Lake Champlain Long-Term Water Quality and Biological Monitoring Program

Project Description

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Project Background and Purpose

The Lake Champlain Long-Term Water Quality and Biological Monitoring Project began in 1992. The project is conducted annually by the Vermont Department of Environmental Conservation (DEC) and the New York State DEC, with funding provided by the Lake Champlain Basin Program and the two states.

The current monitoring effort grew from the Lake Champlain Diagnostic-Feasibility Study conducted by Vermont DEC and New York State DEC (1997). The Diagnostic-Feasibility Study focused primarily on the measurement of phosphorus and chloride concentrations in the lake and its tributaries to support a phosphorus loading budget and mass balance model for Lake Champlain. The Diagnostic-Feasibility Study also provided vertical water column profile data on several other water quality measurements at deep-water stations. The present long-term monitoring project continued sampling a subset of the lake and tributary station network that was established for the previous Lake Champlain Diagnostic-Feasibility Study, and extended the program to include a broader range of chemical and biological measurements.

The purposes, scope, and methods for the current monitoring project are described in annual work and quality assurance project plans, approved by the U.S. Environmental Protection Agency. One of the original purposes was to provide a current limnological survey of Lake Champlain, including a data set that would support the development of hydrodynamic, eutrophication, and food web models for the lake (e.g., Applied Science Associates, Inc.1996, Levine *et al.*1997, HydroQual, Inc. 1995). The primary purpose of the project was redefined in 1995 to be the detection of long-term environmental change in the lake, and the sampling approach was modified to more efficiently serve this purpose. The list of sampling variables was narrowed to include those lake and tributary constituents judged by the Lake Champlain Basin Program Technical Advisory Committee to be the most meaningful for assessing the long-term effects of management actions and other changes in the environment. Optimum sampling frequencies were determined from a statistical power analysis. The power analysis was conducted to ensure that sample sizes would be adequate, but not excessive, for the purpose of statistically documenting the anticipated magnitude of water quality changes in the lake and its tributaries over time.

The Technical Advisory Committee of the Lake Champlain Basin Program reviewed the project again in 2006-2007 and began to incorporate the concept of "ecological indicators" into the work plan. Criteria for these indicators require that they be ecologically and socially relevant, measurable, statistically sound, and interpretable (Watzin *et al.* 2005). Changes to the monitoring approach were implemented to more closely align sampling parameters and methodology with ecological indicators to provide quantifiable measures of overall ecosystem health. This is an on-going process and sampling will continue to incorporate elements of the ecological indicators program over the next several years.

The project data are stored in a computerized database and are freely available on request and on the Internet to researchers, management agencies, consultants, students, and the general public. The purpose of this report is to describe the project methods and document the database for users of the data.

Sampling and Analytical Methods

Detailed descriptions of the field sampling and analytical methods and quality assurance procedures can be found in the annual Work and Quality Assurance Project Plan (New York State DEC and Vermont DEC 2018). Past plans are available upon request. A brief summary of methods is provided here.

The sampling station network includes the core set of 15 lake stations and 22 tributary stations shown in Figure 1 and listed in Table 1. The tributary stations are located as near to the river mouths as possible on rivers which have continuous flow gages operated by the U.S. Geological Survey (USGS) or the Quebec Ministry of Environment, and the Fight Against Climate Change (MELCC). Most tributary stations have been sampled consistently during the entire monitoring period since 1992, however the following changes have occurred:

- The sampling station on Rock River was added in 2007,
- Sites on Stevens Brook and Jewett Brook were added late in 2008.
- In 2010, a USGS gaging station was installed on the Mill River.
- In 2015, the gage was discontinued on Putnam Creek in New York.
- Beginning in 2017, a new gauge was installed on Stevens Brook. Comparisons to the existing gauge are still underway.
- In 2018, access to LOTT01 was posted as private property. For safety and access, a new site was evaluated in spring 2019, (LOTT03) on Satterly Road, Ferrisburg by collecting paired samples with the original site. Water quality data were similar and LOTT03 has replaced LOTT01.

Most lake stations have been sampled consistently over the entire monitoring period, with the following changes:

- Stations 9 and 16 were added in 2001.
- Station 51 was added in 2006.
- Station 53 was added in 2019 and station 51 was dropped after a coordinate error was discovered that had resulted in NY and VT field teams sampling two different locations as Station 51. Database records have been updated to their correct location and station name, either station 51 or 53.

The 15 core lake stations are sampled for most chemical tests using Kemmerer or Van Dorn water bottle devices, with discrete depth samples combined to form vertical water column composites. The lake stations are sampled approximately biweekly from May to mid-October each year. When thermal stratification exists, composite samples (composed of 2-3 discrete-depth samples) are obtained from both the epilimnion and hypolimnion layers. Temperature and dissolved oxygen concentrations are measured in vertical profile at discrete depths at the deeper stations. Chlorophyll-a is sampled as a vertically integrated composite of the photic zone, defined as twice the Secchi disk depth.

Quantitative biological sampling in the lake for phytoplankton, zooplankton including two invasive species, and mysids is conducted concurrently with the water quality sampling. Beginning in 2006, net phytoplankton and zooplankton have been sampled biweekly concurrently with water quality collections. Mysids are sampled monthly, six months per year. Changes in the biological sampling approach include:

- Zooplankton and mysid samples are analyzed at the Lake Champlain Research Institute (LCRI) at SUNY-Plattsburgh under contract with the New York State DEC.
- From 2006 to 2016, phytoplankton samples were analyzed by the Vermont DEC. Samples are currently analyzed by LCRI.
- Routine monitoring for spiny waterflea (*Bythotrephes longimanus*) in the Champlain Canal and Glens Falls Feeder Canal, initiated in 2012, was terminated following confirmation of its presence in Lake Champlain in 2014. Sampling was then re-directed to assess distribution and densities in the lake beginning in 2015.
- Fishhook waterflea (*Cercopagis pengoi*) was found in 2017 and is now tracked in the lake.

Close-interval *in situ* vertical profiles for temperature, dissolved oxygen, pH, specific conductance, and turbidity were obtained at some sites in the lake beginning in 1992 using a multi-probe sonde unit. Beginning 2006, all sites are now monitored using sonde units, providing close-interval profiles for temperature, dissolved oxygen, pH, and specific conductance. Vermont added chlorophyll-a in 2011.

Tributary samples are obtained from bridges using depth and velocity-integrating sampling devices. Sampling effort focuses on a high proportion of samples during high flow conditions in order to improve the precision of tributary annual mass loading estimates (Vermont DEC and New York State DEC 1997) and the target is currently set at 13. Beginning in 2006, four additional collections during base flow conditions were added to the workplan.

A list of the tests sampled in the lake and the tributaries and the current chemical analytical methods is given in Table 2. During the period of this program, chemical analyses have been conducted by the Vermont DEC Laboratory, the New York State Department of Health Laboratory, and other private contracted laboratories in New York. In some cases, samples were split in the field and analyzed concurrently at laboratories in both states. Currently, all samples are analyzed at the Vermont Agriculture and Environmental Laboratory (formerly the VT DEC laboratory) only. Care should be taken by data users when combining results of samples analyzed at different laboratories. A previous analysis of paired samples (Vermont DEC and New York State DEC 1998) revealed small but statistically significant differences between the results obtained by the different laboratories for many of the tests. The laboratory where each sample was analyzed (VT or NY) is recorded in the project database and accessible through the project webpage. A historical record of field and laboratory methodology can be found on the webpage in the Program Documents.

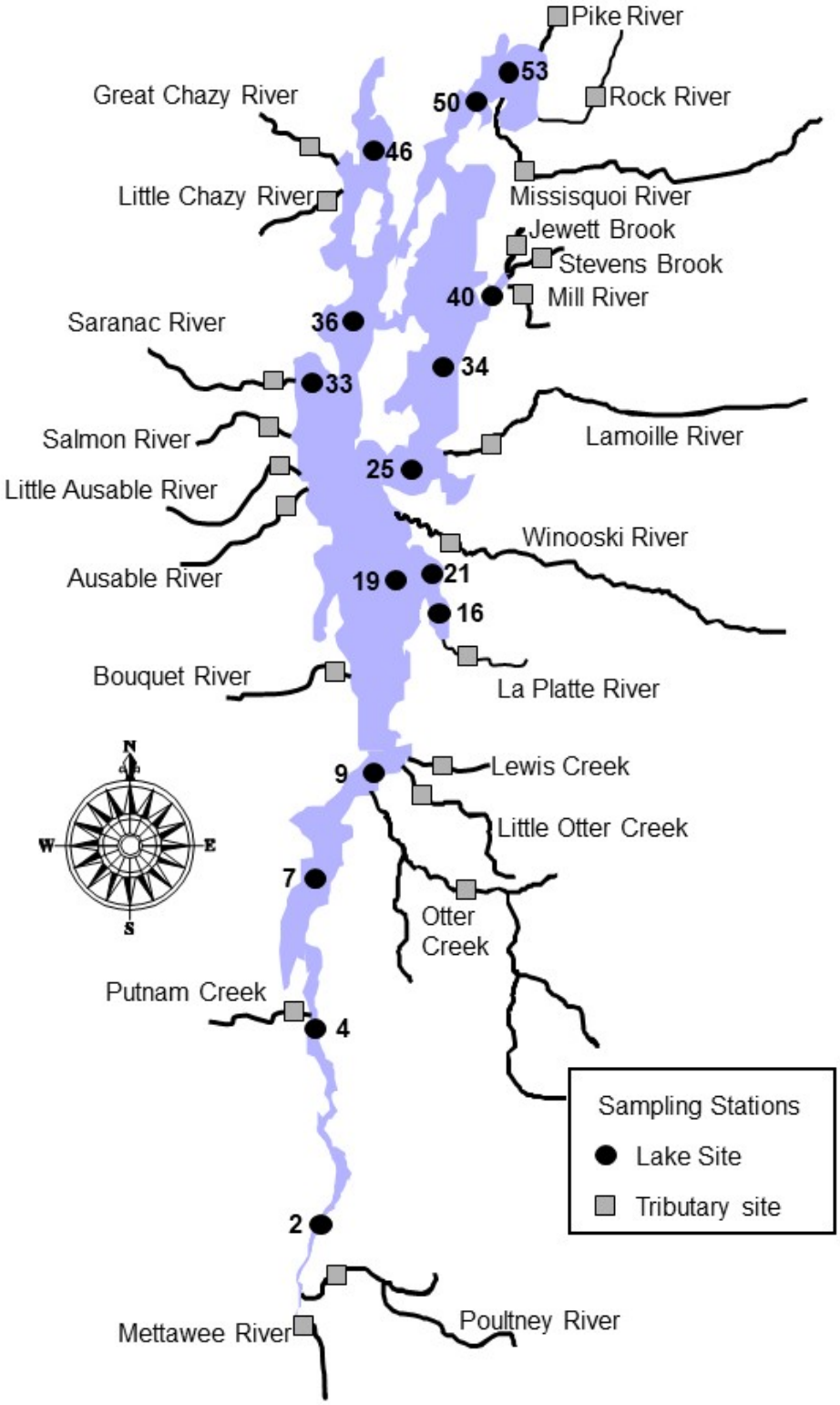

Figure 1. Lake and tributary sampling sites.

Table 1. List of lake and tributary sampling stations and their locations. The station codes used in the database for the tributary stations are given in parentheses.

Lake Station	Latitude N	Longitude W	Tributary Station	Latitude N	Longitude W
2	43° 42.89'	73° 22.98'	Winooski (WINO01)	44° 31.52'	73° 15.41'
4	43° 57.10'	73° 24.47'	Otter (OTTE01)	44° 09.94'	73° 15.40'
7	44° 07.56'	73° 24.77'	Missisquoi (MISS01)	44° 55.23'	73° 07.63'
9[1]	44° 14.53'	73° 19.75'	Lamoille (LAMO01)	44° 37.96'	73° 10.39'
16[1]	44° 25.55'	73° 13.92'	Poultney (POUL01)	43° 34.24'	73° 23.53'
19	44°28.26'	73° 17.95'	Pike (PIKE01)	45° 07.38'	73° 04.18'
21	44° 28.49'	73° 13.90'	Lewis (LEWI01)	44° 14.80'	73° 14.77'
25	44° 34.92'	73° 16.87'	Little Otter (LOTT01)[9]	44° 12.24'	73° 15.11'
33	44° 42.07'	73° 25.09'	Little Otter (LOTT03)[8]	44° 11.47'	73° 14.21'
34	44° 42.49'	73° 13.61'	LaPlatte (LAPL01)	44° 22.21'	73° 13.01'
36	44° 45.37'	73° 21.30'	Saranac (SARA01)	44° 41.52'	73° 27.19'
40	44° 47.12'	73° 09.73'	Ausable (AUSA01)	44° 33.63'	73° 26.95'
46	44° 56.90'	73° 20.40'	Mettawee (METT01)	43° 33.33'	73° 24.10'
50	45° 00.80'	73° 10.43'	Great Chazy (GCHA01)	44° 58.81'	73° 25.96'
53[2]	45° 02.13'	73° 07.53'	Bouquet (BOUQ01)	44° 21.84'	73° 23.41'
51[7]	45° 02.22'	73º 06.99'	Little Ausable (LAUS01)	44° 35.65'	73° 29.79'
			Salmon (SALM01)	44° 38.40'	73° 29.70'
			Putnam (PUTN01)[6]	43° 57.35'	73° 25.99'
			Little Chazy (LCHA01)	44° 54.12'	73° 24.88'
			Rock River (ROCK02)[3]	44° 59.49'	73° 04.22'
			Stevens Brook (STEV01)[4]	44° 50.95’	73° 07.15’
			Jewett Brook (JEWE02)[4]	44° 51.37’	73° 09.06’
			Mill River (MILL01)[5]	44° 46.46’	73° 08 39’

[1] Added in 2001.
[2] Added in 2006 as station 51, renamed to 53 in 2019.
[3] Added in 2007.
[4] Added in 2008.
[5] Added in 2010.
[6] Discontinued in 2015.
[7] Discontinued in 2019.
[8] Added in 2019.
[9] Discontinued in 2020

Table 2. Current Analytical Methods for Tests Included in the Project Database.

Measurement	Test Code	Reporting Units	Method Reference[3]	Method Number
Total Phosphorus	TP	µg/L	APHA (2005)	4500-P H
Dissolved Phosphorus	DP	µg/L	APHA (2005)	4500-P H
Ortho-Phosphorus[1]	OP	µg/L	USEPA (1983)	365.1
Chloride	TCl, DCl	mg/L	APHA (2005)	4500-Cl E
Dissolved Silica[2, 4]	DSi	mg/L	APHA (2005)	4500-SiO_2 F
Alkalinity	RegAlk	mg/L	APHA (2005)	2320-B
Total Nitrogen	TN	mg/L	APHA (2005)	4500-N C
Total Kjeldahl Nitrogen[1]	TKN	mg/L	USEPA (1983)	351.2
Total Nitrate/Nitrite Nitrogen[1]	TNOX	mg/L	USEPA (1983)	353.2
Total Ammonia Nitrogen[1]	TNH3	mg/L	USEPA (1983)	350.1
Total Suspended Solids[5]	TSS	mg/L	APHA (2005)	2540-D
Total Organic Carbon[1]	TOC	mg/L	APHA (2005)	5310 B
Dissolved Organic Carbon[1]	DOC	mg/L	APHA (2005)	5310 B
Dissolved Inorganic Carbon[1]	DIC	mg/L	APHA (2005)	5310 B
Non Purgeable Organic Carbon[6]	NPOC	mg/L	APHA (2005)	SM 5310 B NPOC
Iron[1]	TFe	µg/L	USEPA (1994)	6020B
Aluminum, Calcium, Magnesium, Sodium, Potassium[4]	TAl, TCa, TMg, TNa, TK	mg/L	USEPA (1994)	6020B
Lead[1]	Pb	µg/L	USEPA (1983)	239.2
Dissolved Oxygen[2]	DO	mg/L	APHA (2005) Hydrolab (1997, 2006)	4500-OC
Chlorophyll-a[2]	Chla	mg/L	USEPA (1997) Hydrolab (1997)	445.0
Temperature	TempC	°C	VT DEC (2012) YSI (1998) Hydrolab (1991)	3.7.2
Conductivity	Cond	µS/cm	VT DEC (2012) YSI (1998) Hydrolab (1991)	3.7.2
pH	pH		VT DEC (2012) YSI (1998) Hydrolab (1997)	3.7.2
Secchi Disk Depth[2]	Secchi	m	VT DEC (2012)	3.2.1
Net phytoplankton, total density	NP_Tot_den	cells/L	APHA 2005	10200 F 2a
Net phytoplankton, total biovolume	NP_Tot_bio	$\mu m^3/L$	Wetzel and Likens 2000	
Net phytoplankton, Cyanobacteria density	NP_Cya_den	cells/L	APHA 2005	10200 F 2a

Measurement	Test Code	Reporting Units	Method Reference[3]	Method Number
Net phytoplankton, Cyanobacteria biovolume	NP_Cya_bio	$\mu m^3/L$	Wetzel and Likens 2000	
Net phytoplankton, Chlorophyta density	NP_Chl_den	cells/L	APHA 2005	10200 F 2a
Net phytoplankton, Chlorophyta biovolume	NP_Chl_bio	$\mu m^3/L$	Wetzel and Likens 2000	
Net phytoplankton, Chrysophyta density	NP_Chr_den	cells/L	APHA 2005	10200 F 2a
Net phytoplankton, Chrysophyta biovolume	NP_Chr_bio	$\mu m^3/L$	Wetzel and Likens 2000	
Net phytoplankton, Pyrrophyta density	NP_Pyr_den	cells/L	APHA 2005	10200 F 2a
Net phytoplankton, Pyrrophyta biovolume	NP_Pyr_bio	$\mu m^3/L$	Wetzel and Likens 2000	
Net zooplankton, total density	NZ_Tot_den	organisms/m^3	APHA 2005	10200 G
Net zooplankton, Cladoceran density	NZ_Cla_den	organisms/m^3	APHA 2005	10200 G
Net zooplankton, Copepod density	NZ_Cop_den	organisms/m^3	APHA 2005	10200 G
Net zooplankton, Rotifer density	NZ_Rot_den	organisms/m^3	APHA 2005	10200 G

[1] No longer included in the sampling program.
[2] Not currently sampled in the tributaries. Chlorophyll-a was sampled in tributaries from 1995-2005.
[3] APHA = American Public Health Association
USEPA = U.S. Environmental Protection Agency
VT DEC = Vermont Department of Environmental Conservation
YSI = Yellow Springs Instrument, Corp.
[4] Sampling frequency varies over the life of the project
[5] Not sampled in the lake after 2005.
[6] Sampling began in 2019

Project Database

The project database is maintained by the Vermont DEC on its computer network using the commercial database program Microsoft® Access 2003 in conjunction with a SQL® server. Daily backup is provided, and copies of backup files are archived in separate locations. The SQL Server's robust security features are used to prevent editing or deletion of the original data by users other than the authorized database administrators. Copies of the current database are also available at the New York State DEC.

In 2008, a major reorganization of the database was initiated to improve the database design and replace three Microsoft Access® databases with a single SQL Server database. The use of the SQL Server database improves query performance and allows the use of the T-SQL database language to create more advanced queries. The data tables were normalized to conform to relational database requirements and new tables were added to store plankton data. The SQL Server database was made accessible from both the internal Vermont DEC Access front-end databases and the public web server Lake Champlain Monitoring Program application, which resulted in the elimination of multiple and duplicative Access databases. A single database improves the efficiency of storing

and updating data and improves the accuracy of the data as additions and changes are made only in one database. SQL Server Views were created to increase the speed and functionality of the Lake Champlain Monitoring web application.

Database integrity is enforced in several ways. Primary keys are defined to uniquely identify each record in the database and prevent duplication. The primary keys are composed of multiple fields that uniquely identify each sample (e.g., field id, station, date). Foreign keys and check constraints on fields are used to ensure that only valid data are entered.

The database is updated annually within a few months of the end of the field season. Data are freely available to other government agencies, researchers, consultants, students, and the general public. Water chemistry data and plankton summaries can be downloaded via the Internet (http://dec.vermont.gov/watershed/lakes-ponds/monitor/lake-champlain). Other electronic formats or paper copies are available upon request. Data are also uploaded to EPA's "STORET" data system annually. Table 3 provides a crosswalk of Champlain stations and corresponding STORET location identifiers.

Table 3. Crosswalk of Champlain station names with STORET location identifiers.

Champlain Station	Waterbody Type	STORET Identifier
02	Lake	503387
04	Lake	503288
07	Lake	500449
09	Lake	500451
16	Lake	503506
19	Lake	500458
21	Lake	500459
25	Lake	503519
33	Lake	500468
34	Lake	503485
36	Lake	500470
40	Lake	503488
46	Lake	503535
50	Lake	503515
53	Lake	500476
AUSA01	Trib	500500
BOUQ01	Trib	500498
GCHA01	Trib	500492
JEWE02	Trib	500665
LAMO01	Trib	501794
LAPL01	Trib	501594
LAUS01	Trib	500501
LCHA01	Trib	500490

Champlain Station	Waterbody Type	STORET Identifier
LEWI01	Trib	500503
LOTT01	Trib	501371
LOTT03	Trib	522443
METT01	Trib	500508
MILL01	Trib	501563
MISS01	Trib	500505
OTTE01	Trib	500509
PIKE01	Trib	500512
POUL01	Trib	500578
PUTN01	Trib	500495
ROCK02	Trib	500652
SALM01	Trib	500502
SARA01	Trib	500491
STEV01	Trib	501575
WINO01	Trib	501903

Chemistry results for both tributary and lake samples are maintained in a single table, named 'ChemistryData,' distinguished by waterbody type, station name, field accession number, visit date, collection method, and analysis type. The analytical results for each water quality sample are contained in database fields with names corresponding to the test codes indicated in Table 2. Each chemical test field in the database has an associated remark field in which "less than" or "greater than" signs are entered where necessary for results below or above analytical detection limits. Additional database codes are noted in Table 4.

The tributary stations were sampled during 1990-1992 for total phosphorus, dissolved phosphorus, and chloride by the Lake Champlain Diagnostic-Feasibility Study (Vermont DEC and New York State DEC 1997) using the same sampling and analytical methods employed by the current long-term monitoring program. These earlier tributary data have been added to the project database.

Plankton data are housed in two tables. The first, 'PlanktonData,' contains the original count data distinguished by plankton type (phytoplankton, zooplankton), station name, field accession number, species name, visit date, sample type, and result type. The second, 'PlanktonStats,' contains data aggregated by major taxonomic group. During phytoplankton analysis, organisms are frequently observed outside of the designated counting boundaries. These are noted as "present but not counted" and are not quantified or incorporated into summary statistics. The data available for download from the web interface include phytoplankton cell densities and biovolumes, and zooplankton densities, grouped by major taxonomic category. Counts by individual taxa will eventually be added to the web page, but are currently available only by request. Multiprobe data were made available for download via the website in 2014.

Additional tables store tributary flow data, wastewater treatment facility data, plankton taxonomic information, and station location coordinates. These data are not available through the web page but can be obtained by request. Mysid and spiny waterflea data are housed with the NY DEC and also available upon request.

Table 4. Additional database codes.

Data Table	Data heading	Data code	Description
Chemistry	WaterbodyType	Trib Lake	Tributary Lake
	CollectionMethod	CompDH59 Kemmerer Thermister Secchi Hose CompKemm	Depth/flow integrated sampler Kemmerer Thermister Secchi disk Integrated sample by hose Composite by Kemmerer
	Depth		Sample depth (m)
	Stratum	E H P U	Epilimnion Hypolimnion Profile Unstratified (as of 2009, 'com' is no longer noted)
	QA	A D	Field sample Field duplicate sample
	Lab	NY VT	Location (state) of lab responsible for analysis
Plankton	PlanktonType	Phyto Zoo	Phytoplankton Zooplankton
	Depth		Integrated net tow or hose collection depth (m)
	QA	A D DC QCC	Field sample Field duplicate sample Laboratory duplicate count (phyto. only) Repeat Aliquot count (phyto. only)
	SampleType	Net tow, 63µm Net tow, 153µm	Plankton net, 63µm mesh, 13cm diameter Plankton net, 153µm mesh, 30cm diameter
	ResultType	Biovolume Cell density Colony density Organism density	Biovolume Number of cells (phytoplankton only) Number of Colonies (phytoplankton only) Number of individuals (zooplankton only)
	IsPresentNotCounted	-1	Taxon present in sample outside of counting boundaries (phytoplankton only)

Flow rates in the monitored tributaries are continuously measured by the USGS or the Quebec MDDELCC. A list of the downstream-most flow gages on these tributaries is given in Table 5. The flow data can be used with the water quality sampling results to estimate mass loading rates, and for other purposes. The historical daily flow data for many of the USGS gages are available at the following website: http://waterdata.usgs.gov/vt/nwis/rt

Table 5. List of U.S. Geological Survey (USGS) and Quebec Ministry of Sustainable Development, Environment, and Parks (MDDELCC) stream flow gages on monitored tributaries.

Tributary	Gage Location	State	Reference No.	Agency
Ausable	Au Sable Forks	NY	4275500	USGS
Bouquet	Willsboro	NY	4276500	USGS
Great Chazy	Perry Mills	NY	4271500	USGS
Little Ausable	Valcour	NY	4273800	USGS
Little Chazy	Chazy	NY	4271815	USGS
Mettawee	Middle Granville	NY	4280450	USGS
Putnam[6]	Crown Point Center	NY	4276842	USGS
Salmon	S. Plattsburgh	NY	4273700	USGS
Saranac	Plattsburgh	NY	4273500	USGS
Pike	Bedford	QC	030420	MDDEP
Pike[1]	Notre-Dame-de-Stanbridge	QC	030424	MDDEP
Lamoille	E. Georgia	VT	4292500	USGS
LaPlatte	Shelburne Falls	VT	4282795	USGS
Lewis	N. Ferrisburg	VT	4282780	USGS
Little Otter	Ferrisburg	VT	4282650	USGS
Missisquoi	Swanton	VT	4294000	USGS
New Haven[2]	Brooksville	VT	4282525	USGS
Otter	Middlebury	VT	4282500	USGS
Poultney	Fair Haven	VT	4280000	USGS
Winooski	Essex Jct.	VT	4290500	USGS
Rock[1]	St. Armand	QC	030425	MDDEP
Stevens[3]	St. Albans	VT	4292770	USGS
Jewett[4]	St, Albans	VT	4292810	USGS
Mill[5]	St, Albans	VT	4292750	USGS

[1]New gages on the Pike and Rock were installed by Quebec MDDELCC in 2002.
[2]The New Haven River is a tributary to the Otter Creek that is not directly sampled by the project, but is included in the gage network to supplement the hydrologic coverage for the Otter Creek watershed.
[3]Current gage on Stevens Brook was installed by USGS in 2017.
[4]New gage on the Jewett Brook was installed by USGS in 2008.
[5]New gage on Mill River was installed by USGS in 2010.
[6]The gage on Putnam Creek was discontinued in 2015.

Accessing the Data

The project website (http://dec.vermont.gov/watershed/lakes-ponds/monitor/lake-champlain) provides the ability for data users to selectively view the original data for specific sampling stations, time periods, and analytical tests using simple, interactive query forms. Beginning in 2009, users have a choice to view a webpage or download the data as an EXCEL® spreadsheet. They also may choose to download only the current year's data for all stations and dates, or all data available for a particular station. The project's webpage includes links to the necessary metadata descriptions needed to properly interpret the data summaries, including the project quality assurance plan, this project description, and a summary of field and analytical methodology used over the life of the project.

Simple summary figures have been prepared for each parameter currently sampled. Cumulative data are presented on the website as box plots of the median, 10^{th}, 25^{th}, 75^{th} and 90^{th} percentiles for each station for the entire sampling period. Annual data are presented as scatterplots with trend lines determined by Lowess smoothing analysis. Lake data are presented as both annual and cumulative summaries of unstratified and epilimnetic samples. Tributary data are presented as cumulative summaries only. Plankton data are presented as annual and cumulative summaries for total plankton and the major taxonomic groups. Figures are updated annually after the new data are reviewed and added to the database.

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