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WATERSHED-SCALE RESPONSE TO AGRICULTURAL DIFFUSE POLLUTION CONTROL PROGRAMS IN VERMONT, USA

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ABSTRACT

From 1979 to 1990, the LaPlatte River Watershed and the St. Albans Bay Watershed Rural Clean Water Program projects in Vermont (USA) sought to reduce sediment, nutrient, and bacteria loads to parts of Lake Champlain impaired by eutrophication. Best Management Practices (BMPs) to control diffuse sources of pollution from dairy agriculture were widely implemented through a voluntary program of technical assistance and cost-sharing by agencies of the U.S. Department of Agriculture. Intensive water quality monitoring was undertaken to document water quality changes resulting from the land treatment programs, including studies of BMP effectiveness and long-term watershed-scale trend monitoring. Some BMPs significantly reduced edge-of-field pollutant delivery to surface waters. Phosphorus export from corn fields was up to 1500% higher where manure was winter spread and up to 15% of the phosphorus applied in winter-spread manure was lost in runoff. A vegetated filter strip retained more than 90% of sediment and nutrients in milking center waste and functioned effectively year-round. Watershed-level response, however, was not simply the sum of edge-of-field changes. Sediment concentration and export decreased in both project areas, but anticipated decreases in nutrient concentrations and loads did not occur. The most significant water quality trends observed were 50–75% reductions in indicator bacteria counts in all study watersheds. Factors contributing to the lack of general response in nutrient levels, recommendations for future agricultural pollution control projects, and implications for planning of diffuse source pollution control programs are discussed. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

KEYWORDS

Agriculture; animal waste; bacteria; best management practices; diffuse pollution; diffuse pollution control; land treatment; nonpoint source pollution; phosphorus; Vermont.

INTRODUCTION

Diffuse source pollution is widely recognized as a significant cause of surface water impairment. Eutrophication resulting from phosphorus enrichment, for example, represents the most serious diffuse source impairment to lakes across the U.S. and in Vermont (U.S. EPA, 1990; VT ANR, 1994). Loading studies have shown that efforts to control eutrophication in Lake Champlain cannot succeed unless diffuse sources of phosphorus are controlled (VTDEC and NYSDEC, 1994); a recent study indicated that two-thirds of the diffuse source phosphorus load to Lake Champlain originates from agricultural land (Budd and Meals, 1994).

In the late 1970s, Shelburne Bay and St. Albans Bay were identified as the most critical eutrophication problem areas on the Vermont side of Lake Champlain (NERBC, 1979). Algae blooms, extensive macrophyte growth, and high bacteria counts impaired recreation, aesthetics, and other beneficial uses in both bays. Phosphorus and bacteria from runoff of animal and milkhouse wastes and sediment from cropland erosion were significant agricultural diffuse source pollutants contributing to these problems (VTAEC, 1977; USDA-SCS, 1978). Major sources included improper manure management (e.g. year-round spreading due to lack of waste storage), poor milkhouse waste and barnyard runoff management, improper fertilizer management, cropland soil erosion, and streambank erosion. During the 1980s, two Vermont watersheds received intensive land treatment to control agricultural diffuse source pollution to Shelburne and St. Albans Bays.

In 1979, a plan to reduce sediment and nutrient loads to Shelburne Bay from the LaPlatte River Watershed, the major tributary to the Bay, was developed under the Watershed Protection and Flood Prevention Land Treatment Program (P.L. 83-566) by the U.S. Department of Agriculture Soil Conservation Service (USDA-SCS) (USDA-SCS, 1979). The land treatment program called for implementation of Best Management Practices (BMPs) for animal waste management and conservation land treatment, based on voluntary contracting with landowners, with cost-share incentives and technical assistance from USDA-SCS. In 1980, a similar effort began in the St. Albans Bay Watershed under the Rural Clean Water Program (RCWP). The goal was to improve water quality and restore beneficial uses in St. Albans Bay and its tributaries by implementation of agricultural BMPs through voluntary participation by landowners, with technical and financial assistance from the USDA.

Both projects included long-term, intensive water quality monitoring and evaluation programs to document changes in surface water quality resulting from the land treatment programs. Monitoring in the LaPlatte River Watershed began in 1979 and concluded in 1989; monitoring was conducted in the St. Albans Bay Watershed from 1980 to 1990. Results of both projects have been presented in detail elsewhere (Clausen and Meals, 1989; Meals, 1990; VT RCWP Coord., Comm., 1991; Meals, 1992 a, b, and c; Clausen, *et al.*, 1992; Schlagel, 1992; and others). This paper summarizes some of the major findings of both projects.

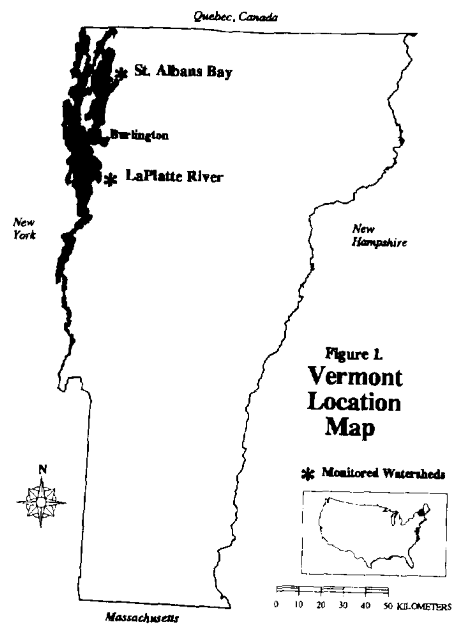

Figure 1. Vermont Location Map.

STUDY AREA

The two study watersheds are located in northwestern Vermont, along eastern Lake Champlain (Fig. 1). The 13,800 ha LaPlatte River Watershed lies 10 km south of Burlington and drains to Shelburne Bay of Lake Champlain. The watershed is 47% agricultural, forests cover 40% of the area, and residential areas encompass 10%. There are 40 active farms, mostly dairy in the watershed, averaging 120 ha in size. Dairy herd size averages 120 animals. The only point source in the watershed – a 0.01 m^3/sec aerated lagoon wastewater treatment plant serving the village of Hinesburg – discharges to the LaPlatte River 8 km above its mouth.

The St. Albans Bay Watershed, 40 km north of Burlington, drains 13,000 ha of agricultural (65%), forested (20%), and urban/residential (10%) land to St. Albans Bay. There are 102 farms in the watershed. Dairy farms predominate and average 134 ha in size, with a mean herd size of 110 animals. The city of St. Albans wastewater treatment plant discharges about 0.18 m^3/sec to a wetland at the head of the Bay. At the beginning of the project in 1980, the aging treatment plant contributed an estimated 40-50% of the annual phosphorus load to St. Albans Bay; following a 1987 upgrade to tertiary treatment, the point source represented less than 10% of the Bay's annual phosphorus load.

Both watersheds are located primarily in the Champlain Lowlands, an area of generally low relief between Lake Champlain and the foothills of the Green Mountains. Soils in the watersheds formed on lacustrine deposits (30–40%) and glacial tills (35–60%), many of which are poorly drained. The climate of the region is cool and humid, with pronounced seasonal variations. Mean annual temperature is 7.0°C; average annual precipitation is 850 mm (NOAA, 1989). Average annual snowfall is 1750 mm.

Dairy agriculture is the dominant land use in both watersheds. Corn for silage is the principal cultivated crop, typically covering up to 10–15% of watershed area. Substantially more land is devoted to hay, ranging from 30–35% of watershed area. Some cropland has been in continuous corn cultivation, but a 3 year corn/5 year hay rotation is the prevalent practice. Both manure and commercial fertilizers are commonly applied to corn cropland; hayland generally receives manure twice a year, immediately following hay cuts.

METHODS

A variety of monitoring programs were undertaken in both project areas to evaluate the effects of land treatment on water quality. Several short-term studies of BMP effectiveness were conducted: winter manure application on corn land, milkhouse wastewater and barnyard runoff treatment by vegetated filter strips, and summer manure application to hayland. The methods and results of these studies have been reported in detail (VT RCWP Coord. Comm., 1984; Schellinger, 1988; Schwer and Clausen, 1989; King, 1990).

Major tributaries were continuously monitored to determine long-term patterns of streamflow and both concentration and load of sediment, nutrients, and other pollutants. In the LaPlatte River Watershed, streams draining four subwatersheds with areas of 165 to 8,800 ha were monitored, along with the point source discharge. In the St. Albans Bay Watershed, the four major tributaries draining areas from 1,400 to 5,800 ha were monitored, along with the discharge from the St. Albans treatment plant.

Networks of recording gages measured precipitation in each watershed. Stream stage was recorded continuously with ISCO bubbler-type stage recorders and discharge was calculated from site-specific stage-discharge ratings. At each of the tributary trend stations, water samples were collected automatically at eight-hour intervals using refrigerated ISCO automatic samplers and combined into 3–5 composite samples each week for analysis. During some stormflow periods, discrete samples were collected more frequently. Samples were analyzed for total and volatile suspended solids (TSS and VSS), total and soluble reactive phosphorus (TP and SRP), and total Kjeldahl and ammonia nitrogen (TKN and NH3-N). Weekly grab samples were analyzed for pH, conductance, and fecal coliform (FC) and fecal streptococcus (FS) bacteria; temperature and dissolved oxygen measurements were made *in situ* at the time of grab sampling. St. Albans

Bay was sampled at four locations twenty times annually using a Kemmerer sampler. Samples were analyzed for TSS, VSS, TP, SRP, TKN, NH3-N, and Chlorophyll a. *In situ* measurements were made of temperature, dissolved oxygen, pH, conductance, and Secchi disk transparency. No monitoring was conducted in Shelburne Bay. All analyses were performed by accepted methods (APHA, 1980; USEPA, 1983).

RESULTS

Land Treatment

The LaPlatte River Watershed land treatment program was completed in 1985. Treatment included 25 BMP animal waste storage systems, 1600 ha of proper animal waste utilization (i.e., no winter spreading, soil incorporation), 18 milkhouse waste BMP systems, 10 barnyard runoff control BMPs, and 950 ha of cropland erosion control. Overall, an average of 67% of watershed animals were under BMP waste management; in several subwatersheds, 100% waste management was achieved. Land treatment in the St. Albans Bay Watershed was completed in 1986 and included 64 manure storage BMP systems, 3800 ha of proper waste utilization, 43 milkhouse waste BMP systems, 61 barnyard runoff control BMPs, and 3760 ha of cropland erosion control. A total of $1.0 and $2.25 million were spent on implementation of management practices in the LaPlatte River and St. Albans Bay watersheds, respectively, including governmen t cost-share and landowner expenditures.

In the LaPlatte River Watershed, participating farmers controlled 80% of watershed cropland and 68% of the livestock. In the St. Albans Bay Watershed, 60% of the farmers participated, representing about 75% of the farmland and livestock in the watershed. This participation rate represents a high level of watershed treatment compared to other agricultural nonpoint source projects in the U.S. (NWQEP, 1988).

BMP Effectiveness

Some BMPs significantly reduced edge-of-field pollutant delivery to surface waters. Where the traditional practice of winter manure spreading was followed, total P concentration in runoff from a St. Albans Bay watershed corn field was more than twice that observed when improved waste management was followed; SRP levels were about 15 times higher (VT RCWP Coord. Comm., 1984). Increases exceeding 100% and 500% were observed for TKN and NH3-N concentrations, respectively, when manure was winter-spread. Total P mass export from the winter-spread field increased by 11% and SRP export increased by 1500%. Up to 15% of the phosphorus content of the manure and 17% of the nitrogen was lost in runoff from winter applied manure. Similar patterns were observed in a companion study on cornfields in the LaPlatte River Watershed, where 5% of phosphorus applied in winter manure was lost in runoff (Clausen, 1987). These results confirm that animal waste BMPs which reduce winter spreading should have the potential to significantly reduce nutrient losses from cropland.

In the LaPlatte River Watershed, a vegetated filter strip reduced concentrations of TSS (92%), TP (86%), and TKN (83%) in surface runoff and TSS (97%), TP (92%), and TKN (93%) in subsurface output compared to levels in input milkhouse waste (Schwer and Clausen, 1989). The filter strip retained 95% of TSS, 89% of TP, and 92% of TKN on a mass basis over the course of a year. Mass retention was greatest during the growing season and poorest during snowmelt in the spring. Results indicate that filter strips can significantly reduce pollutant loading from milkhouse operations. In contrast, a vegetated filter strip was relatively ineffective for treating runoff from a paved barnyard (Schellinger, 1988). The hydraulically overloaded filter strip retained only 33% of TSS, 12% of TP, and 18% of TKN on an annual basis; retention of solids and nutrients was significant only during the growing season.

Surface application of manure to a hay field during the summer did not significantly change sediment, phosphorus, or nitrogen export in runoff compared to unmanured hayland, although a 60% increase in total P concentration in runoff from the manured hayland was noted (King and Clausen, 1989; King, 1990). Of the applied P and N, only 1.9% and 0.75%, respectively, was lost in runoff. Since these results were obtained in an unusually dry year, greater export could have resulted from normal summer precipitation.

Tributary Trends

In contrast to field-scale studies, evaluation of watershed scale response to treatment was difficult. Water quality in monitored streams varied between subwatersheds and between years throughout the project, influenced by significant differences in precipitation, runoff, and streamflow. This variation, combined with the lack of pre-project water quality data, the concurrent start-up of monitoring and land treatment, and the incremental implementation of BMPs made straightforward before/after comparisons impossible. Evaluation of treatment effects on a watershed scale relied, therefore, on analysis of long-term trends.

Water quality trends in the monitored subwatersheds of the LaPlatte River and St. Albans Bay Watersheds were evaluated using a variety of techniques in order to address problems of seasonality, autocorrelation, and flow dependence characteristic of nonpoint source pollution. Trend analysis techniques included analysis of variance, analysis of covariance, paired watershed regression, and nonparametric tests such as the seasonal Kendall and Mann-Whitney.

Concentrations and export of suspended solids decreased significantly in both project areas. In the LaPlatte River Watershed, TSS and VSS concentrations decreased by 10–60% and reductions of 40–60% in TSS load were indicated in some monitored watersheds (Meals, 1990). Concentrations and export of suspended solids declined in all but one tributary to St. Albans Bay. Observed TSS levels declined by 1.1–4.1 mg/l/year and TSS export decreased by about 60% in three of four monitored streams (VT RCWP Coord. Comm., 1991; Meals, 1992a).

Widespread dramatic decreases in phosphorus levels did not occur in either project watershed. Phosphorus concentrations in streams in the St. Albans Bay Watershed, in fact, increased by 0.006–0.010 mg/l/year, even accounting for variations in streamflow. No significant changes in nonpoint source phosphorus export in the tributaries to St. Albans Bay were observed over the study period. (VT RCWP Coord. Comm., 1991; Meals, 1992a).

In the LaPlatte River Watershed, similar patterns were observed for actual phosphorus concentration and export. However, in that project, monitoring data from a control watershed where no land treatment took place allowed the application of paired watershed regression analysis which controls for changes in background conditions (Hewlett and Pienaar, 1973). When background increases in phosphorus concentrations and load were accounted for, this analysis suggested reductions of 0.01–0.14 kg/ha/year (26–44%) in post-treatment phosphorus loads compared to loads projected under similar hydrologic conditions without land treatment (Meals, 1992c). Nitrogen concentration and export generally increased across both study areas, even when hydrologic differences were accounted for (Meals, 1990; VT RCWP Coord. Comm., 1991).

Bacteria counts declined significantly in both the LaPlatte River and St. Albans Bay watersheds the study period (Meals, 1989; VT RCWP Coord. Comm., 1991). Monthly fecal coliform counts decreased by 50–70% in monitored streams in the St. Albans Bay watershed. Fecal streptococcus counts dropped by 50–75% in monitored streams in both watersheds (Fig. 2). This widespread decline in indicator bacteria counts was the strongest and most clearly documented water quality trend observed in the watershed projects.

Although nonpoint source nutrient loads to St. Albans Bay did not decrease significantly during the project period, the annual phosphorus load from the city of St. Albans wastewater treatment plant dropped 85% following the upgrade to tertiary treatment. However, despite the significant decrease in overall phosphorus load to St. Albans Bay, water quality improved only very slightly in the innermost portion of the bay, but declined in the rest of the bay over the project period (VT RCWP Coord. Comm., 1991). Nutrient concentrations and algal production generally increased in the bay, while water transparency decreased. The lack of response in the Bay has been attributed to internal phosphorus loading from the sediment (Fowler, 1984; Smeltzer, 1991).

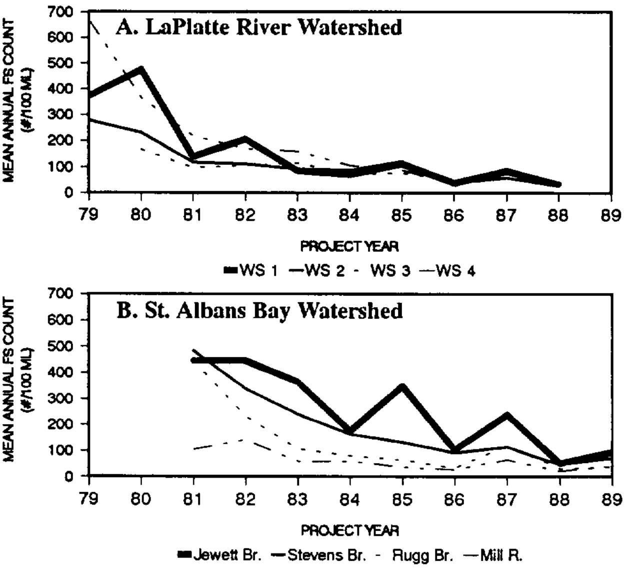

Figure 2. Trends in fecal streptococcus (FS) bacteria counts: A. LaPlatte River Watershed; B. St. Albans Bay Watershed.

DISCUSSION

In both the LaPlatte River and St. Albans Bay Watersheds, land treatment to control agricultural nonpoint source pollution was extensive. The effectiveness of some of the principal BMPs implemented was established in field studies. However, major improvements in water quality were observed only for bacteria; the anticipated dramatic reductions in phosphorus load did not occur.

Several factors may explain the lack of strong water quality response. The nature, timing, or level of land treatment may have been inadequate. Some practices, such as riparian zone management or livestock exclusion were not applied in either project. Despite the relatively high level of farmer participation in both projects, loads from a few non-participants may have overwhelmed treatment effects. Winter manure spreading continued to occur on many non-contract farms, for example. There was also some evidence in the LaPlatte River Watershed for the existence of a threshold effect, where a minimum level of implementation must be achieved before a response to treatment can be observed (Meals, 1992c). Only a few subwatersheds reached the high levels of treatment that may be needed. There may be a substantial lag time in the system between application of land treatment and improvements in water quality and this lag time is likely to exceed even the relatively long monitoring period of these projects (Clausen, *et al.*, 1992). Just as St. Albans Bay sediments serve as a reservoir for continued phosphorus supply, so too may watershed soils that have been farmed and fertilized for many decades act as a continuing nutrient source despite recent changes in management.

The dramatic decline in indicator bacteria counts is encouraging and argues that land treatment did in fact affect water quality. Strong correlations between improved animal waste management and reduced bacteria levels in streams have been documented (Meals, 1989 and 1992b). Declines in bacteria counts would be expected to result from improvements in animal waste management. Manure storage alone reduces bacteria levels in manure (Patni, *et al.*, 1985) and animal waste BMPs tend to decrease the availability of manure for runoff to surface waters. Finally, unlike phosphorus, indicator bacteria are not readily stored in the environment and decreases in their numbers in streams suggest that the rate at which they are being supplied to surface waters has decreased.

Future agricultural nonpoint source control projects should include implementation of additional practices such as riparian zone management. Practices such as nutrient management which reduce nutrient inputs to agricultural land should also be promoted. Projects should strive for high levels of participation and should consider ways to address problems arising from non-participants in voluntary programs. Monitoring programs would benefit from including an untreated control watershed in the monitoring plan. Projects should also include studies of important natural processes that may affect watershed response to treatments, such as materials transport in streams or phosphorus storage in soils and aquatic sediments. Finally, if documentation of treatment effects is the prime goal, monitoring and evaluation should be sustained long enough to account for lag time between treatment and response.

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REFERENCES

American Public Health Association. (1980). *Standard Methods for the Examination of Water and Wastewater.* 15th ed., Washington, D.C., USA.

Budd L. F. and Meals D. W. (1994). *Lake Champlain Nonpoint Source Pollution Assessment.* Technical Report No. 6, Lake Champlain Basin Program, Grand Isle, VT, USA.

Clausen J. C. (1987). Bushey field study. In: Meals, D. W., *LaPlatte River Watershed Water Quality Monitoring and Analysis Program – Year 8.* Program Report No. 9, Vermont Water Resources Research Center, Univ. Vermont, Burlington, VT, USA, pp 106-132.

Clausen J. C. and Meals D. W. (1989). Water quality achievable with agricultural best management practices. *J. Soil and Water Cons.* **44(6)**, 594–596.

Clausen J. C., Meals D. W. and E. A. Cassell (1992). Estimation of lag time for water quality response to BMPs. In: *Proc. Natl. RCWP Symp., Orlando, FL,* EPA/625/R-92/006, pp 173-180.

Fowler B. (1984). *Phosphorus fluxes from sediments of St. Albans Bay.* M.S. Thesis, Geology Dept., University of Vermont, Burlington, VT, USA.

Hewlett J. D. and Pienaar L. (1973). Design and analysis of the catchment experiment. In: E.M. White, ed., *Proc. Symp. Use of Small Watersheds in Determining the Effects of Forest Land on Water Quality.* Univ. Kentucky, Lexington, KY, USA.

King J. R. and Clausen J. C. (1989). Hayland manure applications and the quality of surface runoff. In: *Dairy Manure Management, Proc. Symp.* Northeast Reg. Agr. Eng. Serv., Cornell Univ., Ithaca, NY, USA.

King J. R. (1990). *Hayland manure applications and the quality of surface runoff.* M.S. Thesis, School Nat. Resour, Univ. Vermont, Burlington, VT, USA.

Loehr R. C., Haith, D. A., Walter, M. F. and Martin C. S. (eds). (1979). *Best management practices for agriculture and silviculture.* Ann Arbor Science, Ann Arbor, MI, USA.

Meals D. W. (1989). Bacteriological water quality in Vermont agricultural watersheds undergoing land treatment. *Lake Reserv. Manage.* **5(1)**, 53–62.

Meals D. W. (1990). *LaPlatte River Watershed Water Quality Monitoring and Analysis Program Comprehensive Final Report.* Program Report No. 12, Vermont Water Resources Research Center, University of Vermont, Burlington, VT, USA.

Meals D. W. (1992a). Water quality trends in the St. Albans Bay watershed following RCWP land treatment. In: *Proc. Natl. RCWP Symp., Orlando, FL,* EPA/625/R-92/006, pp 47-58.

Meals D. W. (1992b). Relating land use and water quality in the St. Albans Bay watershed, Vermont. In: *Proc. Natl. RCWP Symp., Orlando, FL,* EPA/625/R-92/006, pp 131-144.

Meals D. W. (1992c). Assessing nonpoint source phosphorus control in the LaPlatte River Watershed. *Lake Reserv. Manage.* **8(1)**, 71–83.

Meyers C. F., Meek J., Tuller S. and Weinberg A. (1985). Nonpoint sources of water pollution. *J. Soil Water Cons.* **40(1)**, 14–18.

National Oceanographic and Atmospheric Administration (NOAA). (1989). *Local climatological data for Burlington,* VT. Natl. Climatic Data Center, Asheville, NC, USA.

National Water Quality Evaluation Project (NWQEP). (1988). *Status of agricultural nonpoint source projects.* NC State University, Raleigh, NC, USA.

New England River Basins Commission (NERBC). (1979). *Shaping the Future of Lake Champlain.* Final Report of the Lake Champlain Basin Study, Burlington, VT, USA.

Patni N. K., Toxopeus M. R., and P. Y. Jui (1985). Bacterial quality of runoff from manured and non-manured cropland. *Trans. Am. Soc. Agric. Eng.* **28(6)**, 1871–84.

Schellinger G. R. (1988). *A vegetative filter strip to treat dairy barnyard runoff in cold regions.* M.S. Thesis, School Nat. Resour., Univ. Vermont, Burlington.

Schlagel, J. D. (1992). Spatial and temporal change in animal waste application in the Jewett Brook watershed, Vermont: 1983–1990. In: *Proc. Natl. RCWP Symp., Orlando, FL*, EPA/625/R-92/006, pp 145-150.

Schwer, C. B. and Clausen J. C. (1989). Vegetative filter treatment of dairy milkhouse wastewater. *J. Environ. Qual.* **18(4)**, 446–451.

Smeltzer, E. (1991). *The response of St. Albans Bay, Lake Champlain to phosphorus loading reductions.* Vermont Dept. of Environ. Conserv., Waterbury, VT, USA.

U.S. Department of Agriculture Soil Conservation Service. (1978). *Erosion and sedimentation nonpoint sources and controls – LaPlatte River Watershed.* Tech. Rep. LCBS-19, Lake Champlain Basin Study, Burlington, VT, USA.

Department of Agriculture Soil Conservation Service. (1979). *Watershed plan for LaPlatte River Watershed.* USDA-SCS, Winooski, VT.

U.S. Environmenal Protection Agency. (1983). *Methods for chemical analysis of water and wastes.* EPA-600/4-79-020. Off. Res.Develop., Cincinnati, OH, USA.

U.S. Environmental Protection Agency. (1990). *National Water Quality Inventory 1990 Report to Congress.* EPA 503/9-92/006, Office of Water, Washington, D.C., USA.

Vermont Agency of Environmental Conservation. (1977). *Nutrient loading to Shelburne Bay and St. Albans Bay, Lake Champlain, Vermont, 1975–1976.* Department of Environ. Conservation, Waterbury, VT, USA.

Vermont Agency Natural Resources. (1994). *State of Vermont 1994 water quality assessment, 305(b) report.* Department of Environ. Conservation, Waterbury, VT.

Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation. (1994). *A phosphorus budget, model, and load reduction strategy for Lake Champlain, Lake Champlain Diagnostic–Feasibility Study final report.* Vermont Dept. of Environ. Conserv., Waterbury, VT, USA.

Vermont RCWP Coordinating Committee. (1984). *St. Albans Bay Rural Clean Water Program Summary Report, 1984.* Vermont Water Resources Research Center, University of Vermont, Burlington, VT, USA.

Vermont RCWP Coordinating Committee. (1991). *St. Albans Bay Rural Clean Water Program Final Report 1980–1990.* Vermont Water Resources Research Center, University of Vermont, Burlington, VT, USA.