NUTRIENT LOADING RATES

Analysis and Results

Nutrient loading rates for 17 sites in the French Creek watershed are given in Table 10. Loading rates were calculated by multiplying the discharge and the nutrient concentrations at each site. To determine which sites are significantly different from what is typically observed in the entire watershed, we compared site-specific data to the mean and 95 % confidence intervals (denoted by two numbers in parenthesis following the mean) for all sites. Nutrient loading rates for main-stem sites are given in Table 11.

We expected a linear relationship between discharge and nutrient loading, as discharge increases so will the nutrient loading rates. We used simple least squares regression models to determine the rate at which the loading rates increase with increasing discharge. From this we are able to make predictions of nutrient loading rates at a given discharge. We calculated 95% simultaneous confidence intervals for the fitted regression lines to determine which of our data fall outside what is predicted by the model (Mathsoft 1999). We calculated separate models for main-stem loading rates, because discharge was substantially higher in the main-stem than in the sub-basins. Because very few data points were taken during the spring and summer rain events, we only calculated regression models for base flow.

Safety considerations and extremely high flows prevented water velocity measurements from being taken at all sites during the spring and summer rain events. Additionally, some sites were too deep or slow moving for accurate velocity measurements to be made even during the summer base flow sampling. Whenever possible, sampling sites were coordinated with active USGS gauging stations and discharge data was obtained from the USGS website. It should be noted that because water velocities were not taken at every site during every sampling period, discharge and nutrient loading rates were not calculated for those sites. Nutrient loading rates were not calculated on any sites in Conneaut Outlet or Conneauttee Creek during the summer rain event, in Sugar Creek or West Branch of French Creek during spring rain or summer base flow events, and in Woodcock Creek during the base flow event. The lack of measurements within these sub-basins must be taken into consideration when interpreting the following figures and tables.

Nitrogen (Nitrate + Nitrite)

Sub-basins

Nitrogen loading rates are illustrated in Figure 9. The highest nitrogen loading rates occurred during the spring rain event with a mean of 1.81 (0.66, 2.96). Site 67 on Watson Run in Conneaut Outlet had nitrogen loading rates above the 95% confidence interval (4.67 g/s) for the spring rain event. During the summer rain event, the mean nitrogen-loading rate was 0.75 g/s (0,1.53). During base flow, the mean nitrogen-loading rates were 0.09 g/s (0.02, 0.15). The mouth of South Branch French Creek (site 13) and the mouth of Sugar Creek (site 103) both had above average nitrogen loading rates during the summer rain and base flow sampling events.

We found a significant linear relationship, as discharge increases, nitrogen loading-rates increase (p-value=0.00). Four sites fell outside of the 95% simultaneous confidence intervals for nitrogen loading rates; Woodcock Creek (site 49) had lower than expected N loading rates and the mouth of West Branch French Creek (site 7), Watson Run (site 67) and Muddy Creek (site 23) had higher than expected N loading rates.

Main-stem French Creek

Instead of a linear relationship, we observed a log-linear increase in nitrogen loading, as discharge increased along the main-stem of French Creek, meaning the rate of increase seems to level off after a certain discharge. This trend is largely affected by the low nitrogen-loading rate observed at the mouth of French Creek at Franklin (0.25 g/s). One site that had a higher than expected nitrogen-loading rate, 0.93 g/s, site 61 below Meadville.

Total Phosphorus

Sub-basins

Phosphorus loading rates are illustrated in Figure 10. The highest phosphorus loading rates occurred during the spring rain event, with a mean of 0.54 (0, 1.22). Site 67 on Watson Run in Conneaut Outlet had phosphorus loading rates above the 95% confidence interval (2.50 g/s). During the summer rain event, the mean phosphorus-loading rate was 0.1 g/s (0,0.2). During base flow, the mean phosphorus-loading rates were 0.01 g/s (0, 0.02). Site 13, the mouth of South Branch French Creek and site 103, the mouth of Sugar Creek both had above average phosphorus loading rates during base flow. Watson Run on Conneaut Outlet (site 67), site 13, and site 103 all had above average phosphorus loading rates during the summer rain event.

We found a significant linear relationship, as discharge increases, phosphorus loading-rates increase (p-value=0.00). Three sites fell outside the 95% simultaneous confidence intervals for phosphorus loading rates; site 67, located at Watson Run on Conneaut Outlet had higher than expected phosphorus loading rates, and Woodcock Creek (site 49) and Sugar Creek (site 103) both had lower than expected phosphorus loading rates.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, phosphorus loading rates increase (p-value= 0.000). One site fell outside of the 95% simultaneous confidence intervals for phosphorus loading rates, site 61 below Meadville had higher loading rates than expected.

Kjeldahl nitrogen

Sub-basins

Kjeldahl nitrogen loading rates are illustrated in Figure 11. The highest kjeldahl nitrogen loading rates occurred during the spring rain event, with a mean of 5.36 g/s (1.91, 8.81). Site 16 on the East Branch of Le Boeuf Creek and site 67 on Watson Run in Conneaut Outlet had kjeldahl nitrogen loading rates above the 95% confidence interval (11.01 and 10.24 g/s). During the summer rain event, the mean kjeldahl nitrogen loading rate was1.25 g/s (0.37,2.14). During base flow, the mean kjeldahl nitrogen-loading rate was 0.17 g/s (0.05, 0.3). The mouth of South Branch French Creek (site 13), Watson Run on Conneaut Outlet (site 67), and the mouth of Sugar Creek (site 103) all had above average kjeldahl nitrogen loading rates during base flow. Site 13 and site 103 had above average kjeldahl nitrogen loading rates during the summer rain event.

Table 10: Discharge and loading rates for 17 sites in the French Creek watershed.

WQ site	Sub-shed		Discharge (cfs)			N (g/s)			P, total (g/s)			N, kjeldahl (g/s)			TDS (g/s)			SS (g/s)			N, ammonia (g/s)			N, organic (g/s)		
			Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer
7	West Branch FC	Mouth	*	5.6	21.2		0.17	0.54		0.01	0.03		0.24	2.28		42.8	138.1		1.0	4.2		0.02	0.06		0.07	1.74
10	South Branch FC	Slaughter Run	40.7	0.2	*	0.91	0.00		0.06	0.00		1.38	0.01		85.3	1.2		13.8	0.0		0.12	0.00		0.47	0.00	
13	South Branch FC	Mouth	*	13.5	70.9		0.26	1.65		0.05	0.30		0.50	2.01		114.7	421.6		1.9	42.2		0.04	0.20		0.24	0.36
16	Le Boeuf Creek	East Branch Le Boeuf	144.0	2.1	*	1.06	0.01		0.49	0.01		11.01	0.10		407.8	11.9		130.5	0.3		0.41	0.01		9.95	0.09	
18	Le Boeuf Creek	Trout Run	51.3	1.1	*	0.99	0.02		0.23	0.00		1.74	0.03		188.9	9.0		14.5	0.2		0.14	0.00		0.76	0.01	
20	Le Boeuf Creek	Mouth	*	2.2	7.0		0.07	0.14		0.00	0.02		0.06	0.16		13.3	45.6		0.3	3.6		0.01	0.02		-0.01	0.02
23	Muddy Creek	Muddy Creek	85.3	3.2	*	2.49	0.14		0.22	0.01		5.07	0.09		219.8	18.1		724.6	0.5		0.24	0.01		2.59	-0.05	
27	Muddy Creek	Federal Run (mouth)	175.0	2.0	*	2.43	0.01		0.30	0.01		4.46	0.06		436.1	9.6		89.2	0.3		0.50	0.01		2.03	0.06	
30	Muddy Creek	Mouth	*	3.1	22.1		0.00	0.03		0.01	0.06		0.07	0.44		14.7	106.4		0.8	16.9		0.01	0.06		0.07	0.44
33	Conneauttee Creek	Conneauttee	20.9	1.3	*	0.35	0.04		0.03	0.00		0.47	0.06		76.9	9.9		5.9	0.2		0.06	0.00		0.12	0.02	
48	Woodcock Creek	Woodcock Creek	351.0	4.1	28.0		0.03			0.00			0.10			18.6			0.6			0.01			0.07	
49	Woodcock Creek	Mouth	*	9.7	*		0.03			0.01			0.17			33.1			1.4			0.03			0.10	
51	Cussewago Creek	Cussewago	187.0	0.5	*	1.59	0.00		0.48	0.00		8.47	0.02		529.5	2.6		58.3	0.1		0.53	0.00		6.88	0.02	
57	Cussewago Creek	Mouth	*	1.3	4.1		0.01	0.04		0.00	0.01		0.03	0.16		4.4	25.5		0.2	1.2		0.00	0.01		0.02	0.12
67	Conneaut Outlet	Watson Run	402.0	8.4	*	4.67	0.12		2.50	0.04		10.24	0.31		1252	95.1		762.7	3.3		1.14	0.03		5.58	0.16	
74	Little Sugar Creek	Mouth	*	4.5	46.2		0.05	0.69		0.01	0.13		0.10	1.70		21.5	274.7		0.6	57.6		0.01	0.13		0.05	1.01
103	Sugar Creek	Mouth	*	24.7	102.2		0.48	2.17		0.04	0.14		0.98	2.03		111.8	520.9		3.5	14.5		0.07	0.29		0.50	-0.14

**Discharge was not calculated during this sampling period.*

Table 11: Discharge and nutrient loading rates calculated for sites on the main-stem of French Creek, including the mean loading rates for each sampling period are given.

WQ site	Sub-shed		Discharge (cfs)			N (g/s)			P, total (g/s)			N, kjeldahl (g/s)			TDS (g/s)			SS (g/s)			N, ammonia (g/s)			N, organic (g/s)		
			Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer	Spring	Base	Summer
1	French Creek Main	Hubbel Run NY	816	7.0	20	11.32	0.02	0.18	1.85	0.02	0.04	37.0	0.30	0.85	3004	38	96	578	1	7	4.39	0.02	0.06	21.3	0.28	0.67
3	French Creek Main	West Branch	*	7.3	*	*	0.09			0.01			0.46			52			1			0.02			0.37	
8	French Creek Main	South Branch	*	11.5	*	*	0.05			0.01			0.26			65			5			0.03			0.21	
14	French Creek Main	Le Boeuf	*	26.4	*	*	0.46			0.03			0.75			134			4			0.07			0.29	
21	French Creek Main	Muddy	*	32.2	*	*	0.52			0.03			0.64			164			5			0.09			0.12	
47	French Creek Main	Woodcock	*	64.9	*	*	0.72			0.06			1.29			349			9			0.18			0.57	
61	French Creek Main	Meadville	4490	76.0	182	61.03	0.93	2.47	17.80	0.09	0.52	178.0	2.15	4.64	13986	430	876	6611	11	186	12.71	0.22	0.52	117.0	1.23	2.17
78	French Creek Main	Utica	6020	98.0	170	98.87	0.75		17.05	0.08		119.3	1.94		20456	666		4944	14		17.05	0.28		20.5	1.19	
105	French Creek Main	Mouth	*	112.1	*	*	0.25			0.10			2.86			603			16			0.32			2.60	
	MEAN					57.07	0.42	1.33	12.23	0.05	0.28	111.4	1.18	2.74	12482	278	486	4044	7	96	11.4	0.14	0.29	52.9	0.76	1.40

**Discharge was not calculated during this sampling period.*

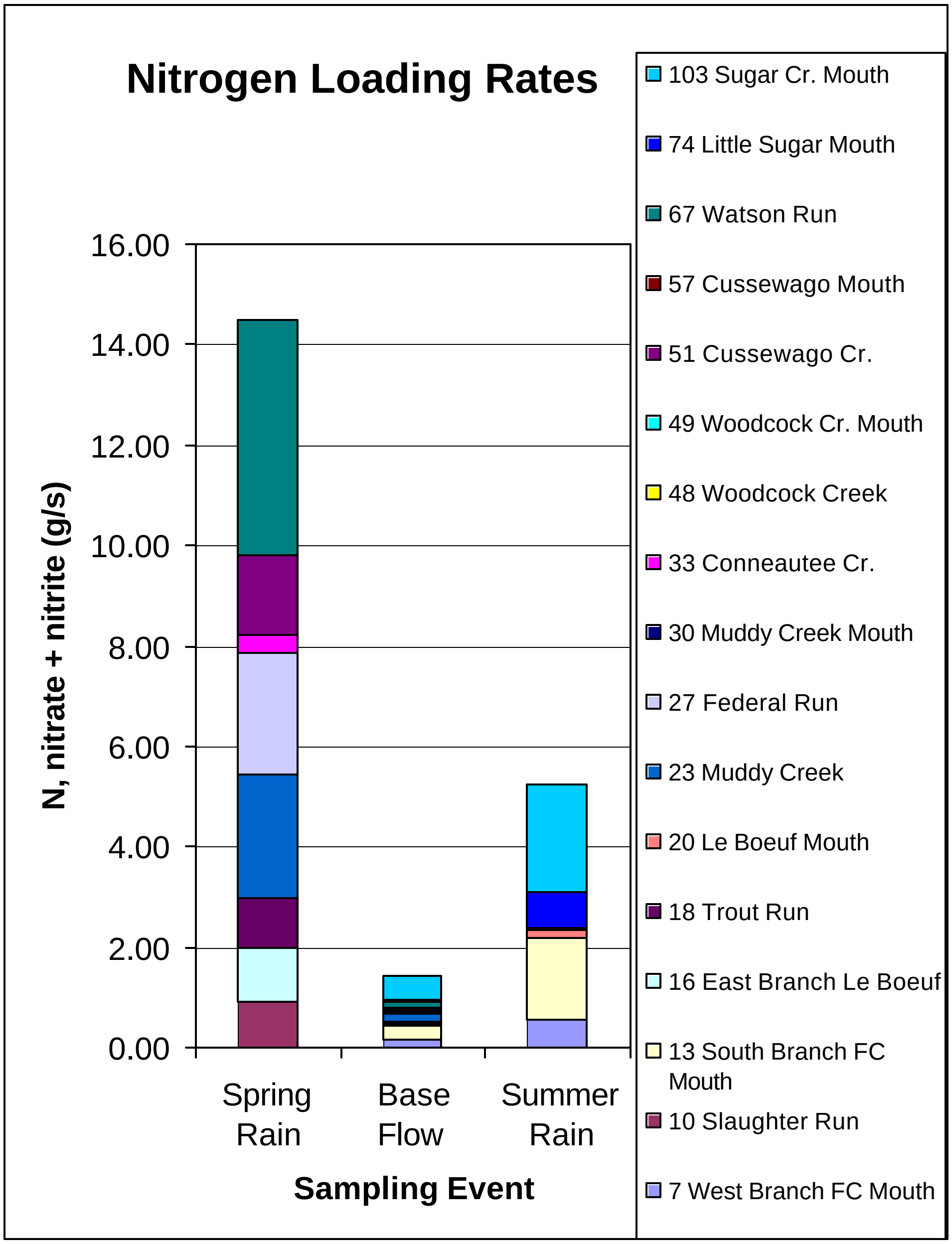

Figure 9: Nitrogen loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

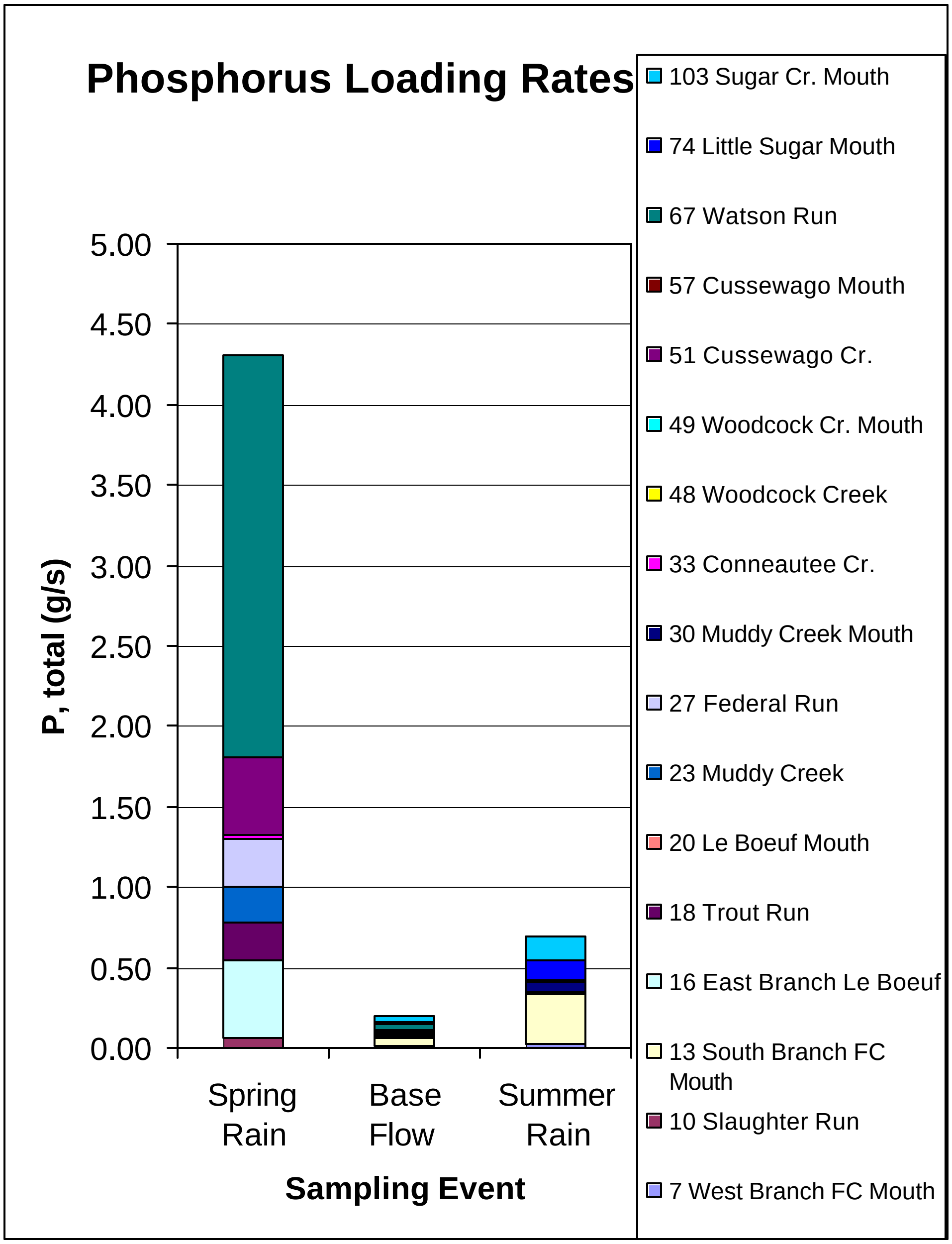

Figure 10: Phosphorus loading rates for 17 sites throughout the 10 sub-basins of French Creek watershed for three sampling events. (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

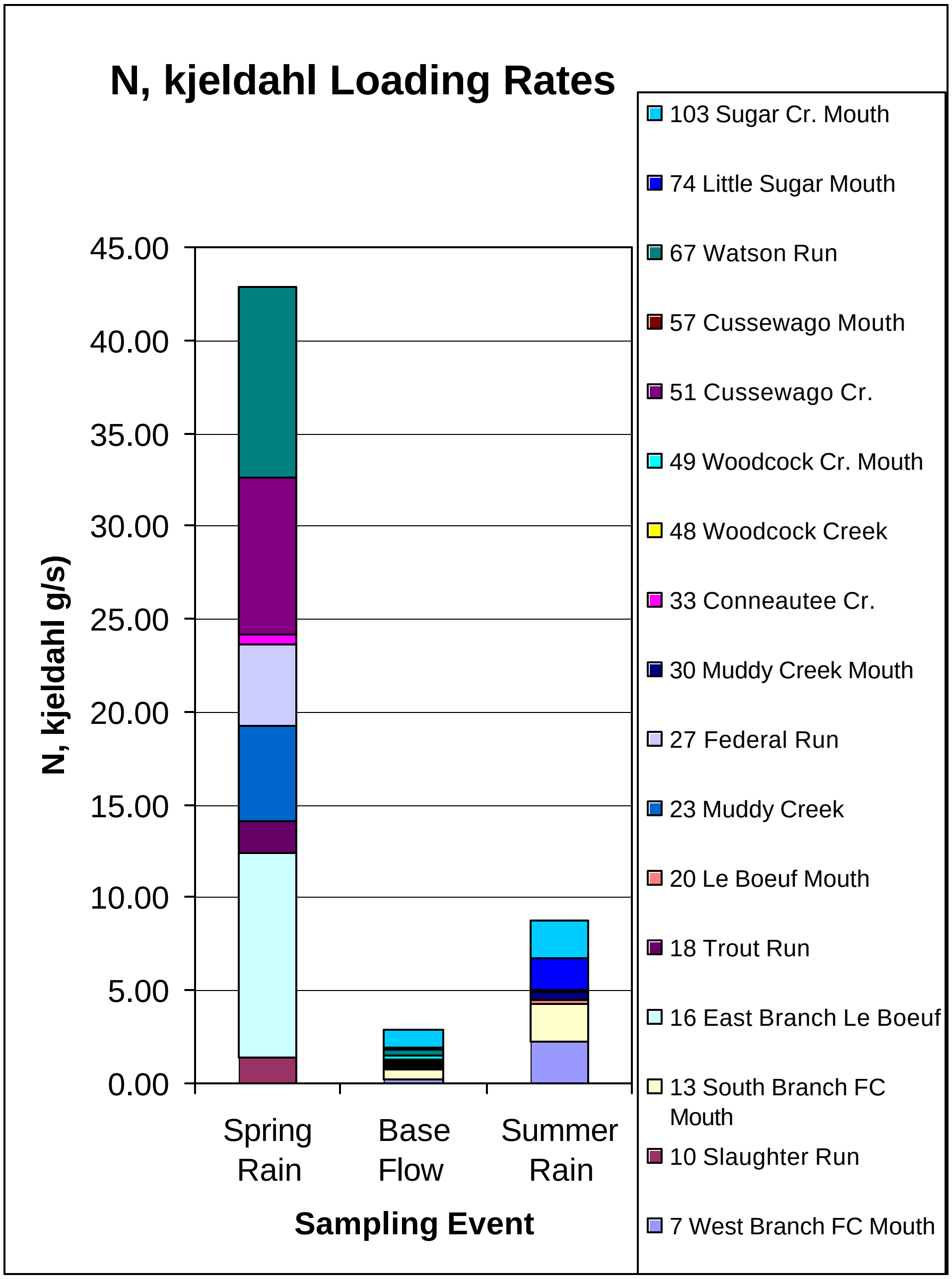

Figure 11: Kjeldahl nitrogen loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

We found a significant linear relationship, as discharge increases, kjeldahl loading-rates increase (p-value =0.00). One site fell outside our 95% simultaneous confidence intervals for kjeldahl nitrogen loading rates; site 49 on Woodcock Creek had lower than expected kjeldahl nitrogen loading rates.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, kjeldahl loading-rates increase (p-value =0.00). Two sites fell outside of the 95% simultaneous confidence intervals for kjeldahl nitrogen loading rates, site 78 at Utica and site 47 at Woodcock Creek were both lower than expected.

Ammonia Nitrogen

Sub-basins

Ammonia loading rates are illustrated in Figure 12. The highest ammonia loading rates occurred during the spring rain event, with a mean of 0.39 g/s (0.1, 0.68). Site 67 on Watson Run in Conneaut Outlet had ammonia loading rates above the 95% confidence interval (1.14 g/s). During the summer rain event, the mean ammonia-loading rate was 0.11 g/s (0.02,0.21). During base flow, the mean ammonia-loading rate was 0.02 g/s (0.01, 0.02). The mouth of South Branch French Creek (site 13), the mouth of Woodcock Creek (site 49), Watson Run on Conneaut Outlet (site 67), and the mouth of Sugar Creek (site 103) all had above average ammonia loading rates during base flow. Only the mouth of Sugar Creek had an above average ammonia-loading rate during the summer rain-sampling event (0.29 g/s).

We found a significant linear relationship, as discharge increases, base flow ammonia loading rates increase (p-value =0.00). Two sites fell outside our 95% simultaneous confidence intervals for ammonia nitrogen loading rates; site 49 on Woodcock Creek, and Watson Run (site 67) both had loading rates lower than expected.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, base flow ammonia loading rates increase (p-value =0.00). None of the sites fell outside of the 95% simultaneous confidence intervals for ammonia loading rates.

Suspended solids (SS)

Sub-basins

Suspended solids loading rates are illustrated in Figure 13. The highest suspended solids loading rates occurred during the spring rain event, with a mean of 224.94 g/s (0, 495.07). Site 23 on Muddy Creek and site 67 on Watson Run in Conneaut Outlet had suspended solids loading rates above the 95% confidence interval (724.63 and 762.69 g/s). During the summer rain event, the mean suspended solids loading rate was 20.0 g/s (0,40.0). During base flow, the mean suspended solids loading rate was 0.89 g/s (0.34, 1.44). The mouth of South Branch French Creek (site 13), Watson Run on Conneaut Outlet (site 67), and the mouth of Sugar Creek (site 103) had above average suspended solids loading rates during base flow. Site 74 on Little Sugar Creek had an above average suspended solid loading rate during the summer rain-sampling event.

We found a significant linear relationship, as discharge increases, base flow suspended solids loading rates increase (p-value =0.00). Three sites fell outside of the 95% simultaneous confidence intervals for suspended solids loading rates. Site 67, located at Watson Run on Conneaut Outlet had a higher than expected loading rate. The mouth of Sugar Creek (site 103) and the mouth of South Branch French Creek (site 13), both had lower than expected suspended solid loading rates.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, base flow suspended solids loading rates increase (p-value =0.00). Site 8, at its confluence with South Branch French Creek, fell outside the 95% simultaneous confidence intervals, with a loading rate higher than expected.

Total dissolved solids (TDS)

Sub-basins

Total dissolved solids loading rates are illustrated in Figure 14. Total dissolved solid loading rates into the system were high in both the spring and the summer rain events, although different sub-basins were the major known contributors at each sampling event. The highest total dissolved solids loading rates occurred during the spring rain event, with a mean of 399.55 g/s (79.67, 719.43). Site 67 on Watson Run in Conneaut Outlet had a total dissolved solids loading rate above the 95% confidence interval (1252.17g/s). During the summer rain event, the mean total dissolved solids-loading rate was 218.98 g/s (41.07, 396.89). During base flow, the mean total dissolved solids-loading rate was 31.31g/s (11.85, 50.78). The mouth of South Branch French Creek (site 13), Watson Run on Conneaut Outlet (site 67), and the mouth of Sugar Creek (site 103) had above average nutrient loading rates during base flow. Site 13 and site 103 also had above average nutrient loading rates during the summer rain event.

We found a significant linear relationship, as discharge increases, base flow TDS loading-rates increase (p-value =0.00). Three sites fell outside our 95% simultaneous confidence intervals for TDS loading rates; site 103, at the mouth of Sugar Creek, and site 49 on Woodcock Creek both had lower than expected TDS loading rates, while Watson Run (site 67) had higher than expected TDS loading rates.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, base flow TDS loading rates increase (p-value=0.00). None of the sites fell outside of the 95% simultaneous confidence intervals for base flow TDS loading rates.

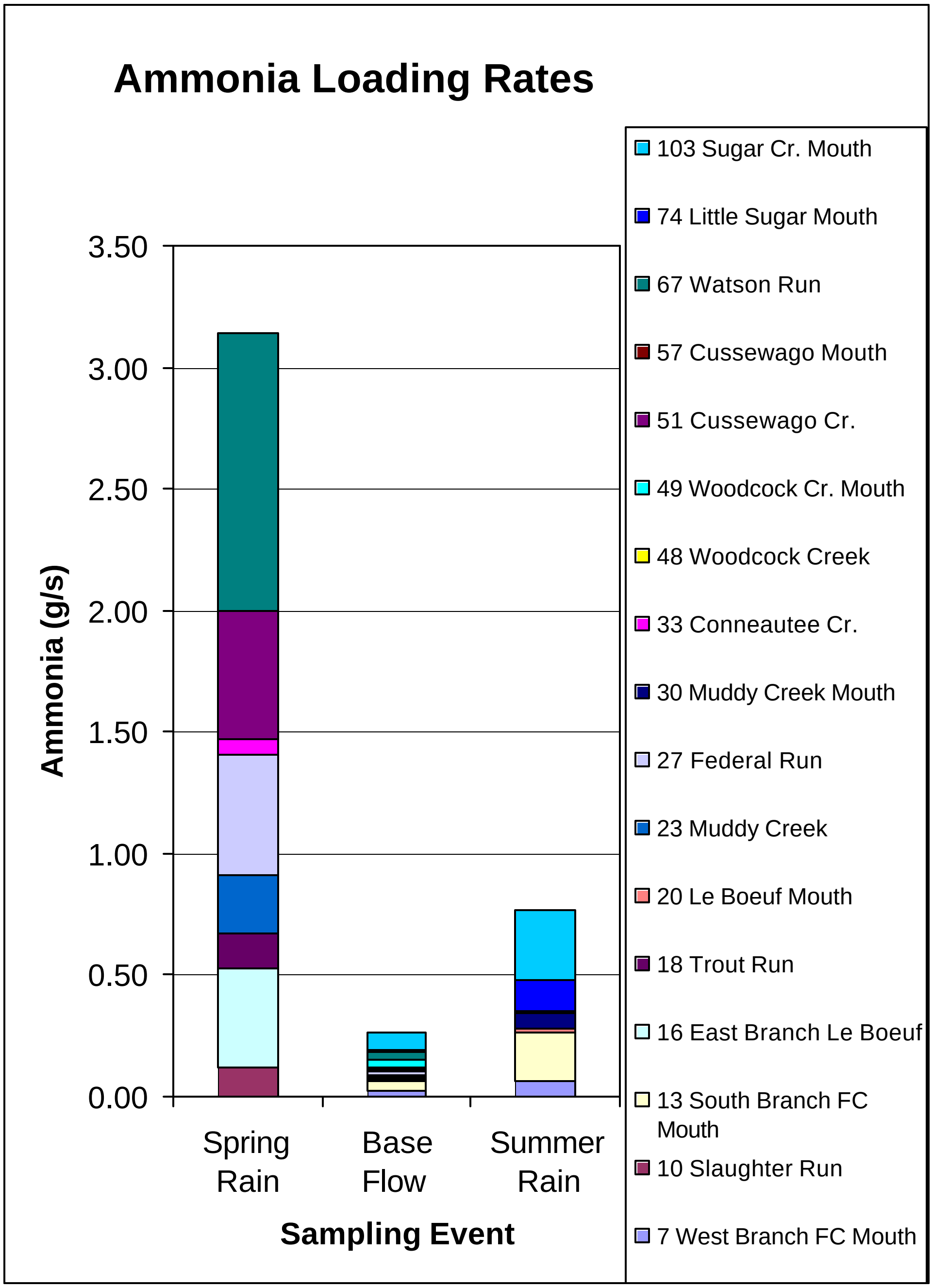

Figure 12: Ammonia loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

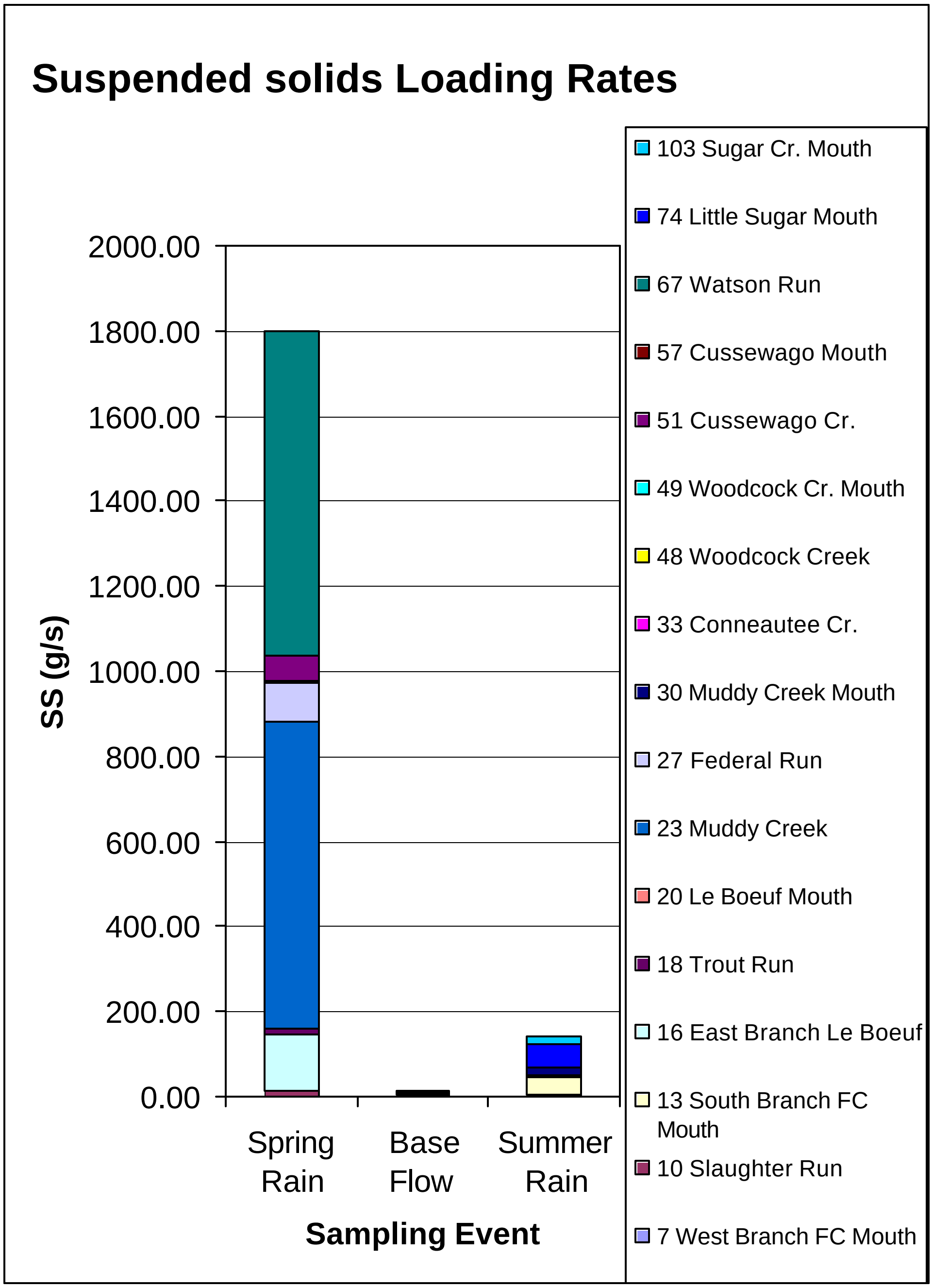

Figure 13: Suspended solids loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

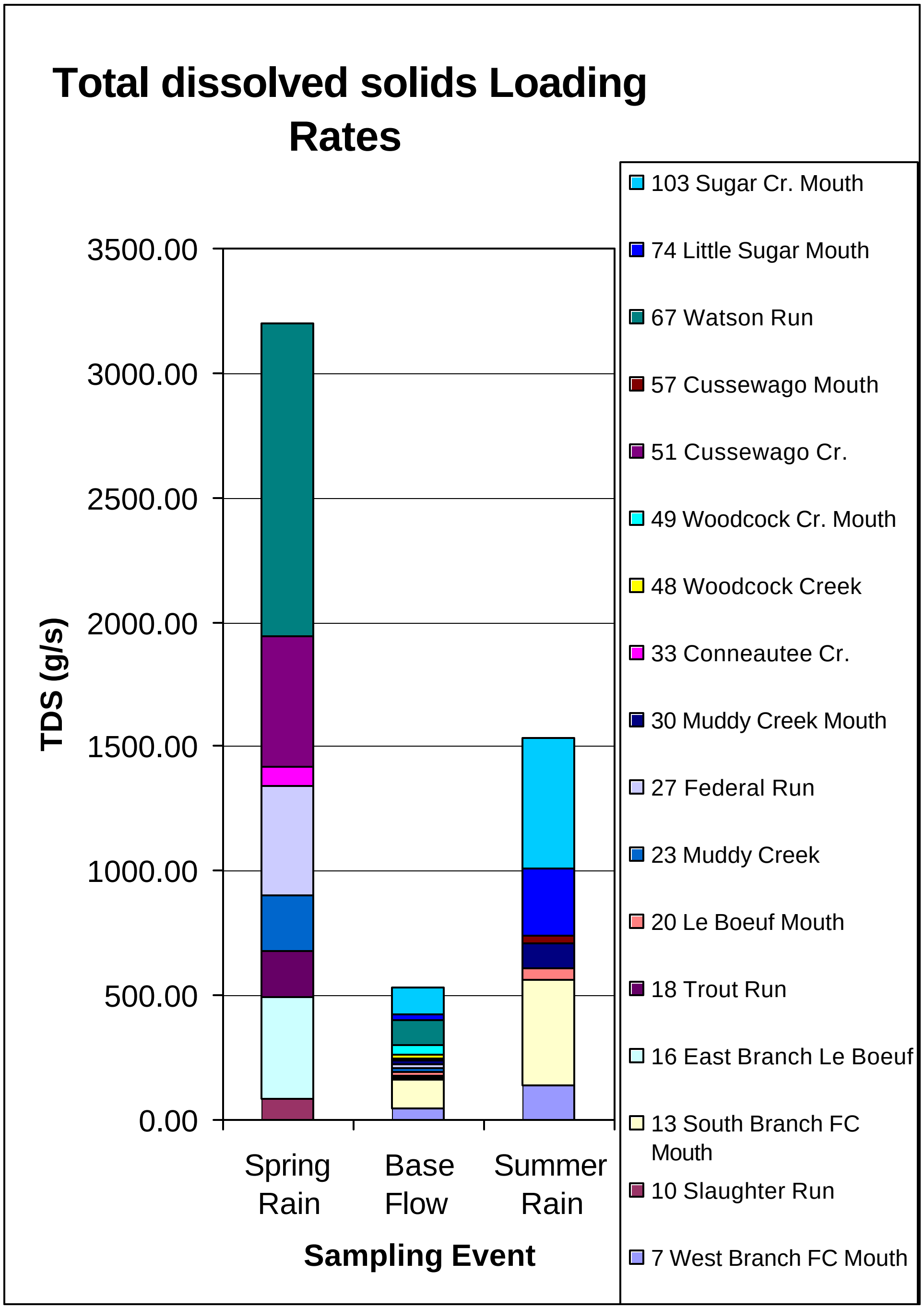

Figure 14: Total dissolved solids loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).

Organic Nitrogen

Sub-basins

Organic nitrogen loading rates are illustrated in Figure 15. The highest organic nitrogen loading rates occurred during the spring rain event, with a mean of 3.55 g/s (0.57, 6.52). East Branch Le Boeuf Creek (site 16) and Cussewago Creek (site 51) had organic nitrogen loading rates above the 95% confidence interval. During the summer rain event, the mean organic nitrogen-loading rate was 0.51 g/s (0,1.12). During base flow, the mean organic nitrogen-loading rate was 0.08 g/s (0.02, 0.15). The mouth of South Branch French Creek (site 13), Watson Run on Conneaut Outlet (site 67), and the mouth of Sugar Creek (site 103) had above average organic nitrogen loading rates during base flow. Site 7, near the mouth of West Branch French Creek had an above average suspended solid loading rate during the summer rain-sampling event.

We found a significant linear relationship, as discharge increases, base flow organic nitrogen loading-rates increase (p-value =0.00). Several sites fell outside the 95% simultaneous confidence intervals for expected N loading rates Muddy Creek (site 23) and the mouth of Woodcock Creek (site 49) had organic nitrogen loading rates lower than expected. East Branch of Le Boeuf Creek (site 16) and Federal Run on Muddy Creek (site 27) both had higher than expected organic nitrogen loading rates.

Main-stem French Creek

We found a significant linear relationship, as discharge increases, base flow organic nitrogen loading rates increase (p-value =0.00). Two of the sites fell outside of the 95% simultaneous confidence intervals for TDS loading rates; site 47 at its confluence with Woodcock Creek, and site 78 at Utica both had lower than expected organic nitrogen loading rates.

Nutrient contribution

Next we wanted to determine which sub-basins were contributing the most nutrients per unit area into French Creek. We calculated the rate of nutrient loading rates per day per acre for g/day/acre for eight of the sub-basins by dividing the loading rates at the mouths of each sub-basin by the total area of the sub-basin in acres. To test if sub-basin means were different from the overall mean, we compared 95% confidence intervals. First, we calculated the overall mean and 95% confidence interval (denoted by two numbers in parenthesis following the mean) for each parameter using all the data for each of the 8 sub-basins. If the sub-basin mean did not fall within the overall 95% confidence interval, there is significant difference at the a= 0.05 level (Table 12). These analyses give us a good picture of which sub-basins are outliers compared to what was typically observed for the whole. Because measurements we were unable to take measurements at the mouths during the spring rain event, we were only able to calculate these rates for the base flow and summer rain events. We were unable to calculate these rates for Conneaut and Conneauttee sub-basins, so they were kept out of this analysis.

Two sub-basins stood out with the most nutrient contributions into the system; South Branch French Creek and Little Sugar Creek. South Branch French Creek contributes a significantly high amount of nitrogen and phosphorus, during both the base flow and summer rain events. During the summer, South Branch had a significantly higher contribution of ammonia. South Branch also had high contributions of total dissolved solids, organic nitrogen and kjeldahl nitrogen during the base flow event. Little Sugar Creek had significantly high contributions of phosphorus, ammonia, total dissolved solids, organic nitrogen, kjeldahl nitrogen, and suspended solids during the summer rain event.

Table 12: Nutrient loading rates per unit area (g/day/acre) of 8 sub-basins. Bolded type indicates values significantly higher than the overall mean at the a = 0.05 level.

		Woodcock	Little Sugar	West Branch	Le Boeuf	Muddy	South Branch	Cussewago	Sugar Creek	Mean
N, nitrate + nitrite	Base	0.00132	0.00213	**0.00703**	0.00248	0.00000	**0.00709**	0.00023	**0.00644**	0.003340
(g/day/acre)	Summer	NA	0.02940	0.02232	0.00496	0.00089	**0.04500**	0.00092	0.02909	0.016573
P, total	Base	0.00044	0.00043	0.00041	0.00000	0.00030	**0.00136**	0.00000	0.00054	0.000435
(g/day/acre)	Summer	NA	**0.00554**	0.00124	0.00071	0.00178	**0.00818**	0.00023	0.00188	0.002445
N, kjeldahl	Base	0.00751	0.00426	0.00992	0.00213	0.00207	**0.01364**	0.00069	**0.01314**	0.006670
(g/day/acre)	Summer	NA	**0.07245**	**0.09424**	0.00567	0.01302	0.05482	0.00368	0.02722	0.033888
TDS	Base	1.46182	0.91494	1.76943	0.47204	0.43581	**3.12769**	0.10013	1.49845	1.22254
(g/day/acre)	Summer	NA	**11.7075**	5.70673	1.61564	3.14775	**11.4986**	0.58789	6.98373	5.15599
SS	Base	**0.06095**	0.02685	0.03927	0.01134	0.02308	**0.05209**	0.00414	0.04679	0.033064
(g/day/acre)	Summer	NA	**2.45290**	0.17359	0.12652	0.50002	1.14984	0.02670	0.19399	0.57795
N, ammonia	Base	0.00132	**0.00043**	**0.00083**	**0.00035**	**0.00030**	0.00109	0.00000	0.00094	0.000338
(g/day/acre)	Summer	NA	**0.00554**	0.00248	0.00071	0.00178	**0.00545**	0.00023	0.00389	0.002510
N, organic	Base	0.00442	0.00213	0.00289	-0.00035	0.00207	**0.00655**	0.00046	**0.00670**	0.003109
(g/day/acre)	Summer	NA	**0.04304**	**0.07192**	0.00071	0.01302	0.00982	0.00276	-0.00188	0.017424

Discussion of Results

Even though we did not sample the same sites throughout all three time periods, our analyses show comparatively higher rates of nutrients and pollutants being washed into the system during the spring rain event. Springtime plowing and application of fertilizers to agricultural fields are likely the cause of these increased nutrient levels. Several studies have attributed much of the increased nutrient levels in surface and groundwater to applications of commercial fertilizers, manures or other nutrient sources (Mason et al. 1990, Omernik et al. 1981). In addition, physical alteration to the land surface due to agriculture can also cause detrimental effects on water quality. Plowing exposes unstable topsoil to the effects of weathering, while compaction by grazing animals and machinery may lower infiltration rates, thereby promoting runoff. Furthermore, agricultural land has less developed root systems than forested land, which may lead to a reduced capacity to retain nutrients (Wood 1994).

The only nutrient that had somewhat similar loading rates during the spring and summer rain was nitrogen (nitrate + nitrite). As stated in water quality discussion, acid rain may be a significant source of nitrogen during this time period.

One site on the main-stem of French Creek fell outside of what was expected for nutrient loading rates, site 61 just below Meadville. Meadville is the most heavily populated urban area in the watershed, with approximately 13,000 people. High sediment and nutrient loading may be due to any number of factors associated with an urban environment, such as road runoff, sewage, and industrial discharge.

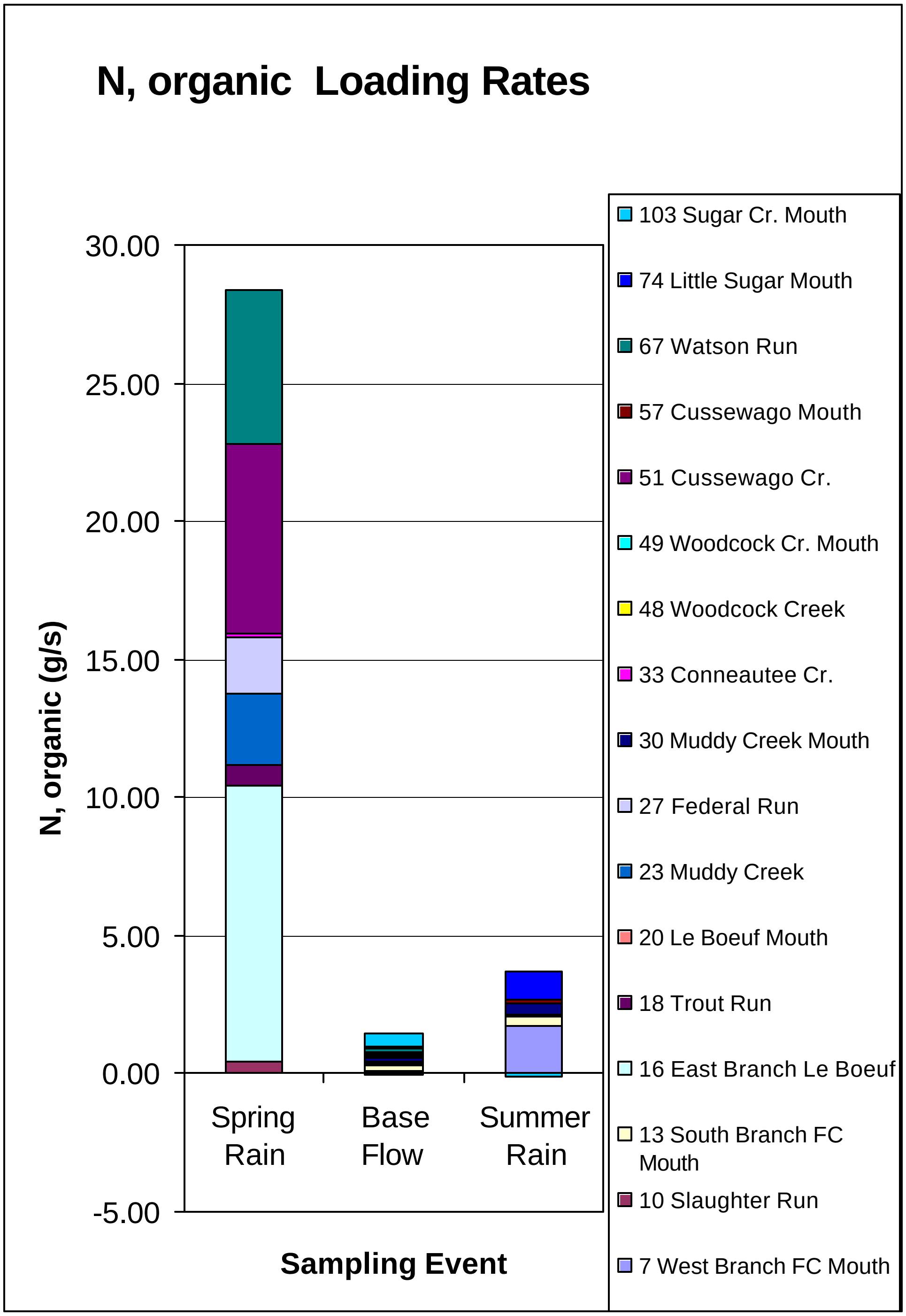

Figure 15: Organic nitrogen loading rates for the 17 sites spread throughout the French Creek sub-basins for three sampling events (N =8 for spring rain, N=17 for base flow, N=7 for summer rain).