock on account of the accumulation of sawdust at that point" (Plattsburgh Republican, Sept. 9, 1876). The Vermont actually grounded on the waste beds a decade later. Concerns continued to be voiced some 80 years later as indicated by the following excerpt "Industrial experts from the Diamond Match Company denied yesterday that the company's Plattsburgh plant is responsible for the bulk of the industrial waste to be found in Lake Champlain ... there are probably four types of foreign material presently in Cumberland Bay, namely: sawdust, oil and other refuse, residues of fish and aquatic growth commonly associated with the lake purging itself, and pulp fibre material ... There is a bed of pulp in the immediate vicinity of the Diamond Match plant 1,500 feet in length ... Periodic tests have revealed that the greatest part of the pulp bed has been on the bottom of the lake for more than 20 years" (Plattsburgh Republican Press, July 19, 1951). The Diamond Match

Company plant discharge entered the bay near Wilcox Dock. The primary concern during this era related to solids and bacterial contamination. In 1958 the State Water Pollution Control Board approved a comprehensive water pollution abatement plan for the Lake Champlain Basin which recommended specific abatement steps for industries within the basin. Industries mentioned in the plan include Diamond Gardner Corp., Imperial Paper and Color Corp., and Vanity Fair Paper Mills, Inc., all located within Plattsburgh (Plattsburgh Press-Republican, June 6, 1958). Articles from the early 1960's continued to indicate concerns over the waste beds "Initial steps to alleviate the water problem have been taken by two of Plattsburgh's paper mills which discharge thousands of pounds of solid wastes directly into receiving waters." (Plattsburgh Republican Press, Jan. 13, 1962). In spite of actions by the regulatory community during the 1960s and early 1970's, direct discharges to the bay by local paper mills were not curtailed until 1973. In 1973 local industries began to direct their effluents to the Plattsburgh Wastewater Treatment Plant (WWTP). While this action significantly improved existing loading to the bay, it failed to address the legacy of decades of disposal to the bay and its tributary waters.

The iron industry also had its origins in the late 1700s. The first iron-smelting forge on the Saranac River began operation in 1798, and processed ore from Monkton, Vermont, and later from Port Henry. It was not until the 1840s that iron ore was discovered in the Saranac basin. At this point mining and smelting within the basin grew significantly. It is estimated that by 1880 Clinton and Essex counties produced nearly one-tenth of all the iron mined in the United States. Charcoal from available wood supplies and available water power from the Saranac River were used to operate blast furnaces and small foundries, which produced a variety of iron products including machinery, nails, cables, anchors, and other products (Sargent, et al., 1964). The iron industry, and its need for ore, prompted development of the Saranac River Plank Road, and later development of a railroad line from Plattsburgh to Dannemora (Everest, 1985), which enabled supplementation of a diminishing ore supply within Clinton County. The iron industry flourished until the discovery of vast, easily accessible iron ore deposits in the mid-west (Sargent, et al., 1964). The last iron-related industry in the area, Republic Steel at Lyon Mountain, closed its plant in 1967 (Everest, 1985).

Table I.1: Significant events in the history of Plattsburgh (adapted from Lake Champlain-Lake George Regional Planning Board, 1981)

1609	Samuel de Champlain discovered the lake that bears his name.
1766	Captain Charles de Fredenburg received a grant of 30,000 acres settled near the mouth of the Saranac River.
1785	Town of Plattsburgh erected. First gristmill and sawmill began operation on the Saranac River.
1788	Plattsburgh declared county seat of Clinton County.
1800	Population of the town 1,400. Magnetite discovered in Clinton County.
1812	War with England.
1814	Battle of Plattsburgh Bay.
1823	Peak of passenger steam boat traffic.
1835	Peak of cargo shipping on Lake Champlain.
1840s	Iron deposits discovered in the Saranac Valley.
1880	Population 8,283. Peak of the iron industry.
1886	The steamship Vermont grounded on a sawdust reef in Plattsburgh Bay. 25 million board feet of logs were floated down the Saranac in one year. Street lights first used in Plattsburgh.
1900	Population 11,612. Lozier Motor Car Company opens in Plattsburgh.
1902	City of Plattsburgh incorporated.
1953	Final approval for construction of Plattsburgh Air Force Base.
1967	Adirondack Northway completed to the Canadian border. Last iron mine closed at Iron Mountain.
1973	Raw waste discharges to Cumberland Bay end, industrial wastes routed to the Plattsburgh STP.
1980	Population of the city 21,057.
1984	Major employers in Plattsburgh are U.S. Air Force, State University at Plattsburgh, Champlain Valley Hospital, paper products industry (Imperial Paper, Georgia Pacific, Diamond National).
1995	Plattsburgh Air Force Base closes.

Problem Definition

With substantial resolution of contemporary loadings of wood byproducts to the bay in the early 1970s, attention turned to the question of what, if anything, to do with sizable quantities of waste materials residing on the bottom of Cumberland Bay. While sediment deposits often suffer from neglect due to an "out of site, out of mind" societal mentality, this particular waste bed had a propensity to, in effect, rear its less than attractive head. The waste bed adjacent to Wilcox Dock was known to exhibit fluctuations in buoyancy and at times float to the surface. In addition, due to a combination of physical phenomenon (namely water depth, wind, and wave action) the waste bed has undergone considerable scour over the years. The beaches north and northeast of the bay have been the unwilling recipients of significant portions of this material over the years. Several studies were conducted during the 1970s concerning the quantification and possible removal of the offending material (SUNY Plattsburgh Lakes and Rivers Research Laboratory, 1974).

In the late 1970s and early 1980s there were indications of more serious problems within the bay, namely, the presence of polychlorinated biphenyl (PCB) contamination, and the sludge deposits (or portions thereof) would eventually be found to be a primary player in that contamination. The NYSDEC, which has periodically analyzed fish from Lake Champlain since the late 1970s, noticed increased levels of PCB contamination in certain species of fish collected from Cumberland Bay. The results from these and later efforts are the basis for the fish consumption advisories now in place.

There are two specific fish consumption advisories on Lake Champlain due to PCBs: (1) a lakewide advisory relating to lake trout over 25 inches and walleye over 19 inches; and (2) a specific advisory within Cumberland Bay relating to American eel, brown bullhead, and yellow perch. The recommendation is as follows: (1) Eat no more than one meal per month; and (2) Women of childbearing age, infants and children under the age of 15 should not eat any species of fish from Cumberland Bay (NYSDOH, 1996-97).

The FDA action level for PCBs is 2.0 ppm. Thus, a fish consumption advisory is issued when fish flesh sampling results exceed 2 ppm of total PCBs for a given area. Table I.2 provides a summary of NYSDEC fish sampling through 1992. Additional fish were collected from Cumberland Bay in September 1994, and sample results indicate significant contamination of several additional species.

The source of contamination within Cumberland Bay was not identified until the early 1990s. A study of toxic contaminants within lake surficial sediments, conducted during the early 1990's (McIntosh, 1994), discovered significant levels of PCBs in the vicinity of Wilcox Dock in association with the sludge bed. A study of toxics contamination of tributary surficial sediments was also conducted during the early 1990's (Coleman, 1994). Sample collection for PCBs focused primarily on the mouths of major tributaries to Lake Champlain. However, samples were also collected adjacent to Wilcox Dock, and showed similar results to the McIntosh study. The site has since been more fully investigated by the NYSDEC. The NYSDEC Division of Water (DOW) conducted sampling of the sludge deposits in June of 1993 and March of 1994. The 1993 effort involved the collection of 11 composite samples from bottom sediments adjacent to Wilcox Dock. The sampling grid covered approximately 15-20 acres primarily north of the dock. Samples ranged in total sediment depth from 20.5-39.5 cm. Total PCB concentrations ranged from 9.4-87 ppm. The 1994 effort involved the collection of 7 sediment cores ranging from 30-67 cm in total sediment depth. The core samples overlapped the 1993 efforts with some expansion toward the north. The cores were sectioned in 2 cm sections from 0-8 cm and 4 cm sections from 8 cm to the bottom of the core. Cores were analyzed as follows: (1) six of the cores were analyzed for Aroclors; (2) one complete core and the upper sections of a second core were analyzed for congeners. Sampling results indicate total PCB concentrations ranging from 0-1800 ppm (the upper value was found in one 2 cm section), and that the primary signal from the Wilcox Dock contamination site is Aroclor 1242. Results of these sampling efforts are summarized in Tables I.3 and I.4.

Table I.2: New York State PCB Data from Lake Champlain Fish.

Year	Species	Location	# Fish / # Analyzed	Total PCB (ppm) Mean	Range	Length Range (mm)
1979	American eel	*Plattsburgh*	9/9	3.91	1.48-7.08	560-800
1979	American eel	Ticonderoga	10/10	0.84	0.20-2.10	400-870
1982	American eel	*Plattsburgh*	13/13	1.43	0.13-3.26	na
1982	Brown bullhead	*Plattsburgh*	7/2	3.4	2.29-4.26	292-335
1982	Yellow perch	*Plattsburgh*	15/1	1.58	-	208-242
1982	Largemouth bass	Rouses Point	24/2	0.20	0.17-0.22	320-421
1982	Yellow perch	Rouses Point	19/1	0.26	-	200-227
1982	Largemouth bass	Ticonderoga	21/2	0.14	0.12-0.16	336-411
1982	Yellow perch	Ticonderoga	8/1	0.14	-	235-267
1983	American eel	Plattsburgh	15/15	9.84	3.93-19.5	654-876
1983	American eel	Ticonderoga	11/11	0.948	0.61-1.34	660-817
1983	American eel	Ticonderoga	6/6	0.996	0.67-1.29	665-834
1983	American eel	Willsboro	13/13	1.51	0.82-2.97	397-816
1985	American eel	*Plattsburgh*	20/8	3.7	0.87-6.6	530-840
1985	American eel	Point AuRouche	17/8	1.6	0.7-2.8	460-1010
1985	American eel	Ticonderoga	20/8	0.93	0.62-1.3	660-940
1985	American eel	Valcour	20/8	2.0	1.3-2.4	670-910
1987	Atlantic salmon	Bouquet River	10/10	0.27	0.06-0.48	479-672
1987	Cisco	Willsboro	20/20	0.22	0.02-0.87	274-319
1987	Lake trout	Willsboro	20/20	1.22	0.22-4.54	406-742
1987	Whitefish	Willsboro	20/20	0.79	0.21-3.44	452-1601
1988	Walleye	Great Chazy River	20/20	0.29	0.11-1.45	426-603
1992	Chain pickerel	Crown Point	2/2	< 0.02	< 0.02-< 0.02	458-560
1992	Channel catfish	Crown Point	4/4	0.38	0.17-0.77	609-710
1992	Northern Pike	Crown Point	3/3	0.04	< 0.02-0.05	428-550
1992	Yellow perch	Crown Point	13/13	0.05	< 0.02-0.15	204-279
1992	Lake trout	lake-wide	36/36	1.07	0.41-3.48	320-700
1992	Brown bullhead	*Plattsburgh*	12/12	2.04	0.74-4.07	195-308
1992	Carp	*Plattsburgh*	5/5	1.49	0.54-2.87	655-798
1992	Largemouth bass	*Plattsburgh*	2/2	0.52	0.41-0.62	362-371

Table I.3: Results of NYSDEC Wilcox Dock sampling conducted in June, 1993

Site #	Total PCB (ppm)	Sample Depth (cm)	Sample Description
1	14	20.5	clay/silt
2	11	20.5	na
3	22	35	clay/silt
4	13	34	na
6	36	19.5	fibrous bottom, clay/silt
7	63	39.5	fibrous
8	87	28	fibrous with oily smell
9	84	22	fibrous with oily smell
10	40	22	fibrous
11	61	-	na
12	14	23.7	na
14	9.4	23.7	na

Table I.4: Results of NYSDEC Wilcox Dock sampling conducted in March, 1994 (units of ppm)

Site #	Core Depth (cm)	Aroclors 1016/1242 Range
1	26	13-30
7a	28	24-182
9	47	0-1850
12	33.6	0-13
18	45.3	0-344
19	43.5	0-231

The NYSDEC Division of Hazardous Waste Remediation in conjunction with the DOW and the NYS Department of Health conducted additional sampling (sediment cores, PISCES, wood chip material, etc.) in and around the bay during 1994 which indicated some migration of the contamination to other parts of the bay. The sludge bed adjacent to Wilcox Dock was listed as an inactive hazardous waste site in late 1994. The contaminated sludge bed is estimated to cover approximately 34 acres with a total volume of between 90,000 - 95,000 cubic yards (Rust, 1995).

Various remedial plans have been evaluated for the Wilcox Dock site (Rust, 1996), and discussions are underway with potentially responsible parties (PRPs) concerning remediation of the site. The Department will begin remediation of the site in 1999, and the current plan is as follows: (1) Isolation of the sludge bed with temporary sheet piling and silt curtains; (2) Removal of the sludge bed through dredging and dry excavation; (3) Construction and operation of a temporary de-watering facility and wastewater treatment facility; (4) Transport of the de-watered sludge off site for disposal at a permitted landfill; and (5) Follow-up fish sampling and fish monitoring.

Polychlorinated Biphenyls

PCBs are a class of man-made organic compounds characterized by two benzene rings and from 1-12 chlorine atoms (see Appendix A). Such a structure affords up to 209 possible permutations, which are termed congeners. Congeners are often classified by homologue group which relates to the number of chlorine atoms present. Thus, there are 10 homologue groups representing congeners containing from 1-10 chlorine atoms (e.g., monochlorobiphenyl, dichlorobiphenyl, trichlorobiphenyl, etc.). Homologue groups provide a convenient simplification, and while not fail-safe, such a categorization provides a degree of uniformity within groups with respect to the behavior of the given congeners in the environment. For example, congeners in homologue group 1 are more susceptible to both biodegradation and volatilization than are congeners in homologue group 10. The homologue and/or congener pattern found at a contamination site can, in certain instances, be used to identify the commercial formulation causing the contamination, and may assist in source identification. Table I.5 provides summary information on homologues for commercial PCB products sold in the US. Homologue patterns for Aroclors 1242 and 1260 are shown in Appendix A.

Table I.5: Weight percentages for homologue groups of certain Aroclors (derived from Schulz, 1989)

Homologue	Aroclor 1016	Aroclor 1242	Aroclor 1254	Aroclor 1260
1	-	-	-	-
2	21.47	14.95	-	-
3	49.76	35.33	1.21	0.1
4	27.83	32.64	16.61	0.99
5	0.99	13.16	50.96	13.51
6	0.19	2.39	23.86	46.98
7	-	0.22	4.38	33.83
8	-	-	0.68	7.27
9	-	-	-	0.67
10	-	-	-	0.05

Originally introduced for industrial use in 1929, US production of PCBs reached a peak of 85 million pounds in 1970 (HHS, 1993). The Monsanto Company was the sole manufacturer of PCBs in the US (CEC, 1996). The total quantity of PCBs produced in the US between 1929 and 1977 is estimated at 1.4 billion pounds (635 million kilograms) (CEC, 1996). From an industrial perspective, PCBs offer a number of attractive properties. The properties of greatest value to industry include low conductivity (good insulator), flame retardant properties, and chemical stability. PCBs were used in products ranging from electrical transformers to carbon-less copy paper (Table I.6 provides a quantitative estimate for major uses and Figure I.1 provides a more comprehensive list of past PCB uses). Electrical transformers and capacitors accounted for 61 percent of PCB use prior to 1971, and 100 percent of PCB use from 1971-1979 (NAS, 1979). Commercial PCB formulations have specific mixtures of congeners, which, in certain instances, allows for identification of contamination sources. The sole commercial mixtures used within the US have the trade name of Aroclors. Seven Aroclor formulations (1016, 1221, 1232, 1242, 1248, 1254, and 1260) account for 98 percent of the PCBs sold in the US since 1970. With the exception of Aroclor 1016, the Aroclor number can be interpreted as follows: the first 2 digits refer to the number of carbon atoms present in the compound (two benzene rings contain 12 carbon atoms), while the later 2 digits indicate the approximate weight percentage of chlorine (i.e., Aroclor 1242 is approximately 42 percent chlorine by weight). Aroclor 1242 was the most prevalent formulation used in the US.

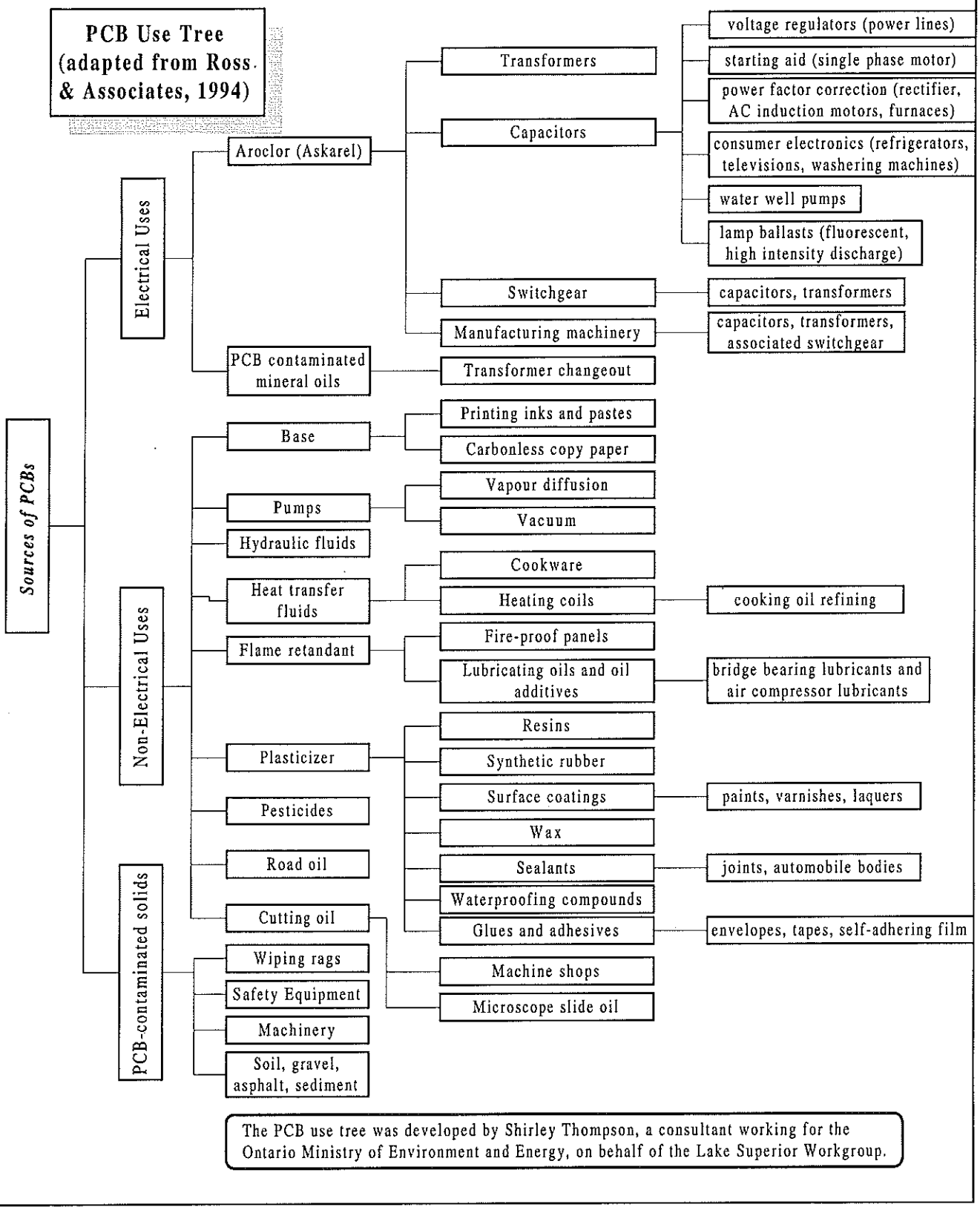
Table I.6: Domestic Uses of PCBs

Category	Type of Product	% of New total Use
Closed Electrical Systems	Transformer, Capacitors, other (minor) electrical insulating/cooling applications	61 % until 1971; 100 % after 1971
Nominally Closed Systems	Hydraulic fluids, heat transfer fluids, lubricants	13 % until 1971, 0 % after 1971
Open-End Applications	Plasticizers, surface coatings, ink and dye carriers, adhesives, pesticide extenders, carbonless copypaper, dyes	26 % until 1971, 0 % after 1971

PCBs were first recognized as potential environmental contaminants in the mid-1960s. A Swedish researcher was the first to report the accumulation of PCBs in biota. Results showed PCB accumulation in several hundred pike collected from all over Sweden, and in one eagle (Jensen, 1966). Since that time, numerous studies have documented the bioaccumulative potential of PCBs in the environment. *Bioaccumulation* refers to the process by which a compound (i.e., PCBs) increases in concentration from one trophic level to the next. Bioaccumulation is composed of two components: (1) *bioconcentration*: process by which an organism absorbs contaminants directly from the water - in fish this occurs primarily as water crosses the gill; and (2) *biomagnification*: process by which an organism accumulates contaminants from its food source. The bioconcentration factor (BCF), which is the ratio of contaminant concentration in an organism to contaminant concentration in the water, varies significantly depending upon the Aroclor and/or congener in question, as well as the organism of interest. The BCFs of various Aroclors in aquatic organisms range from 26,000 to 660,000 (USDOH, 1993). In general, BCF increases with higher levels of chlorination and/or higher trophic levels.

The propensity of PCBs to bioaccumulate is due to its persistence in the environment and its lipophilic/hydrophobic nature. The property of persistence allows PCBs to circulate for extended periods within the environment, while the properties of lipophilicity and hydrophobicity facilitate the molecule's association with organic and particulate matter, respectively. The first evidence of PCB bioaccumulation within Cumberland Bay occurred in the late 1970's as a result of fish contamination sampling conducted by the NYSDEC. Elevated PCB concentrations were first observed in American eel and brown bullhead. Follow-up investigations in the early 1980s led to issuance of a specific health advisory for the Bay.

Figure I.1: PCB "use tree" (adapted from Ross, 1994)



The fact that PCBs tend to preferentially associate with particulate organic material, indicates that organic sediments and biotic lipids act as environmental repositories for PCBs, and that monitoring activities should focus on those environmental compartments containing such materials (e.g., bottom sediments, suspended sediments, biota). As with bioconcentration factors discussed above, there is significant variation in particulate affinity between different Aroclors and congeners. This can be illustrated by comparing several of the partitioning coefficients used to characterize organic compounds. For example, the octanol water partition coefficient (K_{ow}), a measure of the relative distribution of a chemical between octanol and water, varies by a factor of approximately 100 between Aroclor 1221 and Aroclor 1260. The magnitude of variation is similar for both sorption coefficient (K_{oc}) and water solubility. Various partition coefficients are reported for a number of Aroclors in Table I.7. In general, the higher the degree of chlorination the higher the K_{ow} and K_{oc}, and the lower the water solubility of the mixture.

Table I.7: Summary of various environmental coefficients for selected Aroclors.

Coefficient	Aroclor 1016	Aroclor 1221	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260
* Log K_{ow}	5.6	4.7	5.6	6.2	6.5	6.8
** Log K_{oc}	no data	no data	3.36-4.09	4.74-5.44	4.81-6.65	5.54-6.83
* H_2O Sol. (mg/l)	0.42 (25°C)	0.59(24°C)	0.10-0.34	0.054-0.06	0.012-0.057	0.0027-0.08
* Henry's Law C	2.9×10^{-4}	3.5×10^{-3}	5.2×10^{-4}	2.8×10^{-3}	2.0×10^{-3}	4.6×10^{-3}

Henry's Law Constant reported in atm-m3/mol at 25°C.
Log K_{ow} & Log K_{oc} are unitless.
* USDOH, 1993.
** Mackay, et al., 1992.

The primary toxicological effect of concern with PCBs is carcinogenicity. PCBs are known to cause cancer in laboratory animals, and are suspected to cause cancer in humans (USDOH, 1993). Other effects observed in laboratory animals include hepatic, gastrointestinal, hematological, dermal, immunological, neurological, developmental, and reproductive abnormalities. Oral exposure through consumption of contaminated food is believed to be the major route of exposure to PCBs in the general human population, however, inhalation can also represent a significant exposure pathway, particularly near a hazardous waste facility (USDOH, 1993). Evaluation of the health effects of PCB mixtures is complicated by numerous factors, the most important of which is their congeneric composition, since the toxicity of the mixture depends upon the toxicity of individual congeners (USDOH, 1993). In general, the higher the level of chlorination the higher the level of toxicity. However, coplanar congeners, substituted in both para, at least two meta, and no ortho positions represent the most toxic members of this class, and 3,3',4,4',5-Pentachlorobiphenyl is considered the most toxic PCB congener (USDOH, 1993).

Regulation of PCBs in the United States began in the middle to late 1970's under the Toxic Substances Control Act (TSCA; PL94-469). The first set of regulations were issued by the USEPA in 1977 and related to effluent standards for PCBs. These were followed in 1979 by regulations concerning the manufacture and importation of PCBs. TSCA has a separate section devoted exclusively to PCBs. Under the existing regulatory regime, PCBs are banned from manufacture, import, export, and use except under limited circumstances. PCB-containing products or equipment are regulated based on concentration. PCBs at concentrations less than 50 ppm are largely unregulated. Equipment with PCB concentrations between 50 - 500 ppm have some regulatory requirements, and equipment with PCB concentrations greater than or equal to 500 ppm have the most stringent regulations; these include limited disposal options, and storage, marking, location, and record keeping requirements (CEC, 1996). PCB releases are also regulated by the Clean Air Act, Clean Water Act, Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The EPA is currently in the process of modifying the PCB rules to help increase the pace of PCB disposal in the United States.

II. Purpose and Objectives

The purpose of this study is to investigate and model the transport and fate of PCBs within Cumberland Bay. Specific objectives are as follows: (1) develop a screening level mass balance model for PCBs within Cumberland Bay; (2) determine the relative magnitudes of various PCB sources (i.e., Wilcox Dock waste bed, Saranac River, etc.) and sinks (i.e., burial, volatilization, etc.) within the bay; (3) estimate the total PCB load across the mouth of Cumberland Bay; and (4) simulate various remedial action scenarios with respect to predicted PCB levels in the water column of the bay over time.

III. Study Design and Methods

This study involved the collection of a number of different data sets, from various environmental compartments within the bay, the main lake, and the Saranac River. Those efforts are described in detail below. In addition, the study drew upon several existing data sets collected by other offices within the NYSDEC (additional sediment cores and fish flesh analyses), and other agencies (e.g., flow data from the USGS). These data sets are also described, albeit in less detail, below.

Sampling sites for this study were as follows: (1) the Saranac River at Bridge Street (east bank), which is approximately 0.6 km upstream of the river mouth, served as the primary sampling site for the Saranac; this was occasionally supplemented with a background site at Redford, which is located approximately 50 km upstream of the mouth of the Saranac River; (2) there were 4 primary sites within the bay designated sites CB5, CB12, CB15, and CB30; an additional 18 sites in the bay were sampled for surrogate parameters over two intensive sampling periods in 1995; and (3) there were 4 main lake sites designated site CB45 and long-term monitoring sites 14 (LTM14), 26 (LTM26) and 36 (LTM36). Coordinates and sample parameters for the primary sampling sites are given in Table III.1.

Table III.1: Primary sample locations and sample parameters

Site	Latitude	Longitude	Depth(m)	Samples/Parameters Collected
Saranac R.	44 41.74	73 27.40	~ 1	surrogates, water column PCBs, PISCES
CB5	44 42.86	73 26.15	3	surrogates, water column PCBs, PISCES
CB12	44 42.43	73 25.01	11	surrogates, water column PCBs, PISCES, sediment core
CB15	44 42.05	73 26.14	4	surrogates, water column PCBs, PISCES
CB30	44 41.20	73 25.04	15	surrogates, water column PCBs, PISCES, sediment core & traps
CB45	44 40.35	73 23.32	36	surrogates, water column PCBs, PISCES, sediment core & traps
LTM14	44 24.84	73 19.72	43	surrogates, water column PCBs
LTM26	44 35.11	73 21.40	42	surrogates, PISCES, sediment core & traps
LTM36	44 45.37	73 21.30	50	surrogates, water column PCBs, PISCES, sediment core & traps

Sample site selection was predicated upon an attempt to get as complete a picture of the system as possible within the constraints of the relatively modest budget allotted the project. The Cumberland Bay sampling sites and the Saranac River sample site are shown in Figure III.1.

Bay sites CB5, CB12, CB15, and CB30 provided reasonably good spatial coverage within the bay. Additionally, site CB5 is located fairly close to the waste bed and is thought to provide a reasonable, albeit low, approximation of conditions above the bed, while site CB15 provided additional information concerning the Saranac River and Plattsburgh Waste Water Treatment Plant (WWTP). Site CB45, located just outside the bay, provided information concerning mixing with the main lake, while sites LTM14 & LTM26 and LTM36 provided information about the main lake both south and north of the bay, respectively.

The Bridge Street site on the Saranac River was selected for the following reasons: (1) provided near complete coverage of the Saranac River drainage basin; (2) sufficiently upstream to avoid influence of backwater from Cumberland Bay; and (3) provided a location for siting an automatic sampler, thanks to the cooperation of Mr. Herb Carpenter, owner of Northeast Printing Company.

Surrogates, water column PCBs, and PISCES deployments were conducted at all sites, with the exception that PISCES were not deployed at LTM14 or the Bridge Street site. Collection of sediment cores was restricted to sites CB12, CB30, LTM26 and LTM36. The reasons for limiting core sampling to these sites were both technical (e.g., core collection should be restricted to depositional areas) and budgetary (radiometric dating was approximately $1,000 per core). Sediment trap deployments were restricted to deep-water sites due to known concerns over non-vertical transport processes within shallow areas. Finally, the purpose for looking at LTM26 and LTM36 was as follows: given the prevailing south to north flow of the lake, if Cumberland Bay were a significant source of PCB contamination to the main lake, then one would expect greater contamination levels north of the bay than south of the bay.

Water Column Surrogates

A number of surrogate parameters were collected from the Saranac River, the bay, and the main lake as part of the study. Table III.2 provides a summary of surrogate parameters, analytical method, and the purpose for collection.

Table III.2: Surrogate parameter, methodology and study purpose

Parameter	Methodology	Purpose of Collection
Total Suspended Solids (TSS)	APHA (1983); 209A	loadings, solids balance, PCB dynamics
Chlorides	USEPA (1983); 325.1	computing bulk dispersion
Total Phosphorus (TP)	USEPA (1983); 365.1	limnology
Total Kjeldahl Nitrogen (TKN)	USEPA (1983); 351.2	limnology
Total Organic Carbon (TOC)	USEPA (1983); 415.2	PCB dynamics
Dissolved Organic Carbon (DOC)	USEPA (1983); 415.2	PCB dynamics
Chlorophyll a	APHA (1983); 1002	limnology, solids balance
River Flow	USGS Gage # 04273500	loading estimates

There were several reasons for the collection of surrogate parameters. For example, the purposes for the collection of TSS were as follows: (1) given the costs of PCB analysis and the propensity for PCBs to adsorb to particulate material, it was thought that extensive collection of TSS data would allow the limited PCB measurements to be extended based upon a TSS vs PCB relationship both on the Saranac River and within the bay; (2) TSS data are used to determine a solids loading rate from the Saranac River; and (3) TSS measurements are used to calibrate a solids mass balance model for the bay. As will be discussed later, the surrogate data proved to be of limited value.

Surrogate data was collected from one site on the Saranac River (Bridge Street site), 4 main sites within Cumberland Bay (sites CB5, CB12, CB15, and CB30), as well as numerous additional short-term sites within the bay, and 4 main lake sites - site CB45 and long-term monitoring sites LTM14, LTM26 and LTM36. Field duplicates and laboratory matrix spikes were done for all surrogate parameters.

Water Column PCBs

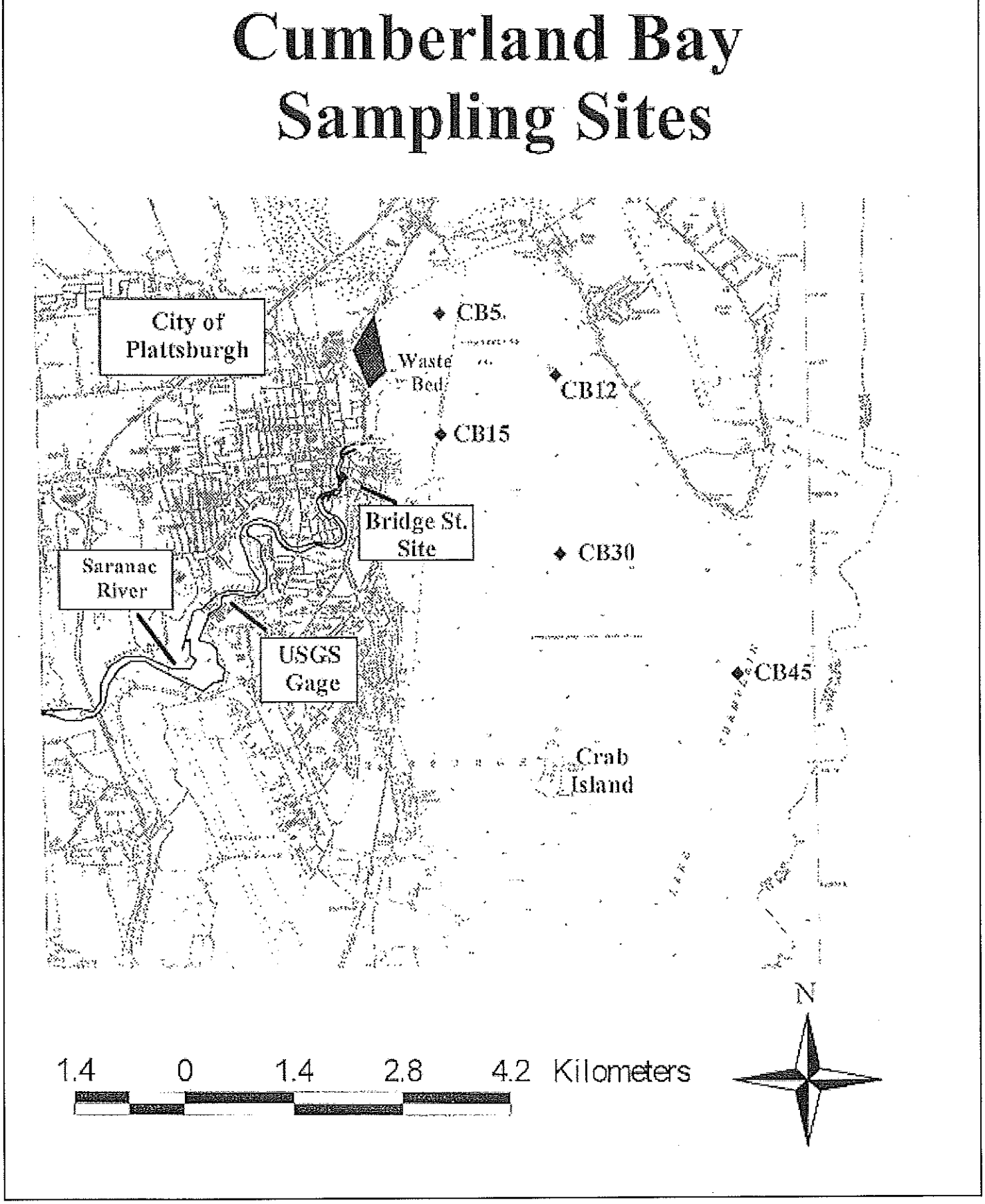
The methods used for analysis of water column PCB concentrations are described more fully in Fuller, et al. (1997, unpublished report - Appendix B). The procedure allowed for extremely low detection and quantification levels, which were essential for tracking PCB migration within the bay and into the main lake.

A submersible stainless steel pump, with teflon tubing, was used to collect between 80-160 liters of water in rigorously cleaned 20 liter glass carboys. Samples were immediately returned to the SUNY lab, filtered and extracted onto XAD-2 resin within 24 hours of sample collection. Samples were analyzed using an HP 5890 Gas Chromatograph with electron capture detectors, electronic pressure control, and an HP 7673 auto-sampler.

Water column PCB samples were collected from the following stations: CB5, CB12, CB15, CB30, CB45, LTM14, LTM26, LTM36, and the Saranac River at Bridge Street.

The water column PCB measurements are used for calibration of the mass balance model, PCB loading estimates from the Saranac River, and congener pattern analyses.

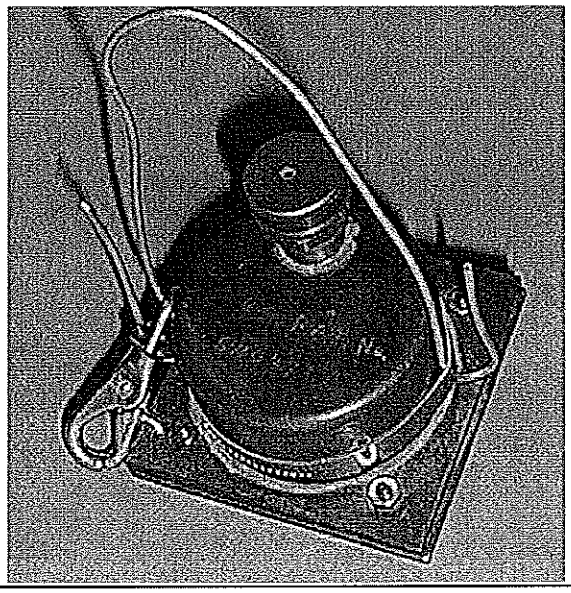
Figure III.1: Cumberland Bay Sampling Sites.



PISCES

Passive In-situ Concentration/Extraction Samplers (PISCES; see Figure III.2) were used at sampling sites CB5, CB12, CB15, CB30, CB45, LTM26, and LTM36. The PISCES unit, developed by Dr. John Hassett (State University of New York, College of Environmental Science and Forestry), is a patented device designed to concentrate organic contaminants. The unit, composed of various pieces of standard copper pipe and fittings, is fitted with a polyethylene membrane, and also contains a venting cap with a Teflon gasket designed to vent any oxygen build-up within the unit. At time of deployment the unit is filled with a solvent (e.g., hexane).

Figure III.2: Passive In-situ Concentration/Extraction Samplers



In theory, organic contaminants in the aqueous phase of the water column diffuse through the polyethylene membrane and are sorbed to the hexane present in the unit. Contaminant transport across the membrane is a diffusion process and is controlled primarily by the concentration gradient of the contaminant and by ambient water temperature.

PISCES were deployed at each of the primary bay sites and site CB45 on two separate occasions, and at LTM26 and LTM36 on a single occasion. Deployments at sites CB45 and the long-term monitoring sites involved sampling from multiple depths. PISCES were deployed for approximately 2-3 weeks duration.

The field procedure for PISCES deployment is as follows: (1) a field blank is prepared by pouring an aliquot of hexane into a glass amber bottle at the first sample site, the field blank is capped and stored until all PISCES are retrieved; (2) PISCES unit is triple rinsed with hexane; (3) the unit is filled to the port neck with hexane and the cap screwed on securely; (4) the unit is inspected for leaks, volume of hexane noted, and ambient water temperature recorded; (5) the unit is then attached to a concrete block anchor and surface buoy, and lowered to predetermined depth; and (6) assuming the unit survived the deployment period (these units are apparently collectors items for local boaters), retrieval involves pulling the unit to the surface, inspecting the unit for leaks, noting hexane volume, recording ambient water temperature, pouring the hexane into sample bottles, and submitting the hexane samples to the laboratory for analysis.

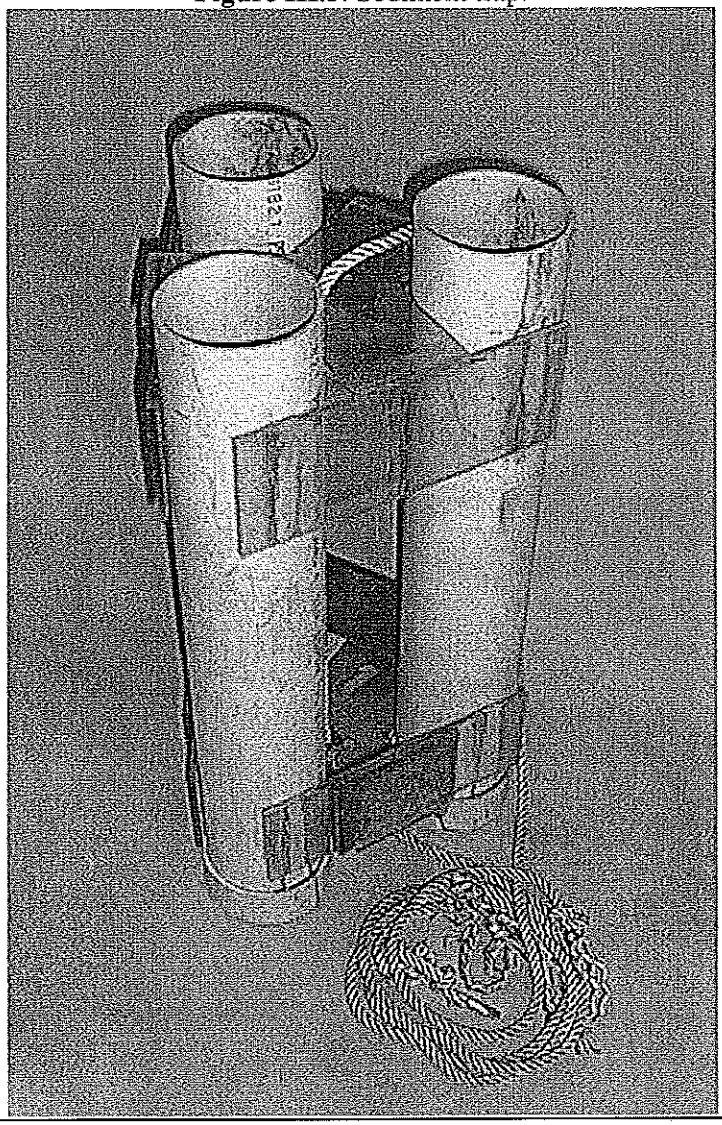
The procedure used for PCB analysis was NYSDEC Method 91-11 (fused silica capillary column gas chromatography with electron capture detector). Each PISCES deployment involved submission of a field blank and laboratory matrix spike.

The purposes for PISCES deployments were: (1) to determine the *relative* levels of PCBs within Cumberland Bay, the main lake, and the Saranac River; and (2) to compare the congener pattern between sample locations for the purpose of source identification and quantification.

Sediment Traps

Sediment traps were deployed at three deep water sites (CB30, CB45, and LTM36). At site CB45 the traps were deployed at two depths, while at sites CB30 and LTM36 traps were deployed at a single depth. Traps were constructed of 4" ID pipe of either PVC or copper composition. Both sets of traps had similar designs of three sections of 4" pipe strapped together (see Figure III.3), with aspect ratios (length to diameter) of 6:1, and drain ports located approximately 14 cms from the base of the cylinders. The PVC traps were used for conventional settling rate determinations, while the copper traps were used for both settling rate determinations and PCB analysis. Traps were deployed for a period ranging from 15-21 days. The field procedure for trap deployment and retrieval is as follows: (1) trap assemblies are threaded through and secured to deployment lines at predefined positions, then anchor blocks and surface buoys are attached; (2) trap assemblies are lowered into the water; (3) at the end of the sampling period the traps are brought to the surface and the supernatant is drained from trap ports and parameter specific (TSS, TP, TKN, TOC) aliquots are drawn from the supernatant; (4) the remaining trap slurry is composited and either sub-sampled for the same parameters as the supernatant (PVC traps) or the entire volume submitted for PCB analysis (copper traps). PCB analyses were conducted using NYSDEC Method 91-11.

Figure III.3: Sediment trap.



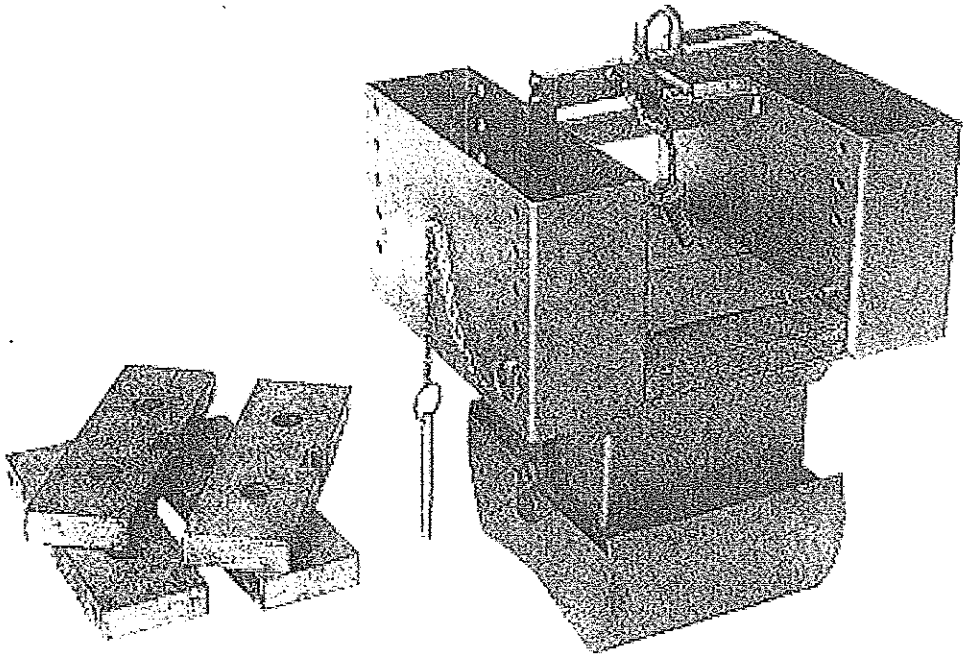
Deployments were restricted to sites CB30, CB45, and LTM36, due to known difficulties with determining settling rates within shallow, non-stratified conditions. In essence, particle vectors must be predominantly vertical for an accurate determination of settling rate, and particle vectors within shallow waters tend to be non-vertical.

The purpose for sediment trap deployments was to determine the solids and PCB settling rates for Cumberland Bay and the main lake. Average settling rate is used in the mass balance model. Settling represents a loss process from the water column for both suspended solids and PCBs.

Sediment Cores

Sediment cores were collected at sites CB12, CB30, LTM26, and LTM36. Cores were collected with either a modified Wildco box corer model # 191-A15 (see Figure III.4 - modified to include a 1 meter long core) or a Kahl Scientific Ewing Portable Piston Corer (model # 217WA230). All coring was conducted from the SUNY Plattsburgh research vessel the "Monitor" using an A-frame and winch assembly. The coring procedure is as follows: (1) corer is prepared for deployment on site; (2) corer is lowered to within approximately 2 meters of lake bottom; (3) corer is then allowed to free-fall to the lake bottom; (4) corer is retrieved, and, if successful, the core liner is capped and secured on board; and (5) upon arrival at shore, or shortly thereafter, cores are extruded and sectioned.

Figure III.4: Wildco box corer and supplemental weights (Wildco 1997-98 catalog).



Each core section was then sub-sampled and submitted for either radiometric dating or PCB analysis. Cores were sectioned into 1-4 cm sections (upper layers - more recent material - were generally sectioned by 1-2 cm sections, while lower layers - older material - were sectioned into 2-4 cm sections). PCB analyses were conducted using NYSDEC Method 91-11.

Coring information is used to estimate net depositional rates and to confirm burial rate constants used in the PCB mass balance model. Furthermore, cores taken from north and south of the bay, respectively, were intended to provide a qualitative estimate regarding the importance of the Cumberland Bay PCB load to the main lake.

Hazardous Waste Cores

The department's Division of Hazardous Waste Remediation collected additional cores and water column PCB samples over the waste bed. One of these cores was collected in close proximity to our CB12 site, and provides important information with respect to PCB contamination chronology.

Fish & Wildlife Fish Flesh Analyses

As indicated earlier, the NYSDEC has an ongoing monitoring program for fish flesh analyses. Several collection efforts were conducted in Cumberland Bay over the past several years. These analyses are used for congener pattern comparison.

USGS Flow Data, etc.

Discharge measurements for the Saranac River were obtained from the USGS gaging station # 04273500 located on the right bank (as viewed looking downstream) 600 feet downstream of the old Imperial Paper and Color Corp. dam.

Discharge measurements are used to determine annual loading of both solids and PCB from the Saranac River, and to determine advective flow in the PCB mass balance model.

IV. Results/Discussion

Water Column Surrogates

Water column surrogate data for the primary sampling sites is summarized in Table IV.1. As mentioned earlier, additional surrogate sampling was conducted at 18 secondary locations within the bay over two intensive sampling periods during 1995, however, the results are not included in this report.

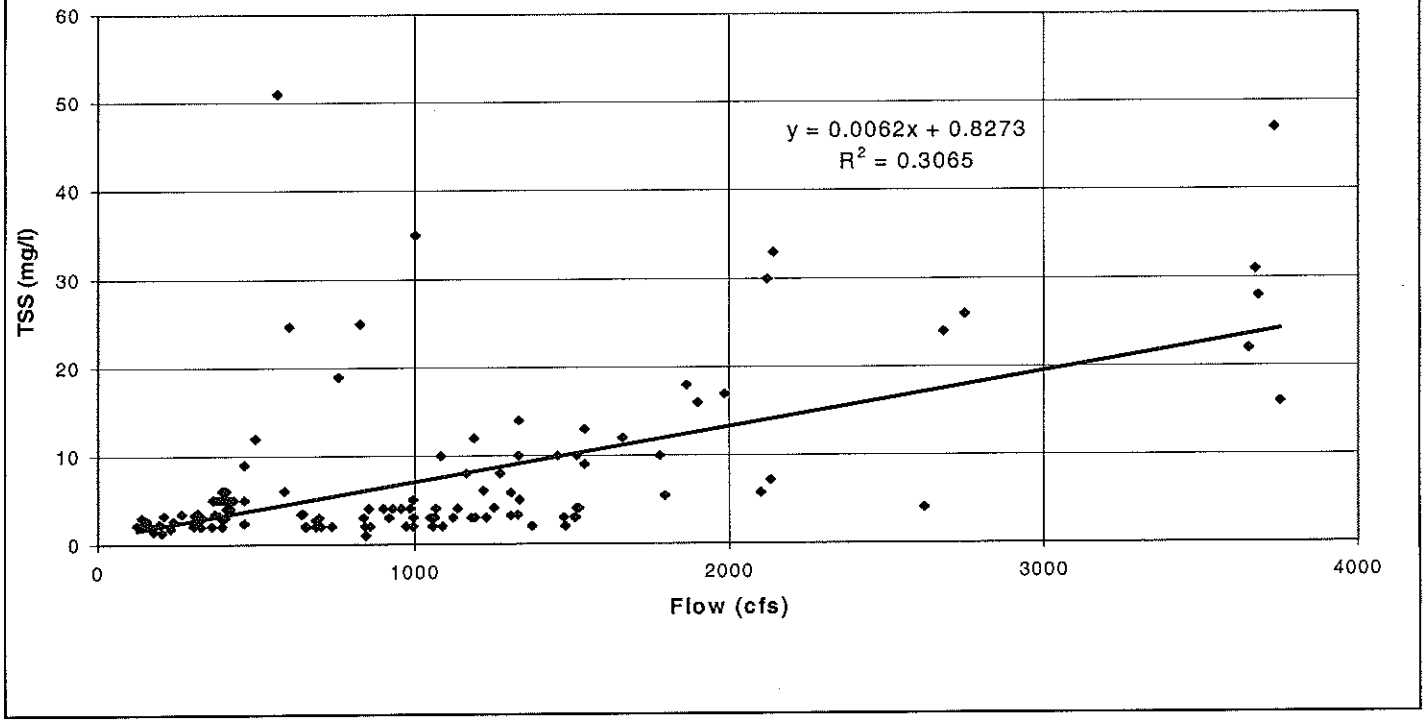
Table IV.1: Surrogate data summary - mean (n, standard deviation).

Site Name	TSS (mg/l)	Chlorides (mg/l)	TOC (mg/l)	Flow (cfs)
CB5	1.36 (20, 1.57)	12.14 (19, 1.24)	3.42 (18, 0.76)	na
CB12	0.73 (22, 0.29)	12.46 (20, 0.97)	3.21 (19, 0.50)	na
CB15	0.76 (21, 0.48)	12.57 (20, 0.84)	3.31 (19, 0.57)	na
CB30	0.68 (25, 0.40)	12.63 (24, 0.57)	3.17 (25, 0.50)	na
CB45	0.57 (55, 0.19)	12.55 (50, 0.60)	3.22 (50, 0.71)	na
Saranac R. @ Bridge St.	7.28 (130, 8.91)	8.3 (114, 5.0)	6.8 (114, 1.9)	923 (717, 753)

The purposes for surrogate sample collection were only partially realized. The TSS data are sufficient to establish a solids mass balance within the bay, and to estimate the solids load from the Saranac River. However, our attempts to derive surrogate correlations for: (1) TSS vs flow in the Saranac River; and (2) TSS vs wind velocity and direction within the bay, were less than successful.

Figure IV.1 shows the relationship between TSS and flow for the Saranac River during the study period, and while there is a discernible positive relationship between flow and TSS, the correlation coefficient is poor (r^2 = 0.3065). If one excludes a small number of the sample points (4 out of 130), corresponding to the rising limb of a particularly strong rainfall event, the r^2 value jumps to a semi-respectable 0.5. Saranac River TSS loading estimates were derived using the load estimation program FLUX developed by Walker (1990). Methods 5 (Regression Method 2) provided the best loading estimate at 8,213,473 kg/yr (CV = 0.215).

Figure IV.1: TSS vs flow for the Saranac River sampling site at Bridge Street.



The chloride data was also somewhat problematic. Ideally, one would desire the chloride data to form a concentration gradient from the inner-bay to the main lake, or the reverse. This allows for the derivation of a bulk dispersion rate. The results from this study indicate a maximum chloride concentration at the mouth of the bay, or arguably, a uniform chloride concentration from the inner-bay to the main lake. In addition, QA/QC results for chloride indicated that the mean variation between duplicate samples was 0.14 mg/l, which exceeds the differences shown between certain sample locations.

Water Column PCBs

Water column PCB analyses demonstrated a consistent concentration gradient with the highest PCB concentrations adjacent to the waste bed (site CB5 - average concentration of 3.65 ng/l), somewhat lower concentrations within the northern half or inner bay (sites CB12 and CB15 - average concentrations of 0.8 and 1.33 ng/l, respectively), further reduction in the southern or outer bay (site CB30 - average concentration of 0.38 ng/l). Concentrations continue to decline within the main lake (site CB45 - average concentration of 0.287 ng/l), and, as hypothesized, PCB concentrations were higher north of the bay (site LTM36) then they were south of the bay (site LTM26), although the congener patterns are somewhat contradictory (see congener pattern analysis below). Water column PCB results are summarized in Table IV.2.

Table IV.2: Water column PCB data summary.

Site	Mean Concentration (ng/l)	n	Individual Measurements (ng/l)
Saranac River	0.60	4	0.52, 0.43, 0.28, 1.15
CB5	3.65	3	2.22, 5.96, 2.78
CB12	0.80	2	1.23, 0.373
CB15	1.33	2	0.93, 1.72
CB30	0.38	3	0.26, 0.223, 0.666
CB45	0.287	4	0.387, 0.210, 0.297, 0.253
LTM14	0.072	2	0.071, 0.073
LTM26	0.147	3	0.244, 0.099, 0.099
LTM36	0.253	2	0.284, 0.221

PCB concentrations at specific sites varied temporally by between 28 and 400 percent. The largest temporal variation occurred at the Saranac River site, reflecting variations in river flow. In general, results for the bay and main lake indicate greater temporal variation in proximity to the waste bed. Station specific congener patterns will be discussed briefly below, however, a more thorough discussion of congener patterns involving integration with other sample types will be presented later. As a preface to these discussions, it is important to keep in mind that previous studies have suggested that the predominant contaminant pattern in the bay is different from contaminant patterns present in the main lake. For example, while the contaminant pattern in the Wilcox Dock sludge bed has been identified as Aroclor 1242, main lake fish samples have, by in large, been identified as Aroclor 1254/1260.

1. *Saranac River*: A total of four PCB water column samples were collected at the Bridge Street site on the Saranac River. Concentrations varied by approximately a factor of 4 (0.28 ng/l to 1.15 ng/l), and demonstrated a weak, but discernible, positive correlation between flow and concentration (see Figure IV.2). The congener patterns for all four samples were quite consistent (see cluster analysis Figure IV.4 below), with the particulate phase of mid-weight congeners predominating. The congeners and/or congener groups consisting of IUPAC #s 153/132/105, 110/107, 66, and 70/76 were found to be in highest concentration. This pattern, while not an exact match for Aroclors 1254 and 1260, is more consistent with the pattern of these Aroclors than with Aroclors 1242.

2. *CB5*: A total of three PCB water column samples were collected at site CB5. Concentrations varied temporally by approximately a factor of 2.5 (2.22 ng/l to 5.96 ng/l). The congener patterns for all three samples were quite similar (see cluster analysis Figure IV.4 below), with the aqueous phase of lower chlorinated congeners predominating. The dominant congener at site CB5 was IUPAC #s 31/28. These findings are consistent with the congener pattern present in the reference waste bed core and with Aroclor 1242.

3. *CB12*: A total of two water column PCB samples were collected at site CB12. Concentrations varied temporally by approximately a factor of 3 (0.373 ng/l to 1.23 ng/l). The congener patterns for both samples were similar and again consistent with the congener pattern present in the reference waste bed core and in Aroclor 1242.

4. *CB15*: A total of two water column PCB samples were collected at site CB15. Concentrations varied temporally by approximately a factor of 2 (0.93 ng/l to 1.72 ng/l). The congener patterns were again quite similar to each other, and consistent with the congener pattern present in the reference waste bed core and in Aroclor 1242. Thus, while this site was expected to be influenced substantially by the Saranac River, the congener patterns observed appear to indicate otherwise.

5. *CB30*: A total of three water column PCB samples were collected at site CB30. Concentrations varied temporally by approximately a factor of 3 (0.223 ng/l to 0.666 ng/l). The congener patterns for these samples are somewhat more equivocal then the samples from the inner-bay. The sample collected on July 30, 1996 appears to resemble the pattern observed in the inner-bay and in Aroclor 1242, characterized by predominantly lower chlorinated congeners, however, the other two samples show a fairly uniform congener pattern with the exception of IUPAC #s 31/28. Once again, notice in Figure IV.4, how samples W30_7/11 and W_30-6/26 are aligned together, while W30-7/30 is grouped nearer the inner-bay samples. This would suggest that PCB patterns at site CB30 vary significantly over time, and that the site is influenced by multiple water sources.

6. *CB45*: A total of four water column PCB samples were collected at site CB45. Concentrations varied by approximately a factor of 2 (0.210 ng/l to 0.387 ng/l). The congener patterns observed at CB45 varied substantially during the study period. For example, the sample collected on July 24, 1996 had a congener pattern which was quite similar to the pattern observed within the inner-bay. However, two of the remaining three samples, and particularly the sample collected on June 14, 1996, showed a markedly different congener pattern. In these two samples there was a very significant elevation in higher chlorinated congeners. Furthermore, many of these higher chlorinated congeners, including those with the highest concentrations (IUPAC #s 203/196 and 201), are not present in Aroclor 1242 - the primary Aroclor present in the Wilcox Dock waste bed.

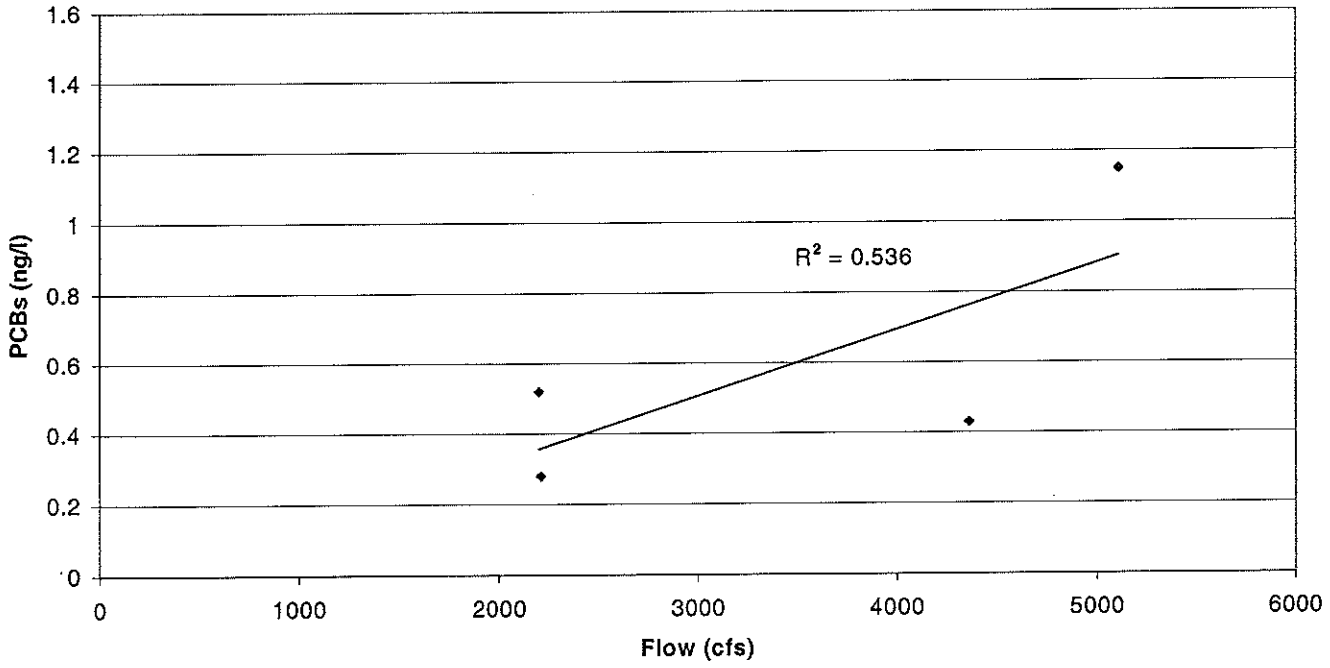
7. *LTM14*: A total of two water column PCB samples were collected at site LTM14. The concentrations of the two samples varied by only about 2 percent (0.071 ng/l and 0.073 ng/l), however, the congener patterns observed varied somewhat. The concentrations were so low as to preclude realistic congener pattern comparisons.

8. *LTM26*: A total of three water column PCB samples were collected at the LTM26 site. The concentrations varied by approximately a factor of 2.5 (0.099 ng/l to 0.244 ng/l). The concentration of two of these samples were so low as to preclude realistic pattern comparisons. The congener pattern in the remaining sample showed some resemblance to the pattern observed in the inner-bay. This later observation is somewhat surprising given that LTM26 is south of Cumberland Bay.

9. *LTM36*: A total of two water column PCB samples were collected at the LTM36 site. The concentrations varied temporally by approximately 25 percent (0.221 ng/l and 0.284 ng/l). The congener pattern for these two samples varied considerably. The August 19th sample fell somewhere between the pattern observed in the inner-bay and a pattern characteristic of Aroclor 1254. However, the June 18th sample appeared quite similar to the pattern observed in Aroclor 1260, with the exception of a pronounced presence of IUPAC #s 31/28.

Comparison of results from sites LTM26 (average PCB concentration of 0.147 ng/l) and LTM36 (average PCB concentration of 0.253 ng/l), representing conditions south and north of the bay, respectively, are consistent with the hypothesis that PCB loading from the bay is influencing the main lake north of the bay. However, this finding is based upon only two data points at each of the sites. Furthermore, the Aroclor pattern observed in one of the LTM36 samples presented a congener pattern distinctly different from the pattern of the waste bed.

Figure IV.2: Plot of Total PCB concentration versus flow for Saranac River.



A more thorough discussion of the water column PCB results and quality control procedures can be found in Appendix B.

PISCES

While PISCES results in other studies have been used to derive water column PCB concentrations, our efforts to derive water column PCB concentrations from the PISCES data were deemed unsuccessful. Computed water column concentrations were some 10-100 fold higher than the observed water column PCB concentrations discussed above. Thus, the following discussions will be confined to actual PCB mass uptake by the PISCES units, rather than computed concentrations. It should be noted that for the 1995 deployment the field blank was contaminated and had a recorded PCB mass of 555.3 ng. In contrast, the 1996 field blank had a recorded PCB mass of 8.3 ng. As will be shown below in Figure IV.6, the 1995 blank would appear to have been contaminated with Aroclor 1254.

The PISCES results are summarized in Table IV.3. The results were, for the most part, consistent with the water column PCB measurements, in that a PCB gradient was observed, with higher PCB uptake observed in the inner bay, and lower PCB uptake measured in the outer bay and main lake. The PISCES gradient was, however, less pronounced than the gradient observed for actual water column measurements. For example the ratio of PCB (mass or concentration, respectively) at site CB5 vs site CB30 was 2.0 for the PISCES and 9.6 for the water column measurements. Furthermore, there was one rather glaring exception to this gradient, this occurred for the August, 1996 deployment at CB45 at a depth of 34 meters. In this instance, the total uptake of PCB was 1,499.4 ng, or approximately 3 times the uptake observed at site CB5. Possible reasons for this very high result include: (1) unit might have come in contact with the bottom sediments due to its proximity to the lake bottom - the unit was deployed at a depth of 34 meters and total site depth was recorded to be 36 meters - thus, wave action during the deployment may have resulted in the unit being submerged in bottom sediments at times; (2) the depth of deployment might have accelerated transport of PCB across the permeable membrane; and/or (3) might indicate the existence of a nepheloid layer which is transporting PCB along the bottom of the bay.

This latter scenario raises significant concern with respect to contaminant transport and model projections. As will be discussed below, the model developed for this study assumes PCB concentrations are vertically homogeneous within the water column. If PCB contamination is disproportionately being shunted along the bottom of the bay, it would represent an additional, and possibly significant, flux from the bay to the main lake. Unfortunately, time and resource constraints, precluded follow-up work on this issue. Ideally, such a deployment should be repeated, with the deepest deployment being tethered to a rigid pipe anchored securely to the bottom. These findings warrant additional study, and may suggest the need for vertical segmentation of the mass balance model.

The congener patterns observed in the PISCES were, by and large, as expected. The patterns observed within the inner bay (stations CB5, CB12, and CB15) were similar to the patterns observed in the waste bed. The patterns observed in the outer bay (station CB30) and the main lake (CB45 and LTM36) were less definitive. A more comprehensive discussion of congener results is presented below.

Table IV.3: PISCES PCB data summary.

Site	Deploy Depth (m)	Mean Mass (ng)	n	Individual Deployments (ng)
CB5	2	465	3	523.8, 546.9, 324.4
CB12	8	480	2	378.9, 580.2
CB15	2	374	2	406, 341.5
CB30	2	na	1	195.8
CB30	8	250	2	212.6, 287.4
CB45	2	na	1	239.4
CB45	12	na	1	231.6
CB45	24	218.5	2	231.6, 205.4
CB45	34	na	1	1,499.4
Valcour Island	2	na	1	304.4
Valcour Island	30	na	1	198.3
LTM36	30	na	1	89.5

Sediment Traps

Sediment trap results are summarized in Table IV.4. Mean settling rates ranged from 1,135 mg/m^2-day in the main lake (site LTM36) to 2,039 mg/m^2-day at the mouth of the bay (site CB30). The rates recorded are within the range of values recorded for fresh water lakes (Mudrock, et al., 1991), and are consistent with expectations of higher settling rates in the bay than in the main lake. PCB deposition rates averaged 0.75 mg/m^2-year at sites 30 and 45.

Table IV.4: Summary of settling trap deployments.

Station	Depth (m)	(n)	Solids Settling Rate (g/m^2/day)	Settling Velocity (m/day)
30	10-12	4	2.04 (0.54 - 3.29)	1.02 (0.45 - 1.64)
45	24	5	1.37 (1.10 - 2.17)	0.90 (0.30 - 1.56)
45	34	3	1.75 (0.53 - 3.21)	0.83 (0.28 - 1.89)
LTM26	28	1	0.45	0.15
LTM36	35	1	1.14	1.13
Avg. 30/45	-	12	1.55	0.89

As discussed above, sediment trap deployments were restricted to deep-water areas due to known problems with trap deployments within shallow, non-stratified areas. Unfortunately, this leaves a fairly large unknown with respect to settling rates within the inner bay. Presumably, settling rates in the inner bay are somewhat lower due to current patterns and resultant horizontal particle vectors. However, actual settling rate magnitudes at these sites can not be accurately estimated.

The congener patterns observed in the sediment traps were, for the most part, quite similar. They also appeared to be skewed toward higher chlorinated congeners relative to the water column and/or PISCES data. This is not unexpected, given the fact that the traps are selectively capturing particulate matter, which would preferentially sorb higher chlorinated congeners. Once again, congener results will be discussed more fully below.

Sediment Cores

Three sediment cores were collected from the bay and main lake as part of this study. An additional sediment core (core 99), collected during 1994 in close proximity to CB12, will also be discussed. Unfortunately, the cores from sites CB30 and LTM36 were of little historical value because they failed to show discernible ^{137}Cs profiles.

Figures IV.2 and IV.3 show the ^{137}Cs and total PCB concentration profiles for the core at LTM26 and a core taken during 1994 (core 99).

Figure IV.3: ^{137}Cs and total PCB profiles for 1994 sediment core near site 12.

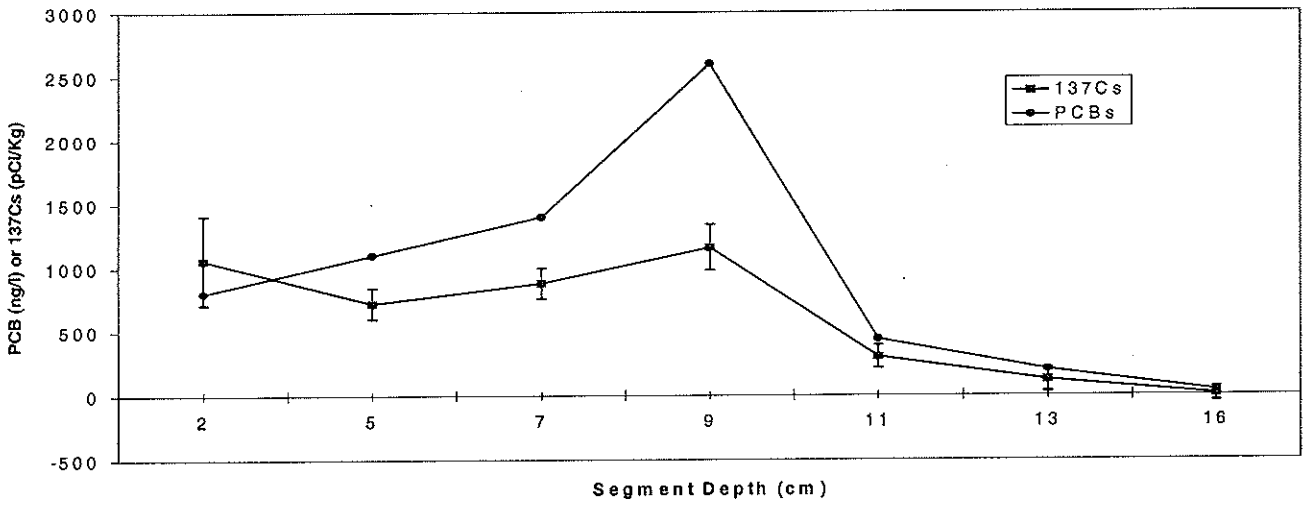
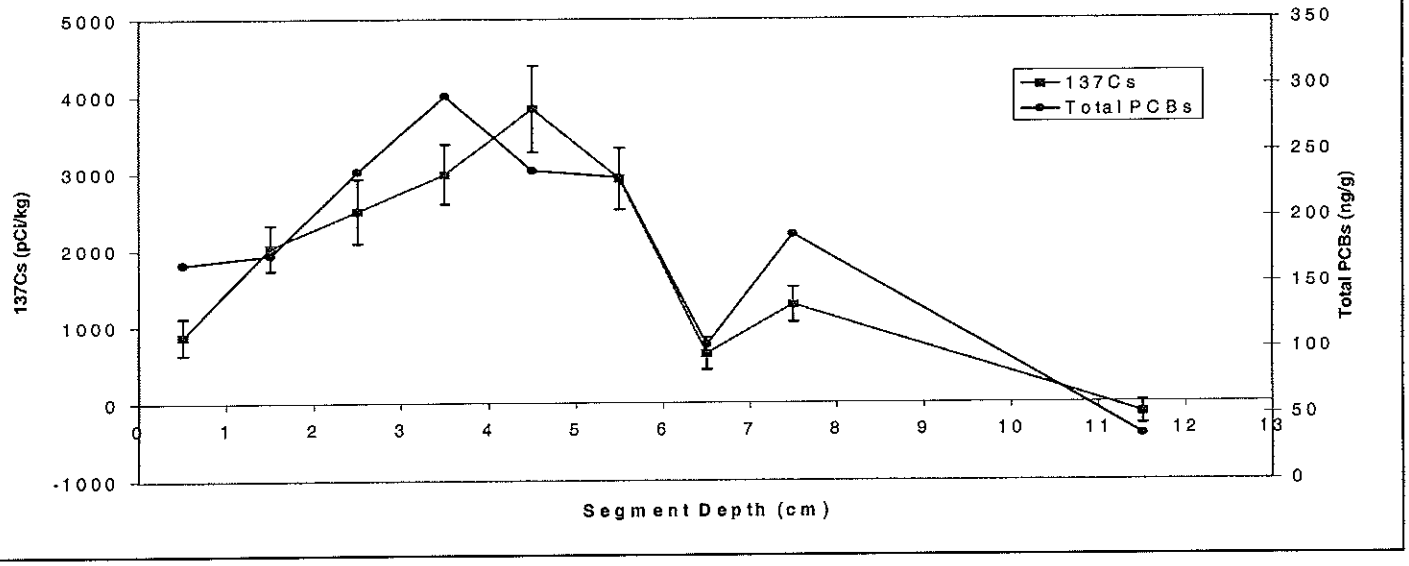


Figure IV.4: ^{137}Cs and total PCB profiles for LTM26 sediment core.



^{137}Cesium, a by-product of nuclear weapons testing, provides two useful markers for the dating of sediment cores. The first marker, an initial ^{137}Cs horizon, corresponds to the beginning of nuclear weapons testing. This is generally believed to represent the early 1950s. The second marker, the ^{137}Cs peak relates to the peak in nuclear fallout. The peak is generally thought to have occurred in 1963 (Davis, et al., 1984).

The inner-bay core (Figure IV.3) indicates that PCB concentrations within the bay increased significantly just prior to the ^{137}Cs peak (between 9-11 cms), suggesting that the primary source of contamination to the bay began sometime during the early 1960s. This is consistent with the potentially responsible parties (PRP) investigation, and the finding that paper mills discharging waste materials to the northwest corner of the bay were processing secondary fiber (recycled waste paper) which may have been contaminated with Aroclor 1242 (NYSDEC, 1997). The plot shows relatively low PCB concentrations below 11 cms, indicating a relatively distinct change within the bay during this time frame. ^{137}Cs concentrations decline to non-detectable levels at about 18 cms. Thus, the sedimentation rate within the inner-bay is estimated to be between 0.3-0.4 cm/year (0.3 cm/year based upon ^{137}Cs peak and 0.4 cm/year based upon ^{137}Cs horizon). The LTM26 core (Figure IV.4) from the main lake showed a similar chronology with a marked increase in PCB concentration just prior to the ^{137}Cs peak and subsequent decline thereafter. Net sedimentation rates for the inner bay core and main lake core at LTM26 were 0.3 cm/yr and 0.15 cm/yr, respectively. These sedimentation rates are within the range of sedimentation rates generally recorded for lakes (Mudrock, et. al, 1991), and appear reasonable in that the more productive bay exhibits a higher sedimentation rate than the main lake.

The similarity in temporal patterns (PCB spike corresponding to ^{137}Cs peak) from these two cores might suggest similar sources of contamination. However, while it is fairly certain that PCB contamination in the inner bay core came primarily from the Wilcox Dock waste bed, the evidence is not conclusive that the source of contamination at LTM26 was also the Wilcox Dock waste bed.

In the case of the inner bay core, while there is a bit of ambiguity with respect to the Aroclor determination, the pattern of contamination in the sediment core and the prevailing pattern in the waste bed are similar. The ambiguity arises from the fact that the contamination pattern observed in the sediment core near CB12 was determined to be Aroclor 1248, while the contaminant pattern in the waste bed has been consistently determined to be Aroclor 1242. However, the congener patterns for Aroclor 1242 and 1248 are quite similar with 1248 having a slightly greater ratio of higher chlorinated congeners than does 1242. Thus, it is apparent that the principle source of PCBs to the bay is the waste bed.

The case for the main lake is less definitive. As mentioned above, the original intent for the north/south cores was to discern the relative importance of Cumberland Bay contamination to the main lake. Given the prevailing flow in the lake, one would anticipate that contamination from Cumberland Bay would primarily affect areas north of the bay. Unfortunately, ^{137}Cs results from sediment cores taken at LTM36 (northern site) and CB30 (mouth of bay) indicate that both locations are subject to significant scour (lack of intact ^{137}Cs profile). In contrast, cores from LTM26 and the 1994 core taken proximate to CB12 show fairly classic ^{137}Cs profiles. Both cores show increasing ^{137}Cs levels from the surface down to a given depth (peak in nuclear weapons testing - corresponding to the early 1960s), and then decreasing levels thereafter (to ^{137}Cs horizon - corresponding to the beginning of nuclear testing in about 1950). The findings at LTM36 and CB30 were unexpected given the water depths at both sites. It is postulated that the internal seiche is responsible for the lack of deposition at these locations. These findings are consistent with those of Tom Manley from Middlebury College, who has been studying the hydrodynamics of Lake Champlain over the last several years. He has found evidence of significant erosion in areas around Valcour Island and Cumberland Head (personal communication, Manley, 1997). Thus, sediment core results from the main lake are insufficient for a north/south comparison of PCB depositional rates. The information that is available concerning the source(s) of PCBs to the main lake (particularly south of the bay) are mixed. Recall from the water column PCB results presented above, PCB concentrations were found to be higher north of the bay than south of the bay. Furthermore, from a hydraulic perspective, it is difficult to make a case for contaminant transport southward given the prevailing flow direction of the lake. On the other hand, as will be discussed below, the congener patterns observed at site LTM26 are, in certain instances, consistent with the congener pattern observed within the bay. This finding, as well as others, will be discussed further in the next section.

Congener Pattern Analysis

A cluster analysis was conducted on all PCB samples collected during the study using the statistical package Statistica - version 5.1 (StatSoft, Inc., 1997). The analysis was patterned after the work of Rachdawong and Christensen (1997), in that only a select group of congeners were compared (IUPAC #s 44, 52, 87, 101, 118, 138, 153, an 180). This congener group is fairly representative of the Aroclors in question while excluding certain problematic congeners. While we attempted to use the same group of congeners, a few adjustments were needed due to co-elution of certain congeners. For the PISCES, sediment traps, sediment cores, and fish sample analyses congener 87 co-eluted with congener 115, and congener 101 co-eluted with congener 90. For the water sample analyses congener 138 co-eluted with congener 163, and congener 153 co-eluted with congeners 132 and 105.

Obviously, congener concentrations varied significantly depending upon the environmental compartment sampled (e.g., bottom sediment samples generally contain higher concentrations than water column samples). Thus, to allow sample comparisons, data for each sample was normalized by dividing each congener value by the total of all selected congeners for the given sample. This operation results in relative congener values between 0-1.0.

Before proceeding with discussion of the analysis a few cautionary notes are in order. First, this analysis involves the comparison of congener patterns in samples collected from various environmental compartments. As such, it is important to keep in mind that individual congeners vary in their affinity for particular environmental compartments, and, thus, the environmental compartment being sampled will influence the congener pattern observed. As discussed earlier, lower chlorinated congeners (smaller IUPAC #s) have higher water solubilities (i.e., tend to associate more strongly with the dissolved phase of the water column), while higher chlorinated congeners (larger IUPAC #s) have lower water solubilities (i.e., tend to associate more strongly with organic material and sediments). Second, environmental processing results in a "weathering" of the original signal both spatially and temporally. The reader should keep the following points in mind: (1) *water column samples*: the dissolved phase tends to preferentially accumulate lower chlorinated congeners, while the particulate phase tends to preferentially accumulate higher chlorinated congeners; (2) *PISCES*: operate on only dissolved phase of water column (bias toward lower chlorinated congeners), however, the solvent hexane may preferentially scavenge higher chlorinated congeners which cross the membrane; (3) *sediment traps*: operate exclusively on particulate phase, thus, are biased toward higher chlorinated congeners; (4) *sediment cores*: similar bias as sediment traps; 5. *biota*: preferentially uptake higher chlorinated congeners. While these issues are not trivial, it was still deemed informative to compare the congener patterns observed in all PCB samples.

The tree diagram for the cluster analysis is shown in Figure IV.4. While, for the purpose of completeness, all PCB samples collected during this study (as well as samples from earlier studies) are included in the cluster diagram, certain of the samples (particularly several of the water column PCB samples) are of such low concentration that their positioning is of little value. The discussions to follow will focus upon those samples deemed of sufficient concentration and/or magnitude to draw legitimate conclusions. General findings from the analysis are as follows:

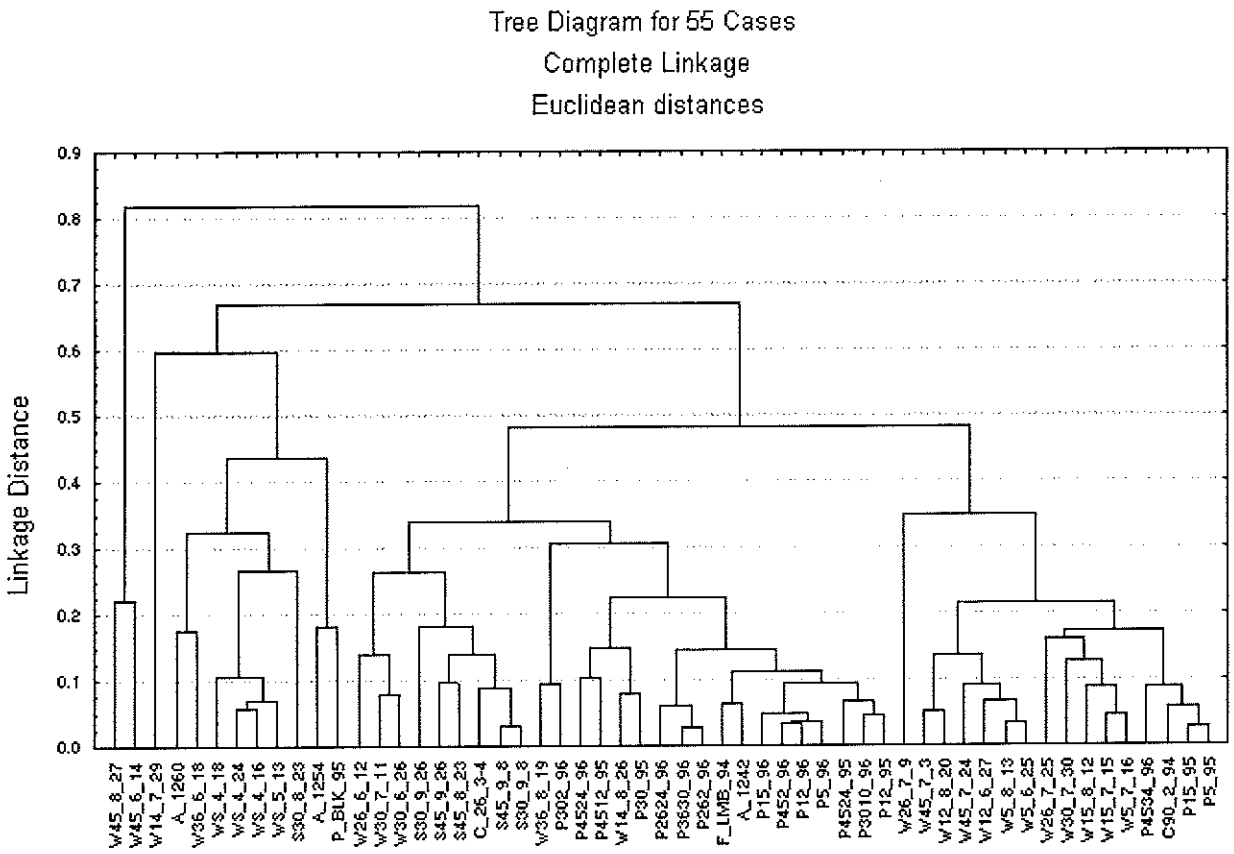
(a) All samples (PISCES and water column) from stations CB5, CB12, and CB15 are restricted to the upper half of the cluster diagram (from Aroclor 1242 on up). Also present in the upper half of the diagram are the core sample from the waste bed (C90_2_94), the fish sample from the inner bay (F_LMB_94), and Aroclor 1242;

(b) Samples from sites CB30, CB45, LTM26, and LTM36 fluctuate between the lower and upper half of the cluster diagram;

(c) Sediment trap samples are clustered closely together between Aroclors 1242 and 1254;

(d) All four Saranac River water samples are grouped together, are significantly distant from the inner bay samples and Aroclor 1242, and are situated between Aroclors 1254 and 1260.

Figure IV.5: Cluster analysis for all PCB samples.



Key

W: water sample
P: PISCES sample
S: Sediment trap sample
C: Core sample
F: Fish flesh sample
A: Aroclor

Findings "a" and "d" would suggest that the main source of contamination to the inner bay (represented by stations CB5, CB12, and CB15) is the waste bed adjacent to Wilcox Dock. The similarity (proximity within cluster diagram) between contamination patterns in the waste bed core and contamination patterns within the inner bay samples, coupled with the dissimilarity between the Saranac River samples and the inner bay samples would support the connection between the waste bed and contamination in the inner bay. Thus, while it is clear that the Saranac River is contributing PCBs to the bay, the clumping of the Saranac samples and there distance from their inner-bay counterparts, indicate that the river is not the principal source of PCBs to the bay.

The situation in the outer bay and main lake (represented by stations CB30, CB45, and the long-term monitoring stations) is somewhat more equivocal. There are instances when the outer bay and main lake stations from LTM26 northward appear related to the contaminant patterns within the inner bay. For example note P4534-96, which is a PISCES sample from station CB45 at 34 m depth taken in 1996, which is closely associated with the core sample taken from the waste bed (C90-2/94). On the other hand, there are instances when these stations appear

unrelated to the patterns observed in the bay. For example, note sample W45-8/27, a water column sample taken from station CB45 in August of 1996, which is quite unrelated to the pattern shown in the waste bed core. One hypothesis for this temporal variability at a given station is that the internal seiche causes waters of different origins to pass a given station. Thus, it is conceivable that on certain occasions Cumberland Bay water predominates at sites CB30 and CB45, while in other instances main lake water predominates.

Congener plots for selected samples are presented in Figures IV.6 & IV.7. The plots reinforce the results of the cluster analysis shown in Figure IV.5, and provide a more tangible illustration of the pattern similarities observed. Toward these ends, the reader should focus their attention on the overall congener pattern of the samples, while remaining aware of the caveats expressed earlier concerning inter-media comparisons. Additionally, the following points should be kept in mind: (1) congeners reported (x-axis) vary somewhat between samples from different media due to slight variations in analytical protocol; and (2) reporting units (y-axis) vary depending upon the media sampled and are not included. While these issues preclude a quantitative comparison of these samples, a qualitative comparison of congener patterns remains a viable exercise. The reader's focus should be directed toward the general congener pattern observed for the sample. Finally, for those unfamiliar with the congener patterns found in Aroclors 1242, 1254, and 1260, it is suggested that they begin by committing the general pattern of these compounds to memory (see Figures IV.6a, IV.7a, & IV.7h, respectively).

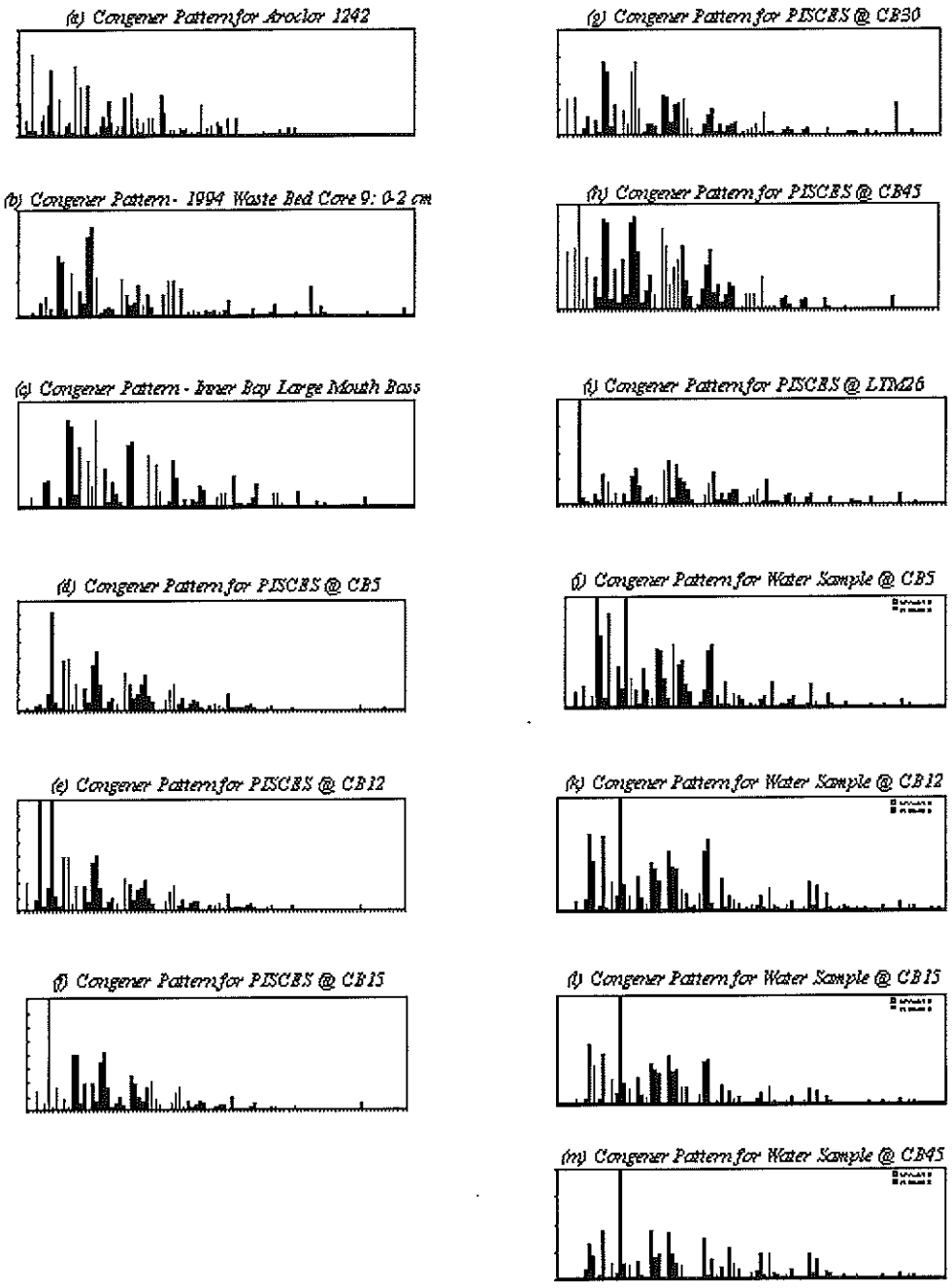
Congener plots will be presented in association with the Aroclor pattern deemed most representative of the sample. These associations are consistent with the cluster diagram developed above. However, given the number of samples collected, only selective plots are presented here. The samples chosen for display are considered either representative of the compartment/site in question and/or illustrative of the pattern variation observed in the compartment/site.

The congener pattern in the first series of plots (Figures IV.6 b-m) most closely resemble the congener pattern present in Aroclor 1242 (Figure IV.6a). These plots are characterized by primarily lower to middle chlorinated congeners with little or no higher chlorinated congeners. Aroclor 1242, in its pure form, is devoid of congeners greater than IUPAC 180.

Once again, note that all inner bay samples (all PISCES and water column samples from sites CB5, CB12, and CB15) are consistent with the congener pattern of the *waste bed core*, thus suggesting a direct link between the waste bed and water column contamination within the inner bay. Also note that the congener pattern from several PISCES samples collected from the outer bay and main lake also resemble the congener pattern of the waste bed and Aroclor 1242. As discussed earlier, this later observation is not consistent over time and in other instances the congener pattern observed in the outer bay and main lake sites appear to resemble higher chlorinated Aroclors. Finally, note the similarity in congener pattern for the large mouth bass collected from the inner bay in 1996. This pattern is consistent with other fish sampled from the inner bay.

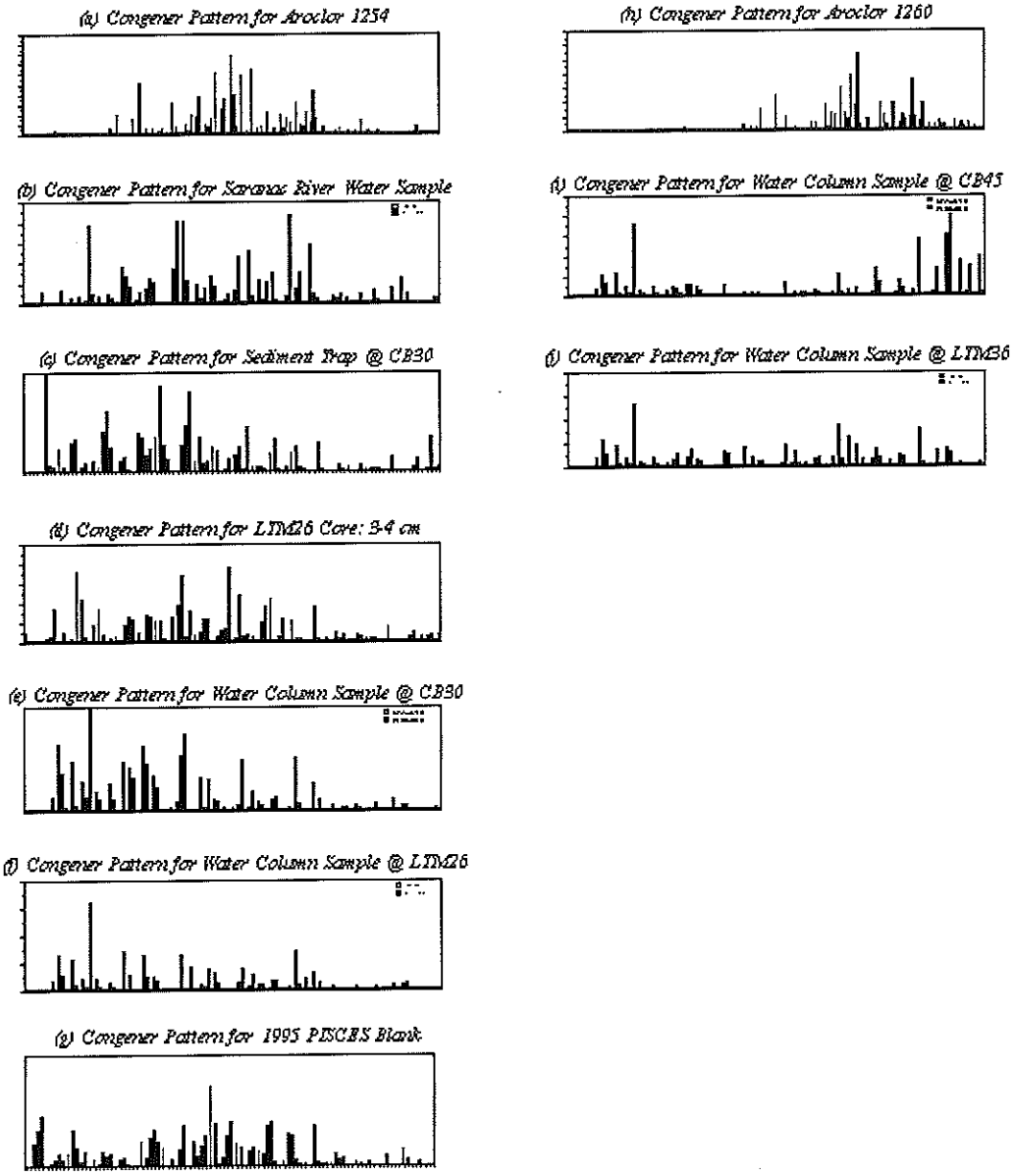
Perhaps most remarkable of this subset, is the PISCES sample collected at LTM26 (Figure IV.6i) in 1996. This site is located several miles south of Cumberland Bay, thus, one might assume the site to be out of the influence of Wilcox Dock and Cumberland Bay. While the congener profile is not a definitive link to the waste bed, and in fact appears contradictory to findings on other occasions, it does raise questions concerning the influence of Cumberland Bay on southern portions of the main lake.

Figure IV.6: Congener Patterns for Samples Resembling Aroclor 1242



The next series of plots (Figures IV.7 b-g) most closely resemble the congener pattern present in Aroclor 1254 (Figure IV.7a). These plots are characterized by congeners primarily in the mid-chlorinated range, with some presence of higher chlorinated congeners.

Figure IV.7: Congener Patterns for Samples Resembling Aroclors 1254 and 1260.



Plots in this series include a Saranac River water column sample (Figure IV.7b), a sediment trap sample from site CB30 (Figure IV.7c), a sediment core segment collected at site LTM26 (Figure IV.7d), water column samples collected at sites CB30 and LTM26 (Figures IV.7e and IV.7f, respectively), and the 1995 PISCES blank (Figure IV.7g).

While the congener pattern similarities between Aroclor 1254 and this series of samples are not as definitive as the similarities shown for the inner-bay samples and Aroclor 1242, they are considered sufficient to warrant concern about an additional source of PCBs to the main lake.

Most remarkable of this series of samples are the two LTM26 samples, which appear to indicate a distinctly different congener pattern than was observed in the waste bed. This stands in contrast to the PISCES sample collected at LTM26 (see Figure IV.6i), which appears consistent with the congener pattern observed in the waste bed. However, this finding, of a distinctly different Aroclor pattern from that found in the inner-bay, is consistent with: (1) our initial hypothesis that this site would not be influenced strongly by Cumberland Bay due to the prevailing south-to-north flow in the lake; and (2) past analyses suggesting that the contamination pattern in fish from the main lake are consistent with Aroclor 1254/1260. Thus, while conditions at LTM26 are somewhat equivocal, there would appear to be an additional source of PCB contamination, distinct from the Wilcox Dock waste bed, exerting an influence at this site. Furthermore, the sediment core from LTM26 represents an integrated view of conditions at the site, suggesting that Aroclor 1254 is the predominant congener signal occurring at LTM26.

As a final comment about this series of samples, the contamination pattern observed in the 1995 PISCES blank would appear to be consistent with the congener pattern of Aroclor 1254. The source of this contamination remains unclear, and, fortunately, did not recur in subsequent samples.

The final series of plots (Figures IV.7i-j) most closely resemble the congener pattern found in Aroclor 1260 (Figure IV.7h). These plots are characterized by primarily higher-chlorinated congeners. While this subset consisted of only two samples, they were quite interesting. The samples were water column samples collected at sites CB45 (Figure IV.7i) and LTM36 (Figure IV.7j). The CB45 sample appears somewhat suspicious in that a relatively large percentage of the higher chlorinated congeners reported occurred in the dissolved phase - one would expect to find the majority of higher chlorinated congeners to be associated with the particulate phase. However, the sample collected from LTM36 is quite defensible in this regard. There is also an additional sample collected at LTM36, which is consistent with the congener pattern shown in this sample. As in the previous discussion of samples consistent with the congener pattern of Aroclor 1254, this would again suggest the existence of an addition source(s) of PCBs to the main lake, beyond the waste bed in Cumberland Bay.

While this study suggests the existence of an additional source(s) of PCBs to the lake, it can offer only limited insight as to its possible location of such a source(s), and can provide no insight concerning the actual source. PCB sampling results from LTM14 (located south of Burlington) were quite low (mean concentration of 0.072 ng/l). Thus, the most tenable location for an additional source(s) to the lake is within the watershed from around Burlington northward. The location of this additional source(s) might be within the lake itself, or within the contributing drainage basin. While atmospheric deposition derived from sources outside the basin remain a possibility, the existence of an apparent gradient within the lake would suggest a less homogeneous source(s), namely, a localized, in-basin source(s).

As will be presented next, the findings of the congener pattern analysis are, to a large degree, consistent with the results derived from the mass balance model. Both approaches support the premise that the Wilcox Dock hazardous waste site is the predominant source of PCB contamination to the inner portion of Cumberland Bay. Furthermore, both analyses are consistent with an assessment of the Saranac River as a secondary source of PCB contamination to the bay.

Modeling

A mass balance model is basically an accounting procedure, which tracks the movement of a contaminant through various environmental compartments. Figure IV.8 and IV.9 depict the various equations used in the mass balance model and provide a schematic of environmental processing, respectively.

Figure IV.8: Mass Balance Equations (adapted from Chapra, 1997).

Solids Equations

$$V_1\, dm_1/dt = Qm_{in} - Qm_1 - v_s A m_1 + v_r A m_2 + E'(m_L - m_1) \quad \text{(water column)}$$

$$V_2\, dm_2/dt = v_s A m_1 - v_r A m_2 - v_b A m_2 \quad \text{(mixed sediment)}$$

Contaminant Equations

$$V_1\, dc_1/dt = Qc_{in} - Qc_1 - v_v A F_{d1} c_1 - v_s A F_{p1} c_1 + v_r A c_2 + v_d A(F_{d2} c_2 - F_{d1} c_1) + E'(c_L - c_1) \quad \text{(water column)}$$

$$V_2\, dc_2/dt = v_s A F_{p1} c_1 - v_r A c_2 - v_b A c_2 + v_d A(F_{d1} c_1 - F_{d2} c_2) \quad \text{(mixed sediment)}$$

where,

- Q = flow (L^3/T)
- V_1 = volume of water column (L^3);
- V_2 = volume of mixed sediments layer (L^3);
- A = area of the water body (L^2);
- m_1 = solids concentration in the water column of bay (M/L^3);
- m_2 = solids concentration in the mixed sediment layer (M/L^3);
- m_L = solids concentration in the water column of main lake segment (M/L^3);
- v_s = solids settling rate (L/T);
- v_r = solids resuspension rate (L/T);
- v_b = solids burial rate (L/T);
- v_v = volatilization rate (L/T);
- v_d = diffusion mixing velocity (L/T);
- E' = bulk dispersion coefficient (L^3/T);
- c_1 = total concentration of contaminant in the bay water column (M/L^3);
- c_2 = total concentration of contaminant in the mixed sediment layer (M/L^3);
- c_L = total concentration of contaminant in the main lake water column (M/L^3);
- F_p = fraction of contaminant in particulate phase (unitless);
- F_d = fraction of contaminant in the dissolved phase (unitless).

The factors on the right side of the water column contaminant equation represent the following processes, inflow, outflow, volatilization, settling, resuspension, diffusion, and bulk dispersion. The factors to the right of the mixed sediment equation represent settling, resuspension, burial, and diffusion. Each unit process is defined and discussed individually below. The processes are grouped based upon whether they act as a loss, an input, or both to the water column. Processes which are deemed insignificant (e.g., PCB decay) within the model time scale are not discussed.

A one-dimensional horizontal and two-dimensional vertical (water column and mixed sediment layer) mixed reactor screening model was developed as part of this study. The model is developed using an annualized time-step. While these criteria simplify the model substantially, they were deemed appropriate given the goals and resources of the project. Preliminary work was also initiated on a more refined, horizontally discretized, model which includes a waste bed segment, inner bay segment, and outer bay segment. The models are developed with the modeling package STELLA V (High Performance Systems, 1997).

Loss Processes

Settling

Settling refers to the process by which suspended particulate material moves downward through the water column. Settling velocity can be derived by: (a) direct measurement using settling traps; or (b) application of Stokes Law (from Chapra, 1997):

$$v_s = \alpha (g / 18) (\rho_s - \rho_w / \mu) d^2$$

where

v_s = settling velocity (L/T);
α = a dimensionless form factor reflecting the effect of the particle's shape on settling velocity (for a sphere it is 1.0);
g = acceleration due to gravity (981 cm s^{-1});
ρ_s, ρ_w = densities of the particle and water, respectively (M/L^3);
μ = dynamic viscosity (M/L^3);
d = effective particle diameter (L).

As can be seen from the above equation, gravity is the driving force for particle settling. Additionally, settling velocity is directly related to particle properties (shape, density, and diameter) and inversely proportional to the viscosity of the medium.

Deployment of settling traps is the preferred approach due to site specific variations in several of the variables in the above equation. For example, in a real world environment it is unlikely to find uniformity in particle diameter and/or density. For this reason, settling traps were used as part of this study. Settling traps were deployed at Cumberland Bay stations CB30 and CB45 a total of 11 times during 1995-96 (between the months of June and September), and at Long Term Monitoring stations LTM26 and LTM36 for a single occasion in August, 1996. A summary of settling trap results is shown in Table IV.3.

The averages (for stations 30 and 45) of all trap data for which complete data sets were obtained, excluding one deployment at station 30 which showed anomalously high solids concentration in the slurry, are 1.55 g/m^2-day for solids settling rate and 0.89 m/day for settling velocity. The values for solids settling rate fall within the ranges reported for other lakes of 0.1-30 g/m^2/day (Mudroch, et al., 1991), as do the values for settling rates reported for both phytoplankton of 0.08-6.8 m/day and particulate organic carbon of 0.2-2.3 m/day (Chapra, 1997). The average settling rate for stations 30 and 45 (0.89 m/day) is used in the mass balance screening model.

Burial

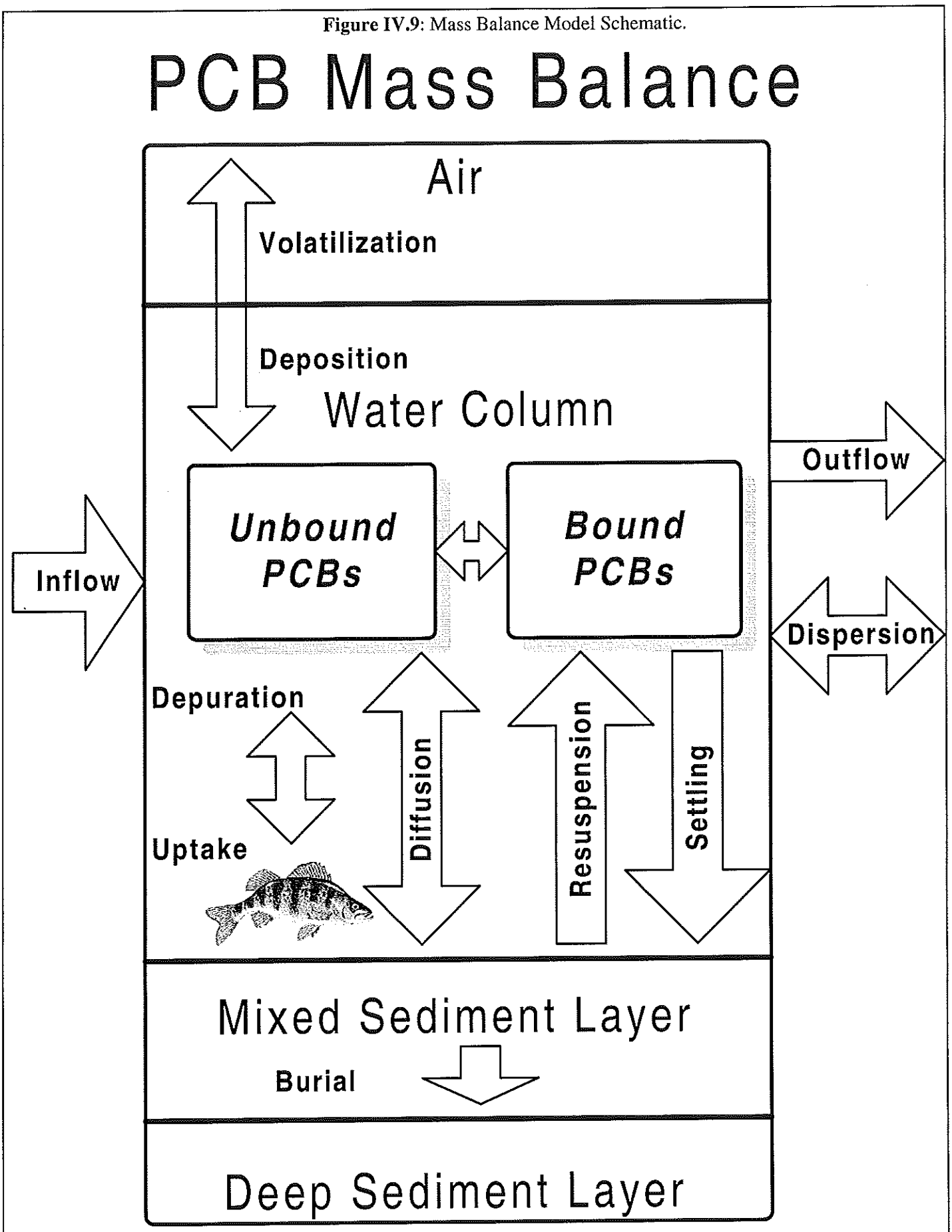
Burial refers to a "permanent" loss of bottom sediments, in the sense that those sediments are no longer susceptible to reentry into the water column via resuspension, etc. Factors that govern burial are current, wind speed and direction, particle adhesion, and water depth. The equation for burial, derived from a steady state mass balance on solids, is as follows:

$$v_b = (Q/A) ((m_{in} - m) / (1 - \phi) \rho)$$

where,

ϕ = porosity (unitless);
ρ = particle density (M/L^3)

Figure IV.9: Mass Balance Model Schematic.



Neither porosity nor particle density was measured during this study. The values used in the model, 0.75 and 2.6×10^6 g/m^3, respectively, were typical values taken from Chapra (1997). The burial rate derived for the 1-segment model is 8.7×10^{-4} m/year.

Sedimentation rates were derived from the dated sediment cores taken from the bay and main lake. Sedimentation rate generally refers to net sedimentation because the actual rate of accumulation is the result of both accumulation processes (e.g., settling and sediment focusing) and loss processes (e.g., scour or resuspension and decay). The sedimentation rates for the inner bay and the main lake were computed to be 0.30 cm/yr (3×10^{-4} m/year) and 0.15 cm/yr, respectively. Unfortunately, sedimentation rate could be derived from only one core within the bay, thus, the algorithm given above was used to derive burial rate. However, the theoretical rate is within an order of magnitude of the measured rate within the bay.

Obviously, the deeper the sediment layer the less susceptible it is to scour. For the purposes of modeling, burial is an operational definition based on a given sediment depth. The model assumes that bottom sediments below 4 cm are effectively buried.

Volatilization

Volatilization refers to the process by which a contaminant is lost from the water column to the overlying air column. The reverse scenario is also possible in which the contaminant can move from the air to the water column. However, for a situation like Cumberland Bay, where the water has a significant contaminant concentration, the transfer is primarily from water to air. The factors which control both the direction of movement and the rate of contaminant transfer are: (1) the difference in contaminant concentration between the water column (aqueous phase only) and the air, the larger the concentration gradient the higher the transfer rate; (2) turbulence at the water-air interface, more turbulence equals greater volatilization; (3) temperature in both water and air, higher temperatures produce higher volatilization. Transfer velocity is calculated based upon the two-film theory. The governing equations are as follows (Chapra, 1997):

$$v_v = K_l \left(H_e / (H_e + RT_a (K_l/K_g) \right),$$

$$K_l = K_{l,O2} (32/M)^{0.25},$$

$$K_g = 168 U_w (18/M)^{0.25},$$

where,

v_v = transfer velocity (L/T);
K_l = mass-transfer coefficient for the liquid film (L/T);
K_g = mass-transfer coefficient for the gas film (L/T);
H_e = Henry's constant (atm m^3/mole);
R = universal gas constant [8.206×10^{-5} atm m^3 (K mole)$^{-1}$];
T_a = absolute temperature (°K);
M = molecular weight of compound (gmole)
U_w = wind speed (L/T).

The transfer velocity (v_v) is computed to be 185.95 m/yr for Aroclor 1242, which has been identified as the primary Aroclor present in Cumberland Bay.

Beach Losses

While not a conventional component of a mass balance and not actually used in the mass balance, there is specific information available concerning sludge loss, and associated PCB losses, to the beaches north of Wilcox Dock (see Table IV.5). This information was derived from beach clean-up data during 1995-96.

This information might be of use in determining the rate of scour for the sludge bed over time. While the rate of scour is not attempted here, there are several methods that might be used to estimate the loss of PCBs from the

sludge bed. Possible approaches include: (1) changes in estimated sludge volume and mass over time; (2) extrapolation from beach cleanup estimates; and (3) extrapolation from water column PCB sample results at site CB5.

Table IV.5: Cumberland Bay Beach Cleanup Data (Clough, Harbor, & Assoc., 1996)

Roll-Off #	Disposal Date	Weight (kg)	Approximate Volume (m^3)	PCB Conc. (mg/kg)	Mass of PCBs (kg)
1	5/3/95	14,016	23.63	43.20	0.606
2	6/02/95	15,712	26.48	1.85	0.029
3	6/02/95	11,467	19.33	9.62	0.110
4	6/02/95	9,353	15.77	5.80	0.054
5	6/06/95	11,494	19.37	5.04	0.058
6	6/06/95	14,270	24.05	11.65	0.166
7	6/08/95	12,510	21.09	12.03	0.151
8	6/08/95	14,052	23.69	19.27	0.271
9	6/16/95	12,093	20.38	4.39	0.053
10	6/16/95	13,880	23.40	19.04	0.264
11	6/30/95	9,571	16.13	11.71	0.112
12	6/30/95	11,367	19.16	19.10	0.217
13	7/11/95	9,045	15.25	6.54	0.059
14	7/11/95	9,671	16.30	3.03	0.029
15	10/12/95	4,128	6.96	26.20	0.108
16	10/12/95	8,092	13.69	4.89	0.040
Totals		**180,721**	**304.68**		**2.327**

Input Processes

External Loading

There are two named tributaries entering Cumberland Bay, the Saranac River and Dead Creek (also known as Scomotion Creek). The Saranac is a large river, with a drainage area of 15.7 square kilometers (USGS, 1994), while Dead Creek is a relatively small stream. Given the disparity is discharge volumes and reported PCB concentrations for these two systems, Dead Creek is not included in the mass balance analysis.

The Saranac River is a flow-regulated river with a relatively long industrial history dating back approximately 3 centuries. Average flow from the Saranac River as measured at the USGS gage (#04273500) during the study period was 923 cfs (8.24×10^8 m^3/year). The average flow during the period of record (78 years) is 844 cfs (USGS, 1994), thus, flows during the study period were approximately 10 percent higher than the historical average. The average flow during the study period is used for model calibration. The loading estimation program FLUX is used to determine solids loading from the Saranac River. The estimated annual solids load during the study period was 9.2×10^6 kg/yr.

Over the years, there have been several known or suspected sources of PCBs along the Saranac River. Thus, it was important to estimate the PCB load from the river. Given the prohibitive costs associated with PCB analyses, the Saranac River was sampled for PCBs on only 4 occasions during the study period. The average PCB concentration during the study period was 0.596 ng/l total PCBs, with a particulate average of 0.454 ng/l and a dissolved average of 0.142 ng/l. The total PCB value is used in the mass balance model.

Resuspension

Resuspension refers to the process by which bottom sediments are reintroduced into the water column. The factors which influence resuspension include wind (both speed and direction), internal seiche, navigation, sediment cohesion, and water depth. Resuspension is notoriously difficult to measure. We had hoped to develop an empirical relationship between wind (velocity and direction) and TSS, which could be used to estimate resuspension based on wind. It was hypothesized that if one could derive such a relationship, then by backing out autochthonous production and tributary loading one could arrive at a resuspension rate for the bay. Unfortunately, attempts to develop a correlation between wind and TSS proved unsuccessful.

A more theoretical approach, and the approach used in the mass balance model, involves use the following equation (Chapra, 1997):

$$v_r = v_s (m / (1 - \phi) \rho) - v_b$$

where,

v_r = resuspension rate (L/T);
v_s = settling rate (L/T);
v_b = burial rate (L/T);
m = suspended solids concentration in the water column (M/L^3);
ϕ = porosity (unitless);
ρ = particle density (M/L^3)

The resuspension rate used for the massbalance model is 7.12×10^{-5} m/yr, and is derived from the previous equation.

Other Processes and Model Details

Bulk Dispersion

Bulk dispersion refers to the process by which water moves between adjacent compartments, and is composed of turbulent mixing and molecular diffusion. In Lake Champlain generally, and Cumberland Bay specifically, the internal seiche is the main driving force for dispersion. The bulk dispersion coefficient is derived based upon a conservative tracer, in this instance chlorides. The steady state equation used to derive the bulk dispersion coefficient is as follows (Chapra, 1997):

$$E' = Q_{0,1}(s_0 + s_1) - Q_{1,2}(s_1 + s_2) / 2(s_1 - s_2)$$

where,

E' = bulk dispersion (L^3/T);
Q = flow (L^3/T);
s = chloride concentration (M/L^3).

The chloride data collected during this study is summarized in Table IV.1. Ideally, chloride data should show a gradient between sample locations (i.e., highest concentrations in the inner bay and lowest concentrations in the main lake, or visa versa). The data obtained during this study proved problematic in that no apparent gradient was found, in fact, the maximum chloride concentration occurs at CB30 which is in the middle of the sample grid.

The approach deemed most appropriate for chloride analysis was to aggregate stations CB5 and CB12 (average chlorides = 12.3 mg/l) for the inner bay and stations CB30 and CB45 (average chlorides = 12.59 mg/l) for the outer bay/main lake. This results in a concentration gradient of 0.29 mg/l and a bulk dispersion rate of 17.43 km^3/yr, or approximately double the 8.672 km^3/yr rate computed for the Diagnostic Feasibility Study (VTDEC and NYSDEC, 1997). We decided to use the rate derived in the Diagnostic Feasibility Study for model calibration based for the following reasons: (a) the earlier study had data from a longer time frame, thus, likely providing a better estimate of long term conditions; and (b) the earlier study provided a greater spatial representation for salinity in the main lake.

While chloride data is used as the conservative tracer for model calibration, we feel there are significant concerns over the use of chlorides in this capacity. Chloride is frequently the preferred choice as a conservative tracer for fresh water systems. The common scenario is that chlorides discharged by sewage treatment facilities gradually mix with the receiving water and set-up a steady-state chloride gradient from which to derive bulk dispersion. This scenario is, to a degree, compromised in Lake Champlain in that an industrial discharge at the south end of the lake exerts a nearly lake-wide effect on chloride levels.

Molecular Diffusion

Molecular diffusion refers to the process by which a contaminant will move from an area of higher concentration to an area of lower concentration. Molecular diffusion occurs within the following model compartments: (1) between bottom sediments and the overlying water column; (2) between the water column of adjacent segments – this was encompassed within the lumped parameter of bulk dispersion discussed above; and (3) between the water column and the overlying air - this instance was dealt with separately above as volatilization;

Molecular diffusion acts only on the dissolved fraction of the contaminant, and the equation used to derive the diffuse mixing velocity is as follows (Chapra, 1997):

$$v_d = 69.35\ (\phi)\ (M^{-2/3})$$

where,

v_d = diffuse mixing velocity (L/T)
M = molecular weight of the compound (gmole)

Model Segmentation

The mass balance model assumes the water column of the bay to be a completely mixed reactor with input from the Saranac River and exchange with underlying sediments and the main lake. The surface area of the bay, computed from a digitized image of the navigational chart for the bay, is 14.2 x 10^6 m^2, which is approximately 30 percent higher than that reported in the Diagnostic Feasibility Study (DFS) - 10.75 x 10^6 m^2 (VTDEC and NYSDEC, 1997). It is unclear why the previous study reported a substantially lower value. It is conceivable that variation in boundary delineation could account for part of the difference, however, it is difficult to envision that this could account for such a large difference. The model uses the surface area estimate from the present study. The discrepancy in surface area delineation is also reflected in volumetric estimates in the bay. This study estimates the bay volume at 9.9 x 10^7 m^3 (this is the value used in the model), while the DFS estimates the volume at 6.3 x 10^7 m^3.

Screening Model

Table IV.6 provides a summary of the input parameters for calibration, and calibration results are shown in Table IV.7. Observed values for TSS and PCBs are derived by taking a volume-weighted average of stations CB12, CB15, CB30, and CB45. Station CB5 is excluded from this average because it is considered reflective of a relatively small area, namely, the waste bed. With respect to CB45, while it is actually within the main lake, it is included in the average for the bay in order to expand the data set for the deeper bay. The fact that the station is relatively close to the bay, and the average PCB concentration is similar to that at station CB30, suggests that this is a reasonable step.

Table IV.6: Summary of input parameters for the one-segment model calibration.

Process/Parameter	Value	Source	Comments
Saranac River Load			
Saranac Flow (m^3/yr)	8.24×10^8	USGS	Gage # 04273500
Saranac PCB Conc. (ng/l)	0.6	Study	
Saranac TSS Conc. (mg/l)	7.28	Study	
Bulk Dispersion			
Bay Volume (m^3)	9.91×10^7	Study	Discrepancy with DFS.
Bulk Dispersion Rate (m^3/yr)	8.67×10^9	DFS	Based on chloride data from DFS.
Main Lake TSS Conc. (mg/l)	0.57	Study	
Main Lake PCB Conc. (ug/m3)	0.29	Study	
Settling			
Settling Velocity (m/yr)	324.85	Study	Settling Traps in deep water
Bay Area (m^2)	1.43×10^7	Study	Discrepancy with DFS.
Resuspension/Burial			
Particle Density (g/m^3)	2.6×10^6	Chapra	
Sediment Porosity (unitless)	0.75	Chapra	
Sediment PCB Conc. (ug/m^3)	1.5×10^6	Study	PCB conc.; 0-1 cm section of core near site 12.
Molecular Diffusion			
Molecular Weight of PCBs (gmole)	266.5	Chapra	Aroclor 1242
Volatilization			
K_{ow} (unitless)	5.29	Chapra	Aroclor 1242

Calibration

With virtually no manipulation of rate constants the one-segment model simulates observed water column concentrations for TSS and PCBs quite well. The predicted TSS concentration (0.77 mg/l) is about 15 percent higher than the observed value (0.66 mg/l), and the predicted water column PCB concentration (0.65 ng/l) is approximately 20 percent above the observed value (0.56 ng/l).

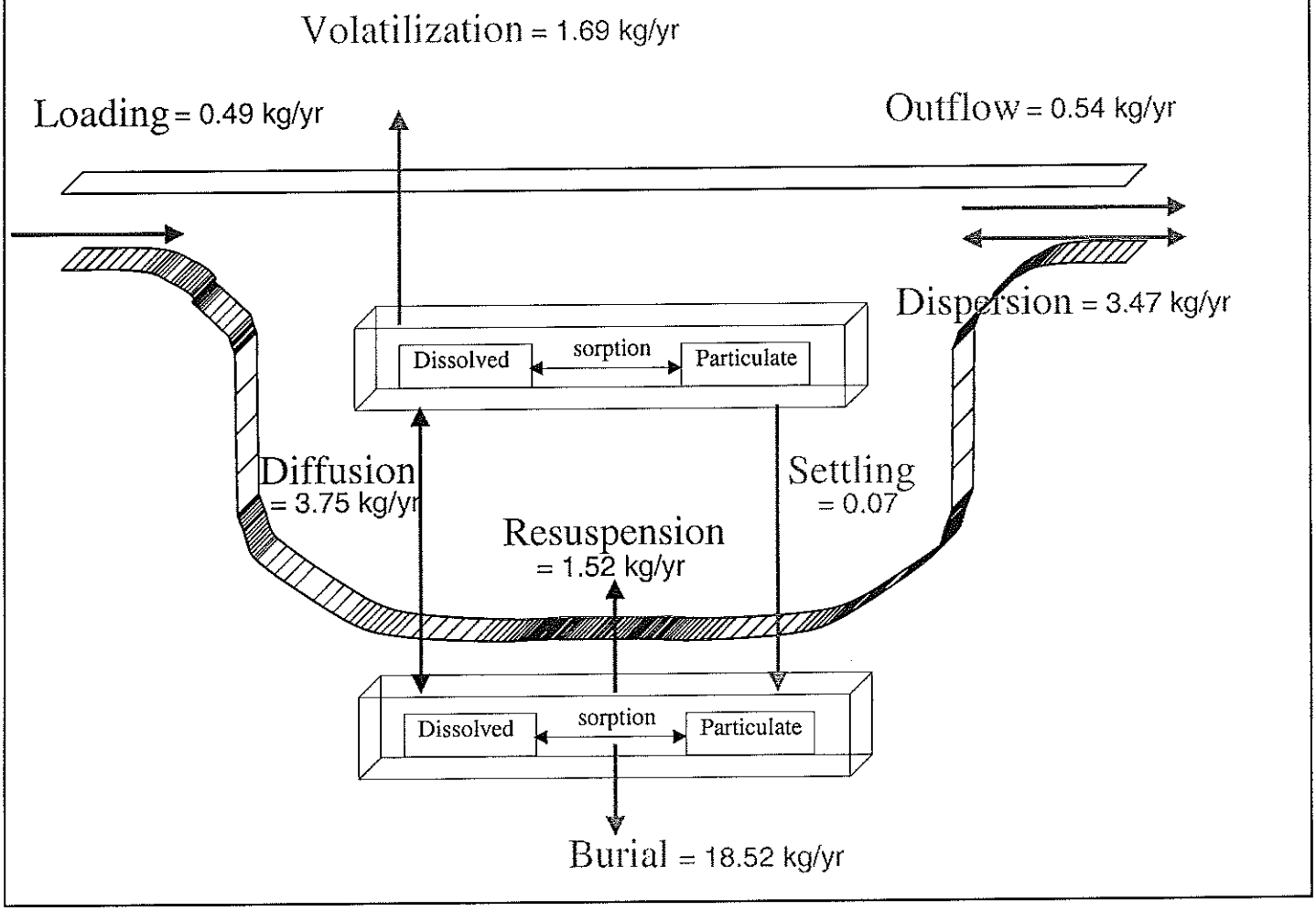
Thus, the model fulfills one of the two principal tests for model validity, namely, calibration. The second principal test of model validity, namely verification or validation, is not possible at this time, and will require collection of additional data under another set of conditions (different forcing functions). It is suggested that model verification be undertaken following site remediation. This would provide an ideal opportunity to: (1) assess the robustness of the model under distinctly different loading conditions; and (2) assess how well the model simulates remedial measures - see remedial simulations below.

Table IV.7: Model calibration results (observed versus predicted).

Parameter	Observed	Predicted
Water Column TSS Concentration (mg/l)	0.66	0.77
Water Column PCB Concentration (ng/l)	0.56	0.65

Figure IV.31 depicts PCB flux estimates within the study area, based upon the model calibration run. The numbers provided represent annualized estimates based upon study conditions.

Figure IV.10: Annualized PCB Flux Estimates.



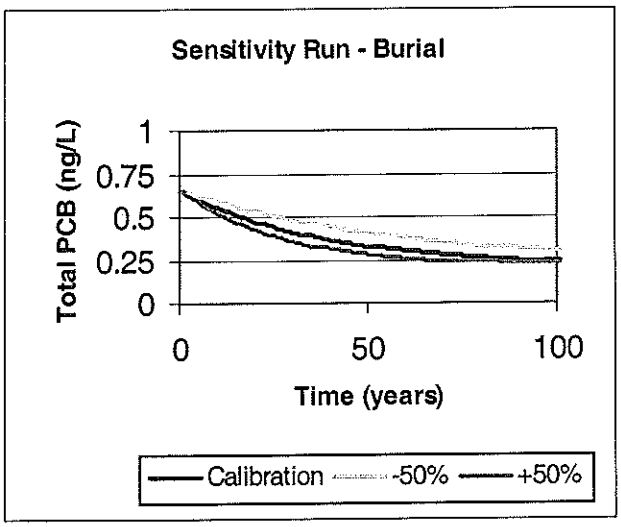
Model results indicate that the principal source of PCBs to the bay is from the sediments (composed of diffusion and resuspension processes), accounting for approximately 90 percent of the PCB load to the water column. This, of course, is somewhat misleading in that the model assumes a uniform concentration of 1.5 ppm within the sediment mixed layer and homogeneous releases throughout the bay, while, in actuality, conditions within the bay are quite heterogeneous, with a highly concentrated PCB source in a relatively small area of the bay. However, despite this disconnect, the model simulates average conditions reasonably well. A secondary source of loading to the bay is the Saranac River.

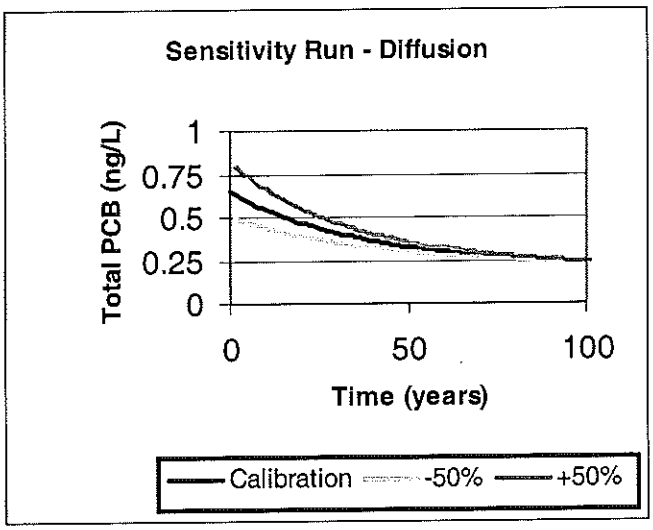
The primary loss mechanism for PCBs within the water column of the bay is deep burial, accounting for 76 percent of total PCB loss within the bay. Secondary losses include dispersion, volatilization, outflow and settling.

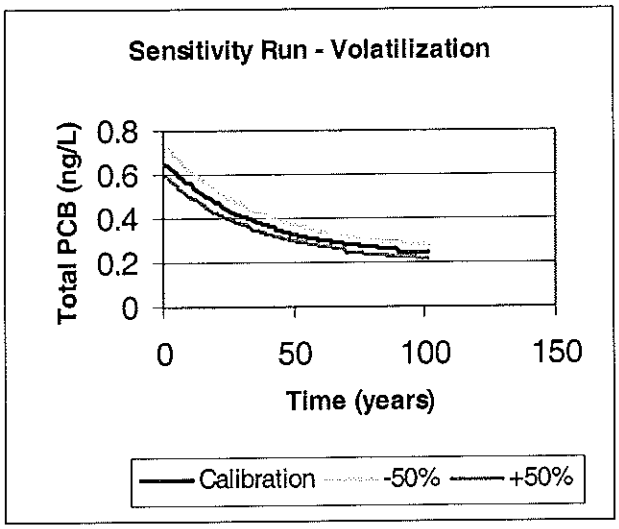
Sensitivity Analyses

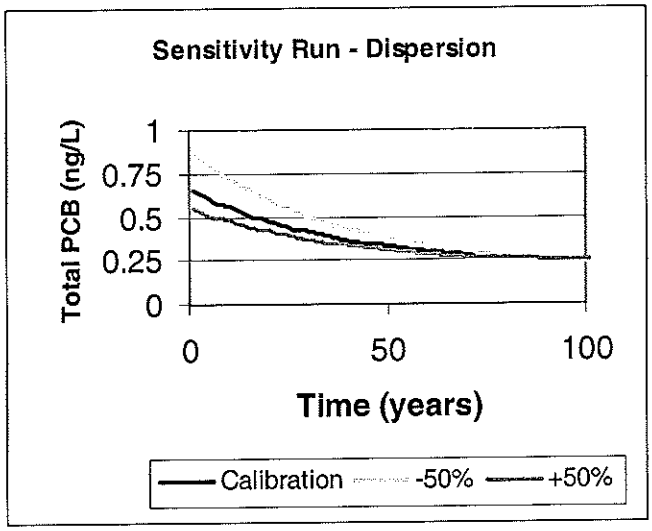
Sensitivity analysis runs were conducted for all major rate constants and model parameters. Each rate constant or parameter, where appropriate, was run at +/- 50 % of the calibration value, and the resulting water column total PCB concentration was computed. Results of the sensitivity runs are shown in Figure IV.32.

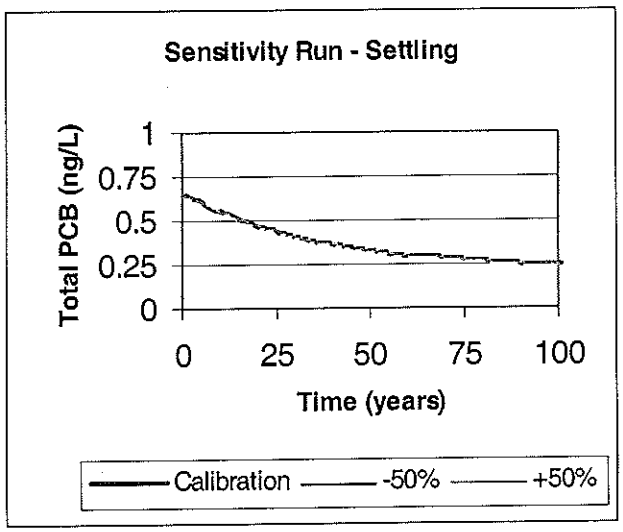
Figure IV.11: Sensitivity Runs for Selected Rate Constants.

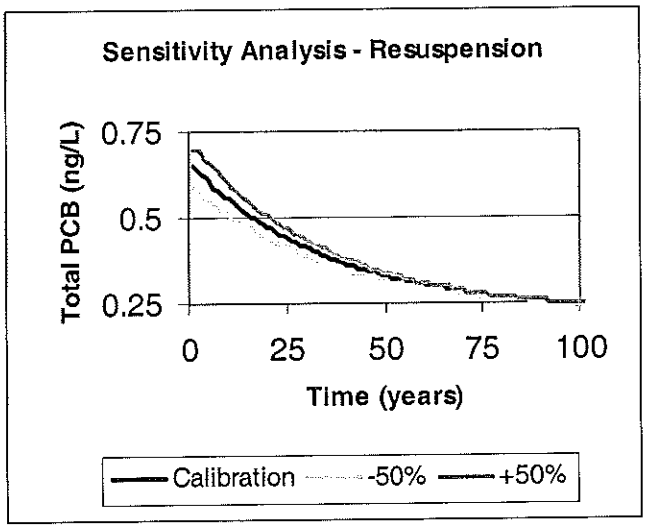












Simulation Model Runs

Several model runs were conducted to simulate possible remediation scenarios. As indicated earlier, the principle contaminant source to the bay, namely the Wilcox Dock waste site, has existed for approximately 30 years. As a result, a substantial proportion of the PCB mass originally associated with the waste bed has migrated beyond the 34 acre "waste site", and will not be removed during proposed remediation. Furthermore, the actual quantity of PCB contamination that has migrated from the waste bed, as well as the location of this contamination and its availability, remains uncertain.

Thus, the approach taken here will be to simulate a range of possible reductions. As discussed above, a screening model is not the ideal approach for modeling Cumberland Bay. Remediation simulations involve reducing the PCB concentrations in the mixed benthic layer throughout the bay by a set percentage, rather than the more realistic scenario of removing more highly contaminated sediments from a limited area. Once again, this is necessitated because of the simplifying assumptions inherent in the model.

The model is run using three reduction scenarios (50, 75, and 90 percent reduction in sediment PCB concentration). Model output is reported as resultant water column PCB concentrations relative to time after remediation.

Results of the three projections, as well as the no action scenario, are presented in Figures IV.12. The PCB concentration in the main lake (flat line at 0.25 ng/l) is included as a reference level. For all practical purposes this line can be viewed as an asymptote.

Figure IV.12: Model Projections for Remediation Scenarios

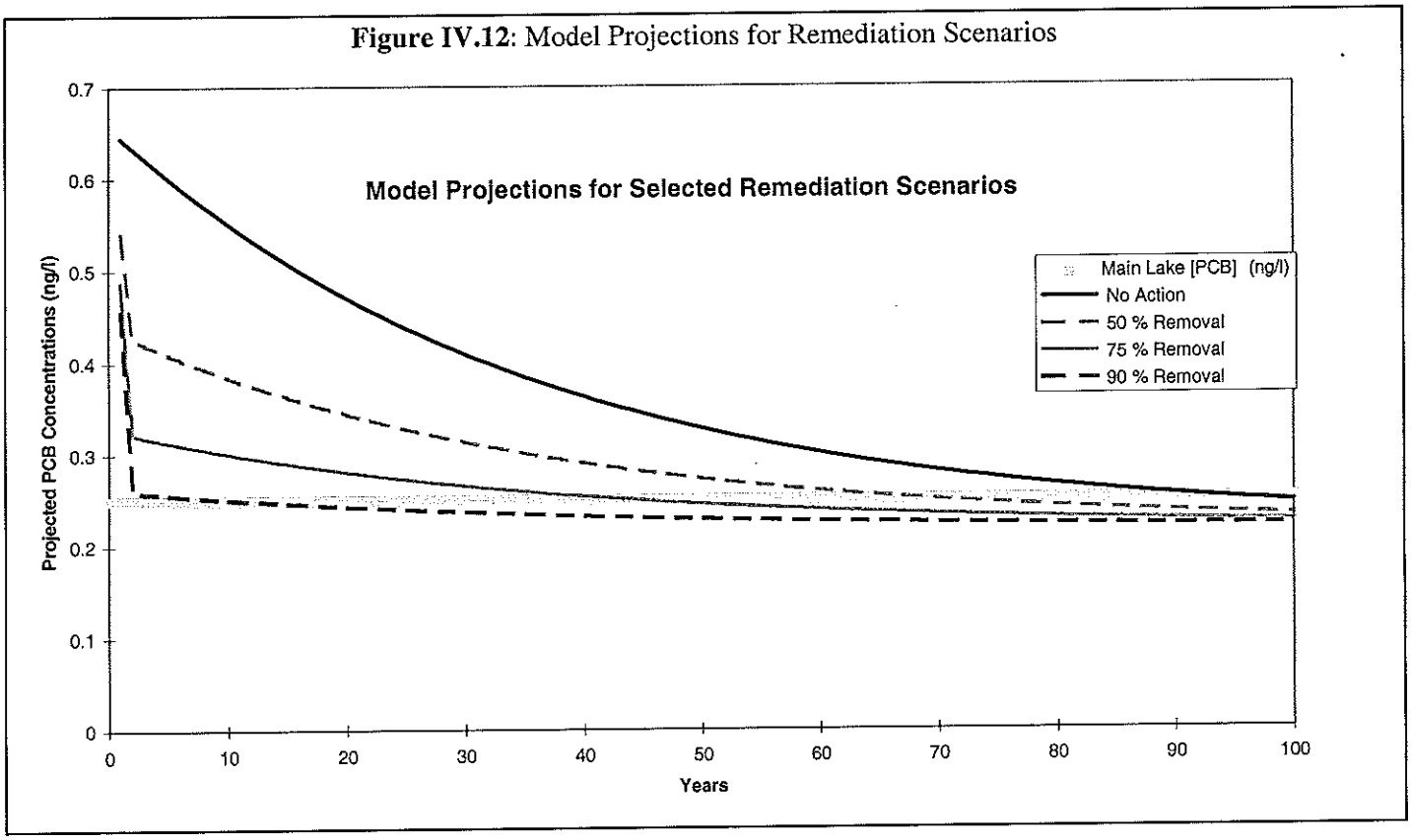


Table IV.8 provides a summary of estimated water column PCB concentration projections for the remediation scenarios.

Model predictions for the no action scenario are that PCB concentrations in the bay will remain above main lake levels for approximately 90 years, with concentrations of 0.59 ng/l and 0.47 ng/l at 5 and 20 years out, respectively. Model predictions for the 50 percent reduction scenario indicate that PCB concentrations within the bay will reach main lake levels in approximately 65 years, with concentrations of 0.41 ng/l and 0.34 ng/l at 5 and 20 years out, respectively.
Model predictions for the 75 percent reduction scenario indicate that PCB concentrations within the bay will reach main lake levels in approximately 40 years, with concentrations of 0.31 ng/l and 0.28 ng/l at 5 and 20 years out, respectively. Model predictions for the 90 percent reduction scenario indicate that PCB concentrations within the bay will reach main lake levels in approximately 6 years, with concentrations of 0.26 ng/l and 0.24 ng/l at 5 and 20 years out, respectively.

Table IV.8: Summary Results for Remediation Model Runs

Reduction Scenario (%)	PCB (ng/l) @ 5 years	PCB (ng/l) @ 20 years	Time (years) to PCB = 0.25 ng/l
0	0.59	0.47	90
50	0.41	0.34	65
75	0.31	0.28	40
90	0.26	0.24	6

Thus, as one would expect, all remediation scenarios predict a significant decline in water column PCB concentration shortly (within 5 years) after remediation of the waste bed. On a more sobering note, however, is the length of time before the bay reaches the concentration of the main lake (as represented by average water column PCB concentrations at site LTM26). Under the 90 percent removal scenario "background" concentrations are reached within a relatively brief 6 years, whereas, under the 50 percent removal scenario "background" concentrations are not attained for 65 years.

Preliminary Multi-Segment Model

As mentioned earlier, preliminary work has begun on a multi-segment model for the Cumberland Bay system, however, resource limitations preclude further development of the model.

There are several advantages of a multi-segment model over the initial model. First, as one would suspect, the multi-segment model provides enhanced spatial resolution with respect to model predictions. This additional spatial resolution could prove important to management decisions relating to fish consumption health advisories, remediation issues, etc. For example, it is conceivable that the localized fish consumption advisory might be narrowed if one could demonstrate a contamination gradient within the bay whereby the biota in the outer bay fell below actionable levels. A multi-segment model also provides a refinement with respect to specific unit processes within the bay. This is particularly important when the waterbody under investigation is heterogeneous, as is the case with Cumberland Bay.

The multi-segment model divides the bay into 3 horizontal segments, a waste bed segment, an inner bay segment, and an outer bay segment. Each horizontal segment is underlain with an associated mixed bottom sediment layer, and a deep burial layer. The area and volume estimates for the three-segment model are listed in Table IV.6

Table IV.9: Morphometry for preliminary three-segment model.

Segment	Area (m^2)	Volume (m^3)
Waste Bed	8.4×10^4	8.4×10^4
Inner Bay	6.7×10^6	3.0×10^7
Outer Bay	7.5×10^6	6.9×10^7

As mentioned above, the multi-segment model is in the preliminary stages of development. If additional funding becomes available, the multi-segment model will be more fully developed.

Transport/Fate Discussion

Bay

Results from this study indicate significant migration of PCB contamination from the Wilcox Dock hazardous waste site to the broader bay. Water column sampling within the bay shows a clear PCB concentration gradient with highest concentrations occurring in the northwest corner of the bay (adjacent to the waste bed), intermediate concentrations in the middle of the bay, and lowest bay concentrations in the outer bay. Perhaps most disturbing from a management perspective is the length of time that has elapsed between introduction of PCB contamination to the bay and proposed remediation of the waste site. Sediment cores collected from the bay indicate that PCB contamination levels within the bay increased dramatically during the early to mid 1960s. Thus, the Wilcox Dock waste bed has been subject to substantial scour for approximately 35 years, and a significant amount of PCB contamination has migrated beyond the boundaries of the existing waste site.

Study results indicate that the principal source of PCB contamination within the inner bay is the hazardous waste site adjacent to Wilcox Dock. An important caveat to this finding is, of course, that it refers to the existing 34 acre waste bed and contamination now dispersed within the bay which originated at the site. The conclusion that the Wilcox Dock waste bed is the primary source of PCB contamination within the inner bay is supported by several semi-independent lines of evidence.

The first line of evidence supporting the waste bed as the primary source of PCB contamination to the bay is the water column PCB gradient, which, in effect, provides a chemical "track or path" leading back to the origins of the contamination, in this instance the waste bed. The second line of evidence is the similarity in congener patterns observed at the inner bay sample sites and the waste bed. The congener patterns observed in the waste bed cores and all samples (water column, PISCES, and core) collected within the inner bay are similar, and consistent with Aroclor 1242. The congener pattern, in effect, provides a "fingerprint" of the contamination source. While similarity in congener patterns does not provide a direct link between the waste bed and the inner bay contamination, when coupled with the final piece of evidence, namely, the congener pattern observed in the Saranac River, it does provide a rational link based on deduction reasoning. This is due to the somewhat fortuitous fact that the Saranac River congener pattern is distinctly different from that observed in the inner bay and in the waste bed. The Saranac signal is indicative of a more highly chlorinated Aroclor (most likely Aroclor 1254). Thus, given the relatively limited universe of possible inputs to the bay (waste bed and/or Saranac River), the similarity of the waste bed and inner bay contamination coupled with the dissimilarity between the Saranac River signal and the inner bay contamination would support the premise that the waste bed is the primary source of contamination to the inner bay. Along a similar vein, the mass balance model results also provide a deductive case for the waste bed as the primary source of contamination to the bay. The mass balance model annualized loading estimates are as follows: (1) annual benthic load is estimated at 5.27 kg/yr - which is composed of a diffusive load of 3.75 kg/yr and a resuspension load of 1.52 kg/yr; and (2) advective flow from the Saranac River at 0.49 kg/yr. Thus, assuming the benthic load is primarily due to the waste bed, the Saranac River represents only 8 percent of the annual PCB load to the bay.

The principal loss mechanism for PCBs within the bay appears to be deep burial, which accounts for greater than 75 percent of the annualized PCB losses within the bay. Secondary loss mechanisms include dispersion (14 percent), volatilization (7 percent), advective outflow (2 percent), and settling (< 1 percent).

Saranac River

The annual PCB load from the Saranac River during the study period, based upon the average flow and the average PCB concentration, is estimated at 0.49 kg/year. This value may be somewhat skewed given the fact that PCB sampling occurred primarily during high flow events. The average flow in the Saranac River during the four sampling events was 3470 cfs as compared to the historical average of 844 cfs. The PCB sampling events were weighted toward higher flows in order to capture the elevated levels of particulate material and attached PCBs often associated with runoff events. The mean PCB concentration computed for the Saranac River during this study was 0.6 ug/l. For comparison purposes, the mean PCB concentrations observed at CB30 and LTM26 are 0.38 ug/l and 0.147, respectively. Therefore, while PCB loading estimates for the river may be on the high side, it would appear that PCB

concentrations in the Saranac River are elevated above background conditions, and further investigation of the river is warranted.

However, as discussed above, it is clear that the Saranac River represents a relatively minor PCB load to the bay when compared to the Wilcox Dock waste bed. The estimated flux across the mouth is roughly 8 times the estimated loading from the Saranac River.

Main Lake

The PCB flux from Cumberland Bay to the main lake is estimated to be approximately 4.0 kg/yr, and is composed of a dispersive transport component (3.47 kg/yr) and an advective transport component (0.54 kg/yr). These estimates are based upon the following assumptions: (1) uniform water column PCB concentration across the mouth of the bay; and (2) steady state dispersion rate across the mouth of the bay. As indicated earlier, both of these assumptions have been called into question during this study. With respect to the assumption of a uniform PCB concentration, results from several of the PISCES samples suggested significant variation in PCB levels based upon depth. In particular, a deep water PISCES deployment at CB45 showed a marked elevation in PCB mass when compared to shallower deployments. One hypothesis offered for this observation is the possibility of a benthic nepheloid layer, which might provide an unaccounted shunt for PCB transport to the lake. With respect to dispersion rate, questions arose concerning the applicability of the chloride data used to derive these rates. Chloride data collected during this study suggested significantly higher dispersion rates than did results from earlier studies. Both factors introduce serious qualifiers to the model projections presented, and leave open the possibility of higher PCB flux rates to the main lake.

While Cumberland Bay is clearly a source of PCBs to the main lake, this study, as well as historical fish flesh analyses, suggest the existence of additional PCB source(s) to the main lake.

Historical fish sampling within the main lake has repeatedly shown Aroclors 1254 and/or 1260 as the principal Aroclors present in main lake fish.

Results from this study also indicated the existence of contaminant signals consistent with Aroclors 1254 and 1260 within the main lake. In fact, several samples collected at the mouth of Cumberland Bay appear to resemble Aroclor 1254, suggesting the possibility that the main lake may, in certain instances, contribute PCBs to the bay. Perhaps most perplexing are the contaminant signals observed at LTM36. As discussed above, certain samples from this site show contaminant patterns consistent with Aroclor 1260. Recall that LTM36 is located north of Cumberland Bay. Given the prevailing south-to-north flow within the lake, it would seem likely that Cumberland Bay contamination would exert a relatively strong influence at this site. However, at least in certain instances, any signal reaching LTM36 from Cumberland Bay appears masked by a distinctly different (higher chlorinated) signal. Furthermore, the congener pattern observed in the LTM26 core appeared similar to the congener pattern of Aroclor 1254, again suggesting the existence of an additional source(s) within the main lake.

In contrast, the PCB concentrations observed in the main lake, albeit limited, suggest that Cumberland Bay is influencing contaminant levels north of the bay. Consider the PCB gradient observed within the main lake proceeding north to south: (1) LTM36 - mean PCB concentration of 0.253 ng/l; (2) CB45 - mean PCB concentration of 0.287; (3) LTM26 - mean PCB concentration of 0.147 ng/l; and (4) Four Brothers Island - mean PCB concentration of 0.072 ng/l. However, once again, reflecting upon the flow direction in the lake, the concentration observed at LTM26 (approximately 2 km south of Cumberland Bay) would appear surprisingly high. It is conceivable that the seiche pulls water that far south, however, this fails to account for the congener patterns observed. Thus, it would still appear likely that an additional source(s) is contributing to the main lake, and that the most likely location for such a source(s) is between Four Brothers Island and Cumberland Bay.

V. Recommendations

The three primary recommendations of this study are as follows:

1. **Remediation of Wilcox Dock Waste Bed**: Results from this study, as well as previous information (beach clean-ups, etc.), indicate that the PCB contaminated waste materials adjacent to Wilcox Dock have undergone substantial scour over approximately the past 30 years. As a result, PCB contamination has been transported throughout the bay and to the main lake. It is clear that until the waste bed is effectively remediated it will continue to be a significant source of PCB contamination to the bay. Future rates of loss from the waste bed will depend upon the processes governing scour and transport, namely, wind and wave action. However, it is a virtual certainty that the waste bed will continue to be a significant source of PCBs to the system until the site has been remediated. Thus, the most pressing recommendation is that the waste bed be remediated as soon as possible. The remedial measures undertaken should: (a) minimize loss of the contamination to the bay during remediation; and (b) attempt to remove as much of the contamination as is economically feasible.

2. **Post-Remediation Study of Cumberland Bay**: Information to date suggests that the PCB contamination associated with the Wilcox Dock sludge bed has been present since the early to middle 1960s. Furthermore, it is clear that a significant quantity of the contamination has been transported to the larger bay and perhaps the main lake due to erosion and transport processes occurring within the bay. Thus, while it is clear that remediation of the Wilcox Dock sludge bed is a necessary and prudent action, it is important to assess the success of the proposed remediation with respect to PCB contamination levels within the bay and main lake. It is proposed that monitoring, within the bay and adjacent main lake segment, continue during and after remediation of the Wilcox Dock hazardous waste site. Monitoring activities conducted during remediation would help insure that remedial measures (e.g., dredging) minimize the loss of contaminants to the bay, while post-remediation monitoring would provide the information necessary to assess the ultimate effectiveness of the remediation. Furthermore, work should continue on the PCB mass balance model for the bay. Specifically, the model should be refined and exercised as follows: (a) the model should be segmented horizontally to reflect physical and chemical heterogeneity within the bay; (b) the possibility of nepheloid layer transport should be investigated, and if found to represent a significant route of contaminant transport, the water column should be segmented vertically to reflect actual conditions; (c) the model should be revised to incorporate biotic uptake and primary productivity; and (d) the multi-segment model should be calibrated, verified, and exercised under various management scenarios.

3. **Basin-Wide PCB Study**: While it is apparent that the Wilcox Dock waste bed, and/or materials eroded from the waste bed, are the primary source of PCB contamination to the inner portion of Cumberland Bay, the primary source(s) of contamination to the outer bay and the main lake remain uncertain. Findings from this study (e.g., congener patterns observed in outer-bay and main lake samples), and previous information (e.g., congener pattern observed in main lake fish flesh samples), suggest an additional PCB source(s) to the lake. These findings certainly warrant additional study. It is proposed that a basin-wide PCB study be conducted within the basin. Objectives of a Basin-Wide PCB Study should include: (a) *loading estimates* and *source track-down*: derivation of accurate loading estimates from the major tributaries to the lake, and identification of the principal sources of PCBs to the basin and lake. This should involve investigation of potential atmospheric, terrestrial, and aquatic sources, and should include an assessment of the significance of Cumberland Bay contamination to the broader lake; (b) *ecosystem processing*: evaluation of the ecological processing of PCBs within the basin - including investigation of biotic uptake and whether the congener pattern observed within biota are an accurate reflection of the congener pattern of suspected sources; and (c) *basin-wide PCB model*: a mass balance model should be developed for the lake which would assist in management decisions concerning remediation of PCB contamination within the system.

Secondary recommendations of this study are as follows:

4. **Internal Seiche and Benthic Nepheloid Layer**: results from this Study indicate that the internal seiche within Lake Champlain may be playing a significant role in the scour and transport of sediments. Sediment coring results indicated that bottom sediments at water depths as great as 50 meters were subject to scour on a regular basis. This has significant implications concerning the transport and ecosystem-availability of hydrophobic contaminants (e.g., PCBs, mercury, etc.), and may also be an important factor in phosphorus availability. Our findings of elevated PCB concentrations at depth, perhaps in association with the benthic nepheloid layer, also warrant further investigation, as it might represent an important route of contaminant transport.

5. **Chloride Tracer**: Chloride is often used as a conservative tracer in fresh water systems, and was used for this purpose during our study. However, the use of chloride as a conservative tracer is complicated by the presence of a significant chloride discharge at the southern end of the lake that influences the chloride concentration in much of the lake. The conventional scenario is that a municipal treatment plant discharge, which has a relatively high chloride concentration, creates a chloride gradient with concentration progressively diminishing toward the main lake. This scenario is compromised when the main lake is influenced by an additional source of chlorides, which can interfere with establishment of a gradient. This has implications for derivation of bulk dispersion rates which are dependent upon intact gradients. Thus, it is recommended that an alternative tracer be evaluated (e.g., boron) and that the dispersion rates derived throughout the lake be reevaluated.

6. **Bay Morphometry**: The surface area derived for Cumberland Bay during this study was approximately 30 percent greater than the value used for the DFS. Given the importance of morphometry to mass balance model development, further investigation of lake morphometry is recommended.

7. **Saranac River**: Study results from the Saranac River indicate that it represents a secondary PCB load to Cumberland Bay. It is suggested that additional investigation be conducted on the Saranac River to determine the source(s) of PCBs entering the river. The study should include a spatial investigation of the river during storm events. Appropriate actions might include deployment of PISCES at several locations along the river.

8. **Fish Flesh Analyses**: It is important that future fish flesh analyses include at least some congener specific analyses. This is crucial to the investigation of source identification and apportionment.

9. **Other Monitoring Approaches**: It is suggested that additional monitoring approaches (i.e., zebra mussels) be explored for tracking PCB migration within the Lake Champlain basin. This could be included within the basin-wide PCB study discussed above.

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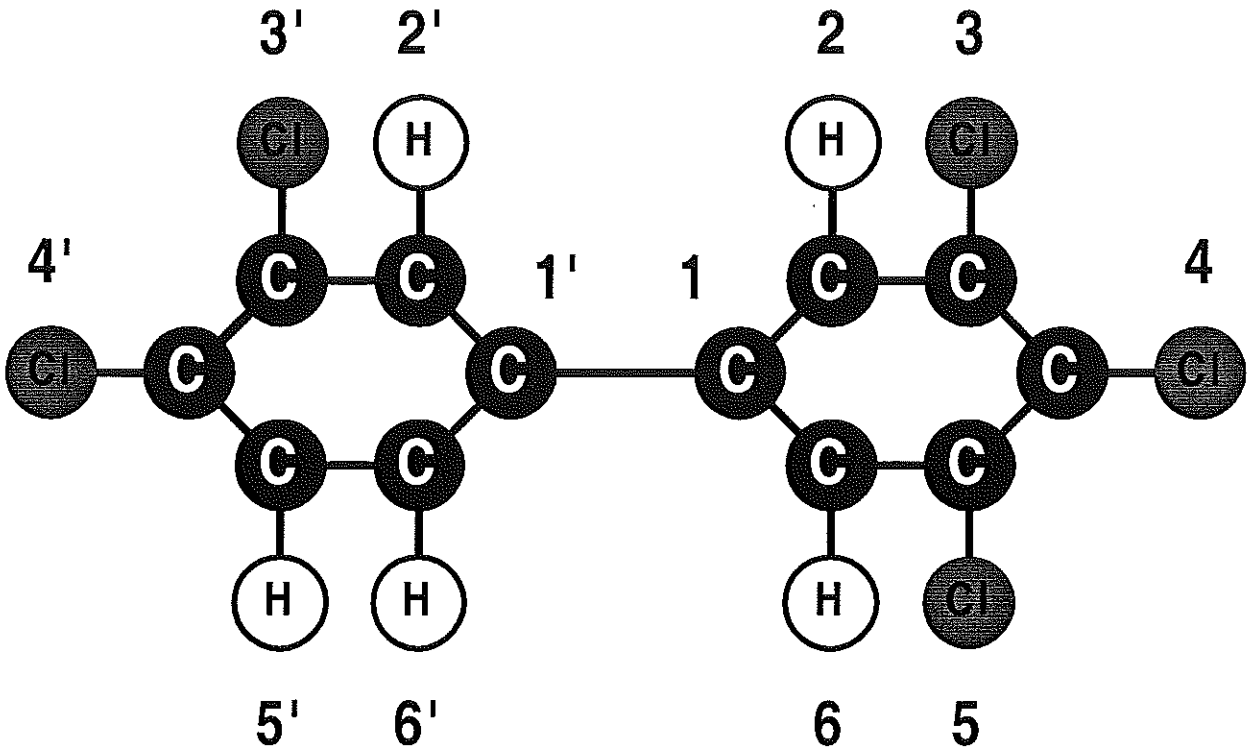
Appendix A
PCB Chemistry

Polychlorinated Biphenyl structure.



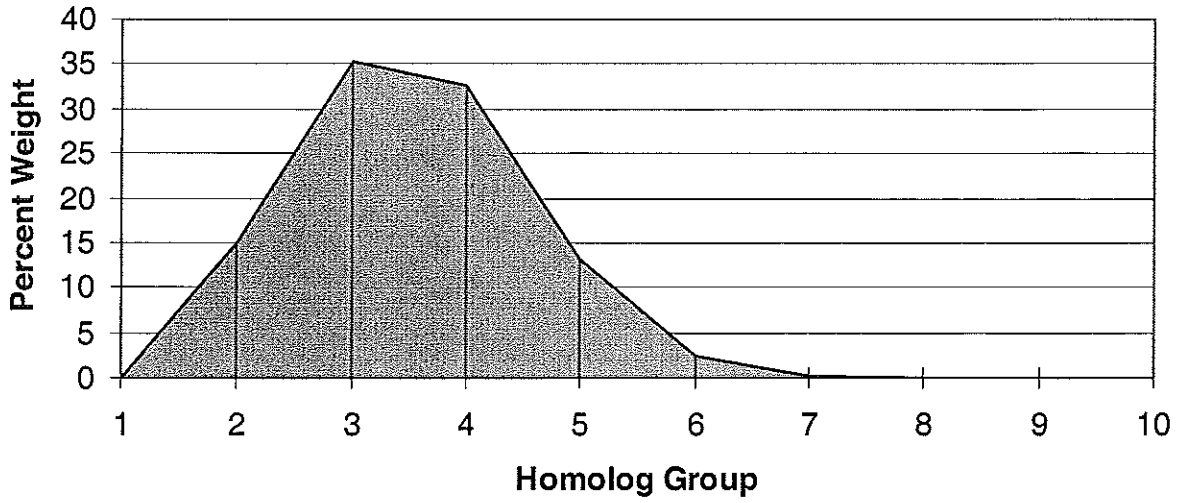
3, 3', 4, 4', 5 [IUPAC 126]

General Formula: $C_{12}\ H_X\ Cl_Y$

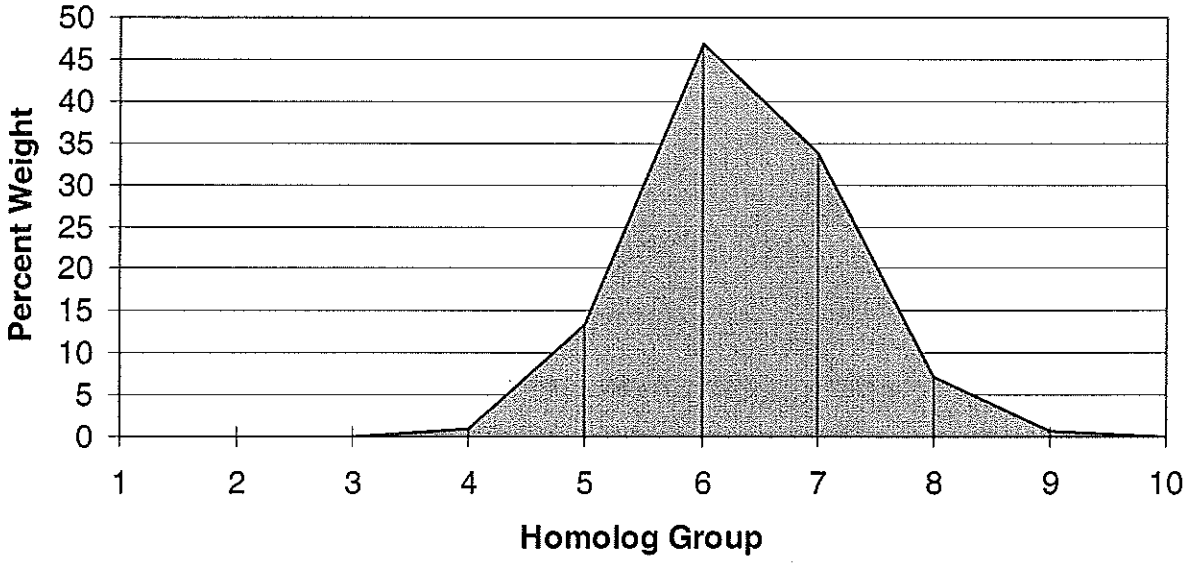
X: 1 - 10 Chlorine Atom(s)

Y: 10 - X Hydrogen Atom(s)

Schulz 1242



Schulz 1260



Appendix B
Water Column PCB Report

Quality Assurance Document and Data Report

Individual copies available upon request from the Lake Champlain Basin Program.