Nutrients

The streams of Florida are naturally rich in nutrients (Odum 1953; Omernik 1977; Bass and Cox 1985; Tables 32 and 33). Total phosphorus and total nitrogen concentrations, as well as many other minor nutrients in Florida streams, generally increase from west to east in panhandle Florida and from north to south in peninsular Florida (Bass and Cox 1985), which is similar to the regional patterns of nutrient concentrations in Florida's lakes (Canfield 1981). Spring-fed streams and streams draining geologic formations rich in phosphorus typically have some of the highest natural nutrient concentrations (Odum 1953; Rosenau et al. 1977; Bass and Cox 1985). The regional patterns in nutrient levels and the high concentrations of nutrients in spring-fed streams are determined primarily by changes in geology and physiography (Brooks 1981; Canfield 1981), but other factors, such as the discharge of nutrient-rich water from wastewater treatment plants and agricultural operations, also have contributed to high nutrient concentrations (Bass and Cox 1985).

Total phosphorus concentrations in the upper Little Wekiva River upstream of the discharge of the Altamonte Springs Regional Wastewater Treatment Plant ranged from 0.04 to 0.19 mg/L during 1985 and 1986 (Table 34). Total phosphorus concentrations at Station 3 averaged 0.09 mg/L in 1985 and 0.08 mg/L in 1986, reflecting the eutrophic nature of the stream. Total phosphorus concentrations in the waters discharged from the Altamonte Springs Regional Wastewater Treatment Plant averaged 1.6 mg/L

Table 32. Mean, minimum, and maximum total phosphorus (TP) concentrations measured in all study streams. Sampling periods are given in text and values for the Little Wekiva River are for stations 14 to 25. Mean values include no point-source measurements. Numbers in parentheses are the 95% confidence limits.

	TP (mg/L)		
Stream	Mean	Minimum	Maximum
Little Wekiva	0.36 (± 0.02)	0.19	0.78
Alexander Springs	0.07 (± 0.05)	0.04	0.60
Ichetucknee River	0.06 (± 0.01)	0.04	0.13
Alligator Creek	0.22 (± 0.10)	0.01	0.76
Rock Springs Run	0.08 (± 0.05)	0.05	0.10
Little Econlockhatchee	0.19 (± 0.2)	0.11	0.28
Wacissa River	0.03 (± 0.002)	0.02	0.05
Wekiva River	0.15 (± 0.02)	0.09	0.30
Alafia River	2.8 (± 0.4)	1.5	5.2
Reedy Creek	0.24 (± 0.11)	0.02	0.70
Pottsburg Creek	0.24 (± 0.08)	0.08	0.57
Mills Creek	0.61 (± 0.01)	0.15	0.88
St. Marks River	0.03 (± 0.004)	0.02	0.04
Econlockhatchee	0.10 (± 0.04)	0.03	0.26
Hillsborough River	0.29 (± 0.09)	0.15	0.61
Hogtown Creek	0.50 (± 0.09)	0.31	0.79
Upper Sante Fe River	0.24 (± 0.10)	0.06	0.50

Table 33. Mean, minimum, and maximum total nitrogen (TN) concentrations measured in all study streams. Sampling periods are given in text and values for the Little Wekiva River are for stations 14 to 25. Mean values include no point-source measurements. Numbers in parentheses are the 95% confidence limits.

	TN (mg/L)		
Stream	Mean	Minimum	Maximum
Little Wekiva	1.1 (± 0.1)	0.59	2.0
Alexander Springs	0.34 (± 0.07)	0.07	0.56
Ichetucknee River	0.43 (± 0.08)	0.18	0.96
Alligator Creek	0.80 (± 0.26)	0.15	2.2
Rock Springs Run	1.2 (± 0.2)	0.70	2.0
Little Econlockhatchee	2.0 (± 0.7)	0.52	6.5
Wacissa River	0.28 (± 0.07)	0.12	0.68
Wekiva River	0.92 (± 0.10)	0.44	2.2
Alafia River	1.4 (± 0.3)	0.67	2.8
Reedy Creek	1.8 (± 0.38)	1.2	4.0
Pottsburg Creek	0.74 (± 0.11)	0.35	0.98
Mills Creek	1.4 (± 0.23)	0.86	1.9
St. Marks River	0.36 (± 0.09)	0.24	0.66
Econlockhatchee	1.5 (± 1.0)	0.62	6.5
Hillsborough River	0.83 (± 0.09)	0.64	1.0
Hogtown Creek	0.56 (± 0.04)	0.47	0.66
Upper Sante Fe River	0.93 (± 0.10)	0.59	1.1

Table 34. Mean, minimum, and maximum total phosphorus (TP concentrations for major point-- source discharges and station along the length of the Little Wekiva River during 1985 an 1986. Numbers in parentheses are the 95% confidence limit.

		TP (mg/L)		
Station	Year	Mean	Minimum	Maximum
Lotus Lake	1985	0.08 (± 0.02)	0.04	0.14
	1986	0.05 (± 0.02)	0.04	0.07
2	1985	0.07 (± 0.02)	0.04	0.12
3	1985	0.09 (± 0.03)	0.04	0.19
	1986	0.08 (± 0.05)	0.05	0.15
Altamonte	1985	1.6 (± 0.8)	0.31	3.6
Springs STP	1986	2.5 (± 1.3)	1.4	4.3
6	1985	0.89 (± 0.38)	0.27	2.0
	1986	1.1 (± 1.0)	0.28	2.4
Weathersfield	1985	6.6 (± 0.8)	4.2	8.4
STP	1986	8.5 (± 1.2)	7.2	9.7
8	1985	0.87 (± 0.39)	0.30	2.1
Hi-Acres	1985	0.08 (± 0.03)	0.06	0.25
	1986	0.07 (± 0)	0.07	0.07
10	1985	0.61 (± 0.25)	0.25	1.4
	1986	1.1 (± 0.8)	0.31	1.9
11	1985	0.60 (± 0.22)	0.28	1.1
12	1985	0.59 (± 0.20)	0.23	1.3
	1986	0.84 (± 0.80)	0.32	2.0
Sanlando (13.1)	1985	0.18 (± 0.01)	0.16	0.21
Spring	1986	0.18 (± 0.01)	0.17	0.20
(13.3)	1985	0.18 (± 0.01)	0.16	0.23
	1986	0.17 (± 0.01)	0.16	0.18
Palm Spring	1985	0.13 (± 0.002)	0.12	0.13
	1986	0.13 (± 0.01)	0.12	0.13
Starbuck Spring	1985	0.15 (± 0.004)	0.14	0.16
	1986	0.15 (± 0.01)	0.15	0.16

Table 34. Continued

Station	Year	TP (mg/L) Mean	Minimum	Maximum
14	1985	0.35 (± 0.10)	0.21	0.75
15	1985	0.32 (± 0.08)	0.19	0.64
16	1985	0.35 (± 0.10)	0.20	0.67
	1986	0.38 (± 0.15)	0.25	0.60
17	1985	0.38 (± 0.11)	0.20	0.78
	1986	0.41 (± 0.14)	0.29	0.56
18	1985	0.37 (± 0.11)	0.20	0.77
19	1985	0.38 (± 0.11)	0.21	0.74
20	1985	0.37 (± 0.09)	0.21	0.72
21	1985	0.39 (± 0.11)	0.21	0.72
	1986	0.37 (± 0.14)	0.28	0.54
22	1985	0.36 (± 0.09)	0.20	0.72
23	1985	0.36 (± 0.09)	0.21	0.72
24	1985	0.36 (± 0.09)	0.23	0.71
25	1985	0.38 (± 0.11)	0.22	0.71
	1986	0.34 (± 0.12)	0.23	0.50

during 1985 and 2.5 mg/L in 1986, which substantially raised stream total phosphorus concentrations (Table 34). The Weathersfield Sewage Treatment Plant also discharged waters rich in phosphorus (6.6 mg/L in 1985 and 8.5 mg/L in 1986), but the low volume of discharge from the plant did not significantly change stream total phosphorus concentrations (Table 34). Downstream of the discharge from the Hi-Acres Citrus processing plant, total phosphorus concentrations in the upper Little Wekiva River were generally lower due to dilution. Total phosphorus concentrations in the cooling waters discharged from the Hi-Acres Citrus plant averaged 0.08 mg/L in 1985 and 0.07 mg/L in 1986. Total phosphorus concentrations in the stream, however, remained highly elevated at Station 12, averaging 0.59 mg/L in 1985 and 0.84 mg/L in 1986.

Total phosphorus concentrations in the lower Little Wekiva River downstream of Sanlando Spring, Palm Spring, and Starbuck Spring averaged 0.36 mg/L during 1985 and 1986 (Table 32). The reduction in total phosphorus concentrations below Station 12 was due to the discharge of water from the springs. Although total phosphorus concentrations in the springs were substantially lower than the values measured at Station 12, the springs discharged water rich in phosphorus (Table 34), which is natural for many Florida springs (Rosenau et al. 1977). Total phosphorus concentrations at Sanlando Spring averaged 0.18 mg/L and ranged from 0.16 to 0.23 mg/L (Table 34). Total phosphorus concentrations averaged 0.13 mg/L at Palm Spring and 0.15 mg/L at Starbuck Spring. Average phosphorus concentrations along the length of the lower Little Wekiva River did not change significantly between Station 14 and Station 25 during 1985 and 1986, but total phosphorus concentrations > 0.50 mg/L were measured during periods of high streamflow.

The springs contributed about 14% of the total phosphorus load exported from the Little Wekiva River during 1985 and 1986. The Altamonte Springs Regional Wastewater Treatment Plant (34%), the Weathersfield Sewage Treatment Plant (6%), and the Hi-Acres Citrus processing plant (1%) contributed 41% of the total phosphorus load; thus, the anthropogenic point-source discharges are a major contributor to the nutrient regime of the Little Wekiva River. The relative contribution of nutrients from the major point-sources to the total load of nutrients exported from the Little Wekiva River on any given day ranged from < 10% during periods of high flow to more than 70% during periods of low flow. Similar changes were reported by McClelland (1982).

Total nitrogen concentrations in Lotus Lake during 1985 and 1986 averaged > 0.8 mg/L and ranged from 0.62 to 1.3 mg/L, reflecting the highly eutrophic nature of Lotus Lake (Table 35). Downstream of Lotus Lake, total nitrogen concentrations averaged < 1 mg/L (range 0.57 to 1.3 mg/L) until the discharge from the Altamonte Springs Regional Wastewater Treatment Plant. During 1985, total nitrogen concentrations in the discharged effluent averaged 5.5 mg/L. The average in 1986 was 7.1 mg-N/L. Nitrogen-rich (> 5 mg/L) water was also added to the Little Wekiva River by the Weathersfield Sewage Treatment Plant. The discharge wastewater effluents increased average stream total

Table 35. Mean, minimum and maximum total nitrogen concentrations for major point-source discharges and stations along the length of the Little Wekiva River during 1985 and 1986. Numbers in parentheses are the 95% confidence limit.

Station	Year	Total Nitrogen (mg/L)		
		Mean	Minimum	Maximum
Lotus Lake	1985	0.87 (± 0.14)	0.62	1.3
	1986	1.0 (± 0.3)	0.87	1.2
2	1985	0.85 (± 0.15)	0.57	1.3
3	1985	0.87 (± 0.09)	0.67	1.1
	1986	0.96 (± 0.16)	0.82	1.2
Altamonte	1985	5.5 (± 1.0)	2.8	7.7
Springs STP	1986	7.1 (± 3.6)	3.8	11
6	1985	4.4 (± 1.2)	1.9	8.3
	1986	4.0 (± 2.8)	1.5	7.3
Weathersfield	1985	6.9 (± 1.9)	2.7	13
STP	1986	5.5 (± 3.7)	2.9	11
8	1985	4.5 (± 1.5)	1.8	9.0
Hi-Acres	1985	0.27 (± 0.07)	0.12	0.58
	1986	0.22 (± 0.06)	0.19	0.26
10	1985	3.0 (± 0.9)	1.4	5.7
	1986	3.6 (± 3.1)	1.6	8.2
11	1985	2.7 (± 0.8)	1.3	4.5
12	1985	2.4 (± 0.5)	1.3	4.4
	1986	2.9 (± 1.8)	1.4	5.1
Sanlando (13.1)	1985	0.55 (± 0.09)	0.29	0.86
Springs	1986	0.60 (± 0.18)	0.38	0.81
(13.3)	1985	0.55 (± 0.09)	0.35	0.85
	1986	0.60 (± 0.13)	0.41	0.72
Palm Spring	1985	0.55 (± 0.04)	0.33	0.66
	1986	0.59 (± 0.09)	0.50	0.67
Starbuck Spring	1985	0.37 (± 0.09)	0.19	0.57
	1986	0.56 (± 0.17)	0.34	0.74

Table 35. Continued

Station	Year	Total Nitrogen (mg/L) Mean	Minimum	Maximum
14	1985	1.2 (± 0.2)	0.8	1.6
15	1985	0.97 (± 0.10)	0.78	1.2
16	1985	0.95 (± 0.10)	0.77	1.3
	1986	1.3 (± 0.5)	1.0	2.0
17	1985	0.97 (± 0.15)	0.59	1.4
	1986	1.4 (± 0.2)	1.2	1.7
18	1985	0.99 (± 0.11)	0.67	1.3
19	1985	1.0 (± 0.1)	0.67	1.3
20	1985	1.0 (± 0.1)	0.70	1.3
21	1985	1.1 (± 0.1)	0.80	1.5
	1986	1.3 (± 0.3)	1.0	1.8
22	1985	1.0 (± 0.1)	0.79	1.3
23	1985	1.1 (± 0.1)	0.91	1.3
24	1985	1.2 (± 0.1)	0.95	1.4
25	1985	1.1 (± 0.1)	0.81	1.6
	1986	1.2 (± 0.3)	0.93	1.6

nitrogen concentrations above 3 mg/L (Table 35). Total nitrogen concentrations in the stream, however, decreased after the cooling effluent from the Hi-Acres Citrus processing plant was added to the river. Total nitrogen concentrations in the discharge from Hi-Acres Citrus averaged < 0.3 mg/L during 1985 and 1986. Total nitrogen concentrations at Station 12 averaged 2.4 mg/L in 1985 and 2.9 mg/L in 1986 but ranged from 1.3 mg/L to 5.1 mg/L (Table 35).

Total nitrogen concentrations in the lower Little Wekiva River averaged 1.1 mg/L during 1985 and 1986 (Table 33). Similar to total phosphorus, stream total nitrogen concentrations below Station 12 were reduced because of the influx of large amounts of spring-water. Total nitrogen concentrations in the discharge from Sanlando Spring averaged 0.55 mg/L in 1985 and 0.60 mg/L in 1986. Nearly identical total nitrogen concentrations were measured in the discharge from Palm Spring (Table 35). Starbuck Spring had an average total nitrogen concentration of 0.37 mg/L in 1985 but averaged 0.56 mg/L in 1986. During 1985, average total nitrogen concentrations declined slightly between Station 14 and Station 18 and then increased to 1.1 mg/L between Station 19 and 25 (Table 35). During 1986, no significant changes in total nitrogen concentrations were found along the length of the lower Little Wekiva River.

The discharge of nitrogen-rich wastewater into the upper Little Wekiva River caused not only an increase in stream total nitrogen concentrations but a change in the relative abundance of different forms of nitrogen (Tables 36 and 37). Nitrate

Table 36. Mean, minimum and maximum total nitrate concentrations for major point-source discharges and stations along the length of the Little Wekiva River during 1985 and 1986. Numbers in parentheses are the 95% confidence limit.

Station	Year	Nitrate (mg-N/L) Mean	Minimum	Maximum
Lotus Lake	1985	0.02 (± 0.02)	0	0.05
	1986	0.13 (± 0.17)	0	0.27
2	1985	0.03 (± 0.01)	0	0.06
3	1985	0.18 (± 0.09)	0	0.50
	1986	0.20 (± 0.19)	0	0.43
Altamonte Springs STP	1985	4.4 (± 1.1)	1.7	6.9
	1986	4.2 (± 3.3)	1.1	7.9
6	1985	3.3 (± 1.3)	0.88	7.6
	1986	1.9 (± 1.8)	0.64	4.3
Weathersfield STP	1985	5.6 (± 1.9)	2.0	11
	1986	2.5 (± 4.1)	0.47	8.9
8	1985	3.4 (± 1.5)	0.84	8.3
Hi-Acres	1985	0.04 (± 0.02)	0	0.15
	1986	0.01 (± 0.02)	0	0.02
10	1985	2.2 (± 0.9)	0.55	5.1
	1986	1.5 (± 1.1)	0.58	3.0
11	1985	2.1 (± 0.9)	0.61	4.1
12	1985	1.7 (± 0.6)	0.47	3.9
	1986	1.6 (± 1.2)	0.51	3.0
Sanlando (13.1) Springs	1985	0.30 (± 0.08)	0.16	0.55
	1986	0.34 (± 0.10)	0.23	0.43
(13.3)	1985	0.30 (± 0.08)	0.15	0.46
	1986	0.35 (± 0.10)	0.22	0.43
Palm Spring	1985	0.39 (± 0.06)	0.26	0.50
	1986	0.45 (± 0.07)	0.36	0.51
Starbuck Spring	1985	0.23 (± 0.08)	0.10	0.42
	1986	0.35 (± 0.11)	0.19	0.44

Table 36. Continued

Station	Year	Nitrate (mg-N/L) Mean	Minimum	Maximum
14	1985	0.88 (± 0.17)	0.46	1.3
15	1985	0.64 (± 0.11)	0.36	0.96
16	1985	0.67 (± 0.11)	0.43	0.98
	1986	0.82 (± 0.40)	0.49	1.4
17	1985	0.63 (± 0.14)	0.25	1.1
	1986	0.86 (± 0.25)	0.68	1.2
18	1985	0.65 (± 0.09)	0.44	0.92
19	1985	0.67 (± 0.10)	0.43	0.98
20	1985	0.66 (± 0.13)	0.36	1.1
21	1985	0.68 (± 0.14)	0.29	1.1
	1986	0.66 (± 0.34)	0.29	1.0
22	1985	0.64 (± 0.14)	0.22	1.0
23	1985	0.64 (± 0.14)	0.21	1.0
24	1985	0.65 (± 0.16)	0.20	1.1
25	1985	0.73 (± 0.18)	0.20	1.2
	1986	0.63 (± 0.34)	0.20	0.94

Table 37. Mean, minimum, and maximum total kjeldahl nitrogen (TKN) concentrations for major point-source discharges and stations along the length of the Little Wekiva River during 1985 and 1986. Numbers in parentheses are the 95% confidence limit.

Station	Year	TKN (mg-N/L) Mean	Minimum	Maximum
Lotus Lake	1985	0.85 (± 0.15)	0.60	1.3
	1986	0.88 (± 0.16)	0.76	1.0
2	1985	0.82 (± 0.15)	0.54	1.2
3	1985	0.69 (± 0.11)	0.44	1.0
	1986	0.76 (± 0.18)	0.54	0.97
Altamonte Springs STP	1985	1.1 (± 0.4)	0.65	2.8
	1986	2.9 (± 4.6)	0.89	10
6	1985	1.1 (± 0.4)	0.65	2.7
	1986	2.1 (± 2.8)	0.86	6.4
Weathersfield STP	1985	1.3 (± 0.2)	0.71	1.7
	1986	2.9 (± 1.0)	2.2	4.0
8	1985	1.0 (± 0.3)	0.66	2.4
Hi-Acres	1985	0.24 (± 0.05)	0.12	0.43
	1986	0.21 (± 0.04)	0.19	0.24
10	1985	0.83 (± 0.33)	0.45	2.3
	1986	2.1 (± 3.0)	0.70	6.8
11	1985	0.65 (± 0.19)	0.40	1.3
12	1985	0.65 (± 0.13)	0.39	1.1
	1986	1.4 (± 1.3)	0.54	3.4
Sanlando Springs (13.1)	1985	0.25 (± 0.03)	0.13	0.31
	1986	0.26 (± 0.09)	0.15	0.38
(13.3)	1985	0.25 (± 0.03)	0.19	0.39
	1986	0.25 (± 0.05)	0.19	0.31
Palm Spring	1985	0.16 (± 0.05)	0.07	0.34
	1986	0.14 (± 0.04)	0.08	0.18
Starbuck Spring	1985	0.14 (± 0.03)	0.04	0.22
	1986	0.21 (± 0.09)	0.15	0.35

Table 37. Continued

Station	Year	TKN (mg-N/L) Mean	Minimum	Maximum
14	1985	0.34 (± 0.08)	0.19	0.55
15	1985	0.35 (± 0.09)	0.14	0.50
16	1985	0.28 (± 0.07)	0.13	0.48
	1986	0.44 (± 0.14)	0.25	0.56
17	1985	0.35 (± 0.06)	0.24	0.58
	1986	0.51 (± 0.12)	0.34	0.63
18	1985	0.34 (± 0.08)	0.18	0.51
19	1985	0.35 (± 0.07)	0.20	0.60
20	1985	0.38 (± 0.08)	0.22	0.62
21	1985	0.38 (± 0.07)	0.24	0.65
	1986	0.61 (± 0.19)	0.35	0.76
22	1985	0.37 (± 0.09)	0.24	0.66
23	1985	0.43 (± 0.10)	0.28	0.78
24	1985	0.49 (± 0.13)	0.29	0.91
25	1985	0.40 (± 0.09)	0.23	0.69
	1986	0.60 (± 0.18)	0.34	0.73

concentrations in the upper Little Wekiva River averaged < 0.25 mg-N/L and constituted < 25% of the total nitrogen in the stream upstream of the Altamonte Springs Regional Wastewater Treatment Plant. The regional wastewater treatment plant discharged effluent with an average nitrate concentration of 4.4 mg-N/L during 1985 and 1986. Nitrate constituted over 55% of the total nitrogen in the effluent during 1985 (80%) and 1986 (59%). Nitrate concentrations averaged 1.7 mg-N/L at Station 12, and nitrate constituted over 50% of the total nitrogen exported to the lower Little Wekiva River. Nitrate concentrations in Sanlando Spring, Palm Spring, and Starbuck Spring ranged from 0.10 to 0.55 mg-N/L (Table 36). Nitrate generally represented over 55% of the total nitrogen discharged from the springs. Nitrate concentrations at Station 25 averaged 0.73 mg-N/L during 1985 and 0.63 mg-N/L in 1986 but still constituted over 50% of the total nitrogen leaving the Little Wekiva River.

Total iron concentrations in the upper Little Wekiva River ranged from 0.04 to 0.21 mg/L (Table 38). Total iron concentrations in the river increased downstream of the Altamonte Springs Regional Wastewater Treatment Plant, averaging 0.30 mg/L in 1985 and 0.20 mg/L in 1986. Total iron concentrations in the effluent from the regional wastewater treatment plant averaged 0.40 mg/L in 1985 but only 0.22 mg/L in 1986. The Hi-Acres Citrus processing plant discharged water with a total iron concentration < 0.04 mg/L, which caused a general reduction in total iron concentrations in the stream. Total iron concentrations at Station 10 averaged 0.18 mg/L in 1985 and 0.17

Table 38. Mean, minimum, and maximum total iron concentrations for major point-source discharges and stations along the length of the Little Wekiva River during 1985 and 1986. Numbers in parentheses are the 95% confidence limit.

Station	Year	Iron (mg/L) Mean	Minimum	Maximum
Lotus Lake	1985	0.10 (± 0.02)	0.04	0.16
	1986	0.15 (± 0.05)	0.10	0.18
2	1985	0.08 (± 0.02)	0.04	0.19
3	1985	0.12 (± 0.02)	0.06	0.20
	1986	0.16 (± 0.05)	0.08	0.21
Altamonte Springs STP	1985	0.40 (± 0.08)	0.20	0.58
	1986	0.22 (± 0.08)	0.16	0.34
6	1985	0.30 (± 0.09)	0.14	0.55
	1986	0.20 (± 0.05)	0.16	0.24
Weathersfield STP	1985	0.12 (± 0.04)	0.05	0.32
	1986	0.08 (± 0.03)	0.04	0.12
8	1985	0.27 (± 0.07)	0.14	0.45
High-Acres	1985	0.03 (± 0.02)	0.01	0.14
	1986	0.02 (± 0.02)	0.01	0.03
10	1985	0.18 (± 0.04)	0.11	0.31
	1986	0.17 (± 0.05)	0.11	0.22
11	1985	0.18 (± 0.04)	0.10	0.28
12	1985	0.19 (± 0.03)	0.13	0.32
	1986	0.30 (± 0.26)	0.12	0.70
Sanlando (13.1) Spring	1985	0.01 (± 0.01)	0	0.02
	1986	0.01 (± 0)	0	0.01
(13.3)	1985	0.01 (± 0.01)	0	0.03
	1986	0.02 (± 0.02)	0.01	0.04
Palm Spring	1985	0 (± 0)	0	0.01
	1986	0 (± 0)	0	0.01
Starbuck Spring	1985	0.01 (± 0.01)	0	0.02
	1986	0.15 (± 0.01)	0.15	0.16

Table 38. Continued

Station	Year	Iron (mg/L) Mean	Minimum	Maximum
14	1985	0.06 (± 0.02)	0.03	0.11
15	1985	0.06 (± 0.03)	0.02	0.16
16	1985	0.04 (± 0.02)	0.01	0.11
	1986	0.07 (± 0.05)	0.03	0.14
17	1985	0.05 (± 0.02)	0.02	0.11
	1986	0.07 (± 0.05)	0.03	0.14
18	1985	0.05 (± 0.02)	0.01	0.14
19	1985	0.05 (± 0.02)	0.02	0.11
20	1985	0.06 (± 0.02)	0.03	0.12
21	1985	0.06 (± 0.02)	0.03	0.16
	1986	0.10 (± 0.06)	0.03	0.18
22	1985	0.06 (± 0.02)	0.02	0.18
23	1985	0.08 (± 0.04)	0.03	0.23
24	1985	0.09 (± 0.04)	0.03	0.21
25	1985	0.07 (± 0.04)	0.02	0.21
	1986	0.11 (± 0.07)	0.03	0.20

mg/L in 1986. The reductions in iron, however, were less during periods of high stream flow. Although there was no significant difference between the average total iron concentrations measured at Station 10 and Station 12, total iron concentrations at Station 12 were extremely variable during 1986 and ranged as high as 0.70 mg/L (Table 38). The reason or reasons for these changes are unknown.

Sanlando Spring, Palm Spring, and Starbuck Spring generally discharged water with an average total iron concentration < 0.03 mg/L (Table 38). Starbuck Spring, however, discharged water with an average total iron concentration of 0.15 mg/L in 1986. The cause or causes of the elevated iron concentrations are unknown, but it corresponds with a major increase in average spring flow (Table 4). Downstream of the springs, total iron concentrations in the lower Little Wekiva River averaged < 0.10 mg/L between Station 14 and Station 21 (Table 38). Slightly higher concentrations were measured downstream of Station 21, but the increases seem to be related in part to the increase in stream color. Total iron concentrations are directly correlated with color concentrations (Kaufman 1975; Canfield et al. 1984).

Silica concentrations in the upper Little Wekiva River were increased significantly during 1985 and 1986 by discharges from the Altamonte Springs Regional Wastewater Treatment Plant, the Weathersfield Sewage Treatment Plant, and the Hi-Acres Citrus processing plant (Table 39). Silica concentrations in the Little Wekiva River between Lotus Lake and the discharge from the Altamonte Springs Regional Wastewater Treatment Plant averaged <

Table 39. Mean, minimum, and maximum silica concentrations for major point-source discharges and stations along the length of the Little Wekiva River during 1985 and 1986. Numbers in parentheses are the 95% confidence limit.

Station	Year	Silica (mg/L) Mean	Minimum	Maximum
Lotus Lake	1985	1.4 (± 0.7)	0.1	3.1
	1986	1.8 (± 0.9)	1.3	2.6
2	1985	1.5 (± 0.5)	0.4	3.1
3	1985	2.5 (± 0.5)	1.3	3.7
	1986	2.0 (± 0.3)	1.6	2.3
Altamonte Spring STP	1985	12 (± 1)	10	12
	1986	12 (± 1)	11	12
6	1985	8.3 (± 1.5)	4.0	11
	1986	5.7 (± 2.3)	3.4	7.7
Weatherfield STP	1985	11 (± 1)	8.9	14
	1986	13 (± 2)	12	15
8	1985	8.4 (± 1.6)	4.0	11
Hi-Acres	1985	9.5 (± 0.2)	8.7	9.9
	1986	9.9 (± 0.3)	9.7	10
10	1985	8.5 (± 1.3)	4.6	10
	1986	6.3 (± 2.2)	3.9	8.2
11	1985	8.3 (± 1.4)	4.1	11
12	1985	7.9 (± 1.1)	4.5	10
	1986	6.0 (± 2.3)	3.6	8.6
Sanlando (13.1) Spring	1985	8.5 (± 0.1)	8.2	8.8
	1986	8.8 (± 0.5)	8.3	9.4
(13.1)	1985	8.5 (± 0.1)	8.3	8.8
	1986	9.0 (± 1.4)	8.0	11
Palm Spring	1985	9.0 (± 0.2)	8.6	9.4
	1986	9.3 (± 0.7)	8.7	10
Starbuck Spring	1985	9.0 (± 0.2)	8.5	9.5
	1986	9.2 (± 0.6)	8.7	10

Table 39. Continued

Station	Year	Silica (mg/L) Mean	Minimum	Maximum
14	1985	8.3 (± 0.8)	5.8	9.3
15	1985	8.1 (± 0.8)	5.7	9.4
16	1985	8.2 (± 0.7)	5.7	9.2
	1986	7.8 (± 1.3)	5.8	8.6
17	1985	8.2 (± 0.6)	6.2	9.2
	1986	7.3 (± 1.6)	4.8	8.2
18	1985	8.2 (± 0.6)	6.0	9.3
19	1985	7.9 (± 1.1)	3.6	9.4
20	1985	8.1 (± 0.6)	6.1	9.4
21	1985	8.1 (± 0.6)	6.5	9.2
	1986	7.0 (± 1.4)	4.9	8.1
22	1985	8.0 (± 0.6)	6.6	9.2
23	1985	7.9 (± 0.6)	6.3	9.4
24	1985	8.0 (± 0.6)	6.6	9.4
25	1985	8.0 (± 0.6)	6.4	9.3
	1986	7.0 (± 1.4)	4.9	7.8

3 mg/L but increased to ≥ 6 mg/L downstream of the Hi-Acres Citrus processing plant. Silica concentrations in the stream were further increased by discharges from Sanlando Spring, Palm Spring, and Starbuck Spring (Table 39). Silica concentrations in the springs ranged from 8 to 10 mg/L. Downstream of the springs, silica concentrations generally averaged about 8 mg/L, with lower values occurring during periods of high stream flow.

Effects on Downstream Water Bodies

The United States Geological Survey (U.S.G.S.) has monitored streamflow in the Wekiva River at State Highway 46 (U.S.G.S. Station 02235000) for over 50 years (U.S.G.S. 1985, 1986, 1987). The site is 7.2 km downstream of the Little Wekiva River and 10.8 km upstream of the Wekiva River's confluence with the St. Johns River. Stream discharge over the period of record averaged 8.1 m^3/s. The maximum recorded stream discharge was 58.3 m^3/s (September 17, 1945), and the minimum discharge was 2.97 m^3/s (June 5-13, 1939). During 1985 and 1986, stream discharge averaged 7.7 and 6.8 m^3/s, respectively. The maximum discharge recorded in 1985 was 21 m^3/s, and the minimum discharge was 6.2 m^3/s. Maximum streamflow in 1986 was 27 m^3/s, and the minimum recorded streamflow was 5.7 m^3/s. The Little Wekiva River had an average discharge of 3.2 m^3/s in 1985 and 4.4 m^3/s in 1986 (Table 4). Thus, water from the Little Wekiva River constituted a significant amount of the streamflow in the Wekiva River at the State Highway 46 bridge.

Discharges from the Little Wekiva River did not significantly affect water temperatures in the Wekiva River during 1985 and 1986 (Table 40). Water temperatures in the Wekiva River below Rock Springs Run (Station 1) averaged 22 ^{o}C. Downstream of the confluence with the Little Wekiva River (Station 3), water temperatures averaged 21 ^{o}C, but averaged 22 ^{o}C at Katie's Landing (Station 4). Temperatures in the Wekiva River were lower (mean 20 ^{o}C) just upstream of the confluence with the St. Johns River (Station 5). Water temperatures were cooler primarily because the lower Wekiva River was heavily shaded by streambank vegetation. Discharges from the Wekiva River, however, did not affect temperatures in the St. Johns River (Table 40).

Dissolved oxygen concentrations in the Wekiva River, downstream of Rock Springs Run, averaged 5.5 mg/L (Table 40). Upstream of the confluence with the Little Wekiva River, the Wekiva River flowed through an area supporting abundant growths of aquatic plants. Dissolved oxygen concentrations were increased and averaged 6.2 mg/L just upstream of the Little Wekiva River. Discharges of water low in oxygen from the Little Wekiva River caused dissolved oxygen concentrations in the Wekiva River to decline, and oxygen concentrations at Station 3 averaged 5.5 mg/L. Further downstream, the Wekiva River widened significantly, and abundant growths of aquatic plants occurred in the river. Dissolved oxygen concentrations downstream of the aquatic plants at Katie's Landing averaged 8.9 mg/L during the day. Below Katie's Landing, the Wekiva River narrowed and submerged aquatic plants virtually disappeared. The Wekiva River

Table 40. Mean water chemistry values for different stations along the Wekiva and St. Johns Rivers. The Little Wekiva River discharges into the Wekiva River between stations 2 and 3. See Table 2 for the location of each sampling station.

Parameter		Wekiva River 1	Wekiva River 2	Wekiva River 3	Wekiva River 4	Wekiva River 5	Wekiva Falls	St. Johns 1	St. Johns 2
Temperature (°C)	Mean	22	22	21	22	20	22	22	22
	CL	± 2	± 2	± 2	± 3	± 3	± 1	± 4	± 4
	Range	20-24	19-24	19-24	19-26	18-24	21-23	18-28	18-28
Dissolved Oxygen (mg/L)	Mean	5.5	6.2	5.5	8.9	5.6	6.3	7.5	7.2
	CL	± 1.0	± 1.4	± 1.2	± 2.3	± 1.2	± 0.5	± 1.7	± 1.4
	Range	4.5-7.1	4.5-8.3	3.8-7.4	5.8-12	4.1-7.0	5.7-6.8	4.9-9.2	5.1-9.2
pH	Mean	7.8	7.8	7.6	7.9	7.5	7.9	8.1	7.6
	CL	± 0.2	± 0.4	± 0.2	± 0.4	± 0.2	± 0.1	± 0.7	± 0.2
	Range	7.3-8.1	7.3-8.8	7.1-7.8	7.5-8.5	7.2-7.7	7.8-8.0	7.4-9.5	7.4-7.9
Total Alkalinity (mg/L as $CaCO_3$)	Mean	92	92	90	92	86	105	63	68
	CL	± 7	± 5	± 10	± 10	± 12	± 3	± 14	± 18
	Range	79-101	81-99	70-101	75-101	69-99	100-107	37-79	46-97
Specific Conductance (µS/cm @ 25 °C)	Mean	287	302	355	571	700	1460	996	812
	CL	± 25	± 27	± 124	± 91	± 60	± 60	± 352	± 198
	Range	265-357	270-343	284-728	466-728	627-790	1385-1525	578-1680	582-1100
Total Suspended Solids (mg/L)	Mean	2.8	3.0	3.7	4.8	4.4	1.4	9.9	9.0
	CL	± 2.0	± 1.1	± 1.9	± 2.1	± 3.6	± 1.6	± 7.3	± 11
	Range	1.4-8.6	1.4-5.5	1.8-8.4	2.3-7.4	1.2-9.3	0.4-4.6	3.0-27	3.3-31
Organic Suspended Solids (mg/L)	Mean	1.8	2.0	2.3	2.9	2.8	0.4	6.4	6.1
	CL	± 1.2	± 0.7	± 1.3	± 1.4	± 2.2	± 0.4	± 6.2	± 8.9
	Range	0.9-5.4	1.0-3.8	1.1-5.6	1.3-4.8	0.9-6.0	0-1.0	1.3-21	1.4-24

Table 40. Continued

Parameter		Wekiva River 1	Wekiva River 2	Wekiva River 3	Wekiva River 4	Wekiva River 5	Wekiva Falls	St. Johns 1	St. Johns 2
Inorganic Suspended Solids (mg/L)	Mean	1.0	1.0	1.4	2.0	1.6	0.9	3.5	3.0
	CL	± 0.8	± 0.4	± 0.6	± 0.7	± 1.4	± 1.3	± 1.2	± 2.2
	Range	0.3-3.2	0.4-1.7	0.6-2.8	1.0-2.6	0.3-3.5	0.1-3.6	1.7-6	1.7-7.3
Total Phosphorus (mg/L)	Mean	0.10	0.14	0.20	0.18	0.14	0.04	0.11	0.12
	CL	± 0.01	± 0.05	± 0.05	± 0.4	± 0.02	± 0.01	± 0.02	± 0.02
	Range	0.09-0.10	0.11-0.29	0.14-0.30	0.14-0.25	0.11-0.16	0.03-0.06	0.06-0.16	0.03-0.10
Total Nitrogen (mg/L)	Mean	1.0	1.0	0.94	0.82	0.75	0.26	1.4	1.3
	CL	± 0.2	± 0.4	± 0.20	± 0.19	± 0.2	± 0.16	± 0.2	± 0.39
	Range	0.8-1.4	0.7-2.2	0.66-1.4	0.58-1.1	0.44-0.97	0.09-0.64	1.0-1.9	0.48-0.83
Chlorophyll *a* (mg/m^3)	Mean	1.1	1.5	1.0	2.0	1.7	0.9	46	33
	CL	± 0.4	± 0.6	± 0.2	± 0.9	± 1.4	± 0.3	± 26	± 26
	Range	0.6-2.2	0.7-3.1	0.6-1.3	1.0-3.4	0.7-4.2	0.3-1.4	2.5-94	2.6-94
Color (Pt-Co units)	Mean	60	60	75	50	70	5	115	120
	CL	± 85	± 65	± 80	± 40	± 40	± 5	± 55	± 40
	Range	5-300	10-250	15-300	15-110	30-125	0-20	45-225	70-200
Current Velocity (m/s)	Mean	0.23	0.18	0.23	0.22	0.16	0.21	0.09	0.12
	CL	± 0.06	± 0.05	± 0.05	± 0.7	± 0.06	± 0.02	± 0.02	± 0.04
	Range	0.15-0.41	0.10-0.26	0.11-0.29	0.12-0.31	0.06-0.23	0.18-0.24	0.07-0.11	0.08-0.2

also received water that had drained through extensive swampy areas, which caused dissolved oxygen concentrations in the lower Wekiva River to decline, averaging only 5.6 mg/L just above its confluence with the St. Johns River (Table 40).

The total alkalinity and pH of the Wekiva River were not significantly changed by the waters discharged from the Little Wekiva River, but slightly lower total alkalinity and pH values were measured at the mouth of the Wekiva River due to the influx of waters draining extensive swamp forests (Table 40). The average specific conductance of the Wekiva River, however, increased significantly from its headwaters to its confluence with the St. Johns River (Table 40). Specific conductance values just downstream of Rock Springs Run averaged 287 µS/cm @ 25 ^{o}C. Downstream of the Little Wekiva River, specific conductance values averaged 355 µS/cm @ 25 ^{o}C at Station 3. The higher average specific conductance of the Wekiva River at Station 3, however, can not be attributed to discharges from Little Wekiva River. The specific conductance of the water discharged from the Little Wekiva River never exceeded 345 µS/cm @ 25 ^{o}C. The maximum specific conductance value measured at Station 3 was 728 µS/cm @ 25 ^{o}C. This suggests that mineral-rich groundwater enters the Wekiva River just downstream of the confluence with the Little Wekiva River. Wekiva Falls and several springs between Station 3 and Station 4 discharge water to the Wekiva River. The specific conductance of the waters leaving Wekiva Falls was > 1000 µS/cm @ 25 ^{o}C during 1985 and 1986. Specific conductance values averaged 571 µS/cm @ 25 ^{o}C at Katie's Landing but increased to 700 µS/cm @ 25 °C at the river's confluence with the St. Johns River (Table 40). The increase in total salinity was caused primarily by discharges of saline ground water. The total salinity of the Wekiva River, however, was significantly lower than the salinity of the St. Johns River, and discharges from the Wekiva River caused average specific conductance values in the St. Johns River to be slightly lower (996 vs. 812 µS/cm @ 25 °C) downstream of the Wekiva River.

Average concentrations of total, organic, and inorganic suspended solids in the Wekiva River were not significantly affected by discharges from the Little Wekiva River, but suspended solids concentrations tended to be greater in the lower Wekiva River (Table 40). The tendency for higher suspended solids concentrations in the lower Wekiva River may be due to a greater abundance of easily resuspended sediments. During the course of this study, it was observed that increased streamflow, boat traffic, and strong winds often caused the waters to become turbid. Total suspended solids concentrations > 5 mg/L, however, were measured at all sampling stations. Higher suspended solids concentrations were primarily associated with increased streamflow during periods of wet weather. The waters from Wekiva Falls had an average total suspended solids concentration of 1.4 mg/L; thus, the water from Wekiva Falls is not an important source of suspended solids in the lower Wekiva River.

Average color concentrations along the length of the Wekiva River ranged between 50 and 75 Pt-Co units (Table 40). Discharges from the Little Wekiva River had no significant impact on water color in the Wekiva River. The primary factor regulating color levels was runoff. Color concentrations were typically < 30 Pt-Co units during periods of low rainfall, and waters in the Wekiva River appeared very clear. Following heavy rains, stream color concentrations typically exceeded 100 Pt-Co units, and the Wekiva River became noticeably stained.

Total nitrogen concentrations in the Wekiva River, upstream of the Little Wekiva River, averaged 1 mg/L (Table 40). The high nitrogen concentrations were due in part to nitrogen-rich discharges (average 1.2 mg/L) from Rock Springs Run (Table 33). Total nitrogen concentrations in the Little Wekiva River averaged 1.1 mg/L in 1985 and 1.2 mg/l in 1986. Consequently, the Little Wekiva River had little impact on stream nitrogen concentrations in the Wekiva River. Total nitrogen concentrations in the Wekiva River also declined downstream of the Little Wekiva River and averaged 0.75 mg/L at the confluence with the St. Johns River (Table 40). The declines in nitrogen concentrations seemed to be due primarily to dilution by groundwaters low in nitrogen. For example, Wekiva Falls discharged water with an average total nitrogen concentration of 0.26 mg/L (Table 40).

Total phosphorus concentrations in the Wekiva River, downstream of Rock Springs Run, averaged 0.10 mg/L but increased to 0.14 mg/L just upstream of the confluence with the Little Wekiva River (Table 40). Discharges from the Little Wekiva River caused stream phosphorus concentrations to increase further. Total phosphorus concentrations at Station 3 averaged 0.20 mg/L, but total phosphorus concentrations, like total nitrogen concentrations, declined further downstream due to an influx of groundwaters with lower phosphorus concentrations (e.g., Wekiva Falls; mean TP = 0.04 mg/L; Table 40). Total phosphorus concentrations at the confluence with the St. Johns River averaged 0.14 mg/L. Total phosphorus concentrations in the St. Johns River upstream and downstream of the Wekiva River, however, were not significantly different (Table 40).

AQUATIC PLANTS

Excessive growths of aquatic plants in lakes and streams have been linked to increased nutrient inputs from various anthropogenic sources (National Academy of Sciences 1969; Dillon and Rigler 1974; Jones and Bachmann 1976; Wong and Clark 1976; Canfield 1983; Mace et al. 1984; Wright and McDonnell 1986a, 1986b). Because whole-lake experiments demonstrated that algal concentrations responded strongly to the addition or removal of nutrients in some lakes (Schindler et al. 1973; Schindler 1975), nutrient control programs were established at many water bodies to reduce the influx of nutrients. Although the control of nutrients has reduced excessive growths of aquatic plants in some lakes, critical nutrient concentrations for streams have not been established. Consequently, the efficacy of nutrient removal for the control of aquatic plants in streams is unknown. The ability of nutrient control programs to reduce the abundance of plants in flowing waters has also been questioned because physical factors such as current, hydrology, and light availability, rather than nutrients, are often the factors limiting aquatic plants (Kofoid 1903; Rheinhard 1931; Odum 1957; Swanson and Bachmann 1976).

Suspended Algae

Lotus Lake, an eutrophic lake, supported abundant growths of viable suspended algae (phytoplankton) during 1985 and 1986 (Tables 41 and 42). Chlorophyll a concentrations (an index of algal biomass) ranged from 16.8 to 35.1 mg/m^3. Downstream of

Table 41. **Mean,** minimum, **and maximum chlorophyll *a* concentrations for major** point-source **discharges and stations along the length of the** Little **Wekiva River during 1985 and 1986. Numbers in parentheses are the 95% confidence limit.**

Station	Year	Chlorophyll a (mg/m^3) Mean	Minimum	Maximum
Lotus Lake	1985	26.2 (± 5.5)	16.8	34.6
	1986	24.9 (± 10.5)	17.4	35.1
2	1985	11.0 (± 5.5)	3.6	26.6
3	1985	3.8 (± 1.6)	1.3	10.1
	1986	5.3 (± 3.9)	1.8	9.8
Altamonte Springs STP	1985	1.4 (± 0.6)	0.1	3.3
	1986	2.2 (± 2.2)	0.9	5.4
6	1985	2.2 (± 0.8)	1.1	4.6
	1986	4.1 (± 2.7)	1.3	6.4
Weathersfield STP	1985	29.4 (± 25.6)	1.9	126
	1986	42.0 (± 24.6)	9.0	65.4
8	1985	2.9 (± 1.2)	1.2	6.7
Hi-Acres	1985	0.5 (± 0.4)	0	2.3
	1986	0.4 (± 0.5)	0.1	0.6
10	1985	2.3 (± 1.5)	0.6	8.3
	1986	3.9 (± 2.4)	1.6	5.8
11	1985	1.8 (± 1.1)	0.6	6.4
12	1985	2.1 (± 1.1)	0.6	7.0
	1986	3.6 (± 1.8)	1.9	5.9
Sanlando Spring (13.1)	1985	2.5 (± 1.4)	0.7	7.5
	1986	0.9 (± 0.2)	0.7	1.1
(13.3)	1985	2.0 (± 1.1)	0.5	5.3
	1986	1.1 (± 0.4)	0.8	1.6
Palm Spring	1985	0.4 (± 0.3)	0.1	1.8
	1986	0.3 (± 0.3)	0	0.6
Starbuck Spring	1985	1.7 (± 0.8)	0.1	9.3
	1986	1.4 (± 1.7)	0.3	4.0

Table 41. Continued

		Chlorophyll a (mg/m^3)		
Station	Year	Mean	Minimum	Maximum
14	1985	1.5 (± 0.7)	0.6	4.2
15	1985	1.2 (± 0.4)	0.5	2.4
16	1985	1.1 (± 0.4)	0.5	2.6
	1986	1.2 (± 0.4)	0.7	1.7
17	1985	1.4 (± 0.4)	0.6	2.6
	1986	1.7 (± 0.6)	0.9	2.4
18	1985	1.5 (± 0.6)	0.6	3.4
19	1985	0.9 (± 0.2)	0.5	1.8
20	1985	0.9 (± 0.2)	0.3	1.6
21	1985	0.8 (± 0.2)	0.2	1.3
	1986	1.2 (± 0.4)	0.8	1.7
22	1985	1.0 (± 0.3)	0.4	1.6
23	1985	1.4 (± 0.4)	0.6	2.3
24	1986	1.5 (± 0.4)	0.6	2.6
25	1985	0.9 (± 0.2)	0.5	1.4
	1986	1.1 (± 0.5)	0.4	1.5

Table 42. Mean, minimum, and maximum phaeophytin concentrations for major point-source discharges and stations along the length of the Little Wekiva River during 1985 and 1986. Numbers in parentheses are the 95% confidence limit.

Station	Year	Phaeophytin (mg/m^3) Mean	Minimum	Maximum
Lotus Lake	1985	5.7 (± 1.8)	1.6	8.9
	1986	7.7 (± 5.1)	4.4	13
2	1985	5.7 (± 1.8)	2.3	9.3
3	1985	2.2 (± 0.8)	0.5	4.6
	1986	2.3 (± 2.0)	0.3	5.0
Altamonte Springs STP	1985	0.1 (± 0.1)	0	0.4
	1986	0.1 (± 0.3)	0	0.5
6	1985	0.5 (± 0.4)	0	1.6
	1986	1.2 (± 1.1)	0	2.3
Weathersfield STP	1985	3.5 (± 3.1)	0	12
	1986	2.1 (± 2.3)	0	5.4
8	1985	0.9 (± 0.6)	0	2.4
Hi-Acres	1985	0.2 (± 0.1)	0	1.5
	1986	0 (± 0)	0	0
10	1985	0.4 (± 0.3)	0	1.4
	1986	1.2 (± 0.8)	0.4	2.1
11	1985	0.6 (± 0.4)	0	1.9
12	1985	0.6 (± 0.4)	0	1.5
	1986	1.1 (± 1.5)	0	3.1
Sanlando (13.1) Spring	1985	1.6 (± 1.4)	0	6.8
	1986	0.3 (± 0.4)	0	0.9
(13.3)	1985	1.2 (± 0.8)	0	3.6
	1986	0.2 (± 0.3)	0	0.7
Palm Spring	1985	0 (± 0)	0	0
	1986	0 (± 0.1)	0	0.2
Starbuck Spring	1985	0.6 (± 0.8)	0	4.6
	1986	0.3 (± 0.5)	0	1.0
14	1985	0.5 (± 0.3)	0	1.1

Table 42. Continued

Station	Year	Phaeophytin (mg/m^3) Mean	Minimum	Maximum
15	1985	0.4 (± 0.2)	0	0.9
16	1985	0.4 (± 0.2)	0	1.0
	1986	0.5 (± 0.4)	0.1	1.1
17	1985	0.4 (± 0.2)	0	0.8
	1986	0.6 (± 0.5)	0	1.2
18	1985	0.6 (± 0.4)	0	2.1
19	1985	0.3 (± 0.1)	0	0.7
20	1985	0.3 (± 0.2)	0	0.8
21	1985	0.3 (± 0.2)	0	0.7
	1986	0.4 (± 0.5)	0	1.0
22	1985	0.5 (± 0.2)	0	0.8
23	1985	0.5 (± 0.3)	0	1.4
24	1985	0.6 (± 0.4)	0	1.4
25	1985	0.5 (± 0.3)	0	1.4
	1986	0.3 (± 0.3)	0	0.6

Lotus Lake, suspended algal levels in the upper Little Wekiva River declined precipitously (Table 41), despite high total phosphorus (Table 34) and total nitrogen (Table 35) concentrations. Chlorophyll a concentrations at Station 3 averaged 3.8 mg/m^3 in 1985 and 5.3 mg/m^3 in 1986. Further declines in chlorophyll a concentrations occurred in the upper Little Wekiva River following the discharge of waters from the Altamonte Springs Regional Wastewater Treatment Plant and the Hi-Acres Citrus processing plant. Chlorophyll a concentrations in the wastewater effluent averaged 1.4 mg/m^3 in 1985 and 2.2 mg/m^3 in 1986. Chlorophyll a concentrations in the Hi-Acres Citrus effluent averaged 0.5 mg/m^3. The waters discharged from the Weathersfield Sewage Treatment Plant had high concentrations of suspended algae (Table 41). Chlorophyll a concentrations averaged 29.4 mg/m^3 in 1985 and 42 mg/m^3 in 1986 but ranged as high as 126 mg/m^3 during algal blooms in the final treatment pond. The low discharge from this plant, however, precluded any major increases in stream chlorophyll a concentrations. Consequently, chlorophyll a concentrations at Station 12 averaged 2.1 mg/m^3 in 1985 and 3.6 mg/m^3 in 1986.

Sanlando Spring, Palm Spring, and Starbuck Spring also discharged waters with low chlorophyll a concentrations during 1985 and 1986 (Table 41) and caused an additional reduction in stream chlorophyll a concentrations. Chlorophyll a concentrations averaged $\leq$ 2.5 mg/m^3 in the springs but occasionally exceeded 5 mg/m^3 in Sanlando Spring and Starbuck Spring. Downstream of the springs, chlorophyll a concentrations in the lower Little Wekiva River were very low, averaging < 2 mg/m^3 at all sampling stations (Table 41). Maximum chlorophyll *a* concentrations measured at the sampling stations were also typically < 3 mg/m^3 (Table 41), which supports conclusions of McClelland (1982) that algal populations are low in the Little Wekiva River even during periods of low streamflow. Chlorophyll *a* concentrations in the Wekiva River also did not change significantly downstream of the confluence with the Little Wekiva River and averaged $\leq$ 2 mg/m^3 along the length of the Wekiva River (Table 40). Chlorophyll *a* concentrations > 30 mg/m^3, however, were measured in the St. Johns River (Table 40).

Studies on the relationship between nutrient concentrations and chlorophyll *a* concentrations (Dillon and Rigler 1974; Jones and Bachmann 1976; Canfield 1983) suggest that chlorophyll *a* concentrations in the Little Wekiva River and the other small streams sampled during our study (Table 43) should be substantially higher given their total phosphorus (Table 32) and total nitrogen (Table 33) concentrations. We examined the possibility that the nutrients in the study streams were not biologically available through a series of algal assays. Studies performed with waters taken from various stations along the length of the Little Wekiva River demonstrated that significantly higher chlorophyll *a* concentrations could be obtained if algal populations were given sufficient time (> 2 days) to develop (Table 44). Even the unpolluted waters from Sanlando Spring, Palm Spring, and Starbuck Spring had the capacity to develop chlorophyll *a* concentrations > 20 mg/m^3. Algal assay studies,

Table 43. Mean, minimum, and maximum chlorophyll *a* concentrations measured in all study streams. Sampling periods are given in text values for the Little Wekiva River are for stations 14 to 25. Mean values include no point-source measurements. Numbers in parentheses are the 95% confidence limits.

Stream	Chlorophyll a (mg/m^3) Mean	Minimum	Maximum
Little Wekiva	1.2 (± 0.1)	0.2	4.2
Alexander Springs	1.3 (± 0.2)	0.6	2.2
Ichetucknee River	0.7 (± 0.2)	0.1	1.2
Alligator Creek	1.4 (± 0.4)	0	2.8
Rock Springs Run	1.4 (± 0.7)	0.5	7.0
Little Econlockhatchee	1.8 (± 1.0)	0.3	7.1
Wacissa River	0.9 (± 0.2)	0.4	2.3
Wekiva River	1.4 (± 0.1)	0.6	4.2
Alafia River	1.4 (± 0.6)	0.3	4.8
Reedy Creek	22 (± 42.4)	0.2	300
Pottsburg Creek	17 (± 13.6)	0.1	59
Mills Creek	2.5 (± 2.1)	0.3	9.9
St. Marks River	0.9 (± 0.3)	0.3	2.0
Econlockhatchee	0.5 (± 0.1)	0.2	0.8
Hillsborough River	3.0 (± 1.7)	0.5	8.8
Hogtown Creek	1.4 (± 0.4)	0.4	2.2
Upper Sante Fe River	1.1 (± 0.5)	0.1	3.0

Table 44. Total phosphorus, total nitrogen, initial and maximum chlorophyll *a* obtained in bioassay experiment performed on grab samples taken from stations along the Little Wekiva River.

STATION	Nutrients (mg/L)		Chlorophyll a (mg/m^3)	
	TP	TN	Initial	Bioassay
3	0.15	1.0	9.8	42
12	0.75	3.4	5.9	320
13.1	0.18	0.38	1.1	61
13.4	0.13	0.50	0.5	21
13.5	0.16	0.34	0.8	53
17	0.56	1.2	2.0	320
25	0.50	1.3	1.5	210

using waters from our other study streams, also demonstrated that very high chlorophyll a concentrations (> 30 mg/m^3) could be reached after 3 to 12 days of incubation (Tables 45 and 46). We, therefore, conclude that nutrients are not the primary factor limiting suspended algal populations in the Little Wekiva River and the other study streams.

The declines in chlorophyll a concentrations downstream of Lotus Lake and the low chlorophyll a concentrations measured in the Little Wekiva River and our other study streams seem to be due primarily to physical factors. Chandler (1937) demonstrated that suspended algal populations from lakes undergo a progressive, quantitative decline in abundance as the water moves downstream. He observed the greatest decrease in algal abundance occurred in heavily vegetated areas or where other submerged debris occurred. Trout Lake, being completely filled with vegetation and decaying organic debris, removed substantial amounts of the suspended algae from the waters leaving Lotus Lake (Table 41). Aquatic macrophytes probably also contributed to the low suspended algal concentrations measured in the lower Little Wekiva River and some of our other study streams that had extensive growths of aquatic macrophytes, but dilution by waters containing low levels of suspended algae (i.e., spring-water) was probably a more important factor. Neither the presence of aquatic macrophytes nor dilution, however, can explain low suspended algal concentrations in all the streams.

Kofoid (1903) stated that the "age" of the water in a stream was the most vital of all hydrographic factors regulating stream

Table 45. Influence of time on the development of suspended algal populations in Florida streams.

	Chlorophyll a (mg/m^3)			
Stream	Initial	Day 3	Day 7	Day 12
Little Wekiva	5.1	42.9	72.9	69.5
Alexander Spring	1.3	7.1	9.9	32.0
Ichetucknee Springs	0.7	8.1	36.4	34.6
Alligator Creek	1.3	41.3	42.1	103.5
Rock Springs	1.2	74.4	78.3	33.2
Little Econlockhatchee	13.1	43.9	69.3	40.1
Iron Bridge	3.1	224.0	429.0	560.0
Wacissa	0.7	10.2	8.6	13.6
Big Wekiva	1.5	30.5	112.8	45.9
Wekiva Springs	1.3	8.5	12.4	7.8
Alafia	2.3	120.6	64.9	218.7
Reedy	51.5	24.2	129.8	79.3
St. Johns	81.4	50.2	34.6	27.1
Pottsburg	19.6	30.9	27.4	48.8
Mills	4.9	59.1	53.8	124.4
St. Marks	0.9	15.1	9.1	7.4
Big Econlockhatchee	0.5	19.8	28.3	27.5
Hillsborough	4.5	53.4	44.1	215.5
Hog Town	1.1	27.9	158.8	325.7
Santa Fe	1.6	26.2	64.1	172.0

Table 46. Average values for algal bioassays conducted on waters taken from select Florida streams.

Variable	N	Mean	Minimum	Maximum
Initial TP (mg/L)	154	0.99	0.01	90
Initial TN (mg/L)	154	1.7	0.10	90
Initial Chla (mg/m^3)	154	7.9	0.0	300
Day 3 Chla (mg/m^3)	126	39	0.0	275
Day 7 Chla (mg/m^3)	151	66	1.9	595
Day 12 Chla (mg/m^3)	126	90	3.7	560

algal populations. He observed that rainwater and spring-water are practically barren of phytoplankton, but that abundant algal populations could develop given sufficient time. Kofoid (1903) also documented that algal populations were generally higher during low-flow periods due to reduced hydraulic flushing. Most of the streams sampled during our study had average water residence times < 2 days (Table 3), which was shorter than the time needed for indigenous algal populations to develop (Tables 44, 45, and 46). Consequently, very few of the streams developed abundant algal populations (Table 43). The two streams that had average chlorophyll a concentrations > 4 mg/m^3 were Reedy Creek (21.7 mg/m^3) and Pottsburg Creek (17.5 mg/m^3). Although these streams had average water residence times < 1 day, flows in the streams were erratic and occasionally ceased. During periods of low rainfall, streamflow in Reedy Creek ceased, and chlorophyll a concentrations > 100 mg/m^3 were measured. In Pottsburg Creek, low discharge and tidal action increased water residence time during periods of low rainfall, and a maximum chlorophyll a concentration of 59 mg/m^3 was measured. These data and our algal assay data, therefore, strongly support the conclusion of Kofoid (1903) that the "age" of the water is an important determinant of suspended algal populations in flowing waters.

The development of large algal populations should not be expected in most of our small study streams unless the current velocity is reduced sufficiently to increase the length of time the water is in the streams. This probably will not occur in small spring-fed streams like the Little Wekiva River because of discharges from major springs. The algal populations, however, would have the potential to develop in downstream water bodies such as lakes, the St. Johns River, or coastal estuaries if other physical factors did not become limiting.

Periphyton

Algae attached to aquatic macrophytes (periphyton) contribute significantly to aquatic primary production (Butcher 1940; Wetzel 1964; Allen 1971). Periphyton abundance, as measured by chlorophyll a concentrations, averaged 63 mg/m^2 of plant surface in the Little Wekiva River (Table 47). Periphyton abundance in the stream, however, was extremely variable, ranging from 1 to 465 mg of Chlorophyll a/m^2 of plant surface. Average periphyton abundance in our other study streams ranged from 26 (Econlockhatchee River) to 109 mg of chlorophyll a/m^2 (St. Marks River), but, as with the Little Wekiva River, periphyton abundances within the individual streams were highly variable (Table 47). Periphyton abundances > 400 mg of chlorophyll a/m^2 of plant surface were measured in the Little Wekiva River, Alexander Springs, Ichetucknee Springs, Rock Springs Run, and the Wekiva River.

Several studies (e.g., Traaen 1978; Bothwell 1985) have suggested that periphyton abundance in flowing water is increased by the addition of nutrients, but other studies have shown no effect of nutrient enrichment on stream periphyton (e.g., Patrick 1966; Wuhrmann and Eichenburger 1975). We found no significant correlations between either total phosphorus or total nitrogen

Table 47. Mean periphyton chlorophyll *a* collected from plants in 13 survey streams[1].

Stream	Periphyton abundance (mg chlorophyll a/m^2 of plant surface area)			
	N	Mean	Minimum	Maximum
Little Wekiva	106	63	1	465
Alexander Springs	68	95	5	815
Ichetucknee	59	46	0	447
Alligator Creek	27	56	3	387
Rock Springs	26	101	2	609
Little Econlockhatchee	13	56	5	351
Wacissa	36	32	3	281
Wekiva	40	83	7	650
Alafia	44	30	2	166
St. Marks	19	109	19	246
Econlockhatchee	11	26	5	59
Hillsborough	21	57	6	216
Hogtown	9	42	2	101

[1]Periphyton not recorded for Mills Creek, Pottsburg Creek, Reedy Creek, and upper Santa Fe because of small sample size.

concentrations and periphyton abundance in the Little Wekiva River or our other study streams. The three streams with the highest average periphyton abundance were the St. Marks River (109 mg of chlorophyll a/m^2), Rock Springs Run (101 mg of chlorophyll a/m^2), and Alexander Springs (95 mg of chlorophyll a/m^2). These streams are spring-fed, and none are enriched with nutrients from a municipal wastewater treatment plant. Recent studies on northern streams have suggested that periphyton abundance is not limited by nutrients when total phosphorus concentrations exceed 0.025 mg/L (Dr. Val Smith, Limnologist-University of North Carolina, personal communication). All the streams we sampled had average total phosphorus concentrations $\geq$ 0.030 mg/L. We, therefore, conclude that nutrients are not limiting the abundance of periphyton in our study streams, and the removal of nutrient sources like the Altamonte Springs Regional Wastewater Treatment Plant will not reduce periphyton abundance in the Little Wekiva River.

The variability in periphyton abundance observed during this study seems to be due to several factors. Part of the variability is directly attributable to the type of host plant (Table 47) and the age of the host aquatic macrophyte. New macrophytic growth tends to have less periphyton than older plants. Changes in current velocity, however, also impact periphyton abundance. Several studies have shown that flowing waters within certain limits can support more periphyton than nonflowing aquatic systems (Whiteford 1960; Whiteford and Schumacher 1964; Horner and Welch 1981). Our studies suggest that this is also true in Florida. The Florida streams we sampled had a higher average periphyton abundance (57 mg of chlorophyll a/m^2) than 14 Florida lakes (22 mg of chlorophyll a/m^2) sampled during a recent lake survey (Canfield and Hoyer, unpublished data), but high current velocities, especially those reached during storm events, can significantly reduce periphyton abundance by scouring the periphyton from the host plant. Current velocity and the time between periods of rapid flow are probably the major factors influencing periphyton abundance in Florida streams, but shading from the forest canopy can also reduce abundance.

Aquatic Macrophytes

Aquatic macrophytes were abundant in the Little Wekiva River during 1985 and 1986 (Table 48). Above-ground plant standing crops averaged 1.3 kg fresh weight/m^2 in March 1985, 1.9 kg fresh weight in September 1985, and 3.3 kg fresh weight/m^2 in August 1986. The abundance of plants in different sections of the stream, however, varied considerably. Measured macrophyte standing crops ranged from 0 to 18 kg fresh weight/m^2. Fewer plants (primarily *Colocasia esculentum* growing in shallow water along the stream bank) were collected in the upper Little Wekiva River than in the lower Little Wekiva River. Above-ground plant standing crops upstream of Sanlando Spring averaged 0.7 kg fresh weight/m^2 in 1985 and 1.3 kg fresh weight/m^2 in 1986. Downstream of the springs, macrophyte standing crops averaged 2.4 kg/m^2 in 1985 and 5.4 kg/m^2 in 1986.

Table 48. Mean fresh weight standing crop of aquatic macrophytes in Little Wekiva River and other Florida streams.

		Macrophyte Standing Crop (kg/m^2)			
River	Date	Mean	Std Error of Mean	Minimum	Maximum
Little Wekiva	3/13/85	1.3	0.3	0	13
	9/12/85	2.0	0.5	0	11
	8/12/86	3.3	1.1	0	18
Rock Springs	6/11/85	1.3	0.4	0	6.9
	11/20/85	3.9	1.2	0	13
	6/18/86	1.4	0.5	0	4.4
Wekiva	7/9/85	1.3	0.3	0	6.3
	11/19/85	2.6	0.6	0	10
	6/17/86	1.4	0.3	0	5.4
Alexander Spring	5/14/85	3.4	0.8	0	23
	11/25/85	5.2	1.3	0	16
	6/23/86	4.4	1.1	0	15
Ichetucknee	5/29/85	4.7	0.8	0.8	15
	11/13/85	2.5	0.5	0.5	5.7
	6/3/86	3.7	0.8	0	9.6
Wacissa	6/26/85	11	1.0	2.8	23
	11/14/85	7.1	1.6	0	20
	7/11/86	11	1.0	0	22
St. Marks	7/2/86	3.9	0.9	0.7	12
Alligator Creek	6/6/85	0.5	0.3	0	5.9
	11/6/85	0.6	0.4	0	5.6
	6/5/86	0.6	0.2	0	2.8
Alafia	7/16/85	0.2	0.1	0	3.1
	11/7/85	0.2	0.03	0	0.4
	8/13/86	0.03	0.02	0	0.6
Little Econlock-hatchee	6/12/85	0.1	0.08	0	2.1
	12/10/85	0	0	0	0
	7/1/86	0	0	0	0
Econlochatchee	7/2/86	0.02	0.02	0	0.5

Table 48. Continued

River	Date	Macrophyte Standing Crop (kg/m^2) Mean	Std Error of Mean	Minimum	Maximum
Reedy	7/16/86	0.05	0.05	0	0.8
Pottsburg	6/20/86	0	0	0	0
Mills	6/30/86	0.3	0.1	0	1.6
Hillsborough	8/14/86	3.7	1.6	0	35
Hogtown	6/16/86	0.3	0.2	0	3.7
Santa Fe	6/19/86	0.1	0.1	0	1.2

We collected over 25 species of aquatic macrophytes in the Little Wekiva River during 1985 and 1986 (Table 49). Our species list, however, probably does not include all plant species growing in the stream because our sampling methodology recorded only those plants growing along the sampling transects. Our visual surveys of the Little Wekiva River, however, indicated that we had sampled all the major plant species occurring in the stream. The plants encountered most often during our study (listed according to their frequency of occurrence) were elephant-ear (Colocasia esculentum), alligator weed (Alternanthera philoxeroides), hydrilla (Hydrilla verticillata), water pennywort (Hydrocotyle umbellata), paragrass (Brachiaria mutica), tapegrass (Vallisneria americana), common salvinia (Salvinia rotundifolia), common duckweed (Lemna minor), water hyacinth (Eichhornia crassipes), and water lettuce (Pistia stratiotes). Six of these plant species (elephant-ear, alligator weed, hydrilla, paragrass, and water hyacinth) are known exotic plants, and most of them have caused or cause aquatic weed problems throughout peninsular Florida. Water lettuce may also be an exotic based on some new research (William T. Haller, University of Florida, personal communication), and it too has caused aquatic weed problems in different Florida waters.

Paragrass caused the most severe aquatic weed problems during the study because it blocked the stream downstream of Springs Landing Boulevard at several locations, and its standing crops often exceeded 5 kg fresh weight/m^2, which was well above flood-safe standing crops (2-4 kg fresh weight/m^2) established

Table 49. Aquatic macrophyte species collected in each survey river. N is the number of transects the species was collected in.

River	Common Name	Scientific Name	N
Little Wekiva	Water-lettuce	*Pistia stratiotes*	18
	Common duckweed	*Lemna minor*	19
	Floating water-hyacinth	*Eichhornia crassipes*	18
	Common salvinia	*Salvinia rotundifolia*	21
	Common arrowhead	*Sagittaria latifolia*	1
	Alligator-weed	*Alternanthera philoxeroides*	31
	Watercress	*Nasturtium officinale*	1
	Slender spikerush	*Eleocharis baldwinii*	16
	Spatterdock	*Nuphar luteum*	17
	Red ludwigia	*Ludwigia repens*	2
	Water sprite	*Ceratopteris thalictroides*	2
	Smartweed	*Polygonum hydropiperoides*	3
	Pickerelweed	*Pontederia cordata*	3
	Baby-tears	*Micranthemum umbrosum*	1
	Cat-tail	*Typha spp.*	6
	Water pennywort	*Hydrocotyle umbellata*	27
	Coontail	*Ceratophyllum demersum*	2
	Variable-leaf milfoil	*Myriophyllum heterophyllum*	2
	Brazilian elodea	*Egeria densa*	2
	Hydrilla	*Hydrilla verticillata*	31

Table 49. Continued

River	Common Name	Scientific Name	N
	Tapegrass	Vallisneria americana	22
	Illinois pondweed	Potamogeton illinoensis	1
	Elephant-ear	Colocasia esculenta	66
	Water primrose	Ludwigia octovalis	4
	Sawgrass	Cladium jamaicense	1
	Flat-sedge	Cyperus odoratus	1
	Maidencane	Panicum hemitomon	3
	Para grass	Brachiaria mutica	25
Alexander Springs	Water-lettuce	Pistia stratiotes	35
	Common duckweed	Lemna minor	16
	Floating water-hyacinth	Eichhornia crassipes	24
	Azolla	Azolla caroliniana	1
	Duck-potato	Sagittaria lancifolia	1
	Common arrowhead	Sagittaria latifolia	9
	Alligator-weed	Alternanthera philoxeroides	3
	Slender spikerush	Eleocharis baldwinii	4
	Frog's-bit	Limnobium spongia	1
	Spatterdock	Nuphar luteum	37
	Fragrant water-lily	Nymphaea odorata	1
	Smartweed	Polygonum hydropiperoides	1

Table 49. Continued

River	Common Name	Scientific Name	N
	Pickerelweed	<u>Pontederia cordata</u>	34
	Lemon bacopa	<u>Bacopa caroliniana</u>	4
	Bacopa	<u>Bacopa monnieri</u>	3
	Cat-tail	<u>Typha spp.</u>	20
	Water pennywort	<u>Hydrocotyle umbellata</u>	42
	Strap-leaf sag	<u>Sagittaria kurziana</u>	2
	Coontail	<u>Ceratophyllum demersum</u>	7
	Tapegrass	<u>Vallisneria americana</u>	43
	Southern naiad	<u>Najas guadalupensis</u>	16
	Variable-leaf pondweed	<u>Potamogeton diversifolius</u>	1
	Sawgrass	<u>Cladium jamaicense</u>	2
	Flat-sedge	<u>Cyperus odoratus</u>	2
	Giant bulrush	<u>Scirpus californicus</u>	3
	Soft-stem bulrush	<u>Scirpus validus</u>	3
	Maidencane	<u>Panicum hemitomon</u>	4
	Para grass	<u>Brachiaria mutica</u>	13
	Water paspalum	<u>Paspalum fluitans</u>	1
	Giant cutgrass	<u>Zizaniopsis miliacea</u>	1
	Soft rush	<u>Juncus effusus</u>	7
	---------	<u>Fuirena scirpoidea</u>	11
	---------	<u>Leersia hexandra</u>	21

Table 49. Continued

River	Common Name	Scientific Name	N
	---------	Websteria confervoides	4
	---------	Rhynchospora tracyi	1
	Bloodroot	Lachnanthes caroliniana	1
Ichetucknee	Water-lettuce	Pistia stratiotes	46
	Common duckweed	Lemna minor	22
	Common salvinia	Salvinia rotundifolia	2
	Common arrowhead	Sagittaria latifolia	1
	Watercress	Nasturtium officinale	1
	Spatterdock	Nuphar luteum	1
	Red ludwigia	Ludwigia repens	2
	Baby-tears	Micranthemum umbrosum	4
	Water pennywort	Hydrocotle umbellata	20
	Strap-leaf sag	Sagittaria kurziana	18
	Coontail	Ceratophyllum demersum	14
	Variable-leaf milfoil	Myriophyllum heterophyllum	9
	Tapegrass	Vallisneria americana	35
	Soft-stem bulrush	Scirpus validus	1
	Wild rice	Zizania aquatica	24
	Soft rush	Juncus effusus	1
	---------	Leersia hexandra	6

Table 49. Continued

River	Common Name	Scientific Name	N
	---------	*Websteria confervoides*	13
Alligator Creek	Alligator-weed	*Alternanthera philoxeroides*	25
	Slender spikerush	*Eleocharis baldwinii*	3
	Water pennywort	*Hydrocotyle umbellata*	2
	Hydrilla	*Hydrilla verticillata*	6
	Elephant-ear	*Colocasia esculenta*	4
Rock Springs	Water lettuce	*Pistia stratiotes*	19
	Common duckweed	*Lemna minor*	13
	Floating water-hyacinth	*Eichhornia crassipes*	13
	Duck potato	*Sagittaria lancifolia*	1
	Common arrowhead	*Sagittaria latifolia*	1
	Alligator-weed	*Alternanthera philoxeroides*	2
	Spatterdock	*Nuphar luteum*	23
	Smartweed	*Polygonum hydropiperoides*	4
	Pickerelweed	*Pontederia cordata*	21
	Lizard's-tail	*Saururus cernuus*	1
	Cat-tail	*Typha spp.*	5
	Water Pennywort	*Hydrocotyle umbellata*	21
	Strap-leaf sag	*Sagittaria kurziana*	2

Table 49. Continued

River	Common Name	Scientific Name	N
	Brazilian elodea	Egeria densa	1
	Hydrilla	Hydrilla verticillata	2
	Tapegrass	Vallisneria americana	16
	Elephant-ear	Colocasia esculenta	3
	Sawgrass	Cladium jamaicense	1
	Flat-sedge	Cyperus odoratus	4
	Umbrella-grass	Fuirena squarrosa	1
	Giant bulrush	Scirpus californicus	1
	Soft-stem bulrush	Scirpus validus	1
	Maidencane	Panicum hemitomon	5
	Wild rice	Zizania aquatica	6
	Giant cutgrass	Zizaniopsis miliacea	1
	---------	Fuirena scirpoidea	1
	---------	Leersia hexandra	4
	---------	Websteria confervoides	4
	St. John's wort	Hypericum spp.	4
	---------	Rhynchospora tracyi	5
	Yellow-eyed grass	Xyris spp.	1
Little Econlockhatchee	Common duckweed	Lemna minor	1
	Alligator-weed	Alternanthera philoxeroides	2
	Slender spikerush	Eleocharis baldwinii	4

Table 49. Continued

River	Common Name	Scientific Name	N
	Baby-tears	*Micranthemum umbrosum*	5
	Water pennywort	*Hydrocotyle umbellata*	8
	Flat-sedge	*Cyperus odoratus*	1
	Maidencane	*Panicum hemitomon*	1
	Soft rush	*Juncus effusus*	1
Wacissa	Common duckweed	*Lemna minor*	24
	Floating water-hyacinth	*Eichhornia crassipes*	52
	Azolla	*Azolla caroliniana*	14
	Duck-potato	*Sagittaria lancifolia*	5
	Common arrowhead	*Sagittaria latifolia*	7
	Alligator-weed	*Alternanthera philoxeroides*	1
	Watercress	*Nasturtium officinale*	2
	Frog's-bit	*Limnobium spongia*	10
	Spatterdock	*Nuphar luteum*	3
	Red ludwigia	*Ludwigia repens*	2
	Pickerelweed	*Pontederia cordata*	24
	Baby-tears	*Micranthemum umbrosum*	1
	Cat-tail	*Typha spp.*	1
	Water pennywort	*Hydrocotyle umbellata*	5
	Strap-leaf sag	*Sagittaria kurziana*	33

Table 49. Continued

River	Common Name	Scientific Name	N
	Coontail	Ceratophyllum demersum	10
	Water-moss	Fontinalis spp.	1
	Brazilian elodea	Egeria densa	20
	Hydrilla	Hydrilla verticillata	34
	Tapegrass	Vallisneria americana	13
	Southern naiad	Najas guadalupensis	36
	Illinois pondweed	Potamogeton illinoensis	6
	Sawgrass	Cladium jamaicense	2
	Soft-stem bulrush	Scirpus validus	1
	Wild rice	Zizania aquatica	40
	Giant cutgrass	Zizaniopsis miliacea	1
	----------	Fuirena scirpoidea	1
	----------	Leersia hexandra	27
	----------	Websteria confervoides	3
	Bloodroot	Lachnanthes caroliniana	2
	----------	Eleocharis elongata	4
Big Wekiva	Water lettuce	Pistia stratiotes	32
	Common duckweed	Lemna minor	14
	Floating water-hyacinth	Eichhornia crassipes	35
	Common salvinia	Salvinia rotundifolia	14

Table 49. Continued

River	Common Name	Scientific Name	N
	Duck-potato	Sagittaria lancifolia	2
	Commom arrowhead	Sagittaria latifolia	1
	Alligator-weed	Alternanthera philoxeroides	18
	Spatterdock	Nuphar luteum	37
	Smartweed	Polygonum hydropiperoides	1
	Pickerelweed	Pontederia cordata	11
	Lizard's tail	Saururus cernuus	1
	Cat-tail	Typha spp.	18
	Water pennywort	Hydrocotyle umbellata	22
	Strap-leaf sag	Sagittaria kurziana	1
	Variable-leaf milfoil	Myriophyllum heterophyllum	1
	Brazilian elodea	Egeria densa	6
	Hydrilla	Hydrilla verticillata	4
	Tapegrass	Vallisneria americana	31
	Sago pondweed	Potamogeton pectinatus	1
	Flat-sedge	Cyperus odoratus	1
	Giant bulrush	Scirpus californicus	2
	Maidencane	Panicum hemitomon	1
	Para grass	Brachiaria mutica	1
	Water paspalum	Paspalum fluitans	3

Table 49. Continued

River	Common Name	Scientific Name	N
	Wild rice	*Zizania aquatica*	4
	Giant cutgrass	*Zizaniopsis miliacea*	1
	-----------	*Fuirena scirpoidea*	3
	-----------	*Websteria confervoides*	1
	St. John's wort	*Hypericum spp.*	2
	-----------	*Rhynchospora inundata*	2
	Yellow-eyed grass	*Xyris spp.*	1
Alafia	Common duckweed	*Lemna minor*	3
	Alligator-weed	*Alternanthera philoxeriodes*	34
	Smartweed	*Polygonum hydropiperoides*	1
	Baby-tears	*Micranthemum umbrosum*	5
	Water pennywort	*Hydrocotyle umbellata*	5
	Hydrilla	*Hydrilla verticillata*	8
Reedy Creek	Common duckweed	*Lemna minor*	2
	Floating water-hyacinth	*Eichhornia crassipes*	4
	Common salvinia	*Salvinia rotundifolia*	3
	Alligator-weed	*Alternanthera philoxeroides*	2
	Water pennywort	*Hydrocotyle umbellata*	1
	Maidencane	*Panicum hemitomon*	1

Table 49. Continued

River	Common Name	Scientific Name	N
Pottsburg Creek	Alligator-weed	Alternanthera philoxeroides	4
	Spider lily	Hymenocallis spp.	1
Mills Creek	Common duckweed	Lemna minor	1
	Common arrowhead	Sagittaria latifolia	1
	Alligator-weed	Alternanthera philoxeroides	1
	Spatterdock	Nuphar luteum	6
	Smartweed	Polygonum hydropiperoides	2
	Pickerelweed	Pontederia cordata	5
	Lizard's-tail	Saururus cernuus	2
	Cat-tail	Typha spp.	2
	Sawgrass	Cladium jamaicense	4
	Wild rice	Zizania aquatica	5
	---------	Leersia hexandra	2
	---------	Websteria confervoides	1
St. Marks	Common duckweed	Lemna minor	8
	Floating water-hyacinth	Eichhornia crassipes	12
	Azolla	Azolla caroliniana	5
	Pickerelweed	Pontederia cordata	3
	Strap-leaf sag	Sagittaria kurziana	16

Table 49. Continued

River	Common Name	Scientific Name	N
	Brazilian elodea	Egeria densa	15
	Hydrilla	Hydrilla verticillata	2
	Tapegrass	Vallisneria americana	2
	Southern naiad	Najas guadalupensis	5
	Illinois pondweed	Potamogeton illinoensis	6
	Wild rice	Zizania aquatica	5
	----------	Leersia hexandra	1
	----------	Websteria confervoides	1
Big Econlockhatchee	Slender spikerush	Eleocharis baldwinii	1
	Smartweed	Polygonum hydropiperoides	3
	Baby-tears	Micranthemum umbrosum	2
	Water pennywort	Hydrocotyle umbellata	4
	Barnyard grass	Echinochloa crusgalli	7
Hillsborough	Water-lettuce	Pistia stratiotes	7
	Common duckweed	Lemna minor	10
	Floating water-hyacinth	Eichhornia crassipes	9
	Common salvinia	Salvinia rotundifolia	12
	Alligator-weed	Alternanthera philoxeroides	11
	Spatterdock	Nuphar luteum	7

Table 49. Continued

River	Common Name	Scientific Name	N
	Red ludwigia	*Ludwigia repens*	1
	Water pennywort	*Hydrocotyle umbellata*	4
	Coontail	*Ceratophyllum demersum*	6
	Brazilian elodea	*Egeria densa*	5
	Hydrilla	*Hydrilla verticillata*	9
	Green fanwort	*Cabomba caroliniana var. multipartita*	1
	Illinois pondweed	*Potamogeton illinoensis*	4
	Para grass	*Brachiaria mutica*	2
	Water paspalum	*Paspalum fluita*	14
	Wild rice	*Zizania aquatica*	1
	----------	*Fuirena scirpoidea*	1
Hog-town Creek	Alligator-weed	*Alternanthera philoxeroides*	4
	Water pennywort	*Hydrocotyle umbellata*	1
	Elephant-ear	*Colocasia esculenta*	1
	Willow	*Salix spp.*	1
	Wild rice	*Zizania aquatica*	2
Upper Santa Fe	Common duckweed	*Lemna minor*	2
	Alligator-weed	*Alternanthera philoxeroides*	1
	Water pennywort	*Hydrocotyle umbellata*	1

for streams (Kern-Hansen and Holm 1982). During 1986, paragrass completely blocked the Little Wekiva River for over 0.7 km downstream of Springs Landing Boulevard and nearly blocked the stream channel between Station 16 and 18. Other plant species, however, also caused aquatic weed problems. Elephant-ear and hydrilla became progressively more abundant in the Little Wekiva River between 1985 and 1986 and blocked small portions of the stream channel on several occasions during 1986. Water pennywort during periods of cooler weather expanded in several areas of the stream and either blocked or narrowed the stream channel. Water hyacinths did not cause any aquatic weed problems in 1985 and 1986 but did block considerable portions of the stream during 1974 (Figure 51). Aquatic herbicides, however, have been used by the United States Army Corps of Engineers to achieve maintenance control of water hyacinths in the Little Wekiva River, and aquatic herbicides are now (1987) being used to control weed problems caused by other exotic and native plants (Dave Bowman, U.S. Army Corps of Engineers, personal communication).

Nuisance growths of aquatic macrophytes and large algae in some northern streams have been linked to the deterioration of water quality resulting from eutrophication (Wong and Clark 1976; Wright and McDonnell 1986a, 1986b). There was no relationship between nutrient (total phosphorus and total nitrogen) concentrations and the abundance of aquatic macrophytes along the length of the Little Wekiva River during 1985. This seemed to support the U.S. Environmental Protection Agency's conclusion that excessive growths of aquatic macrophytes in the Little

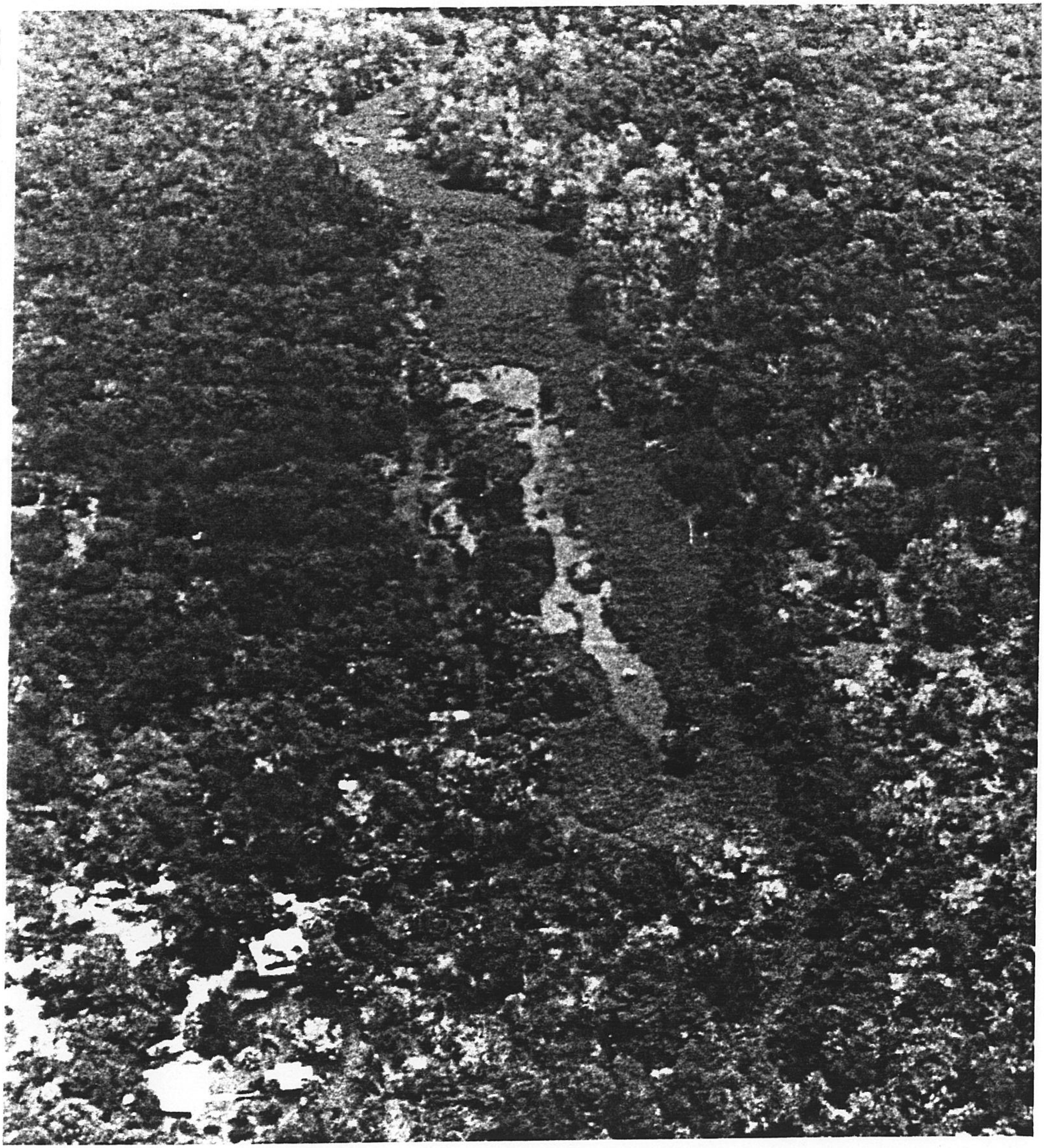

Figure 51. Water hyacinths blocking the Little Wekiva River 1974.

Wekiva River were not related to excessive nutrient enrichment. To determine if there was an adequate supply of nutrients in the Little Wekiva River to support the measured standing crops of aquatic macrophytes, we estimated what percent of the annual total phosphorus and total nitrogen exports from the stream would be used by the plants assuming all nutrients had to be extracted from the water. Our estimates indicated that < 1% of the annual phosphorus and nitrogen exported from the Little Wekiva River would be needed to support the mean or maximum measured standing crops of aquatic macrophytes in 1985 (Tables 50 and 51). Even if we restricted our estimates to the May to December period of maximum growth, the plants would need < 2% of the nutrients exported from the Little Wekiva River.

We also compared average macrophyte standing crops to nutrient concentrations in Alexander Springs, Ichetucknee River, Alligator Creek, Rock Springs Run, Little Econlockhatchee River, Wacissa River, and Alafia River during 1985 to determine if plant abundance was correlated to the level of nutrient enrichment (Tables 52 and 53). Average above-ground macrophyte standing crops in the streams ranged from 1.3 to 11 kg fresh weight/m^2 (Table 48). The highest above-ground standing crops of aquatic macrophytes were measured in the Wacissa River (11 kg fresh weight/m^2 in June and 7.1 kg fresh weight/m^2 in November), which had an average total phosphorus concentration of 0.04 mg/L and an average total nitrogen concentration of 0.20 mg/L (Tables 52 and 53). The other nonpolluted spring-fed streams also supported either equivalent or greater above-ground standing crops of

Table 50. Annual total phosphorus export, total phosphorus content in plant tissue, and percent of total phosphorus export in plant tissue for the Little Wekiva River in 1985 using measured plant biomass and predicted annual production of plant biomass.

	Annual Total Phosphorus Export (kg/yr)	Total Phosphorus in Plant Tissue (kg)[1]	Percent of Phosphorus Export in Plant Tissue
Mean 1985 Plant Biomass	39,000	80	0.2
Maximum 1985 Plant Biomass	39,000	94	0.2
1.5 x Mean 1985 Plant Biomass	39,000	120	0.3
Growing Period May - December 1985	21,000	94	0.5

[1]Assuming 95% water weight for all plants.

able 51. Annual total nitrogen export, total nitrogen content in plant tissue, and percent of total nitrogen export in plant tissue for the Little Wekiva River in 1985 using measured plant biomass and predicted annual production of plant biomass.

	Annual Total Nitrogen Export (kg/yr)	Total Nitrogen in Plant Tissue (kg)[1]	Percent of Nitrogen Export in Plant Tissue
Mean 1985 Plant Biomass	114,000	500	0.4
Maximum 1985 Plant Biomass	114,000	590	0.5
1.5 x Mean 1985 Plant Biomass	114,000	750	0.6
Growing Period May - December 1985	59,000	590	1.0

[1]Assuming 95% water weight for all plants.

Table 52. Annual total phosphorus export, total phosphorus content in plant tissue, and percent of phosphorus export in plant tissue for all survey rivers in 1985.

Stream	Mean Total Phosphorus Concentration (mg/L)	Annual Total Phosphorus Export (kg/yr)	Total Phosphorus in Plant Tissue (kg)[1]	Percent of Yearly Export in Plant Tissue
Alexander Springs	0.04	6,100	460	7.5
Ichetucknee	0.05	19,000	120	1.0
Alligator Creek	0.38	12,000	4.4	<0.1
Rock Springs	0.08	6,900	140	2.0
Little Econlockhatchee	0.23	34,000	1.5	<0.1
Wacissa	0.04	13,000	1,500	12
Wekiva	0.21	71,000	410	0.6
Alafia	1.95	380,000	8.9	<0.1

[1]Assuming 95% water weight for all plants and a phosphorus content of 3.7 mg/g dry weight of plant tissue.

Table 53. Annual total nitrogen export, total nitrogen content in plant tissue, and percent of nitrogen export in plant tissue for all survey rivers in 1985.

Stream	Mean Total Nitrogen Concentration (mg/L)	Annual Total Nitrogen Export (kg/yr)	Total Nitrogen in Plant Tissue (kg)[1]	Percent of Yearly Export in Plant Tissue
Alexander Springs	0.41	62,500	2,800	4.5
Ichetucknee	0.26	98,000	710	0.7
Alligator Creek	0.82	28,000	28	0.1
Rock Springs	1.25	99,000	900	0.9
Little Econlockhatchee	2.60	400,000	9.5	<0.1
Wacissa	0.20	59,000	9,100	15
Wekiva	0.88	330,000	2,600	0.8
Alafia	1.31	240,000	55	<0.1

[1]Assuming 95% water weight for all plants and a nitrogen content of 23.4 mg/g dry weight of plant tissue.

aquatic macrophytes than the Little Wekiva River (Table 48), despite having lower nutrient concentrations (Tables 52 and 53). The percent of the annual total phosphorus and total nitrogen exports that would be needed to support the measured above-ground standing crops was < 2% for all streams except Alexander Springs (7.5% for total phosphorus and 4.5% for total nitrogen) and Wacissa River (12% for total phosphorus and 15% for total nitrogen), which had some of the lowest nutrient concentrations and greatest average above-ground macrophyte standing crops measured in our study.

In 1986, we surveyed 17 streams to determine if plant abundance was related to the level of nutrient enrichment (Tables 54 and 55). Mean above-ground standing crops ranged from 0 to 11 kg fresh weight/m^2 (Table 48). Again, some of the highest macrophyte standing crops were measured in nonpolluted spring-fed streams (Alexander Springs, Ichetucknee River, Rock Springs Run, Wacissa River, St. Marks River, and Hillsborough River) (Table 48). Our estimates of the percentage of the yearly exports of total phosphorus and total nitrogen contained in the macrophyte beds of the survey streams averaged < 2% for all but two streams, Alexander Springs and Wacissa River (Tables 54 and 55). These findings agree with those of Casey (1977) and Madsen (1986) who studied several northern streams. Our estimates, however, are probably highly conservative, because many studies have demonstrated rooted aquatic macrophytes can also obtain nutrients from the hydrosoil (Bristowe and Whitcombe 1971; Carignan and Kalff 1980).

Table 54. Annual total phosphorus export, total phosphorus content in plant tissue, and percent of phosphorus export in plant tissue for all survey streams in 1986.

Stream	Annual Total Phosphorus Export (kg/yr)	Total Phosphorus in Plant Tissue (kg)[1]	Percent of Yearly Export in Plant Tissue
Little Wekiva	48,000	170	0.4
Alexander Springs	7,400	480	6.5
Ichetucknee	15,000	130	0.9
Alligator Creek	7,600	3.9	0.1
Rock Springs	12,000	71	0.6
Little Econlockhatchee	36,000	<0.1	<0.1
Wacissa	15,000	2,700	18
Wekiva	61,000	240	0.4
Alafia	790,000	<0.1	<0.1
Reedy	6,800	<0.1	<0.1
Pottsburg	170,000	<0.1	<0.1
Mills Creek	44,000	14	<0.1
St. Marks	18,000	320	1.8
Econlockhatchee	27,000	<0.1	<0.1
Hillsborough	130,000	210	0.2
Hogtown	15,000	0.7	<0.1
Santa Fe	96,000	4.1	<0.1

[1]Assuming 95% weight of all plants and a phosphorus content of 3.7 mg/g dry weight of plant tissue.

Table 55. Annual total nitrogen export, total nitrogen content in plant tissue, and percent of nitrogen export in plant tissue for all survey streams in 1986.

Stream	Annual Total Nitrogen Export (kg/yr)	Total Nitrogen in Plant Tissue (kg)[1]	Percent of Yearly Export in Plant Tissue
Little Wekiva	160,000	1,000	0.6
Alexander Springs	48,000	3,000	6.3
Ichetucknee	100,000	830	0.8
Alligator Creek	28,000	24	0.1
Rock Springs	200,000	440	0.2
Little Econlockhatchee	690,000	<0.1	<0.1
Wacissa	200,000	17,000	8.5
Wekiva	350,000	1,500	0.4
Alafia	500,000	<0.1	<0.1
Reedy	490,000	<0.1	<0.1
Pottsburg	740,000	<0.1	<0.1
Mills Creek	140,000	84	0.1
St. Marks	220,000	2,000	0.9
Econlockhatchee	760,000	<0.1	<0.1
Hillsborough	450,000	1,300	0.3
Hogtown	14,000	4	<0.1
Santa Fe	480,000	26	<0.1

[1]Assuming 95% water weight for all plants and a nitrogen content of 23.4 mg/g dry weight of plant tissue.

Other evidence also suggests that nutrients are not the factor causing aquatic weed problems in the Little Wekiva River or other Florida streams. Studies on northern streams have suggested that aquatic macrophytes are not limited by nutrients unless phosphorus concentrations fall well below 0.02 mg/L (Owens and Edwards 1961; Casey and Westlake 1974; Kern-Hansen and Dawson 1978). Nutrient (especially phosphorus) concentrations in Florida streams are naturally high due to edaphic factors (Odum 1953; Omernik 1977). Total phosphorus and total nitrogen concentrations in spring-fed streams typically exceed 0.03 mg/L and 0.3 mg/L, respectively, and these streams have historically supported an abundance of aquatic macrophytes (Beck 1965; Rosenau et al. 1977). Consequently, Florida has had a long history of aquatic plant problems in its streams (Figure 52). The United States Congress passed the Rivers and Harbor Act of 3 March 1899 to establish aquatic plant control programs in Florida. Old aerial photographs also clearly demonstrate that aquatic plants blocked the Little Wekiva River in 1940 (Figures 44 and 48), long before any significant amounts of wastewater were added to the stream. We, therefore, concur with the conclusion of the United States Environmental Protection Agency (1981) that nutrients are not the factor limiting the abundance of aquatic macrophytes in the Little Wekiva River. We must also conclude that nutrients are not the factor causing aquatic weed problems in other Florida streams. Consequently, the control of nutrients discharged from wastewater treatment plants can not be used as an indirect method for aquatic macrophyte management in Florida streams (including

Figure 52. Water hyacinths blocking the St. John's River 1898.

large rivers such as the St. Johns River), even if stream nutrient concentrations could be reduced to their pristine levels.

Butcher (1933) observed that the chief factor governing the distribution and abundance of aquatic macrophytes in English streams was water current. Other factors that he recognized as important included bottom substrates and light availability. The upper Little Wekiva River had fewer aquatic macrophytes primarily because current velocity reached levels that caused scouring of the sand bottom. Sections of some of our other study streams, such as the Alafia River and Ichetucknee Springs, also had high current velocities that scoured the bottom substrates, but average current velocities were generally low (< 36 cm/s). Because current velocity was low, bottom substrates in most of the study streams were dominated by sand, silt, and mud which provide excellent substrate for the growth of aquatic macrophytes (Butcher 1933). Only the Alafia River and portions of the Ichetucknee River had large areas of unsuitable bottom substrates (limestone outcrops) for macrophytes.

The United States Environmental Protection Agency (1981) suggested that the growth of aquatic plants in the Little Wekiva River appeared to be primarily controlled by shading, stream velocity, and substrate quality. Our studies suggest that the chief factor limiting the abundance of aquatic macrophytes in the Little Wekiva River and our other study streams is light availability. During the aquatic macrophyte surveys, it was visually obvious that the distribution and abundance of aquatic macrophytes was governed by openings in the forest canopy. Macrophyte abundance in the Little Wekiva River was significantly ($p < 0.05$) correlated to the percent forest canopy coverage ($r = -0.77$), and our estimates of percent forest canopy coverage were significantly correlated to light availability (microeinsteins/m^2/s) reaching the stream surface as measured by a LiCorr model LI-185B quantum radiometer photometer equipped with a LI-190SB quantum sensor ($r = 0.76$). Using mean transect data ($n = 661$) from all streams and all years (Table 56), the average (SC_{avg}) and maximum (SC_{max}) above-ground standing crops of aquatic macrophytes in the Florida streams were significantly correlated to the percent forest canopy (%C), and the relationships were described by the following logarithmic regression equations:

$$\log (SC_{avg}) = 1.06 - 0.026 (\%C) \quad R^2 = 0.93 \quad (1)$$

$$\log (SC_{max}) = 1.54 - 0.014 (\%C) \quad R^2 = 0.94 \quad (2).$$

Dawson and Kern-Hansen (1978, 1979) demonstrated a strong inverse relationship between light available at the stream surface and the biomass of aquatic plants in some English and Danish streams. Equations 1 and 2 demonstrate the same strong relationships between forest canopy coverage and mean and maximum above-ground standing crops of aquatic macrophytes. This suggests that the control of aquatic weed problems in Florida's shallow, slow flowing, nutrient-rich streams depends in part on the maintenance of a forest canopy cover. Increased shading also

Table 56. Mean, minimum, and maximum plant standing crop for consecutive 10% canopy cover groups. Data are from 17 Florida streams sampled during 1985 or 1986.

Percent Canopy	Number of Transects	Plant Standing Crop (kg fresh wt./m^2) Mean	Minimum	Maximum
0.0 - 9.9	134	6.0	0.0	35
10.0 - 19.9	59	5.3	0.0	20
20.0 - 29.9	84	2.5	0.0	16
30.0 - 39.9	75	1.4	0.0	8.9
40.0 - 49.9	52	1.0	0.0	10
50.0 - 59.9	54	0.3	0.0	5.0
60.0 - 69.9	37	0.5	0.0	4.0
70.0 - 79.9	28	0.2	0.0	3.1
80.0 - 89.9	20	0.2	0.0	5.1
90.0 - 100	118	0.01	0.0	1.0

reduces the extreme and rapid development of aquatic macrophytes and can, if the forest canopy is sufficiently dense, prevent the growth of aquatic plants (Dawson and Kern-Hansen 1978, 1979).

MACROINVERTEBRATES

The production of drift materials in streams is one of the inevitable effects of current, and a variety of aquatic organisms, including many macroinvertebrates, are often found amongst the drift (Dendy 1944; Waters 1972). Macroinvertebrates are a major food source of many stream fishes; thus, factors that affect the macroinvertebrate population can have a major impact on a stream's fishery resources. The theories and data relating invertebrate drift to benthic production and population dynamics have been extensively reviewed by Waters (1972).

Little Wekiva River

Macroinvertebrate drift was highly variable in the Little Wekiva River during our study (Table 57). Macroinvertebrate drift averaged 150 organisms/100 m^3 upstream (Station 3) of the discharge of the Altamonte Springs Regional Wastewater Treatment Plant but averaged 780 organisms/100 m^3 downstream (Station 6). This suggests that macroinvertebrate abundance immediately downstream of the Altamonte Springs Regional Wastewater Treatment Plant is being enhanced by the discharge of organic materials and nutrient rich water. The number of drift organisms in the upper Little Wekiva River, however, declined between Station 6 and

Table 57. Mean macroinvertebrate drift for Little Wekiva River and seven other survey streams. Numbers and grams per 100 m^3 of water with 95% confidence interval.

			Invertebrate Drift	
River	Station	N	Numbers/100 m^3	g/100 m^3
Little Wekiva	3	12	150 ± 121	3.1 ± 2.7
	6	14	780 ± 600	1.3 ± 1.1
	10	14	280 ± 200	0.5 ± 0.2
	12	15	370 ± 200	0.9 ± 0.6
	14	10	220 ± 160	0.5 ± 0.2
	16	15	270 ± 170	0.6 ± 0.3
	17	6	170 ± 200	0.3 ± 0.4
	18	9	140 ± 110	0.5 ± 0.5
	19	10	150 ± 95	0.3 ± 0.2
	21	14	110 ± 55	1.0 ± 1.1
	23	9	120 ± 130	1.0 ± 1.2
	25	15	110 ± 64	0.5 ± 0.3
Alexander Springs	1	6	200 ± 270	3.5 ± 5.6
	2	5	150 ± 180	8.6 ± 22
	3	6	93 ± 97	0.4 ± 0.4
Ichetucknee Springs	1	5	120 ± 210	0.5 ± 0.7
	2	4	40 ± 63	0.1 ± 0.1
	3	4	52 ± 130	0.1 ± 0.3
Alligator Creek	1	4	28 ± 37	0.2 ± 0.3
	2	4	200 ± 540	2.6 ± 6.4
	3	2	25 ± 310	0.1 ± 0.1
Rock Springs	1	4	230 ± 510	1.1 ± 1.8
	2	4	200 ± 200	2.2 ± 2.9
	3	5	100 ± 130	0.7 ± 0.8
Little Econlockhatchee	1	3	91 ± 140	0.8 ± 1.9
	2	1	72 ± -	1.5 ± -
	3	3	300 ± 230	1.0 ± 0.9
Big Wekiva	1	5	490 ± 920	1.0 ± 1.5
	2	7	300 ± 240	1.7 ± 1.9
	3	7	200 ± 120	0.9 ± 0.6
	4	5	430 ± 720	0.7 ± 1.2
Hog Town	1	4	110 ± 130	1.4 ± 2.1
	2	4	88 ± 200	4.7 ± 9.8
	3	4	97 ± 200	0.6 ± 0.7

Station 12 but averaged > 250 organisms/100 m^3. In the lower Little Wekiva River, macroinvertebrate drift declined further but tended to be higher in the reaches where aquatic plants were abundant (Table 57). Macroinvertebrate drift averaged $\geq$ 140 organisms/100 m^3 between Station 14 and Station 19 but $\leq$ 120 organisms/100 m^3 between Station 19 and the confluence with the Wekiva River.

Survey Streams

We measured macroinvertebrate drift in 7 other streams to provide a comparison between the Little Wekiva River and other Florida streams. Similar to our findings in the Little Wekiva River, macroinvertebrate drift was highly variable at different sampling stations and at individual stations over time in the survey streams (Table 57). Drift rates of macroinvertebrates, however, were generally comparable to those measured in the Little Wekiva River. There was also a tendency for macroinvertebrate drift to be higher downstream of wastewater treatment plants (i.e., Station 2 in Alligator Creek and Station 3 in the Little Econlockhatchee River) and areas where aquatic plants were abundant (i.e., Stations 1 and 2 in Alexander Springs and Rock Springs Run; Station 1 in Ichetucknee Springs; Wekiva River).

Macroinvertebrate populations, as well as their drift rates, are strongly influenced by a variety of biotic, chemical, and physical factors (Hynes 1970). Consequently, it is extremely difficult to obtain quantitative data on the macroinvertebrate fauna of streams, and such data as can be obtained are bound to be approximate (Hynes 1970). Our observations suggest macroinvertebrate drift is greater during periods of higher streamflow. This probably occurs because current velocities increase, and the flowing waters have a greater chance of removing macroinvertebrates from aquatic macrophytes and the stream bottom. Macroinvertebrate drift in the Florida streams, however, was comparable to that measured in the nutrient-rich streams of Iowa (Zimmer and Bachmann 1978). Zimmer and Bachmann (1978) demonstrated invertebrate drift density was related to habitat diversity. Our data indicate that drift density tends to be higher in areas with aquatic macrophytes (greater habitat diversity) than areas having only shifting sand bottoms. This also agrees with the findings of Percival and Whitehead (1929) who were among the first to show that stream reaches with aquatic macrophytes contain much larger and more varied invertebrate populations than those without aquatic macrophytes.

Our studies also indicate that the discharges from the wastewater treatment plants are probably increasing macroinvertebrate abundance in stream reaches immediately downstream. This agrees with Hynes (1960) and others who have shown that nutrient enrichment usually causes an increase in the density of the normal benthic invertebrate fauna, but that qualitative changes in the fauna can occur if organic loadings become excessive. The variable nature of macroinvertebrate drift in the Florida streams, however, makes it impossible at this time to definitively document the factors directly affecting the drift of organisms. Additional research will have to be conducted before any comprehensive understanding of the factors influencing macroinvertebrate production in Florida streams can be achieved.

FISH

A major concern regarding the discharge of domestic wastewaters to any aquatic system is the potential effect(s) on the fishery resources. Early fisheries studies demonstrated that the discharge of excessive amounts of untreated sewage to streams caused decreases in the number and kinds, abundance per unit area, and average size of fish (Kofoid 1903; Thompson and Hunt 1930; Larimore and Smith 1963). These studies also noted that the detrimental effects on the fisheries were not due to a lack of fertility or food but to conditions or substances that result from untreated sewage or its products of decomposition that fish can not tolerate. The most important factor influencing fish populations was the loss of dissolved oxygen due to the discharge of waters with a high biochemical oxygen demand (BOD). These studies and others, however, also showed that discharges of domestic sewage within certain limits, or discharges from wastewater treatment plants which removed significant amounts of the organic load, often increased the overall productivity of the stream and led to increased fish abundance (Kofoid 1903; Thompson and Hunt 1930; Brinley 1943; Swingle 1953; Odum 1956; Larimore and Smith 1963).

Little Wekiva River

The Altamonte Springs Regional Wastewater Treatment Plant discharged a significant quantity of nutrient-rich water to the Little Wekiva River during 1985 and 1986 (Tables 4, 34, and 35). We collected 33 species of fish from the river during our study (Table 58). Mosquito fish (Gambusia affinis) constituted about 49% of the total number of fish caught but represented < 1% of the biomass caught. Sport fish comprised about 36% of the total number of fish caught and 53% of the total fish biomass collected. Largemouth bass (Micropterus salmoides) represented 3.4% of the total number of fish caught and about 19% of the total weight of fish caught. The distribution and abundance of fish, however, varied considerably along the length of the Little Wekiva River.

We sampled above and below the discharge from the Altamonte Springs Regional Wastewater Treatment Plant to determine if the discharges of treated municipal wastewater were causing a reduction in the number of fish species, abundance per unit area, and average size of fish in the upper Little Wekiva River. Our sampling sites were just upstream of Station 3 and Station 6. These sections of the Little Wekiva River had similar stream widths and mean depths. We did not find any significant alteration in the species composition of the fish population. We collected 17 species of fish above and 13 species of fish below the discharge. The higher number of species collected at Station 3 was due to the collection of one Florida spotted gar

Table 58. Total fish species for sample streams and percentage importance by weight and number. The number under stream name is the total number of species collected.

Stream	Name	Percentage of all fish collected over time: Number	Weight
Little Wekiva[1]	Florida spotted gar	0.6	6.4
(33)	Longnose gar	0.3	4.7
	Bowfin	0.6	19.4
	Gizzard shad	0.1	1.0
	Redfin pickerel	0.2	0.1
	Chain pickerel	0.1	1.0
	Golden shiner	1.2	1.3
	Taillight shiner	<0.1	<0.1
	Lake chubsucker	2.5	8.7
	Yellow bullhead	0.7	2.7
	Brown bullhead	0.1	0.5
	White catfish	0.1	0.4
	Tadpol madtom	<0.1	<0.1
	Speckled madtom	<0.1	<0.1
	American eel	0.4	3.5
	Seminole killifish	0.5	0.1
	Bluefin killifish	0.2	<0.1
	Mosquito fish	49.2	0.4
	Least killifish	1.5	<0.1
	Sailfin molly	1.0	0.1
	Brook silverside	<0.1	<0.1
	Pirate perch	0.1	<0.1
	Bluespotted sunfish	<0.1	<0.1
	Redbreast sunfish	17.8	16.8
	Warmouth	1.2	2.2
	Bluegill	2.6	1.9
	Dollar sunfish	0.2	0.1
	Redear	1.0	3.1
	Spotted sunfish	9.5	6.6
	Largemouth bass	3.4	18.6
	Black crappie	0.1	0.3
	Blackbanded darter	0.2	<0.1
	Unidentified shiner	4.6	0.1
Alexander Springs	Florida spotted gar	1.0	3.6
(23)	Longnose gar	0.2	0.4
	Bowfin	2.8	20.0
	Redfin pickerel	0.4	0.2
	Chain pickerel	0.2	0.8
	Golden shiner	5.4	1.2
	Lake chubsucker	14.9	29.5
	Brown bullhead	0.2	0.1
	White catfish	0.6	2.0
	American eel	0.6	0.5

Table 58. Continued

Stream	Name	Percentage of all fish collected over time: Number	Percentage of all fish collected over time: Weight
Alexander Springs (continued)	Seminole killifish	4.8	0.4
	Mosquito fish	0.6	<0.1
	Sailfin molly	0.6	<0.1
	Bluespotted sunfish	0.8	<0.1
	Redbreast sunfish	18.5	3.4
	Warmouth	1.2	0.8
	Bluegill	9.5	2.3
	Redear	6.3	2.6
	Spotted sunfish	14.9	2.8
	Largemouth bass	10.1	16.1
	Blackbanded darter	0.2	<0.1
	Unidentified shiner	3.0	<0.1
	Striped mullet	3.0	13.5
Itchetucknee (26)	Bowfin	0.3	9.2
	Redfin pickerel	4.4	4.0
	Golden shiner	0.2	<0.1
	Lake chubsucker	4.9	4.1
	Spotted sucker	0.3	2.2
	Yellow bullhead	1.9	3.7
	Tadpol madtom	0.1	<0.1
	American eel	2.5	12.5
	Seminole killifish	0.2	0.1
	Starhead topminnow	0.4	<0.1
	Bluefin killifish	0.6	<0.1
	Mosquito fish	1.2	<0.1
	Sailfin molly	1.5	<0.1
	Pirate perch	2.6	0.3
	Everglades pygmy sunfish	0.1	<0.1
	Redbreast sunfish	2.2	1.8
	Warmouth	0.2	0.3
	Bluegill	0.4	0.4
	Redear	1.4	2.5
	Spotted sunfish	19.6	11.7
	Largemouth bass	4.0	14.9
	Suwannee Bass	11.7	25.2
	Black crappie	0.3	0.8
	Unidentified shiner	36.6	0.6
	Hogchoker	0.9	0.3
	Needlefish	0.1	0.2
Alligator Creek[1] (28)	Florida spotted gar	0.1	0.5
	Longnose gar	<0.1	1.7
	Bowfin	0.6	14.8
	Gizzard shad	0.2	0.3
	Threadfin shad	2.3	0.4

Table 58. Continued

Stream	Name	Percentage of all fish collected over time: Number	Weight
Alligator Creek (continued)	Redfin pickerel	<0.1	<0.1
	Chain pickerel	0.9	5.5
	Golden shiner	5.4	5.5
	Lake chubsucker	1.5	3.7
	Brown bullhead	<0.1	0.5
	American eel	<0.1	0.3
	Golden topminnow	0.2	<0.1
	Seminole killifish	3.6	0.9
	Bluefin killifish	0.7	<0.1
	Mosquito fish	0.5	<0.1
	Least killifish	<0.1	<0.1
	Sailfin molly	0.1	<0.1
	Brook silverside	0.4	<0.1
	Everglades pygmy sunfish	<0.1	<0.1
	Redbreast sunfish	12.7	8.8
	Warmouth	2.0	1.6
	Bluegill	19.3	10.5
	Dollar sunfish	0.3	<0.1
	Redear	32.8	11.1
	Spotted sunfish	4.5	1.7
	Largemouth bass	9.3	31.7
	Black crappie	<0.1	<0.1
	Unidentified shiner	2.5	0.1
Rock Springs (22)	Bowfin	0.3	16.5
	Lake chubsucker	1.6	5.4
	Yellow bullhead	1.5	2.0
	Brown bullhead	0.6	1.9
	Tadpol madtom	0.4	<0.1
	American eel	0.2	2.0
	Seminole killifish	6.3	2.2
	Mosquito fish	0.8	<0.1
	Least killifish	0.1	<0.1
	Sailfin molly	2.5	0.1
	Brook silverside	0.2	<0.1
	Pirate perch	0.6	<0.1
	Redbreast sunfish	22.0	22.2
	Warmouth	0.8	0.5
	Bluegill	0.3	0.3
	Redear	0.6	1.5
	Spotted sunfish	20.0	14.8
	Largemouth bass	5.9	28.1
	Blackbanded darter	1.9	0.1
	Unidentified shiner	30.0	0.8
	Striped mullet	0.1	1.1
	Needlefish	0.2	0.1

Table 58. Continued

Stream	Name	Percentage of all fish collected over time	
		Number	Weight
Little Econlockhatchee[1]	Florida spotted gar	0.3	0.3
	Longnose gar	2.1	4.4
(21)	Bowfin	1.1	6.0
	Gizzard shad	1.6	3.5
	Chain pickerel	0.3	0.7
	Lake chubsucker	2.4	4.8
	Yellow bullhead	0.3	0.5
	Channel catfish	0.3	2.7
	White catfish	20.1	44.6
	American eel	0.5	0.3
	Mosquito fish	0.3	<0.1
	Redbreast sunfish	16.4	5.0
	Warmouth	1.9	0.5
	Bluegill	9.9	2.9
	Redear	8.0	6.8
	Spotted sunfish	9.7	1.4
	Largemouth bass	8.8	11.4
	Striped bass	0.3	3.1
	Black crappie	1.6	1.0
	Unidentified shiner	13.9	0.1
	Needlefish	0.3	0.1
Wacissa	Florida spotted gar	0.6	3.3
	Longnose gar	0.3	0.3
(30)	Bowfin	3.5	49.0
	Gizzard shad	0.1	<0.1
	Redfin pickerel	2.4	2.2
	Lake chubsucker	2.5	4.0
	Sharpfin chubsucker	7.1	3.8
	Spotted sucker	6.6	15.8
	Yellow bullhead	0.3	0.6
	Tadpol madtom	0.1	<0.1
	American eel	0.8	2.1
	Seminole killifish	1.3	0.2
	Starhead topminnow	1.3	<0.1
	Bluefin killifish	0.1	<0.1
	Mosquito fish	2.4	<0.1
	Sailfin molly	0.6	<0.1
	Brook silverside	0.6	<0.1
	Pirate perch	2.3	0.1
	Everglades pygmy sunfish	0.3	<0.1
	Bluespotted sunfish	0.1	<0.1
	Redbreast sunfish	3.3	1.3
	Warmouth	0.3	0.1
	Bluegill	0.6	0.2

Table 58. Continued

Stream	Name	Percentage of all fish collected over time: Number	Weight
Wacissa (continued)	Redear	0.4	0.2
	Spotted sunfish	17.3	4.6
	Largemouth bass	8.2	7.9
	Unidentified shiner	35.3	0.4
	Striped mullet	0.6	3.8
	Hogchoker	0.4	0.1
	Spotfin mojarra	0.3	<0.1
Wekiva[1] (19)	Florida spotted gar	0.1	0.5
	Bowfin	0.1	<0.1
	Golden shiner	0.8	2.5
	Lake chubsucker	1.8	7.9
	Yellow bullhead	0.2	<0.1
	Tadpol madtom	0.2	<0.1
	Seminole killifish	16.6	4.8
	Mosquito fish	0.8	<0.1
	Sailfin molly	0.9	<0.1
	Brook silverside	0.6	<0.1
	Redbreast sunfish	39.0	33.0
	Warmouth	0.6	0.7
	Bluegill	1.4	1.7
	Redear	1.2	5.1
	Spotted sunfish	9.4	7.1
	Largemouth bass	8.6	33.8
	Blackbanded darter	0.4	<0.1
	Unidentified shiner	17.1	0.5
	Striped mullet	0.2	2.3
Alafia (24)	Florida spotted gar	0.2	5.0
	Longnose gar	0.5	8.5
	Yellow bullhead	0.2	<0.1
	White catfish	0.4	<0.1
	American eel	0.5	2.6
	Seminole killifish	10.8	1.3
	Mosquito fish	4.1	<0.1
	Sailfin molly	1.8	0.1
	Brook silverside	2.6	0.1
	Pirate perch	1.4	0.1
	Redbreast sunfish	0.2	<0.1
	Warmouth	0.4	<0.1
	Bluegill	5.6	1.8
	Dollar sunfish	0.2	<0.1
	Redear	0.5	1.3
	Spotted sunfish	37.0	8.9
	Largemouth bass	1.8	20.6
	Unidentified shiner	19.2	0.7

Table 58. Continued

Stream	Name	Percentage of all fish collected over time	
		Number	Weight
Alafia (continued)	Striped mullet	2.8	37.8
	Hogchoker	0.9	0.1
	Spotfin mojarra	2.8	0.6
	Blue tilapia	5.5	6.9
	Blackchin tilapia	0.2	2.1
	Sheephead	0.5	1.5
Reedy[1]	Florida spotted gar	0.5	2.2
	Bowfin	10.6	65.4
(19)	Redfin pickerel	0.5	0.1
	Golden shiner	1.0	0.3
	Lake chubsucker	3.5	2.8
	Yellow bullhead	0.5	0.1
	Brown bullhead	1.5	0.5
	Walking catfish	0.5	0.2
	Sailfin molly	0.5	<0.1
	Pirate perch	0.5	<0.1
	Bluespotted sunfish	0.5	<0.1
	Warmouth	17.6	3.1
	Bluegill	33.2	4.2
	Dollar sunfish	1.5	<0.1
	Redear	6.0	4.9
	Spotted sunfish	15.6	4.1
	Largemouth bass	4.0	10.9
	Black crappie	1.5	1.0
	Unidentified shiner	0.5	<0.1
Pottsburg[1]	Longnose gar	2.0	12.7
	Gizzard shad	5.2	0.9
(17)	Threadfin shad	0.9	0.1
	Golden shiner	0.7	0.3
	White catfish	0.7	2.5
	Seminole killifish	0.9	0.2
	Bluefin killifish	0.5	<0.1
	Mosquito fish	0.2	<0.1
	Redbreast	30.2	17.2
	Warmouth	11.9	5.8
	Bluegill	24.8	20.2
	Redear	4.0	6.8
	Spotted sunfish	4.7	1.6
	Largemouth bass	8.9	18.2
	Black crappie	0.7	0.1
	Swamp darter	0.2	<0.1
	Striped mullet	3.4	13.5

Table 58. Continued

Stream	Name	Percentage of all fish collected over time: Number	Weight
Mills[1] (19)	Florida spotted Gar	4.7	7.9
	Bowfin	0.5	4.8
	Gizzard shad	3.6	3.8
	Golden shiner	10.9	1.3
	Yellow bullhead	1.0	0.9
	Brown bullhead	3.1	4.7
	Channel catfish	0.5	0.7
	White catfish	7.3	7.1
	Mosquito fish	0.5	<0.1
	Brook silverside	0.5	<0.1
	Pirate perch	0.5	<0.1
	Redbreast	0.5	0.1
	Warmouth	5.2	4.7
	Bluegill	11.4	4.4
	Redear	6.2	5.1
	Spotted sunfish	5.2	0.9
	Largemouth bass	7.3	11.5
	Black crappie	1.0	1.6
	Striped mullet	29.7	40.2
St. Marks (27)	Florida spotted gar	0.2	1.4
	Longnose gar	0.2	0.5
	Bowfin	0.7	27.4
	Redfin pickerel	0.1	<0.1
	Chain pickerel	0.1	<0.1
	Taillight shiner	0.1	0.1
	Lake chubsucker	6.5	10.2
	Spotted sucker	6.1	8.4
	Tadpol madtom	0.1	<0.1
	American eel	1.2	8.1
	Starhead topminnow	0.6	0.1
	Mosquito fish	1.4	<0.1
	Least killifish	0.1	<0.1
	Brook silverside	4.4	0.1
	Pirate perch	0.2	<0.1
	Everglades pygmy sunfish	0.3	<0.1
	Redbreast sunfish	1.0	0.9
	Warmouth	2.4	1.6
	Bluegill	0.3	0.4
	Dollar sunfish	0.5	<0.1
	Redear	0.1	0.5
	Spotted sunfish	27.3	17.0
	Largemouth bass	5.9	20.1
	Blackbanded darter	0.2	<0.1
	Unidentified shiner	39.0	0.7
	Striped mullet	0.1	1.9

Table 58. Continued

Stream	Name	Percentage of all fish collected over time Number	Weight
St. Marks (continued)	Hogchoker	0.3	0.0
Econlockhatchee	Florida spotted gar	0.5	0.5
	Bowfin	1.9	36.1
(15)	Yellow bullhead	0.5	3.2
	American eel	1.9	3.4
	Mosquito fish	3.4	<0.1
	Least killifish	0.5	<0.1
	Brook silverside	1.4	<0.1
	Redbreast	53.9	22.6
	Warmouth	1.9	0.7
	Bluegill	3.4	1.2
	Spotted sunfish	20.4	7.9
	Largemouth bass	6.3	16.5
	Black crappie	0.5	<0.1
	Unidentified shiner	2.4	<0.1
	Striped mullet	1.0	7.6
Hillsborough	Florida spotted gar	3.5	28.0
	Longnose gar	2.7	13.0
(18)	Bowfin	0.3	8.1
	Golden shiner	0.1	<0.1
	Lake chubsucker	0.5	0.4
	Yellow bullhead	0.3	0.4
	Starhead topminnow	0.1	<0.1
	Mosquito fish	0.6	<0.1
	Brook silverside	1.4	<0.1
	Pirate perch	0.8	0.1
	Redbreast sunfish	14.5	5.3
	Warmouth	6.0	2.2
	Bluegill	6.3	1.8
	Dollar sunfish	0.1	<0.1
	Redear	3.3	3.7
	Spotted sunfish	46.0	16.0
	Largemouth bass	7.0	20.4
	Unidentified shiner	5.8	0.1
Hogtown	Golden shiner	0.2	1.2
	Lake chubsucker	0.2	1.7
(17)	Yellow bullhead	0.3	2.7
	Tadpol madtom	0.1	0.2
	Golden topminnow	1.1	2.2
	Flagfish	0.5	0.5
	Mosquito fish	70.0	30.2
	Least killifish	0.1	<0.1

Table 58. Continued

Stream	Name	Percentage of all fish collected over time	
		Number	Weight
Hogtown (continued)	Sailfin molly	13.0	12.1
	Pirate perch	<0.1	<0.1
	Redbreast sunfish	<0.1	0.1
	Warmouth	0.6	4.4
	Bluegill	1.2	5.7
	Redear	1.4	8.9
	Spotted sunfish	9.8	28.7
	Largemouth bass	<0.1	0.1
	Unidentfied shiner	1.5	1.1
Upper Santa Fe	Florida spotted gar	0.2	0.1
	Longnose gar	3.0	19.6
(27)	Bowfin	1.5	14.0
	Redfin pickerel	0.3	<0.1
	Chain pickerel	0.2	0.6
	Taillight shiner	1.0	<0.1
	Spotted sucker	8.2	35.1
	Brown bullhead	0.2	<0.1
	White catfish	0.2	<0.1
	Tadpol madtom	1.0	<0.1
	American eel	0.7	1.6
	Mosquito fish	1.9	<0.1
	Brooksilverside	3.7	<0.1
	Pirate perch	2.0	0.1
	Bluespotted sunfish	0.2	<0.1
	Redbreast sunfish	18.4	7.5
	Warmouth	6.5	1.5
	Bluegill	2.4	0.3
	Dollar sunfish	0.2	<0.1
	Redear	0.7	<0.1
	Spotted sunfish	3.9	0.4
	Largemouth bass	5.8	15.5
	Suwannee bass	0.2	1.5
	Black crappie	1.9	1.6
	Swamp darter	0.2	<0.1
	Blackbanded darter	0.2	<0.1
	Unidentified shiner	35.4	0.3

[1] Streams with known sewage inputs.

Table 59. Fish stock and standing crop immediately above and below Altamonte Springs Regional Wastewater Treatment Plant discharge in the upper Little Wekiva River.

Date		Section	Stock (number/Ha)		Standing Crop (Kg/Ha)	
			Total Fish	Harvestable Fish	Total Fish	Harvestable Fish
July	1985	Above	21000	0	6	0
		Below	27000	180	72	10
April	1986	Above	36000	41	130	3
		Below	9900	2100	470	210
February	1987	Above	16000	32	73	2
		Below	11000	240	120	44

Table 60. Fish stock estimates for rivers. Mean is listed ± 95% confidence limits.

Stream	Date	Canopy Cover	Fish Population (numbers/ha)	
			Total Fish	Harvestable Fish
Little Wekiva[1]	May '85	Closed	1100	280
		Closed	720	210
		Open	1200	320
		Open	3000	150
	March '86	Closed	1000	210
		Open	1000	200
	Feb. '87	Closed	1800	310
		Open	3300	320
	Mean		1600 ± 820	250 ± 55
Alexander Springs	Aug. '85	Closed	130	28
		Closed	58	8
		Open	360	51
		Open	590	110
	Feb. '86	Closed	520	30
		Open	670	56
	Nov. '86	Closed	380	39
		Open	260	21
	Mean		370 ± 180	43 ± 26
Ichetucknee Springs	Oct. '85	Closed	1000	21
		Open	1100	46
	May '86	Closed	970	27
		Open	720	42
	Mean		960 ± 280	34 ± 19
Alligator Creek[1]	July '85	Closed	5400	610
		Open	11000	850
		Open	2300	110
		Open	4700	230
	Feb. '86	Closed	2100	310
		Open	2000	640
	Nov. '86	Open	1500	160
		Open	2200	330
	Mean		3800 ± 2600	410 ± 220
Rock Springs	Aug. '85	Closed	1300	350
		Closed	700	82
		Open	4500	230
	March '86	Closed	1100	53
		Open	3300	150
	Jan. '87	Closed	880	41
		Open	3000	180
	Mean		2100 ± 1400	160 ± 100

Table 60. Continued

Stream	Date	Canopy Cover	Fish Population (numbers/ha) Total Fish	Harvestable Fish
Little Econlockhatchee[1]	July '85	Closed	650	290
		Closed	310	150
		Closed	570	470
	Feb. '86	Closed	720	160
		Closed	440	79
	Jan. '87	Closed	1000	420
		Closed	330	140
	Mean		570 ± 230	240 ± 140
Wacissa River	Oct. '85	Open	1500	3
		Open	1700	18
	March '86	Open	1000	75
		Open	820	44
	Nov. '86	Closed	930	28
		Open	2300	100
	Mean		1400 ± 610	45 ± 39
Wekiva[1]	Sept. '85	Closed	500	97
		Open	590	100
	March '86	Closed	2000	290
		Open	1200	140
	Jan. '87	Closed	2700	120
		Closed	1200	250
	Mean		1400 ± 820	170 ± 87
Alafia River	April '86	Open	150	0
		Open	170	11
	Jan. '87	Closed	170	12
		Open	500	15
	Mean		250 ± 250	10 ± 10
Reedy Creek[1]	March '86	Closed	650	52
		Closed	550	83
	Jan. '87	Closed	250	25
		Closed	490	67
	Mean		490 ± 270	57 ± 39
Pottsburg Creek[1]	March '86	Closed	1200	470
		Open	1100	480
	Feb. '87	Closed	1200	350
		Open	1300	430
	Mean		1200 ± 160	430 ± 94

Table 60. Continued

Stream	Date	Canopy Cover	Fish Population (numbers/ha) Total Fish	Harvestable Fish
Mills Creek[1]	March '86	Open	450	89
		Open	300	110
	Nov. '86	Closed	160	36
		Open	110	34
	Mean		260 ± 240	66 ± 59
St. Marks River	May '86	Open	2200	170
		Open	1400	57
	Jan. '87	Open	5900	88
		Open	1400	30
	Mean		2700 ± 3400	86 ± 94
Econlockhatchee	Feb. '86	Closed	710	72
		Closed	270	50
	Jan. '87	Closed	250	55
		Closed	610	52
		Closed	280	40
	Mean		420 ± 270	54 ± 16
Hillsborough	April '86	Closed	620	80
		Open	560	19
	Jan. '87	Closed	3400	210
		Closed	1200	120
	Mean		1400 ± 2200	110 ± 130
Hogtown	April '86	Closed	15000	0
		Open	56000	0
	Nov. '86	Closed	11000	0
		Open	1100	0
	Mean		21000 ± 38000	0
Upper Santa Fe	April '86	Closed	2200	67
		Open	820	59
	Nov. '86	Closed	1000	320
		Open	710	140
	Mean		1200 ± 1100	150 ± 195

[1]Streams with known sewage inputs.

(*Lepisosteus platyrhincus*), one seminole killifish (*Fundulus seminolis*), one yellow bullhead (*Ictalurus natalis*), and two golden shiners (*Notemigonus crysoleucas*). We often captured a greater number of fish above the discharge (Table 59), but this was due primarily to the capture of large numbers of mosquito fish (*Gambusia affinis*) and redbreast sunfish (*Lepomis auritus*). The total and harvestable standing crops (kg/ha) of fish, however, were significantly greater downstream of the discharge from the Altamonte Springs Regional Wastewater Treatment Plant (Table 59). The standing crop of harvestable sport fish was < 5 kg/ha upstream of Station 3 but ranged between 10 and 210 kg/ha at Station 6. The stock (numbers/ha) of harvestable fish was also greater downstream of the Altamonte Springs Regional Wastewater Treatment Plant (Table 59) and ranged from 180 to 2100 fish/ha. Upstream of the discharge, the stock of harvestable fish was < 45 fish/ha on all sampling dates. The discharges from the Altamonte Springs Regional Wastewater Treatment Plant, therefore, seemed to be enhancing fish standing crops in the upper Little Wekiva River rather than decreasing them.

We captured 33 species of fish in the lower Little Wekiva River. The increased number of species reflected the greater habitat diversity in the lower Little Wekiva River. Thompson and Hunt (1930) and Larimore and Smith (1963) also demonstrated that the number of species collected from Illinois streams increased significantly downstream as the streams became larger. The total stock of fish (numbers/ha), however, declined significantly in the lower Little Wekiva River, averaging 1600 fish/ha (Table 60), but reduced numbers of fish could not be attributed to the discharge of treated wastewater from the Altamonte Springs Regional Wastewater Treatment Plant.

The total number of fish declined primarily because fewer small fish like the mosquito fish were captured. Total fish standing crops during the study also averaged 150 kg/ha (Table 61). The decline in the total number of fish, therefore, seemed to be attributable primarily to the fact that large fish were more abundant in the lower Little Wekiva River. For example, the stock of harvestable fish was significantly higher, averaging 250 fish/ha (Table 60). The dominance of large fish, however, is not an unusual occurrence as streams become larger. Thompson and Hunt (1930) and Larimore and Smith (1963) also demonstrated that the total number of fish collected per unit area in streams decreases downstream and that the average size of the fish increases.

Our data do not indicate that the discharges of treated municipal wastewaters are causing any reduction in the number of fish species, fish abundance per unit area, or the average size of fish in the Little Wekiva River. The stock (Table 60) and standing crop (Table 61) of fish in the lower Little Wekiva River, however, were highly variable over time and in different habitats, suggesting other ecological factors besides nutrient enrichment influenced fish populations. Our sampling indicated that reaches of the stream that supported an abundance of aquatic macrophytes due to an open forest canopy tended to support a greater stock (numbers/ha) and standing crop (kg/ha) of fish.

Table 61. Fish standing crops estimates for streams. Mean is listed ± 95% confidence interval.

Stream	Date	Canopy Cover	Fish Population (kg/ha) Total Fish	Harvestable Fish
Little Wekiva[1]	May '85	Closed	67	34
		Closed	54	32
		Open	250	83
		Open	220	18
	March '86	Closed	91	34
		Open	100	25
	Feb. '87	Closed	78	37
		Open	340	62
	Mean		150 ± 87	41 ± 18
Alexander Springs	Aug. '85	Closed	9	2.5
		Closed	11	2.9
		Open	57	22
		Open	62	18
	Feb. '86	Closed	48	5.5
		Open	75	6.9
	Nov. '86	Closed	43	6.9
		Open	52	4.9
	Mean		45 ± 20	8.7 ± 6.1
Ichetucknee Springs	Oct. '85	Closed	44	10
		Open	49	14
	May '86	Closed	55	5.2
		Open	43	6.1
	Mean		48 ± 9	8.9 ± 6.7
Alligator Creek[1]	July '85	Closed	200	65
		Closed	500	190
		Open	170	73
		Open	98	21
	Feb. '86	Closed	190	46
		Open	160	82
	Nov. '86	Open	34	20
		Open	77	36
	Mean		180 ± 120	67 ± 47
Rock Springs	Aug. '85	Closed	130	51
		Closed	32	13
		Open	100	40
	March '86	Closed	31	6.5
		Open	75	14
	Jan. '87	Closed	21	4.2
		Open	72	31
	Mean		66 ± 38	23 ± 16

Table 61. Continued

Stream	Date	Canopy Cover	Fish Population (kg/ha) Total Fish	Harvestable Fish
Little Econlockhatchee[1]	July '85	Closed	120	100
		Closed	65	50
		Closed	240	230
	Feb. '86	Closed	93	54
		Closed	130	80
	Jan. '87	Closed	110	61
		Closed	57	20
	Mean		120 ± 57	85 ± 63
Wacissa River	Oct. '85	Open	150	0.6
		Open	200	4.6
	March '86	Open	100	18
		Open	49	6.0
	Nov. '86	Closed	45	2.0
		Open	200	31
	Mean		120 ± 72	10 ± 12
Wekiva[1]	Sept. '85	Closed	53	15
		Open	38	22
	March '86	Closed	86	53
		Open	38	14
	Jan. '87	Closed	54	19
		Closed	60	38
	Mean		55 ± 18	27 ± 16
Alafia River	April '86	Open	18	0
		Open	48	3.6
	Jan. '87	Closed	18	11
		Open	28	16
	Mean		28 ± 18	7.6 ± 12
Reedy Creek[1]	March '86	Closed	170	15
		Closed	120	27
	Jan. '87	Closed	8	2.1
		Closed	23	7.7
	Mean		80 ± 123	13 ± 17
Pottsburg Creek[1]	March '86	Closed	120	84
		Open	190	79
	Feb. '87	Closed	70	49
		Open	100	65
	Mean		120 ± 82	69 ± 24

Table 61. Continued

Stream	Date	Canopy Cover	Fish Population (kg/ha) Total Fish	Harvestable Fish
Mills Creek[1]	March '86	Open	83	30
		Open	73	31
	Nov. '86	Closed	54	21
		Open	29	9.4
	Mean		60 ± 38	23 ± 16
St. Marks River	May '86	Open	200	28
		Open	130	13
	Jan. '87	Open	110	45
		Open	35	2.7
	Mean		120 ± 110	22 ± 29
Econlockhatchee	Feb. '86	Closed	42	11
		Closed	26	9.0
	Jan. '87	Closed	81	38
		Closed	14	5.7
		Closed	21	6.4
	Mean		37 ± 29	14 ± 20
Hillsborough	April '86	Closed	40	13
		Open	98	5.2
	Jan. '87	Closed	120	58
		Closed	47	19
	Mean		75 ± 63	24 ± 37
Hogtown	April '86	Closed	12	0
		Open	68	0
	Nov. '86	Closed	7	0
		Open	9	0
	Mean		24 ± 47	0
Upper Santa Fe	April '86	Closed	15	8.8
		Open	110	19
	Nov. '86	Closed	190	110
		Open	280	29
	Mean		150 ± 180	41 ± 72

[1]Streams with known sewage inputs.

Total fish stocks averaged 2100 fish/ha in open forest canopy areas and 1200 fish/ha in closed forest canopy areas (Table 60). Total fish standing crops in areas with an open forest canopy averaged 228 kg/ha versus 73 kg/ha in reaches with a closed forest canopy (Table 61). Standing crops of harvestable fish averaged 47 kg/ha in the open forest canopy areas and 34 kg/ha in closed forest canopy areas (Table 61). Our observations on the distribution of harvestable fish in the lower Little Wekiva River also indicated that the larger harvestable sport fish like the largemouth bass tended to seek deeper waters near aquatic vegetation. For example, the section of stream between Station 17 and Station 18 was dredged during the 1960's, and water depths during our study were generally > 1.5 m in the main channel. The standing crop of harvestable fish in this section averaged 83 kg/ha during May of 1985. The standing crop of harvestable fish in the open forest canopy area between Station 21 and Station 22 averaged only 18 kg/ha, but water depths were < 0.5 m.

Survey Streams

Numerous fishery and ecological studies have been conducted by the Florida Game and Fresh Water Fish Commission on the major rivers of Florida (see review by Bass and Cox 1985). These studies have demonstrated that the streams can be divided into two groups, those of the northwest and those of the peninsula, based on their ichthyofauna and their productivity. Streams of northwest Florida are typically rich in numbers of species of fish but relatively infertile. Streams of peninsular Florida typically have fewer species of fish but are more productive than northwestern streams due to the fact that they are naturally rich in nutrients. Many of the streams of Florida, however, are believed to be experiencing problems of excessive nutrient enrichment due to agricultural, domestic, and industrial pollution (Bass and Cox 1985). Fish kills in some of the larger rivers like the St. Johns River have been attributed to nutrient enrichment, but the effects of nutrient enrichment on the fishery resources of smaller streams like the Little Wekiva River remain poorly understood. Bass and Cox (1985), therefore, recommended that a systematic survey of the streams be initiated.

During our study, we sampled the Little Wekiva River and 16 additional streams to provide a comparative data base that we could use to assess how nutrient enrichment and other limnological factors were affecting the fish populations in smaller Florida streams. We sampled relatively pristine spring-fed streams like Alexander Springs, Ichetucknee Springs, and Wacissa River as well as streams like Alligator Creek, the Little Econlockhatchee River, and Pottsburg Creek that receive major inputs of treated municipal wastewaters (Tables 58, 60, and 61). We collected between 15 and 33 species of fish from the individual streams (Table 58). There was no strong evidence that the discharges of treated municipal effluents were causing major shifts in the species composition of fish in the sampled Florida streams. Differences in the total number of species captured in the individual streams seemed to be due primarily to differences in habitat diversity and the presence or absence of endemic species like the Suwannee bass (*Micropterus notius*) or anadromous species like the American eel (*Anguilla rostrata*), striped bass (*Morone saxatilis*), and Atlantic needlefish (*Strongylura marina*). Our sampling methodology (electrofishing), however, was biased towards fish > 100 mm TL, and we certainly did not collect specimens of all the species that might inhabit a particular stream. For example, we collected only 19 species of fish during our sampling of the Wekiva River, but more than 40 species are known to inhabit the river. Our data, therefore, should not be used to assess either the total number of species that may actually be found in the streams or the potential impacts of nutrient-rich discharges on the populations of rarer fish species. Our data, however, can be used to assess the relative abundance of the larger fish species, especially those that contribute to the sport fish community, and these data do not indicate any significant shifts to dominance by undesirable rough fish in the streams receiving treated wastewaters (Table 58).

Our estimates of total and harvestable fish stocks (numbers/ha), excluding Hogtown Creek (see below), indicated that the streams receiving nutrient-rich discharges from wastewater treatment plants tended, as a group, to support more total and harvestable fish per hectare (Table 60). Harvestable fish stocks for the streams receiving treated wastewaters averaged 230 fish/ha versus 80 fish/ha in the streams receiving no wastewater discharges. Our estimates of the total and harvestable fish standing crops (kg/ha) also indicated that the streams receiving discharges of treated wastewater tended to support more fish

(Table 61). The standing crops of harvestable fish in the streams receiving treated wastewater averaged, as a group, 46 kg/ha versus 18 kg/ha in the streams receiving no treated wastewater discharges. Three of the unpolluted spring-fed streams (Alexander Springs, Ichetucknee Springs, and Wacissa River) had standing crops of harvestable fish that averaged < 11 kg/ha. Three of the streams (Alligator Creek, Little Econlockhatchee River, and Pottsburg Creek) that received significant inputs of treated wastewater had standing crops of harvestable fish that averaged > 65 kg/ha. The growth rates of two sport fish, redbreast sunfish and largemouth bass, also tended to be greater in the streams receiving treated wastewaters (Tables 62 and 63). Based on these data, we conclude that the discharges of treated municipal wastewater, given their current levels of treatment and flow, are not causing a decrease in the abundance or growth of fishes. The discharges of treated wastewater seem to be enhancing the abundance of fish, especially harvestable fish. This agrees with numerous fisheries studies that have shown limited discharges of untreated domestic sewage or discharges of nutrient-rich effluent from wastewater treatment plants, which remove a significant amount of the organic load, often lead to increases in fish abundance (Kofoid 1903; Thompson and Hunt 1930; Brinley 1943; Swingle 1953; Odum 1956; Larimore and Smith 1963; McFadden et al. 1965; Lewis et al. 1981).

Studies of lakes and ponds have demonstrated that nutrient enrichment, especially the addition of phosphorus, can significantly increase total and harvestable fish production by

Table 62. Mean growth of redbrested sunfish for age classes I-IV, back-calculated from examinations of otolith annuli in whole view. Growth is recorded in mm total length (TL) and N is the total number of fish examined.

Stream	N	Mean Size (mm) for Age Classes I	II	III	IV
Little Wekiva[1]	280	67	100	134	165
Alexander Springs	117	64	101	129	162
Ichetucknee	10	51	91	135	-
Alligator Creek[1]	184	73	136	167	184
Rock Springs	154	66	108	143	168
Little Econlockhatchee[1]	19	82	-	-	-
Wacissa	21	44	86	137	-
Wekiva	132	64	107	139	181
Pottsburg[1]	68	89	137	141	-
St. Marks	7	53	90	105	141
Econlockhatchee	51	68	116	168	-
Hillsborough	20	60	93	119	149
Upper Santa Fe	34	57	109	146	170
	Means of Means (Range)	64 (44-89)	106 (86-137)	139 (105-168)	164 (141-184)

[1]Streams receiving known sewage effluents.

Table 63. Mean growth of largemouth bass for age classes I-IV, back-calculated from examinations of otolith annuli in whole view. Growth is recorded in mm total length (TL) and N is the total number of fish examined.

Stream	N	Mean Size (mm) for Age Classes I	II	III	IV
Little Wekiva[1]	138	126	199	248	274
Alexander Springs	23	120	189	224	266
Ichetucknee	24	125	196	249	341
Alligator Creek[1]	201	128	242	305	350
Rock Springs	33	113	187	239	285
Little Econlockhatchee[1]	13	145	226	249	310
Wacissa	86	87	181	241	-
Wekiva	47	115	182	225	269
Pottsburg[1]	30	117	222	276	332
Mills[1]	6	108	188	266	283
St. Marks	76	116	174	239	271
Econlockhatchee	5	83	115	136	167
Hillsborough	27	132	194	248	-
Upper Santa Fe	11	112	173	226	264
	Mean of Means (Range)	116 (83-145)	191 (115-242)	241 (136-305)	284 (167-350)

[1]Streams receiving known sewage effluents.

increasing lake productivity (Oglesby 1977; Hanson and Leggett 1982; Jones and Hoyer 1982; Bays and Crisman 1983). We found no significant relationship in our study streams between the total standing crop of fish and either total phosphorus or total nitrogen concentrations. Hogtown Creek, however, had an average depth < 0.2 m during our sampling period and supported no harvestable fish. We also learned after our sampling of the Alafia River that the river had received discharges of acid waste from some phosphate processing plants and that these discharges had contributed to fish kills. After eliminating these streams from our data base, the standing crops of harvestable fish in our study streams were significantly correlated to stream total phosphorus ($r = 0.55$; $P \leq 0.05$)) and total nitrogen ($r = 0.45$;$P \leq 0.10$) concentrations. Data presented by Kautz (1981) and Bass and Cox (1985) further suggest that the standing crop of sport fish in Florida's rivers are correlated to nutrient levels. Recent studies by the Florida Game and Fresh Water Fish Commission on the Suwannee River also indicate that the productivity of sport fish increases downstream of streams draining phosphate mining areas (Krummrich et al. 1985). We, therefore, conclude that the addition of nutrients to many of Florida's small streams will most likely lead to an increase in the abundance of harvestable fish because of an increase in stream productivity. In the case of discharges from domestic wastewater treatment plants, the fish populations should not be adversely affected if the organic loadings are reduced to levels that prevent the loss of dissolved oxygen and no toxic substances are discharged. The release of small amounts of organic matter, however, may stimulate fish production by providing a food source for macroinvertebrates.

We agree with Bass and Cox (1985) that many other factors besides nutrient-enrichment including depth, current velocity, and habitat quality exert profound influences upon the biological production of streams. Our estimates of the average total stock (numbers/ha) of fish in the study streams ranged from 250 fish/ha at the Alafia River to 21,000 fish/ha at Hogtown Creek (Table 60). Harvestable stocks of fish averaged between 0 at Hogtown Creek and 430 fish/ha at Pottsburg Creek. The large number of fish captured at Hogtown Creek and the lack of harvestable fish were due to the extremely shallow nature of the stream at the time of our sampling. Water depths at the sampling sites averaged < 0.2 m, and we captured many small fish like the mosquito fish (Table 58). Mosquito fish and sailfin mollys (Poecilia latipinna) constituted 83% of the total number of fish collected and 42% of the total weight of fish collected. Small sport fish constituted more than 50% of the total weight of fish collected; thus, larger sport fish must have migrated to deep water refugia that were not sampled. Hogtown Creek, like the upper Little Wekiva River above the Altamonte Springs Regional Wastewater Treatment Plant, however, demonstrates that the small shallow streams of Florida, like those of Illinois (Thompson and Hunt 1930; Larimore and Smith 1963), support large numbers of small fish but few large or harvestable fish. Some of the variability in stock size and standing crops of fish in the study streams, however, is undoubtedly due to other factors that affect habitat quality. During our studies, we generally captured more fish from areas of the streams having aquatic macrophytes (i.e., Alexander Springs). This agrees with the findings of Bass and Cox (1985), but, given the inherent variability of fisheries data we can not at this time delineate a strong statistical relationship between fish and aquatic macrophytes in streams. Data provided by Bass and Cox (1985) also show a significant inverse relationship between stream gradient and the weight of sport fish ($r = -0.70$). Additional research, however, will have to be conducted before any comprehensive understanding of the factors influencing fish populations in Florida's streams can be achieved.

CONCLUSIONS AND RECOMMENDATIONS

The development of excessive growths of aquatic weeds in the Little Wekiva River during the late 1970's and early 1980's caused concern regarding the effects of cultural eutrophication on the Little Wekiva River. Our studies and those of McClelland (1982) have demonstrated that the anthropogenic discharges, especially those from the Altamonte Springs Regional Wastewater Treatment Plant, are responsible for a significant nutrient enrichment of the Little Wekiva River as well as changes to general stream chemistry. We have, however, found no evidence that the distribution and abundance of aquatic plants in the Little Wekiva River are related to nutrient enrichment (see also Canfield and Hoyer 1988, Appendix I).

Aquatic macrophytes in the Little Wekiva River and most of our other study streams contained < 2% of the annual nutrient loads discharged from the streams. Aquatic macrophyte standing crops in unpolluted spring-fed streams were equivalent or greater than the standing crops measured in streams receiving significant discharges of nutrient-rich water from anthropogenic sources. We also found no correlations between nutrient concentrations or loading rates and macrophyte standing crops for our 17 study streams. In addition to our work, studies on northern streams have suggested that the standing crops of aquatic macrophytes are not limited by nutrients unless phosphorus concentrations fall well below 0.02 mg/L (Owens and Edwards 1961; Casey and Westlake

1974; Kern-Hansen and Dawson 1978). We, therefore, conclude that the control of nutrients discharged from sources like the Altamonte Springs Regional Wastewater Treatment Plant can not be used as an indirect method for controlling the abundance of aquatic plants in the Little Wekiva River, even if stream nutrient concentrations could be reduced to their pristine levels.

The major factors controlling the distribution and abundance of aquatic vegetation in streams are substrate quality, current velocity, and light availability (Butcher 1933). For our study streams, shading by streambank vegetation was the dominant factor governing the location and abundance of aquatic macrophytes. Statistical analyses demonstrated that the average and maximum standing crops of aquatic macrophytes in Florida streams were strongly related to forest canopy coverage, and the relationships were described by the equations:

$$\log (SC_{avg}) = 1.06 - 0.026\ (\%C) \qquad R^2 = 0.93 \qquad (1)$$

$$\log (SC_{max}) = 1.54 - 0.014\ (\%C) \qquad R^2 = 0.94 \qquad (2)$$

where SC_{ave} and SC_{max} are the average and maximum standing crop of aquatic macrophytes (kg fresh weight/m^2), respectively, and %C is the percent canopy coverage by streambank vegetation. We, therefore, recommend that the streambank vegetation along small Florida streams be protected to help prevent nuisance growths of aquatic plants.

Suspended algal and periphyton populations in the Little Wekiva River and the other small Florida streams studied during 1985 and 1986 were not related to stream nutrient concentrations.

Algal bioassays, however, demonstrated that the nutrients in the streams were biologically available and that significantly greater standing crops of algae could be obtained if indigenous algal populations were given sufficient time (> 2 days) to develop. Even the unpolluted waters taken from springs or spring-fed streams had sufficient nutrients to support chlorophyll a concentrations in excess of 20 mg/m^3. We, therefore, conclude that physical factors such as hydrographic instability and current velocity are more important factors governing the abundances of periphyton and suspended algae in our study streams than nutrient enrichment. Because the water residence times of our study streams were generally < 2 days, we believe that the most important factor determining algal standing crops in the study streams was the "age" of the water.

Although nutrient enrichment is not the primary factor governing the abundance (coverage and standing crops) of aquatic plants in the Little Wekiva River and the other small Florida streams sampled during our study, discharges of nutrient-rich waters and/or organic matter from anthropogenic sources seem to be stimulating stream productivity. Harvestable fish stocks and standing crops in the Little Wekiva River were greater downstream of the Altamonte Springs Regional Wastewater Treatment Plant. Harvestable fish stocks and standing crops were also greater in our study streams that received treated domestic wastewaters, averaging 230 fish/ha and 46 kg/ha, respectively, versus 80 fish/ha and 18 kg/ha in the streams that received no treated wastewater. Three of the unpolluted spring-fed streams

(Alexander Springs, Ichetucknee Springs, and Wacissa River) sampled during our study had standing crops of harvestable fish that averaged < 11 kg/ha, whereas the three study streams (Alligator Creek, Little Econlockhatchee River, and Pottsburg Creek) that received significant inputs of treated wastewater had standing crops of harvestable fish that averaged > 65 kg/ha. We also found that the standing crops of harvestable fish in our study streams were significantly correlated to stream total phosphorus ($r = 0.55$; $P \leq 0.05$) and total nitrogen ($r = 0.43$; $P \leq 0.10$) concentrations. The Florida Administrative Code, however, states that nutrient concentrations of a water body shall not be altered so as to cause an imbalance in the natural populations of aquatic flora and fauna. Whether the increases in stream productivity and the resultant increases in the stocks and standing crops of harvestable fish represent such an imbalance can be debated. We, however, have no evidence at this time that nutrient enrichment via discharges from anthropogenic sources like the Altamonte Springs Regional Wastewater Treatment Plant will adversely affect future fish populations in the Little Wekiva River, if the discharges meet current water quality criteria established by the Florida Department of Environmental Regulation. We, therefore, believe it would be difficult to justify expensive nutrient control programs for the sole purpose of reducing stream productivity in the Little Wekiva River, given the importance of recreational fishing in Florida.

Although our studies have not demonstrated any significant detrimental effects of nutrient enrichment on the abundance of aquatic plants and fish in the Little Wekiva River or our other study streams, we do not wish to imply that the nutrient-enrichment of the Little Wekiva River or other small Florida streams should be of no concern or that nutrient removal may not ultimately be needed. The Little Wekiva River, like most streams, is characterized by an almost continuous downstream flow of water, nutrients, and organic matter. The nutrient assimilation capacity of the Little Wekiva River is very limited, and over 90% of the nutrients entering the stream is exported downstream to water bodies like the Wekiva River and the St. Johns River. Our studies have not indicated that nutrient-enrichment is currently having an adverse effect on the biology of the Wekiva River, but Bass and Cox (1985) have suggested that algal blooms and fish kills in the lower St. Johns River are attributable to nutrient pollution from wastewater treatment plants, agricultural operations, and industrial sources. Our algal assay studies demonstrate that waters from streams receiving discharges of treated domestic wastewater have the potential to develop large populations of suspended algae, but the same is also true of waters from unpolluted springs, spring-fed streams, and natural drainage streams that drain phosphatic regions. The importance of nutrients derived from anthropogenic sources like the Altamonte Springs Regional Wastewater Treatment Plant will, therefore, depend upon what proportion of the total nutrient load they contribute to the downstream water bodies.

Our studies strongly indicate that the Altamonte Springs Regional Wastewater Treatment Plant by itself has little impact on the lower St. Johns River, but we must consider the total cumulative effects of discharges from all anthropogenic sources in the St. Johns River watershed. We can not determine at this time if the algal blooms and fish kills in the St. Johns River are the direct result of nutrient-enrichment by human activities. It is possible that the elimination of anthropogenic nutrient discharges to the lower St. Johns River will not eliminate algal blooms and fish kills. It is also possible that the nutrients are helping support the major sport and commercial fisheries that currently exist in the lower St. Johns River. We, therefore, recommend that a major study be initiated to determine how geomorphology and human activities, especially anthropogenic nutrient discharges, influence algal and fish populations in the St. Johns River ecosystem (including the St. Johns River estuary). If the study can show that nutrients derived from human activities are adversely affecting the St. Johns River, further reductions in nutrient exports from distant wastewater treatment plants, like the Altamonte Springs Regional Wastewater Treatment Plant, may well be required in future years to help alleviate biological problems in the downstream water bodies.

Issues related to the potential effects of cultural eutrophication on the lower St. Johns River will undoubtedly command considerable attention in future years as the population of Florida continues to expand. We should not, however, forget that aquatic weeds still constitute a major problem for the Little Wekiva River as well as the Wekiva River and the St. Johns River. Prior to 1975, water hyacinth (*Eichhornia crassipes*) was the dominant aquatic weed in the Little Wekiva River, and chemical control programs were used to reduce nuisance growths and prevent the downstream movement of these plants to the Wekiva River and ultimately the St. Johns River. During our studies, we observed the downstream spread of exotic plants like elephant-ear (Colocasia esculentum), hydrilla (Hydrilla verticillata), and paragrass (Brachiaria mutica). Where these plants became well established, they displaced native aquatic plants. We, therefore, believe that a long-term aquatic plant management program should be established for the Little Wekiva River to prevent excessive growths of exotic plants and prevent their downstream movement into the Wekiva River Aquatic Preserve.

Our studies demonstrated that shading by streambank vegetation reduced the extreme and rapid development of aquatic macrophytes and prevented the growth of aquatic plants in areas where the forest canopy became sufficiently dense. Protection and re-establishment of the streambank vegetation, therefore, could represent an inexpensive, ecologically-sound method for the control of aquatic macrophytes in small streams, and it is strongly recommended for the Little Wekiva River. It must be recognized, however, that current conditions in the Little Wekiva River will not permit the use of this method alone. It will take considerable time to re-establish the forest canopy where no trees currently exist. Below Starbuck Spring, sections of the Little Wekiva River are too wide for shading by large trees. We, therefore, recommend that long-term maintenance control of problematic vegetation be established through the use of aquatic herbicides or other aquatic plant management techniques approved by the Florida Department of Natural Resources, the Florida Department of Environmental Regulation, and the Florida Game and Fresh Water Fish Commission.

We initiated our study because it was hypothesized that nutrient enrichment was causing excessive growths of aquatic plants in the Little Wekiva River. Our observations during the study, however, suggest that erosion may be the most insidious problem requiring immediate attention. Development of the Little Wekiva River watershed caused not only the removal or thinning of the streambank vegetation but the drainage and channelization of wetlands, stream channelization, and an increased discharge of urban runoff. These alterations have all contributed to the downstream movement of large amounts of sand. These moving sands during 1985 and 1986 destroyed beds of native submerged vegetation and encouraged the expansion of paragrass beds in the Little Wekiva River by filling in deeper sections of the stream between Springs Landing Boulevard and the home of Colonel Russell Fisher. The destruction of deep water areas near Colonel Fisher's home also eliminated habitat for harvestable sport fish. Although the downstream movement of sand is part of the natural geomorphological cycle, much of the increased erosion can be attributed to various human activities and the removal of streambank vegetation. We, therefore, recommend that efforts be made to protect and re-establish trees and bushes along the streambank of the Little Wekiva River.

The establishment of viable bank vegetation in the upper

Little Wekiva River could ultimately provide an inexpensive, long-term method of streambank protection, but it must again be recognized that current conditions in the Little Wekiva River will not permit the use of this method alone. Some sections of the upper Little Wekiva River will require structural modifications to permit the development of streambank vegetation and protect existing property. It might also become necessary to re-dredge areas between Sanlando Spring and the home of Colonel Fisher to provide flood protection and prevent the movement of large amounts of sand to the Wekiva River where the sands could destroy native submersed vegetation and encourage the spread of exotic plants like elephant-ear and paragrass. If the wide areas of the Little Wekiva River downstream of Starbuck Spring are dredged, a series of islands should be created. These islands should then be planted with fast growing trees and shrubs as well as with long-lived trees like cypress. Although the dredging operations will cause some short-term degradation of water quality and habitat quality, the establishment of a forest canopy in this reach of stream could eventually reduce the need for aquatic plant management programs. The proper configuration of the redredged channel could also provide flood protection as well as increase habitat diversity for the fauna of the Little Wekiva River.

Whatever actions are taken, it must be remembered that the Little Wekiva River is a dynamic ecosystem that is intimately linked to the Wekiva River and ultimately the St. Johns River. The Little Wekiva River, therefore, must be managed as part of the St. Johns River ecosystem. The nature of the Little Wekiva River in its pristine state changed along its length from Lotus Lake to the Wekiva River primarily because of geomorphology. Human activities during the last 80 years have significantly affected the stream's morphometry, hydrology, water quality, and biology, and human activities will undoubtedly continue to influence the nature of the Little Wekiva River as the region's population expands. The effects of development can be either beneficial or detrimental depending upon how the Little Wekiva River and its watershed are managed. Management of the Little Wekiva River, however, requires that well-defined management objectives be established. The objectives, however, must be well founded in science. It must also be recognized that it may not be possible to optimize conditions for every management objective and that compromise will be necessary to protect the region's natural resources and the needs and desires of society.

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APPENDIX I

INFLUENCE OF NUTRIENT ENRICHMENT AND LIGHT AVAILABILITY ON THE ABUNDANCE OF AQUATIC MACROPHYTES IN FLORIDA STREAMS

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Influence of Nutrient Enrichment and Light Availability on the Abundance of Aquatic Macrophytes in Florida Streams[1]

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Canfield, D. E. Jr., and M. V. Hoyer. 1988. Influence of nutrient enrichment and light availability on the abundance of aquatic macrophytes in Florida streams. Can. J. Fish. Aquat. Sci. 45: 1467–1472.

A survey of 17 Florida streams was conducted between October 1984 and August 1986 to determine if the abundance of aquatic macrophytes was related to nutrient enrichment. Macrophyte standing crops were not correlated with in-stream total phosphorus or total nitrogen concentrations. Aquatic macrophytes contained less than 2% of the annual nutrient discharge in nearly all streams. Nutrients are, therefore, not considered to be the primary factor regulating the abundance of aquatic macrophytes in most Florida streams. Shading by riparian vegetation seems to be the dominant factor controlling the location and abundance of aquatic macrophytes. Statistical analyses indicated that the potential average and maximum standing crop of aquatic macrophytes in the sampled streams could be estimated by the equations

$$\log(SC_{avg}) = 1.06 - 0.026\,(\%C) \qquad R^2 = 0.93$$
$$\log(SC_{max}) = 1.54 - 0.014\,(\%C) \qquad R^2 = 0.94$$

where SC_{avg} and SC_{max} are the average and maximum standing crop of aquatic macrophytes (kilograms fresh weight per square metre), respectively, and %C is the percent canopy coverage by riparian vegetation.

Entre octobre 1984 et août 1986, on a fait une étude de 17 cours d'eau de la Floride pour déterminer si l'abondance des macrophytes aquatiques était liée à la fertilisation par des substances nutritives. On n'a pas établi de corrélation entre la biomasse des macrophytes et les concentrations d'azote ou de phosphore totaux dans les cours d'eau. Dans presque tous les cours d'eau, les macrophytes aquatiques contenaient moins de 2 % de substances nutritives déversées annuellement. Par conséquent, les substances nutritives ne sont pas considérées comme le facteur primordial régissant l'abondance des macrophytes aquatiques dans la plupart des cours d'eau de la Floride. L'ombre créée par la végétation des rives semble être le facteur dominant influant sur l'emplacement et l'abondance des macrophytes aquatiques. Les analyses statistiques ont montré que la biomasse potentielle moyenne et maximale de macrophytes aquatiques dans les cours d'eau échantillonnés pouvait être estimée à partir des équations suivantes :

$$\log(BM_{moy}) = 1{,}06 - 0{,}026\,(\%\,C) \qquad R^2 = 0{,}93$$
$$\log(BM_{max}) = 1{,}54 - 0{,}014\,(\%\,C) \qquad R^2 = 0{,}94$$

où BM_{moy} et BM_{max} sont respectivement la biomasse moyenne et maximale de macrophytes aquatiques (kilogrammes de poids frais (par mètre carré), et % C est le pourcentage du couvert fourni par la végétation des rives.

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Many Florida streams experience problems with aquatic macrophytes. Major aquatic plant management programs have, therefore, been established to prevent aquatic weed problems (Nelson and Dupes 1985). The growth of aquatic macrophytes and large algae (i.e. *Cladophora* sp.) to nuisance levels in some northern streams has been linked to the deterioration of water quality resulting from eutrophication (Wong and Clark 1976; Wright and McDonnell 1986a, 1986b). This linkage suggests that the control of nutrients will reduce or eliminate aquatic weed problems (Wright and McDonnell 1986b), but other studies suggest that light availability rather than nutrients is the primary factor limiting aquatic macrophytes in streams (Casey and Westlake 1974; Kern-Hansen and Dawson 1978; Dawson and Kern-Hansen 1978, 1979). Consequently, the efficacy of nutrient removal for the control of aquatic macrophytes in streams is unknown and no assurance can currently be given that the control of anthropogenic nutrient inputs will reduce or eliminate aquatic weed problems in Florida streams. Our purpose here is to examine the influence of nutrient enrichment and light availability on the abundance of aquatic macrophytes in Florida streams.

Methods

An intensive 1-yr study of the Little Wekiva River (Seminole County, Florida) and a survey of eight other streams were initiated in October 1984 to assess the relationship between in-stream water quality and the abundance of aquatic macro-

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phytes. The Little Wekiva River was chosen for study because it was thought that excessive growths of aquatic macrophytes were linked to the introduction of treated wastewater from the Altamonte Springs Regional Sewage Treatment Plant (STP). The eight survey streams were chosen to provide a comparison between streams with low and high nutrient concentrations. After October 1985, the study was expanded to include a total of 17 streams. Six streams (Alexander Springs, Econlockhatchee River, Ichetucknee Springs, Rock Springs, Wacissa River, and St. Marks River) were chosen because they have experienced no significant cultural eutrophication. Six streams (Alligator Creek, Little Econlockhatchee River, Mills Creek, Pottsburg Creek, Reedy Creek, and Wekiva River) were chosen because they receive major inputs of nutrients from anthropogenic sources such as wastewater treatment plants. The final four streams (Alafia River, Hillsborough River, Hogtown Creek, and Santa Fe River) were selected because they receive nutrients primarily from naturally occurring phosphatic formations. Spring-fed streams (Alexander Springs, Ichetucknee Springs, Rock Springs, St. Marks River, Little Wekiva River, and Wekiva River) were studied from their origin at the springs to their mouth. The other streams were studied only in specific reaches to eliminate downstream pollution sources.

Water quality sampling stations were established at 29 sites in the Little Wekiva River to measure nutrient inputs from both point and nonpoint sources and to measure changes in in-stream nutrient concentrations along the length of the stream. For the survey streams, water quality samples were collected from three stations (headwater, midstream, and stream mouth). Water quality samples from the Little Wekiva River were collected monthly between October 1984 and December 1985. After December 1985, samples were collected from the Little Wekiva River and the survey streams every 2 mo until January 1987.

Water velocities were measured at each sampling site by use of a Marsh-McBirney model 201m portable current meter and stream discharge was estimated by use of the procedures described by Platts et al. (1983). Water samples were collected from just below the surface at mid-stream in 1-L, acid-cleaned nalgene bottles. Water samples were placed on ice and then transported to the laboratory for analysis. Total phosphorus (TP) concentrations were determined by using the procedures of Murphy and Riley (1962) with a persulfate digestion (Menzel and Corwin 1965). Total nitrogen (TN) concentrations were determined by using a modified Kjeldahl technique (Nelson and Sommers 1975).

Aquatic macrophytes including large algae such as *Cladophora* sp., *Lynbya* sp., and *Chara* sp. were sampled in the Little Wekiva River and the survey streams from one to three times between March 1985 and August 1986. All sampling was done between March and November of each year because this period corresponds to the period of peak plant abundance in Florida's subtropical streams. Aquatic vegetation was sampled by use of boats and divers. Plants were sampled at roughly uniform intervals as the boats were motored at idle speed from 1 to 7 min. The time of movement was adjusted for the length of each stream so that a minimum of 20 stations (maximum of 90 in the Little Wekiva River) were sampled in each stream. A sampling transect was established perpendicular to the main line of stream flow at each station. Stream width was measured by use of either measuring tapes or calibrated range finders. Stream depth, tree canopy coverage, and the above-ground standing crop of aquatic macrophytes were then measured at five equally spaced locations starting from the middle of the stream channel.

At each sampling location, a 0.25-m^2 quadrat was randomly dropped and the divers removed all vegetation present within the quadrat. The sampled vegetation was then spun in nylon mesh bags to remove excess water and weighed to the nearest 0.1 kg. Tree canopy coverage was visually estimated as either 0, 50, or 100% cover above each plant sampling site. The five canopy coverage values, the above-ground macrophyte standing crop values, and the water depths were then averaged to provide a mean value for each sampling transect.

Composite plant samples from the streams were analyzed using the methods described by Canfield et al. (1983) to determine average plant tissue nutrient levels. The water content of all macrophytes was assumed to be 95%. The content of TP in the plant tissues ranged from 2.4 to 7.5 mg/g dry weight and TN levels ranged from 12 to 32 mg/g dry weight. Because these values were similar to those found for aquatic macrophytes in other Florida waters (Canfield et al. 1983), mean tissue nutrient levels for TP (3.7 mg/g dry weight) and TN (23 mg/g dry weight) were used with the average above-ground standing crop values expressed as dry weight to determine the total mass of nutrients associated with the aquatic macrophytes in each stream. The annual TP and TN discharge rates for each stream were calculated according to the methods of Platts et al. (1983) for the last downstream station.

Results

The Little Wekiva River begins at the outlet of Lotus Lake (Seminole County, Florida) and flows unimpeded for 17 km to its junction with the Wekiva River. The upper portion (8 km) drains an elevated physiographic region known as the Apopka Hills, a sandhill region that is highly modified by karst processes (Brooks 1981). The dominant geologic formation is the Hawthorne Formation which consists primarily of sand, silty sand, and clay with phosphorite granules. The Little Wekiva River in this region falls from an elevation of 18.6 to 6.1 m mean sea level. The stream channel is narrow (3–9 m) and water depths in 1985 ranged from 0.1 to 0.8 m (mean 0.4 m). The average instantaneous discharge rate prior to the point source discharges was 0.4 m^3/s (range 0.05–1.9 m^3/s) in 1985. Flow in the upper section of the Little Wekiva River, however, was augmented by the Altamonte Springs Regional STP (0.25 m^3/s), the Weathersfield STP (0.01 m^3/s), and the High Acres Citrus Plant (0.27 m^3/s). TP and TN concentrations in the stream prior to the point source discharges averaged 0.09 and 0.87 mg/L, respectively. After the addition of water from the Altamonte Springs STP (TP = 1.6 mg/L, TN = 5.5 mg/L), the Weathersfield STP (TP = 6.6 mg/L, TN = 6.9 mg/L), and the High Acres Citrus Plant (TP = 0.08 mg/L, TN = 0.27 mg/L), average TP and TN concentrations in the Little Wekiva increased to 0.60 and 2.7 mg/L, respectively.

The lower portion (9 km) of the Little Wekiva River flows through the St. Johns River Offset physiographic region (Brooks 1981). The geology of this physiographic region is dominated primarily by estuarine and riverine deposits, but some limestone occurs near the surface. Stream elevation in this section decreases from 6.1 to 4.2 m mean sea level and the stream channel widens greatly (6–50 m). Water depths in 1985 ranged from 0.3 to 2.5 m (average 0.5 m). The average instantaneous discharge rate at the mouth of the Little Wekiva River was 3.2 m^3/s (range 2.2–6.2 m^3/s) during 1985. Flow in the lower section of the Little Wekiva River increased primarily because of groundwater discharge via three major springs: Sanlando Spring

TABLE 1. Mean plant standing crop, percent canopy cover, and stream depth and width for survey streams. *N* is the number of transects sampled for each stream on a given date. Numbers in parentheses are the lengths of the stream sampled.

Stream	Date	*N*	Plant standing crop (kg fresh wt/m²)	Percent canopy cover	Depth (m)	Width (m)
Little Wekiva (17 km)	March 1985	90	1.3	—	0.5	12
	September 1985	32	2.0	51	0.7	17
	August 1986	22	3.3	44	1.0	16
	Mean		2.2	48	0.7	15
Alexander Springs (13 km)	May 1985	30	3.4	—	0.8	47
	November 1985	18	5.3	29	1.0	38
	June 1986	16	4.4	19	0.8	45
	Mean		4.4	24	0.9	43
Ichetucknee Springs (7.5 km)	May 1985	23	4.7	—	1.0	25
	November 1985	9	2.5	24	1.2	21
	June 1986	17	3.7	21	1.2	26
	Mean		3.6	23	1.1	24
Alligator Creek (5.0 km)	June 1985	27	0.5	—	0.5	7
	November 1985	13	0.6	74	0.8	8
	June 1986	20	0.6	45	0.5	7
	Mean		0.6	60	0.6	7
Rock Springs (12 km)	June 1985	29	1.3	49	0.6	23
	November 1985	16	3.9	38	0.8	26
	June 1986	14	1.4	57	0.8	23
	Mean		2.2	48	0.7	24
Little Econlockhatchee (7.5 km)	June 1985	31	0.1	68	1.3	11
	December 1985	22	0	75	1.5	10
	July 1986	24	0	80	1.2	9
	Mean		0.04	74	1.3	10
Wacissa (16 km)	June 1985	23	11	9	1.3	39
	November 1985	14	7.1	14	1.2	69
	July 1986	25	11	6	1.2	83
	Mean		9.7	10	1.2	64
Wekiva (19 km)	July 1985	34	1.3	34	0.9	50
	November 1985	20	2.6	26	1.0	70
	June 1986	27	1.4	26	0.9	51
	Mean		1.8	29	0.9	57
Alafia (16 km)	July 1985	29	0.2	42	0.9	15
	November 1985	28	0.2	35	0.9	14
	August 1986	26	0	35	1.7	18
	Mean		0.1	37	1.1	16
Reedy Creek (7.5 km)	July 1986	14	0	86	0.8	10
Pottsburg Creek (9.5 km)	June 1986	12	0	33	1.4	28
Mills Creek (14 km)	June 1986	20	0.3	26	2.1	18
St. Marks (10 km)	July 1986	18	3.9	26	1.7	45
Econlockhatchee (11 km)	July 1986	22	0	50	1.0	10
Hillsborough (10 km)	August 1986	22	3.7	35	2.0	31
Hogtown (3.0 km)	June 1986	16	0.3	72	0.2	4
Santa Fe (16 km)	June 1986	16	0.1	39	0.9	14

TABLE 2. Annual TP and TN exports, TP and TN content in plant tissue, and percent of TP and TN exports in plant tissue for Little Wekiva River using measured mean and maximum (September) plant standing crops in 1985.

	Mean 1985 plant standing crop	Maximum 1985 plant standing crop	Growing period May–October 1985
Annual TP export (kg/yr)	39 000	39 000	21 000
TP in plant tissue (kg)[a]	80	94	94
Percent of TP export in plant tissue	0.2	0.2	0.5
Annual TN export (kg/yr)	114 000	114 000	59 000
TN in plant tissue (kg)[a]	500	590	590
Percent of TN export in plant tissue	0.4	0.5	1.0

[a]Assuming 95% water weight for all plants and a phosphorus content of 3.7 mg/g dry weight of plant tissue and a nitrogen content of 23 mg/g dry weight of plant tissue.

(0.3 m^3/s), Palm Spring (0.15 m^3/s), and Starbuck Spring (0.5 m^3/s). These springs and some small groundwater seeps discharge to the Little Wekiva River at the base of the Apopka Hills. TP and TN concentrations averaged greater than 0.1 and 0.3 mg/L, respectively, in Sanlando Spring (TP = 0.17 mg/L, TN = 0.55 mg/L), Palm Spring (TP = 0.13 mg/L, TN = 0.55 mg/L), and Starbuck Spring (TP = 0.15 mg/L, TN = 0.37 mg/L). After the water from the springs had completely mixed with the stream water (0.7 km), in-stream TP averaged 0.36 mg/L and TN averaged 1.1 mg/L along the entire length of the stream. Constant nutrient conditions occurred primarily because the water residence time in the Little Wekiva River averaged 12 h in 1985 and was reduced to less than 2 h when heavy rains occurred.

The above-ground standing crop of aquatic macrophytes (including large algae) in the Little Wekiva River was estimated at 90 transects established along the length of stream in March 1985 and 32 transects in September 1985. Standing crops averaged 1.3 kg fresh weight/m^2 in March and 2.0 kg fresh weight/m^2 in September (Table 1). Standing crop estimates for individual sampling quadrats ranged from 0 to 13 kg fresh weight/m^2, with the greatest abundance of plants occurring in the lower, wider portions of the stream where the forest canopy was open. There was no relationship between the abundance of aquatic macrophytes and nutrient concentrations along the length of the Little Wekiva. To determine if there were sufficient nutrients present in the Little Wekiva River to support the measured standing crops of aquatic macrophytes, we estimated what percentage of the annual TP and TN exports from the stream would be used by the plants, assuming all nutrients had to be extracted from the water (Table 2). Our estimates indicated that <2% of the annual phosphorus and nitrogen exported from the Little Wekiva River would be needed to support the mean or maximum (September, Table 1) measured standing crops of macrophytes in 1985. Even if we restricted our estimates to the May–October period of maximum growth, the plants would need <2% of the nutrients exported from the Little Wekiva (Table 2).

We compared average macrophyte standing crops with nutrient levels in eight additional streams during 1985 to determine if plant abundance was correlated with the level of nutrient enrichment (Table 3). Average macrophyte standing crops in the streams ranged from 0 to 11 kg fresh weight/m^2 (Table 1). The highest above-ground standing crops of aquatic macrophytes were measured in the Wascissa River (11 kg fresh weight/m^2 in June and 7.1 kg fresh weight/m^2 in November), which had an average TP concentration of 0.04 mg/L and an average TN concentration of 0.20 mg/L (Table 3). The other nonpolluted spring-fed streams also supported either equivalent or greater above-ground standing crops of aquatic macrophytes than the Little Wekiva River (Table 1) despite having lower nutrient concentrations (Table 3). The percentage of the annual TP and TN exports that would be needed to support the measured above-ground standing crops was <3% for all streams except Alexander Springs (7.5% for TP and 4.5% for TN) and Wacissa River (12% for TP and 15% for total TN) which had the lowest nutrient concentrations and greatest average above-ground macrophyte standing crops measured in our study (Tables 1 and 3).

In 1986, we surveyed 17 streams to determine if plant abundance was related to the level of nutrient enrichment (Table 4). Mean above-ground standing crops ranged from 0 to 11 kg fresh weight/m^2 (Table 1). Again, some of the highest macrophyte standing crops were measured in nonpolluted spring-fed streams (Alexander Springs, Ichetucknee River, Rock Springs, Wacissa River, St. Marks River, and Hillsborough River) (Table 1). Our estimates of the percentage of the yearly exports of TP and TN contained in the macrophyte beds of the survey streams averaged <2% for all but two streams, Alexander Springs and Wacissa River (Table 4).

Macrophyte abundance in the Little Wekiva River during September 1985 was significantly ($p < 0.05$) correlated with the percent forest canopy coverage ($r = -0.77$), and our estimates of percent forest canopy coverage were significantly correlated with light availability (microeinsteins per square metre per second) reaching the stream surface, as measured by a LiCor model LI-185B quantum radiometer photometer equipped with a LI-190SB quantum sensor ($r = 0.76$). Using mean transect data ($n = 661$) from all streams and all years (Table 5), the average (SC_{avg}) and maximum (SC_{max}) above-ground standing crops of aquatic macrophytes in the Florida streams were inversely related to the percent forest canopy cover (%C) and the relationships can be described by the following logarithmic regression equations:

(1) $\log(SC_{avg}) = 1.06 - 0.026\,(\%C) \quad R^2 = 0.93$

(2) $\log(SC_{max}) = 1.54 - 0.014\,(\%C) \quad R^2 = 0.94.$

Discussion

Nutrient concentrations (especially phosphorus) in Florida streams are naturally high due to edaphic factors (Odum 1953; Omernik 1977). TP and TN concentrations in nonpolluted spring-fed streams typically exceed 0.03 and 0.3 mg/L, respectively, and these streams support an abundance of aquatic macrophytes (Rosenau et al. 1977). Our study demonstrates that aquatic plants in most Florida streams probably need <2% of the annual nutrient exports. This finding agrees with those of Casey (1977) and Madsen (1986) who studied northern streams. Our estimates are also probably highly conservative because many studies have demonstrated that rooted aquatic

TABLE 3. Annual TP and TN exports, TP and TN content in plant tissue, percent TP and TN exports in plant tissue, and mean TP and TN concentrations for all survey streams in 1985.

Stream	Annual TP export (kg/yr)	TP in plant tissue (kg)[a]	Percent of yearly export in plant tissue	Annual TN export (kg/yr)	TN in plant tissue (kg)[a]	Percent of yearly export in plant tissue	Mean TP concentration (mg/L)	Mean TN concentration (mg/L)
Alexander Springs	6 100	460	7.5	62 000	2 800	4.5	0.04	0.41
Ichetucknee Springs	19 000	120	1.0	98 000	710	0.7	0.05	0.26
Alligator Creek	12 000	4.4	<0.1	28 000	28	0.1	0.38	0.82
Rock Springs	6 900	140	2.0	99 000	900	0.9	0.08	1.25
Little Econlockhatchee	34 000	1.5	<0.1	400 000	9.5	<0.1	0.23	2.60
Wacissa	13 000	1 500	12	59 000	9 100	15	0.04	0.20
Wekiva	71 000	410	0.6	330 000	2 600	0.8	0.21	0.88
Alafia	380 000	8.9	<0.1	240 000	55	<0.1	1.95	1.31

[a]Assuming 95% water weight for all plants and a phosphorus content of 3.7 mg/g dry weight of plant tissue and a nitrogen content of 23 mg/g dry weight of plant tissue.

TABLE 4. Annual TP and TN exports, TP and TN content in plant tissue, and percent of TP and TN exports in plant tissue for all survey streams in 1986.

Stream	Annual TP export (kg/yr)	TP in plant tissue (kg)[a]	Percent of yearly export in plant tissue	Annual TN export (kg/yr)	TN in plant tissue (kg)[a]	Percent of yearly export in plant tissue
Little Wekiva	48 000	170	0.4	160 000	1 000	0.6
Alexander Springs	7 400	480	6.5	48 000	3 000	6.3
Ichetucknee Springs	15 000	130	0.9	100 000	830	0.8
Alligator Creek	7 600	3.9	0.1	28 000	24	0.1
Rock Springs	12 000	71	0.6	200 000	440	0.2
Little Econlockhatchee	36 000	<0.1	<0.1	690 000	<0.1	<0.1
Wacissa	15 000	2 700	18	200 000	17 000	8.5
Wekiva	61 000	240	0.4	350 000	1 500	0.4
Alafia	790 000	<0.1	<0.1	500 000	<0.1	<0.1
Reedy Creek	6 800	<0.1	<0.1	490 000	<0.1	<0.1
Pottsburg Creek	170 000	<0.1	<0.1	740 000	<0.1	<0.1
Mills Creek	44 000	14	<0.1	140 000	84	0.1
St. Marks	18 000	320	1.8	220 000	2 000	0.9
Econlockhatchee	27 000	<0.1	<0.1	760 000	<0.1	<0.1
Hillsborough	130 000	210	0.2	450 000	1 300	0.3
Hogtown	15 000	0.7	<0.1	14 000	4	<0.1
Santa Fe	96 000	4.1	<0.1	480 000	26	<0.1

[a]Assuming 95% water weight for all plants and a phosphorus content of 3.7 mg/g dry weight of plant tissue and a nitrogen content of 23 mg/g dry weight of plant tissue.

macrophytes can obtain a large fraction of their nutrients from the hydrosoil (Bristowe and Whitcombe 1971; Carignan and Kalff 1980). We therefore conclude that nutrients are not the factor limiting the abundance of aquatic macrophytes in Florida streams and that the control of nutrients entering Florida streams from wastewater treatment plants will not reduce the aquatic weed problems even though nutrient concentrations could be reduced significantly.

Butcher (1933) observed that the chief factor governing the distribution and abundance of aquatic macrophytes in English streams was water current. Other factors that he recognized as important included bottom substrate and light availability. Average current velocity in our Florida streams was low (<36 cm/s) and very few sections of the streams had sufficient current to limit the abundance of aquatic macrophytes. Because current velocity was low, bottom substrates in most of the study streams were dominated by sand, silt, and silty clays, which provide excellent substrate for the growth of aquatic macrophytes (Butcher 1933). Only the Alafia River and portions of Ichetucknee River had unsuitable bottom substrates (limestone outcrops) for macrophytes.

Our study suggests that the chief factor limiting the growth of aquatic macrophytes in Florida streams is light availability, although substrate type, water depth, and current velocity were

TABLE 5. Mean, minimum, and maximum plant standing crop for consecutive 10% canopy cover groups. Data are from 17 Florida streams sampled during 1985 or 1986.

Percent canopy	Number of transects	Plant standing crop (kg fresh wt/m²) Mean	Minimum	Maximum
0.0–9.9	134	6.0	0	35
10.0–19.9	59	5.3	0	20
20.0–29.9	84	2.5	0	16
30.0–39.9	75	1.4	0	8.9
40.0–49.9	52	1.0	0	10
50.0–59.9	54	0.3	0	5.0
60.0–69.9	37	0.5	0	4.0
70.0–79.9	28	0.2	0	3.1
80.0–89.9	20	0.2	0	5.1
90.0–100	118	0.01	0	1.0

limiting macrophyte standing crops in some sections of our streams. During the aquatic macrophyte surveys, it was visually obvious that the distribution and abundance of aquatic macrophytes were governed primarily by openings in the forest canopy coverage. Equations 1 and 2 demonstrate strong relationships between forest canopy coverage and potential mean and maximum above-ground standing crops of aquatic macrophytes. This is similar to the findings of Dawson and Kern-Hansen (1978, 1979) who demonstrated a strong inverse relationship between light available at the stream surface and the biomass of aquatic macrophytes in English and Danish streams. Our data, however, indicate that macrophyte standing crops increase rapidly only after the forest canopy coverage is reduced below 50%, but macrophyte standing crops in streams with limited or no forest canopy coverage can be limited by light availability when water depths exceed the depth of light penetration. The control of aquatic weed problems in Florida's small (<50 m width), shallow (<2 m), slow-flowing, nutrient-rich streams and other similar streams, therefore, depends in part on the maintenance of a forest canopy cover.

Assessing macrophyte standing crops and nutrient loads in streams is difficult, but our study and others (e.g. Kern-Hansen and Dawson 1978) suggest that nutrient control through the diversion of wastewaters offers no solution for aquatic weed problems in flowing water systems with background TP concentrations exceeding 0.03 mg/L. In small, nutrient-rich streams, maintenance of the forest canopy cover and reestablishment of the canopy cover where it has been removed are probably the only feasible natural methods of controlling aquatic weed problems. In larger streams or stream reaches where the forest canopy is open naturally, nuisance growths of aquatic macrophytes will have to be controlled through management techniques such as mechanical harvesting (Westlake and Dawson 1982) or use of aquatic herbicides. Nutrient control might prove useful for the control of aquatic macrophytes in oligotrophic streams (TP concentrations <0.01 mg/L), but additional research will be needed to establish critical nutrient concentrations.

Acknowledgments

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APPENDIX II

REPLY TO COMMENTS FROM THE FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION AND THE FLORIDA GAME AND FRESH WATER FISH COMMISSION

FLORIDA GAME AND FRESH WATER FISH COMMISSION

C. TOM RAINEY, D.V.M. Chairman, Miami | MRS. GILBERT W. HUMPHREY Vice-Chairman, Miccosukee | THOMAS L. HIRES, SR. Lake Wales | WILLIAM G. BOSTICK, JR. Winter Haven | DON WRIGHT Orlando

ROBERT M. BRANTLY, Executive Director
ALLAN L. EGBERT, Ph.D., Assistant Executive Director

Fla. Game & Fresh Water Fish Comm.
Lower St. Johns River Fisheries
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DeLeon Springs, FL 32028
(904) 985-5282

August 26, 1988

Daniel E. Canfield, Jr., Ph.D.
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Dear Dan:

Thank you for the opportunity to review your completion report on "The Nutrient Assimilation Capacity of the Little Wekiva River". I agree with your basic conclusion that, due to the high flushing rate of the stream (0.5 to 2 days), the addition of nutrients from the Altamonte Springs Sewage Treatment plant (STP) has little effect on the plant community in the Little Wekiva River. The expansion of para grass and other macrophytes is apparently related to erosion that has caused a shallowing effect in wide areas of the stream and a filling in of old dredge areas. Several points, however, require clarification and will be addressed in the order presented in the report.

Stream Morphometry and Hydrology

Stream discharge, page 67, first paragraph. You state that average stream flow between Station 3 (0.6 m^3/sec) and Station 12 (1.0 m^3/sec) increased over 40% due to the effluent from the Altamonte Springs STP, the Weatherfield STP and the High Acres Citrus Processing Plant (0.48 m^3/sec). The increase attributable to the above mentioned influents was actually 80% as stream flow nearly doubled. It would be correct to say that 48% of the flow at Station 12 can be attributed to these point source discharges as is stated on page 71. It was interesting to note that these three point sources can contribute over 20% of the total flow leaving the Little Wekiva River and virtually all the flow in the upper Little Wekiva River during low flow conditions.

Current velocity, page 76, second paragraph. You attribute the increase in mean current velocities below Station 3 to a significant increase in the slope of the stream bed. You further stated these higher velocities resulted in increased erosion and sediment load. However, you failed to mention that the increased volume of water moving through this area, from the three previously mentioned point sources, must exacerbate the erosion problem. It is interesting that data show a 50% reduction in water velocity leaving the Altamonte Springs STP from 1985 to 1986 but a concurrent decrease in average flow of only 16%.

Water Quality

Temperature, page 83. You state that effluent from the three previously mentioned point sources caused the average stream water temperature to increase significantly. This warming effect was even more apparent during cold weather and may result in a warm water thermal refuge for local fauna.

Dissolved Oxygen

Table 11. Although your discussion of dissolved oxygen was extensive, I was disappointed that you did not speak to, or report on, BOD for each water quality sampling station.

Suspended Solids

The total suspended solids discharge from the Altamonte Springs STP significantly increased the suspended solids in the upper Little Wekiva River. By the time water reached the lower portion of the river, mean organic suspended solids were lower than for Alexander Springs Run, a spring fed stream that does not receive nutrient enriched effluent. This is apparently achieved through dilution, and is pertinent to discussion of invertebrate and fish communities.

Nutrients

My copy of the report is missing Table 33.

The average total phosphorus (TP) concentration at Station 3 is used to support the statement that the stream is naturally eutrophic without reference to the fact that this station is impacted by upstream cultural activities. Additionally, a lake or river with a mean total phosphorus concentration of 0.08 ppm would be considered marginally eutrophic.

Phosphorus concentrations in the discharge from the Altamonte Springs STP averaged 20 to 30 times background level with peaks approaching 50 times background. Although inflow from downstream springs resulted in dilution, water leaving the Little Wekiva River was two to three times the concentration that would normally occur. An additional 14.2 tons of phosphorus in 1985 and 18.3 tons in 1986 were added to the nutrient load of the St. Johns River from the Altamonte Springs STP.

Data show the average yearly phosphorus concentration in the water leaving the Wekiva River was similar to that existing in the St. Johns River, but certain considerations were not mentioned. First, pulses of water with extremely high phosphorus levels leave the Wekiva River at times. Our water quality samples taken near the mouth of the Wekiva River revealed phosphorus peaks of 0.40 ppm TP. Second, the increase in phosphorus concentrations in the water leaving the Wekiva River eliminates the potential for this tributary to dilute high phosphorus concentrations in the St. Johns River that result from upstream influents. These factors should be of concern since, as you stated, the springs contributed only 14% of the phosphorus load exported from the Little Wekiva River during 1985 and 1986, while the three major point sources contributed an average 41% with peak highs of more than 70% during periods of low flow. The Altamonte Springs STP contributed 16.2% and 27.1% of the total phosphorus load of the Wekiva River in 1985 and 1986, respectively. Similar concerns may be expressed for total nitrogen (TN) concentrations.

Aquatic Plants

It was stated that no relationship between total phosphorus or total nitrogen concentrations and phytoplankton, aquatic macrophytes or periphyton existed and therefore, elimination of nutrients from STP discharges cannot be used as a method for aquatic plant management. This suggests that primary productivity is not enhanced by increased total phosphorus and total nitrogen levels in small streams with rapid flushing rates. However, again you failed to mention potential impacts on the St. Johns River which are of crucial importance.

Macroinvertebrates

Although you go to great lengths to discuss the increase in number of aquatic invertebrates collected downstream of the Altamonte Springs STP, you do not mention that invertebrate biomass was less than half that of the upstream station. Table 57 reveals that the invertebrates immediately downstream of the point source had an average weight of 0.002 grams while organisms upstream had an average weight of 0.020 grams. Average weight per organism gradually increased at downstream stations as total nitrogen and total phosphorus concentrations decreased. As you stated earlier, higher stream flows occur downstream of the STP, most likely due in part to increased water volume as well as stream-bed gradient. These increased flows would be expected to result in increased macroinvertebrate drift but do not explain what appears to be a shift in body weight or species diversity. Although data may support the statement that macroinvertebrate abundance immediately downstream of the Altamonte Springs STP is being enhanced the statement that production has been increased by such discharges does not necessarily follow. You also failed to identify the species of organisms collected. Species diversity and overall population composition should be considered, especially since drift rates of macroinvertebrates in all study streams were highly variable but generally comparable. Finally, due to the extremely large confidence intervals for all stations in all sample streams, no definitive statement can be made, nor should subjective interpretations be offered, suggesting that invertebrate drift mechanisms can be understood at this time.

Fish

As you are well aware, assessing fish population data is difficult at best when one is not present during sampling and only has numbers to interpret. I have personally visited sample sites 3 and 6 and offer the following comments. Site 3 was considerably narrower, shallower and had less flow than site 6. Although the width and depth of these stations are not mentioned in the study report, data indicate a doubling of flow and instantaneous discharge between these two stations. As mentioned earlier, temperature differences also existed and were quite pronounced during periods of cold weather. Due to these factors alone, I am not surprised to see increases in stock and standing crop of harvestable fish. Other factors that made data interpretation difficult included: 1) the absence of a description of vegetation types (habitat diversity) for each station, 2) no explanation of sampling techniques by site (whether the entire river run or only shoreline transects were sampled and whether electrofishing by boat or by personnel wading with a back-pack unit was utilized), 3) no data on species composition or contribution by numbers and weight for each station, and 4) no mention of the total number of fish sampling stations on each stream, or their locations. However, even without this information, several conclusions can be made from your following statements:

1) Discharge from the Altamonte Springs STP appears to be enhancing harvestable fish standing crops.

2) The distribution and abundance of fish varied considerably along the length of the Little Wekiva River.

3) The increased number of species collected in the lower Little Wekiva River reflected greater habitat diversity.

4) The decline in the total number of fish in the lower Little Wekiva River was attributed to the fact that large fish were more abundant and sampling methodology was biased toward larger fish.

5) Stock and standing crop of fish in the lower Little Wekiva River were highly variable over time and in different habitats suggesting ecological factors other than nutrient enrichment influenced fish populations.

6) Areas of the stream that supported an abundance of aquatic macrophytes tended to support a greater stock and standing crop of fish.

7) Larger harvestable sportfish such as largemouth bass tended to seek deeper water near aquatic vegetation.

You did not describe the mechanism whereby discharge from the STP enhances fish standing crop. Total fish stock was higher upstream of the STP on two of the three sampling dates due to large numbers of mosquito fish and redbreast sunfish. Since the standing crop of harvestable fish was extremely low at the station upstream of the STP, very few of the redbreast sunfish were of harvestable size. This would be expected considering the physical attributes of the site. Since no fish population data prior to this study exist, a valid assessment of the actual impact of the STP discharge cannot be made. An increase in harvestable fish biomass would be expected with a doubling of water volume and associated habitat changes. The decrease in biomass of macroinvertebrates collected downstream of the STP should not result in an increase in harvestable fish standing crop.

Your statements also suggest that positive correlations exist between fish populations and water volume, depth, and aquatic vegetation (habitat requirements) and support the fact that larger fish will be found in deeper downstream areas.

Survey Streams

Tables 60 and 61 were difficult to interpret, especially for the Little Wekiva River. Although the tables suggest these averages are for all samples from each stream, the text references the tables when speaking of sample averages for the lower Little Wekiva River. I am not sure that these tables include fish population data for the upstream areas. It also appears that you are using only four stations per sampling period in 1985, and two stations per sampling period during the rest of the study, to determine fish population standing stock and crop for the entirety of each study stream. This is in contrast to your statement in the methods section that "two to six sections... were sampled in each stream on two or three dates between May 1985 and February 1987". The use of data from only two stations (one with open canopy cover and one with closed canopy cover) to describe total standing stock and crop in a stream can lead to unacceptable estimates.

You mention that three unpolluted spring-fed streams with average concentrations of 0.03 to 0.07 ppm TP (Alexander Springs, Ichetucknee Springs and the Wacissa River) had standing crops of harvestable fish averaging less than 12 kg/ha, while three streams receiving treated waste water and having average total phosphorus ranging from 0.19 to 0.24 ppm (Alligator Creek, Little Econlockhatchee River, and Pottsburg Creek) had the highest standing crops of harvestable fish averaging more than 65 kg/ha. I feel it would be pertinent to mention that the three streams with the highest average TP levels (Alafia River, 2.8 ppm; Mills Creek, 0.61 ppm; and Hogtown Creek, 0.50 ppm) had harvestable fish standing stocks of 8, 26, and 0.0 kg/ha, respectively. Also three streams with relatively low average TP levels (Rock Springs, 0.08 ppm; St. Marks River, 0.03 ppm; and Wekiva River, 0.15 ppm) had harvestable fish standing crops of 23, 24, and 28 kg/ha, respectively.

Although instantaneous sampling of phytoplankton, aquatic macrophytes, periphyton and macroinvertebrates does not measure productivity, the fact that these parameters were comparable between all sample streams again suggests that "factors other than nutrient enrichment influenced fish populations" (your statement).

It is interesting that although you found no correlation between the total standing crop of fish and either TP or TN concentrations, you found a significant correlation between standing crops of harvestable fish and stream TP ($r=0.55$) and TN ($r=0.43$) at the $P \leq 0.10$ level. I was not able to duplicate the TP/harvestable fish biomass correlation using a product moment correlation analysis based on data contained in Tables 32 and 61. My calculation suggests a slight negative correlation and may be the result of including data from all your study streams. When I excluded the three study streams with the highest phosphorus levels, my correlation coefficient (0.50) came very close to the one you reported. These streams must be included in any correlation based purely on total phosphorus/harvestable fish relationships. I could not run a product moment correlation between total nitrogen and harvestable fish biomass as my copy of the report was missing Table 33. I am not comfortable with using data that have such extremely large 95% confidence intervals (as you reported for both total phosphorus and harvestable fish biomass) for anything other than trend analysis. I do not feel these data lend themselves to correlation analysis.

It may not be pertinent to correlate total stream phosphorus or nitrogen with harvestable fish biomass when standing crops are more likely related to water depth and habitat availability as you suggest earlier. In any case, one should not lead the reader to possibly confuse significant correlation with causation. Once established, such an association can lead to speculation about casual relationships between the variables when it is possible that an illusory correlation exists. Therefore, your statement on page 247, "We conclude that the addition of nutrients to many of Florida's small streams will most likely lead to an increase in the abundance of harvestable fish because of an increase in stream productivity", is insupportable and should not be made.

The statement that growth rates of redbreast sunfish and largemouth bass tend to be greater in the streams receiving treated wastewater is not supported by your data and would be questionable at best due to the small number of individuals examined in any particular age-class. An additional problem in dealing with largemouth bass relates to sexually-dimorphic growth rates. Unless you differentiate between male and female growth rates, mean size by age-class is meaningless considering the relatively few older individuals collected. The average total length (TL) reported for age IV largemouth bass from the little Wekiva River (275 mm TL) does not compare favorably to the average size of either male (375 mm TL) or female (411 mm TL) Age IV largemouth bass from Lake George and the adjacent St. Johns River.

Although the importance of any recreational fishing in Florida should not be understated, the relative value of the fishery in the Little Wekiva River is minimal when compared with the fishery in the downstream receiving waters (St. Johns River) and the ultimate negative impacts of increased nutrient loading of the St. Johns River will far outweigh any positive benefits that you suggest may occur in the Little Wekiva River.

The major study you recommend for the St. Johns River is currently underway (the Game and Fresh Water Fish Commission has committed 13 full time biologists) and has been expanded under the auspices of the SWIM bill. You may be pleased to note that stream and lake degradation can be related to nutrient loading. After the Iron Bridge Advanced Wastewater Treatment Plant became operational, eliminating discharges from the numerous "dirty" package plants and decreasing the nutrient load entering the river, water quality in Lake Harney (downstream) has improved, while algae blooms have decreased in intensity and no further fish kills have been documented in the lake.

Finally, the methods you propose for aquatic plant management would in all likelihood result in decreased fish standing stock and biomass due to a decrease in vegetative habitat. Erosion will most likely continue to occur in the upper section of the Little Wekiva River, with the increased flow caused by the Altamonte Springs STP effluent being partly responsible.

If you would like to discuss these items further, do not hesitate to call.

Sincerely,

Lawson E. Snyder

Lawson E. Snyder, Leader
Lower St. Johns River Project

LES/jl

cc. Forrest J. Ware
David Cox

FRIENDS OF THE WEKIVA RIVER, INC.

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December 4, 1988

Daniel E. Canfield, Jr. Ph.D
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Dear Dan:

We appreciate the opportunity to comment on your final report "The Nutrient Assimilation Capacity of the Little Wekiva River" and apologize for our tardy reply. Our volunteer membership has been quite overworked with the many ongoing projects effecting the Wekiva Basin.

The report presents much interesting and useful data. Particularly, that in 1985 and 1986, the Altamonte Springs Regional Wastewater Treatment Plant (ASRWTP) did not meet advanced wastewater treatment requirements for suspended solids, total nitrogen, and total phosphorus (Tables 27,34,35). It certainly verifies that the ASRWTP does contribute a large amount of nutrients which apparently have a minimum effect on the Little Wekiva and Wekiva Rivers, but which may be significantly effecting the already nutrient rich St. Johns River.

The report also verifies that erosion is a major problem to the health of the river. Erosion has economically impacted adjacent communities and their citizens as well. The ASRWTP adds to the erosion problem, as it contributes volume and velocity to the Little Wekiva River.

It was agreed by all parties that Lake Lotus would be considered the headwaters of the Little Wekiva River for the purposes of your study. It must be kept in mind, however, that Lake Lotus is downstream of major development and numerous anthropogenic influences. Water quality in this reach of the stream can not be considered "natural background".

The following comments address specific areas of the report which we believe are of concern.

Nutrients

Total phosphorus and total nitrogen were discussed in terms of concentrations of mg/l. A more meaningful interpretation would have included pounds loading.

Field Ph data may have been more meaningful that laboratory Ph.

We are concerned that you did not include BOD measurements at any of your sample points, as BOD is considered an important aspect of receiving stream analysis.

While nutrients may not effect plant growth in the Little Wekiva and Wekiva Rivers, we agree the potential impacts to the St. Johns River need to be addressed.

Macroinvertebrates

Some important data was missed by not taxonomically identifying macroinvertebrate species. Species diversity and Class (Biotic Index) of organisms provide important information on biological water quality. Knowing wether the species present were pollution tolerant or intolerant would have provided additional useful data.

Fish

You stated "the most important factor influencing fish populations was the loss of dissolved oxygen due to the discharge of domestic sewage with a high biological oxygen demand (BOD)". As stated previously, BOD measurements for this study would have contributed important data for analysis, especially as it pertains to fisheries. We find your comparison of standing crop of fish and total phosphorus to be misleading. The interpretation did not discuss the standing crop of several other streams with low total phosphorus. The fisheries analysis appears speculative and there is little data on fisheries prior to the wastewater discharges for comparison. A more detailed discussion of available fish habitat at the various sampling stations (substrate, depth, plant species) would have provided a basis for correlation other than total phosphorus.

In closing, we agree that erosion control and revegetation, where feasible, would enhance the Little Wekiva River.

Sincerely,

Jim Thomas (jw)

Jim Thomas
President

Stream Morphometry and Hydrology

It is correct to state that stream discharge increased over 40% between Station 3 and Station 12 in the Little Wekiva River. The actual increase, however, as noted by the Florida Game and Fresh Water Fish Commission was over 60% during the study period. The three major point-source discharges contributed nearly all the flow in the upper Little Wekiva River and constituted over 20% of the flow leaving the lower Little Wekiva River during low flow conditions. It, however, is important to note that the Hi-Acres Citrus Processing Plant no longer discharges to the river. This will have significant effects on not only stream discharge, but stream water chemistry.

The increases in current velocity below Station 3 are primarily due to an increase in the slope of the stream bed. The report, however, has been amended to recognize the importance of increased flow due to anthropogenic inputs, but the role of these inputs in increasing erosion needs further investigation given the changes that occur in stream slope. It is important to recognize that significant erosion would occur in the upper Little Wekiva River even if all point-source discharges were eliminated because the stream experiences high discharge during storm events and many of the embankments are unprotected.

Temperature

The springs and anthropogenic point-source discharges of the Little Wekiva River cause a significant warming of the river during the winter months. This may provide thermal refuge for some of the local fauna, but our sampling was not intensive enough to determine how important this increase in water temperature is to the biota. Our observations and published data on the thermal tolerances of the majority of fish we collected in the Little Wekiva River, however, suggest that the anthropogenic additions of warm-water are having no major beneficial or deleterious effects on the stream biota.

Dissolved Oxygen

BOD is an important environmental parameter, but the study had limited funds; thus it was not possible to measure all possible water quality parameters. BOD was not selected as a study variable primarily because earlier studies by the Florida Department of Environmental Regulation had indicated that BOD levels in the Little Wekiva River were not a major problem (see literature cited in references). Modifications being made at the Altamonte Springs Regional Wastewater Treatment Plant during this study also were designed to reduce BOD significantly.

Suspended Solids

Although the concentrations of organic suspended solids decreased in the lower Little Wekiva River and were equivalent to the concentrations found in Alexander Springs, it is important to recognize that the concentration of organic suspended solids may not be as important as the total organic load. Studies in other geographic regions have demonstrated that allochthonous inputs of organic matter can increase stream fertility and thus increase

Aquatic Plants

This project has demonstrated that the standing crops of aquatic plants in the Little Wekiva River and other small Florida streams are not related to in-stream nutrient levels. There could be a relationship between stream productivity and nutrient enrichment, but productivity measurements were not made during the course of this study. It should be noted that aquatic weed problems in the Little Wekiva River and other Florida streams are related to plant standing crops, which are not related to nutrient levels (see Appendix I). Thus, the elimination of anthropogenic nutrient sources will not eliminate aquatic weed problems even if stream productivity is reduced. This also has been documented in Europe (see Appendix I).

We have not failed to mention the potential "impacts" on the St. Johns River. We have noted throughout the report that downstream effects need to be considered. We did not have the economic resources or personnel necessary to study the entire St. Johns River. We, however, specifically state in our conclusions that additional holistic studies are needed on the St. Johns River.

Macroinvertebrates

Limitations imposed by funding and the scope of work require that decisions be made regarding which environmental parameters should be measured. At the beginning of this project, we made a decision to measure invertebrate drift and assess macroinvertebrate abundance by measuring the number and weight of organisms caught. Species diversity was not emphasized because the Florida Department of Environmental Regulation was to collect such data during their studies and we believed based on our review of the scientific literature that invertebrate drift could be used not only as an index of macroinvertebrate abundance, but as an index of macroinvertebrate production. The published scientific literature also indicated that macroinvertebrate abundance and production were the primary factors influencing fish abundance (see Hynes 1970; Waters 1972; Zimmer 1975). Our basic approach was therefore accepted by the reviewers of the original study proposal.

Although it is true macroinvertebrate abundance (g/100 m^3) above the Altamonte Springs Regional Wastewater Treatment Plant is higher than below the plant discharge, total macroinvertebrate drift downstream of the discharge is substantially larger due to greater flow. The larger number of drift organisms must reflect greater macroinvertebrate production downstream of the anthropogenic sources, otherwise macroinvertebrate populations would be depleted.

The statistical confidence intervals for the macroinvertebrate data are indeed large as is the case with most biological populations. It is very difficult to sample animal populations and variability is an inherent problem in all sampling programs. Our findings, however, are in general agreement with those conducted elsewhere (see Waters 1972; Zimmer 1975) and we believe our interpretations of the data are appropriate within the scientific context and not subjective.

Additional studies, however, are warranted to better understand invertebrate drift mechanisms in Florida streams.

Fish

The primary purpose of this study was to determine if nutrient enrichment was responsible for the aquatic weed problems in the Little Wekiva River. During the formulation of this project, concerns were raised by the Friends of the Wekiva and personnel from the Florida Department of Environmental Regulation and the Florida Game and Fresh Water Fish Commission that excessive inputs of nutrient-rich water would adversely affect the Little Wekiva River's fish populations and ultimately lead to an ecological collapse. Because of these concerns, the fish component of this study was added. The survey streams were selected in part because Bass and Cox (1985) of the Florida Game and Fresh Water Fish Commission in their publication recommended a systematic survey of streams be initiated. This study provided an opportunity to begin such a survey and at the same time provide a range of environmental conditions. Streams such as Alligator Creek, Pottsburg Creek, and the Little Econlockhatchee River were incorporated into the study based on the recommendations of the Florida Department of Environmental Regulation. These streams had received substantial discharges of treated municipal effluent for years and it was speculated at the beginning of this study that these streams would show the adverse "impacts" of nutrient-rich discharges.

Our studies demonstrated fish were present in all the streams receiving nutrient-rich discharges. The sampling sites above and below the discharge of the Altamonte Springs Regional Wastewater Treatment Plant were selected to be as similar as possible. The exact sampling sites were just upstream of Stations 3 and 6. These sites had statistically equivalent stream widths and average depths, but flows were significantly different due to the wastewater discharges. Temperature differences cannot account for the differences in the fish standing crops. Other environmental factors obviously affect the fish populations, but our studies definitively demonstrated that the Altamonte Springs Regional Wastewater Treatment Plant is discharging water of sufficient quality to permit fish to exist.

There have been no studies of the fish populations in the Little Wekiva River prior to this study. It is, therefore, impossible to determine the exact response of the Little Wekiva River's fish populations to nutrient enrichment. To infer what the probable response would have been, streams receiving substantial inputs of treated effluent were sampled. Our estimates of total and harvestable fish stocks (numbers/ha), excluding Hogtown Creek and Alafia River indicated that the streams receiving nutrient-rich discharges from wastewater treatment plants tended, as a group, to support more total and harvestable fish per hectare (see Table 60). Our estimates of the total and harvestable fish standing crops (kg/ha) also indicated that the streams receiving discharges of treated wastewater tended to support more fish (see Table 61). Based on these data, we concluded that the discharges of treated municipal wastewater, given their current levels of treatment and flow, are not causing a decrease in the abundance of fishes. The discharges of treated wastewater seem to be enhancing the abundance of fish, especially harvestable fish. We believe the mechanism for the increase in fish populations is either an increase in stream productivity or the addition of organic matter. Our findings also agree with numerous fisheries studies that have shown limited discharges of untreated domestic sewage or discharges of nutrient-rich effluent from wastewater treatment plants, which remove a significant amount of the organic load, often lead to increases in fish abundance (Kofoid 1903; Thompson and Hunt 1930; Brinley 1943; Swingle 1953; Odum 1956; Larimore and Smith 1963; McFadden et al. 1965; Lewis et al. 1981).

Tables 60 and 61 report all the samples taken during this study except for the values listed in Table 59 which were obtained from above and below the Altamonte Springs Regional Wastewater Treatment Plant. The statement regarding the number of sample sites reported in the methods is correct for the entire study, but we did sample only two to four sites on the survey streams as reported.

The variability associated with collecting fish samples is great and there was no effort made to hide this natural variability. What is perhaps most interesting is the fact that the streams which received treated wastewater had greater fish abundance when it was initially hypothesized that these streams would have fish populations that were negatively impacted. If the report is read carefully, the reasons for low fish populations in Hogtown Creek and Alafia River are discussed. Hogtown Creek was eliminated from our statistical analyses because the stream had insufficient water to support harvestable fish. Alafia River was eliminated because the river had experienced chemical spills prior to our sampling which was not made known to us until the end of the study. If these two systems are removed from the data base, the reported positive correlations are correct.

We believe it is pertinent to correlate total stream phosphorus and nitrogen concentrations with harvestable fish biomass even when other environmental factors influence fish. Studies of lakes and ponds have demonstrated that nutrient enrichment, especially the addition of phosphorus, can significantly increase total and harvestable fish production by increasing lake productivity (Oglesby 1977; Hanson and Leggett 1982; Jones and Hoyer 1982; Bays and Crisman 1983). Data presented by Kautz (1981), Bass and Cox (1985), and Krummrich et al. (1985) of the Florida Game and Fresh Water Fish Commission also suggest that the standing crop of sport fish in Florida's rivers are correlated to nutrient levels. Our data indicate that stream fertility is a major factor influencing fish populations and we contend our conclusions are supportable based on the data collected.

Our sample sizes for age and growth are small, but we believe the trends we discussed are supported by the data. Since differential growth between the sexes does not occur in largemouth bass until age 2 (see study by Porak et al. 1987 of the Florida Game and Fresh Water Fish Commission; Proc. Annu. Conf. Southeast Assoc. Fish and Wildl. Agencies 40:206-215), age 1 growth in the study streams is faster in the streams enriched by wastewater. Hiranvat (1973; Bulletin of the Georgia Acad. of Science 33:106-116) reported no differential growth in the sexes of redbreasted sunfish and again our fastest growth generally occurred in streams receiving treated effluents. Comparing growth rates of largemouth bass in small Florida streams with those in Lake George is a little like comparing apples and oranges, but it does verify the work of Porak et al. (1987) who found growth to be much slower in the Suwannee River than five large eutrophic Florida lakes.

The Little Wekiva River is only one of many small streams entering the St. Johns River. We did not imply that the recreational fishery of the Little Wekiva River is more valuable than that of the St. Johns River. We, however, believe that additional detailed holistic studies are needed to determine what "impact", if any, nutrient enrichment has on the St. Johns River. We are pleased to hear that the Florida Game and Fresh Water Fish Commission is committing 13 full time biologists to studies on the St. Johns River. Given the fact that the Little Wekiva River project was conducted with one full time biologist and some part-time assistants, the staff of the Florida Game and Fresh Water Fish Commission will undoubtedly be able to conduct much more extensive studies than we were able to conduct. We, however, believe that our major findings will be confirmed.