Water Quality in the Lewis Creek Watershed

A Review of Monitoring Data: 1992-2008

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for

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EXECUTIVE SUMMARY

Lewis Creek originates at in the wooded hills between Ireland and Hillsboro Roads of Starksboro east of Route 116, and flows approximately 27.5 miles through Monkton, Hinesburg, Charlotte, and Ferrisburgh mouth discharging into Hawkins Bay which in turn opens into Town Farm Bay and Lake Champlain. The river drains an area of about 81.1 $mi.^2$, approximately one quarter of which is drained by Pond Brook.

Water quality monitoring in the Lewis Creek watershed has been carried out by the Lewis Creek Association since 1992. The Lewis Creek Association, which was established originally in 1990, is active in the collection and analysis of water quality data in the Lewis Creek watershed, in undertaking fluvial geomorphic studies, in public education and outreach, restoration and conservation within the watershed, and in watershed planning.

Water quality parameters currently monitored in the Lewis Creek watershed include *Escherichia coli*, turbidity, total phosphorus, and total nitrogen. Sampling within the watershed is carried out on a monthly basis in the late spring and summer. Major conclusions from the Lewis Creek Water Quality Monitoring Program include:

- Results of testing for *E. coli* indicate that State standards of 77 organisms/100 ml are exceeded at all sites sampled in most samples, including sites used for recreation, including swimming, fishing, and boating. The stream in its lower and middle reaches where it is used for recreational purposes is listed as an impaired waterway in need of TMDLs as a result of high *E. coli* counts attributed to agricultural runoff.

- Suspended sediment loads transported by Lewis Creek are generally low, and turbidity levels are normally well below the Vermont State standard of 10 NTU, but may increase substantially during periods of high flow or following bank failures.

- Total phosphorus concentrations in Lewis Creek tended to fall below the proposed State Criterion for aquatic life in Class B cold water streams most of the time at most locations sampled except in Pond Brook and in Lewis Creek at LCR 9.9 located downstream from its confluence with Pond Brook.

- Phosphorus loads transported by Lewis Creek are closely related to suspended sediment loads. Any strategy for the reduction of phosphorus loadings to Lake Champlain from the Lewis Creek watershed therefore must depend primarily upon reductions in the sediment load transported by the stream.

- Pond Brook appears to constitute the most important source of phosphorus within the Lewis Creek watershed and should be the subject of a Phase II fluvial geomorphic study in view of the relationship between sediment and phosphorus loads.

- The phosphorus burden carried by suspended sediment falls generally within a range of 1 to 3 mg P/gm TSS, but can exceed 10 mg P/gm TSS when flows and suspended solids concentrations are low (<45 mg/l TSS and 450 cfs at LCR 3.7) and sediment consists largely of clay and very fine silt.

- The fate of fine and coarser sediment particles (as well as dissolved phosphorus) within the lake also should be investigated.

- Total nitrogen concentrations in Lewis Creek were low and fell well below the Vermont State standard of 5 mg/l for nitrate in Class B waters, but exceeded proposed in-stream total nitrogen criteria for aquatic life at most locations sampled at least part of the time.

- Total nitrogen concentrations, and total nitrogen in relation to total phosphorus concentrations (TN:TP ratios) were useful in interpreting data and understanding sources of nutrients entering Lewis Creek.

- Results of geomorphic and water quality studies should be utilized to provide a basis for formulating policies relating to land management and protection of the environment and Lake Champlain and for drafting land use and basin plans.

- The relatively low levels of solids and nutrients, observed in the Lewis Creek watershed should be taken into account when considering stream classification and establishing management types for Lewis Creek.

I. INTRODUCTION

I.1 Lewis Creek Association

The Lewis Creek Association (LCA) was established originally as the Lewis Creek Conservation Committee in 1990. Since its establishment, the Association has been active in the collection of data in the Lewis Creek watershed and their analysis, in public education and outreach, restoration and conservation within the watershed, and watershed planning.

Water quality monitoring in the Lewis Creek watershed has been carried out by the Lewis Creek Association since 1992. The sampling effort in the Lewis Creek watershed is one of a number of water quality monitoring programs supported in part by the Vermont Department of Environmental Conservation (DEC). Other related programs and studies implemented by the DEC, the U.S. Geological Survey (USGS), the U.S. Department of Agriculture (USDA), and the University of Vermont (UVM) complement and can inform the analysis and interpretation of monitoring data collected by the Lewis Creek Association as well as the design of a water quality sampling program for the future. The present review therefore includes a limited analysis of data related to nutrients and suspended solids collected under the Long Term Tributary Monitoring Program implemented by the DEC. It also draws on results of fluvial geomorphic assessments carried out under the DEC River Management Program.

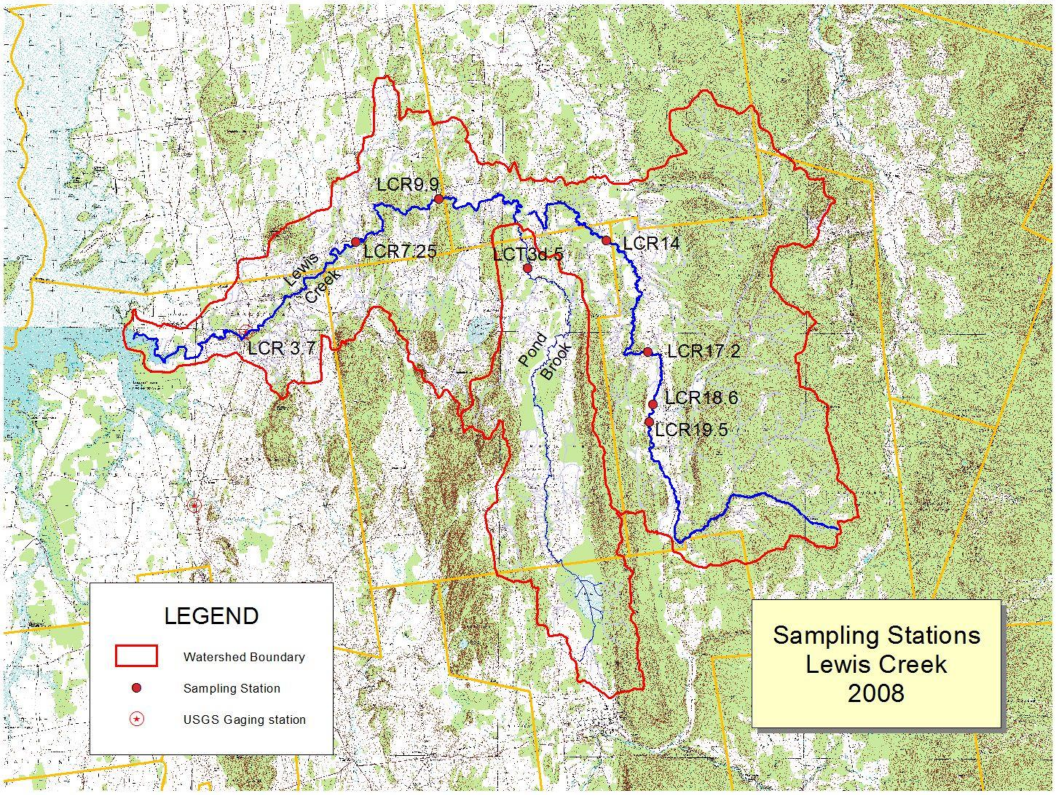
The Long Term Monitoring Program provides water quality monitoring data for Lewis Creek at Route 7 (sampling station LCR 3.7) and is designed to provide a basis for the assessment of nutrient loadings on Lake Champlain. It does not provide information on sources of nutrients originating within the watershed upstream from LCR 3.7 or from sources between LCR 3.7 and the mouth of the stream. The Lewis Creek Association monitoring program, in contrast, aims to provide a greater understanding of the sources of nutrients within the watershed and potential impacts of water quality on water use within the watershed and in Lake Champlain.

I.2 Lewis Creek Watershed

Lewis Creek originates at an altitude of about 1,900 feet in the wooded hills of Starksboro east of Route 116, and flows approximately 27.5 miles through Monkton, Hinesburg, Charlotte, and Ferrisburgh to its point of discharge at Hawkins Bay which opens into Town Farm Bay and Lake Champlain. The river drains an area of about 81.1 $mi.^2$, approximately one quarter of which is drained by its principal tributary, Pond Brook.

Pond Brook itself flows north from Winona Lake in Bristol, joining Lewis Creek in the Town of Hinesburg. The stream drains a flat valley defined by the steep forested slopes of the Hogback Mountains on the east and Monkton Ridge and the Little

Hogbacks on the west. The Pond Brook watershed includes wetlands and agricultural lands.



Land Use/Land Cover. The Lewis Creek watershed is largely rural, only 5% of which can be considered urban. In its upper reaches, the Lewis Creek watershed is largely forested, and forest constitutes about 62% of the total land area falling within the watershed. Agricultural activities including cornfields, dairy operations, and market gardens cover approximately 24% of the Lewis Creek watershed, mainly within the river corridor.

Available Geomorphic Assessment Data

Fluvial Geomorphology. The DEC, through its River Management Program, has promoted fluvial geomorphic assessments of streams in the state to understand physical factors and processes in their watersheds that impact on Lake Champlain, streams and their ecology. The purpose is to predict stream channel and floodplain evolution, resolve conflicts between land use and rivers, reduce the rate of eutrophication in the lake, and provide a sound basis for land use planning.

Fluvial geomorphic assessments provide background on land use and land cover, soils and erosion, as well as the physical conditions of streams, processes taking place in them, and sensitivity to human interventions in their watersheds that can inform interpretation of water quality data and corridor planning.

Phase II fluvial geomorphic studies have been completed on Lewis Creek. Of particular interest in relation to water quality in the Lewis Creek watershed are agricultural use, the predominance of glacio-lacustrine deposits and till, channel evolution stage, and, with limitations, the extent of streambank erosion, as well as stability of the stream channel as characterized by evolution stage. Data on these factors derived from phase II fluvial geomorphic studies are summarized below:

Upstream Land Cover/Land Use and Soil Type

Stream	Sampling Station	Geomorphic Reach	Site Description	Remarks
Lewis Creek	LCR3.7	M06	Old Route 7	**Upstream Subwatershed[2]:** 10.5% Cropland 33% Glacio Lacustrine & Till **Upstream Corridor:** 15.4% Cropland 12.9% Fields 43.1% Forest 10-25% Bank Erosion **Upstream Evolution Stage:** NA[3]
	LCR5.2	M07	Old Hollow Road	**Upstream Subwatershed[2]:** 10.3% Cropland 93% Glacio Lacustrine & Till **Upstream Corridor:** 1.5-6% Cropland 3.8% Fields 56% Forest 5.8% Bank Erosion **Upstream Evolution Stage:** I
	LCR7.25	M10	Lower covered bridge, Spear St.	**Upstream Subwatershed[2]:** 9.8% Cropland 71% Glacio Lacustrine & Till **Upstream Corridor:** 5.6% Cropland 3.6% Fields 55% Forest **Upstream Evolution Stage:** I
	LCR9.9	M11/M12/M13 M14/M15	Upper covered bridge, Roscoe Rd.	**Upstream Subwatershed[2]:** <9% Cropland ~50% Glacio Lacustrine & Till **Upstream Corridor:** 0.9-25% Cropland 27.1% Fields (M11) 23.1-53.5% Forest **Upstream Evolution Stage:** M11-M14 = NA; M15A = I M15B = IV

LCR14	M15 M16 Predominant	Tyler Bridge	**Upstream Subwatershed[2]:** ~5% Cropland ~60% Glacio Lacustrine & Till Dairy farming **Upstream Corridor:** 25.8% Fields (M16) 14.3% Forest 35.6% Bank Erosion Dairy farming **Upstream Evolution Stage:** M15B = IV; M16 = NA
LCR15.6	M17	Kelly Farm driveway	**Upstream Subwatershed[2]:** ~5% Cropland ~98% Glacio Lacustrine & Till Dairy farm **Upstream Corridor:** 15.3% Cropland 14.2% Fields 30.8% Forest 22.8% Bank Erosion Dairy farm/cows have access to stream **Upstream Evolution Stage:** M17A = I; M17B = IV; M17C = III
LCR17.2	M19	Starksboro Ballpark	**Upstream Subwatershed[2]:** 4% Cropland 7% Glacio Lacustrine & Till **Upstream Corridor:** 15-24% Cropland 26.2% Fields 11.3% Forest Vegetable farm **Upstream Evolution Stage:** M19A = I; M19B = IV
LCR18.6	M19	Lewis Creek Farm Footbridge (below Farm)	**Upstream Subwatershed[2]:** <5% Cropland 12.4% Glacio Lacustrine & Till **Upstream Corridor:** ~37% Stream Bank Erosion 23-24% Cropland 26.2% Fields 11.3% Forest Dairy farming upstream to LCR19.5 **Upstream Evolution Stage:** M19A = I; M19B = IV

	LCR19.5	M20/M21/M22	Parsonage Rd. Bridge	**Upstream Subwatershed[2]:** <5% Cropland 12.4-3.6% Glacio Lacustrine & Till **Upstream Corridor:** 5.6% Cropland 17.7% Fields (M20) 22.6% Fields (M22) 39.3-16.4% Forest 12% Bank Erosion Dairy farming and cropland >1 mi. upstream DEC biomonitoring site **Upstream Evolution Stage:** M20A = IV; M20B = II M21A = II; M21B = IV; M22 = II
Pond Brook	LCT3d.5	T3.01-T3.03	Silver Street Bridge over Pond Brook	**Upstream Subwatershed[2]:** 12-12.5% Cropland 75-100% Glacio Lacustrine & Till **Upstream Corridor:** 1.3-9.8% Cropland 15..5% Fields (T3.02) 36.3% (T3.01) – 21.9% (T3.03) Forest **Upstream Evolution Stage:** NA

1. Estimated from Phase II geomorphic data
2. Direct drainage to upstream reach
3. NA = not available

Stream Classification and Vermont Water Quality Standards. Lewis Creek has been designated by the State of Vermont as a Class B stream and as habitat for cold water fish. This classification requires that surface water quality meet water quality standards for *Escherichia coli*, turbidity, total phosphorus, and nitrate. The State also has proposed criteria for total phosphorus and total nitrogen in Wadeable streams which are applicable to Lewis Creek.

I.3 Purpose

It is the purpose of this report to review, assess, and interpret water quality data collected between 1992 and the present, provide a resource and reference document on water quality in the Lewis Creek watershed, and to highlight conclusions and recommendations for follow-up action.

This is part of a broader review which has resulted in the development and implementation in 2008 of a revised sampling plan, and the preparation of outreach materials. The water quality report, along with results of fluvial geomorphic studies, is intended to establish priorities, inform corridor planning and the development of strategies for restoration activities, improvement of water quality, and public education. Outreach activities include presentations to interested landowners, town, regional and state groups, and displays for exhibition at events, Town Meetings, libraries and schools. Efforts are made to inform federal agencies and State and university communities of findings and issues arising from the analysis, and to leverage monitoring efforts to obtain funds for the support of watershed management and improvement efforts.

II. WATER QUALITY IN LEWIS CREEK

Lewis Creek Water Quality Sampling Program. Water quality monitoring by the Lewis Creek Association was initiated in 1992 with testing for *Escherichia coli* during the summer seasons. The program targeted recreational sites and potential sources of animal pollution.

Because phosphorus is considered the most important nutrient contributing to the growth of algae and eutrophication in Lake Champlain, monitoring of total phosphorus was initiated in 1997 in order to provide an understanding of sources and a basis for federal, State, and local planning to maintain and improve water quality in the stream and to reduce nutrient loadings on the lake. The LCA monitoring program thus complements the Long Term Tributary Monitoring Program which was established to monitor nutrient loadings, yet does not provide information on sources. In 2003 the LCA began to partner with the DEC through the Volunteer Water Quality Monitoring Analytical Services Partnership (LaRosa Grant) Program, and monitoring for nutrients was expanded in 2004 when sampling for total nitrogen was initiated. The scope of the monitoring effort was expanded again in 2006 to include suspended sediment, contributing to an understanding of sources and transport of phosphorus. During 2006, both total suspended solids (TSS) and turbidity were determined at 4 stations in order to confirm the relationship of turbidity and TSS. After 2006, determination of TSS was dropped, and the determination of turbidity was continued. Although the determination of TSS permits analysis not possible with turbidity, the parameter was dropped after the first year to reduce costs and workloads at the LaRosa laboratory. It is noted that TSS is determined at LCR 3.7 under the Long Term Tributary Monitoring Program.

History of Sampling and Analysis on Lewis Creek

Stream	Sampling Site ID	Site Description	Years of Record				
			E. coli	**Total P**	**Total N**	**TSS**	**Turbidity**
Lewis Creek	LCR3.7	Old Route 7	1992-2005	1997-2007	2004-2007	2006	2006-2007
	LCR5.2	Old Hollow Road	1992-2002	1997-2002	-	-	-
	LCR7.25	Lower Covered Bridge, Spear Street	1992-2002 2008	1997-2002 2008	2008	-	2008
	LCR9.9	Upper covered bridge, Roscoe Road	1992-2007	1997-2008	2004 2008	-	2008
	LCR14	Tyler Bridge	1992-2008	1997-2008	2004-2008	2006	2006-2008
	LCR15.6	Kelly Farm driveway	2003-2005	2003-2005	-	-	-
	LCR17.2	Starksboro Ballpark	1992-2008	1997-2008	2008	-	2008
	LCR18.6	Lewis Creek Farm Footbridge (below farm)	1993-2002 2008	1997-2008	2008	-	2008
	LCR19.5	Parsonage Rd. Bridge	1993-2008	1997-2008	2004-2008	2006	2006-2008
Pond Brook	LCT3d.5	Silver Street Bridge over Pond Brook	2006-2008	2006-2008	2006-2008	2006	2006-2008

Since its inception, the Lewis Creek monitoring program has included more than 10 stations, although not all stations have been sampled consistently since 1992, as indicated in the above table. In 2007, a decision was made to review results in the monitoring database and the sampling program in the context of the needs and objectives of the program. As a result, the following stations were selected based on recreational significance, potential sources of pollution, and past monitoring results:

2008 Sampling Sites - Lewis Creek

Stream	Site ID	Site Location	PARAMETERS				Comments/Rationales
			E.coli	**TP**	**TN**	**Turbidity**	
Lewis Creek	LCR7.25	Lower Covered Bridge, Spear Street	X	X	X	X	Swimming Site
	LCR9.9	Upper Covered Bridge, Roscoe Road		X	X	X	Swimming Site
	LCR14	Tyler Bridge	X	X	X	X	Swimming and recreation site, downstream from dairy farms
	LCR17.2	Ballpark	X	X	X	X	Recreation Site, upstream from dairy farms
	LCR18.6	Lewis Creek Farm Footbridge	X	X	X	X	Downstream from farm
	LCR19.5	Parsonage Rd. Bridge	X	X	X	X	Upstream from farm
Pond Brook	LCT3D.5	Silver Street Bridge over Pond Brook		X	X	X	Downstream from farms

It is noted that monitoring at sampling station LCR 3.7 is carried out also under the Long Term Tributary Monitoring Program.

II.1 Indicators of Sanitary Quality – *Escherichia coli*

Escherichia coli is a member of the enteric group of bacteria which occurs characteristically in the intestinal tracts of warm blooded animals, but does not occur characteristically in the natural environment independently of fecal contamination. Because *E. coli* is generally harmless and characteristic of the intestinal tract of warm blooded animals, it has been used as an indicator of fecal contamination of water and foods, and thus of the potential presence of pathogenic organisms.

Vermont State Water Quality Standards. The State of Vermont has established a limit for *Escherichia coli* in class B waters of 77 organisms/100 ml. This limit can be waived between October 31 and April 1 provided that no health hazard is created.

The 2008 Vermont 303(d) Part A list of impaired waters not meeting Vermont Standards includes sections of Lewis Creek and its tributary, Pond Brook:

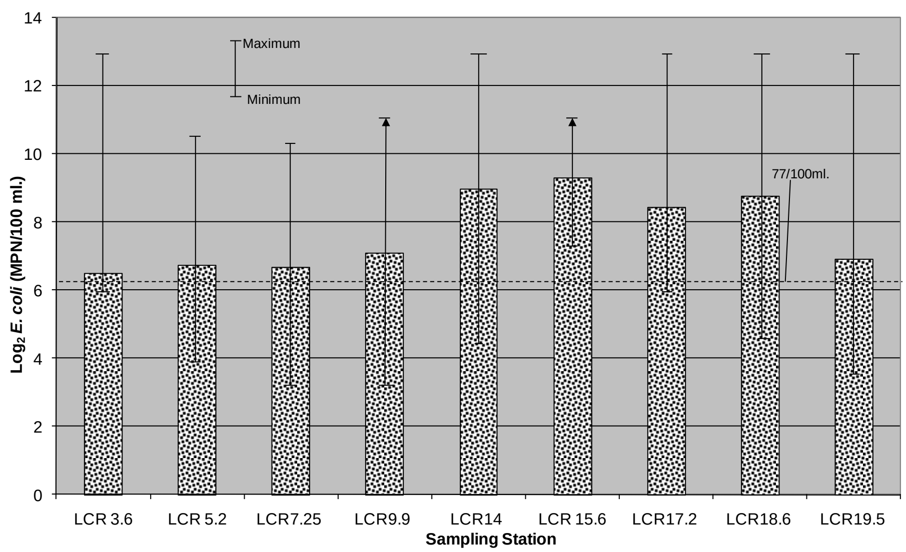
- Lewis Creek from lower Quinlan covered bridge at Spear Street (LCR 7.25) upstream to Lewis Creek Farm footbridge (12.3 miles) – Impaired for contact recreation as a result of high *E. coli* counts caused by agricultural runoff.

- Pond Brook from confluence with Lewis Creek upstream for 1.5 miles - Impaired for contact recreation as a result of high *E. coli* counts caused by agricultural runoff.

II.1.1 Monitoring Results

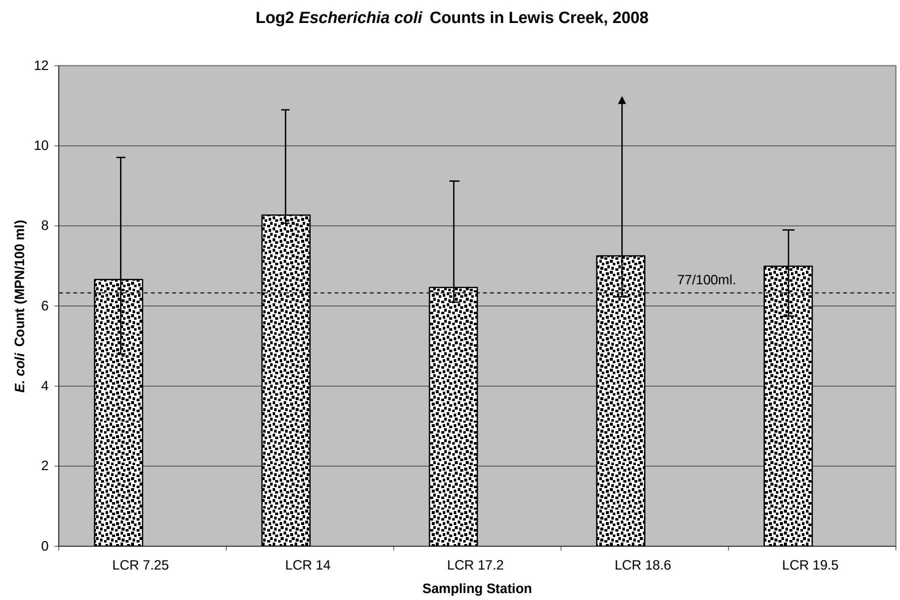
Most probable numbers of *E. coli* in Lewis Creek during the summer months exceeded the State standard of 77 organisms in at least half of the samples taken between 1992 and 2008, as well as 2010. A review of historical results indicates that *E. coli* counts tend to rise between LCR 19.5 and LCR 18.6. High levels tend to persist to LCR 14, after which they drop to levels slightly above the State standard. Potential sources include agricultural activities, beaver and other wildlife, as well as septic tank drainage.

Median Log_2 *Escherichia coli* Counts in Lewis Creek, 1992-2008



Whereas counts at times fall below the State standard at all sampling sites except LCR 15.6, very high counts far in excess of the standard are not uncommon. This is important because sampling points from LCR 17.2, located at the Starksboro ball fields, downstream to LCR 7.25 are located at sites used for swimming and other recreational purposes.

Escherichia coli counts reported during the 2008 summer season tended to be lower at upstream sampling sites, although high counts at LCR 18.6 greatly exceeded those at LCR 19.5 at time of high runoff. Counts remained high at LCR 14, and results at LCR 7.25 were consistent with historical records. All samples taken at LCR 14 and LCR 3.7 during the summer months of 2010 exceeded the State standard, the highest counts occurring on August 4 following heavy rains.



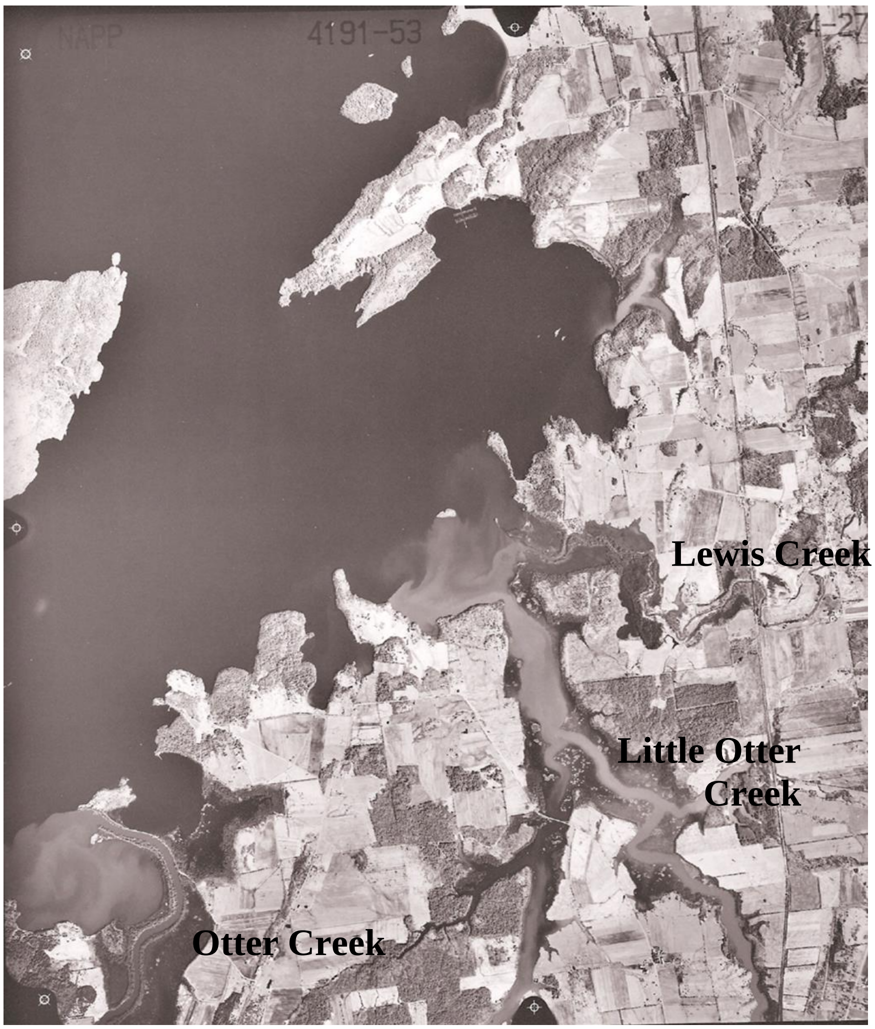
CONCLUSIONS and RECOMMENDATIONS

- Results of monitoring for *E. coli* are consistent with the State's listing of Lewis Creek as an impaired waterway from LCR 7.25 for a distance of 12.3 miles upstream, and including upstream recreational sites.
- There is no evidence of improvement in the sanitary quality of the waters in Lewis Creek over time.
- Sampling for *E. coli* is useful and informative and should be continued.
- Results of sampling should be given to towns and posted at recreational sites.
- Access of all farm animals to stream and its floodplain should be restricted at all times of the year except at gate crossings.

II.2 Suspended Solids

Suspended solids are important in streams and lakes where they can impact directly on aquatic life and where they play a role in the mobilization and transport of phosphorus, as well as determining the clarity and esthetic quality of water.

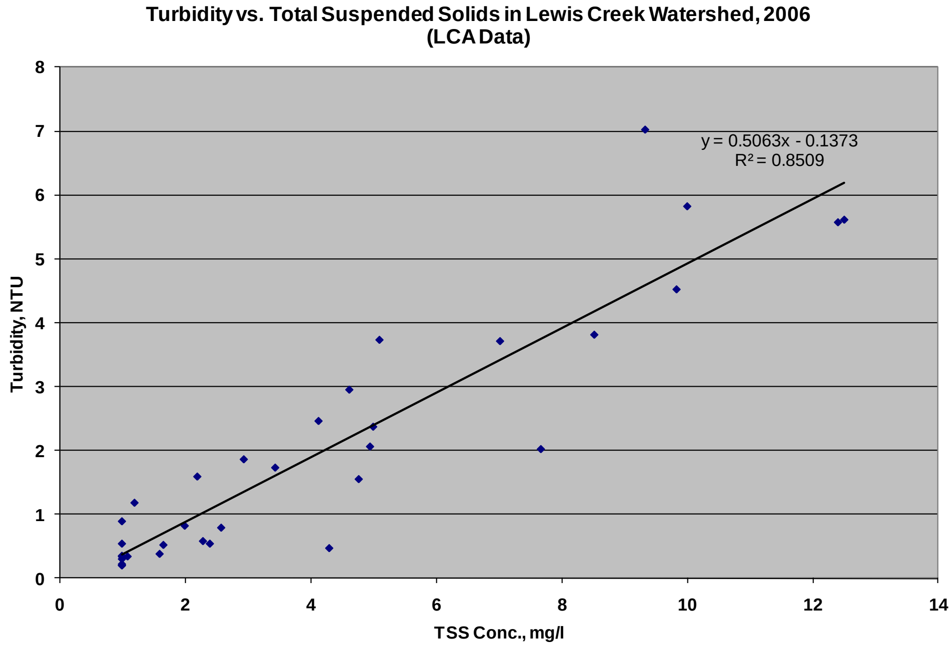
Total suspended solids (TSS) in water include both organic and inorganic solids. Inorganic solids constitute the main component of suspended solids discharging into Hawkins Bay from Lewis Creek. At high flow rates, medium and coarse silt as well as fine sand can be carried in suspension, but are deposited on land as floodwaters recede and settle to the bottom during periods of low flow and in still lake waters, leaving only clay and fine silt in suspension. Whereas larger particles may settle out as the rate of flow decreases in the backwater from the lake and as the stream discharges into the open water of the bay, finer clay and very fine silt may remain in suspension following local currents in the bay as illustrated in the following orthophoto:



II.2.1 Monitoring Results

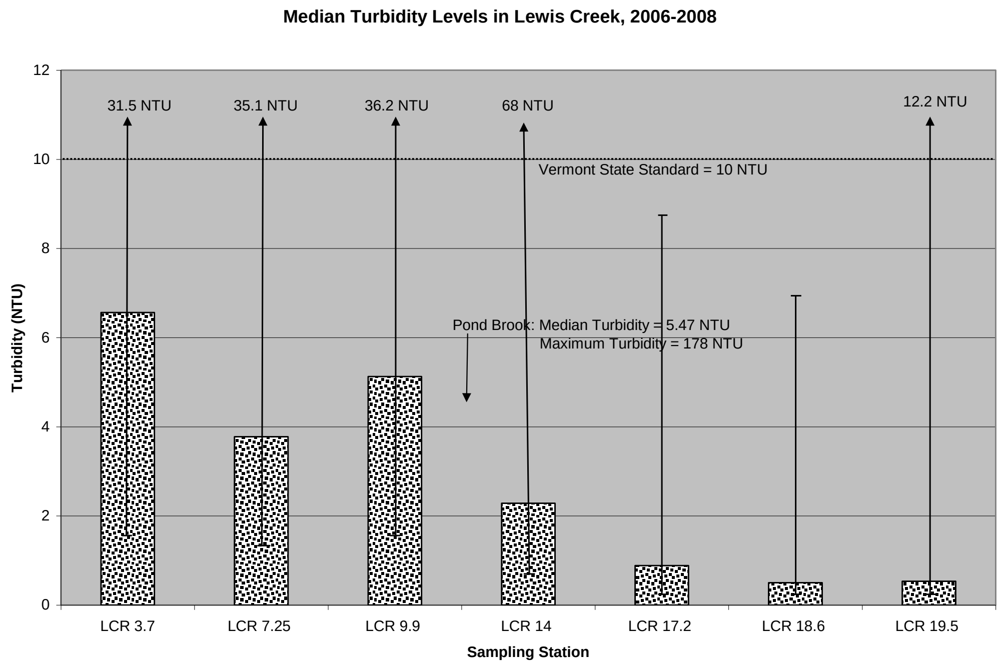
Suspended solids concentrations in the Lewis Creek watershed have been measured both directly (gravimetrically) and as turbidity. Both methodologies have been employed under the volunteer monitoring program in the Lewis Creek watershed in 2006. Prior to and after 2006, turbidity only was determined and will be the only analysis employed in future. This has the advantage of reducing costs of analysis while providing data related to water quality standards. It has the disadvantages i) of a surrogate indicator that may vary in relation to actual solids concentrations, and ii) of not being consistent with data collected under the Long Term Tributary Monitoring Program which includes TSS only.

That turbidity levels determined in Lewis Creek are related directly to TSS concentrations is illustrated by comparisons of these measures in samples taken in 2006:



Suspended Sediment in Lewis Creek and Pond Brook. Suspended sediment loadings have been generally low in Lewis Creek and its tributary, Pond Brook, and turbidity levels generally fall well below the State water quality standard of 10 NTU. Levels have been generally very low at Parsonage Road (LCR 19.5), but have tended to increase steadily downstream from the Starksboro ball park (LCR 17.2) as the stream picks up sediment.

Whereas turbidity levels as a rule fall below the State standard for cold water fish habitat, levels can exceed the standard at most sampling locations, and at all locations from LCR 14 downstream at times of high flow or following bank failures as discussed in the following section.



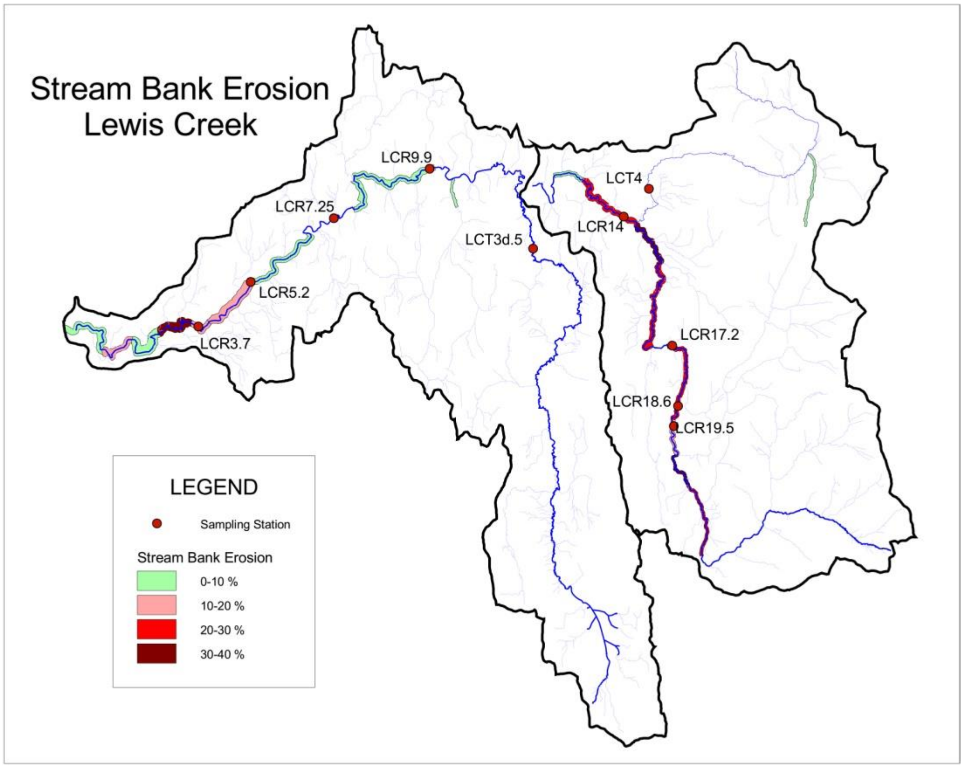
Stream bank erosion has been recorded for sections of the Lewis Creek as part of the fluvial geomorphic assessment of the watershed. This assessment demonstrated relatively extensive erosion starting several miles upstream from LCR 19.5 and continuing to a point about 1 mile downstream from LCR 14, the most intense erosion taking place for about 1 mile upstream from LCR 14. The extent of erosion downstream from LCR 14 was low until about 1.5 miles upstream from Route 7 (LCR 3.7) and particularly downstream from Route 7. At present, these observations do not appear to correlate well with the slow increase in turbidity between LCR 19.5 and LCR 14. Turbidity levels increase substantially between LCR 14 and LCR 9.9 and appear to be influenced by water entering from Pond Brook. Additional factors potentially contributing to the slow increase in sediment upstream from LRC 14 at lower flows, and to higher turbidities maintained downstream from LCR 14 include 1) dilution from tributaries entering between LCR 19.5 and LCR 14, and 2) finer-grained materials dominating stream banks and streambeds in the lower reaches of Lewis Creek which may be mobilized to a greater extent at lower flows relative to coarser-grained materials characteristic of the upper reaches (K. Underwood, personal communication).

The high levels of stream bank erosion may, however, tend to explain the high turbidity levels observed at LCR 14 at times of high flow. A low level of erosion between LCR 14 and LCR 9.9 tends to support the idea that fields in the Lewis Creek and Pond Brook corridors exert a significant influence on Lewis Creek at LCR 9.9 during periods of moderate flow, but may act to lower sediment loads at times of high flow. The low level of erosion, functioning floodplains, and high level of forest cover between LCR 9.9 and LCR 7.25 may help explain the drop in turbidity between these two stations.

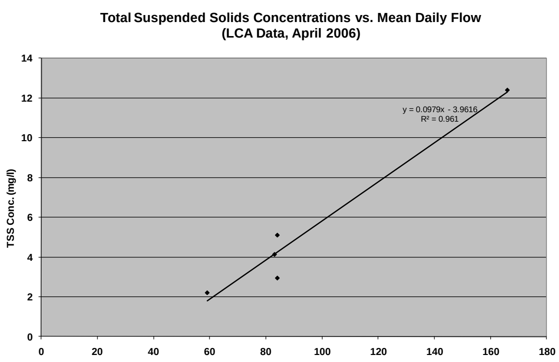
Instability of the channel as reflected in the channel evolution stage may also contribute to sediment load. Thus, adjusting reaches in stage III and IV upstream from

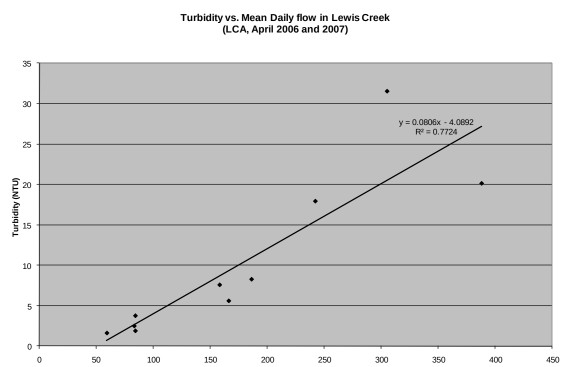
LCR 14 and LCR 9.9 may help explain increases in turbidity at these locations, as well as at LCR 17.2, but does not appear to have exerted great influence at the upstream stations.

All in all, the complexity of factors which may influence sediment load and the limited data available from the monitoring program make it impossible to explain with certainty the behavior of suspended sediment in Lewis Creek.

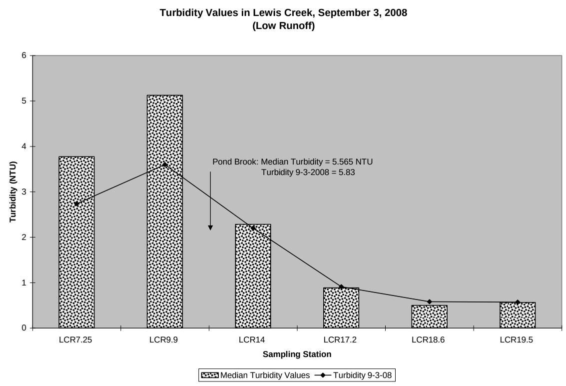


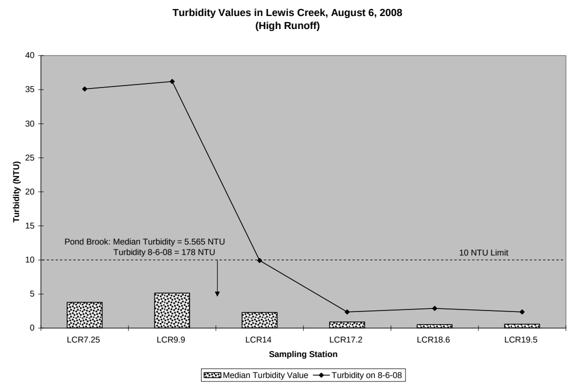
Relation between Suspended Sediment and Flow. While the record of analysis of suspended sediment at the USGS gaging station carried out under the Lewis Creek monitoring programs is short and consists of only a few data points, and these do not include samples taken at times of extreme high flow, the data do suggest a direct relationship.





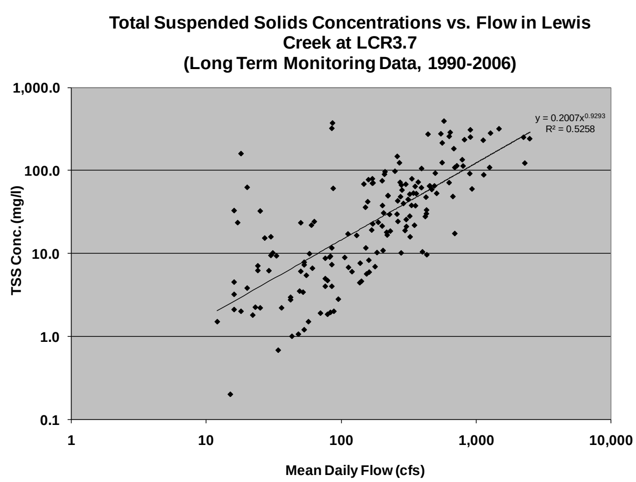
Furthermore, a comparison of turbidity along the river on days of low flow and runoff with turbidity on days of high flow and runoff illustrates the importance of flow rate, at least in the range of low to moderate flows. In the following graphs, the median turbidity levels at sites sampled during the summer of 2008 are shown as bars. On September 3, 2008, when flows in the stream were low, turbidity levels (shown as a line) followed the median to LCR 14, but fell well below the median at LCR 9.9 (upstream from Pond Brook) and LCR 7.25. Turbidity levels at all times fell well below the State standard of 10 NTU.



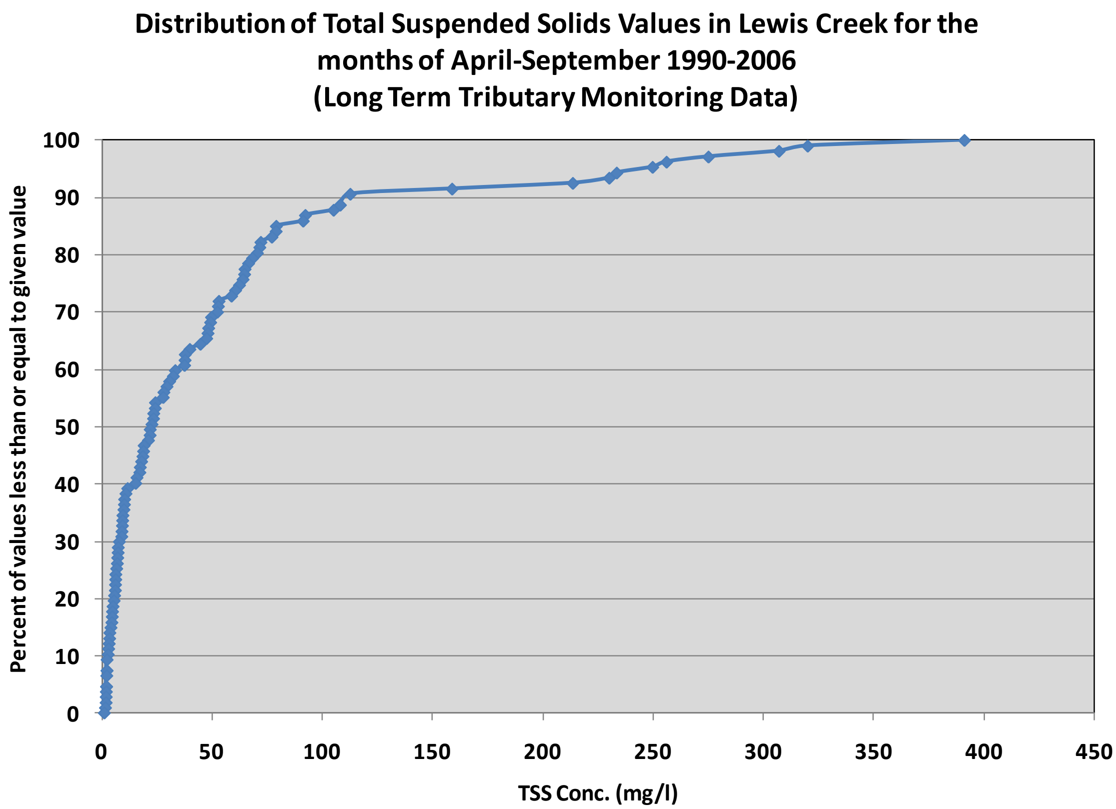


In contrast, on August 6, 2008, when stream flow and runoff were relatively high, the turbidity levels were slightly higher than the median from LCR 19.5 to LCR 17.2, but rose significantly at LCR 14, suggesting the importance of stream bank erosion and channel instability upstream from this sampling site (see discussion of geomorphic assessments above). Turbidity levels rose even higher at LCR 9.9 located downstream from Pond Brook, again illustrating the impact of this tributary on water quality in Lewis Creek. The effect was to boost the turbidity to 3.5 times the State standard.

It is noted, however, that the more extensive data collected under the Long Term Tributary Monitoring Program, which include a variety of rising and declining flow conditions, including bankfull and higher flow events, and are more likely to include extreme events such as bank failures, are more highly variable and do not define a strong relationship between suspended sediment load and flow rate.



An analysis of Long Term Tributary Monitoring data confirm a slightly higher level of solids at LCR 3.7 than the level suggested by limited data available under the LCA monitoring program. The median of all total suspended solids concentration data under the Long Term Tributary Monitoring Program was about 25 mg/l with a maximum value of about 390 mg/l. The comparable figures for data collected between April and September were about 22 mg/l and 390 mg/l, respectively. Applying the relationship between turbidity and total suspended solids determined from very limited data collected throughout the watershed under the LCA monitoring program in 2006, the solids data would translate to media of about 12.5 NTU and 11 NTU for all data and for spring and summer data, respectively, and a maximum turbidity of about 195 NTU.



CONCLUSIONS and RECOMMENDATIONS

- Turbidity correlated moderately well with total suspended solids concentrations in Lewis Creek during the base and moderate flow conditions encountered during the 2006 sampling season.
- Turbidity levels observed in Lewis Creek were generally low and well below the State standard during the generally low to moderate flow conditions typical of the late spring and summer sampling seasons. In contrast, Long Term Tributary Monitoring data suggest higher turbidity levels at LCR 3.7.
- Relatively high sediment loads observed in Pond Brook under the LCA monitoring program, and at LCR 3.7 under the Long Term Tributary Monitoring Program may reflect in part bank failures, but observations on Lewis Creek do not approach extreme events observed in other tributaries to Lake Champlain in Addison and Chittenden Counties.
- A general increase in turbidity and high maximum at LCR 14, suggests the possibility that field runoff and/or stream bank erosion and mobilization of bottom sediments may be important determinants of high levels. This should be investigated further in future.
- Turbidity levels in Pond Brook can reach very high levels at times of high flow and appear to have a significant impact on levels of turbidity in Lewis Creek.
- Turbidity measurements along with geomorphic information can help explain physical processes in Lewis Creek and its watershed, and analysis of turbidity should be continued at all sites sampled under the monitoring program.
- The apparently significant influence of Pond Brook, which drains about a quarter of the total area of the Lewis Creek watershed, suggests the need to undertake a water quality monitoring and Phase II fluvial geomorphic study this tributary.
- Results of geomorphic and water quality studies should be utilized to provide a basis for formulating policies relating to land management and protection of the environment and Lake Champlain and for drafting land use and basin plans.
- The relatively low levels of solids, together with nutrient levels, observed in the Lewis Creek watershed should be taken into account when considering stream classification and establishing management types for Lewis Creek.

II.3 Nutrients – Nitrogen and Phosphorus

The growth of algae and plants in surface waters depends upon the availability of nutrients and trace elements. Of these, nitrogen and phosphorus are of major importance. As a rule, phosphorus is considered most likely to limit productivity. The concept of limiting nutrients is important because increasing the availability of limiting nutrients permits increased growth, or productivity, and thus the process of eutrophication in lakes. It is for this reason that the primary focus of programs to protect the quality of Lake Champlain is on phosphorus. At the same time, nitrogen, the second macronutrient of major concern, should not be neglected.

Vermont State Water Quality Criteria and Standards. The Vermont water quality standards currently state that total phosphorus and nitrate loadings shall be limited so that they will not contribute to the acceleration of eutrophication or the stimulation of the growth of aquatic biota in a manner that prevents the full support of uses. The State of Vermont also has proposed total phosphorus and total nitrogen criteria for wadeable streams applicable for the months of May through September.

Proposed in-stream total phosphorus criteria for aquatic life in medium high-gradient Class B streams vary from 20 to 35 µg/l as P, depending on Management Type. A limit of 0.014 mg/l as P has been established for the Otter Creek section of Lake Champlain into which Lewis Creek discharges.

Proposed total nitrogen criteria for aquatic life in medium high-gradient Class B streams vary from 0.5 to 0.75 mg/l as Nitrogen depending on Management Type. Currently, the State of Vermont has established a limit of 5.0 mg/l as Nitrate-N at flows exceeding low median monthly flows in Class B waters applicable to Lewis Creek.

The 2008 Vermont 303(d) Part C list of impaired waters in need of further assessment for nutrients includes one section of Lewis Creek which fails to meet State water quality standards and is designated as an impaired water:

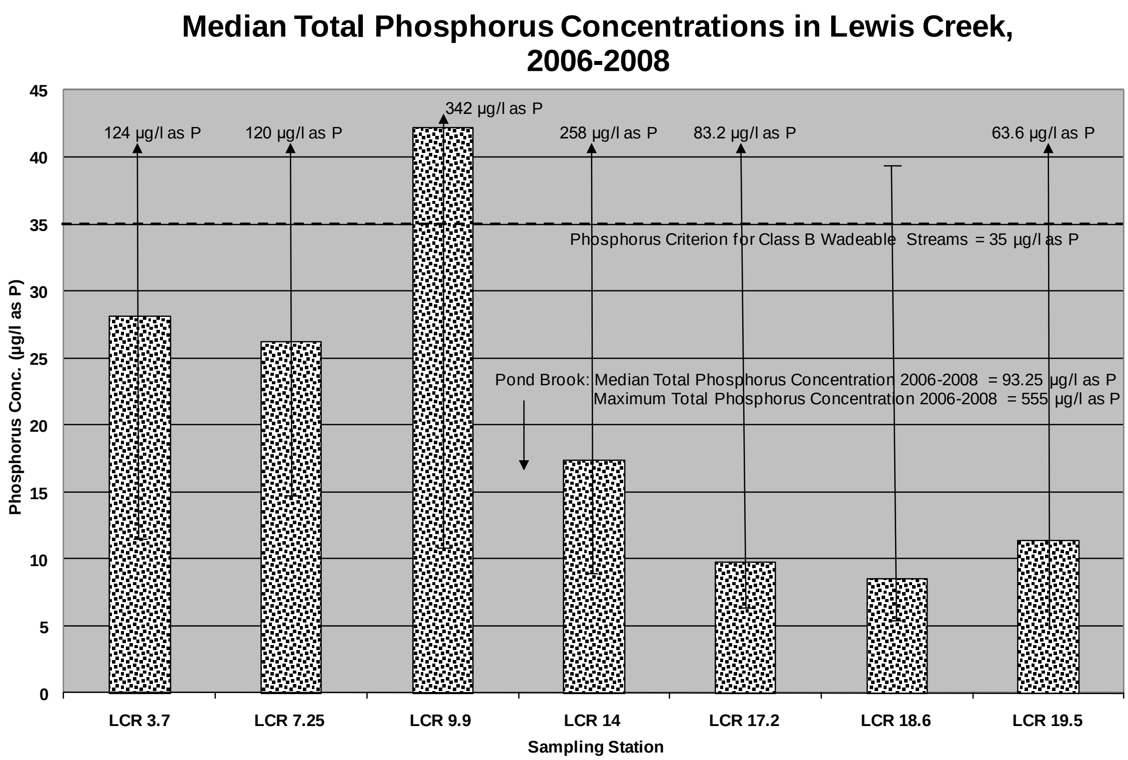
- Lewis Creek from lower covered bridge at Spear Street (LCR 7.5) upstream to river mile 16.6– Impaired for contact recreation and support of aquatic life as a result of bank instability, erosion, and loss of riparian buffer.

II.3.1 Phosphorus

Phosphorus is important in surface waters as it is a nutrient essential to plants and algae, and thus contributes to their growth in aquatic habitats. In shallow margins of lakes, phosphorus also can contribute to the development of nuisance algal blooms and growth of rooted and floating aquatic plants, including invasive species. In some instances, blooms of toxic blue-green algae may occur. Particularly susceptible to the development of nuisance conditions are areas where rivers discharge sediments carrying with them phosphorus which settles to the bottom in near shore areas. It is generally considered that production in open waters of Lake Champlain is limited by the availability of phosphorus, and as a result increases in the phosphorus loading may be expected to result in algal blooms as a result of eutrophication. The State of Vermont has established a total phosphorus limit of 0.014 mg/l for open water in the Otter Creek segment of Lake Champlain into which Lewis Creek discharges. A review of Lay Monitoring data for Town Farm Bay indicates that this limit is exceeded during the summer months.

II.3.1.1 Monitoring Results

Phosphorus Concentrations. The pattern of total phosphorus concentrations in Lewis Creek in general reflects that of suspended sediment. Concentrations have been as a rule low at sampling sites upstream from LCR 14, although at times of high flow they have been observed to increase to moderate, but generally not extremely high levels. It is notable that concentrations tended to decrease from LCR 19.5 to LCR 18.6. The pattern of phosphorus concentrations contrasted with the behavior of *E. coli* counts which were higher in the upper reaches of the stream and which potentially could indicate the presence of agricultural runoff.



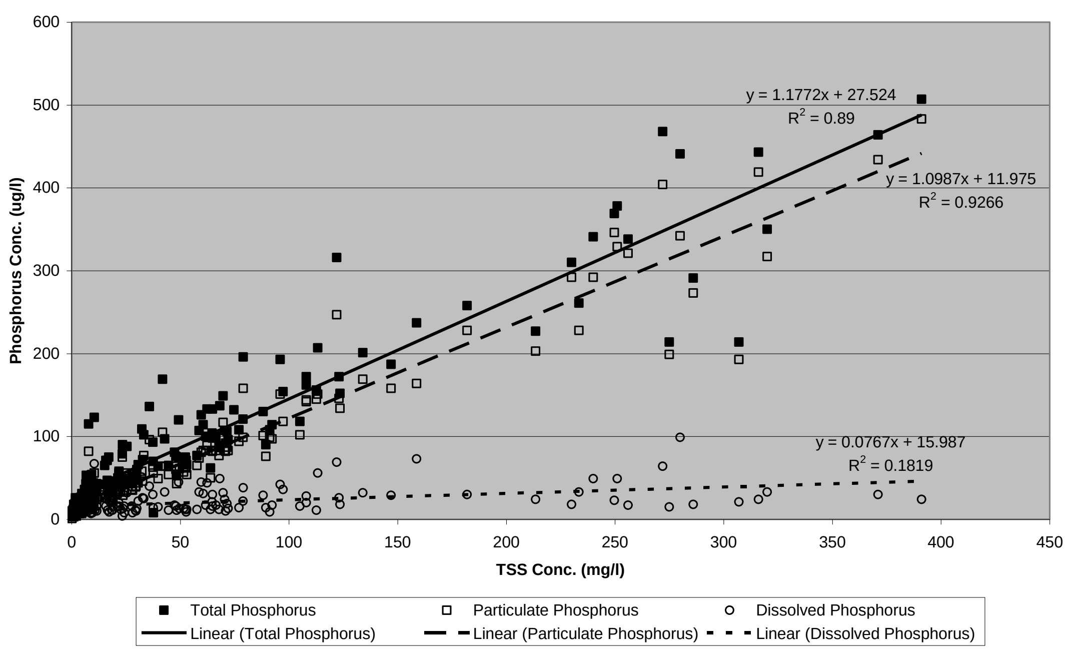
The increase in median total phosphorus concentrations between LCR 17.2 and LCR 14, and in concentrations at times of high flow, reflects increases in turbidity and, in view of total nitrogen data discussed below, could be attributable in part to runoff from dairy operations between the two sites. Further increases between LCR 14 and LCR 9.9 and high concentrations at times of high flow mirror the behavior of turbidity potentially attributable to dairy operations between the two sites and the influence of Pond Brook. Median concentrations observed at LCR 14 and LCR 3.7 during 2010 exceeded slightly the longer term median values, but observed maxima were lower than the historical maxima and exceeded the proposed total phosphorus criterion only at LCR 14.

The close similarity between the behaviors of total phosphorus and suspended sediment measured as turbidity in Lewis Creek and its tributary, Pond Brook, suggest that phosphorus occurs primarily associated with sediment entering and transported by the stream as a result of land runoff, stream bank erosion, and bottom scour. The relationship between phosphorus and suspended sediment is discussed further in the following paragraphs.

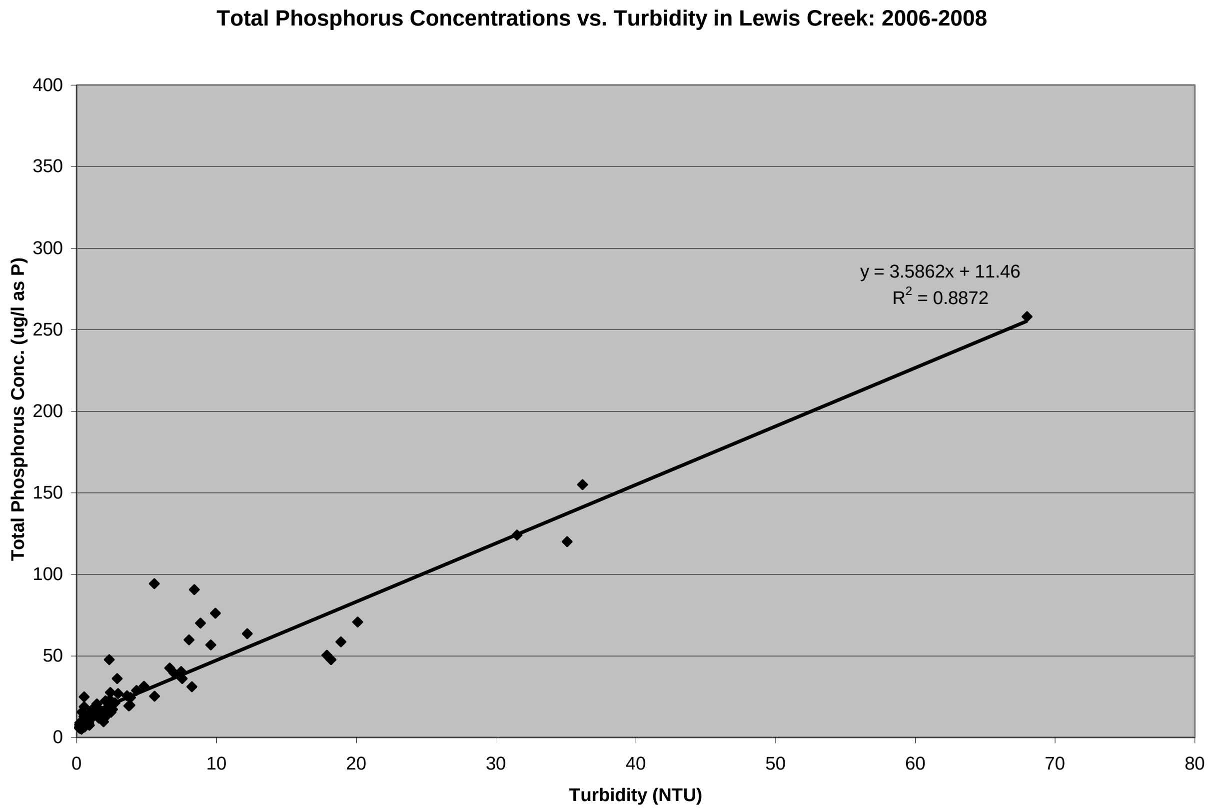
Total phosphorus concentrations tended to fall below the proposed State Criterion for aquatic life in Class B cold water streams except in Pond Brook and at LCR 9.9 located downstream of the confluence with Pond Brook. On the other hand, concentrations exceeded the criterion at least part of the time at all sampling stations.

Association of Phosphorus with Solids. That phosphorus in, and phosphorus transported to Lake Champlain by, Lewis Creek occurs primarily associated with suspended sediment and that particulate phosphorus is the predominate form in which phosphorus occurs in Lewis Creek is demonstrated graphically by results of sampling at LCR 3.7 carried out under the Long Term Tributary Monitoring Program:

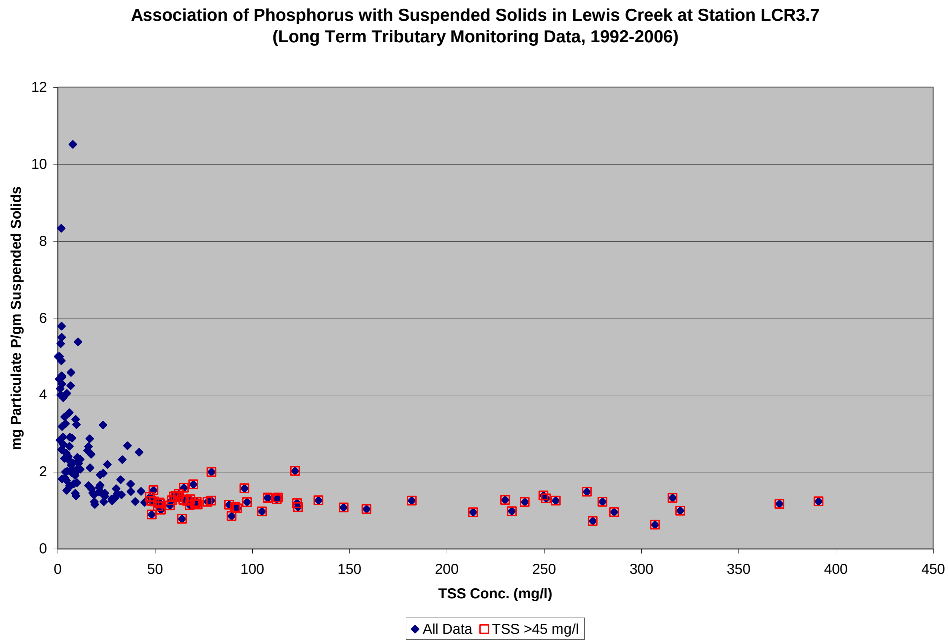
Phosphorus vs. Total Suspended Solids Concentrations in Lewis Creek at LCR3.7
(Long Term Monitoring Program, 1992-2006)



The data show that total and particulate phosphorus concentrations in Lewis Creek and phosphorus loadings to Lake Champlain from the Lewis Creek watershed, although exhibiting some variability, are directly proportional to suspended solids concentrations, and that particulate phosphorus constitutes the bulk of the total phosphorus load. In contrast, concentrations of dissolved phosphorus have been historically very low and constant regardless of sediment load (and flow). The direct relationship between total phosphorus concentrations and sediment load is illustrated also by results of sampling throughout the Lewis Creek watershed under the LCA sampling program:

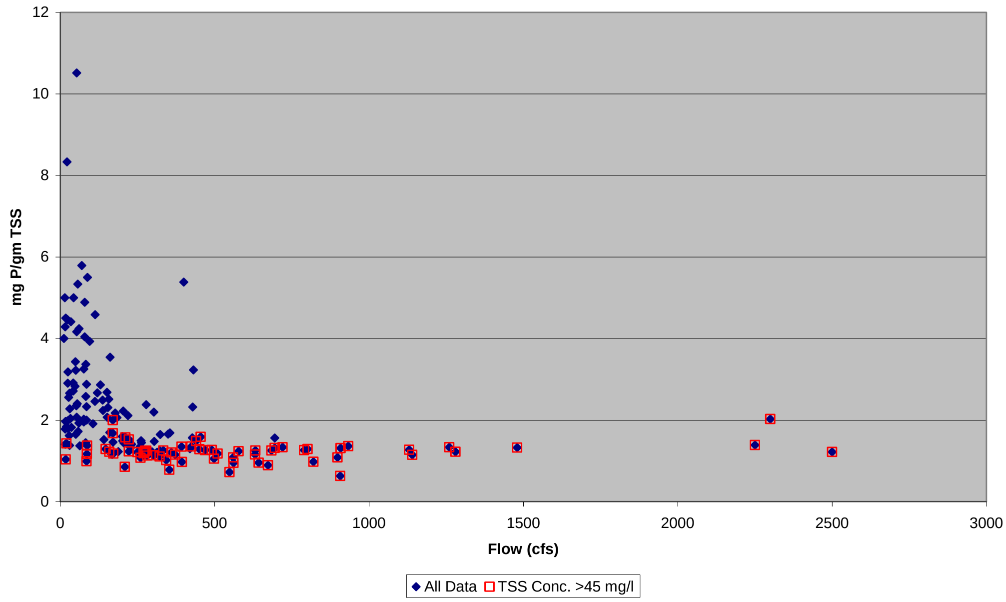


Additional insights can be gained from further examination of data collected under the Long Term Tributary Monitoring Program. When the burdens of particulate phosphorus per gram of suspended sediment (equal to grams of particulate phosphorus/kilogram of total suspended solids) are compared with concentrations of suspended solids, it is evident that phosphorus burdens tend to be high, and at times very high, at low TSS concentrations. At TSS concentrations greater than about 45 mg/l, particulate phosphorus concentrations are relatively constant irrespective of concentrations of solids. This suggests that at low concentrations, suspended sediment consists generally of very fine particles with high surface areas relative to mass (or organic materials rich in phosphorus). It also suggests a larger, more uniform silt loading at higher concentrations of TSS, the sediment load consists predominantly of larger particles having lower surface areas relative to mass.



The apparent association of high particulate phosphorus burdens with solids at low TSS concentrations suggests further that the relationship may extend to flow rate. When particulate phosphorus burdens per gram of TSS are compared with mean daily flows, it is evident that whereas low particulate phosphorus burdens occur over the full range of flows, high burdens are virtually limited to flows of less than 450 cfs, again suggesting that very fine particles carry a heavy burden of phosphorus, and a population of larger particles carry a lower phosphorus burden, but predominate at flows in excess of a "threshold" flow rate, which in Lewis Creek, appears to be at about 450 cfs (it is recognized that instantaneous flows would be more appropriate than mean daily flows as flow rates can vary widely during the course of a day). It is noted that this behavior of phosphorus burdens is observed also in other Vermont streams discharging into Lake Champlain, including Otter Creek, Little Otter Creek, and the LaPlatte River. Particle size analysis carried out on water samples from the LaPlatte River by the Champlain Water District further support the notion of a "threshold" flow below which clay and very fine silt predominate, and above which concentrations of larger particles increase in proportion to flow.

Solids Associated Phosphorus vs. Flow - Lewis Creek at LCR3.7
(Long Term Monitoring Data, 1990-2006)



The monitoring data provide an indication of the phosphorus burden and origins of particulate matter transporting phosphorus in Lewis Creek. Burdens calculated were generally higher than a commonly accepted normal range of 0.1 to 3 mg-P/gm-TSS. Values were highest, far exceeding the normal range at LCR 19.5, perhaps reflecting a history of farming in the upper reaches of the watershed resulting in a build-up of phosphorus in local clay soils, and decreased steadily to LCR 3.7.

	mg TP/gm TSS*		
	LCR 3.7	**LCR 14**	**LCR 19.5**
Median	3.78	4.50	9.05
Minimum	2.03	1.90	5.70
Maximum	5.36	10.58	24.90

*LCA Data, 2006

Particulate phosphorus burdens calculated from the limited LCA monitoring data were consistent with burdens calculated from Long Term Tributary Monitoring data (LCR 3.7). Long Term Tributary Monitoring data suggest that phosphorus burdens carried by suspended sediment and discharged to Lake Champlain were in general within a normal range throughout the year.

	mg PP/gm TSS*			
	QTR 1	**QTR 2**	**QTR 3**	**QTR 4**
		TSS Conc. < 45 mg/l		
Median	1.57	1.86	2.38	2.54
Minimum	1.23	1.15	1.18	1.41
Maximum	5.38	8.33	10.51	5.33

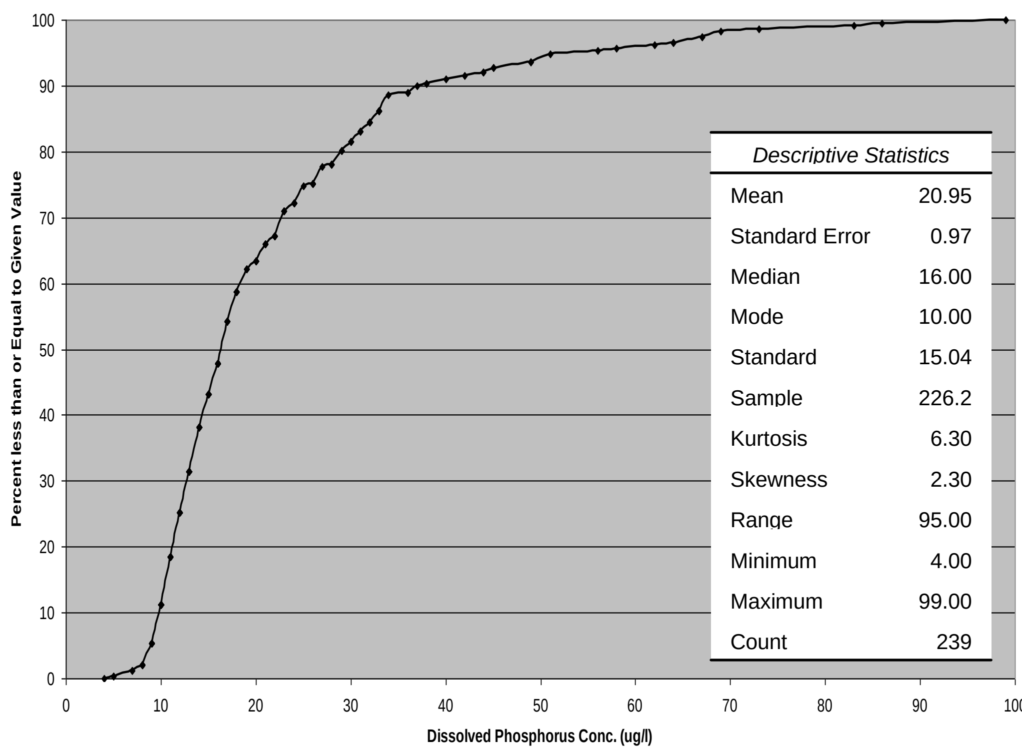
		TSS Conc. > 45 mg/l		
Median	1.17	1.23	1.36	1.26
Minimum	0.85	0.63	1.03	1.15
Maximum	1.68	1.59	1.52	1.36

*Long Term Tributary Monitoring Data, 1993-2006

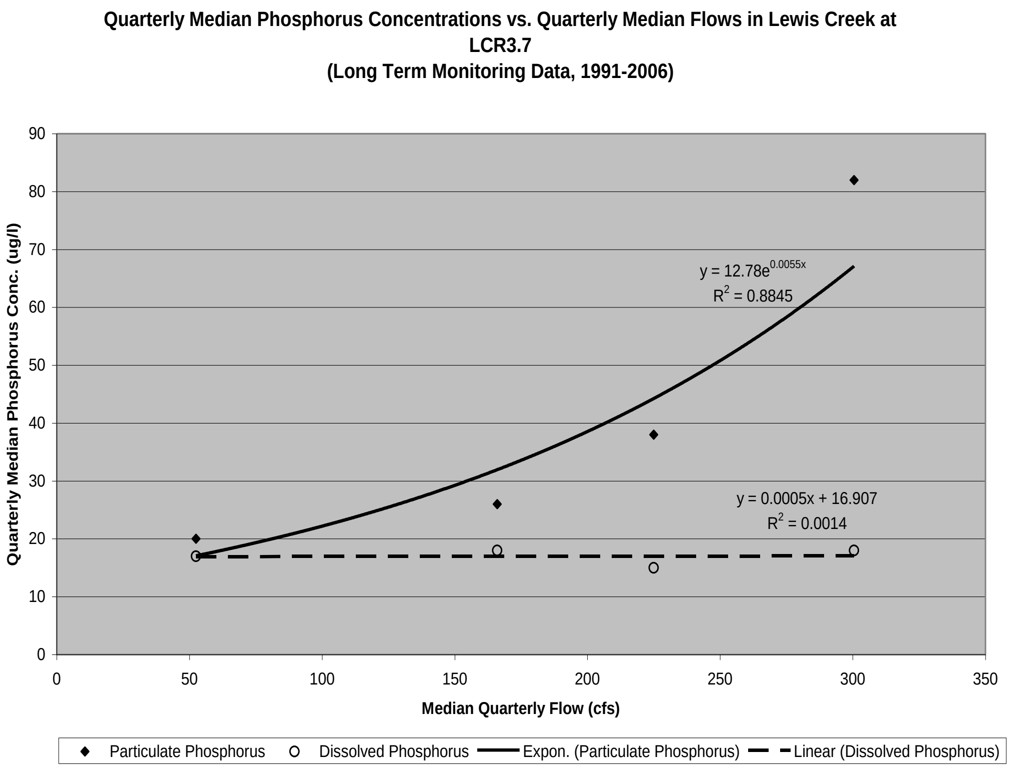
Burdens tended to be higher when the suspended sediment load was below 45 mg/l but still within a normal range, although maximum burdens exceeded the normal range as was observed with the LCA data.

Dissolved Phosphorus. . Whereas dissolved phosphorus is not determined under the Lewis Creek monitoring program, this parameter is determined under the Long Term Tributary Monitoring Program. As suggested in the graph above, concentrations of dissolved phosphorus fall generally below 100 µg/l as P, only two out of a total of 242 samples exceeding this value. Concentration levels and consistency of dissolved phosphorus concentrations in the Lewis Creek watershed resemble those observed in the adjacent LaPlatte River watershed. The median of all dissolved phosphorus determinations under the Long Term Tributary Monitoring Program was 16 µg/l. The distribution of dissolved phosphorus concentrations in Lewis Creek at LCR 3.7 is illustrated in the following graph and table:

Distribution of Dissolved Phosphorus Concentrations in Lewis Creek (Long Term Tributary Monitoring Program, 1990-2006)

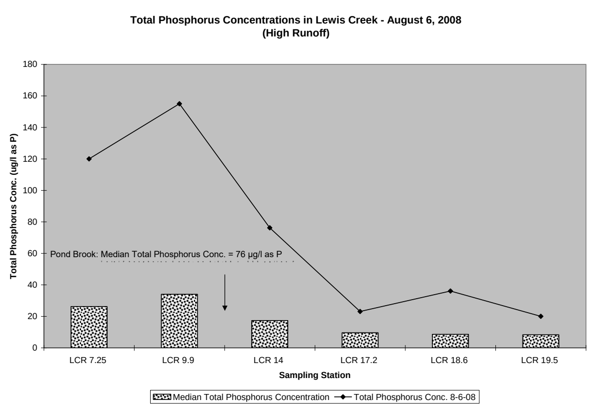


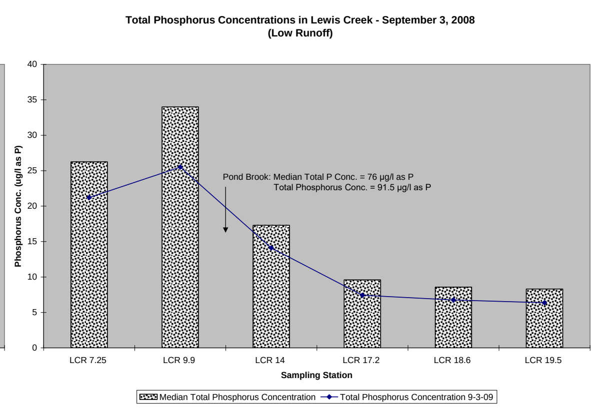
Phosphorus in Relation to Flow. Although the data are highly variable, a sense of how flow affects phosphorus in a general way can be derived from quarterly median dissolved and particulate phosphorus concentrations relative to quarterly median flows.



Results of this very crude analysis illustrate the consistency of dissolved phosphorus concentrations while at the same time a tendency of particulate phosphorus concentrations to increase as flow increases.

The effect of flow on phosphorus concentrations in Lewis Creek is illustrated graphically when phosphorus concentrations at high and low flows are compared. Again,





phosphorus concentrations tend to reflect the general pattern set by median concentrations at both high and low flows, but at high flows, as on August 6, 2008, concentrations were greatly increased, particularly downstream between LCR 17.2 and LCR 14 and below Pond Brook (LCR 9.9). At low flow, as on September 3, 2008, concentrations were reduced, but the pattern of increase between LCR 17.2 and LCR 14 as well as below Pond Brook persisted. These patterns follow closely the behavior of suspended sediment on these dates discussed above.

It is perhaps worth considering the results of the above analyses in terms of their implications with regard to the fate of phosphorus as it enters the backwater from the Lake Champlain, and in Hawkins and Town Farm Bays and the lake itself. In this context, the phosphorus loading on the lake might be thought of as being made up of three components, or phases:

- Particulate phosphorus associated with clay and fine silt particles carrying a heavy burden of phosphorus which may be transported into the bay and the open lake.
- Particulate phosphorus associated with larger particles carrying a lower burden of phosphorus which may settle in the backwaters of the lake and in the near-shore areas of Hawkins and Town Farm bays and the lake.
- Dissolved phosphorus which can be carried with water currents into the open lake.

The data suggest that the bulk of the phosphorus discharged from Lewis Creek would be associated with larger particles at times of higher flow (>450 cfs) which are more likely to remain in the lower reaches of Lewis Creek and near shore areas of Hawkins and Town Farm Bays where it may contribute to the development of algal blooms and growth of floating and rooted aquatic plants.

Of the Long Term Monitoring Program samples taken between 1990 and 2006, 80% were taken on days during which the mean daily flow was 450 cfs or less and fine particles appear to predominate. Although the hydraulic loading contributed by flows of less than 450 cfs constituted less than half of the total flow from Lewis Creek, a very rough estimate of the relative loads of phosphorus discharged annually to Lake Champlain from Lewis Creek suggest that the load contributed by fine particles, relatively rich in phosphorus and present at all flows, could potentially make up on average from 40% to 100% of that contributed by the coarser particles which appear to predominate at higher flows. Dissolved phosphorus in the discharge from Lewis Creek constitutes a very small portion of the total phosphorus loading on the lake.

CONCLUSIONS and RECOMMENDATIONS

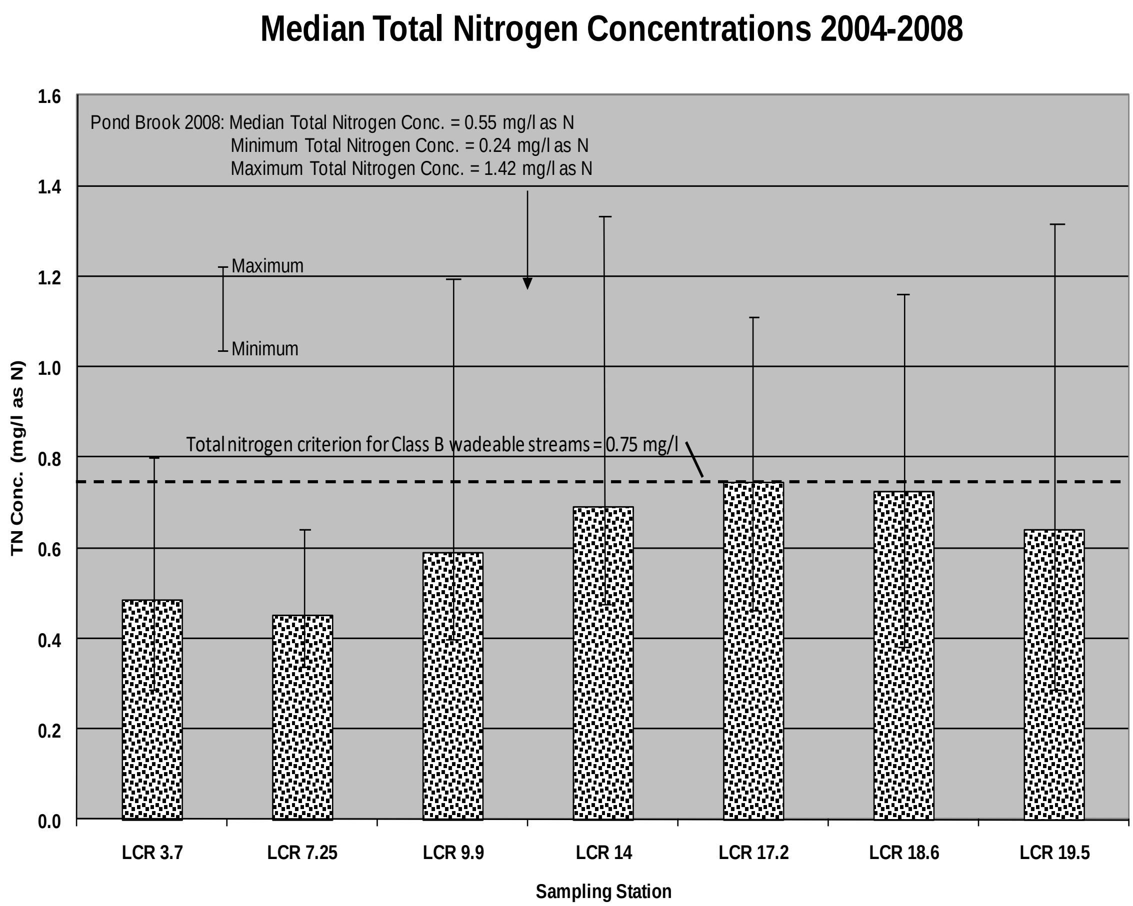
- Phosphorus loadings in Lewis Creek and Pond Brook are largely associated with suspended sediment brought into suspension primarily as a result of stream bank erosion and bottom scour, but also from agricultural land.
- Total phosphorus concentrations in Lewis Creek tend to increase in relation to flow and sediment load.
- Pond Brook appears to be a major contributor to the phosphorus loading in lower Lewis Creek.
- Total phosphorus concentrations tended to exceed the proposed State in-stream criterion in Pond Brook and LCR 9.9 below the confluence with Pond Brook, and exceeded the criterion at all sampling stations at least part of the time.
- At low flows and low TSS concentrations, the phosphorus burden (mg PP/gm TSS) carried by suspended sediment can be higher than at high TSS concentrations and flows.
- Dissolved phosphorus concentrations tended to be very low and independent of flow rate. They appear to be a minor source of phosphorus in Lewis Creek.
- Loadings of fine particulate and larger particulate components of the phosphorus load discharged into Hawkins and Town Farm Bays and Lake Champlain from Lewis Creek (as well as other tributaries to the lake) could have implications with regard to transport of phosphorus within Town Farm Bay and Lake Champlain.
- The fate of particulate and dissolved phosphorus in discharges from tributaries to Lake Champlain should be assessed.
- In view of the predominance of particulate phosphorus and its role in the transport of phosphorus in Lewis Creek, it is not recommended that dissolved phosphorus be determined under the Lewis Creek monitoring program.
- It should be noted that downstream from LCR 3.7, there is considerable potential for additional phosphorus loading to Lewis Creek (including dissolved phosphorus) from agricultural sources. The significance of these should be assessed.
- Results of geomorphic and water quality studies along with floodplain reconnaissances, particularly with regard to phosphorus, should be utilized to provide a basis for formulating policies relating to land management and protection of the environment and Lake Champlain and for drafting land use and basin plans.
- The relatively low levels of phosphorus, together with those of nitrogen and sediment loads, should be taken into account when considering stream classification and establishing management types for Lewis Creek.

II.3.2 Nitrogen

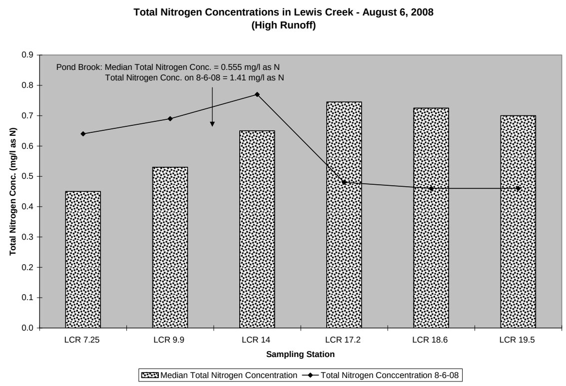
Nitrogen is an essential, and at times, limiting, nutrient required by aquatic plants and algae. With the exception of leguminous plants and certain cyanobacteria which are able to fix atmospheric nitrogen, nitrogen must be derived from the water or sediments.

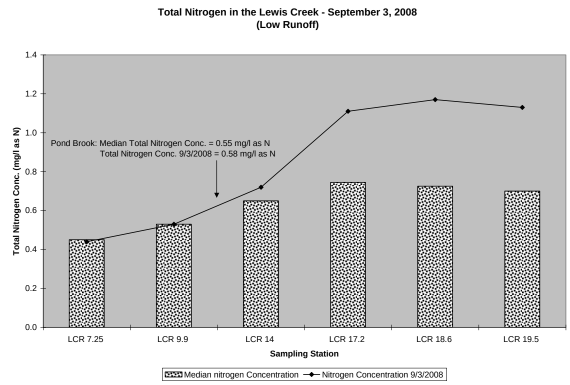
II.3.2.1 Monitoring Results

In contrast to phosphorus concentrations, total nitrogen concentrations tended to be higher in the upper reaches of Lewis Creek, and to decrease downstream from LCR 17.2. Concentrations tended to increase slightly from LCR 19.6 to LCR 17.2, then decline steadily to LCR 7.25.



Total nitrogen concentrations, like those of total phosphorus, are influenced by rate of flow. At high flow rates total nitrogen concentrations tended to remain constant, but at low levels as a result of dilution between LCR 19.6 and LCR 17.2, but to increase between LCR 17.2 and LCR 14 as did total phosphorus concentrations, suggesting that they share a common source contributing to the increase in both nutrients over this reach of the river. However, concentrations did not appear to reach significant levels during high flows.





In contrast, when flows were low, concentrations of total nitrogen were relatively high at the upstream stations, but decreased steadily downstream, suggesting the absence of significant sources downstream from LCR 17.2 in the absence of runoff from the land.

Total nitrogen concentrations in Lewis Creek fell well below the current State standard for nitrate of 5 mg/l as N in all samples over the period 2004-2008. On the other hand, while they tended to fall at or below the proposed State criterion of 0.75 mg/l at all stations sampled, they exceeded the criterion part of the time at LCR 9.9 and all stations located upstream from it.

The determination of total nitrogen under the Lewis Creek monitoring program includes only a 5 year period, and experience in another farmed watershed has shown that sampling for nitrogen can be informative. Whereas analysis for nitrate plus nitrite probably is not worth the effort, sampling for total nitrogen should be continued at all sites sampled.

CONCLUSIONS and RECOMMENDATIONS

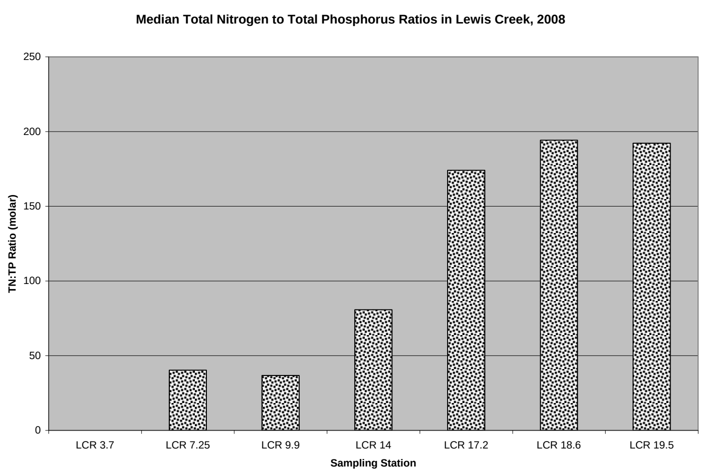
- Total nitrogen concentrations have been well below the current State standard for nitrate in all summer samples, although they at times exceed the proposed total nitrogen criterion at LCR 9.9 and upstream.
- Increases at times of high flow between LCR 17.2 and LCR 14 suggest that external sources, possibly common to sources of phosphorus are located between these sites.
- Monitoring for total nitrogen should be continued at all sampling sites in the Lewis Creek watershed.
- It should be noted that downstream from LCR 3.7, there is considerable potential for additional total nitrogen loading to Lewis Creek (as there is for phosphorus) from agricultural sources. The significance of these should be assessed.

II.3.3 Nutrient Relationships – Limiting Nutrients

The concept of limiting nutrients has long been central to efforts to control productivity and the development of nuisance conditions in water bodies. Whereas a number of trace elements have been shown to limit the growth of algae and rooted aquatic plants in various special situations, nitrogen and phosphorus are generally the major requirements for growth, and either may limit growth. A sense of which nutrient may be limiting in lakes can be derived from the molar ratio of TN:TP. In general, it has been found that when the TN:TP ratio is <20, nitrogen tends to limit growth, and when the ratio is >50, phosphorus deficient growth may be anticipated. At intermediate ratios, either nitrogen or phosphorus may limit growth.[1]

II.3.3.1 Monitoring Results

TN:TP ratios in the Lewis Creek watershed provide a picture which first of all highlight contrasts between patterns and sources of nitrogen and phosphorus in the river. Over the portion of the stream between LCR 19.5 and LCR 17.2, the ratio remained



relatively constant, as did concentrations of both nutrients. Although concentrations of each were relatively low over this reach, the ratios were extremely high, suggesting that nitrogen was in great excess relative to the needs of the biotic community. Below LCR 17.2, total nitrogen concentrations tended to decrease as total phosphorus concentrations increased, resulting in a rapid decline in the ratios to a level generally below 50, but greater than 20. These results provide no clear indication of either nitrogen or phosphorus limitation in the discharge to Hawkins and Town Farm Bays.

Similarly, an analysis of data from the Long Term Tributary Monitoring Program data suggest that in general, neither nitrogen nor phosphorus alone would be clearly limiting in the discharge from Lewis Creek during the summer months. But it should be

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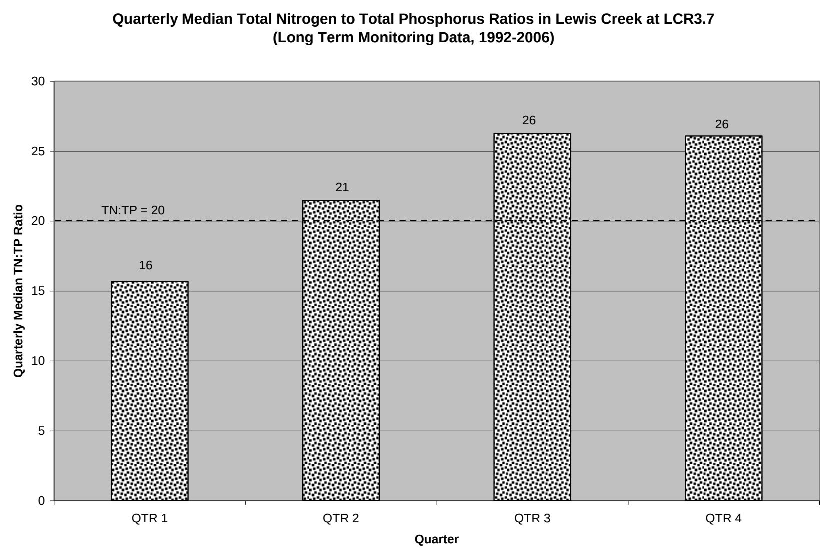
[1] S.J. Guildford and R.E. Hecky (2000). Total nitrogen, total phosphorus, and nutrient limitation in lakes and oceans: Is there a common relationship. Limnol. Oceanogr. *45*, 1213-1223.

noted that the Long Term Tributary Monitoring data are biased in favor of high flow events, and this could result in a decrease in the median ratios as high flows would be expected to result in an increase in phosphorus loadings relative to nitrogen loadings.



CONCLUSIONS

- TN:TP ratios can be useful as interpretive tools highlighting processes taking place in Lewis Creek as well as helping to understand the relative importance of nitrogen and phosphorus as nutrients.
- Future analysis of monitoring results should continue to include TN:TP ratios.