Prepared in cooperation with the Lake Champlain Basin Program and the
Vermont Department of Environmental Conservation

Concentration and Flux of Total and Dissolved Phosphorus, Total Nitrogen, Chloride, and Total Suspended Solids for Monitored Tributaries of Lake Champlain, 1990–2012

Open-File Report 2014–1209

U.S. Department of the Interior
U.S. Geological Survey

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By Laura Medalie

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)
megagram (Mg); also known as metric ton (t)	1.102	ton, short (2,000 lb)
metric ton per year	1.102	ton per year (ton/yr)

Datum and Supplemental Information

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).
Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Abbreviations

DP	dissolved phosphorus
MENV	Ministry of the Environment
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
USGS	U.S. Geological Survey
WRTDS	Weighted Regressions on Time, Discharge, and Season regression model

Concentration and Flux of Total and Dissolved Phosphorus, Total Nitrogen, Chloride, and Total Suspended Solids for Monitored Tributaries of Lake Champlain, 1990–2012

By Laura Medalie

Abstract

Annual and daily concentrations and fluxes of total and dissolved phosphorus, total nitrogen, chloride, and total suspended solids were estimated for 18 monitored tributaries to Lake Champlain by using the Weighted Regressions on Time, Discharge, and Seasons regression model. Estimates were made for 21 or 23 years, depending on data availability, for the purpose of providing timely and accessible summary reports as stipulated in the 2010 update to the Lake Champlain “Opportunities for Action” management plan. Estimates of concentration and flux were provided for each tributary based on (1) observed daily discharges and (2) a flow-normalizing procedure, which removed the random fluctuations of climate-related variability. The flux bias statistic, an indicator of the ability of the Weighted Regressions on Time, Discharge, and Season regression models to provide accurate representations of flux, showed acceptable bias (less than ±10 percent) for 68 out of 72 models for total and dissolved phosphorus, total nitrogen, and chloride. Six out of 18 models for total suspended solids had moderate bias (between 10 and 30 percent), an expected result given the frequently nonlinear relation between total suspended solids and discharge. One model for total suspended solids with a very high bias was influenced by a single extreme value; however, removal of that value, although reducing the bias substantially, had little effect on annual fluxes.

Introduction

The 2010 update to the Lake Champlain “Opportunities for Action” management plan (Lake Champlain Basin Program, 2014) identifies several objectives related to reducing contamination from phosphorus, toxic substances, and pathogens in the Lake Champlain Basin. Production of timely and accessible summary reports, identified as one of the strategies for implementing the “Opportunities for Action” plan (Lake Champlain Basin Program, 2014, sec. 2.2), is addressed directly by this report. By providing estimates of fluxes of total phosphorus (TP), this report delivers the means for assessing progress towards the goal of reducing phosphorus flux in the basin. Estimates of concentrations and fluxes of total suspended solids (TSS), not previously evaluated using the Weighted Regressions on Time, Discharge, and Season (WRTDS) regression model (Hirsch and others, 2010), provide an indicator of transport for many substances (toxic and otherwise) that move through a drainage basin by means of attachment to the suspended particles. The other parameters evaluated in this report, dissolved phosphorus, total nitrogen, and chloride, are not mentioned specifically in the “Opportunities for Action” or other management documents but could be of interest to scientific or planning communities.

This report is an update of two previous U.S. Geological Survey (USGS) reports that used WRTDS (Hirsch and others, 2010) for estimating concentrations and loads in the 18 monitored Lake Champlain tributaries. The first report evaluated TP and total nitrogen (TN) from 1990 through 2009 (Medalie and others, 2012). The second report evaluated TP, TN, dissolved phosphorus (DP), and chloride from 2009 through 2011 (Medalie, 2013). The current report evaluates TP, TN, DP, chloride, and is expanded to include TSS concentrations. WRTDS is a method of estimating water-quality concentration and flux that overcomes many of the limitations of previous estimation methods (Moyer and others, 2012; Hirsch, 2014). A major feature of WRTDS is the provision of flow-normalized estimates of concentrations and fluxes, whereby the variability in water-quality conditions that is directly related to random variations in discharge is removed. Estimates of concentration or flux are commonly used as input to water-quality or other ecological models. Long-term datasets, such as this one for Lake Champlain, are used for climate-related modeling efforts, for comparing water-quality conditions to standards and criteria for regulatory purposes, or for assessing water-quality changes over time in the watershed.

To address the need to provide timely and accessible summary reports to the community of Lake Champlain Basin stakeholders, the USGS, in cooperation with the Lake Champlain Basin Program and the Vermont Department of Environmental Conservation, used WRTDS and available streamflow and concentration data to estimate daily and annual concentrations and fluxes of TP, DP, TN, chloride, and TSS for the 18 monitored tributaries to Lake Champlain (fig. 1; table 1). As determined by the availability of concentration data, daily and annual concentrations and fluxes of TP, DP, and chloride are provided for calendar years 1990 through 2012; and daily and annual concentrations and fluxes of TN and TSS are provided for calendar years 1992 through 2012.

Methods

The WRTDS regression model produces two kinds of concentration and flux estimates: one based on observed discharges and the other based on flow-normalized discharges (Hirsch and others, 2010). The flow-normalized estimate for a given date is an average estimate of concentration or flux that would be made if all of the observed discharges for that date were equally likely to have occurred. Flow-normalized estimates can be used to evaluate the effectiveness of watershed management actions with the effects of annual hydrologic variations mathematically removed.

Details of data collection, data analysis, and the application of WRTDS specifically to Lake Champlain tributary data are documented in Medalie (2013). Water-quality data were retrieved from the Vermont Department of Environmental Conservation (2013) Web site. Daily discharge data for streamgages on the 17 tributaries from the U.S. National Water Information System network were obtained from the U.S. Geological Survey (2014). Daily discharge data for the Pike River streamgages in Canada were obtained from the Centre d’Expertise Hydrique Québec (2014).

Estimates of concentrations and fluxes for the Little Ausable and Poultney Rivers are not presented for days with mean discharges greater than the highest sampled discharge because those days are beyond the valid range of extrapolation of the WRTDS model (Medalie, 2013). For years with unestimated days, annual values are flagged with a greater than (>) remark. User-assigned half-window widths for the regression variables (time, discharge, and season), which inform weights used in the WRTDS regression equations, are shown in table 2. The default half-window widths (10 years for time, two logarithm cycles for discharge, and 0.5 year for season) were changed if model-checking diagnostics indicated that greater widths provided a better model fit. A detailed discussion of the effect of half-window widths on the WRTDS models is provided by Hirsch and others (2010).

A measure of the ability of WRTDS to predict the true flux is provided by the flux bias statistic, calculated as [mean (predicted flux) – mean(observed flux)] / mean (observed flux). A flux bias statistic of zero indicates an unbiased model; acceptable bias is defined as ±0.1, or 10 percent (Hirsch, 2014). Flux bias statistics greater than zero indicate that the model estimates of flux generally are greater than observed fluxes, and values less than zero indicate the model's tendency to underpredict observed fluxes. All of the Lake Champlain tributaries had flux bias statistics of less than ±0.1 for TN and chloride, and only 2 out of 18 tributaries had flux bias statistics greater than ±0.1 for each of TP and DP; thus, 68 out of 72 models for these four constituents had acceptable bias (table 3).

For TSS, 11 tributaries had flux bias statistics less than 0.1; 6 out of the 7 remaining tributaries had flux bias statistics less than 0.3. The large number of tributaries with flux bias statistics greater than 0.1 is not a particular concern because poorer model representations for TSS compared to other constituents are expected because of the highly nonlinear relation between TSS and discharge (Hirsch, 2014). However, one of these tributaries, the Saranac River, has a greater magnitude of potential bias than the others. When all recorded observations are used in the WRTDS model (fig. 2A), the flux bias statistic is –0.839, and the model is seen to severely underestimate the extreme observation of November 9, 1996 (the date of the largest maximum of daily mean discharges, 10,200 cubic feet per second, for the period of record). The WRTDS model without the extreme observation (fig. 2B) yields a flux bias statistic (–0.135) that is much closer to many of the other TSS flux bias statistics (table 3) and a plot in which all points of estimated versus observed concentrations are relatively close to the 1:1 line.

However, the November 1996 observed TSS concentration is needed in the model, despite the poor fit, because even underestimated, the observation still provides the higher 1996 estimate of flux (fig. 2C; appendix 1; 18.3 million kilograms per year (Mkg/yr) compared with 9.3 Mkg/yr for models with and without the observation). The complete time series of annual estimates (fig. 2C) puts the effect of the biased model in perspective; those based on observed discharges (points) for 1996 differ by a factor of 2 when models are run with and without the extreme 1996 observation. The effect of the extreme value lingers into 1997 because the November 1996 observation is close enough to 1997 to render as influential the seasonal component of weight on the regression. However, differences in annual estimates are negligible in all other years. The powerful ability of flow normalization to smooth effects of year-to-year variations and extreme values is illustrated by noting that the two lines in figure 2C representing flow-normalized estimates exhibit very little difference in all years, with differences converging towards zero as time advances from 1996.

The only change in method since previous publications is that streamgage 030420 on the Pike River in Canada that was used previously was discontinued in July 2012 and replaced by Canadian streamgage 030424 further downstream on the Pike River (operational since November 1, 2001). Daily discharge data from station 030420 for January 1, 1990, through October 31, 2001, were multiplied by the drainage-area ratio between the two stations (404 square kilometers [km^2] for 030420 and 584 km^2 for 030424) in order to estimate daily discharges for station 030424 for the record prior to November 1, 2001. Because of the larger drainage area and greater discharges at the Pike River streamgage used for this report compared with previous reports, load estimates for the Pike River for the record since 1990 are larger than those previously reported (Medalie and others, 2012; Medalie, 2013).

Concentrations and Flux

Annual estimated and flow-normalized concentrations and fluxes of TP, DP, and chloride for 1990 through 2012 and of TN and TSS for 1992 through 2012 were calculated for the 18 monitored tributaries of Lake Champlain (figs. 3 through 7 [concentrations] and figs. 8 through 12 [fluxes]; appendix 1). For the same time periods, daily estimated and flow-normalized concentrations and fluxes of TP, DP, TN, chloride, and TSS also were calculated (appendixes 2 through 6).

Summary

The 2010 update to the Lake Champlain “Opportunities for Action” management plan includes strategies for implementing actions for reducing the flux of phosphorus and toxic substances and pathogens into Lake Champlain. One of the strategies is to provide timely and accessible summary reports. To address the need for summary reports, the U.S. Geological Survey, in cooperation with the Lake Champlain Basin Program and the Vermont Department of Environmental Conservation, used a regression-based method to estimate annual and daily concentrations and fluxes of total and dissolved phosphorus, total nitrogen, chloride, and total suspended solids for 18 monitored tributaries to Lake Champlain. Estimates were made on the basis of observed daily discharges and by using a flow-normalizing procedure, which removed the variability in water-quality conditions that is directly related to random variations in discharge.

The flux bias statistic provides a measure of the ability of the regression models to accurately predict flux. Sixty-eight out of 72 regression models for the 18 tributaries for total and dissolved phosphorus, total nitrogen, and chloride had acceptable bias (less than 10 percent). Seven of the 18 regression models for total suspended solids had flux bias of greater than 0.1, as expected, because of the highly nonlinear relation with discharge.

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Appendixes

Available separately at http://pubs.usgs.gov/of/2014/1209/

Appendix 1. Annual Mean Concentration and Total Annual Flux of Estimated and Flow-Normalized Total Phosphorus, Dissolved Phosphorus, Total Nitrogen, Chloride, and Total Suspended Solids in 18 Monitored Tributaries of Lake Champlain From 1990 (or 1992) Through 2012.

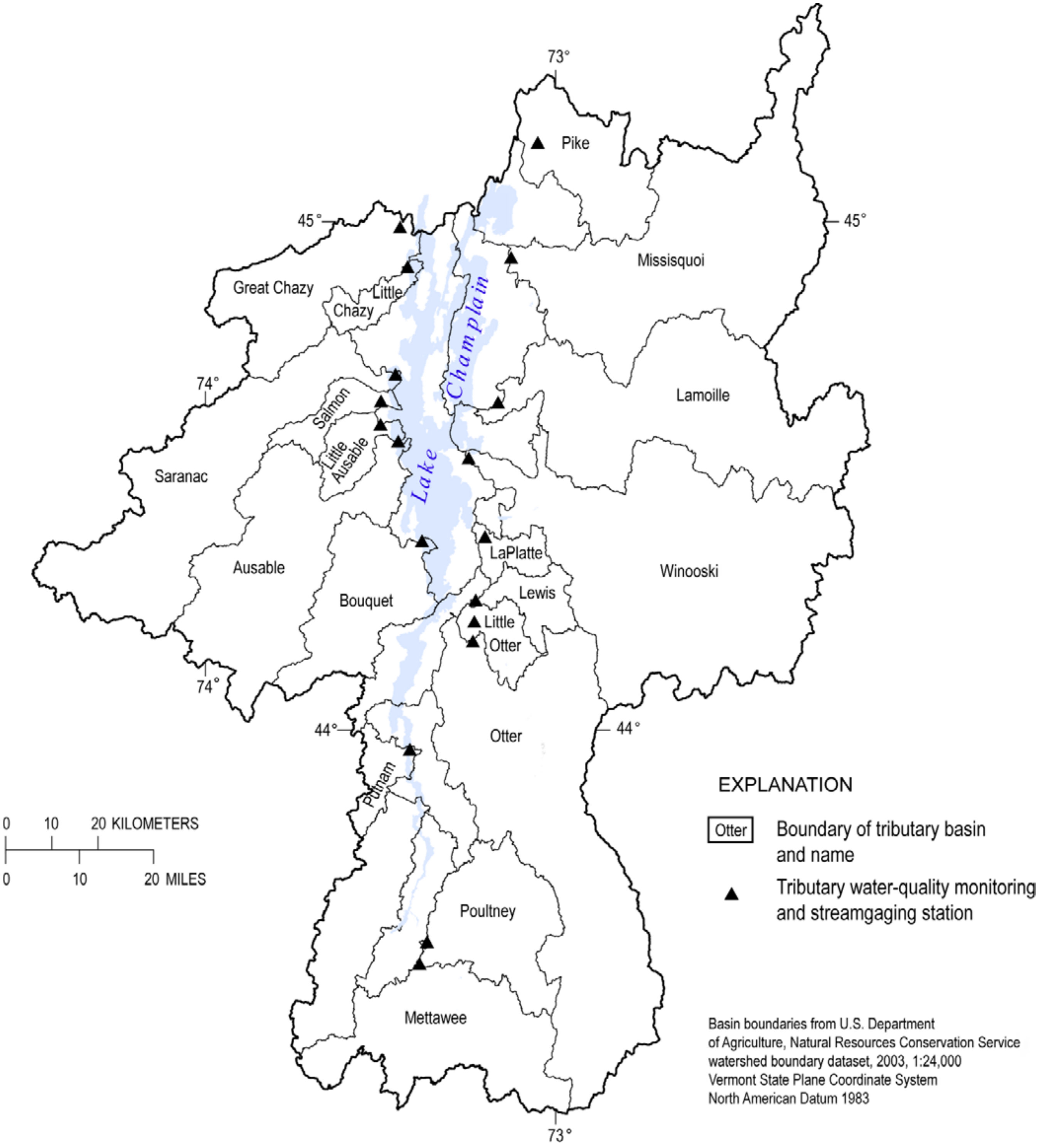
Appendix 2. Daily Estimated and Flow-Normalized Concentration and Flux of Total Phosphorus in 18 Monitored Tributaries of Lake Champlain From 1990 Through 2012.

Appendix 3. Daily Estimated and Flow-Normalized Concentration and Flux of Dissolved Phosphorus in 18 Monitored Tributaries of Lake Champlain From 1990 Through 2012.

Appendix 4. Daily Estimated and Flow-Normalized Concentration and Flux of Total Nitrogen in 18 Monitored Tributaries of Lake Champlain From 1992 Through 2012.

Appendix 5. Daily Estimated and Flow-Normalized Concentration and Flux of Chloride in 18 Monitored Tributaries of Lake Champlain From 1990 Through 2012.

Appendix 6. Daily Estimated and Flow-Normalized Concentration and Flux of Total Suspended Solids in 18 Monitored Tributaries of Lake Champlain From 1992 Through 2012.



Basin boundaries from U.S. Department of Agriculture, Natural Resources Conservation Service watershed boundary dataset, 2003, 1:24,000
Vermont State Plane Coordinate System
North American Datum 1983

Figure 1. Map showing Lake Champlain Basin, water-quality monitoring stations and streamgages, and boundaries of the monitored basins of tributaries to Lake Champlain. Figure modified from Medalie (2013).

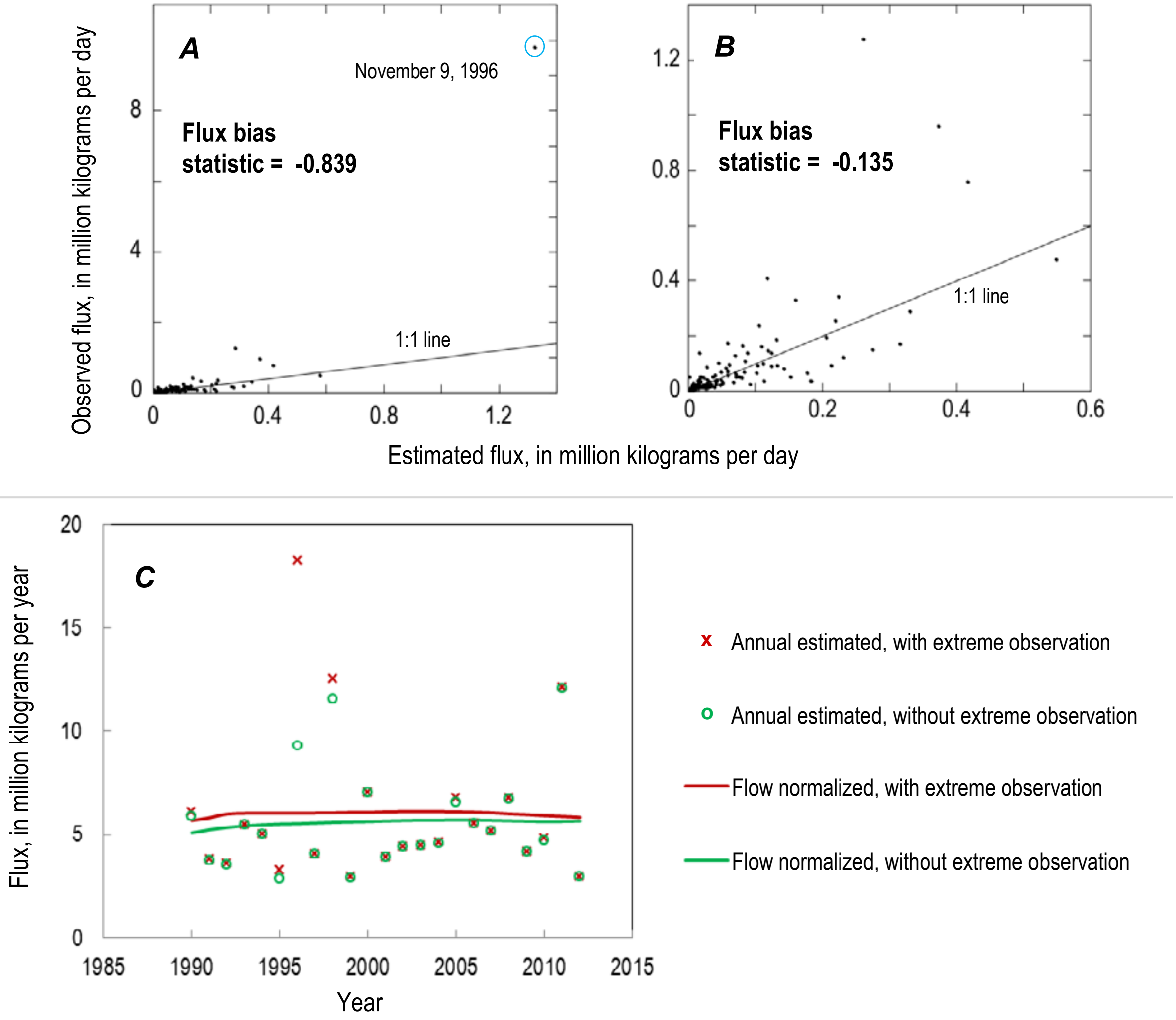


Figure 2. Plots showing estimated flux in relation to observed flux for *A*, model using all observations and *B*, model excluding extreme observation on November 9, 1996, and *C*, differences in annual estimated flux and flow-normalized annual flux for models including and excluding the extreme 1996 observation, for total suspended solids for the Saranac River, from 1990 through 2012.

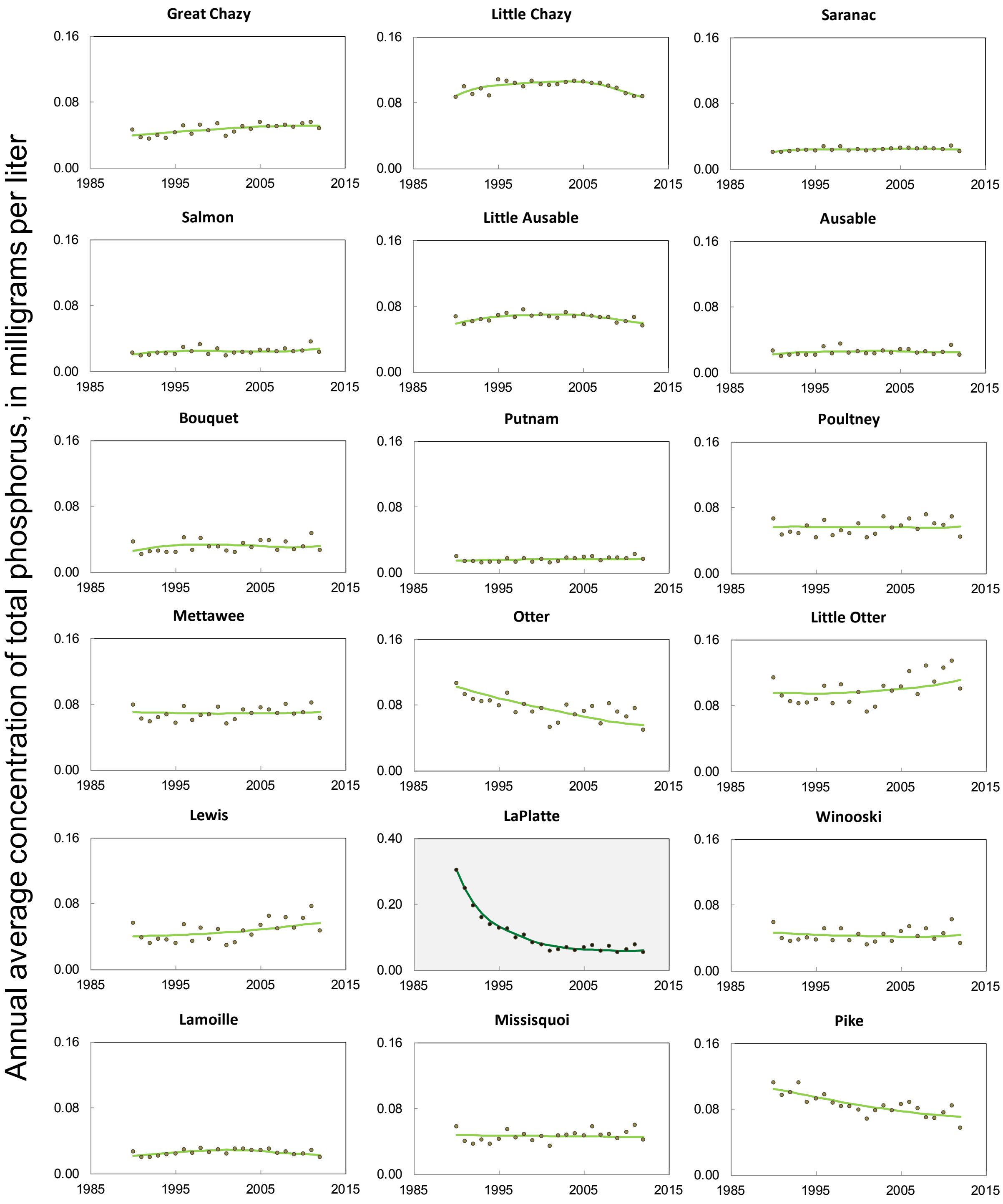


Figure 3. Graphs showing annual estimated (brown dots) and flow-normalized (green lines) concentrations of total phosphorus for the 18 monitored tributaries of Lake Champlain from 1990 through 2012. The y-axis scale for the LaPlatte River plot is different than the rest of the plots.

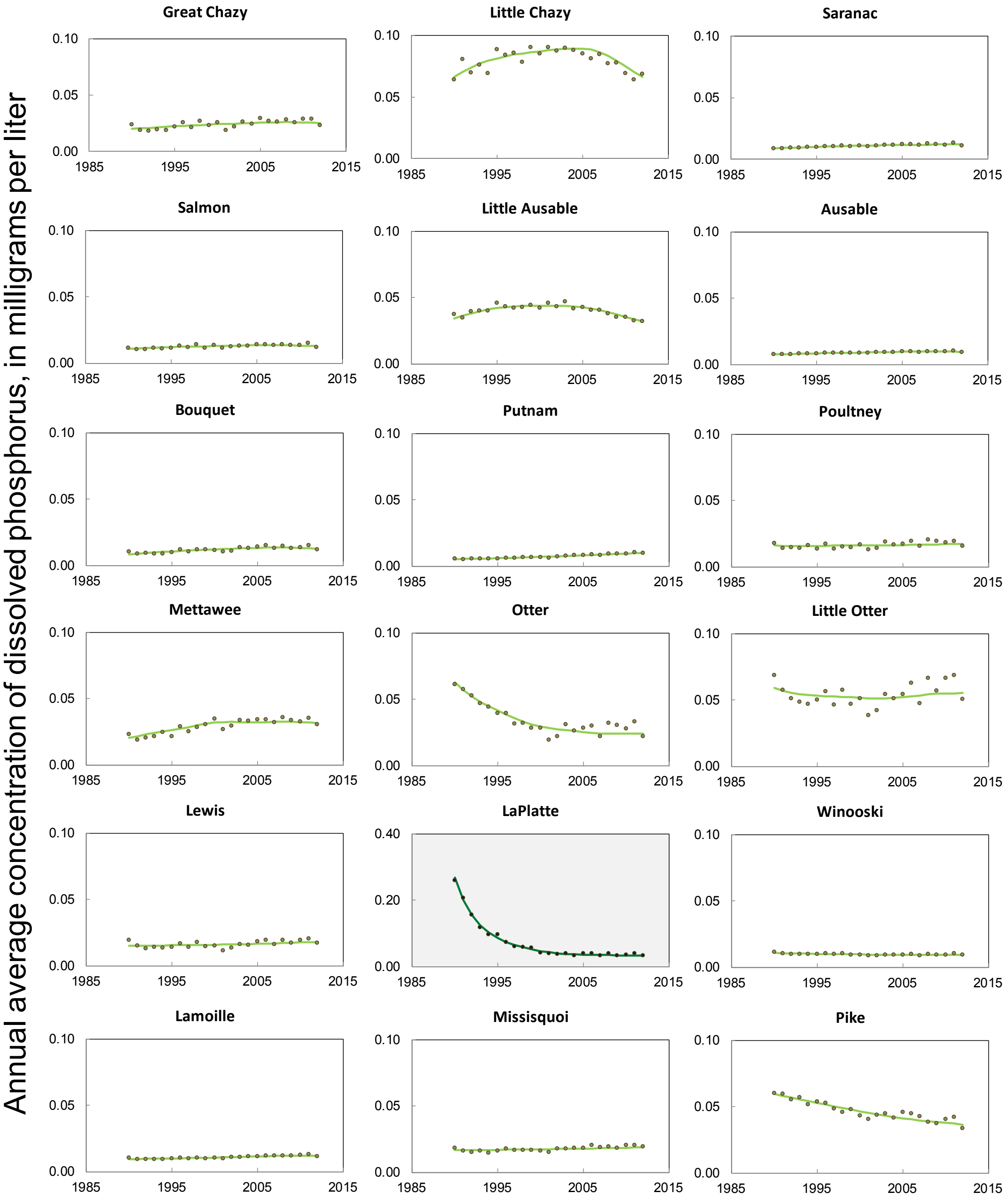


Figure 4. Graphs showing annual estimated (brown dots) and flow-normalized (green lines) concentrations of dissolved phosphorus for the 18 monitored tributaries of Lake Champlain from 1990 through 2012. The y-axis scale for the LaPlatte River plot is different than the rest of the plots.

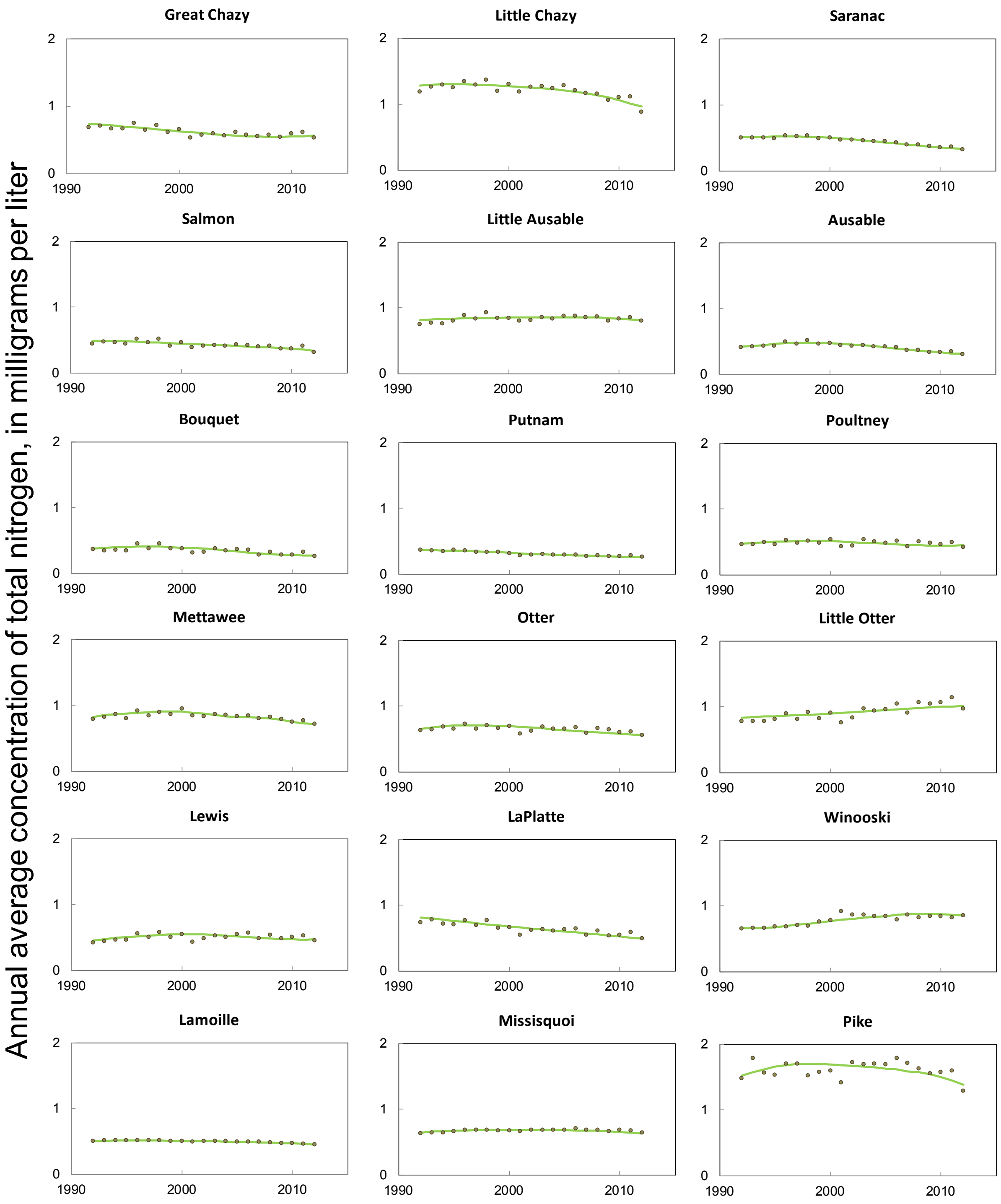


Figure 5. Graphs showing annual estimated (brown dots) and flow-normalized (green lines) concentrations of total nitrogen for the 18 monitored tributaries of Lake Champlain from 1992 through 2012

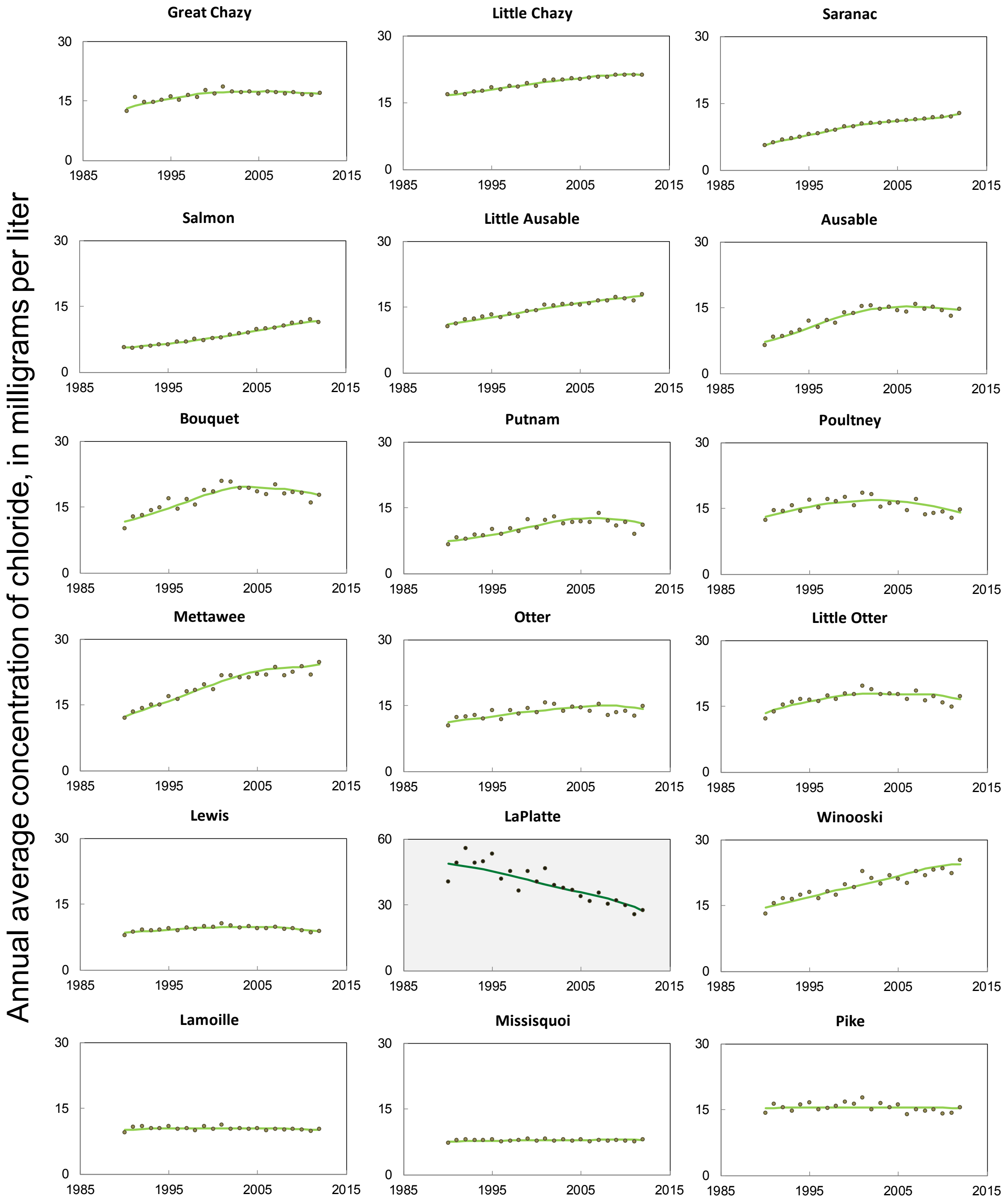


Figure 6. Graphs showing annual estimated (brown dots) and flow-normalized (green lines) concentrations of chloride for the 18 monitored tributaries of Lake Champlain from 1990 through 2012. The y-axis scale for the LaPlatte River plot is different than the rest of the plots.

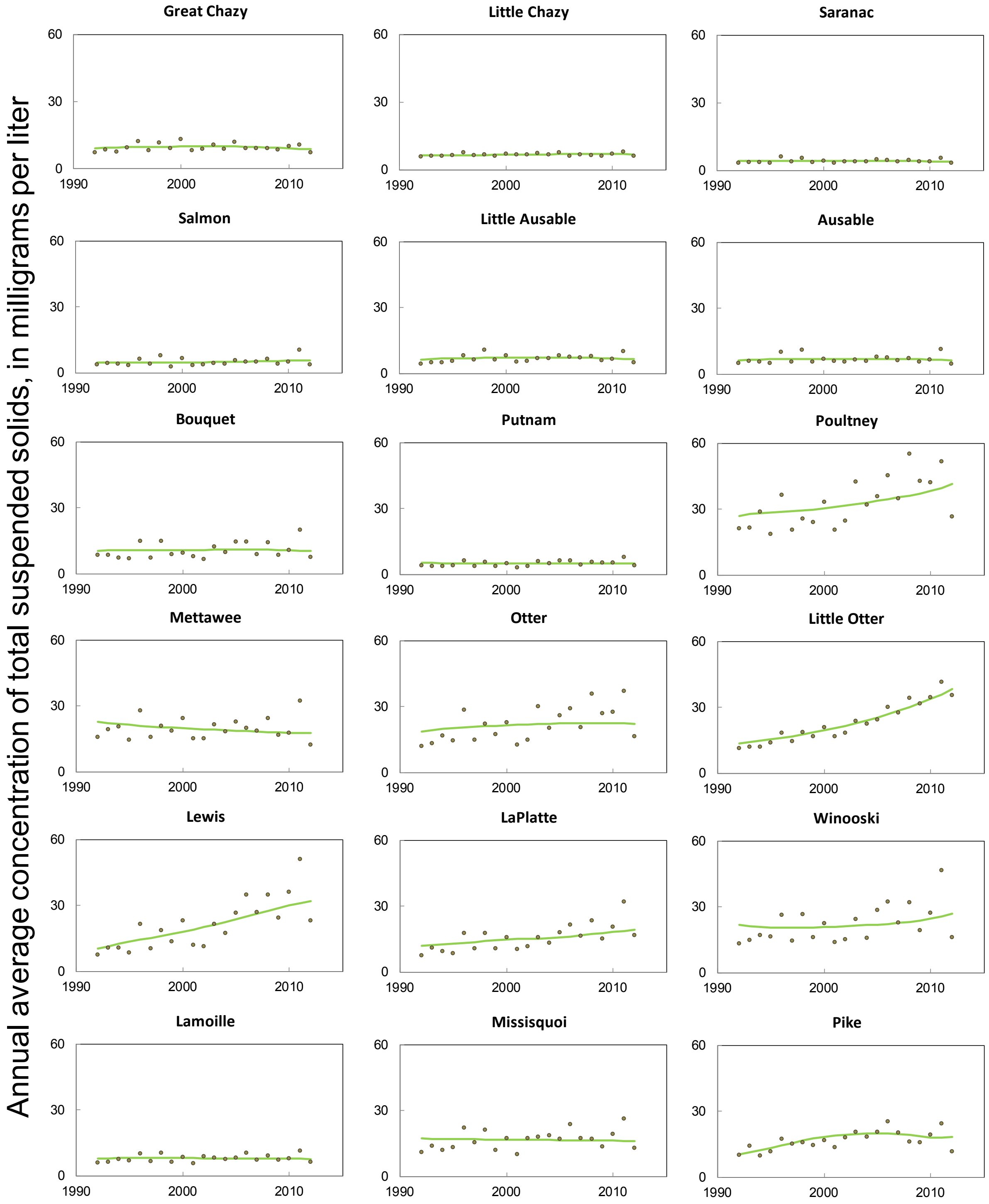


Figure 7. Graphs showing annual estimated (brown dots) and flow-normalized (green lines) concentrations of total suspended solids for the 18 monitored tributaries of Lake Champlain from 1992 through 2012.

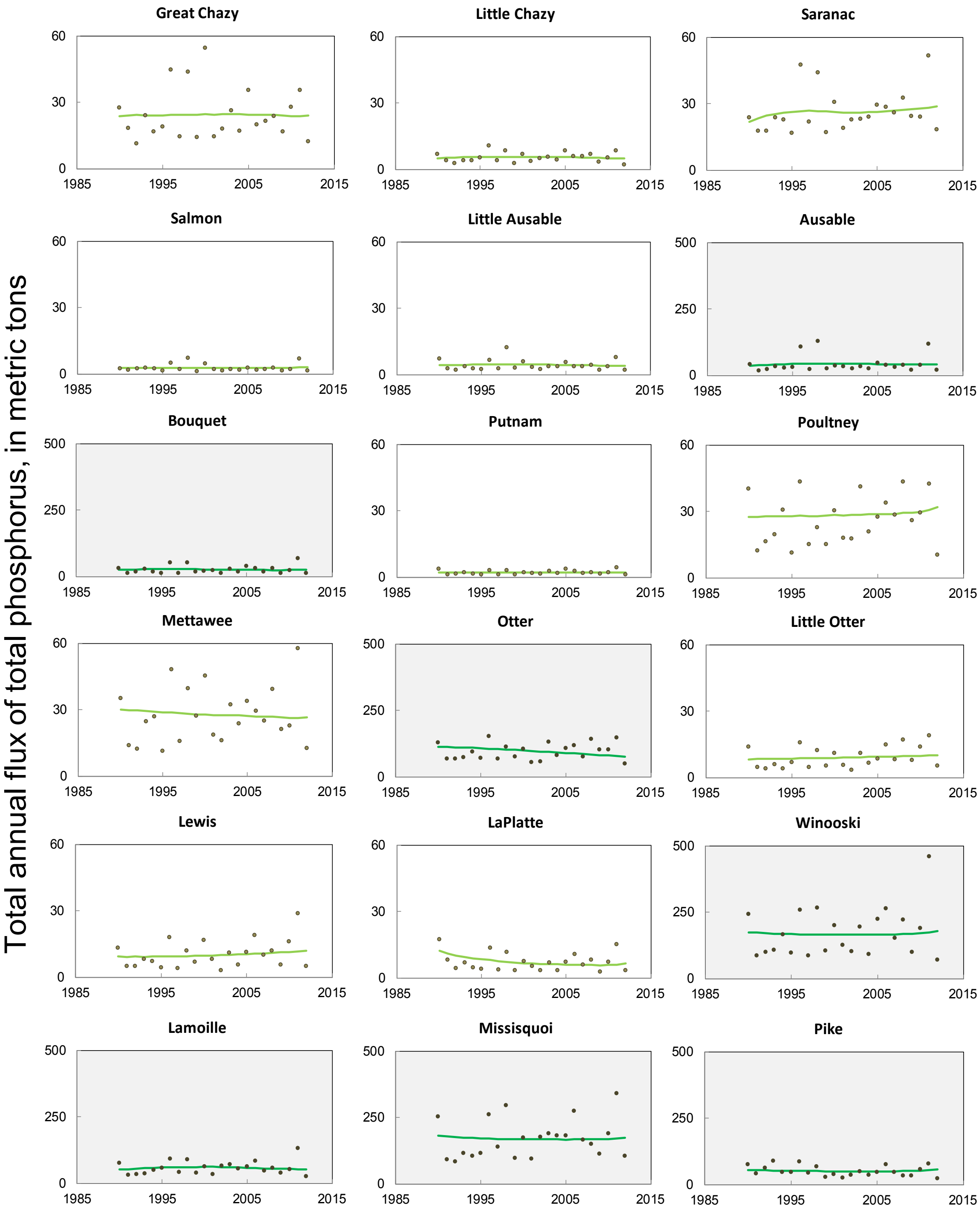


Figure 8. Graphs showing annual estimated (brown dots) and flow-normalized (green lines) flux of total phosphorus for the 18 monitored tributaries of Lake Champlain from 1990 through 2012. The y-axis scales for the shaded plots are different than the rest of the plots.

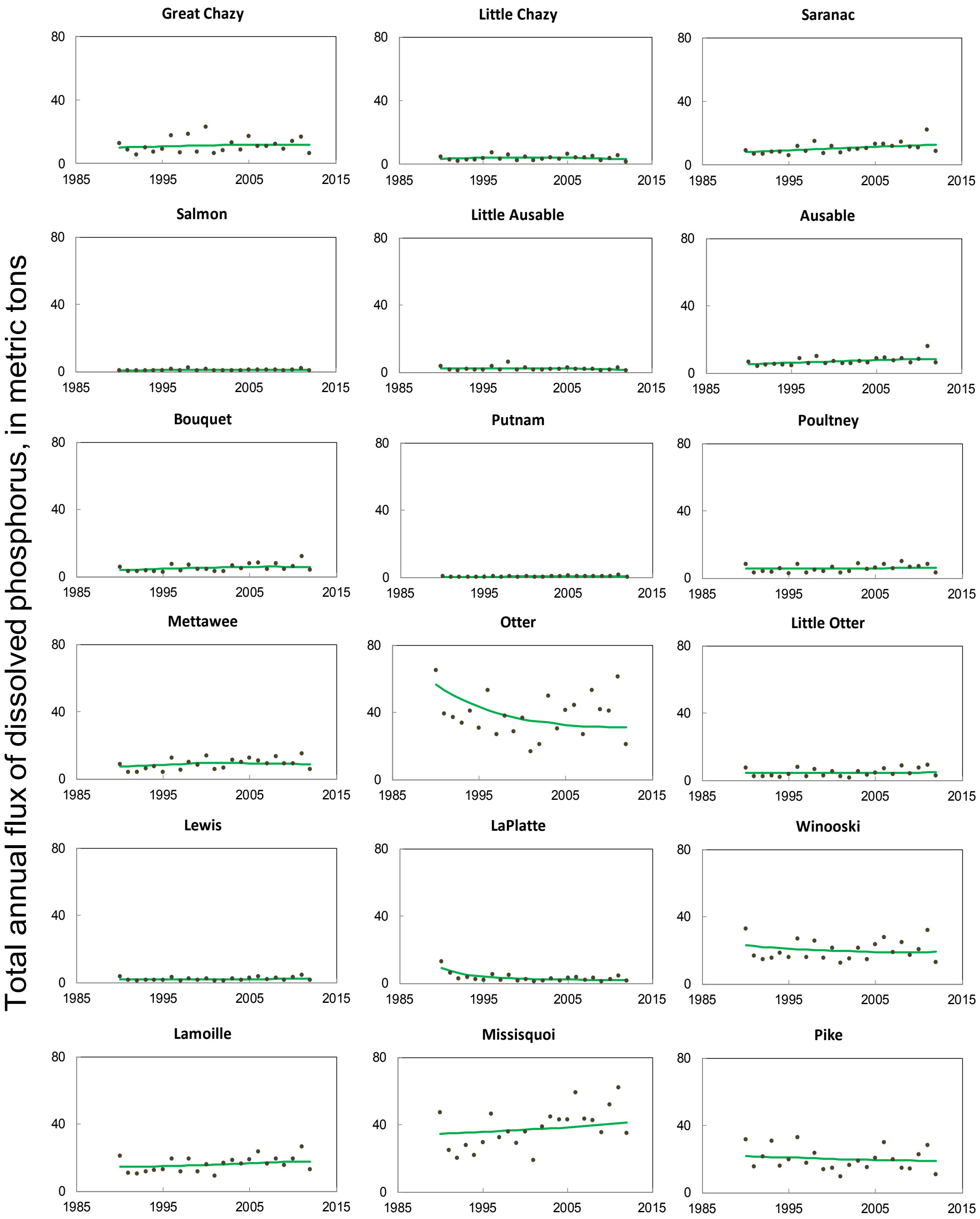


Figure 9. Graphs showing annual estimated (brown dots) and flow-normalized (green lines) flux of dissolved phosphorus for the 18 monitored tributaries of Lake Champlain from 1990 through 2012.

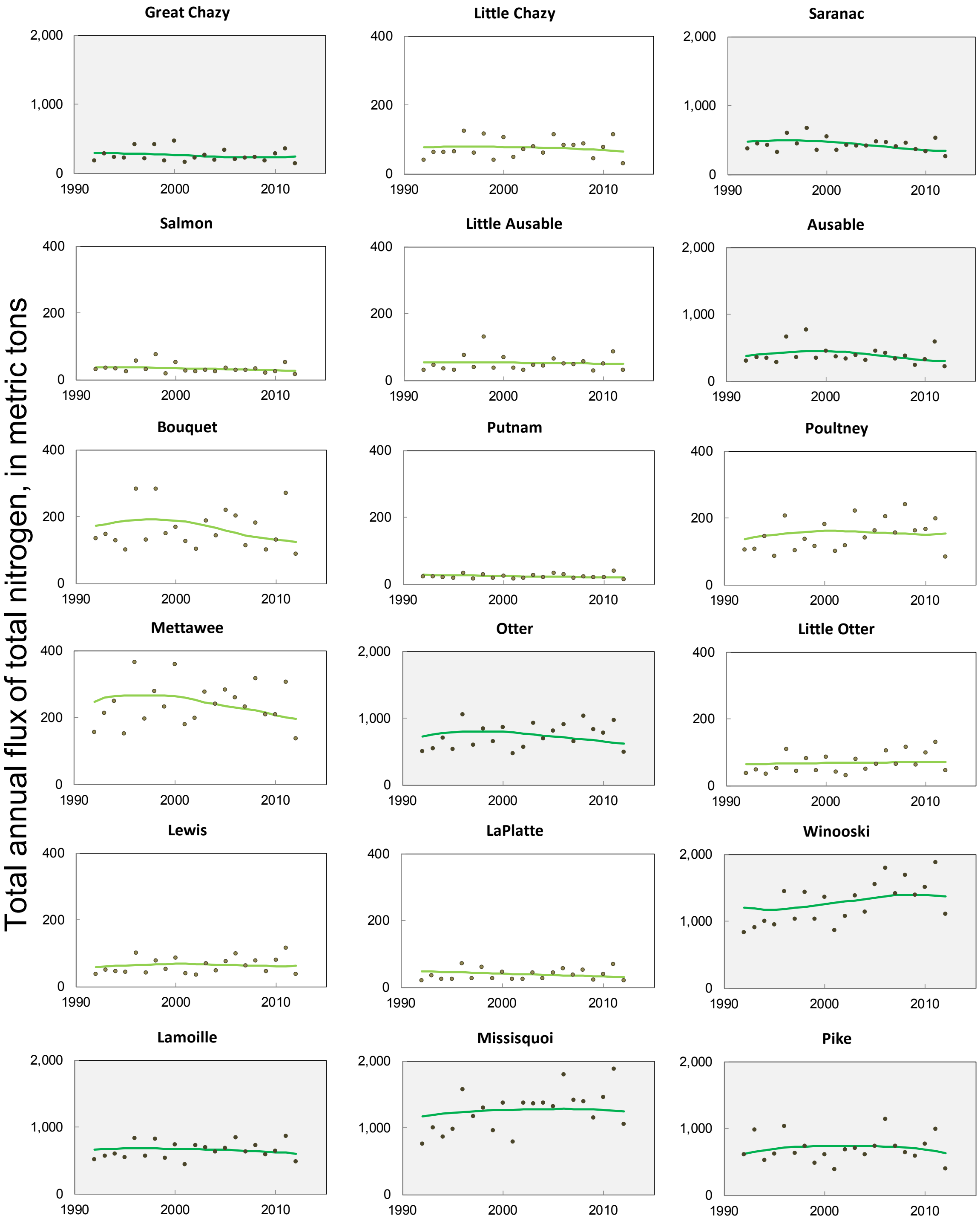


Figure 10. Graphs showing annual estimated (brown dots) and flow-normalized (green lines) flux of total nitrogen for the 18 monitored tributaries of Lake Champlain from 1992 through 2012. The y-axis scales for the shaded plots are different than the rest of the plots.

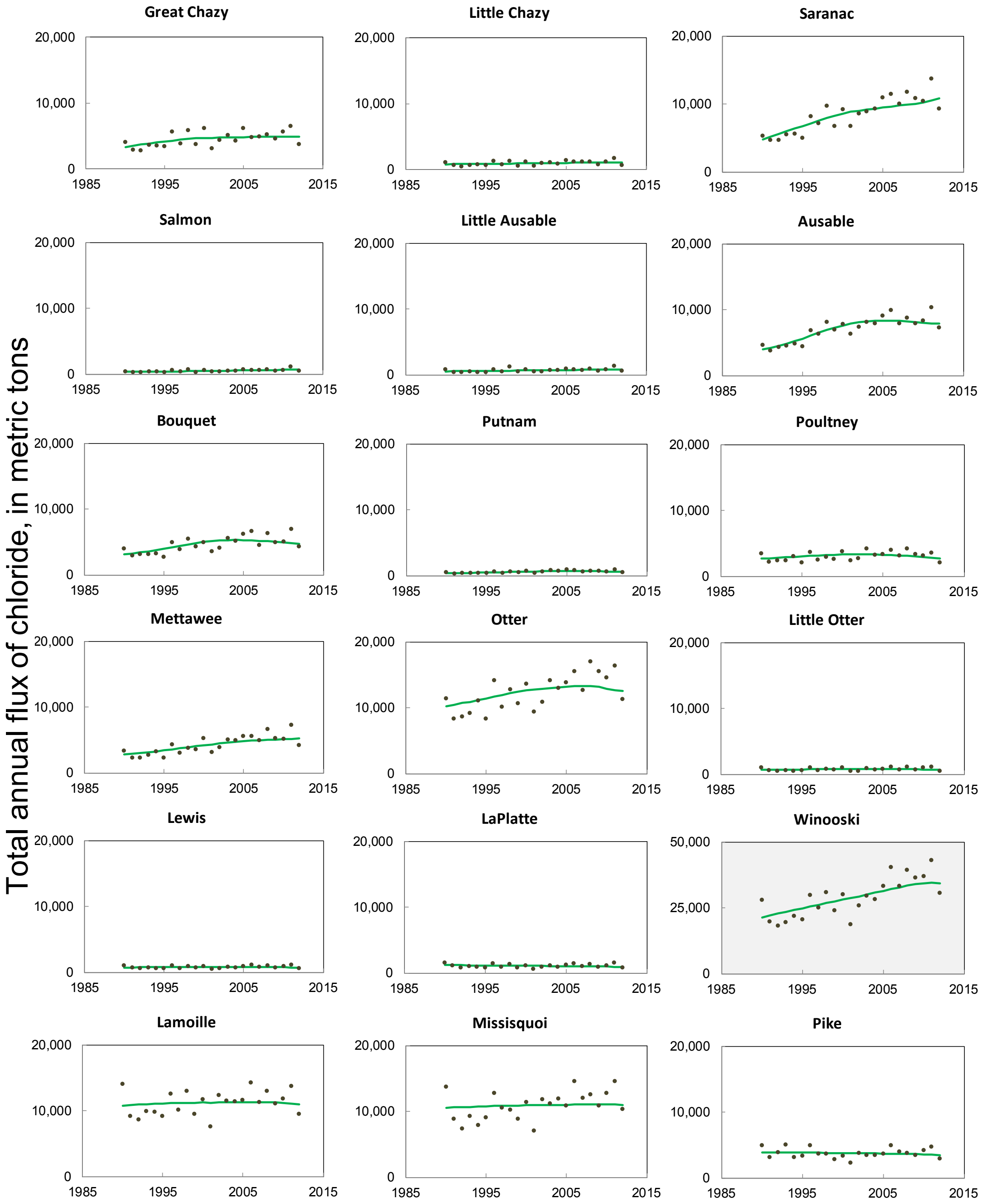


Figure 11. Graphs showing annual estimated (brown dots) and flow-normalized (green lines) flux of chloride for the 18 monitored tributaries of Lake Champlain from 1990 through 2012. The y-axis scale for the Winooski River plot is different than the rest of the plots.

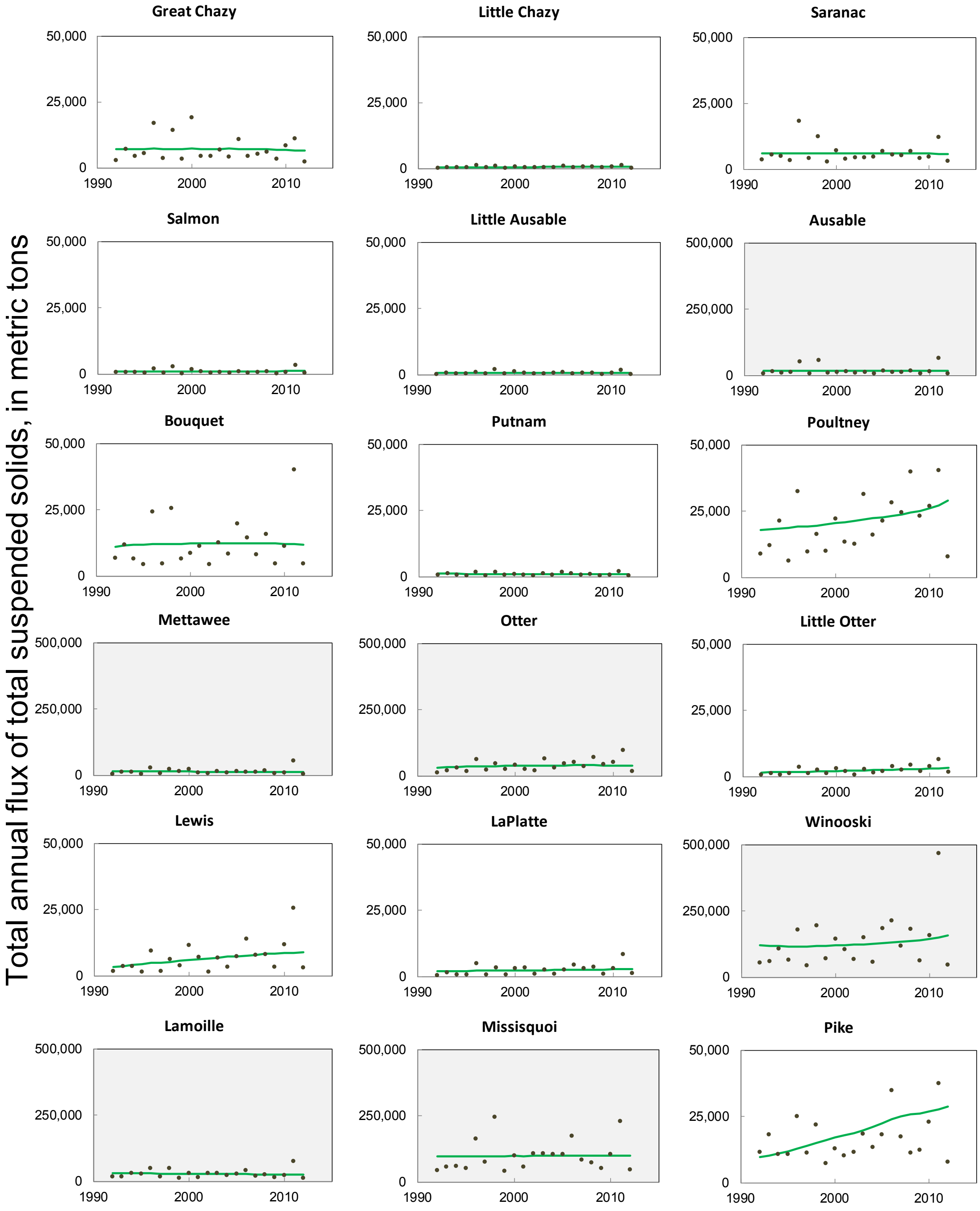


Figure 12. Graphs showing annual estimated (brown dots) and flow-normalized (green lines) flux of total suspended solids for the 18 monitored tributaries of Lake Champlain from 1992 through 2012. The y-axis scales for the shaded plots are different than the rest of the plots.

Table 1. Streamgage and water-quality monitoring station numbers and drainage areas for tributaries to Lake Champlain.

[USGS, U.S. Geological Survey; MENV, Ministry of the Environment (Quebec, Canada); km^2, square kilometers; NY, New York; VT, Vermont; QU, Quebec; tributaries are listed in downstream order]

Tributary name	State or province	USGS or MENV streamgage number	Drainage area	
			At streamgage (km^2)	At tributary outlet (km^2)
Great Chazy	NY	04271500	629	774
Little Chazy	NY	04271815	129	137
Saranac	NY	04273500	1,575	1,590
Salmon	NY	04273700	163	176
Little Ausable	NY	04273800	176	189
Ausable	NY	04275500	1,155	1,329
Bouquet	NY	04276500	699	704
Putnam	NY	04276842	135	161
Poultney	VT/NY	04280000	484	681
Mettawee	VT/NY	04280450	433	1,098
Otter	VT	04282500	1,627	2,445
Little Otter	VT	04282650	148	189
Lewis	VT	04282780	199	210
LaPlatte	VT	04282795	117	137
Winooski	VT	04290500	2,704	2,753
Lamoille	VT	04292500	1,777	1,873
Missisquoi	VT/QU	04294000	2,201	2,240
Pike[1]	QU/VT	030420	404	668
Pike[1]	QU/VT	030424	584	966

[1] Because neither of the Pike River stations had a continuous discharge record from 1990 through 2012, the record from streamgage 030420 was used to reconstruct the record for streamgage 030424 for the missing period from January 1990 through October 2001.

Table 2. Half-window widths for parameters of the Weighted Regression on Time, Discharge, and Season (WRTDS) regression model used to estimate concentration and flux of total and dissolved phosphorus, total nitrogen, chloride, and total suspended solids for tributaries to Lake Champlain.

[Time is in number of years; discharge is in logarithm cycles[1]; season is in fraction of years. The Weighted Regression on Time, Discharge, and Season regression model is from Hirsch and others (2010)]

Tributary	Total phosphorus			Dissolved phosphorus			Total nitrogen			Chloride			Total suspended solids		
	Time	Discharge	Season	Time	Discharge	Season	Time	Discharge	Season	Time	Discharge	Season	Time	Discharge	Season
Great Chazy	20	2	0.5	20	2	0.5	10	3	0.5	10	2	0.5	20	2	0.5
Little Chazy	20	2	0.5	20	2	0.5	20	3	0.5	20	2	0.5	20	2	0.5
Saranac	10	2	0.5	20	2	0.5	10	3	0.5	10	2	0.5	20	2	0.5
Salmon	10	3	0.5	20	2	0.5	20	2	0.5	20	2	0.5	20	3	0.5
Little Ausable	20	2	0.5	20	2	0.5	20	3	0.5	20	2	0.5	20	2	0.5
Ausable	15	2	0.5	20	2	0.5	10	2	0.5	10	2	0.5	20	2	0.5
Bouquet	10	2	0.5	20	2	0.5	10	2	0.5	10	3	0.5	20	2	0.5
Putnam	20	2	0.5	10	2	0.5	10	2	0.5	10	2	0.5	20	2	0.5
Poultney	20	3	1	20	3	0.5	10	3	0.5	10	2	0.5	20	2	0.5
Mettawee	20	2	0.5	10	3	0.5	10	3	0.5	10	2	0.5	20	2	0.5
Otter	20	2	0.5	10	2	0.5	10	2	0.5	10	2	0.5	20	2	0.5
Little Otter	20	2	0.5	10	2	0.5	20	2	0.5	10	2	0.5	30	3	0.5
Lewis	20	2	0.5	30	3	0.5	10	3	0.5	10	2	0.5	20	2	0.5
LaPlatte	10	2	0.5	10	2	0.5	20	3	0.5	20	3	0.5	10	2	0.5
Winooski	20	2	0.5	20	2	0.5	10	3	0.5	20	2	0.5	20	2	0.5
Lamoille	10	2	0.5	20	3	0.5	20	3	0.5	20	3	1	20	2	0.5
Missisquoi	20	2	0.5	30	3	0.5	20	3	1	30	3	0.5	30	3	0.5
Pike	20	2	0.5	20	3	0.5	20	3	0.5	20	2	0.5	10	3	1

[1] One logarithm cycle means that discharge differs by a factor of 10; for two and three logarithm cycles, the factors are 100 and 1,000.

Table 3. Flux bias statistics comparing the Weighted Regressions on Time, Discharge, and Season regression model estimates with water-quality observations for total and dissolved phosphorus, total nitrogen, chloride, and total suspended solids for tributaries to Lake Champlain.

[Flux bias statistics greater than ±0.1 are **bolded** and indicate a potentially biased regression model. The Weighted Regression on Time, Discharge, and Season regression model is from Hirsch and others (2010)]

Tributary	Total phosphorus	Dissolved phosphorus	Total nitrogen	Chloride	Total suspended solids
Great Chazy	-0.005	0.022	0.008	-0.018	**0.188**
Little Chazy	-0.010	-0.039	-0.015	-0.020	0.051
Saranac	**-0.305**	**-0.151**	-0.020	-0.033	**-0.839**
Salmon	-0.031	0.015	-0.026	-0.015	0.072
Little Ausable	-0.096	**-0.108**	0.023	-0.023	**0.122**
Ausable	0.071	-0.045	-0.030	-0.019	**0.178**
Bouquet	0.060	0.050	0.082	-0.029	**0.273**
Putnam	**-0.125**	-0.025	-0.043	-0.052	-0.033
Poultney	0.031	-0.002	-0.023	-0.010	0.062
Mettawee	0.083	0.017	-0.016	-0.003	**0.125**
Otter	-0.001	0.008	-0.033	-0.024	0.005
Little Otter	0.014	0.018	0.003	-0.020	0.030
Lewis	-0.024	-0.060	-0.017	-0.006	0.003
LaPlatte	0.058	0.074	0.011	0.009	0.073
Winooski	0.020	-0.004	-0.020	-0.029	0.052
Lamoille	-0.085	0.009	-0.017	-0.023	**-0.147**
Missisquoi	0.023	0.011	-0.017	-0.018	0.039
Pike	0.004	0.034	-0.049	-0.023	0.001

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For more information concerning this report, contact:

Office Chief
New Hampshire-Vermont Office
New England Water Science Center
U.S. Geological Survey
331 Commerce Way, Suite 2
Pembroke, NH 03275
dc_nh@usgs.gov

or visit our Web site at:
http://nh.water.usgs.gov

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