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History of Phosphorus Loadings to St. Albans Bay, 1850 - 1990

Lake Champlain Basin Program

Prepared by
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Department of Environmental
Conservation

for
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Lake Champlain Basin Program Technical Reports

1. *A Research and Monitoring Agenda for Lake Champlain.* Proceedings of a Workshop, December 17-19, 1991, Burlington, VT. Lake Champlain Research Consortium. May, 1992.

2. *Design and Initial Implementation of a Comprehensive Agricultural Monitoring and Evaluation Network for the Lake Champlain Basin.* NY-VT Strategic Core Group. February, 1993.

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.

4. (A) *Lake Champlain Economic Database Project. Executive Summary.* Holmes & Associates. March 1993.

   (B) *Socio-Economic Profile, Database, and Description of the Tourism Economy for the Lake Champlain Basin.* Holmes & Associates. March 1993

   (C) *Potential Applications of Economic Instruments for Environmental Protection in the Lake Champlain Basin.* Anthony Artuso. March 1993.

   (D) *Conceptual Framework for Evaluation of Pollution Control Strategies and Water Quality Standards for Lake Champlain.* Anthony Artuso. March 1993.

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

   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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INTRODUCTION

There is a need for a better understanding of the time that might be required before water quality in St. Albans Bay, Lake Champlain will improve in response to point and nonpoint source phosphorus reduction programs implemented during the 1980's. Further management intervention may be justified if the recovery time is expected to be very long. Sediment phosphorus modeling studies conducted in St. Albans Bay by Martin *et al.* (1994) examined the long-term accumulation of phosphorus in the bay's sediments in response to historical phosphorus loadings. Martin's modeling analysis estimated the rate at which phosphorus stored in the system may become depleted following the more recent phosphorus loading reductions.

The purpose of this report is to document historical point and nonpoint source phosphorus loadings to St. Albans Bay as quantitatively as possible. These historical phosphorus loading estimates were prepared to support Martin's modeling analysis, and to provide an historical perspective on some of the water quality management issues regarding St. Albans Bay.

The scope of this report includes research into the growth of population, industry, and commerce in the City of St. Albans and it's surrounding region since 1850. Point source phosphorus loadings were estimated using information on the development of sewers and wastewater treatment facilities in St. Albans, including data on the population and industries served by these sewers. Historical nonpoint source phosphorus loading estimates were based primarily on agricultural statistics maintained for Franklin County, Vermont since 1850.

The St. Albans Bay watershed is located adjacent to the Northeast Arm (Inland Sea) of Lake Champlain in northwestern Vermont (Figure 1). The watershed is drained by three major tributaries including the Mill River, Stevens Brook, and Jewett Brook. Stevens and Jewett Brooks, along with the discharge from the City of St. Albans Wastewater Treatment Facility outfall pipe, converge at the head of the Stevens Brook Wetland at a point approximately one mile north of the bay. The wetland then drains into the northern end of the bay through a narrow channel of water.

POINT SOURCE PHOSPHORUS LOADINGS

History of Wastewater Treatment in St. Albans

There have been four phases of sewer construction and wastewater treatment in the City and Town of St. Albans. The first phase began in 1900 when the "trunk" sewer was laid. This sewer main passed through the industrial section of the city and discharged directly into Stevens Brook (labeled Gas Brook on early maps) at a point just outside the city limits. Extension lines were built between 1900 and 1928 when the entire city (encompassing 1,088 acres) was connected to the sewer system (Metcalf and Eddy, Inc., design charts, 1928).

In 1936, the first wastewater treatment plant in St. Albans was constructed in a location north of the city. This primary treatment facility included a three mile outfall pipe which conveyed effluent into the Stevens Brook Wetland.

In 1955, sewer lines were laid into St. Albans Town in anticipation of an upgrade to the treatment facility. This 1959 upgrade incorporated secondary waste processing using a trickling-filter design (Fay, Spofford, and Thorndike, Inc., design charts, 1958). Overflow influent to this

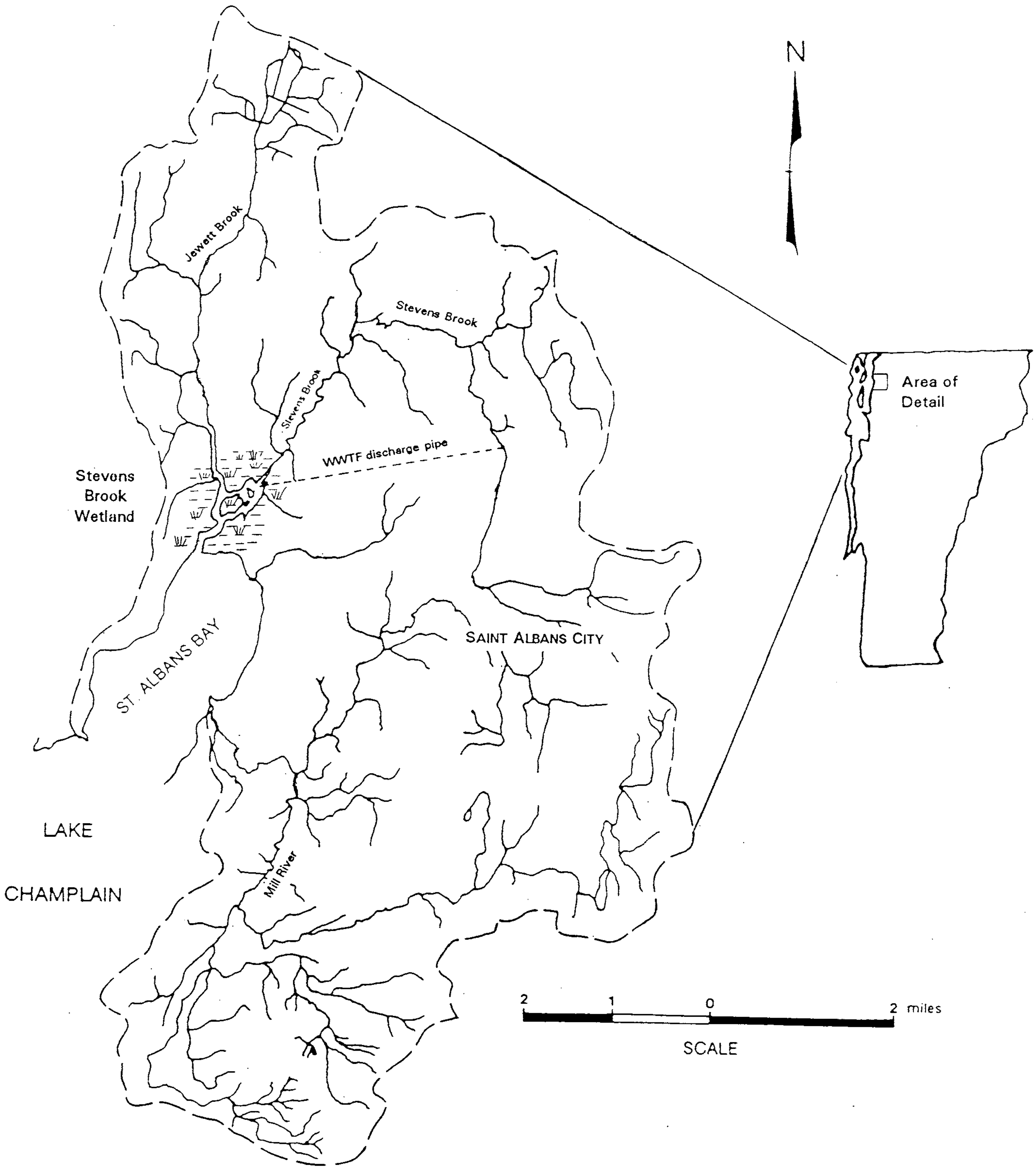

Figure 1. Map of St. Albans Bay Watershed.

plant was directed through the final effluent settling lagoons and on to the wetland via the outfall pipe. By the 1970's, areas north of the treatment facility were added to the sewer network. These included the St. Albans Industrial Park, the Highgate Shopping Center, and the Union Carbide Corporation manufacturing facility. Additionally, a number of storm drains were added to the system. Over time, deterioration of the sewer system in the city made inflow and infiltration into the sewers a major problem. Because of this, combined sewage overflow occurred during periods of excessive rain or high groundwater (Fay, Spofford, and Thorndike, Inc., 1982). Some portion of the effluent was intermittently discharged directly to Stevens Brook at the site of the treatment plant during this period (St. Albans Bay Rural Clean Water Program, 1991).

The most recent phase of wastewater treatment at St. Albans was completed in 1986 when the facility was upgraded and the city sewer system was rehabilitated to reduce inflow and infiltration. The new plant employs advanced wastewater treatment technology for phosphorus removal. The discharge permit for the facility limits the effluent phosphorus concentration to less than 0.5 mg/l, with a permitted maximum flow of 4.0 million gallons per day (mgd). The plant has consistently attained the 0.5 mg/l phosphorus level since the upgrade, which is the lowest effluent limit required for any municipal facility in Vermont.

A second, smaller wastewater treatment facility discharging into Stevens Brook is located at the Northwest State Correctional Facility. This plant currently serves a prison population of approximately 275. Built in 1968, the secondary treatment facility was originally designed to serve a population of 40. The treatment plant for the correctional facility was upgraded in 1986 at the same time as the St. Albans City treatment plant upgrade, and also removes phosphorus to an effluent level of 0.5 mg/l or less at a permitted maximum flow of 0.04 mgd. The phosphorus load from this plant is very small relative to the city's discharge. In 1975, the prison facility contributed 74 kg/yr to Stevens Brook (Vermont Agency of Environmental Conservation, 1977). Recent sampling results show this plant discharging 4 kg/yr (Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation, 1992).

Historical Point Source Phosphorus Loading Estimates

Direct monitoring data on flow and phosphorus loading from the St. Albans City Wastewater Treatment Facility are available only since 1974. Therefore, historical point source loadings were estimated indirectly from information on population and industrial growth, using reasonable assumptions about per capita loading rates and treatment plant efficiency. Domestic and industrial components were estimated separately at ten year intervals from the 1850's through the 1960's, and combined to produce a total point source loading rate for the historical period. Actual sampling measurements were used for the decades of the 1970's-1990's.

Domestic Loadings

The size of the sewered population in the City and Town of St. Albans was estimated using census data given in Arnold (1981) for the period beginning in 1900 when the first sewer line was installed in the City. A linear increase in the sewered population in the City was assumed from 1900 (assumed 10% sewered) through the 1930's (100% sewered), as indicated in Table 1. By 1970, sewer connections were extended to include 20% of the population of the Town of St. Albans (Fay, Spofford, and Thorndike, Inc., 1982).

Table 1. Domestic point source phosphorus loading estimates.

Year	City		Town		Total Sewered Population	Per Capita Loading (g/cap/day)[2]	Total Influent Loading (kg/day)	WWTF Phosphorus Removal Efficiency	Effluent Loading (kg/yr)
	Total Pop.[1]	Percent Sewered	Total Pop.[1]	Percent Sewered					
1900	6239	10	1715	0	624	1.5	0.94	0%	342
1910	6381	33	1617	0	2106	1.5	3.16	0%	1153
1920	7588	66	1583	0	5006	1.5	7.51	0%	2741
1930	9711	100	1691	0	9711	1.5	14.57	0%	5317
1940	8037	100	1733	0	8037	1.5	12.06	10%	3960
1950	8592	100	1908	0	8592	3.4	29.21	10%	9596
1960	8806	100	2303	0	8806	3.4	29.94	10%	9835
1970	8082	100	3270	20	8736	3.4	29.70	10%	(9757)[4]
1980	7339	100	4606	20	8260	1.5[3]	12.39	10%	(4070)[4]

Notes:

1. Population estimates are from Arnold (1981).
2. Bulmer and Hultman (1988), Illinois Environmental Protection Agency (1986), Linsley and Franzini (1972).
3. Phosphorus Detergent Ban in effect.
4. 1970 and 1980 estimates are given only for purposes of comparison with actual meaurements of total phosphorus discharge.

Per capita phosphorus loading rates to the treatment plant were estimated from literature values. Domestic phosphorus loadings include human waste at about 1.5 grams per capita per day (Illinois Environmental Protection Agency, 1986) and household detergents in a range of 0.6-2.0 g/cap/day (Bulmer and Hultman, 1988). A comparison of estimates using these literature values with actual effluent measurements made during the 1970's and 1980's (Vermont Agency of Environmental Conservation, 1977; St. Albans Bay R.C.W.P., 1991) indicated that a total per capita phosphorus loading rate of 3.4 g/cap/day (e.g. 1.5 g/cap/day from human waste and 1.9 g/cap/day from detergents) provided the best fit to the effluent measurements, taking into account the industrial component and the overall treatment efficiency, as described below. A rate of 1.5 g/cap/day was therefore used to estimate domestic phosphorus influent loadings to the treatment plant for the period of 1900 through the 1940's before high phosphorus detergent formulations were in use. From the 1950's until 1978 when the Vermont Phosphorus Detergent Ban took effect, a per capita loading rate of 3.4 g/cap/day was used.

Prior to 1930, when no treatment plant existed, there would have been no phosphorus removal from the influent to the sewer system prior to discharge. Primary treatment facilities typically remove 10% of influent phosphorus under non-overflow conditions, while secondary treatment facilities remove between 20% and 30% of influent phosphorus (Linsley & Franzini, 1972). A phosphorus removal efficiency of 10% was assumed for the decades of the 1930's-1950's when the facility was operating as a primary treatment plant. However, a frequently overloaded trickling-filter wastewater treatment facility will rarely function at even 20% removal (Illinois Environmental Protection Agency, 1986) and the St. Albans City treatment plant experienced a number of operational problems prior to the 1986 upgrade. Therefore, a phosphorus removal efficiency of 10% was assumed for the entire pre-monitoring time period.

Estimates of the domestic component of the phosphorus discharge from the St. Albans City treatment plant since 1900 are summarized in Table 1. As described above, assumptions regarding per capita loading rates and treatment efficiencies were adjusted within reasonable ranges so that the estimates for the 1970's and 1980's compared well with actual sampling measurements made during comparable time periods, as documented in Vermont Agency of Environmental Conservation (1977) and St. Albans Bay R.C.W.P. (1991).

Industrial Loadings

The industrial component of the phosphorus influent to the St. Albans City treatment plant was estimated from a list of major businesses in the City and Town of St. Albans for the period of 1850 to 1980, derived from information in Armstrong (1977) and Manning (1886-1983). In some cases, a limited amount of effluent flow and phosphorus generation data were available from engineering studies of industrial sewer users. In other cases, flows and phosphorus loadings to the treatment plant were estimated using general values for similar industrial processes obtained from sources such as Lamb (1985) and Loehr (1984), using conservative (lower) rates from the ranges given in the literature.

Estimates of the industrial component of the phosphorus influent and effluent from the St. Albans City treatment plant are summarized in Table 2, along with documentation of the data and assumptions used in deriving these estimates. Loadings from each business were assumed to be constant during the entire period of operation. The same treatment plant phosphorus removal efficiencies applied to the domestic loading estimates were used for the industrial loadings given in Table 2.

Table 2. Industrial point source phosphorus loading estimates. Blanks indicate business was not in operation. "ND" indicates business was in operation but insufficient data existed to calculate loadings.

	Industrial Total Phosphorus Loading Estimates by Decade (kg/yr)													
	1850	1860	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980
St. Albans Foundry[1]	69	69	69	69	69	69	69	69	69	69				
Iron & Steel Co.[1]			69	69										
Vermont Construction Co.[1]					69	69	69	69	69					
Green Mountain Packing[2]					1	1	1	1	1	1	1	1		
VanCamp Packing						ND	ND	ND	ND					
Franklin County Creamery[3]					8382	8382	8382	8382						
St. Albans Creamery Cooperative[4]									8382	8382	8382	8382	8382	8382
Hood Dairy[4]									5960	5960	5960	5960	5960	5960
Union Carbide Co.[4]											262	262	262	262
Fonda Container Corporation[4]											ND	ND	ND	ND
St. Albans Industrial Park[5]														ND
Highgate Shopping Center[5]														ND
Total Influent Phosphorus Load (kg/day)	69	69	138	138	8521	8521	8521	8521	14481	14412	14605	14605	14604	14604
Treatment Plant Phosphorus Removal	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	10%	10%	10%	10%
Total Effluent Phosphorus Load (kg/day)	69	69	138	138	8521	8521	8521	8521	14481	12971	13145	13145	(13144)[6]	(13144)[6]

Notes:

1. Lamb (1985). Phosphorus concentration of 5.0 mg/l at 0.010 mgd flow.
2. Loehr (1984). Phosphorus concentration of 2.0 mg/l at 0.0005 mgd flow.
3. Because the Franklin County Creamery occupied the same site as is currently occupied by the St. Albans Creamery Cooperative, phosphorus loads were assumed to be similar.
4. Fay, Spofford, and Thorndike, Inc. (1975):
   St. Albans Creamery Cooperative, 27 mg/l at 0.225 mgd
   Hood Dairy, 27 mg/l at 0.160 mgd
   Union Carbide Co., 0.97 mg/l at 0.195 MGD
   Fonda Container Corporation, no phosphorus data, 0.100 mgd
5. Fay, Spofford, and Thorndike, Inc. (1982).
   St. Albans Industrial Park, no phosphorus data, 0.025 mgd
   Highgate Shopping Center, no phosphorus data, 0.015 mgd
6. 1970 and 1980 estimates are given only for purposes of comparison with actual meaurements of total phosphorus discharge.

Point Source Summary

The combined estimates of domestic and industrial point source phosphorus loadings to St. Albans Bay for the period of 1850 to the present are shown in Figure 2. Figure 2 shows that point source loading rates increased steeply to levels over 20,000 kg/yr by the 1930's, and remained at those levels until relatively recently. The loadings shown for 1970-1990 are based on actual sampling measurements. The sampling results show a modest phosphorus loading reduction in 1980 in response to the implementation of the Vermont Phosphorus Detergent Ban, which affected only the domestic component, and a very sharp drop following the treatment plant upgrade in 1986. The treatment plant upgrade reduced point source phosphorus loadings to the lowest levels since the turn of the century.

NONPOINT SOURCE PHOSPHORUS LOADINGS

History of Agriculture in the St. Albans Bay Watershed

The St. Albans Bay watershed has been primarily agricultural since the early 1800's. European settlement of the watershed began in the late 1700's after which the original forest was rapidly cleared to support farming. By 1870, Vermont was largely deforested and the countryside was used for grazing cattle or sheep (Meeks, 1986). Today, the St. Albans Bay watershed is only 10% forested, and 65% of the land is used for agriculture (St. Albans Bay R.C.W.P., 1991).

Dairy farming is currently the major agricultural practice in the St. Albans Bay region. Franklin County, Vermont supports more cattle now than at any time in its history. Sheep farming was a prospering business in the 1850's, but declined drastically in the 1860's due to a major drop in wool prices.

Agricultural statistics compiled for Franklin County, Vermont from U.S. Department of Commerce Agricultural Census data for 1850-1987 are given in Table 3. The 32,162 acre St. Albans Bay watershed is only about 8% of the total land in Franklin County, but it was assumed that agricultural trends have been similar between the watershed and the county as a whole. The percentage of agricultural land in the county increased to a peak of 89% in 1880 and has since declined gradually to the current level of about 51%.

Corn and hay have been the primary crops grown in the watershed. The area used for hay has always exceeded the area of corn land, but there has been a trend in recent decades toward more corn and less hay. This trend reflects general regional changes in farming practices and feed types produced for farm animals.

Historical Nonpoint Source Phosphorus Loading Estimates

Nonpoint source phosphorus loadings to St. Albans Bay from three major tributary streams were monitored from 1982-1989 by the St. Albans Bay Rural Clean Water Program (1991). The monitoring results are given in Table 4, adjusted for the additional watershed area downstream of each gage and sampling station. The mean 1982-1989 nonpoint source total phosphorus loading rate to St. Albans Bay was estimated to be 26,488 kg/yr, including 12,520 kg/yr to the Stevens Brook Wetland via Jewett and Stevens Brooks, and 13,968 kg/yr from the Mill River.

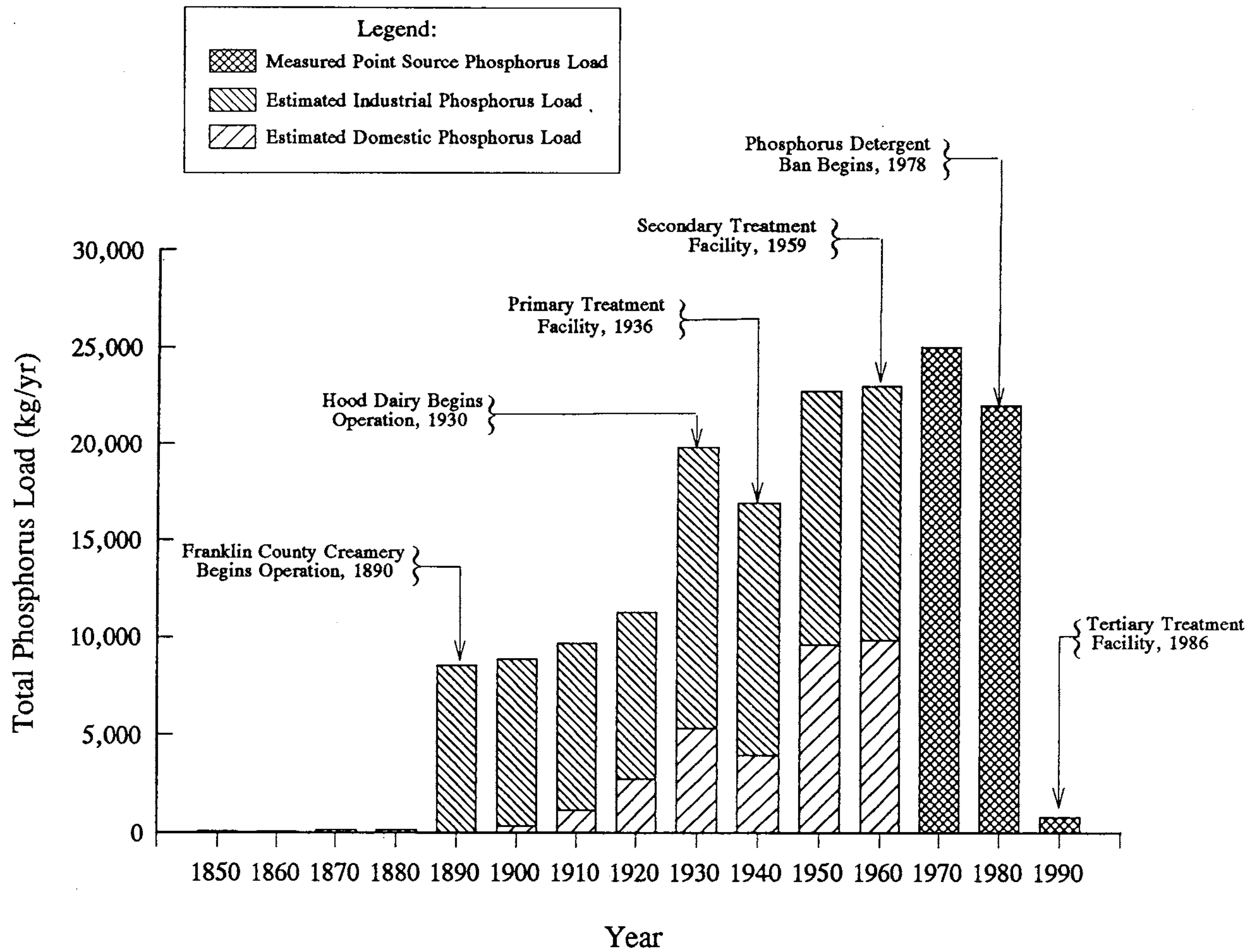

Figure 2. Historical point source loading estimates to St. Albans Bay.
References for actual measurements:
1970: Vermont Agency of Environmental Conservation (1977)
1980: St. Albans Bay Rural Clean Water Program (1991)
1990: Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation (1992)

Table 3. Agricultural Statistics for Franklin County, Vermont from 1850 to 1900. Source: U.S. Department of Commerce (1850-1987).

Year	Number of Farms	Farmland (acres)	Number of Cattle	Number of Sheep	Number of Hogs	Corn Land (acres)	Hay Land (acres)
1850	-	307845	31107	58509	5413	3700	62500
1860	-	345963	38210	32578	4745	3000	70500
1870	2396	-	38259	20054	4564	3100	82800
1880	2581	367162	43939	12699	7730	4356	90661
1890	2401	338435	43297	9016	9102	2671	92365
1900	2581	360862	42878	4821	10659	4528	88026
1910	2698	361777	40321	3213	10812	2725	101417
1920	2444	359249	49649	1933	6157	1259	102774
1930	2303	361109	62396	1768	4105	6386	104390
1940	2157	352604	53093	773	2079	7264	99290
1950	1854	348480	55140	448	1240	6952	93168
1960	1419	328541	61586	636	1801	6994	89068
1970	908	255518	54794	340	239	9129	69899
1980	752	226205	55228	180	277	17416	67568
1990	786	214344	66077	1074	731	16395	66172

Table 4. Tributary total phosphorus loading rates measured by the St. Albans Bay Watershed Rural Clean Water Program during 1982-1989. Data were supplied by D. Meals, Vermont Water Resources and Lake Studies Center, University of Vermont.

Year	Jewett[1] Brook (kg/yr)	Stevens[1] Brook (kg/yr)	Mill[1] River (kg/yr)	Jewett[2] (x1.43) (kg/yr)	Stevens[2] (x1.50) (kg/yr)	Mill[2] (x1.02) (kg/yr)	Total for Watershed
1982	7483	4868	9040	10701	7302	9221	27224
1983	6134	5329	6571	8772	7994	6702	23468
1984	7446	5265	29188	10648	7898	29772	48318
1985	2809	1981	5383	4017	2972	5491	12480
1986	2636	6980	37075	3769	10470	37817	52056
1987	4487	2317	8144	6416	3476	8307	18199
1988	1559	2309	4447	2229	3464	4536	10229
1989	4069	2806	9704	5819	4209	9898	19926
1982-1989 mean	4578	3982	13694	6547	5973	13968	26488

Notes:

1. Annual mean loading rates measured at the R.C.W.P. gage and sampling stations.
2. Loading values adjusted for additional downstream drainage area below the sampling stations.

Nonpoint source loading indexes were developed from the agricultural statistics given in Table 3 in order to extend the St. Albans Bay R.C.W.P. loading estimates backwards in time. For each decade, the cattle numbers, corn acres, and hay acres were calculated as a ratio with the corresponding 1980 value. In this way, three alternative indexes were derived from the agricultural census data. These ratios were multiplied by the 1982-1989 mean loading rates from Table 4 to provide historical nonpoint source loading estimates for 1850-1990, as shown in Table 5.

Historical nonpoint source phosphorus loading estimates derived from the three alternative indexes are plotted in Figure 3. The three indexes produced different historical trends. The hay index suggests a decline in nonpoint source phosphorus loading in recent decades. However, the trend indicated by the hay index is probably not realistic because the decline in hay corresponded with an increase in corn, as discussed earlier, and corn land would be expected to export more phosphorus per acre than hay land.

The corn index suggests a steep increase in nonpoint source phosphorus loadings since the 1930's. The increase indicated by the corn index is probably somewhat exaggerated because runoff from corn land is only one of several major mechanisms of agricultural phosphorus export to surface waters, and the reliance on corn by area farmers has increased disproportionately in relation to the overall level of farming activity in the watershed over time.

The most realistic nonpoint source loading index shown in Figure 3 is probably the one based on cattle. This index suggests a gradual increase in nonpoint source loading rates over the entire 1850-1990 period. Farming practices have changed greatly during this period, however, and the phosphorus export per animal has probably not remained constant. Greater mechanization on the farms and reliance on a federally subsidized chemical phosphate fertilizer program since the 1940's (U.S. Department of Agriculture, 1949) has probably increased the phosphorus yield per animal in recent decades. Thus the actual loading trend is probably somewhere between those derived from the cattle index and the corn index in Figure 3.

The use of agricultural statistics to produce an historical index for the total nonpoint source phosphorus loading from the St. Albans Bay watershed assumes that the total nonpoint source loading from all sources, including non-agricultural sources, is directly proportional to the agriculture based index. This assumption is probably reasonably valid for the St. Albans Bay watershed which has been heavily agricultural since the land was originally cleared. Most of the non-agricultural nonpoint sources would be correlated with the level of agricultural economic activity in the watershed.

SUMMARY

The combined estimates of historical point and nonpoint source phosphorus loadings to St. Albans Bay are presented in Figure 4 and Table 6. The nonpoint source component in Figure 4 and Table 6 was based on the cattle index from Figure 3. For additional perspective, Figure 4 also shows the natural background phosphorus loadings that would have existed in the mid 1700's prior to significant land clearing. The natural background loading estimate was based on a phosphorus export rate of 0.20 kg/ha/yr for undisturbed forest land (Reckhow and Chapra, 1983).

Table 5. Estimated nonpoint source phosphorus loading to St. Albans Bay from 1850 to 1990.

	Ratio of Year Value to 1980 Value[1]			Jewett and Stevens Brooks Phosphorus Load (kg/yr)[2,3]			Mill River Phosphorus Load (kg/yr)[2]			Total St. Albans Bay Watershed Phosphorus Load (kg/yr)		
Year	Corn Index	Hay Index	Cattle Index	Corn Index	Hay Index	Cattle Index	Corn Index	Hay Index	Cattle Index	Corn Index	Hay Index	Cattle Index
1850	.21	.93	.56	2629	11644	7011	2933	12990	7822	5562	24634	14833
1860	.17	1.04	.69	2128	13021	8639	2375	14527	9638	4503	27548	18277
1870	.18	1.23	.69	2254	15400	8639	2514	17181	9638	4768	32580	18277
1880	.25	1.34	.80	3130	16777	10016	3492	18717	11174	6622	35494	21190
1890	.15	1.37	.78	1878	17153	9766	2095	19136	10895	3973	36289	20661
1900	.26	1.30	.78	3255	16276	9766	3632	18158	10895	6887	34434	20661
1910	.16	1.50	.73	2003	18780	9140	2235	20952	10197	4238	39732	19337
1920	.07	1.52	.90	876	19031	11268	978	21231	12571	1854	40262	23839
1930	.37	1.54	1.13	4633	19281	14148	5168	21511	15784	9801	40792	29932
1940	.42	1.47	.96	5258	18404	12019	5867	20533	13409	11125	38937	25428
1950	.40	1.38	1.00	5008	17278	12520	5587	19276	13968	10595	36554	26488
1960	.40	1.32	1.12	5008	16526	14023	5587	18438	15644	10595	34964	29667
1970	.52	1.03	.99	6511	12896	12395	7263	14387	13828	13774	27283	26223
1980	1.00	1.00	1.00	12520	12520	12520	13968	13968	13968	26488	26488	26488
1990	.93	1.01	1.22	11644	12645	15274	12990	14108	17041	24634	26753	32315

Notes:

1. Ratios were calculated from data in Table 3.
2. The loadings were calculated by multiplying the year ratios by the 1982-1989 mean loads from Table 4.
3. Loading to the Stevens Brook Wetland (sum of Jewett and Stevens Brooks).

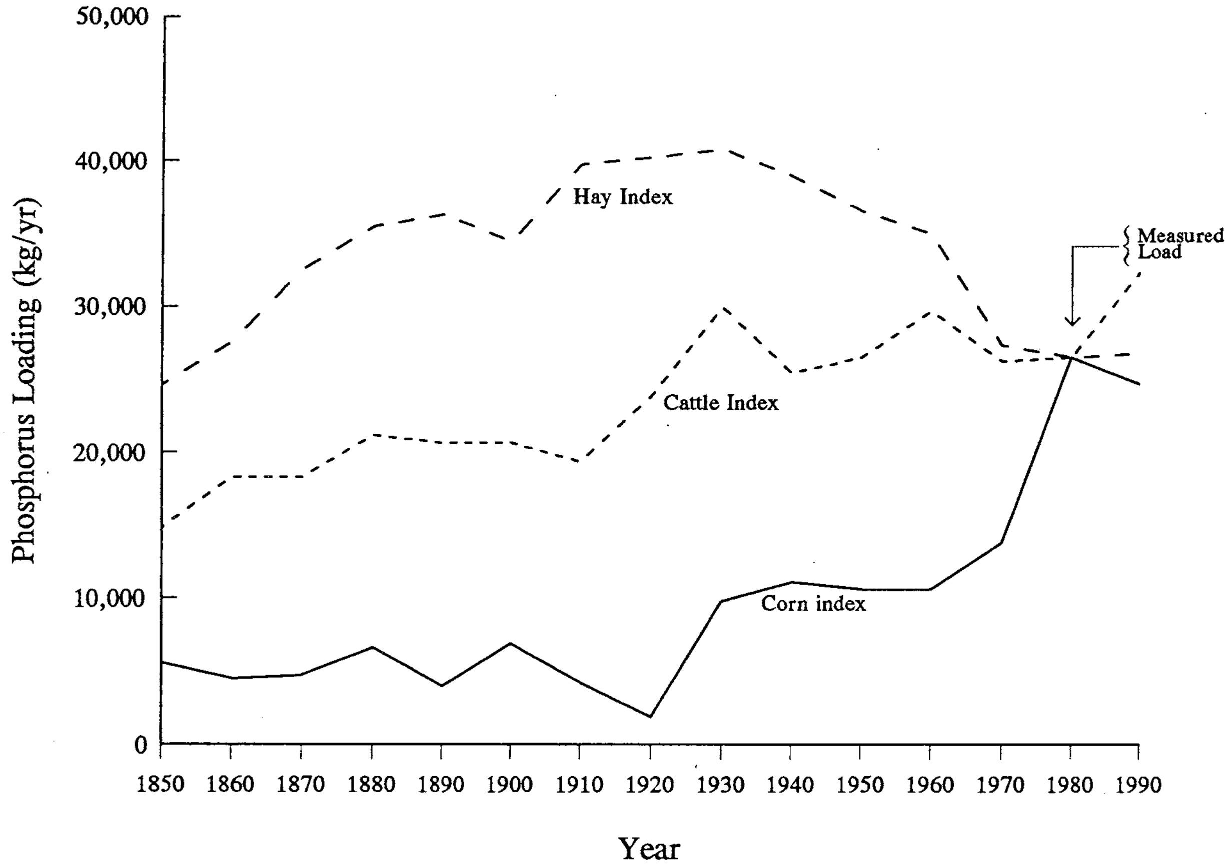

Figure 3. Historical nonpoint source loading estimates based on three alternative agricultural indexes. The plotted "1980 Measured Load" is the 1982-1989 mean value obtained from the St.Albans Bay Rural Clean Water Program (1991).

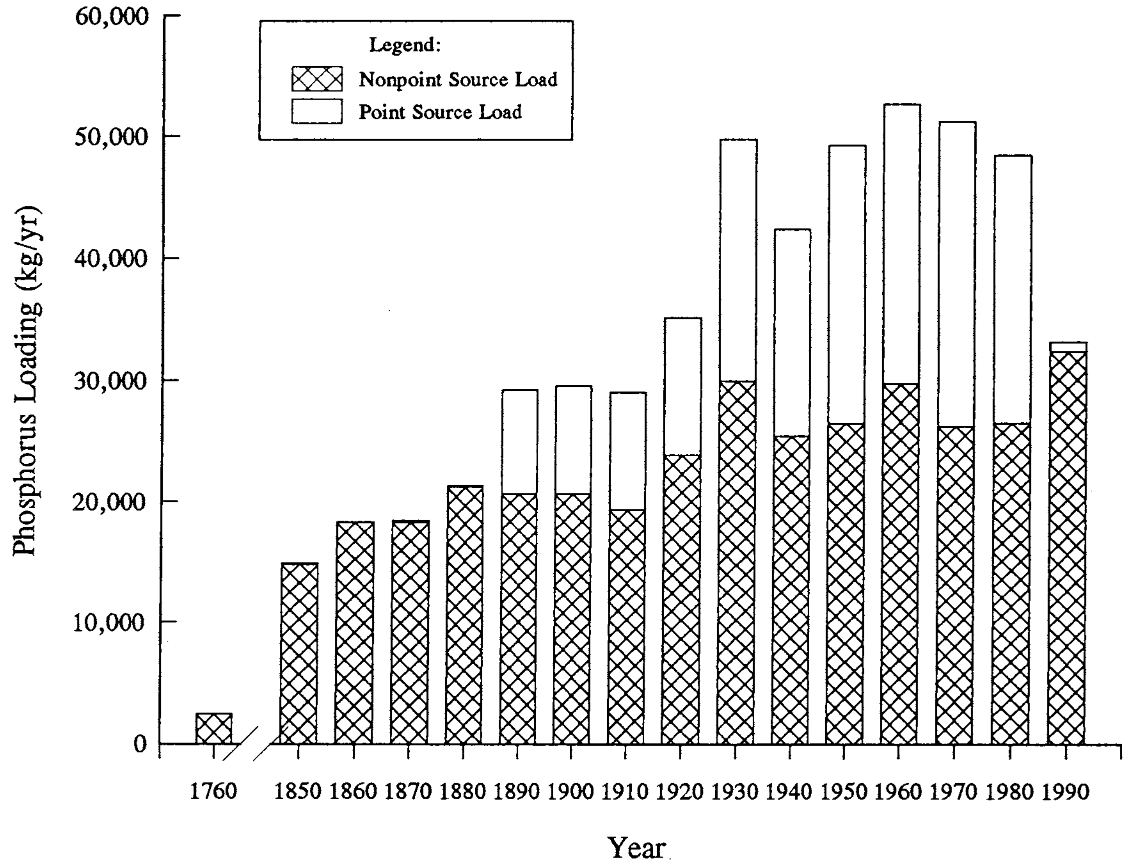

Figure 4. Summary of historical point and nonpoint source phosphorus loading estimates to St. Albans Bay.

Table 6. Summary of historical point and nonpoint source phosphorus loading estimates to St. Albans Bay.

Year	Phosphorus Loading (kg/yr)				
	Jewett and Stevens Brooks			Mill River Nonpoint[1]	Total for Watershed
	Point	Nonpoint[1]	Total		
1850	69	7011	7080	7822	14902
1860	69	8639	8708	9638	18346
1870	138	8639	8777	9638	18415
1880	138	10016	10154	11174	21328
1890	8521	9766	18287	10895	29182
1900	8863	9766	18629	10895	29524
1910	9674	9140	18814	10197	29011
1920	11262	11268	22530	12571	35101
1930	19798	14148	33946	15784	49730
1940	16931	12019	28950	13409	42359
1950	22740	12520	35260	13968	49228
1960	22978	14023	37001	15644	52645
1970	24939[2]	12395	37334	13828	51162
1980	21900[3]	12520	34420	13968	48388
1990	788[4]	15274	16062	17041	33103

Notes:

1. Nonpoint source loads are estimates from Table 5, using the cattle index.
2. Measured point source load, 1975-1976, Vermont Agency of Environmental Conservation (1977).
3. Measured point source load, 1982, St. Albans Bay Rural Clean Water Program (1991).
4. Measured point source load, 1990-1991, Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation (1992), corrected by a recirculated flow adjustment factor of 0.67.

Figure 4 shows a steady increase in phosphorus loadings between 1880 and 1930, followed by sustained loadings of about 50,000 kg/yr for the next several decades. In recent decades prior to the upgrade of the St. Albans City treatment plant, the point source contributed nearly 50% of the total phosphorus loading to the bay. The treatment plant upgrade for phosphorus removal in 1986 resulted in a sharp 30% drop in total annual loading to the bay, with only about 2% of the total now contributed by point sources.

The historical phosphorus loading estimates for the St. Albans Bay watershed summarized in Figure 4 provide a valuable perspective on the current eutrophication problem in the bay. Phosphorus loading to the system has been high and sustained for many decades. Phosphorus reductions brought about by the 1986 upgrade of the treatment plant have been in effect for only a relatively few years. If significant portions the historical phosphorus loads have been retained in the system, stored in the bay sediments or elsewhere, then it may take some time before water quality in the bay improves in response to the recently reduced loading levels.

REFERENCES

Adams, H.K. 1889. Centennial History of St. Albans 1889. Wallace Printing Co., St. Albans, Vermont.

Armstrong, M., P.J. Caldwell, and D.C. Steele (eds.). 1977. St. Albans, Vermont Through the Years 1763-1963. Regal Art Press, St. Albans, Vermont.

Arnold, T.W., 1981. Two Hundred Years and Counting: Vermont Community Census Totals, 1791 to 1980. Center for Rural Studies. University of Vermont. Burlington.

Bulmer, P. and B. Hultman. 1988. Control of phosphorus discharges, present situation and trends. Hydrobiologia. 170:305-319.

Reckhow, K.H. and S.C. Chapra. 1983. Engineering Approaches for Lake Management. Volume 1: Data Analysis and Empirical Modeling. Butterworth. Boston.

Fay, Spofford, and Thorndike, Inc.. 1975. Industry report on industrial effluent flows. Prep. for City of St. Albans, Vermont. Boston, Ma.

Fay, Spofford, and Thorndike, Inc. 1982. Facilities planning for wastewater treatment works improvements, Vol 1. Prep. for City of St. Albans, Vermont, under U.S. Environ. Prot. Agency Grant C500 133-01. Boston, MA.

Greene, F.L. 1905(?). Picturesque St. Albans. St. Albans Messenger Co. St. Albans, Vermont.

Lamb, J.C. 1985. Water Quality and Its Control. J. Wiley and Sons. New York.

Linsley, R.K. and J.B. Franzini. 1972. Water Resources Engineering. McGraw-Hill. New York.

Loehr, R.C. 1984. Pollution Control for Agriculture. Academic Press. New York.

Manning, H.A. 1886, 1891, 1899, 1909, 1938, 1940, 1950, 1958, 1970, 1979, 1983. Manning's St. Albans and Swanton Vermont Directory. Springfield, MA.

Martin, S.C., R. J. Ciotola, P. Malla, N.G. Subramanyaraje Urs, and P.B. Kotwal. 1994. Assessment of sediment phosphorus distribution and long-term recycling in St. Albans Bay, Lake Champlain. Lake Champlain Basin Program Tech. Rep. No. 7c. Grand Isle, VT.

Meeks, H.A. 1986. Time and Change in Vermont. The Globe Pequot Press. Chester, Connecticut.

St. Albans Bay Watershed Rural Clean Water Program. 1991. Final Report. 1980-1990. Submitted by Vermont RCWP Coordinating Committee. Burlington, Vermont.

State of Illinois Environmental Protection Agency. 1986. Phosphorus: A summary of information regarding lake water quality. Springfield, Il.

Thompson, Z. 1853. Appendix to the History of Vermont. Natural, Civil and Statistical. Stacy & Jameson Printers. Burlington, Vermont.

TWM Northeast, Inc. 1991. St. Albans Bay pollution abatement feasibility study. Prep. for Towns of Georgia and St. Albans, Vermont.

U.S. Department of Agriculture. 1949. The fertilizer situation for 1949-50. Washington, D.C.

U.S. Department of Commerce. 1850, 1860, 1870, 1880, 1890, 1900, 1910, 1920, 1930, 1940, 1950, 1959, 1969, 1978, 1987. Census of Agriculture. Bureau of Census. Washington, D.C.

Vermont Agency of Environmental Conservation. 1977. Nutrient loadings to Shelburne Bay and St. Albans Bay 1975-1976. Montpelier.

Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation. 1992. Lake Champlain Diagnostic Feasibility Study. Interim Progress Report. Waterbury, VT and Albany, NY.