Table 15. Statistical summary of and differences in pH measurements between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Measurements are in standard units; --, indicates the distribution of values during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest values occur in the growing season (April-October); LO, significant differences occur between flow conditions and largest values occur at low flow (less than median flow); @, indicates flow as a function of season]

		pH										
		Summary of all data				Seasonal comparison			Flow comparison			
						Median measurement			Median concentration			
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing	Significant seasonal difference	Low flow	High flow	Significant difference with flow	Flow and season interaction (highest median)
01396280	S.B. Raritan River	33	7.3	8.1	8.7	7.9	7.6	--	8.2	8.0	LO	--
01396535	S.B. Raritan River	36	7.3	8.2	8.7	8.1	7.9	--	8.2	8.1	LO	--
01396588	Spruce Run	37	7.1	7.7	8.1	7.8	7.6	--	7.9	7.6	--	--
01396660	Mulhockaway Ck	37	7.1	7.9	8.5	7.9	8.0	--	8.0	7.6	--	--
01397000	S.B. Raritan River	30	7.3	8.0	8.9	8.0	8.0	--	8.4	7.7	LO	--
01397400	S.B. Raritan River	34	7.1	7.9	8.6	7.9	7.9	--	8.1	7.8	--	--
01398000	Neshanic River	55	7.0	8.0	9.4	8.1	7.8	--	8.2	7.8	LO	--
01398260	N.B. Raritan River	34	7.3	7.8	8.5	7.8	7.8	--	8.0	7.6	LO	--
01399120	N.B. Raritan River	35	7.1	8.1	8.9	8.2	8.0	--	8.3	7.9	LO	--
01399500	Lamington River	36	7.3	7.8	8.7	7.9	7.6	--	8.0	7.7	LO	G@LO
01399700	Rockaway Creek	34	7.3	8.0	9.1	8.1	7.8	--	8.1	8.1	--	--
01399780	Lamington River	38	7.0	8.0	8.9	8.1	7.6	G	8.2	7.7	LO	--
01400500	Raritan River	34	7.2	7.8	8.7	8.0	7.6	G	8.0	7.6	LO	--
01400540	Millstone River	33	6.0	6.8	8.1	6.9	6.6	--	7.0	6.8	LO	--
01400650	Millstone River	29	6.5	7.0	7.4	7.0	7.0	--	7.0	6.9	--	--
01401000	Stony Brook	57	6.0	7.8	9.5	7.8	7.8	--	8.0	7.8	--	--
01401600	Beden Brook	37	7.2	7.7	9.0	7.6	7.8	--	7.7	7.6	--	--
01402000	Millstone River	31	6.8	7.3	8.0	7.3	7.6	--	7.2	7.0	--	--
01403300	Raritan River	55	7.1	7.6	8.9	7.6	7.6	--	7.6	7.5	--	--
01405302	Matchaponix Brook	35	4.9	6.6	7.8	6.6	6.4	--	6.9	6.0	LO	--
01405340	Manalapan Brook	35	5.8	6.90	7.9	6.9	6.5	G	7.0	6.5	LO	--

to -0.09) shows small decreases in pH as flow increased. No significant relation between flow and pH was determined at the other four sites. Measurements were significantly higher during the growing season at three sites than during the nongrowing season.

Values of pH were significantly lower at sites located in the Coastal Plain-- Matchaponix Brook, Manalapan Brook, and the Millstone River sites--than at other sites in the basin (fig. 14). Median values of pH ranged from 6.6 to 7.0 for Coastal Plain sites and 7.7 to 8.1 for sites that drain areas entirely outside of the Coastal Plain. Raritan River at Bound Brook and Millstone River at Blackwells Mills sites are located in the Piedmont Province; however, part of the streamflow originates in the Coastal Plain. The median pH at these sites is 7.6 and 7.3, respectively. Values that equal or exceed 9.0 were observed at Neshanic River, Rockaway Creek, Stony Brook, and Beden Brook in the growing season. Values of pH less than 6.0 were recorded at Matchaponix Brook and Manalapan Brook (fig. A11). All measurements less than 6.0 were recorded at high-flow conditions.

In the analyses of season, flow, and the interaction of both variables, flow was a significant factor at 12 sites. Flow was found to be the dominant factor affecting the variability of pH in streams. The interaction of season and flow conditions was a significant factor only at N.B. Raritan River at Burnt Mills; the highest pH was measured at low flow during the growing season (table 15). Season alone was a factor only at the Millstone River at Blackwells Mills, with highest pH measured in the nongrowing season. Values in samples from nine sites did not vary with changes in season or flow.

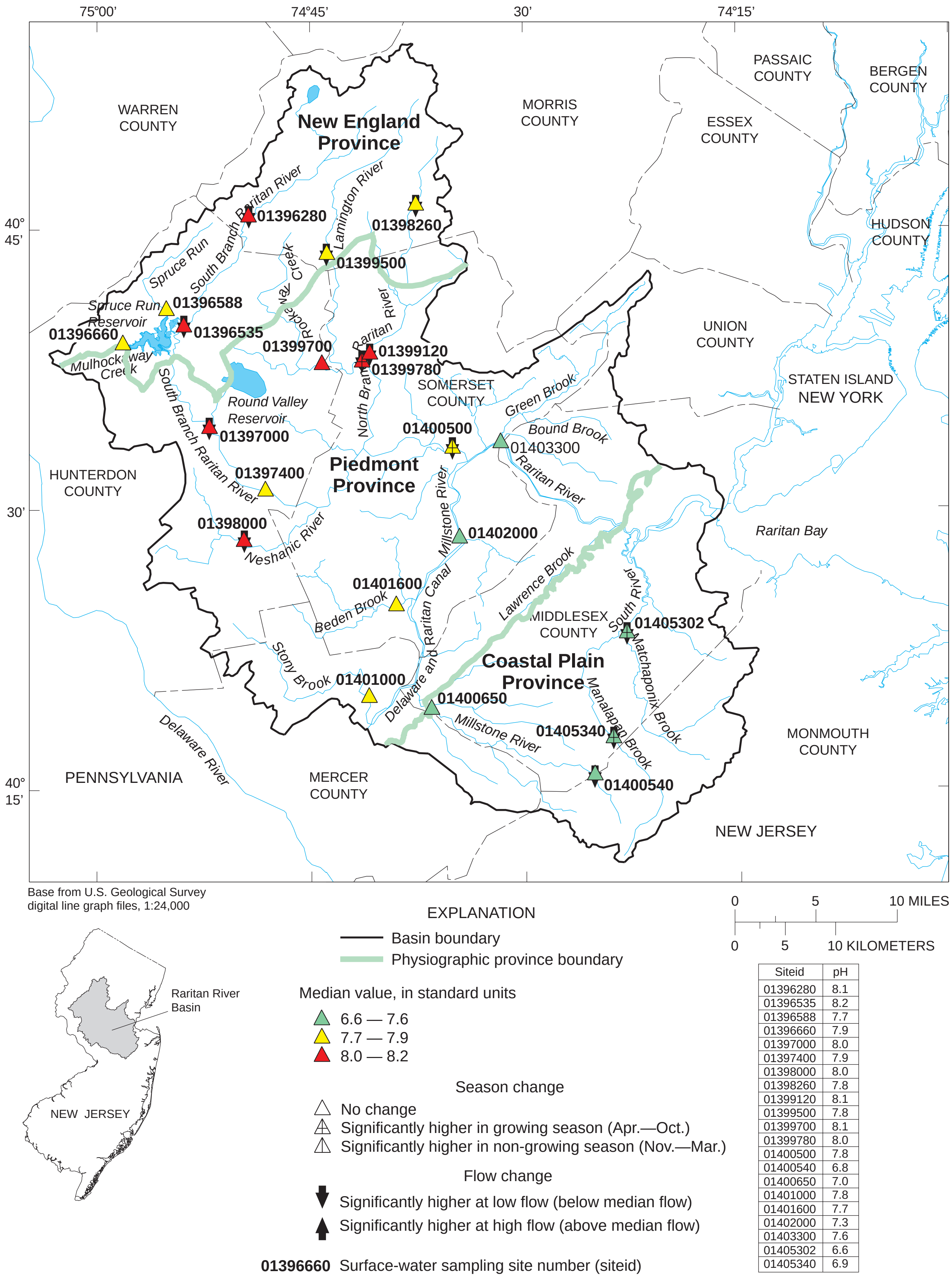
Phosphorus.--Median total phosphorus concentrations were highest in samples from the Millstone River at Blackwells Mills and Grovers Mill sites, S.B. Raritan River at Three Bridges site, and Raritan River at Bound Brook site (fig. 15). Median concentrations exceeded 0.1 mg/L, the instream standard, at these sites. The lowest median concentrations, less than 0.04 mg/L, were present in samples from Mulhockaway Creek, Spruce Run, and S.B. Raritan River at Stanton.

The highest measured concentrations were 0.75 mg/L at Millstone River at Blackwells Mills at low flow in August 1993 and 0.73 mg/L at Millstone River at Grovers Mill at high flow in June 1992. The concentrations in one sample each collected from Neshanic River and Raritan River at Bound Brook at high flow in summer were greater than 0.60 mg/L. Millstone River at Blackwells Mills and Raritan River at Bound Brook were the only two sites studied in which all samples exceeded 0.05 mg/L (figs. A12, C12). In contrast, no concentrations were greater than 0.07 mg/L in samples from the Mulhockaway Creek site.

At 10 of the 21 sites, median concentrations were significantly higher during the growing season than during the nongrowing season (table 16). Sixteen of the 21 sites had higher median concentrations at low flow than high flow. Five sites had significantly higher concentrations at low flow. Median concentrations at Mulhockaway Creek were consistently low during both seasons and both flow conditions--less than or equal to 0.02 mg/L, the laboratory reporting limit (table 16).

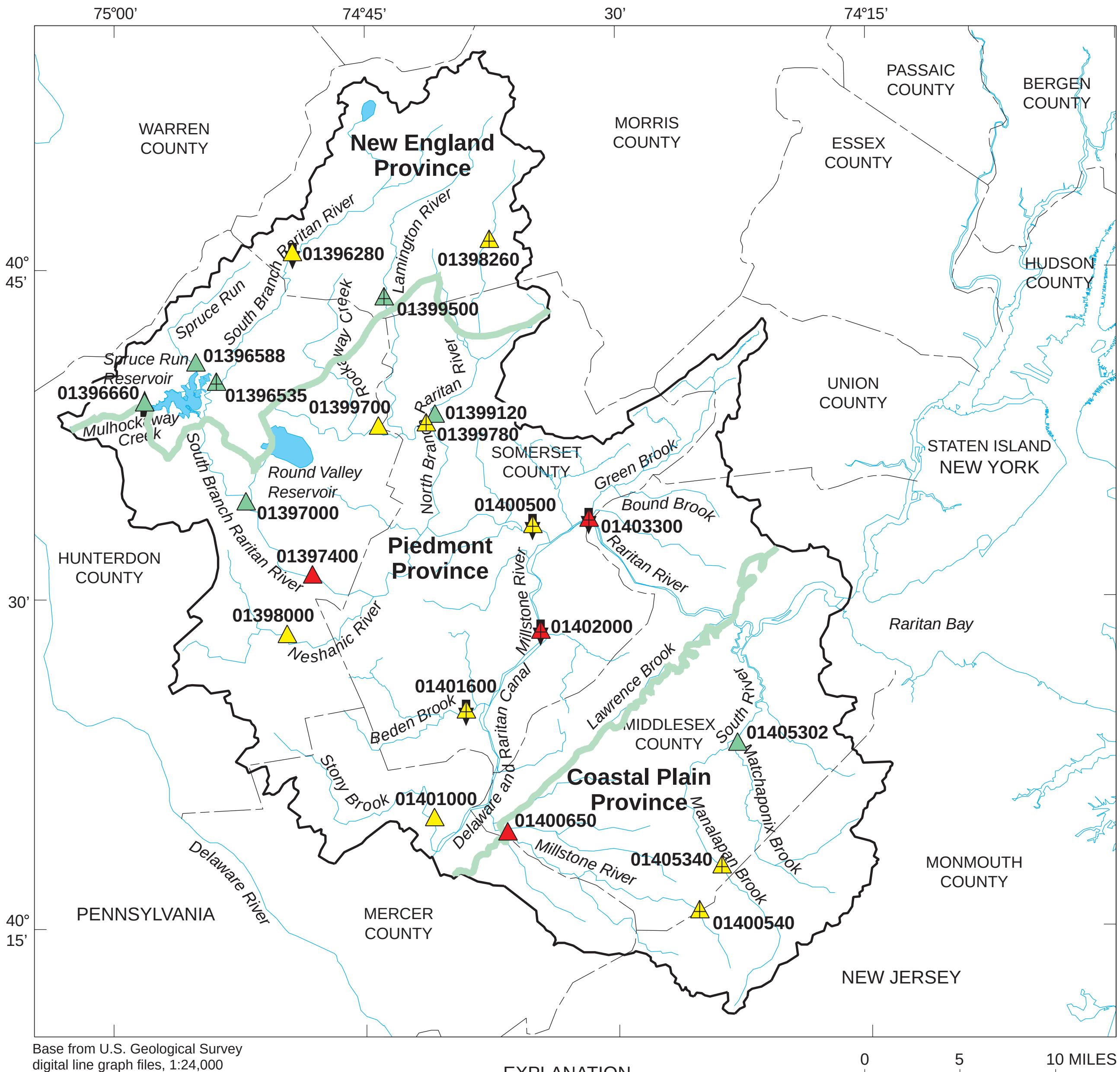
Results of the Tobit regression indicated that phosphorus concentrations were significantly related to flow at eight sites. Concentrations increased as flow increased at three sites--Neshanic River, Stony Brook, and Millstone River at Manalapan. Concentrations at Millstone River at Manalapan increased the most as flow increased. At five sites concentrations of phosphorus decreased as flows increased--the Raritan River sites at Bound Brook and Manville, Millstone River at Blackwells Mills site, Beden Brook site, and Lamington River at Pottersville site.

The variability of phosphorus concentrations was strongly affected by flow and season at about an equal number of streams. When season, flow, and the interaction of both variables were studied together as factors contributing to the variability of phosphorus concentrations, flow was a significant factor at four sites and season was a factor at five sites. Low-flow conditions and growing season were the two factors significantly related to the highest median concentrations at 11 of the 21 sites in the basin (table 16). Median concentrations were



Siteid	pH
01396280	8.1
01396535	8.2
01396588	7.7
01396660	7.9
01397000	8.0
01397400	7.9
01398000	8.0
01398260	7.8
01399120	8.1
01399500	7.8
01399700	8.1
01399780	8.0
01400500	7.8
01400540	6.8
01400650	7.0
01401000	7.8
01401600	7.7
01402000	7.3
01403300	7.6
01405302	6.6
01405340	6.9

Figure 14. Median pH measurements and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin N.J., 1991-97.



EXPLANATION

Basin boundary

Physiographic province boundary

Median concentration, in milligrams per liter

- 0.01 — 0.04
- 0.05 — 0.09
- 0.10 — 0.23

Season change

- No change
- Significantly higher in growing season (Apr.—Oct.)
- Significantly higher in non-growing season (Nov.—Mar.)

Flow change

- Significantly higher at low flow (below median flow)
- Significantly higher at high flow (above median flow)

01396660 Surface-water sampling site number (siteid)

Siteid	Total phosphorus
01396280	0.050
01396535	0.040
01396588	0.030
01396660	0.013
01397000	0.030
01397400	0.135
01398000	0.050
01398260	0.050
01399120	0.040
01399500	0.040
01399700	0.075
01399780	0.060
01400500	0.070
01400540	0.070
01400650	0.125
01401000	0.065
01401600	0.090
01402000	0.228
01403300	0.180
01405302	0.040
01405340	0.070

Figure 15. Median total phosphorus concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Table 16. Statistical summary of and differences in total phosphorus concentrations of phosphorus between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; <, less than the laboratory detection limit; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Phosphorus, total											
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration			Median concentration			
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing	Significant seasonal difference	Low flow	High flow	Significant difference with flow	
01396280	S.B. Raritan River	33	0.03	0.050	0.210	0.08	0.05	--	0.09	0.04	LO	--
01396535	S.B. Raritan River	34	<.01	.040	.100	.06	.03	G	.04	.04	--	--
01396588	Spruce Run	34	<.01	.030	.250	.03	.02	--	.04	.03	--	--
01396660	Mulhockaway Ck	34	<.01	.011	.070	.02	.01	--	.01	.02	--	--
01397000	S.B. Raritan River	31	<.01	.030	.300	.04	.03	--	.04	.02	--	--
01397400	S.B. Raritan River	35	.02	.135	.570	.14	.12	--	.18	.10	--	G@LO
01398000	Neshanic River	55	<.01	.050	.680	.05	.04	--	.05	.04	--	--
01398260	N.B. Raritan River	33	<.01	.050	.280	.08	.04	G	.08	.04	--	--
01399120	N.B. Raritan River	35	<.01	.040	.170	.06	.03	--	.05	.03	--	--
01399500	Lamington River	36	<.01	.040	.240	.06	.03	G	.05	.03	--	--
01399700	Rockaway Creek	34	<.01	.075	.310	.08	.08	--	.12	.07	--	--
01399780	Lamington River	36	<.01	.060	.392	.07	.05	G	.07	.06	--	--
01400500	Raritan River	32	.02	.070	.180	.10	.05	G	.10	.07	LO	G@LO
01400540	Millstone River	35	<.01	.070	.460	.10	.07	G	.06	.07	--	--
01400650	Millstone River	30	.03	.125	.730	.14	.10	--	.14	.11	--	--
01401000	Stony Brook	58	<.01	.065	.600	.08	.05	--	.06	.07	--	--
01401600	Beden Brook	36	<.01	.092	.321	.12	.08	G	.11	.08	LO	--
01402000	Millstone River	30	.08	.228	.750	.31	.19	G	.37	.19	LO	--
01403300	Raritan River	52	.06	.180	.640	.21	.15	G	.34	.14	LO	--
01405302	Matchaponix Brook	35	<.01	.040	.230	.02	.04	--	.02	.04	--	--
01405340	Manalapan Brook	35	<.01	.070	.210	.09	.06	G	.08	.06	--	G@HI

not significantly higher at high flow or during the nongrowing season at any site. The interaction of season and flow conditions was a significant factor at Raritan River at Manville and S.B. Raritan at Three Bridges; the highest concentrations occurred at low flow during the growing season. Concentrations at nine sites did not vary with changes in season or flow.

Sodium.--Median sodium concentrations were highest at Millstone River at Blackwells Mills and Matchaponix Brook (fig. 16). The median concentration was 20 mg/L at these sites. The lowest median concentrations, less than 10 mg/L, were detected for Millstone River at Manalapan (6.65 mg/L), Manalapan Brook (8.6 mg/L), and Mulhockaway Creek (9.2 mg/L) (fig. A13).

The highest measured concentrations exceeded 50 mg/L at S.B. Raritan River at Middle Valley, Matchaponix Brook, Neshanic River, Millstone River at Blackwells Mills, and Stony Brook (table 17). All samples that contained concentrations greater than 50 mg/L, except one, were collected at high flows during the nongrowing season; the exception was a sample collected at Neshanic River at low flow in June. The lowest recorded concentrations were 5.1 mg/L at Millstone River at Manalapan and 5.4 mg/L at Stony Brook at Princeton; both occurred at high flows during the growing season.

Median concentrations at Stony Brook, Raritan River at Bound Brook, and Matchaponix Brook were significantly higher at low flow than at high flow (table 17). Median concentrations at Mulhockaway Creek and Millstone River at Manalapan were significantly higher at high flow than at low flow. Concentrations at S.B. Raritan River at High Bridge, Mulhockaway Creek, and Millstone River at Manalapan were significantly higher in the nongrowing season than in the growing season. Flow as a function of season is a significant variable in determining variability in concentrations at five sites (table 17).

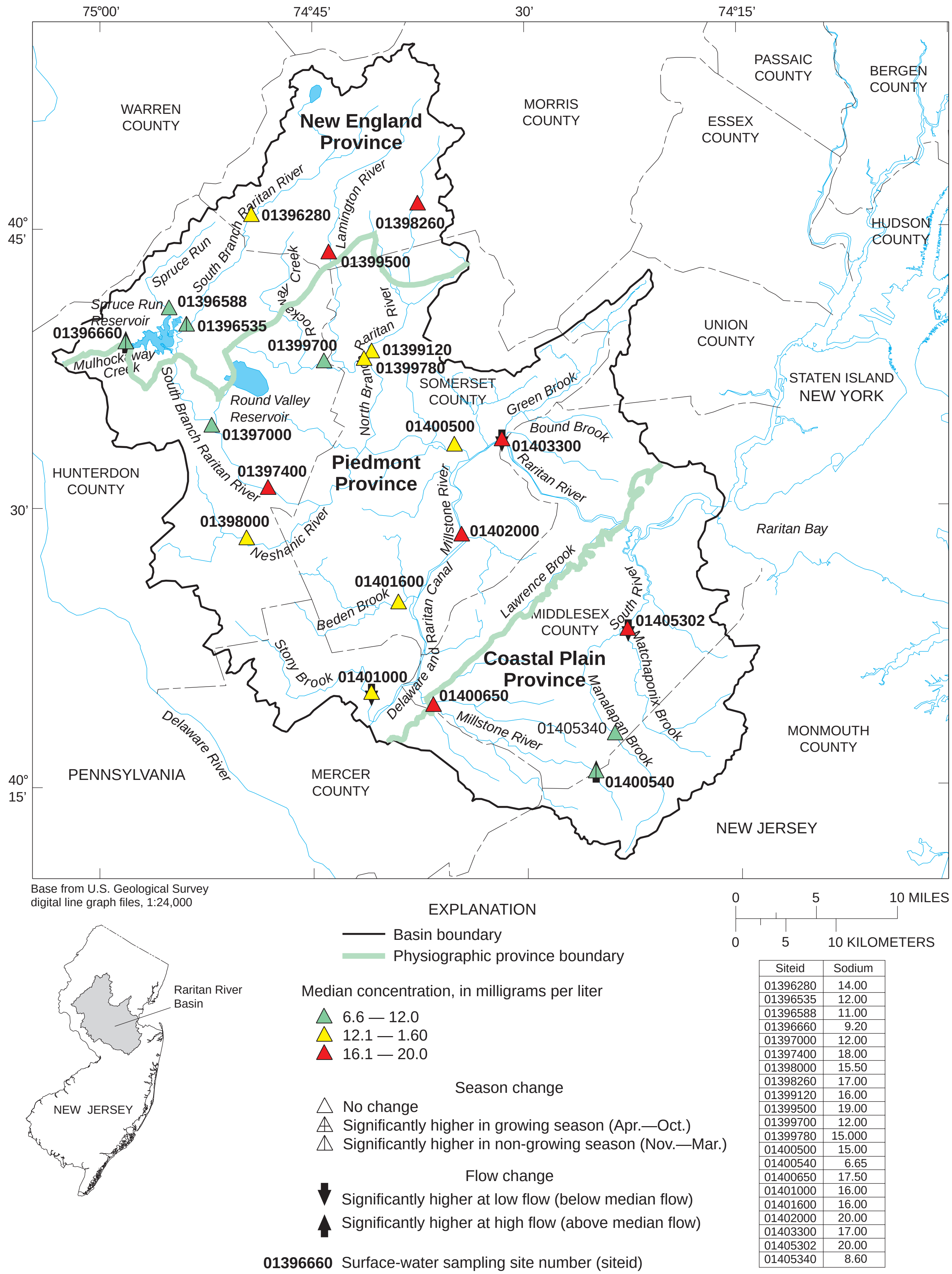
Results of the Tobit regression indicated that sodium concentrations were significantly related to flow at seven sites. Concentrations increased as flow increased at Mulhockaway Creek and S.B. Raritan River at Stanton. Concentrations of sodium decreased at five sites as flows increased.

Flow was the dominant explanatory variable related to the variability of sodium in streams. When season, flow, and the interaction of both variables were studied together as factors in sodium variability, flow was a significant factor at seven sites. Season alone was a significant factor at three sites. The interaction of season and flow was a significant factor in variability at six sites (table 17). The highest concentrations were significantly related to high flow during the nongrowing season at five sites, most likely as a result of de-icing salts in runoff. The sodium concentration was highest at low flow during the growing season at Beden Brook (table 17). Concentrations in samples from 11 sites did not vary with changes in season or flow.

Sulfate.--The highest median sulfate concentration was 49 mg/L at Matchaponix Brook (fig. A14). The second highest median concentration was 29 mg/L at Neshanic River. The lowest median concentrations were at S.B. Raritan River at Middle Valley (11mg/L), Lamington River at Pottersville (11.5 mg/L), and S.B. Raritan River at High Bridge (12 mg/L) (fig. 17).

The highest concentration measured was 96 mg/L at Neshanic River (table 18). All concentrations greater than 70 mg/L were measured at Neshanic River, Beden Brook, and Matchaponix Brook at low flow during the growing season. The lowest concentrations measured were 7.6 mg/L at Lamington River at Pottersville, 8.7 mg/L at Millstone River at Manalapan, and 8.6 mg/L at Stony Brook. The samples were collected during the growing season at high flow at Lamington River and Stony Brook, and at low flow at Millstone River.

Median concentrations were significantly higher at low flow than at high flow at 13 sites (table 18). Millstone River at Manalapan was the only site with significantly higher median concentrations at high flow than at low flow. Median concentrations in samples from four sites were significantly higher during the nongrowing season than during the growing season. Beden



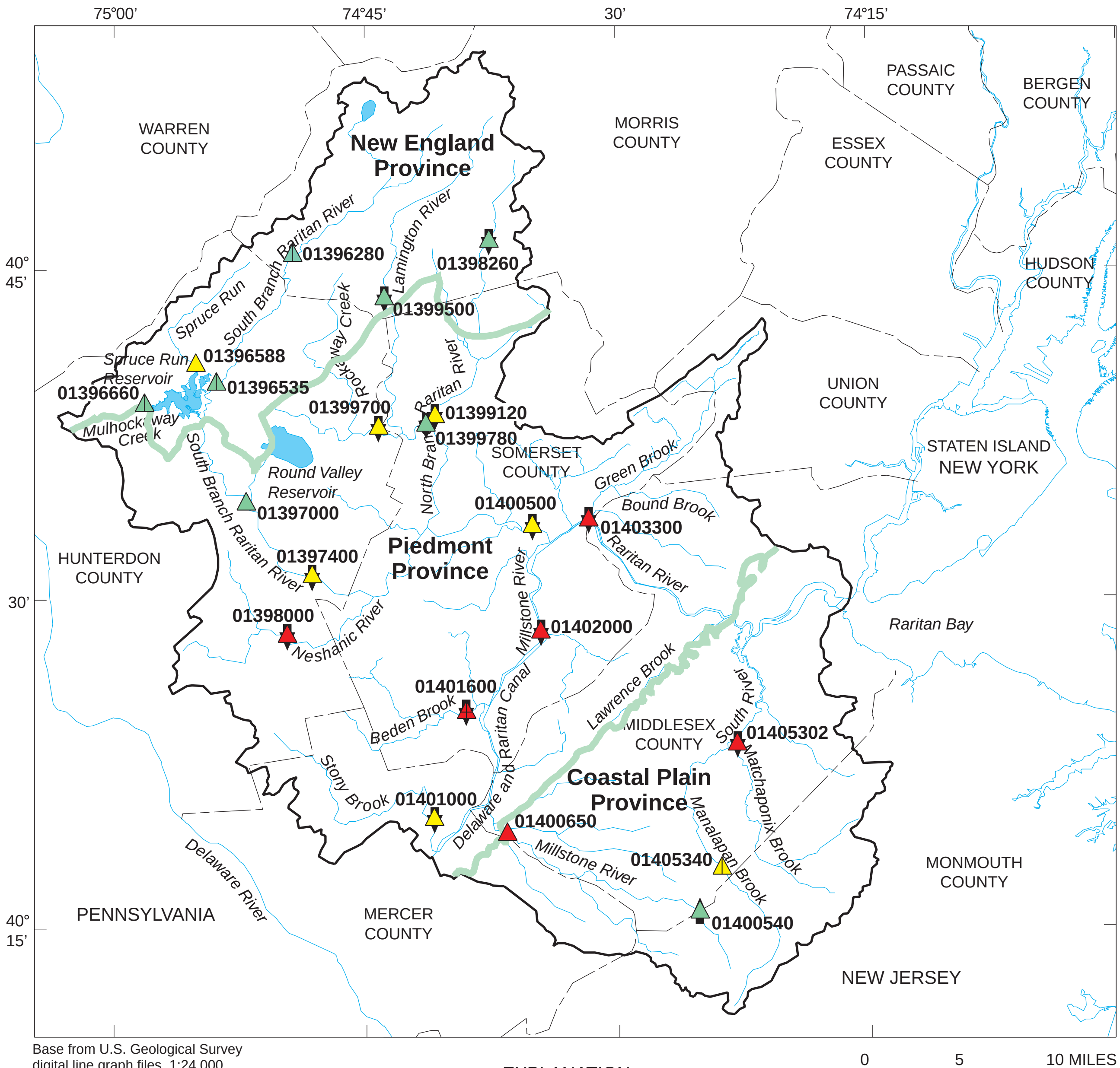
Siteid	Sodium
01396280	14.00
01396535	12.00
01396588	11.00
01396660	9.20
01397000	12.00
01397400	18.00
01398000	15.50
01398260	17.00
01399120	16.00
01399500	19.00
01399700	12.00
01399780	15.000
01400500	15.00
01400540	6.65
01400650	17.50
01401000	16.00
01401600	16.00
01402000	20.00
01403300	17.00
01405302	20.00
01405340	8.60

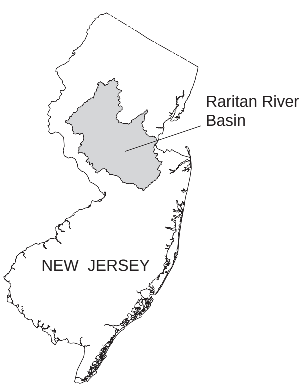
Figure 16. Median sodium concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Table 17. Statistical summary of and differences in sodium concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October); NG, significant differences occur between seasons and largest concentrations occur in the nongrowing season (November-March); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Sodium										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration		Significant seasonal difference	Median concentration		Significant difference with flow	
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Grow-ing	Non-growing		Low flow	High flow		
01396280	S.B. Raritan River	35	8.0	14	81	14	15	--	14	14	--	--
01396535	S.B. Raritan River	36	6.5	12	30	12	17	NG	12	12	--	--
01396588	Spruce Run	36	7.7	11	13	10	11	--	11	11	--	--
01396660	Mulhockaway Ck	36	6.7	9.2	40	9.2	12	NG	9	10	HI	NG@HI
01397000	S.B. Raritan River	31	6.8	12	20	11	13	--	12	12	--	--
01397400	S.B. Raritan River	35	8.3	18	33	17	20	--	21	16	--	--
01398000	Neshanic River	54	9.8	16	67	15	17	--	16	15	--	--
01398260	N.B. Raritan River	35	12	17	37	17	19	--	18	17	--	NG@HI
01399120	N.B. Raritan River	35	9.9	16	33	15	16	--	15	16	--	NG@HI
01399500	Lamington River	36	11	19	26	19	20	--	19	18	--	--
01399700	Rockaway Creek	35	8.0	12	29	11	12	--	13	11	--	--
01399780	Lamington River	36	11	15	34	14	16	--	15	14	--	NG@HI
01400500	Raritan River	35	11	15	37	15	15	--	15	16	--	
01400540	Millstone River	34	5.1	6.6	15	6.4	7.2	NG	6.4	7.4	HI	NG@HI
01400650	Millstone River	30	7.3	18	49	16	19	--	24	16	--	--
01401000	Stony Brook	56	5.4	16	55	16	14	--	16	13	LO	--
01401600	Beden Brook	36	9.8	16	40	16	17	--	18	15	--	G@LO
01402000	Millstone River	31	9.9	20	59	19	20	--	20	18	--	--
01403300	Raritan River	53	6.0	17	33	17	17	--	22	15	LO	--
01405302	Matchaponix Brook	35	7.6	20	68	21	20	--	22	16	LO	--
01405340	Manalapan Brook	35	6.1	8.6	17	8.6	8.6	--	8.6	8.6	--	--





EXPLANATION

Basin boundary

Physiographic province boundary

Median concentration, in milligrams per liter

- 11 — 15
- 15.1 — 22.9
- 23 — 39

Season change

- No change
- Significantly higher in growing season (Apr.—Oct.)
- Significantly higher in non-growing season (Nov.—Mar.)

Flow change

- Significantly higher at low flow (below median flow)
- Significantly higher at high flow (above median flow)

01396660 Surface-water sampling site number (siteid)

Siteid	Sulfate
01396280	11.0
01396535	12.0
01396588	17.0
01396660	15.0
01397000	13.0
01397400	20.0
01398000	29.0
01398260	14.0
01399120	16.0
01399500	11.5
01399700	18.0
01399780	15.0
01400500	20.0
01400540	15.0
01400650	23.0
01401000	21.0
01401600	27.0
01402000	26.0
01403300	24.0
01405302	49.0
01405340	19.0

Figure 17. Median sulfate concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Table 18. Statistical summary of and differences in sulfate concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October); NG, significant differences occur between seasons and largest concentrations occur in the nongrowing season (November-March); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Sulfate										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration			Median concentration			
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing	Significant seasonal difference	Low flow	High flow	Significant difference with flow	
01396280	S.B. Raritan River		9.5	11	15	11	12	NG	11	12	--	--
01396535	S.B. Raritan River		9.3	12	16	12	13	NG	12	12	--	NG@LO
01396588	Spruce Run		13	17	22	17	18	--	17	16	--	
01396660	Mulhockaway Ck		12	15	20	15	17	NG	15	15	--	NG@LO
01397000	S.B. Raritan River		11	13	18	13	13	--	13	13	--	NG@LO
01397400	S.B. Raritan River		12	20	45	20	20	--	24	18	LO	--
01398000	Neshanic River		16	29.	96	32	28	--	44	25	LO	--
01398260	N.B. Raritan River		11	14	20	14	13	--	15	13	LO	--
01399120	N.B. Raritan River		12	16	24	17	16	--	18	15	LO	--
01399500	Lamington River		7.6	12	27	11	12	--	13	11	LO	--
01399700	Rockaway Creek		13	18	35	19	18	--	20	17	LO	--
01399780	Lamington River		11	15	30	15	14	--	18	14	LO	--
01400500	Raritan River		12	20	30	20	20	--	22	18	LO	--
01400540	Millstone River		8.7	15	22	13	20	--	12	16	HI	--
01400650	Millstone River		14	23	29	22	24	--	23	23	--	--
01401000	Stony Brook		8.6	21	34	20	22	--	22	18	LO	--
01401600	Beden Brook		15	27	88	27	25	G	35	25	LO	--
01402000	Millstone River		13	26	39	27	26	--	32	23	LO	--
01403300	Raritan River		9.8	24	48	24	24	--	36	21	LO	--
01405302	Matchaponix Brook		25	49	70	50	45	--	53	44	LO	--
01405340	Manalapan Brook		14	19	29	18	22	NG	18	20	--	--

Brook is the only site with median concentrations significantly higher during the growing season than the nongrowing season. The highest median concentrations were calculated for sulfate at low-flow conditions during the nongrowing season at 19 of the 21 sites.

Results of the Tobit regression indicated that sulfate concentrations were significantly related to flow at 18 sites. Concentrations decreased as flow increased at 17 sites. Millstone River at Manalapan is the only site where concentrations of sulfate increased as flows increased.

Flow was the dominant explanatory variable related to the variability of sulfate in streams. When season, flow, and the interaction of both variables were studied together as factors in sulfate variability, flow was a significant factor at 17 sites. The interaction of season and flow was a significant factor in variability at three sites (table 18); all three sites had significantly higher concentrations at low flow during the nongrowing season than at any other flow or season. Median concentrations were significantly higher at low flow at 13 sites and at high flow at 1 site. Season alone was a factor at five sites. No significant changes in concentration were observed with changes in season or flow at two sites.

Total suspended solids.--Median concentrations of TSS were highest at the Millstone River sites at Grovers Mill and Blackwells Mills, 11.5 mg/L and 10 mg/L, respectively (fig. A15). The lowest median concentrations (2.0 mg/L) were present in samples from Mulhockaway Creek and N. B. Raritan River at Chester (table 19). In general, the lowest concentrations were present in samples from sites in the New England province (fig. 18)

The highest concentrations measured were 510 mg/L at Stony Brook, 501 mg/L at Neshanic River, and 427 mg/L at Raritan River at Bound Brook (table 19). These high concentrations were measured during the highest flows sampled at these sites. The highest concentration measured at N. B. Raritan River at Chester was 9 mg/L.

Concentrations were significantly higher at high flows than at low flows at 10 sites and significantly higher during the growing season than during the nongrowing season at 5 sites (table 19). Only the samples from Matchaponix Brook contained significantly higher concentrations in the nongrowing season than in the growing season. Median concentrations were lowest at low flow during the nongrowing season at 17 sites and highest at high flows during the growing season at 14 sites. Only Beden Brook and S.B. Raritan River at Three Bridges had the highest concentrations at low flows during the growing season. The other five sites had the highest concentrations at high flows during the nongrowing season. Results of the Tobit regression indicated that TSS concentrations significantly increased as flow increased at 13 sites. No significant relation between concentrations and flow was observed for eight sites.

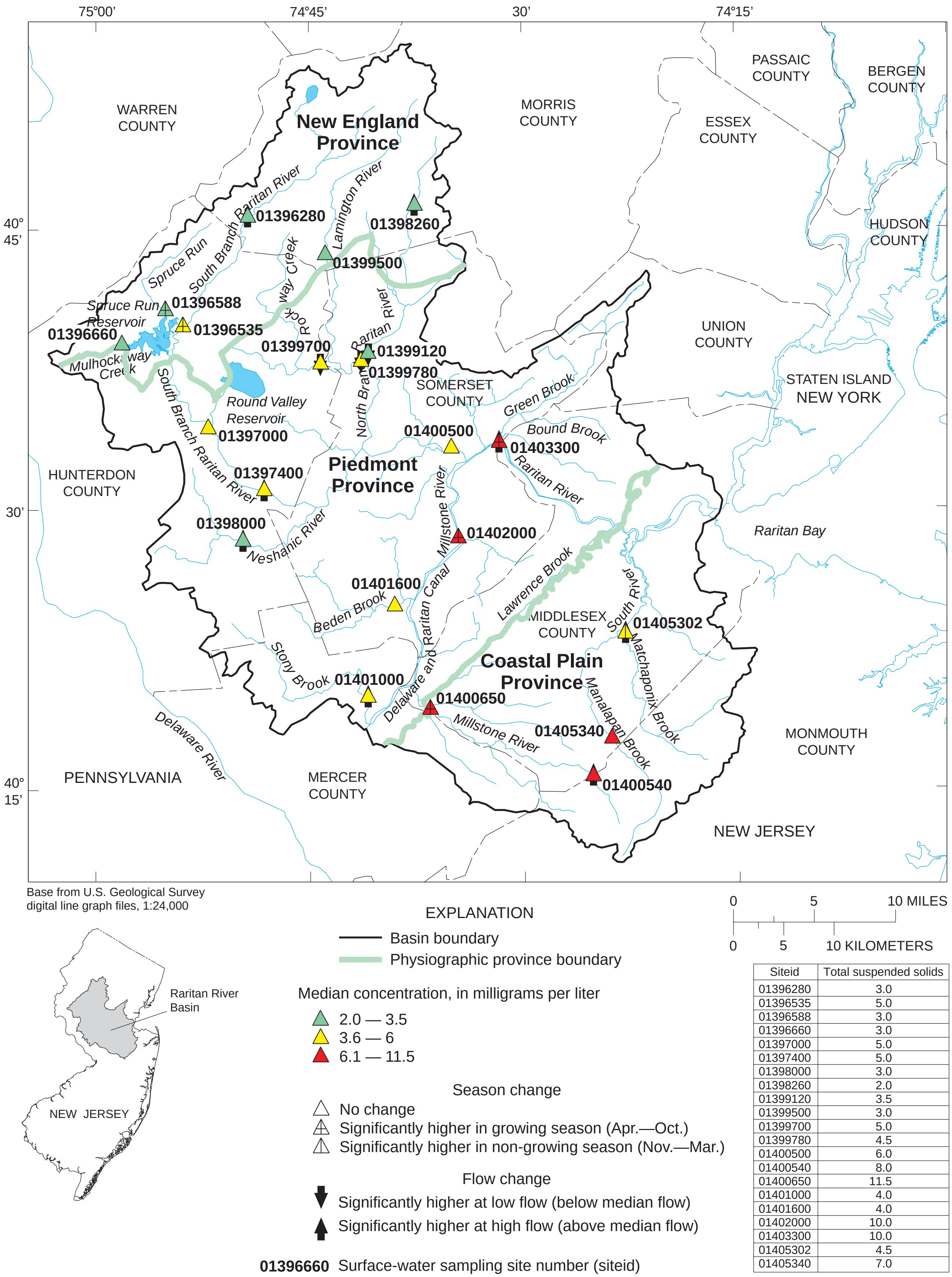
Flow was the dominant explanatory variable related to the variability of TSS in streams. When season, flow, and the interaction of both variables were studied together as factors in TSS variability, flow was a significant factor at 10 sites. Median concentrations were significantly higher at high flow at all 10 sites (table 19). The interaction of season and flow was a significant factor at two sites. Mulhockaway Creek had significantly higher concentrations at high flow during the nongrowing season, and Matchaponix Brook had significantly higher concentrations at high flow during the growing season. Season alone was a factor at six sites; concentrations were higher at five sites during the growing season and at one site during the nongrowing season. No significant changes in concentration were observed with changes in season or flow at six sites.

Un-ionized ammonia.--Un-ionized ammonia was detected in low concentrations at all sites. Median concentrations at nine sites were less than 0.0001 mg/L. The highest median concentration was 0.0006 mg/L at N.B. Raritan River near Chester and Millstone River near Manalapan (fig. 19). Median concentrations were greater than 0.0004 mg/L in samples from S.B. Raritan River at Three Bridges, Stony Brook, and Raritan River at Bound Brook and Manville

Table 19. Statistical summary of and differences in total suspended solids concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

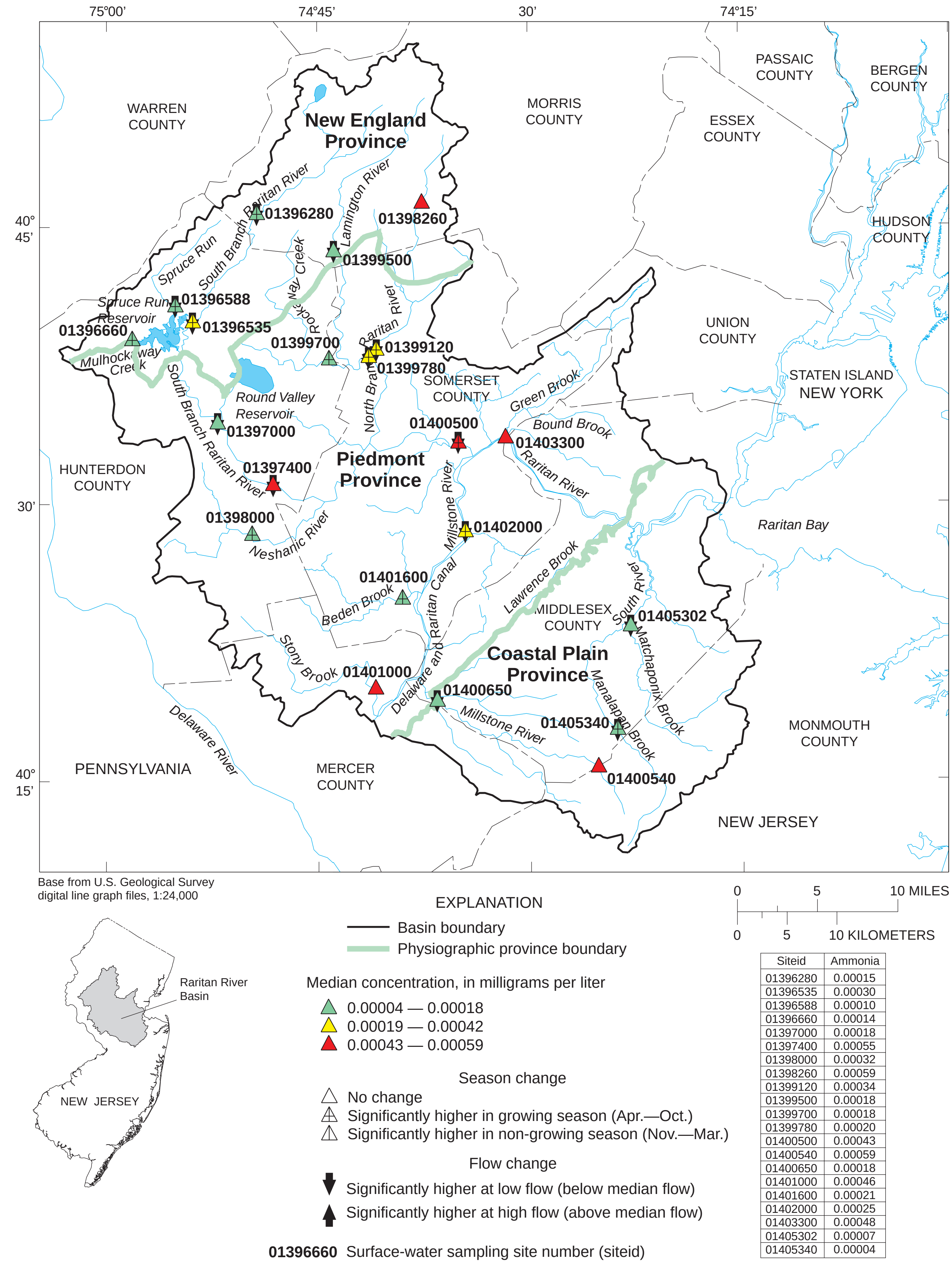
[Concentrations are in milligrams per liter; <, less than the laboratory detection limit; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October); NG, significant differences occur between seasons and largest concentrations occur in the nongrowing season (November-March); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Total suspended solids										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration		Significant seasonal difference	Median Concentration		Significant difference with flow	
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing		Low flow	High flow		
01396280	S.B. Raritan River	30	<1.0	3.0	85	5.0	3.0	--	3.0	7.0	HI	--
01396535	S.B. Raritan River	32	<1.0	5.0	36	6.0	3.5	G	5.0	5.0	--	--
01396588	Spruce Run	32	<1.0	3.0	17	3.0	2.0	G	3.0	3.0	--	--
01396660	Mulhockaway Ck	32	<1.0	2.0	19	2.0	2.0	--	2.0	3.5	--	NG@HI
01397000	S.B. Raritan River	31	<1.0	5.0	43	5.0	3.0	--	4.0	5.0	--	--
01397400	S.B. Raritan River	31	1.0	5.0	74	5.5	5.0	--	3.0	6.0	HI	--
01398000	Neshanic River	50	<1.0	3.0	501	3.0	3.0	--	3.0	6.0	HI	--
01398260	N.B. Raritan River	30	<1.0	2.0	9.0	3.0	1.0	--	2.0	4.0	HI	--
01399120	N.B. Raritan River	31	<1.0	3.0	16	3.0	4.0	--	2.0	6.5	HI	--
01399500	Lamington River	32	<1.0	3.0	106	4.0	2.5	--	3.5	3.0	--	--
01399700	Rockaway Creek	31	<1.0	5.0	34	5.0	4.0	--	4.5	6.0	--	--
01399780	Lamington River	32	<1.0	4.0	103	4.0	5.5	--	4.0	8.0	HI	--
01400500	Raritan River	31	1.0	6.0	24	7.5	6.0	--	5.5	6.0	--	--
01400540	Millstone River	31	3.0	8.0	132	8.0	7.5	--	6.0	9.5	HI	--
01400650	Millstone River	26	1.0	11.5	34	14	8.0	G	7.0	15	--	--
01401000	Stony Brook	53	<1.0	4.0	510	4.0	3.5	--	2.5	7.0	HI	--
01401600	Beden Brook	32	<1.0	4.0	53	5.0	3.0	--	4.0	4.5	--	--
01402000	Millstone River	31	2.0	10	68	13	6.5	G	9.5	10	--	--
01403300	Raritan River	53	<1.0	9.0	427	15	5.0	G	5.0	24	HI	--
01405302	Matchaponix Brook	31	<1.0	4.0	16	2.0	6.5	NG	3.0	8.0	HI	G@HI
01405340	Manalapan Brook	31	2.0	7.0	29	5.0	8.0	--	7.0	7.5	--	--



Siteid	Total suspended solids
01396280	3.0
01396535	5.0
01396588	3.0
01396660	3.0
01397000	5.0
01397400	5.0
01398000	3.0
01398260	2.0
01399120	3.5
01399500	3.0
01399700	5.0
01399780	4.5
01400500	6.0
01400540	8.0
01400650	11.5
01401000	4.0
01401600	4.0
01402000	10.0
01403300	10.0
01405302	4.5
01405340	7.0

Figure 18. Median total suspended solids concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.



Siteid	Ammonia
01396280	0.00015
01396535	0.00030
01396588	0.00010
01396660	0.00014
01397000	0.00018
01397400	0.00055
01398000	0.00032
01398260	0.00059
01399120	0.00034
01399500	0.00018
01399700	0.00018
01399780	0.00020
01400500	0.00043
01400540	0.00059
01400650	0.00018
01401000	0.00046
01401600	0.00021
01402000	0.00025
01403300	0.00048
01405302	0.00007
01405340	0.00004

Figure 19. Median un-ionized ammonia concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

(table 20). The highest concentrations of un-ionized ammonia measured were 0.042 mg/L in samples from Neshanic River, 0.025 mg/L in samples from S.B. Raritan River at Stanton, and 0.024 mg/L in samples from N.B. Raritan River at Burnt Mills. All samples with concentrations greater than 0.02 mg/L, the New Jersey surface-water reference level for trout streams, including three samples from Neshanic River and one each from the S. B. Raritan River at Stanton and N. B. Raritan River at Burnt Mills, were collected during the growing season at low flow.

Median concentrations of un-ionized ammonia were significantly lower at Matchaponix Brook, Manalapan Brook, and Millstone River near Manalapan than at the other sites (fig. A16). Concentrations at 12 sites were significantly higher during the growing season than during the nongrowing season (table 20). Concentrations at the other nine sites did not vary significantly by season.

Concentrations at 13 sites were significantly higher at low flows than at high flows (table 20). Concentrations at the other eight sites did not vary significantly by flow condition. Median concentrations were highest at low flow during the growing season at 18 sites. Median concentrations were highest at high flow during the growing season at Stony Brook and Raritan River at Bound Brook. Matchaponix Brook had the highest median concentration at low flow during the nongrowing season. Results of the Tobit regression indicated that un-ionized ammonia concentrations decreased significantly as flow increased at 13 sites. No significant relation was observed between concentrations and flow for eight sites.

Flow and season strongly affected the variability of un-ionized ammonia in about an equal number of streams. When season, flow, and the interaction of both variables were studied together as factors in un-ionized ammonia variability, flow was a significant explanatory variable at nine sites, with highest concentrations at low flow. Season was a significant variable at eight sites; concentrations at these sites were higher during the growing season. The interaction of season and flow was a significant variable in determining variability in concentrations only at N.B. Raritan River at Burnt Mills. The highest median concentrations were significantly related to low flow during the growing season at the Burnt Mills sampling site (table 20). No significant changes in concentration were observed with changes in season or flow at four sites.

Water temperature.--Median water temperatures did not vary significantly among sites (fig. A17). The highest median temperatures were at Raritan River at Bound Brook (14.4 ^{o}C) and S.B. Raritan River at Three Bridges (14.0 ^{o}C), the sites farthest downstream on the two largest rivers in the basin. The lowest median temperature was 9.5 ^{o}C at Lamington River near Pottersville and Lamington River at Burnt Mills (table 21). Median temperatures generally were lowest in the N.B. Raritan River subbasin and the upper reaches of the S.B. Raritan River subbasin (fig. 20). The highest temperature measured was 26.5 ^{o}C at Raritan River at Bound Brook and at the S.B. Raritan River at Stanton and at Three Bridges. The lowest maximum temperature measured was 20.0 ^{o}C at N.B. Raritan River at Chester. The minimum temperature recorded was less than 0.5 ^{o}C at all sites, except Raritan River at Bound Brook and Millstone River at Grovers Mill where the minimum temperatures were 1.5 ^{o}C and 1.0 ^{o}C, respectively.

Water temperatures were significantly higher during the growing season than during the nongrowing season at all sites. Temperatures were significantly higher at low flow than at high flow at 12 sites. Median temperatures were highest at all sites at low flow during the growing season. Lowest median temperatures were calculated for the nongrowing season at high flow at 12 sites and for the nongrowing season at low flow at 9 sites (table 21). Results of the Tobit regression indicated that water temperatures decreased significantly as flow increased at 14 sites. No significant relation was determined between water temperature and flow for seven sites.

Table 20. Statistical summary of and differences in un-ionized ammonia concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

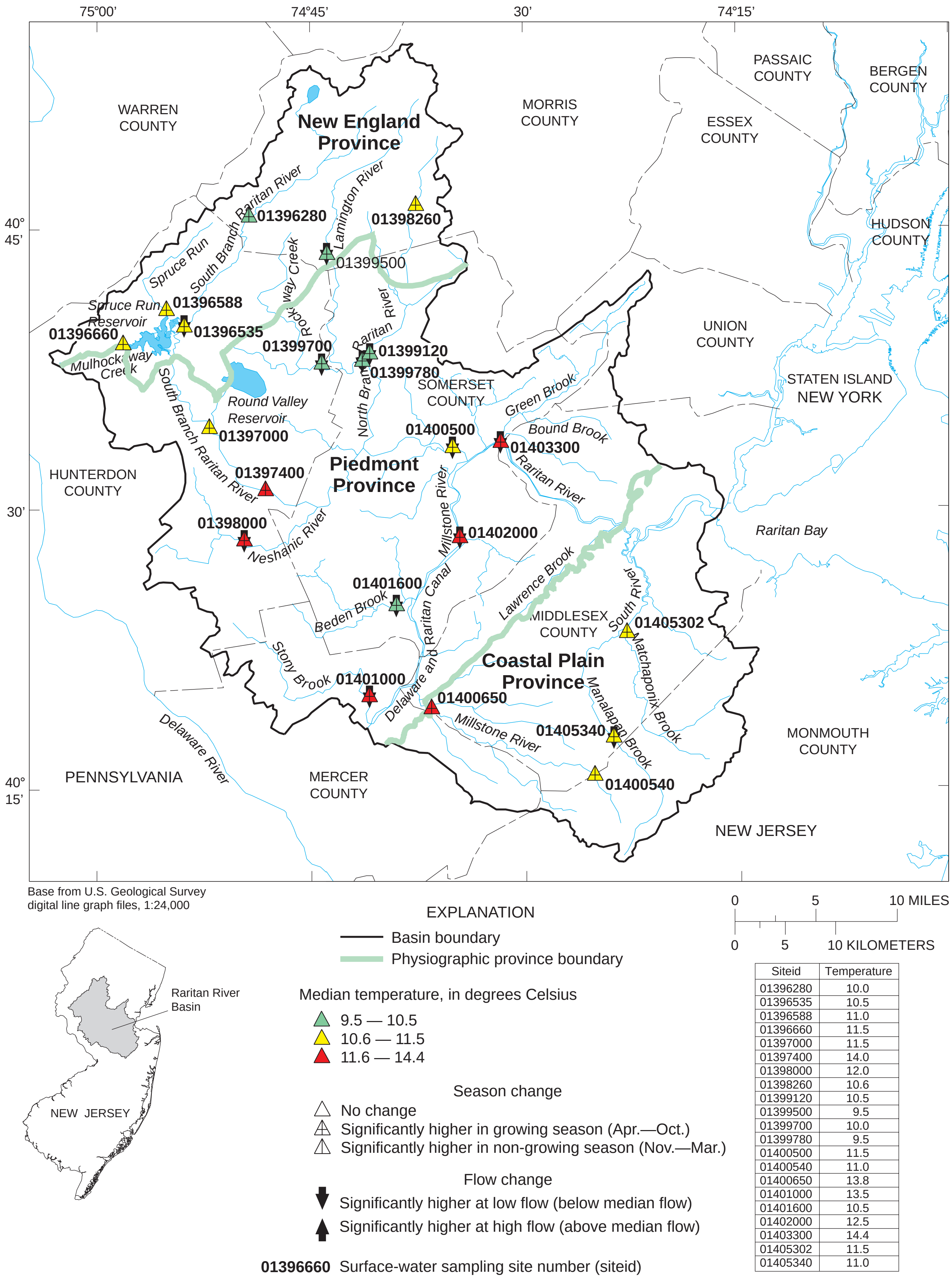
[Concentrations are in milligrams per liter; <, less than the laboratory detection limit; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October); NG, significant differences occur between seasons and largest concentrations occur in the nongrowing season (November-March); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Un-ionized ammonia										
		Summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration		Significant seasonal difference	Median concentration		Significant difference with flow	
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing		Low flow	High flow		
01396280	S.B. Raritan River	34	<0.001	<0.001	.0070	0.00016	0.00014	G	0.0003	0.0002	LO	--
01396535	S.B. Raritan River	34	<.001	<.001	.0077	.00016	.00014	G	.0003	.0002	LO	--
01396588	Spruce Run	35	<.001	<.001	.0013	.00073	.00016	G	.0004	.0001	LO	--
01396660	Mulhockaway Ck	35	<.001	<.001	.0067	.00016	.00008	G	.0003	.0001	--	--
01397000	S.B. Raritan River	29	<.001	<.001	.0253	.0002	.00008	--	.0008	.0002	LO	--
01397400	S.B. Raritan River	34	<.001	.0005	.0092	.0004	.0007	--	.0027	.0005	LO	--
01398000	Neshanic River	35	<.001	.0002	.0421	.0008	.0001	G	.0004	.0002	--	--
01398260	N.B. Raritan River	34	<.001	.0006	.0062	.0006	.0006	--	.0008	.0006	--	--
01399120	N.B. Raritan River	35	<.001	.0001	.0237	.0002	.0001	G	.0003	.0002	LO	G@LO
01399500	Lamington River	34	<.001	<.001	.0019	.0002	.0002	--	.0007	.0002	LO	--
01399700	Rockaway Creek	34	<.001	.0005	.0076	.0006	.0004	G	.0012	.0003	--	--
01399780	Lamington River	35	<.001	<.001	.0081	.0007	.0004	G	.0004	.0001	LO	--
01400500	Raritan River	34	<.001	.0003	.0053	.001	.0002	G	.0009	.0002	LO	--
01400540	Millstone River	34	<.001	<.001	.0008	.001	.0002	--	.00006	.00006	--	--
01400650	Millstone River	29	<.001	.0002	.0032	.0003	.0002	--	.0005	.0001	LO	--
01401000	Stony Brook	34	<.001	.0002	.0135	.0007	.0006	--	.0003	.0002	--	--
01401600	Beden Brook	35	<.001	.0002	.0084	.0004	.0001	G	.0005	.0001	--	--
01402000	Millstone River	31	<.001	.0003	.0027	.0004	.0001	G	.0007	.0001	LO	--
01403300	Raritan River	19	<.001	.0005	.0031	.0006	.0003	--	.0008	.0003	--	--
01405302	Matchaponix Brook	35	<.001	.0001	.0047	.0001	.0001	--	.0004	.00002	LO	--
01405340	Manalapan Brook	35	<.001	<.001	.0006	.0007	.0002	G	.00003	.00002	LO	--

Table 21. Statistical summary of and differences in water temperatures between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data from 1991-97 water years

[Temperature is in degrees celsius; --, indicates the distribution of temperatures during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest temperatures occur in the growing season (April-October); NG, significant differences occur between seasons and highest temperatures occur in the nongrowing season (November-March); LO, significant differences occur between flow conditions and largest temperatures occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest temperatures occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Water temperature										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median temperature			Median temperature			
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing	Significant seasonal difference	Low flow	High flow	Significant difference with flow	
01396280	S.B. Raritan River	35	0.0	10.0	21.0	15	2.5	G	12	9.0	--	G@LO
01396535	S.B. Raritan River	37	0.0	10.5	24.0	17	3.2	G	20	12	LO	--
01396588	Spruce Run	37	0.0	11.0	23.5	17	3.2	G	17	9.2	LO	--
01396660	Mulhockaway Ck	37	0.0	11.5	20.5	17	3.5	G	16	9.0	--	--
01397000	S.B. Raritan River	31	0.0	11.5	26.5	19	3.5	G	16	10	--	--
01397400	S.B. Raritan River	35	0.0	14.0	26.5	20	3.8	G	16	12	--	--
01398000	Neshanic River	54	0.0	12.0	26.0	19	4.5	G	19	6.0	LO	--
01398260	N.B. Raritan River	35	0.0	10.6	20.0	17	3.5	G	17	8.0	--	--
01399120	N.B. Raritan River	35	0.0	10.5	24.5	20	4.0	G	19	5.8	LO	--
01399500	Lamington River	37	0.0	9.50	23.5	14	1.4	G	13	5.5	LO	--
01399700	Rockaway Creek	35	0.0	10.0	25.0	18	3.2	G	14	9.0	--	--
01399780	Lamington River	38	0.0	9.50	25.5	17	2.0	G	14	6.0	LO	--
01400500	Raritan River	35	0.0	11.5	26.0	23	5.5	G	23	6.5	LO	--
01400540	Millstone River	35	0.0	11.0	23.0	16	5.2	G	12	11	--	--
01400650	Millstone River	30	1.00	13.8	26.0	21	6.8	G	16	9.0	--	--
01401000	Stony Brook	55	0.0	13.5	26.0	18	3.2	G	19	7.0	LO	--
01401600	Beden Brook	37	0.0	10.5	24.5	18	2.3	G	18	5.0	LO	G@LO
01402000	Millstone River	31	0.0	12.5	25.0	21	5.6	G	21	7.0	LO	--
01403300	Raritan River	55	1.50	14.4	26.5	21	5.5	G	22	13	LO	G@LO
01405302	Matchaponix Brook	35	0.0	11.5	24.5	18	5.6	G	14	9.2	--	--
01405340	Manalapan Brook	35	0.0	11.0	24.0	16	5.0	G	16	8.5	LO	--



Siteid	Temperature
01396280	10.0
01396535	10.5
01396588	11.0
01396660	11.5
01397000	11.5
01397400	14.0
01398000	12.0
01398260	10.6
01399120	10.5
01399500	9.5
01399700	10.0
01399780	9.5
01400500	11.5
01400540	11.0
01400650	13.8
01401000	13.5
01401600	10.5
01402000	12.5
01403300	14.4
01405302	11.5
01405340	11.0

Figure 20. Median water temperatures and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Season was the dominant explanatory variable related to the variability of water temperature in streams in the Raritan River Basin. When season, flow, and the interaction of both variables were studied together as factors in water temperature variability, season was a significant factor at all sites. The interaction of both variables was also a significant factor at three sites; all three sites had the highest temperatures at low flow during the growing season (table 21). Flow alone was a factor at six sites; at these sites, temperature was highest at low flow.

Water-Quality Rating

Water quality at the 21 sites was rated on the basis of the results of the analysis of major ion, nutrient, and field data collected during 1991-97. The sites and ratings for each constituent are summarized in table 22. The most desirable rating for each constituent was given to the three sites with either the greatest number of samples that meet water-quality reference levels or with the most desirable median values for each constituent. The least desirable rating for each constituent was given to the three sites with either the most samples that do not meet the reference levels or with the most undesirable median value. The sites with a desirable rating for the greatest number of constituents are Mulhockaway Creek, Spruce Run, Millstone River at Manalapan, Manalapan Brook, and Lamington River at Pottersville. The sites with the least desirable rating for the most constituents are Millstone River at Blackwells Mills, Matchaponix Brook, Raritan River at Bound Brook, Neshanic River, and Millstone River at Grovers Mill.

Relation of Total Suspended Solids to Other Constituents

TSS increased significantly at most sites as flow increased. The largest concentration of TSS in surface water typically results from streambank erosion and stormwater runoff. Algae, however, also contribute to increases in TSS concentrations in a stream and typically are found in highest levels at low flow in the summer months. Algae may contribute to the lack of significant increases in TSS concentration with increased flow at some sites.

TSS transport organic nitrogen, phosphorus, organic carbon, and trace elements that are associated with particulates. TKN, total phosphorus, and TOC also are found in dissolved form in water. Concentrations of TKN, total phosphorus, and TOC were found to significantly increase as concentrations of TSS increased at 10, 11, and 13 sites, respectively. Concentrations of NO3+NO2 were inversely related to TSS concentrations at five sites and increased with TSS concentrations at one site. NO3+NO2 is dissolved in the water column and is not associated with solids or sediment transported in storm runoff. NO3+NO2 is mainly transported to streams from point sources and by ground-water discharges.

Comparison of Ground-Water-Quality Data to Surface-Water-Quality Data

Ground-water-quality data were examined and compared with streamwater-quality data in three subbasins. Ground-water-quality data were evaluated to assess the relative importance of ground-water sources to instream quality. Ground-water-quality data and the percentage of mean annual streamflow originating from ground-water sources were used to estimate the amount of instream load originating from ground-water sources in the three subbasins.

Water-quality data from 36 shallow wells (fig. 1) in the three subbasins were compared to surface-water quality data from one sampling site in each of the three subbasins. Ground-water-quality data collected for 1985 through 1994 for wells less than 120 feet deep in unconfined aquifers upstream from the three stream sites were used for the comparison. Data on chloride, TDS, $NO^3 + NO^2$, TKN, orthophosphorus, and dissolved organic carbon were obtained for 23 of the 52 wells located in the drainage area of the S.B. Raritan

Table 22. Summary of water-quality conditions at 21 U.S. Geological Survey/New Jersey Department of Environmental Protection surface-water sampling sites in the Raritan River Basin, N.J., during 1991-97 water years

[**Green Cells** indicate the three sites with greatest number of samples that meet the standard or three sites with lowest median value for each constituent (highest median dissolved oxygen and alkalinity values). **Red Cells** indicate the three sites with most samples that do not meet the standards or three sites with highest median values (lowest median dissolved oxygen and alkalinity values). Alkalinity, biochemical oxygen demand, total ammonia + organic nitrogen (TKN) and total organic carbon do not have a standard. Ratings for pH and hardness are based on the percentage of samples that meet or do not meet both a high and low standard. *, trout maintenance; **, trout production; **#,** Coastal Plain waters have naturally low alkalinity]

Station number	Nutrients					Inorganics						Other constituents					
	Ammonia, Un-ionized	Ammonia + organic nitrogen	Nitrate plus nitrite	Organic carbon, total	Phosphorus, total	Alkalinity	Chloride	Dissolved solids, total	Hardness	Sodium	Sulfate	Biochemical oxygen demand	Dissolved oxygen	Fecal coliform bacteria	pH	Suspended solids, total	Water temperature
S.B. Raritan River sub-basin																	
**01396280																	
*01396535																	
**01396588																	
*01396660																	
*01397000																	
01397400																	
01398000																	
N.B. Raritan River sub-basin																	
**01398260																	
01399120																	
**01399500																	
01399700																	
01399780																	
Millstone River sub-basin																	
01400540						#											
01400650						#											
01401000																	
01401600																	
01402000																	
Raritan River mainstem																	
01403300																	
01400500																	
South River sub-basin																	
01405302						#											
01405340						#											

River at Middle Valley, 6 of the 26 wells in the drainage area of the Lamington River at Pottersville, and 7 of 16 wells in the drainage area of the Millstone River at Grovers Mill.

The S.B. Raritan River at Middle Valley and Lamington River at Pottersville sites were chosen because water-quality data were available for 29 shallow wells sampled during 1988-90 as part of a study of ground-water flow and quality in the valley-fill and carbonate-rock aquifer system in the New England province of New Jersey (Nicholson and others, 1996). The Millstone River at Grovers Mill site in the Coastal Plain also was chosen because concentrations of some constituents in this stream were elevated above background levels and ground-water-quality data were available for shallow wells in the basin. These three sites also are favorable for this type of analysis because there are no surface-water diversions or reservoirs in the basins. Each basin has point sources that contribute to streamflow, however. Effluent flow and load that contribute to instream load at the three sites were subtracted from the estimated base-flow load originating from ground water.

TDS (fig. 21), $NO^3 + NO^2$, TKN, total nitrogen, orthophosphorus, and dissolved organic carbon were chosen for the comparison because ground-water and surface-water data were available for these constituents. Surface-water samples were not analyzed for orthophosphorus, and data on total phosphorus in ground water during 1991-97 were not available. Orthophosphorus in ground water, however, is essentially equivalent to total phosphorus. Therefore, orthophosphorus in ground water was compared to total phosphorus in surface water (table 23). Suspended organic carbon was added to dissolved organic carbon to compute total organic carbon in surface water. Suspended organic carbon was analyzed for only in surface water; therefore, dissolved organic carbon was chosen for comparative purposes. TSS and BOD data were available only for surface-water sampling sites.

The wells are randomly distributed across the three basins. Only one sample was collected from most of the wells; therefore, data from the single sample were used to represent the water quality in the well. Two samples each were collected from two wells in the S.B. Raritan River at Middle Valley subbasin, and five samples each were collected from two wells in the Millstone River at Grovers Mill subbasin. For the wells with more than one sample, a median concentration was computed for each constituent. Concentrations in shallow ground water were computed for each basin from the median concentration or single observation from each well (table 23).

In general, the ground-water-quality data were more variable than the streamwater-quality data in each subbasin. This is probably because the samples of streamwater were collected at a single location and the ground-water samples for each basin were collected from wells at different locations. Concentrations of chloride, TDS, NO3+NO2, and dissolved organic carbon in ground-water samples from each of the three subbasins were more variable than those in streamwater samples. TKN concentrations in ground-water samples from two of the three subbasins were more variable than in surface-water samples. Variability in phosphorus concentrations in ground-water samples could not be compared with those in surface-water samples because a large percentage of concentrations in ground-water samples were below the laboratory reporting level. In general, median concentrations of all constituents studied, except for NO3+NO2, were lower in ground water than in surface water. The distribution of TDS concentrations in ground water and surface water presented in boxplots in figure 21 is typical of the differences in concentrations and variability in concentrations observed for each of the constituents.

Constituent Concentrations in Ground Water and Surface Water

Ground-water-quality data were compared to the surface-water-quality data collected at all flows and to the data collected only at base flow. Streamflow less than or equal to the 75th percentile flow duration was considered to be base flow.

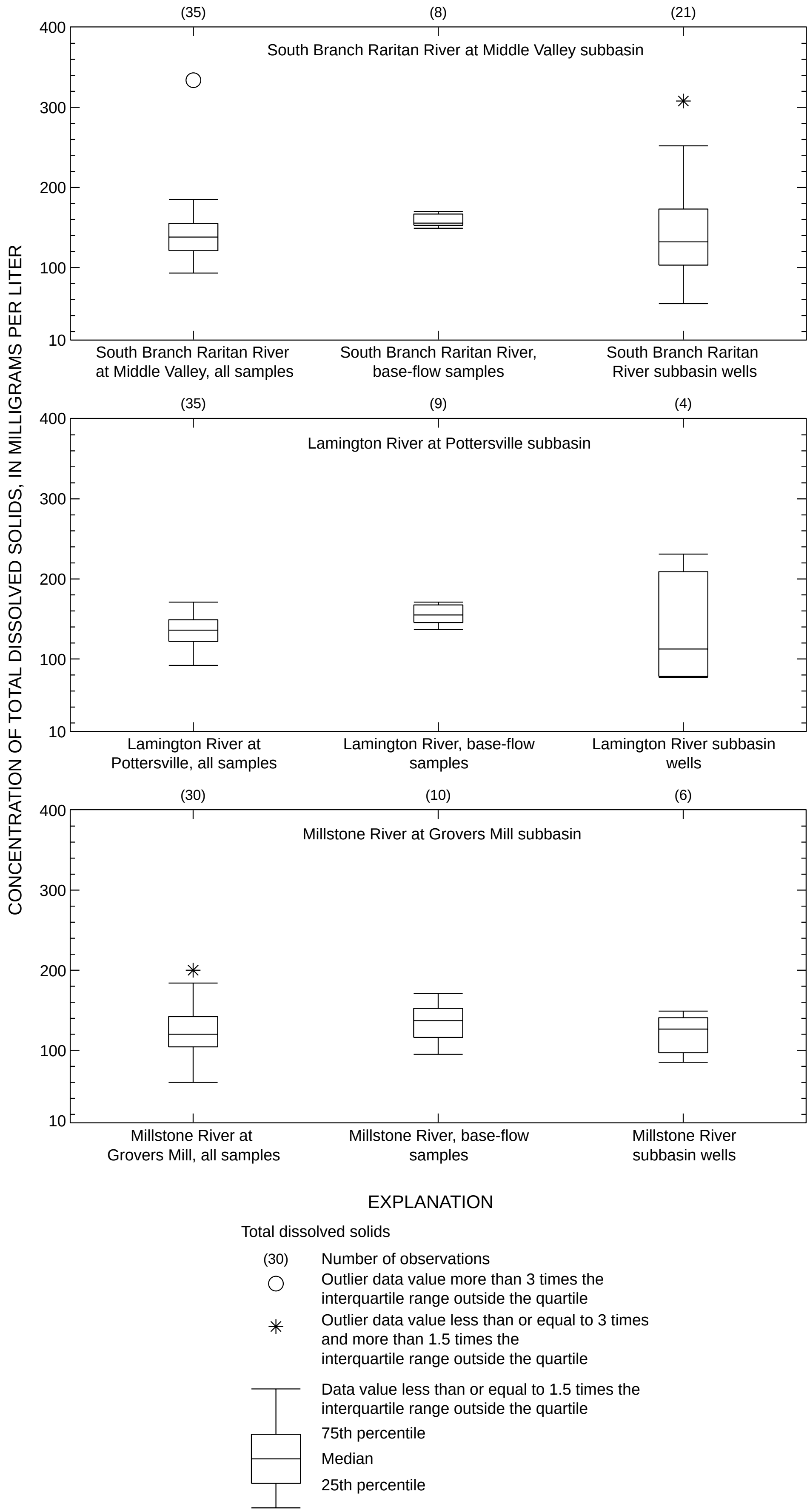


Figure 21. Distribution of total dissolved solids concentrations in all samples and in base-flow samples collected during 1991-97 from three surface-water sampling sites and in samples collected during 1985-94 from shallow wells in the subbasin upstream from the sites, Raritan River Basin, N.J.

Table 23. Median concentrations of selected constituents in samples of surface water and shallow ground water in three subbasins in the Raritan River Basin, N.J., 1985-94

[Concentrations are in milligrams per liter; <, less than; --, no data]

Constituent	South Branch Raritan River at Middle Valley			Lamington River at Pottersville			Millstone River at Grovers Mill		
	Surface water			Surface water			Surface water		
	All flow conditions	Base flow	Ground water	All flow conditions	Base flow	Ground water	All flow conditions	Base flow	Ground water
Chloride	27	25	12	36	37	2.0	24	24	24
Total dissolved solids	138	155	129	136	150	112	120	135	126
Nitrate plus nitrite, nitrogen	1.66	1.95	1.5	.74	.68	1.2	3.7	5.0	9.0
Ammonia plus organic, nitrogen	.29	.23	.30	.30	.27	.30	.53	.48	.25
Organic carbon, dissolved	2.2	2.1	.50	3.9	3.4	1.0	3.4	3.4	.50
Orthophosphorus	--	--	<.01	--	--	.01	--	--	<.01
Total phosphorus	.05	.12	--	.04	.06	--	.12	.15	--

Median chloride concentrations in ground water were an order of magnitude lower than those in surface water at base flow in the Lamington River subbasin, were one-half of those in surface water at base flow in the S.B. Raritan River subbasin, and were equal to those in the Millstone River subbasin. Median concentrations in surface water were similar in each subbasin. Median chloride concentrations were 2.0 mg/L, 12 mg/L, and 24 mg/L in ground-water samples from the Lamington, S.B. Raritan, and Millstone River Basins, respectively.

Median TDS concentrations were slightly lower in ground water than in surface water at base-flow conditions in all three subbasins. The median concentration in ground water of 112 mg/L in the Lamington River subbasin was slightly lower than the median concentrations of 126 and 129 mg/L in the other two subbasins. Variability as measured by inner quartile range was greater in ground water than in surface water in each subbasin (fig. 21).

Median NO3+NO2 concentrations in ground water were more than 75 percent greater than in surface water in the Lamington River and Millstone River subbasins. The median concentration of NO3+NO2 for ground water in the S.B. Raritan River subbasin was less than the median concentration for surface water. Concentrations in ground water were more variable than concentrations in surface water at each site. The median concentration of NO3+NO2 for ground water in the Millstone River subbasin (9.0 mg/L) was more than 7 times the median concentrations of 1.2 and 1.5 mg/L in the other two subbasins (table 23).

Median ammonia plus organic nitrogen concentrations from ground-water data for the Lamington River and S.B. Raritan River subbasins were essentially equal to the median concentration for surface-water data. The median concentration for ground water in the Millstone River subbasin was one-half that for surface water. Median concentrations for ground water were similar in each subbasin, ranging from 0.25 mg/L to 0.30 mg/L (table 23).

Median dissolved organic carbon concentrations for ground water were more than 3 times lower than the median concentrations for surface water in each subbasin. The median concentration for ground water in the Lamington River subbasin was twice those for the Millstone River and S.B. Raritan River subbasins.

Concentrations of total phosphorus at base-flow conditions were greater than concentrations of orthophosphorus in ground water in each subbasin (table 23). Median orthophosphorus concentrations in ground water were less than the 0.01-mg/L detection limit for the constituent in streamwater in the Millstone and S.B. Raritan River subbasins and 0.014 mg/L for the constituent in the Lamington River subbasin. Median total phosphorus concentrations were 0.15 mg/L, 0.12 mg/L, and 0.06 mg/L during base-flow conditions in the Millstone, S.B. Raritan, and Lamington River subbasins, respectively.

Relation of Land Use and Population Density to Water Quality

Mixed land uses predominate in most areas of the Raritan River Basin. The 21 surface-water sampling sites studied are in drainage basins that reflect this mix of land uses. Only one site has a land-use category--urban, agricultural, forested, or wetlands--in the associated drainage basin that represents 50 percent or more of the basin; 52.78 percent of Spruce Run is forested land (table 1).

The land uses shown in table 1 are derived from a 1995/97 GIS coverage (New Jersey Department of Environmental Protection, 2000). The percentage of forested land in the drainage basins upstream from the sampling sites studied ranged from 16.1 percent at Millstone River at Grovers Mill to 52.8 percent at Spruce Run. The percentage of land consisting of urban land use ranged from 16.0 percent in the Millstone River near Manalapan subbasin to 43.2 in the Matchaponix Brook subbasin. Agricultural land use ranged from 5.3 percent at N.B. Raritan River near Chester to 41.5 percent at Neshanic River. The percentage of wetlands ranged from 4.7 percent in the Rockaway Creek subbasin to 30 percent in the Manalapan Brook subbasin.

Total developed land use was computed by adding urban and agricultural land uses in the drainage basins upstream from each site. Total undeveloped land use was computed by adding forested, water, wetland, and barren land-use categories. The percentage of total developed land use ranged from 37 percent at Spruce Run to 65 percent at Neshanic River. Population density computed as people per square mile is derived from the 1990 census data (U.S. Bureau of Census, 1991). Population densities ranged from 127 in the Millstone River near Manalapan subbasin to 1,220 in the Matchaponix Creek basin.

Ordinary least squares regression analysis was performed to evaluate the relations between land uses and (1) median values of constituents and water-quality characteristics and (2) median total yields (lbs/d/mi^2). Significant relations between land use and median concentrations, and land use and median total yields were observed. The results indicate that the relation of yields to land use should not be used as an evaluation of nonpermitted source loads. The relations were found to exist in the basin despite the lack of sites that represent drainage areas with a single predominant land use (figs. 22 and 23; tables 1 and 24).

These results indicate that surface-water quality is related to particular land uses. In this preliminary analysis, however, it was not determined whether the differences in concentrations between developed and undeveloped areas result from nonpermitted sources related to land use or from permitted point sources. Analysis of permitted and nonpermitted loads at the sampling sites is discussed in the sections “Evaluation of loads from permitted sources” and “Evaluation of loads and yields from nonpermitted sources.”

Median constituent concentrations, water temperatures, and pH were compared to percentages of urban, urban residential, agricultural, forested, water, and wetland land uses; population density; and total developed and total undeveloped land uses. Median values of 15 of the 17 constituents studied in the preliminary evaluation of water quality in the basin were

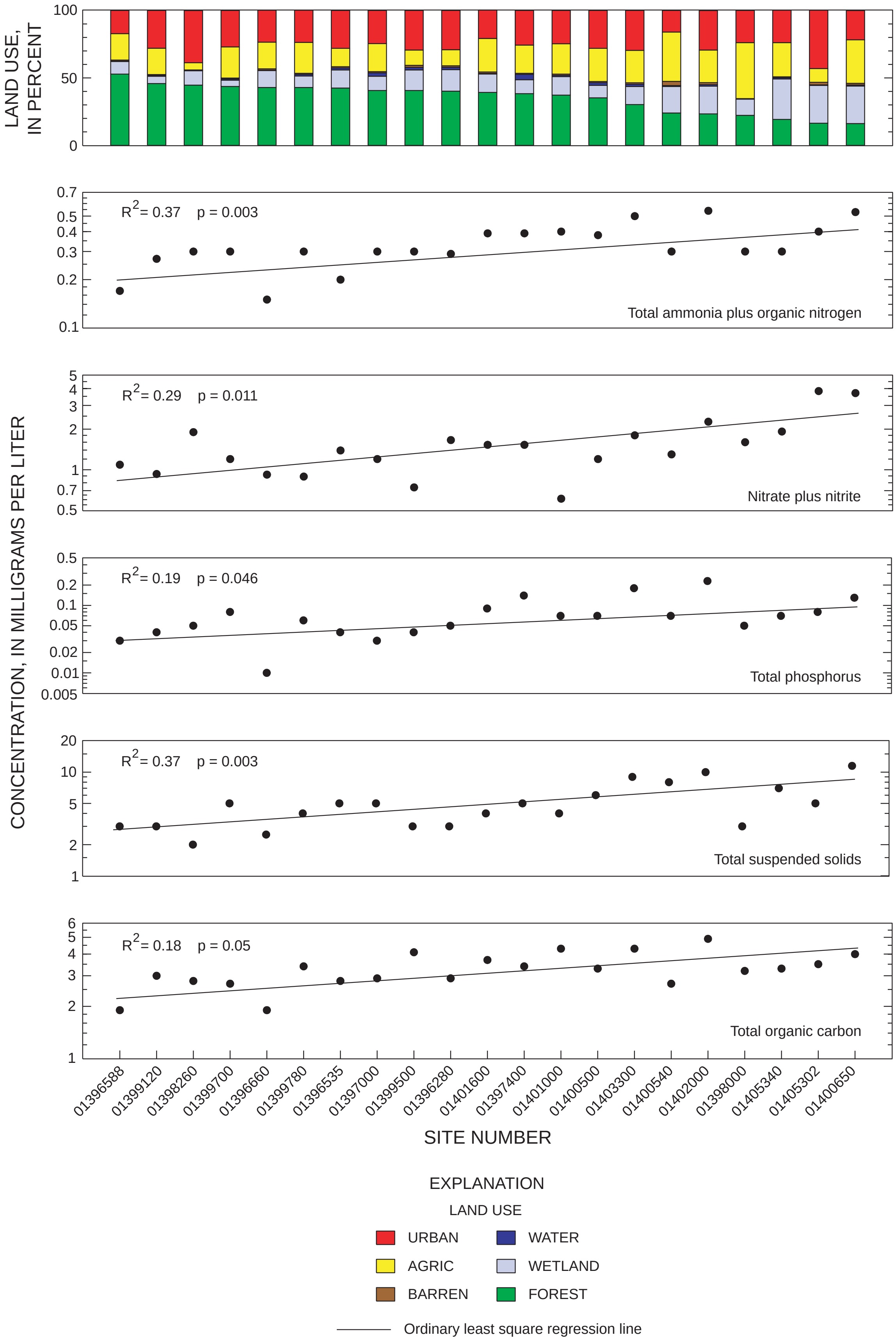


Figure 22. Relation of median concentrations of five constituents in samples collected during 1991-97 to the percentage of forested land use for each subbasin in the Raritan River Basin, N.J. (Five of eight constituents studied for load analysis increased with a decrease in forested land.)

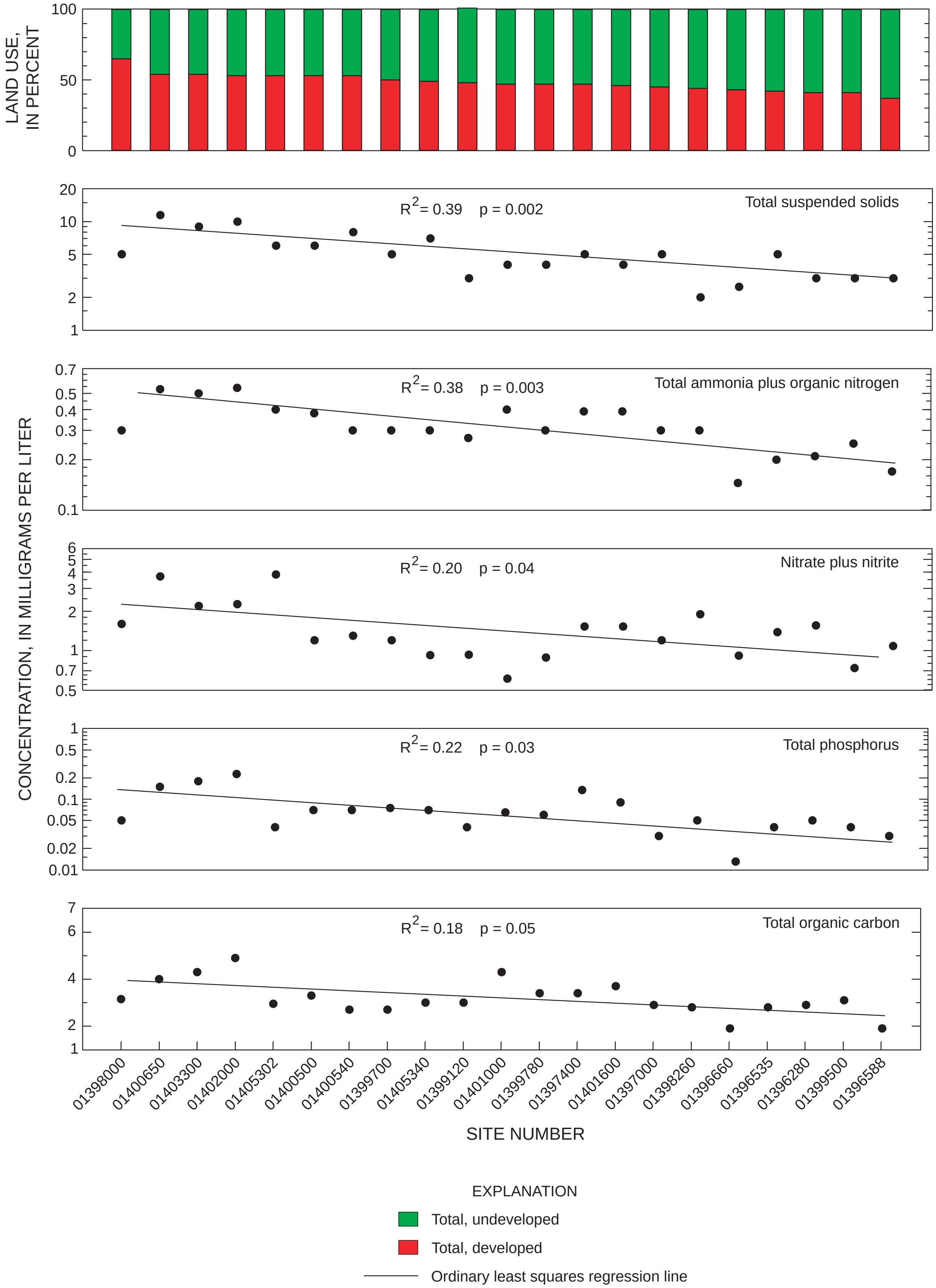


Figure 23. Graphs showing relation of median concentrations of five constituents in samples collected 1991-97 to percentage of total developed land use for each subbasin in the Raritan River Basin, N.J.

Table 24. Summary of significant results of ordinary least squares regression relations between median values of log-normalized values of constituents and land use and population density

[+, median concentrations or values increase as land-use percentage increases; -, median concentrations or values decrease as land-use percentage increases; NS, no significant relation]

Constituent	Land uses						Population density
	Urban	Agri-culture	Forest	Wetland	Total developed	Total un-developed	
Alkalinity	**NS**	**NS**	+	-	**NS**	**NS**	**NS**
Biochemical oxygen demand	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Chloride	+	-	**NS**	**NS**	**NS**	**NS**	+
Dissolved oxygen	**NS**	**NS**	+	-	**NS**	**NS**	-
Fecal coliform bacteria	**NS**	+	**NS**	-	+	-	**NS**
Hardness	**NS**	**NS**	+	-	**NS**	**NS**	**NS**
Total ammonia + organic nitrogen	**NS**	**NS**	-	+	+	-	+
Nitrate + nitrite	+	**NS**	-	+	**NS**	-	+
pH	**NS**	**NS**	+	-	-	+	**NS**
Phosphorus	**NS**	**NS**	-	**NS**	+	-	**NS**
Sodium	+	**NS**	**NS**	**NS**	**NS**	**NS**	+
Sulfate	+	**NS**	-	+	+	-	**NS**
Total disolved solids	+	**NS**	**NS**	**NS**	**NS**	**NS**	+
Total organic carbon	**NS**	**NS**	-	**NS**	+	-	**NS**
Total suspended solids	**NS**	+	-	+	+	-	**NS**
Water temperature	**NS**	**NS**	-	**NS**	+	-	**NS**
Un-ionized ammonia	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

significantly related to at least one land-use category (table 24). Median concentrations of un-ionized ammonia and BOD were not related to any land-use category. BOD did not show significant variability between sites in the study area as was observed for other constituents.

Median values of 11 constituents were significantly related to the percentage of forested land use in the drainage basin upstream from a sampling site, more than to any other land-use category. Median concentrations of alkalinity, DO, and hardness, and median values of pH increased with an increase in forested land in a basin. Concentrations of TKN, NO3+NO2, total phosphorus, sulfate, TOC, and TSS, and measurements of water temperature decreased as forested land increased (fig. 22).

The percentages of total developed and total undeveloped land use were related to eight and nine constituents, respectively. Median concentrations of TKN, total phosphorus, sulfate, TOC, and TSS, median water temperatures, and median fecal coliform counts increased, and pH decreased, with the increased percentage of total developed land use (fig. 23). The same constituents showed significant, opposite relations to undeveloped land use. NO3+NO2 concentrations decreased as total undeveloped land increased; however, no significant relation to total developed land use was determined.

The median values of nine constituents and characteristics were related to the percentage of wetlands; however, only alkalinity was related to the percentage of open water--lakes and ponds. Alkalinity, DO, fecal coliform bacteria, hardness, and pH decreased with an increase in wetlands. Sulfate, TSS, NO3+NO2, and TKN increased with an increase in wetlands. Only three constituents were related to agricultural land use. Median concentrations of chloride decreased, and median concentrations of TSS and median fecal coliform counts increased, as the percentage of agricultural land use increased.

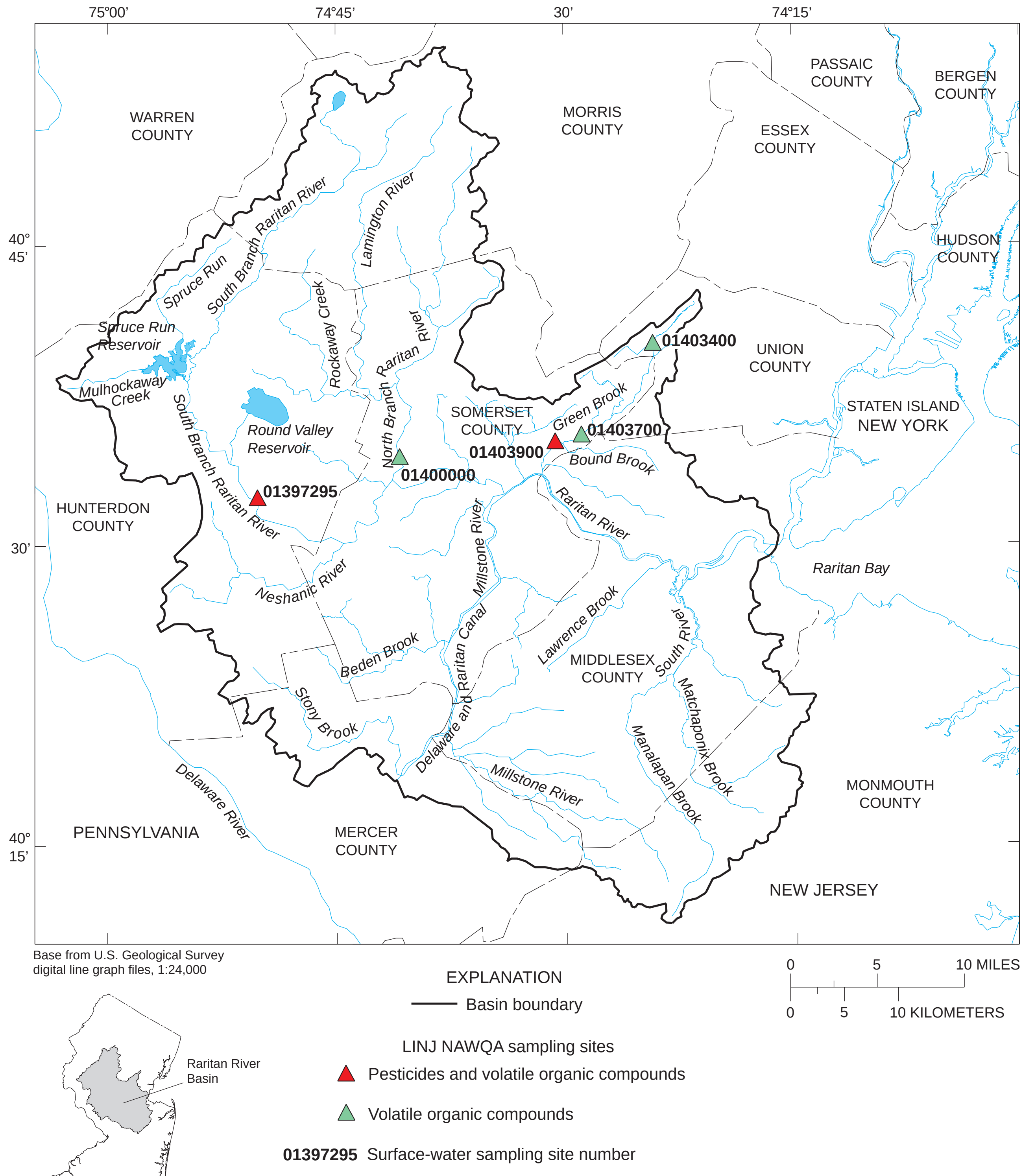
Median values of constituents and characteristics showed a stronger relation to population density and urban land use than to agricultural land use. Densely populated urban land appears to affect more water-quality constituents than less densely populated urban land. Median concentrations of six constituents were related to population density. Chloride, TKN, NO3+NO2, sodium, and TDS increased, and dissolved oxygen decreased, with increased population density. Chloride, sodium, sulfate, NO3+NO2, and TDS also increased with increased urban land use. Only values of fecal coliform bacteria and TSS increased with increased agricultural land use.

Pesticides

A summary of results from USGS studies of pesticides in surface waters in the Raritan River Basin is presented in this section. Pesticides in surface water in the Raritan River Basin were investigated in two studies as part of the LINJ NAWQA project. In the first study, two sites in the basin were routinely sampled for these compounds from April 1996 through June 1998, and two other sites were sampled from April 1996 through September 1996 and in June 1997. In the second study, one sample was collected during June 9-18, 1997, from each of nine sites representing various land uses in the basin. Two of these sites did not coincide with the 21 surface-water sampling sites from the USGS/NJDEP cooperative network used for analysis of other constituents in this study (fig. 24).

Relation to Season, Flow, and Water-Quality and Drinking-Water Reference Levels

The first LINJ NAWQA study, pesticide data from samples collected routinely from seven sites in New Jersey, including four sites in the Raritan River Basin, were evaluated to determine the relation of concentrations to season, streamflow, and land use (Reiser, 1999). The samples were analyzed for 85 pesticides, including 50 herbicides, 28 insecticides, and 7 degradation products. The four sites sampled routinely in the Raritan River Basin include the three sites in the USGS/NJDEP



Siteid	Site name
01397295	South Branch Raritan River upstream Route 523 at Darts Mills, N.J.
01400000	North Branch Raritan River near Raritan, N.J.
01403400	Green Brook at Seeley Mills, N.J.
01403700	Green Brook at Dunellen, N.J.
01403900	Bound Brook, at Middlesex, N.J.

Figure 24. Sites sampled for the Long Island-New Jersey National Water Quality Assessment Program (LINJ NAWQA) for pesticides and volatile organic compounds, Raritan River Basin, N.J., water years 1996-98.

cooperative network and the site at Bound Brook at Middlesex (fig. 24). The three network sites are Neshanic River at Reaville, Stony Brook at Princeton, and Raritan River at Bound Brook. Stony Brook and Neshanic River were sampled only during the growing season.

Specific results in this summary are for sites in the Raritan River Basin. Pesticides were frequently detected in each stream; however, concentrations were generally low. The pesticides most frequently detected from all samples in the study were atrazine, in 97 percent of the samples; prometon, in 96 percent; metolachlor, in 95 percent; desethyl-atrazine, in 91 percent; simazine, in 88 percent; diazinon, in 58 percent; alachlor, in 56 percent; and carbaryl, in 54 percent. More than 97 percent of the samples contained at least five pesticides. Twenty-nine pesticides were detected at the highly urbanized Bound Brook site throughout the sampling period, the most detected at any site in the study, and 17 pesticides were detected at the Neshanic River site, the fewest at any of the three sites in the basin.

The concentrations of nine pesticides infrequently exceeded established water-quality criteria at the Raritan River Basin sites. The 26 detections that exceeded criteria occurred during the growing season. Twenty-two of these detections occurred at high-flow conditions. Concentrations of atrazine and alachlor exceeded the New Jersey drinking-water standard, and cyanazine exceeded the USEPA human health advisory level (HAL) during runoff shortly after spring applications of these pesticides. The high concentrations of atrazine were measured in samples from Stony Brook, Neshanic River, and Raritan River at Bound Brook. The high concentration of alachlor was measured in a sample from Stony Brook. Dieldrin was detected in one sample collected at Stony Brook at low flow during the growing season, and 1,1-dichloro-2,2-bis (p-dichlorodiphenyl) ethylene (DDE) was detected in one sample during runoff in August at Raritan River at Bound Brook. Concentrations of both compounds exceeded the NJDEP surface-water standard. Dieldrin concentrations also exceeded the NJDEP chronic life criteria for the protection of aquatic life (AQCR). In one sample from Bound Brook at Middlesex, chlorpyrifos exceeded the New Jersey surface-water standard. Concentrations of chlorthalonil, diazinon, and ethyl-parathion exceeded the associated AQCR's; they also exceeded Canadian criteria (Canadian Council of Resource and Environment Ministries, 1991), Great Lakes standards (International Joint Commission Canada and United States, 1977), and USEPA standards (U.S. Environmental Protection Agency, 1991), respectively. These criteria were exceeded at Bound Brook at Middlesex and Raritan River at Bound Brook during the growing season, mostly at high-flow conditions. Diazinon exceeded the Great Lakes Standard of 0.08 mg/L in 10 samples from Bound Brook at Middlesex and 3 samples at Raritan River at Bound Brook.

Pesticides were detected more frequently during the growing season than during the nongrowing season. Thirty-seven pesticides were detected during the growing season and 19 pesticides during the nongrowing season in the basin. Twenty pesticides were detected only during the growing season. The highest individual concentrations and the highest median concentrations of most of the pesticides detected occurred during runoff during the growing season, and the lowest concentration typically occurred during runoff during the nongrowing season. The median concentrations of most pesticides at most sites were equally low during base flow and runoff in the nongrowing season. Typically, concentrations were least variable during base-flow conditions during the nongrowing season. All 24 pesticides with the highest concentrations during runoff were sampled during the growing season. The four pesticides with highest concentrations during the nongrowing season were sampled during base-flow conditions.

Pesticide concentrations were related to land use in the drainage basin upstream from the sampling site. The highest median concentration and the maximum concentration of a pesticide typically were found at a site where land use in the drainage basin upstream from the site is generally associated with applications of that pesticide. Herbicides associated with agricultural land use, such as atrazine, generally were detected in higher concentrations than other pesticides, showed the strongest correlation to land use, and had the largest variability in concentration associated with season and streamflow. In general, insecticides were detected more frequently and in greater concentrations at urban sites than at other sites. The highest individual and median concentrations of 10 of the 13 insecticides detected were present in samples from the two sites with the highest percentage of urban land use. Ten of the 13 insecticides were detected at the highest frequencies at the three most urbanized sites.

Concentrations of 13 pesticides correlated significantly with streamflow at one or more sites. The strongest relations were for concentrations of two herbicides used for lawn care at a suburban site and two herbicides used for agriculture at Stony Brook; these compounds correlated positively with streamflow during the growing season. Land use in the Stony Brook subbasin is 28 percent agricultural. A strong positive correlation also was observed for concentrations of the insecticide diazinon and streamflow during both seasons at Raritan River at Bound Brook, a site that drains 804 mi^2 of the 1,105 mi^2 Raritan River Basin. In general, most of the pesticides that correlated positively with streamflow were detected at sites where the predominant land use is associated with the use of the detected pesticide. Most of the pesticides whose concentrations decreased as flow increased were detected at sites where the land use in the basin would not indicate use of the detected pesticide. The number of pesticides detected was found to increase significantly as streamflow increased at the Raritan River site. The numbers of pesticides generally increased with increased streamflow at the other three sites in the basin.

Relation to Land Use

The second LINJ NAWQA study evaluated the presence of 47 pesticides in 1 sample from each of 50 sites in New Jersey and Long Island, New York, including 9 sites in the Raritan River Basin (Reiser and O'Brien, 1999). Pesticide compounds were detected in all 50 streamwater samples analyzed during the June 9-18, 1997, pesticide synoptic study. The samples were collected at high base-flow conditions. The number of pesticides detected at each site ranged from 1 to 14 with a median of 7. The seven most frequently detected pesticides were atrazine (in 93 percent of samples), metolachlor (86 percent), prometon (84 percent), desethyl-atrazine (78 percent), simazine (78 percent), carbaryl (44 percent), and diazinon (44 percent).

Water-quality criteria for aquatic life, MCLs, or HALs have been established for 18 of the 25 compounds detected. None of the pesticides detected exceeded an MCL or HAL or the criteria for aquatic life in the Raritan River Basin.

Detection frequencies of 14 of the 25 pesticides detected were highest at agricultural sites. Acetochlor, azinphos-methyl, carbofuran, and pebulate were detected only at agricultural sites. Seven compounds were detected most frequently at urban sites. Four of these compounds --trifluralin, dieldrin, napropamide, and benfluralin--were detected only at urban sites. Four compounds--carbaryl, simazine, pendimothalin and tebuthivros--were detected most frequently at mixed land-use sites. No pesticides were detected most frequently at forested sites.

The highest median concentration of the sum of pesticides detected at a site was calculated for the agricultural group of sites (0.2 µg/L), and the lowest median was calculated for forested sites (0.025 µg/L). The variability in concentrations of total pesticides was highest for urban sites and lowest for mixed land-use sites. Total concentrations and number of pesticides detected at a site showed a positive trend with increased agricultural land use and an inverse relation with the total undeveloped land use in a basin.

Pesticide application rates in New Jersey were compared to detection frequencies in streams. Pendimethalin and chlorpyrifos, two of the most heavily applied pesticides in New Jersey, have low water solubilities, high soil adsorption coefficients, and low detection frequencies. In addition, chlorpyrifos is used primarily for termite control and is less likely to be applied in areas exposed to water transport to the same degree as other compounds. Prometon has high solubility in water, a low soil sorption coefficient, proportionately low application rates (in pounds of active ingredient), and high detection frequencies in streams.

Volatile Organic Compounds

Results from USGS studies of volatile organic compounds (VOCs) in surface waters in the Raritan River Basin are summarized in this section. For the LINJ NAWQA project, VOCs in surface water in the basin were evaluated in three studies. (1) Three sites in the Raritan River Basin were routinely sampled for VOCs from April 1996 through January 1998, and one site was sampled from April 1996 through January 1997 (Reiser and O'Brien, 1998). (2) One sample was collected at each of 42 sites, including 12 sites in the Raritan River Basin, during January 27-30, 1997 (O'Brien and others, 1997). During this study, one sample was collected at each of nine sites in the Bound Brook subbasin to evaluate VOCs found along stream reaches that drain areas containing different land uses. (3) Five samples were collected at each of three sites along the Green Brook part of the Bound Brook subbasin before, during, and after a storm in February 1998. Five of these sites did not coincide with the 21 surface-water sampling sites from the USGS/NJDEP cooperative network used for analysis of other constituents in this study (fig. 24).

Relation to Season

VOCs were detected in 104 of the 112 samples collected during April 1996 to April 1997 from seven streams, four of which are in the Raritan River Basin (Reiser and O'Brien, 1998). Forty-seven of the 86 VOCs analyzed for were detected. Forty-three additional samples (24 in the Raritan basin) were collected from April 1997 through January 1998. VOCs were not detected in 9 of the 155 samples collected from April 1996 through January 1998; all samples without detections were in collected summer months. The largest numbers of VOCs detected during the study were present in samples from 3 sites in the Raritan River Basin; 40 VOCs were present at Bound Brook at Middlesex, 29 at Raritan River at Bound Brook, and 22 at Neshanic River at Reaville. The Bound Brook site had the highest concentrations measured for 28 of the 47 VOCs detected.

The five most frequently detected VOCs in all samples were MTBE, in 78 percent of the samples; chloroform, 63 percent; TCE, 51 percent; 1,1,1- trichloroethane (TCA), 41 percent; and tetrachloroethene (PCE), 35 percent. MTBE, TCE, and PCE concentrations were higher in the cool months, and chloroform and TCA were higher in the warm months.

Contrasting seasonal patterns could indicate different sources of VOCs in streams. Higher concentrations in cool months, when flows are high, indicate that nonpoint sources may be important in determining the presence and concentration of certain VOCs. Higher concentrations in warm months, when flows are low, indicate that point sources or ground-water contributions may be more important than surface runoff in determining the presence and concentration of other VOCs in streams.

Detection frequencies and median concentrations of MTBE, TCE, and PCE were highest at Bound Brook, the drainage basin with the highest percentage of urban/industrial land use. Detection frequencies and median concentrations of chloroform were highest at the Passaic and Raritan River sites, the sites most affected by discharges from wastewater-treatment plants.

Concentrations of chloroform, bromodichloromethane, TCA, PCE, and chlorobenzene were found to decrease significantly with flow at one or more sites, indicating that dilution is likely an important determinant of concentrations of these VOCs.

Relation to Land Use

Samples from 42 stream sites, including 12 sites in the Raritan River Basin were analyzed for 86 VOCs (O'Brien and others, 1997). The samples were collected at high base-flow conditions during January 27-30, 1997. The results of the study indicate the spatial variability of VOCs in streams that drain different land-use areas.

A total of 50 VOCs were detected at the 42 sites in the study by O'Brien and others (1997). The most frequently detected VOCs were methyl tert-butyl ether (MTBE), acetone, naphalene, tetrachloroethene (PCE), chloroform, and trichloroethene (TCE). MTBE was detected in all samples. All concentrations measured were less than established MCLs and HALs. None of the maximum concentrations were measured in samples collected in the Raritan River Basin, except for 0.04 µg/L of chlorobenzene at Bound Brook. The concentrations and numbers of VOCs detected were highest in the most urbanized areas. Total concentrations of all VOCs detected in samples were lowest in subbasins with predominately forested land use.

Samples for analysis for VOCs were collected along two stream reaches that represent different land uses in the Bound Brook subbasin during January 27-30, 1997. Six VOCs were detected in samples from four sites along the less developed Green Brook reach; however, 37 VOCs were detected in samples from four sites along the more heavily developed Bound Brook subbasin. Fourteen VOCs were detected in samples from a small tributary that drains a basin with a high percentage of urban commercial/industrial land-use areas. Eleven of those VOCs were not detected at another site farther downstream.

Relation to Flow and Land Use in the Bound Brook Subbasin

Three sites along a stream reach in the Bound Brook subbasin were sampled before, during, and after a storm in February 1998. The total numbers of VOCs detected, and the total VOC and MTBE concentrations measured in all the samples from each site are summarized. Samples were collected at Green Brook at Seeley Mills (01403400) (fig. 24), the most upstream site with a high percentage of forested land use. Samples collected during base flow, and before and after the storm, contained five VOCs; samples collected during storm runoff contained only four VOCs. Green Brook at Dunellen (01403700) (fig. 24) is a site in the middle of the stream reach; it is located in an area with a higher percentage of urban land use than the Seeley Mills site. Eleven VOCs were present in samples collected before the storm, 17 in samples collected during the storm runoff, and 5 in samples collected at flow conditions near base flow after the storm. Bound Brook at Middlesex (01403900) is the site farthest downstream; it drains an area with 73 percent urban land use, consisting of residential and commercial/ industrial land uses. The drainage area of this site also contains industrial point sources. Ten VOCs were detected in samples collected before the storm, 23 in samples collected during storm runoff, and 8 in samples collected at low flow after the storm. Thirteen compounds, mostly benzene compounds, were detected in samples only during storm runoff.

Numbers of VOCs and total concentrations were lower at all sites after the storm than before the storm. This could be caused by dilution at the two most downstream sites. Flows when samples were collected after the storm at the Bound Brook and the Green Brook at Dunellen sites were twice as high as flows when samples were collected before the storm. Flow at the Green Brook at Seeley Mills site was lower during sample collection after the storm than during sample collection before the storm. The slightly lower total concentrations observed after the storm at the Seeley Mills site were not caused by dilution. MTBE appears to have been flushed out of the system at the two upstream sites.

EVALUATION OF TOTAL LOADS AND YIELDS

Both loads and yields were used to summarize water quality in this study. Instantaneous loads and yields of the seven selected constituents were computed from concentration and flow data for each sample. Total instream load and yield were estimated at three flow conditions, and an evaluation of that part of total load that originates from permitted and nonpermitted sources is summarized. No permitted point-source data are available for chloride. Values for nonpermitted yield and the percent of total yield from nonpermitted sources at median-flow conditions are shown in figures 29-35. The percentage of instream load contributed by ground water during base flow was estimated for three sampling sites at average flow conditions. Loads are presented in pounds per day (lb/d), and yields are presented in pounds per day per square mile ((lb/d)/mi^2).

The largest loads at a site occurred during the highest flows sampled. The largest yields recorded at most sites also typically occurred during the highest flows sampled. The largest loads for all constituents, except BOD, were recorded for the site in the largest drainage subbasin, Raritan River at Bound Brook. The maximum BOD load occurred at Lamington River at Burnt Mills. Many of the larger yields recorded for the basin occurred at sites with smaller drainage areas. Most of the samples collected at high flows were collected during the receding limb of the hydrograph. These samples are not representative of water-quality conditions throughout the entire hydrograph. Highest loads typically occur on the rising limb of the hydrograph. Therefore, average total instream loads calculated from this data typically will be lower than the long-term average load for the entire hydrograph.

Relation to Streamflow

Tobit regression was used to define the relation between load and streamflow at each sampling site. Instantaneous loads of all constituents except phosphorus correlated significantly with instantaneous streamflow at the 0.05 significance level. P-values were generally less than 0.001 for all constituents except for phosphorus, which ranged from 0.005 to 0.06 at five sites. The only site with a relation that exceeded a p-value of 0.05 was N.B. Raritan River at Burnt Mills. The Tobit regression equation was used to estimate total instream load at various flow conditions.

The slope from the Tobit regression equation is used as an indicator of the increase in load that occurred in the stream between base-flow and high-flow conditions. The larger the slope, the greater the contribution to instream loads from runoff at high flows. The smaller the slope, the larger the contribution from ground water and point sources because the instream load will be constant with increasing flow (Buxton and others, 1999). The results of analysis of load slopes are consistent with results from the previous studies that used Tobit regression of concentration to flow and with results of ANOVA between samples grouped by those collected at flow greater than the median and those collected at flow less than the median.

The largest slopes occurred when TSS was related to flow. TSS was found to significantly increase as flow increased at the majority of sites. On average, the smallest slopes occurred when TDS was related to flow. TDS was found to significantly decrease as flow increased at all sites. TDS was the only constituent with slopes less than 0.98 at all sites. The smallest slope was 0.68 for Matchaponix Brook, a site with the highest percentage of total instream TDS load originating from permitted sources.

The largest variability in slopes between sites was observed for NO3 + NO2 and total phosphorus. The smallest slopes calculated for any constituents were for NO3+NO2 at Matchaponix Brook and N.B. Raritan River near Chester, 0.35 and 0.37, respectively. A large percentage of NO3+NO2 load at both of these sites is from point sources. The largest slope recorded for NO3+NO2 was 1.44 at Neshanic River at Reaville, a stream with highly variable streamflow and no permitted sources. The smallest slopes recorded for total phosphorus ranged from 0.52 to 0.58 at the two N.B. Raritan River sites and Lamington River at Pottersville. At these three sites, a large percentage of total phosphorus loads are from permitted sources. The largest slopes were 1.44 and 1.39 at the Millstone River near Manalapan and Mulhockaway River sites, respectively. The Millstone River site had no phosphorus yield from permitted sources, and the Mulhockaway River site had a small yield (<0.001 lb/d/mi^2 at each flow condition) from permitted sources.

Total Loads and Yields by Constituent

Total instream loads and yields for each of eight constituents--TKN, BOD, chloride, TDS, NO2+NO3, TOC, total phosphorus, and TSS-- are summarized in this section. Loads and yields were computed from instantaneous stream samples. The estimates of loads and yields at low-, median-, and high-flow conditions were derived from Tobit regression analysis of load from instantaneous samples as a function of flow. The results at low-, median-, and high-flow conditions are discussed and compared between sites. Loads and yields estimated at three flow conditions at each of the 21 sites are presented by constituent in tables 25-32. The slopes of the relation of load to streamflow are used as indicators of the relative contributions of load from various sources. At sites with the largest slopes, total instream load was affected most by contributions from intermittent nonpoint sources at high flows. At sites with nearly flat or small slopes, total instream load was affected most by contributions from constant sources from ground water and (or) point sources.

Ammonia Plus Organic Nitrogen, Total

Total yields of TKN were computed from instantaneous samples. The median of the total instantaneous yields ranged from a low of 0.78 (lb/d)/ mi^2 at Beden Brook and Matchaponix Brook to a high of 3.82 (lb/d)/mi^2 at Millstone River at Grovers Mill. The smallest total instantaneous yields were less than 0.10 (lb/d)/mi^2 at Matchaponix Brook, Spruce Run, Mulhockaway Creek, and Neshanic River at low-flow conditions in the summer months. The largest total instantaneous yields were 1,400 (lb/d)/mi^2 at Stony Brook during a 10-year flood in January 1996 and 630 (lb/d)/mi^2 at Neshanic River during runoff in July 1996. Total instantaneous yields at N.B. Raritan River at Burnt Mills did not exceed 7.7 (lb/d)/mi^2 during the study period. Total yields at S.B. Raritan River at Three Bridges were never less than 0.64 (lb/d)/mi^2 during the study period.

The total yield at median-flow conditions ranged from lows of 0.8 to 0.9 (lb/d)/mi^2 at Mulhockaway River and Spruce Run to highs of 2.3 to 3.8 (lb/d)/mi^2 at the Millstone River sites at Blackwells Mill and Grovers Mill, respectively. Total TKN yield at high flow (25th percentile flow) ranged from a high of 7.0 (lb/d)/mi^2 at Millstone River at Grovers Mill to a low of 1.4 (lb/d)/mi^2 at Mulhockaway Creek (table 25). Total yields at base flow (90th percentile flow) were lowest, 0.1 to 0.3 (lb/d)/mi^2, at the Mulhockaway Creek, Spruce Run, Stony Brook, Beden Brook, and Neshanic River sites. Yields were highest, 1.0 to 1.4 (lb/d)/mi^2, at Millstone River at Grovers Mill and the S.B. Raritan River sites at Stanton and Three Bridges.

Median daily instream TKN load during 1991-97 ranged from a low of 9.5 lb/d at Mulhockaway Creek to a high of 1,640 lb/d at Raritan River at Bound Brook (table 25). The largest TKN instream load was 80,634 lb/d at Raritan River at Bound Brook, which occurred during the highest flow sampled at that site, in March 1995.

The slopes for the relation of instream load to streamflow ranged from a high of 1.4 at Matchaponix Brook to a low of 0.79 at Rockaway Creek. The other three sites with the smallest slopes, less than 0.90, are Beden Brook, N.B. Raritan River at Burnt Mills, and Raritan River at Manville. This may indicate that constant sources from ground water and (or) point sources have a greater effect on instream load at these sites than at others. Slopes also are highest, greater than 1.2, at Millstone River at Manalapan and the sites at S.B. Raritan River at Stanton and Middle Valley, indicating that intermittent nonpoint sources during high flows have greater effects at these sites than at other sites.

Biochemical Oxygen Demand

Median instantaneous total yields of BOD ranged from lows of 2.22 (lb/d)/mi^2 at Neshanic River and 2.30 (lb/d)/m^2 at Beden Brook to highs of 11.9 (lb/d)/m^2 at S.B. Raritan River at Three

Table 25. Total instream loads and yields of total ammonia plus organic nitrogen, attentuated contributions from permitted sources, and contributions from nonpermitted sources at 21 surface-water sampling sites in the Raritan River Basin, N.J., at selected flow conditions during the growing season, 1991-97 water years

[Loads are in pounds per day and yields are in pounds per day per square mile; *, load and yield computed for 1996-97; **Red Cells** = largest yield at each flow condition; **Green Cells** = smallest yield at each flow condition; --, nonpermitted sources are a small part of the total load]

Station number	Station name	Load									Yield								
		Base flow (90th percentile)			Median flow			High flow (25th percentile)			Base flow (90th percentile)			Median flow			High flow (25th percentile)		
		Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted
01396280	S.B. Raritan River at Middle Valley	36.0	16.0	20.0	96.6	19.0	77.5	163.4	20.7	142.7	0.8	0.3	0.4	2.0	0.4	1.6	3.4	0.4	3.0
01396535	S. B. Raritan River at Arch Street at High Bridge	47.1	7.6	39.5	123.1	12.1	111.0	222.3	15.2	207.1	.7	.1	.6	1.8	.2	1.6	3.2	.2	3.0
01396588	Spruce Run near Glen Gardner	4.9	.3	4.6	13.7	.3	13.4	25.7	.3	25.4	.3	.0	.3	.9	.0	.9	1.7	.0	1.6
01396660	Mulhockaway Creek at Van Syckel	2.4	.0	2.4	9.5	.0	9.5	17.1	.0	17.1	.2	.0	.2	.8	.0	.8	1.4	.0	1.4
01397000	S. B. Raritan River at Stanton	144.4	35.0	109.5	286.3	42.4	243.9	547.5	47.3	500.2	1.0	.2	.7	1.9	.3	1.7	3.7	.3	3.4
01397400	S. B. Raritan River at Three Bridges	236.3	78.8	157.4	422.0	92.1	329.9	758.2	100.3	657.9	1.3	.4	.9	2.3	.5	1.8	4.2	.6	3.6
01398000	Neshanic River at Reaville	2.2	.0	2.2	26.0	.0	26.0	69.3	.0	69.3	.1	.0	.1	1.0	.0	1.0	2.7	.0	2.7
01398260	N. B. Raritan River near Chester	4.4	4.4	--	13.5	9.4	4.1	21.4	9.7	11.7	.6	.6	--	1.8	1.2	.5	2.8	1.3	1.6
01399120	N. B. Raritan River at Burnt Mills	36.5 38 *	30.5*	6.0 7.5*	97.7 68 *	37.2*	60.5 30.8*	164.4 94 *	39.7*	124.7 54.3*	.6 .6*	.5*	.1 .1*	1.5 1.0*	.6*	.9 .4*	2.6 1.4*	.6*	2.0 .8*
01399500	Lamington River near Pottersville	29.9	7.6	22.3	79.3	14.6	64.6	126.7	17.5	109.2	.9	.2	.7	2.4	.4	2.0	3.9	.5	3.3
01399700	Rockaway Creek at Whitehouse	24.6	24.6	--	51.5	27.4	24.2	80.7	27.9	52.7	.7	.7	--	1.4	.7	.7	2.2	.8	1.4
01399780	Lamington River at Burnt Mills	56.7	22.5	34.2	187.9	38.0	149.9	355.8	45.7	310.1	.6	.2	.3	1.9	.4	1.5	3.6	.5	3.1
01400500	Raritan River at Manville	449.9	76.7	373.2	851.4	129.0	722.5	1477	173.0	1304	.9	.2	.8	1.7	.3	1.5	3.0	.4	2.7
01400540	Millstone River near Manalapan	3.4	.0	3.4	10.3	.0	10.3	20.8	.0	20.8	.5	.0	.5	1.4	.0	1.4	2.8	.0	2.8
01400650	Millstone River at Grovers Mill	61.7	28.9	32.8	164.5	30.9	133.5	304.6	32.7	271.9	1.4	.7	.8	3.8	.7	3.1	7.0	.8	6.3
01401000	Stony Brook at Princeton	4.3	.7	3.6	52.2	2.5	49.7	171.9	3.0	168.8	.1	.0	.1	1.2	.1	1.1	3.9	.1	3.8
01401600	Beden Brook near Rocky Hill	5.4	.9	4.5	33.1	2.7	30.4	77.0	3.1	73.9	.2	.0	.2	1.2	.1	1.1	2.8	.1	2.7
01402000	Millstone River at Blackwells Mills	217.7	104.9	112.8	597.3	134.6	462.7	1141	156.7	983.9	.8	.4	.4	2.3	.5	1.8	4.4	.6	3.8
01403300	Raritan River at Bound Brook	437.4	437.4	--	1640	585.3	1055	3784	666.9	3117	.5	.5	--	2.0	.7	1.3	4.7	.8	3.9
01405302	Matchaponix Brook at Spotswood	25.5	8.9	16.6	83.6	13.9	69.7	184.9	20.1	164.8	.6	.2	.4	1.9	.3	1.6	4.2	.5	3.7
01405340	Manalapan Brook near Manalapan	9.2	.0	9.2	22.1	.0	22.1	40.7	.0	40.7	.4	.0	.4	1.1	.0	1.1	1.9	.0	1.9

Bridges and 8.98 (lb/d)/mi^2 at S.B. Raritan River at Stanton. The smallest yields were less than 0.23 (lb/d)/mi^2 at Stony Brook and at Beden Brook during extreme low-flow conditions, at the 95th percentile flow duration, in August 1993. The largest total yields were 589 (lb/d)/mi^2 at Lamington River at Burnt Mills during runoff in July 1997 and 573 (lb/d)/mi^2 at Stony Brook during runoff in March 1997. Total yields at N.B. Raritan River at Burnt Mills did not exceed 31.9 (lb/d)/mi^2 during this study. Minimum values at all sites were censored and could not be compared between sites. The minimum uncensored total yield was higher at S.B. Raritan River at Stanton (3.9 (lb/d)/mi^2 at the 10th percentile) than at any other site.

The total yield at median-flow conditions ranged from a low of 0.96 lb/d/mi^2 at Millstone River near Manalapan to a high of 9.6 (lb/d)/mi^2 at S.B. Raritan River at High Bridge. Total BOD yield at high flow (25th percentile flow) ranged from a high of 18.0 lb/d/mi^2 at S.B. Raritan River at High Bridge to a low of 1.5 lb/d/mi^2 at Millstone River at Manalapan (table 26). Total yields at base flow (90th percentile flow) were lowest (0.4-0.6 lb/d/mi^2) in the Stony Brook, Beden Brook, Neshanic River, and Millstone River at Manalapan and were highest (5.4 - 5.6 lb/d/mi^2) at S.B. Raritan River sites at Stanton and Three Bridges (table 26).

Median daily instream BOD loads during 1991-97 ranged from a low of 7.1 lbs/d at Millstone River near Manalapan to a high of 4,360 lbs/d at Raritan River at Bound Brook (table 26). The largest instream load was 58,898 lbs/d at N.B. Raritan River at Burnt Mills during the highest flow sampled at this site in July 1997. This is the only constituent in which the largest instream load was not measured at Raritan River at Bound Brook, the site with the largest drainage area.

The slopes of the relation of load to streamflow range from 0.78 at Rockaway Creek to 1.2 at S.B. Raritan River at Middle Valley. Slopes were smallest, less than 0.90, at N.B. Raritan River at Burnt Mills, Neshanic River, and Millstone River at Manalapan. This could indicate that constant sources from ground water and (or) point sources have a greater effect on instream load at these sites than at others. Slopes were highest, greater than 1.1, at Manalapan Brook and S.B. Raritan River at High Bridge, indicating that intermittent nonpoint sources had a greater effect at these sites than at other sites.

Chloride

Median total yields of chloride in instantaneous samples ranged from lows of 57.8 (lb/d)/mi^2 at Stony Brook, 66.4 (lb/d)/mi^2 at Beden Brook, and 76 (lb/d)/mi^2 at Mulhockaway Creek to highs of 253 (lb/d)/mi^2 at Lamington River at Pottersville and 232 (lb/d)/mi^2 at N.B. Raritan River at Chester. The smallest yields, 1.99 (lb/d)/mi^2 at Neshanic River and 7.56 (lb/d)/mi^2 at Stony Brook, were present in samples collected at low-flow conditions in July and August 1995. The largest total yields were 3,636 (lb/d)/mi^2 in samples collected at Stony Brook during a 5-year flood in October 1996 and 3,533 (lb/d)/mi^2 in samples collected at Neshanic River during runoff in February 1994. Yields at Manalapan Brook did not exceed 232 (lb/ d)/mi^2 during the study period. Total yields at Lamington River at Pottersville were never less than 70 (lb/d)/mi^2.

Peak total yields of chloride are related more to high flow in the winter months than to high flow regardless of the season. The maximum yields of chloride occurred from January to April at all sites except Stony Brook. Maximum total yields at 10 sites were measured during the 2d, 3d, and 15th highest flows sampled, but not during the highest flow; typically, the maximum yields for other constituents were measured during the highest flow.

Total yields of chloride at median-flow conditions during 1991-97 ranged from 71.1 (lb/d)/mi^2 at Stony Brook to 265 (lb/d)/mi^2 at Lamington River at Pottersville. Total yields of chloride at high flow (25th percentile flow) ranged from 421 (lb/d)/mi^2 at S.B. Raritan River at High Bridge to 117 lb/d)/mi^2 at Manalapan Brook (table 27). Total yields at base flow (90th percentile flow)

Table 26. Total instream loads and yields of biochemical oxygen demand, attentuated contributions from permitted sources, and contributions from nonpermitted sources at 21 surface-water sampling sites in the Raritan River Basin, N.J., at selected flow conditions during the growing season, 1991-97 water years

[Loads are in pounds per day and yields are in pounds per day per square mile; *, load and yield computed for the 1996-97 period; **Red Cells** = largest yield at each flow condition; **Green Cells** = smallest yield at each flow condition]

Station number	Station name	Load									Yield								
		Base flow (90th percentile)			Median flow			High flow (25th percentile)			Base flow (90th percentile)			Median flow			High flow (25th percentile)		
		Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted
01396280	S.B. Raritan River at Middle Valley	161.7	18.2	143.4	435.9	24.0	411.9	740.0	27.3	713	3.40	0.38	3.01	9.16	0.50	8.65	15.55	0.57	14.97
01396535	S. B. Raritan River at Arch Street at High Bridge	235.5	2.8	232.8	662.4	7.8	654.6	1250	12.6	1238	3.42	.04	3.38	9.63	.11	9.51	18.18	.18	17.99
01396588	Spruce Run near Glen Gardner	35.5	0.3	35.2	104.5	.3	104.1	201.0	.3	200.6	2.29	.02	2.27	6.74	.02	6.72	12.97	.02	12.95
01396660	Mulhockaway Creek at Van Syckel	26.2	0.08	26.0	71.9	.09	71.8	111.4	.09	111.3	2.23	.01	2.22	6.09	.01	6.09	9.44	.01	9.43
01397000	S. B. Raritan River at Stanton	828.9	16.0	812.9	1378	22.5	1356	2232	28.5	2204	5.64	.11	5.53	9.38	.15	9.22	15.19	.19	14.99
01397400	S. B. Raritan River at Three Bridges	979.8	68.4	911.4	1734	82.2	1651.7	3086	91.6	2994	5.41	.38	5.04	9.58	.45	9.13	17.05	.51	16.54
01398000	Neshanic River at Reaville	15.7	0.00	15.7	110.5	.00	110.5	239.6	.00	239.6	.61	.00	.61	4.30	.00	4.30	9.32	.00	9.32
01398260	N. B. Raritan River near Chester	28.2	16.7	11.5	54.6	17.4	37.1	83.7	17.7	66.0	2.55	2.21	0.34	7.21	2.30	4.90	11.06	2.34	8.72
01399120	N. B. Raritan River at Burnt Mills	191.3	21.4	169.9	505.9	36.7	469.2	845.5	43.5	802	3.00	.34	2.66	7.93	.58	7.35	13.25	.68	12.57
01399500	Lamington River near Pottersville	97.1	4.23	92.9	269.5	19.3	250.2	440.4	29.8	410.5	2.96	.13	2.83	8.22	.59	7.63	13.43	.91	12.52
01399700	Rockaway Creek at Whitehouse	115.6 127 *	39.7*	76.0 87.3*	239 284 *	43.8*	195.1 240.2*	370.9 462 *	46.2*	324.7 415.8	3.12 3.42*	1.07*	2.05 2.35 *	6.44 7.65*	1.18*	5.26 6.47*	10.00 12.4*	1.24*	8.75 11.2*
01399780	Lamington River at Burnt Mills	297.2	15.9	281.2	903.3	40.4	862.9	1633	60.4	1572	2.97	.16	2.81	9.03	.40	8.63	16.33	.60	15.72
01400500	Raritan River at Manville	1,871	13.9	1857	3187	55.0	3,132	5050	106.9	4944	3.82	.03	3.79	6.51	.11	6.39	10.31	.22	10.09
01400540	Millstone River near Manalapan	3.4	0.00	3.4	7.1	.00	7.1	11.2	.00	11.21	.47	.00	.47	.96	.00	.96	1.52	.00	1.52
01400650	Millstone River at Grovers Mill	138.8	38.1	100.7	391.1	39.5	351.5	750.3	40.8	709.5	3.20	.88	2.32	9.01	.91	8.10	17.29	.94	16.35
01401000	Stony Brook at Princeton	19.6	1.6	17.9	197.8	8.2	189.5	598.3	10.6	587.7	.44	.04	.40	4.44	.19	4.26	13.45	.24	13.21
01401600	Beden Brook near Rocky Hill	15.2	2.9	12.3	130.8	5.34	125.4	354.4	5.8	348.6	.55	.11	.45	4.74	.19	4.54	12.84	.21	12.63
01402000	Millstone River at Blackwells Mills	547.9	59.2	488.7	1661	107.9	1553	3383	147.6	3235	2.12	.23	1.89	6.44	.42	6.02	13.11	.57	12.54
01403300	Raritan River at Bound Brook	1,501	487.6	1014	4355	612.55	3743	8542	715.9	7826	1.87	.61	1.26	5.42	.76	4.66	10.62	.89	9.73
01405302	Matchaponix Brook at Spotswood	91.1	55.12	36.0	221.6	69.0	152.5	401.4	82.9	318.5	2.07	1.25	.82	5.02	1.57	3.46	9.10	1.88	7.22
01405340	Manalapan Brook near Manalapan	37.2	0.00	37.2	84.3	.00	84.3	149.5	.00	149.5	1.78	.00	1.78	4.03	.00	4.03	7.15	.00	7.15

Table 27. Total instream loads and yields of chloride at 21 surface-water sampling sites in the Raritan River Basin, N.J., at selected flow conditions, 1991-97 water years

[Loads are in pounds per day and yields are in pounds per day per square mile; chloride data were not available from permitted point sources; **Red Cells** = largest yield at each flow condition; **Green Cells** = smallest yield at each flow condition]

Station number	Station name	Load (total instream)			Yield (total instream)		
		Base flow (90th percentile)	Median flow	High flow (25th percentile)	Base flow (90th percentile)	Median flow	High flow (25th percentile)
01396280	S.B. Raritan River at Middle Valley	4,234	9,971	15,750	89.0	209.5	330.9
01396535	S. B. Raritan River at Arch Street at High Bridge	4,529	12,230	22,520	65.8	177.8	327.4
01396588	Spruce Run near Glen Gardner	518.7	1,605	3,186	33.5	103.5	205.6
01396660	Mulhockaway Creek at Van Syckel	290.6	1,193	2,206	24.6	101.1	187.0
01397000	S. B. Raritan River at Stanton	1,1420	21,040	37,530	77.7	143.1	255.3
01397400	S. B. Raritan River at Three Bridges	1,6470	29,210	52,100	91.0	161.4	287.9
01398000	Neshanic River at Reaville	200.6	2,162	5,545	7.8	84.1	215.8
01398260	N. B. Raritan River near Chester	435.4	1,375	2,784	57.5	181.6	367.8
01399120	N. B. Raritan River at Burnt Mills	3,569	12,880	25,380	55.9	201.9	397.7
01399500	Lamington River near Pottersville	3,310	8,690	13,820	100.9	264.9	421.5
01399700	Rockaway Creek at Whitehouse	1,258	3,316	5,963	33.9	89.4	160.7
01399780	Lamington River at Burnt Mills	5,909	16,680	28,980	59.1	166.8	289.8
01400500	Raritan River at Manville	28,500	63,520	127,000	58.2	129.6	259.1
01400540	Millstone River near Manalapan	258.2	568.0	933.3	35.0	77.1	126.6
01400650	Millstone River at Grovers Mill	2,387	6,654	12,680	55.0	153.3	292.2
01401000	Stony Brook at Princeton	492.2	3,166	7,713	11.1	71.1	173.3
01401600	Beden Brook near Rocky Hill	335.1	2,562	6,584	12.1	92.8	238.6
01402000	Millstone River at Blackwells Mills	11,090	32,320	64,150	43.0	125.3	248.6
01403300	Raritan River at Bound Brook	34,150	90,340	167,100	42.5	112.4	207.8
01405302	Matchaponix Brook at Spotswood	4,197	7,513	11,090	95.2	170.4	251.4
01405340	Manalapan Brook near Manalapan	912.1	1,630	2,449	43.6	78.0	117.2

were lowest (7.8-12 (lb/d)/mi^2) for the Stony Brook, Beden Brook and Neshanic River tributaries to the S.B. Raritan River and highest (91-101 (lb/d)/mi^2) for Matchaponix Brook, S.B. Raritan River at Three Bridges, and Lamington River at Pottersville (table 27). All sites along the S.B. Raritan River had higher yields at base flow than other sites, with the exception of the Matchaponix Brook and Lamington River at Pottersville sites.

The median daily instream chloride loads during 1991-97 ranged from 568 lbs/d at Millstone River near Manalapan to 90,340 lbs/d at Raritan River at Bound Brook. The largest load of 1.1 million lbs/d was calculated at Raritan River at Bound Brook during the second highest flow sampled in February 1993. The load calculated for the highest flow sampled at Raritan River at Bound Brook in July 1997 was 663,000 lbs/d. The larger load in February probably was caused by an increase in chloride in runoff from the application of road salt.

The slopes of the relation of chloride load to streamflow ranged from 0.69 at Matchaponix Brook to1.2 at Mulhockaway Creek. Slopes were smallest (less than 0.90) at Raritan River at Bound Brook, Stony Brook, and Manalapan Brook. These results could indicate that constant sources from ground water and (or) point sources have a greater effect on instream load at the sites with the smaller slopes than at the sites with larger slopes. Although the low slope for Raritan River at Bound Brook indicates a greater effect from constant sources (such as ground water or point sources) than from runoff, data indicate that larger loads were calculated for isolated samples collected during runoff in winter. Slopes were highest (greater than 1.1) at S.B. Raritan River at Stanton and S.B. Raritan River at High Bridge, indicating that intermittent nonpoint sources had a greater effect at this site than at other sites. The Mulhockaway Creek and S.B. Raritan River at High Bridge sites had higher concentrations of chloride at high flow during the nongrowing season than at low flow or high flow during the growing season (table 8).

Dissolved Solids, Total

Median instantaneous total yields of TDS computed from samples ranged from lows of 323 (lb/d)/mi^2 at Stony Brook and 357 (lb/d)/mi^2 at Manalapan Brook to highs of 999.8 (lb/d)/mi^2 at Lamington River at Pottersville and more than 900 (lb/d)/mi^2 at all the S.B. Raritan River sites, except Stanton. The maximum total yields observed were 27,150 (lb/d)/mi^2 at Stony Brook at Princeton during runoff in October 1996 and 12,341 (lb/d)/mi^2 at Lamington River at Burnt Mills during runoff in July 1997. The smallest total yields measured were 19 (lb/d)/ mi^2 at Neshanic River and 32 (lb/d)/mi^2 at Stony Brook at low-flow conditions (90-95th percentile flow duration) in July and August 1993. Total instantaneous yields at Manalapan Brook did not exceed 1,038 (lb/d)/mi^2 during this study. Total instantaneous yields at S.B. Raritan River at Three Bridges were never less than 477 lb/ day/mi^2.

Total yields at median flow during 1991-97 ranged from 330.3 (lb/d)/mi^2 at Manalapan Brook to 1,031 (lb/d)/mi^2 at the S.B. Raritan River sites at High Bridge and Middle Valley. Total yields at high flow (25th percentile flow) ranged from 508 (lb/d)/mi^2 at Manalapan Brook to 1,562 (lb/d)/mi^2 at N.B. Raritan River at Burnt Mills (table 28). Yields at base flow (90th percentile flow) were lowest, 57 to 82 (lb/d)/mi^2, at the Stony Brook, Beden Brook, and Neshanic River tributaries to the S.B. Raritan River and highest, 488 to 552 (lb/d)/mi^2, at the mainstem S.B. Raritan River sites and Matchaponix Brook (table 28).

Median daily instream TDS loads during 1991-97 ranged from 2,651 lbs/d at Millstone River near Manalapan to 480,185 lbs/d at Raritan River at Bound Brook (table 28). The largest TDS load in the basin (5.02 million lbs/d) was calculated for Raritan River at Bound Brook during the second highest flow sampled in March 1995. A slightly smaller load (5.01 million lbs/d) was calculated during the highest flow sampled in July 1997.

The slopes of the relation of load to streamflow ranged from 0.98 at Mulhockaway

Table 28. Total instream loads and yields of total dissolved solids, attenuated contributions from permitted sources, and contributions from nonpermitted sources at 21 surface-water sampling sites in the Raritan River Basin, N.J., at selected flow conditions during the growing season, 1991-97 water years

[Loads are in pounds per day and yields are in pounds per day per square mile; **Red Cells** = largest yield at each flow condition; **Green Cells** = smallest yield at each flow condition]

Station number	Station name	Load									Yield								
		Base flow (90th percentile)			Median flow			High flow (25th percentile)			Base flow (90th percentile)			Median flow			High flow (25th percentile)		
		Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted
01396280	S.B. Raritan River at Middle Valley	26,000	3,938	22,060	49,060	3,938	45,120	68,860	3,938	64,920	546.1	82.7	463.4	1031	82.7	947.9	1,446	82.7	1,364
01396535	S. B. Raritan River at Arch Street at High Bridge	32,250	3,938	28,320	70,960	3,938	67,020	115,200	3,938	111,300	468.8	57.2	411.6	1031	57.2	974.1	1,675	57.2	1,617
01396588	Spruce Run near Glen Gardner	3,490	110.5	3,380	9,623	110.5	9,513	17,810	110.5	17,700	225.2	7.1	218.1	620.9	7.1	613.7	1,149	7.1	1,142
01396660	Mulhockaway Creek at Van Syckel	2,940	10.2	2,930	8,271	10.2	8,261	12,970	10.2	12,960	249.1	0.9	248.3	700.9	0.9	700.1	1,099	0.9	1,098
01397000	S. B. Raritan River at Stanton	71,760	4,629	67,130	118,200	4,629	113,600	189,700	4,629	185,100	488.2	31.5	456.7	804.2	31.5	772.7	1,291	31.5	1,259
01397400	S. B. Raritan River at Three Bridges	99,830	16,740	83,080	158,800	16,740	142,100	253,800	16,740	237,000	551.5	92.5	459.0	877.3	92.5	784.8	1,402	92.5	1,310
01398000	Neshanic River at Reaville	1,784	0	1,784	13,550	0	13,550	30,260	0	30,260	69.4	0.0	69.4	527.3	0.0	527.3	1,177	0.0	1,177
01398260	N. B. Raritan River near Chester	2,852	1,773	1,079	7,318	1,773	5,545	10,790	1,773	9,018	376.8	234.3	142.5	966.8	234.3	732.5	1,425	234.3	1,191
01399120	N. B. Raritan River at Burnt Mills	19,500	7,103	12,400	56,700	7,103	49,600	99,640	7,103	92,540	305.6	111.3	194.3	888.8	111.3	777.5	1,562	111.3	1,450
01399500	Lamington River near Pottersville	13,260	10,040	3,222	32,010	10,040	22,000	48,920	10,040	38,890	404.2	305.9	98.2	976.1	305.9	670.1	1,492	305.9	1,186
01399700	Rockaway Creek at Whitehouse	10,910	2,803	8,110	24,280	2,803	21,500	39,400	2,803	36,600	294.2	75.6	218.6	654.5	75.6	579.0	1,062	75.6	986.6
01399780	Lamington River at Burnt Mills	32,380	13,080	19,310	83,690	13,080	70,600	138,800	13,080	125,700	323.8	130.8	193.1	836.9	130.8	706.1	1,387	130.8	1,257
01400500	Raritan River at Manville	174,757	37,570	137,200	342,600	37,570	305,000	612,800	37,570	575,200	356.6	76.7	280.0	699.1	76.7	622.4	1,250	76.7	1,174
01400540	Millstone River near Manalapan	1,202	0	1,202	2,651	0	2,651	4,362	0	4,362	163.1	0.0	163.1	359.7	0.0	359.7	591.8	0.0	591.8
01400650	Millstone River at Grovers Mill	13150	6,866	6,285	31,640	6,866	24,770	54,960	6,866	48,090	303.0	158.2	144.8	729.0	158.2	570.8	1,266	158.2	1,108
01401000	Stony Brook at Princeton	2,536	1,436	1,101	15,970	1,436	14,540	38,520	1,436	37,090	57.0	32.3	24.7	358.9	32.3	326.7	865.7	32.3	833.4
01401600	Beden Brook near Rocky Hill	2,270	2,270	--	14,400	2,394	12,000	33,920	2,394	31,530	82.2	82.2	--	521.6	86.7	434.8	1,229	86.7	1,142
01402000	Millstone River at Blackwells Mills	62,710	51,960	10,750	157,100	51,960	105,200	283,100	51,960	231,200	243.1	201.4	41.7	609.0	201.4	407.6	1,097	201.4	896.0
01403300	Raritan River at Bound Brook	186,187	106,200	79,960	480,200	106,200	374,000	874,200	106,200	768,000	231.6	132.1	99.4	597.2	132.1	429.5	1,087	132.1	955.2
01405302	Matchaponix Brook at Spotswood	21,640	19,400	2,238	38,380	19,400	18,970	56,280	19,400	36,880	490.7	440.0	50.8	870.2	440.0	465.1	1,276	440.0	836.3
01405340	Manalapan Brook near Manalapan	3,733	0	3,733	6,903	0	6,903	10,620	0	10,620	178.6	0.0	178.6	330.3	0.0	330.3	508.1	0.0	508.1

Creek to 0.68 at Matchaponix Brook. Slopes were smallest (less than 0.80) at S.B. Raritan River at Middle Valley and Raritan River at Bound Brook. This could indicate that constant sources of TDS from ground water and (or) point sources had a greater effect on instream load at these sites than at others. Slopes were greatest (greater than 0.91) at Raritan River at Manville, Spruce Run, and S.B. Raritan River at Stanton, indicating that intermittent nonpoint sources had a greater effect at these sites than at others.

Nitrate Plus Nitrite

Median instantaneous total yields of NO3+NO2 ranged from 2.3 (lb/d)/mi^2 at Stony Brook and 4.4 (lb/d)/mi^2 at Manalapan Brook to 24.2 at Matchaponix Brook and 20.6 (lb/d)/mi^2 at Millstone River at Grovers Mill. The maximum yields were 261 (lb/d)/mi^2 at Stony Brook at Princeton during runoff in January 1996 and 163 (lb/d)/mi^2 at Raritan River at Bound Brook during runoff in July 1997. The smallest yields were less than 0.004 (lb/d)/mi^2 at Neshanic River and 0.04 (lb/d)/mi^2 at Stony Brook at extreme low-flow conditions (9th percentile flow duration) in July and August 1995. Yields at Manalapan Brook did not exceed 16.7 (lb/d)/mi^2 during this study period. Yields at Matchaponix Brook were never less than 13.2 lb/d)/mi^2.

Total yields at median flow during 1991-97 ranged from 1.6 (lb/d)/mi^2 at Stony Brook to 23.7 (lb/d)/mi^2 at Matchaponix Brook. Yields at high flow (25th percentile flow) were lowest (4.7 to 8.5 (lb/d)/mi^2) at Stony Brook, Millstone River at Blackwells Mill, Manalapan Brook, and Mulhockaway Creek and highest (17.7 to 30.6 (lb/d)/mi^2) at Millstone River at Grovers Mill, Matchaponix Brook, and S.B. Raritan River at High Bridge (table 29). Yields at base flow (90th percentile flow) were lowest (0.1 to 0.8 (lb/d)/mi^2) at Neshanic River, Stony Brook, and Beden Brook and highest (8.1 to 17.6 (lb/d)/mi^2) at Matchaponix Brook, Millstone River at Grovers Mill, and N.B. Raritan River at Chester (table 29).

Median daily instream NO3+NO2 load for 1991-97 ranged from 51.6 lbs/d at Millstone River near Manalapan to 6,256 lbs/d at Raritan River at Bound Brook. The largest instantaneous load calculated was 131,100 lbs/d at Raritan River at Bound Brook during the highest flow sampled in July 1997.

The slopes of the relation of load to streamflow ranged from 1.44 at Neshanic River to 0.35 at Matchaponix Brook. Slopes were smallest (less than 0.70) at N.B. Raritan River near Chester, Millstone River at Grovers Mill, and S.B. Raritan River at Middle Valley. This could indicate that constant sources had a greater effect on instream load at these sites than at others. Slopes were highest (greater than 1.09) at Raritan River at Manville, Manalapan Brook, and Stony Brook, indicating that intermittent nonpoint sources had a greater effect at these sites than at others.

Organic Carbon, Total

Median instantaneous total yields of total organic carbon ranged from 7.6 (lb/d)/mi^2 at Beden Brook and 8.3 (lb/d)/mi^2 at Neshanic River to 31.1 (lb/d)/mi^2 at Lamington River and 23.8 (lb/d)/mi^2 at S.B. Raritan River at Three Bridges. The maximum yields were 8,145 (lb/d)/mi^2 at Stony Brook at Princeton during the highest flow sampled in October 1996 and 1,472 (lb/d)/mi^2 at Lamington River at Burnt Mills during the highest flow sampled in July 1997. The smallest yields measured were 0.26 (lb/d)/mi^2 at Stony Brook and 0.66 (lb/d)/mi^2 at Neshanic River at extreme low-flow conditions (approximately the 95th percentile flow duration) in July 1995 and August 1993, respectively. Yields at N.B. Raritan River at Burnt Mills did not exceed 77.4 (lb/d)/mi^2 during the study period. Yields at Raritan River at Manville were less than 9.2 (lb/d)/mi^2 during the study period.

Daily total yields at median streamflow during 1991-97 ranged from 10.0 (lb/d)/mi^2 at Neshanic River to 32.3 (lb/d)/mi^2 at Lamington River near Pottersville (table 30). Yields at high flow (25th percentile flow) were lowest

Table 29. Total instream loads and yields of nitrate plus nitrite, attenuated contributions from permitted sources, and contributions from nonpermitted sources at 21 surface-water sampling sites in the Raritan River Basin, N.J., at selected flow conditions during the growing season, 1991-97 water years

[Loads are in pounds per day and yields are in pounds per day per square mile; **Red Cells** = largest yields at each flow condition; **Green Cells** = smallest yields at each flow condition; --, nonpermitted sources contribute a small part of total load]

		Load									Yield								
		Base flow (90th percentile)			Median flow			High flow (25th percentile)			Base flow (90th percentile)			Median flow			High flow (25th percentile)		
Station number	Station name	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted	Total instream	Per-mitted	Non-per-mitted
01396280	S.B. Raritan River at Middle Valley	320.2	110.0	210.1	551.2	126.9	424.3	736.7	135.7	601.0	6.7	2.3	4.4	11.6	2.7	8.9	15.5	2.9	12.6
01396535	S. B. Raritan River at Arch Street at High Bridge	336.6	51.9	284.7	746.5	81.0	665.5	1,218	99.6	1,118	4.9	.8	4.1	10.9	1.2	9.7	17.7	1.4	16.3
01396588	Spruce Run near Glen Gardner	33.9	5.3	28.5	102.7	5.4	97.3	201.4	5.4	196.0	2.2	.3	1.8	6.6	.3	6.3	13.0	.3	12.6
01396660	Mulhockaway Creek at Van Syckel	22.8	.4	22.4	64.1	.5	63.7	100.5	.5	100.0	1.9	.0	1.9	5.4	.0	5.4	8.5	.0	8.5
01397000	S. B. Raritan River at Stanton	623.4	271.1	352.3	1,031	310.1	721.5	1,662	336.6	1,326	4.2	1.8	2.4	7.0	2.1	4.9	11.3	2.3	9.0
01397400	S. B. Raritan River at Three Bridges	1,029	434.3	594.8	1,601	481.6	1,119	2,501	494.8	2,006	5.7	2.4	3.3	8.8	2.7	6.2	13.8	2.7	11.1
01398000	Neshanic River at Reaville	3.3	.0	3.3	92.4	.0	92.4	345.2	.0	345.2	.1	.0	.1	3.6	.0	3.6	13.4	.0	13.4
01398260	N. B. Raritan River near Chester	60.9	60.9	--	92.4	76.0	16.4	109.7	76.9	32.8	8.1	8.1	--	12.2	10.0	2.2	14.5	10.2	4.3
01399120	N. B. Raritan River at Burnt Mills	102.3	93.4	8.9	367.5	145.6	221.9	722.1	170.4	551.7	1.6	1.5	.1	5.8	2.3	3.5	11.3	2.7	8.6
01399500	Lamington River near Pottersville	71.6	71.6	--	189.3	185.3	4.0	302.0	221.8	80.2	2.2	2.2		5.8	5.6	.1	9.2	6.8	2.4
01399700	Rockaway Creek at Whitehouse	87.0	24.3	62.7	220.5	24.4	196.1	387.2	24.4	362.8	2.3	.7	1.7	5.9	.7	5.3	10.4	.7	9.8
01399780	Lamington River at Burnt Mills	163.0	62.2	100.8	534.0	155.8	378.1	1,004	203	801.4	1.6	.6	1.0	5.3	1.6	3.8	10.0	1.2	8.9
01400500	Raritan River at Manville	1,082	322.1	759.7	2,729	525.9	2,203	6,069	663	5,406	2.2	.7	1.6	5.6	1.1	4.5	12.4	1.0	11.4
01400540	Millstone River near Manalapan	24.1	.0	24.1	51.6	.0	51.6	83.4	.0	83.4	3.3	.0	3.3	7.0	.0	7.0	11.3	.0	11.3
01400650	Millstone River at Grovers Mill	454.1	454.1	--	877.5	530.5	347.1	1,328	540.5	787.7	10.5	10.5	--	20.2	12.2	8.0	30.6	12.5	18.1
01401000	Stony Brook at Princeton	6.9	1.1	5.8	69.5	20.2	49.2	209.4	32.7	176.7	.2	.0	.1	1.6	.5	1.1	4.7	.7	4.0
01401600	Beden Brook near Rocky Hill	22.9	35.3	--	157.3	66.1	91.2	384.8	72.8	311.9	.8	.8	--	5.7	2.4	3.3	13.9	2.6	11.3
01402000	Millstone River at Blackwells Mills	1,167	1,167	--	2,630	1,658	972	4,429	1,820	2,609	4.5	4.5	--	10.2	6.2	4.0	17.2	6.4	10.7
01403300	Raritan River at Bound Brook	2,522	2,522	--	6,256	3,694	2,562	11,110	4,188	6,924	3.1	3.1	--	7.8	4.4	3.4	13.8	4.2	9.6
01405302	Matchaponix Brook at Spotswood	774.7	611.1	163.6	1,043	739.7	303.6	1,273	863.0	410.2	17.6	13.9	3.7	23.7	16.8	6.9	28.9	19.6	9.3
01405340	Manalapan Brook near Manalapan	32.8	.0	32.8	73.3	.0	73.3	128.7	.0	128.7	1.6	.0	1.6	3.5	.0	3.5	6.2	.0	6.2

Table 30. Total instream loads and yields of total organic carbon, attentuated contributions from permitted sources, and contributions from nonpermitted sources at 21 surface-water sampling sites in the Raritan River Basin, N.J., at selected flow conditions, 1991-97 water years

[Loads are in pounds per day and yields are in pounds per day per square mile; **Red Cells** = largest yield at each flow condition; **Green Cells** = smallest yield at each flow condition]

Station number	Station name	Load									Yield								
		Base flow (90th percentile)			Median flow			High flow (25th percentile)			Base flow (90th percentile)			Median flow			High flow (25th percentile)		
		Total in-stream	Per-mitted	Non-per-mitted	Total in-stream	Per-mitted	Non-per-mitted	Total in-stream	Per-mitted	Non-per-mitted	Tota in-stream	Per-mitted	Non-per-mitted	Total in-stream	Per-mitted	Non-per-mitted	Total in-stream	Per-mitted	Non-per-mitted
01396280	S.B. Raritan River at Middle Valley	374.2	36.6	337.6	1,042	36.6	1,005	1,799	36.6	1,762	7.9	0.8	7.1	21.9	0.8	21.1	37.8	0.8	37.0
01396535	S. B. Raritan River at Arch Street at High Bridge	535.4	36.6	498.8	1,489	36.6	1,452	2,791	36.6	2,755	7.8	0.5	7.2	21.6	0.5	21.1	40.6	0.5	40.0
01396588	Spruce Run near Glen Gardner	64.0	0.5	63.6	192.5	0.5	192.0	375.4	0.5	374.9	4.1	0.0	4.1	12.4	0.0	12.4	24.2	0.0	24.2
01396660	Mulhockaway Creek at Van Syckel	35.4	0.1	35.3	140.8	0.1	140.7	256.4	0.1	256.3	3.0	0.0	3.0	11.9	0.0	11.9	21.7	0.0	21.7
01397000	S. B. Raritan River at Stanton	1,575	68.6	1,506	2,869	68.6	2,801	5,067	68.6	4,998	10.7	0.5	10.2	19.5	0.5	19.1	34.5	0.5	34.0
01397400	S. B. Raritan River at Three Bridges	2,017	146.1	1,871	3,588	146.1	3,441	6,419	146.1	6,419	11.1	0.8	10.3	19.8	0.8	19.0	34.5	0.5	34.0
01398000	Neshanic River at Reaville	28.9	0.0	28.9	258.1	0.0	258.1	614.5	0.0	614.5	1.1	0.0	1.1	10.0	0.0	10.0	23.9	0.0	23.9
01398260	N. B. Raritan River near Chester	54.9	18.2	36.8	146.8	18.2	128.6	220.1	18.2	201.9	7.3	2.4	4.9	19.4	2.4	17.0	29.1	2.4	26.7
01399120	N. B. Raritan River at Burnt Mills	412.8	49.6	363.2	1,251	49.6	1,201	2,246	49.6	2,196	6.5	0.8	5.7	19.6	0.8	18.8	35.2	0.8	34.4
01399500	Lamington River near Pottersville	385.7	65.3	320.4	1,060	65.3	994.9	1,724	65.3	1,659	11.8	2.0	9.8	32.3	2.0	30.3	52.6	2.0	50.6
01399700	Rockaway Creek at Whitehouse	208.7	48.4	160.3	505.7	48.4	457.3	864.1	48.4	815.6	5.6	1.3	4.3	13.6	1.3	12.3	23.3	1.3	22.0
01399780	Lamington River at Burnt Mills	677.6	146.4	531.2	2,223	146.4	2,077	4,186	146.4	4,039	6.8	1.5	5.3	22.2	1.5	20.8	41.9	1.5	40.4
01400500	Raritan River at Manville	4,393	417.8	3,976	8,522	417.8	8,104	15,110	417.8	14,690	9.0	0.9	8.1	17.4	0.9	16.5	30.8	0.9	30.0
01400540	Millstone River near Manalapan	38.3	0.0	38.3	101.5	0.0	101.5	187.3	0.0	187.3	5.2	0.0	5.2	13.8	0.0	13.8	25.4	0.0	25.4
01400650	Millstone River at Grovers Mill	344.5	48.6	295.9	1,011	48.6	746.5	1,991	48.6	1,942	7.9	1.1	6.8	23.3	1.1	22.2	45.9	1.1	44.7
01401000	Stony Brook at Princeton	46.9	5.3	41.5	542.4	5.3	537.0	1,750	5.3	1745	1.1	0.1	0.9	12.2	0.1	12.1	39.3	0.1	39.2
01401600	Beden Brook near Rocky Hill	45.2	6.8	38.4	355.0	6.8	348.2	923.6	6.8	916.7	1.6	0.2	1.4	12.9	0.2	12.6	33.5	0.2	33.2
01402000	Millstone River at Blackwells Mills	1,799	310.3	1,489	5,262	310.3	4,951	10,470	310.3	10,160	7.0	1.2	5.8	20.4	1.2	19.2	40.6	1.2	39.4
01403300	Raritan River at Bound Brook	3,113	1,280	1,832	12,480	1,280	11,200	30,020	1,280	28,740	3.9	1.6	2.3	15.5	1.6	13.7	37.3	1.6	35.7
01405302	Matchaponix Brook at Spotswood	279.7	48.4	231.3	700.9	48.4	652.5	1,295	48.4	1,247	6.3	1.1	5.2	15.9	1.1	14.8	29.4	1.1	28.3
01405340	Manalapan Brook near Manalapan	121.5	0.0	121.5	259.2	0.0	259.2	440.5	0.0	440.5	5.8	0.0	5.8	12.4	0.0	12.4	21.1	0.0	21.1

(21.1-23.3 (lb/d)/mi^2) at Manalapan Brook, Mulhockaway Creek, and Rockaway Creek. Yields at high flow were highest (40.6-52.6 (lb/d)/mi^2) at the Lamington River sites at Pottersville and Burnt Mills, and Millstone River at Grovers Mill (table 30). Yields at base flow (90th percentile flow) were lowest (1.1-1.6 (lb/d)/mi^2) at Neshanic River, Stony Brook, and Beden Brook. Highest yields during base flow ranged from 10.7 to 11.8 (lb/d)/mi^2 at the S.B. Raritan River sites at Three Bridges and Stanton, and at Lamington River at Pottersville (table 30).

Daily instream TOC load at median flow during 1991-97 ranged from 101 lbs/d at Millstone River near Manalapan to 12,476 lbs/d at Raritan River at Bound Brook. The largest load calculated was 647,879 lbs/d at Raritan River at Bound Brook for a sample collected during the highest flow in July 1997.

The slopes of the relation of load to streamflow ranged from 1.27 at S.B. Raritan River at Middle Valley to 0.88 at N.B. Raritan River at Chester. The slope was smallest (less than 0.90) at Raritan River at Manville. This could indicate that constant sources from ground water and (or) point sources had a greater effect on instream load at these sites than at others. Slopes were highest (greater than 1.2 at Millstone River) at Manalapan and Mulhockaway Creek, indicating a that intermittent nonpoint sources had a greater effect at these sites than at others.

Phosphorus, Total

Median instantaneous total yields of total phosphorus ranged from 0.09 (lb/d)/mi^2 at Mulhockaway River and Neshanic River to 0.98 (lb/d)/mi^2 at Millstone River at Blackwells Mill and 0.93 (lb/d)/mi^2 at S.B. Raritan River at Three Bridges. The maximum yields were 394 (lb/d)/mi^2 at Stony Brook during the highest flow sampled in January 1996 and 214 (lb/d)/mi^2 at Neshanic River during the highest flow sampled in July 1996. The smallest yields were less than 0.01 (lb/d)/mi^2 at Mulhockaway Creek and Neshanic River at low-flow conditions. Samples were collected from the Mulhockaway Creek at approximately the 9th percentile flow duration in August 1995 and from the Neshanic River at a flow between the median and 75th percentile flow duration in October 1996. Yields at Spruce Run did not exceed 1.04 (lb/d)/mi^2 during the study period. Yields at Millstone River at Blackwells Mill were never less than 0.55 (lb/d)/mi^2 during the study period.

Daily total yields at median streamflow during 1991-97 ranged from 0.10 (lb/d)/mi^2 at Mulhockaway Creek and Neshanic River to 1.0 (lb/d)/mi^2 at Millstone River at Blackwells Mills. Yields at high flow (25th percentile flow) were lowest (0.2 (lb/d)/mi^2) at Spruce Run, Mulhockaway Creek, N.B. Raritan River at Burnt Mills, and S.B. Raritan River at Stanton (table 31). The highest yields at high flow ranged from 1.1 to 1.6 (lb/d)/mi^2 at the Millstone River sites at Blackwells Mill and Grovers Mill, Raritan River at Bound Brook, and S.B. Raritan River at Three Bridges (table 31). Yields at base flow (90th percentile flow) were lowest (0.01-0.05 (lb/d)/mi^2) at Neshanic River, Stony Brook, Mulhockaway Creek, and Matchaponix Brook. Highest yields at base flow ranged from 0.3 to 0.6 (lb/d)/mi^2 at the Millstone River sites at Grovers Mill and Blackwells Mill, Raritan River at Bound Brook, and S.B. Raritan River at Three Bridges (table 31).

Median daily instream total phosphorus load during 1991-97 ranged from 1.1 lbs/d at N.B. Raritan River near Chester to 673 lbs/d at Raritan River at Bound Brook. The largest load was 29,772 lbs/d at Raritan River at Bound Brook during the second highest flow sampled in March 1995.

The slopes of the relation of load to streamflow ranged from 1.44 at Millstone River at Manalapan to 0.52 at N.B. Raritan River at Burnt Mills. Slopes were smallest (less than 0.60) at N.B. Raritan River near Chester and Millstone River at Blackwells Mill. This could indicate that instream load was affected more by constant sources from ground water and (or) point sources at these sites than at others. Slopes were highest (greater than 1.3) at Matchaponix Brook and Mulhockaway

Table 31. Total instream loads and yields of total phosphorus, attentuated contributions from permitted sources, and contributions from nonpermitted sources at 21 surface-water sampling sites in the Raritan River Basin, N.J., at selected flow conditions during the growing season, 1991-97 water years

[Loads are in pounds per day and yields are in pounds per day per square mile and are rounded to 1 significant figure; *, load and yield computed for the 1995-97 period; **Red Cells** = largest yield at each flow condition; **Green Cells** = smallest yield at each flow condition; --, nonpermitted sources contribute a small part of total load]

Station number	Station name	Load: Base flow (90th percentile) Total instream	Load: Base flow Per-mitted	Load: Base flow Non-per-mitted	Load: Median flow Total instream	Load: Median flow Per-mitted	Load: Median flow Non-per-mitted	Load: High flow (25th percentile) Total instream	Load: High flow Per-mitted	Load: High flow Non-per-mitted	Yield: Base flow (90th percentile) Total instream	Yield: Base flow Per-mitted	Yield: Base flow Non-per-mitted	Yield: Median flow Total instream	Yield: Median flow Per-mitted	Yield: Median flow Non-per-mitted	Yield: High flow (25th percentile) Total instream	Yield: High flow Per-mitted	Yield: High flow Non-per-mitted
01396280	S.B. Raritan River at Middle Valley	11.6	9.4	2.2	21.7	11.2	10.5	30.3	12.2	18.1	0.2	0.2	--	0.5	0.2	0.2	0.6	0.3	0.4
01396535	S. B. Raritan River at Arch Street at High Bridge	8.8	3.9	4.9	20.8	6.6	14.2	35.2	8.5	26.7	.1	.06	.1	.3	.1	.2	.5	.1	.4
01396588	Spruce Run near Glen Gardner	1.3	.1	1.2	2.5	.1	2.4	3.8	.1	3.7	.1	.0	.1	.2	.0	.2	.2	.0	.2
01396660	Mulhockaway Creek at Van Syckel	.2	.0	.2	1.1	.0	1.1	2.1	.0	2.1	.0	.0	.0	.1	.0	.1	.2	.0	.2
01397000	S. B. Raritan River at Stanton	20.5 14.7*	7.3*	13.2 7.4*	30.9 19.6*	10.8*	20.1 8.8*	45.6 25.8*	13.5*	32.1 12.3*	.1 .1*	.05*	.1 .05*	.2 .1*	.1*	.1 0*	.3 .2*	.1*	.2 .1*
01397400	S. B. Raritan River at Three Bridges	84.7	53.6	31.1	128.9	64.8	64.1	197.0	70.5	126.5	.5	.3	.2	.7	.4	.4	1.1	.4	.7
01398000	Neshanic River at Reaville	.2	.0	.2	3.4	.0	3.4	10.4	.0	10.4	.0	.0	.0	.1	.0	.1	.4	.0	.4
01398260	N. B. Raritan River near Chester	1.3	1.3	--	2.5	2.0	.5	3.1	2.0	1.1	.2	.2	--	.3	.3	.1	.4	.3	.2
01399120	N. B. Raritan River at Burnt Mills	7.0 6.6*	3.5*	3.5 3.1*	13.0 12.3*	5.3*	7.7 7.0*	18.0 17.2*	6.2*	11.8 11.0*	.1 .1*	.1*	.1 .*	.2 .1*	.1*	.1 0*	.3 .2*	.1*	.2 .1*
01399500	Lamington River near Pottersville	5.2	5.2	--	9.4	9.4	--	12.5	12.5	--	.2	.2	--	.3	.3	--	.4	.4	--
01399700	Rockaway Creek at Whitehouse	8.3	8.3	--	15.0	15.0	--	21.3	17.1	4.2	.2	.4	--	.4	.4	--	.6	.5	.1
01399780	Lamington River at Burnt Mills	13.3	12.7	.7	37.8	24.4	13.4	65.8	30.9	35.0	.1	.1	.0	.4	.2	.1	.7	.3	.3
01400500	Raritan River at Manville	98.3	22.8	75.4	168.0	49.4	118.6	267.0	70.8	196.2	.2	.01	.2	.3	.1	.2	.5	.1	.4
01400540	Millstone River near Manalapan	.8	.0	.8	2.7	.0	2.7	5.6	.0	5.6	.1	.0	.1	.4	.0	.4	.8	.0	.8
01400650	Millstone River at Grovers Mill	13.8	11.4	2.4	32.1	11.7	20.4	54.5	12.0	42.5	.3	.3	.1	.7	.3	.5	1.3	.3	1.0
01401000	Stony Brook at Princeton	.6	.5	.1	8.2	5.4	2.8	27.4	7.4	20.0	.01	.01	.0	.2	.1	.06	.6	.2	.4
01401600	Beden Brook near Rocky Hill	2.0	1.7	.2	9.4	5.2	4.2	19.5	6.2	13.3	.07	.06	.01	.3	.2	.15	.7	.2	.5
01402000	Millstone River at Blackwells Mills	143.4	14.0	129.4	268.1	49.9	218.2	400.4	86.4	314.0	.6	.1	.5	1.0	.2	.8	1.6	.3	1.2
01403300	Raritan River at Bound Brook	263.1	206.5	56.6	672.8	306.3	366.5	1,218	377.5	840.9	.3	.3	--	.8	.4	.5	1.5	.5	1.0
01405302	Matchaponix Brook at Spotswood	2.1	2.1	--	7.0	7.0	--	15.3	15.3	--	.0	.1	--	.2	.2	--	.3	.3	--
01405340	Manalapan Brook near Manalapan	2.4	.0	2.4	5.7	.0	5.7	10.3	.0	10.3	.1	.0	.1	.3	.0	.3	.5	.0	.5

Creek, indicating that these sites were affected more by intermittent nonpoint sources than other sites.

Total Suspended Solids

Median instantaneous total yields of TSS ranged from 10.2 (lb/d)/mi^2 at Stony Brook and 10.7 (lb/d)/mi^2 at Neshanic River and Beden Brook to 50.4 (lb/d)/mi^2 at Millstone River at Manalapan and 37.8 (lb/d)/mi^2 at Millstone River at Grovers Mill. The maximum total yields were 247,000 (lb/d)/mi^2 at Stony Brook during the highest flow sampled in October 1996, and 158,000 (lb/d)/mi^2 at Neshanic River during the highest flow sampled in July 1996. The smallest yield was 0.10 (lb/d)/mi^2 at Neshanic River during the lowest flow sampled in July 1995. Yields at N.B. Raritan River at Chester did not exceed 120 (lb/d)/mi^2. Yields at Millstone River near Manalapan were never less than 12.6 (lb/d)/mi^2 during the study period.

Daily yields at median streamflow during 1991-97 ranged from 9.6 (lb/d)/mi^2 at N.B. Raritan River near Chester to 62 (lb/d)/mi^2 at Millstone River at Grover Mill. Total yields at high flow (25th percentile flow) were lowest (23.5-29.8 (lb/d)/mi^2) at N.B. Raritan River near Chester, Mulhockaway Creek, and Spruce Run (table 32). Highest yields at high flow ranged from 118 to 131 (lb/d)/mi^2 at the Millstone River sites at Blackwells Mill and Grovers Mill, and Raritan River at Bound Brook (table 32). Yields at base flow (90th percentile flow) were lowest (0.4-1.8 (lb/d)/mi^2) at Neshanic River, Stony Brook, and Beden Brook. Highest yields at base flow ranged from 10.0 to 19.1 (lb/d)/mi^2 at the Millstone River sites at Grovers Mill and Blackwells Mill, and the S.B. Raritan River sites at High Bridge and Three Bridges (table 32).

Daily instream TSS load at median streamflow for 1991-97 ranged from 72.5 lb/d at N.B. Raritan River near Chester to 25,428 lb/d at Raritan River at Bound Brook (table 32). The largest load was 26 million lb/d at Raritan River at Bound Brook during the second highest flow sampled at the site in March 1995.

The slopes of the relation of load to streamflow ranged from 1.89 at Raritan River at Bound Brook to 0.96 at Beden Brook. Slopes were smallest (less than 1.2) at Lamington River at Pottersville, Millstone River at Grovers Mill, and Rockaway Creek. This could indicate that instream load was affected more by constant sources from ground water and (or) point sources at these sites than at other sites. Slopes were highest (greater than 1.7) at Millstone River near Manalapan and S.B. Raritan River at Middle Valley, indicating that instream load was affected more by intermittent nonpoint sources at these sites than at others.

Relation to Land Use and Population Density

The median instantaneous yields of the eight constituents--TKN, BOD, chloride, TDS, NO3+NO2, TOC, total phosphorus, and TSS--calculated from sample data were compared to land-use percentages and population density. Fewer significant relations were observed between yields and land use than between median concentration and land use. The results that were significant, however, were similar. The smaller number of relations could be caused by the use of drainage area to compute yield and the differences in streamflow per square mile across the study area. Yields of chloride, TKN, NO3+NO2, and TDC studied by load analysis were significantly related to population density; all showed a significant increase as population density increased.

Median yields of TDS were related to more types of land use and population density than that of any other constituent. Yields of chloride, TDS, and NO3+NO2 increased significantly as the percentage of urban land use increased. Yields of chloride, TOC, and TDS decreased as the percentage of agricultural land use increased. TDS was the only constituent for which median yields were related to the percentage of forested land use. TDS yields increased as the percentages of forested

Table 32. Total instream loads and yields of total suspended solids, attentuated contributions from permitted sources, and contributions from nonpermitted sources at 21 surface-water sampling sites in the Raritan River Basin, N.J., at selected flow conditions during the growing season, 1991-97 water years

[Loads are in pounds per day and yields are in pounds per day per square mile; **Red Cells** = largest yields at each flow condition; **Green Cells** = smallest yields at each flow condition]

Station number	Station name	Load									Yield								
		Base flow (90th percentile)			Median flow			High flow (25th percentile)			Base flow (90th percentile)			Median flow			High flow (25th percentile)		
		Total in-stream	Per-mitted	Non-per-mitted	Total in-stream	Per-mitted	Non-per-mitted	Total in-stream	Per-mitted	Non-per-mitted	Total in-stream	Per-mitted	Non-per-mitted	Total in-stream	Per-mitted	Non-per-mitted	Total in-stream	Per-mitted	Non-per-mitted
01396280	S.B. Raritan River at Middle Valley	332.1	37.3	294.8	1,378	38.3	1,339	2,944	38.8	2,906	7.0	.8	6.2	28.9	.8	28.1	61.9	.8	61.0
01396535	S. B. Raritan River at Arch Street at High Bridge	749.7	25.6	724.1	2,305	30.6	2,275	4,599	33.2	4,566	10.9	.4	10.5	33.5	.4	33.1	66.8	.5	66.4
01396588	Spruce Run near Glen Gardner	106.8	.6	106.2	265.7	.6	265.1	462.0	.6	461.4	6.9	.0	6.9	17.1	.0	17.1	29.8	.0	29.8
01396660	Mulhockaway Creek at Van Syckel	36.3	.1	36.2	174.3	.1	174.3	344.9	.1	344.8	3.1	.0	3.1	14.8	.0	14.8	29.2	.0	29.2
01397000	S. B. Raritan River at Stanton	967.9	49.6	918.4	2,226	56.0	2,170	4,900	59.5	4,840	6.6	.3	6.2	15.1	.4	14.8	33.3	.4	32.9
01397400	S. B. Raritan River at Three Bridges	1,806	130.1	1,676	4,463	139.5	4,324	11,130	143.7	10,990	10.0	.7	9.3	24.7	.8	23.9	61.5	.8	60.7
01398000	Neshanic River at Reaville	9.3	.0	9.3	318.1	.0	318.1	1,290	.0	1,289	.4	.0	.4	12.4	.0	12.4	50.2	.0	50.2
01398260	N. B. Raritan River near Chester	16.7	16.7	--	72.5	24.5	48.0	178.3	24.5	153.8	2.2	2.2	--	9.6	3.2	6.3	23.5	3.2	20.3
01399120	N. B. Raritan River at Burnt Mills	228.2	29.4	198.9	1,339	41.3	1,297	3,407	46.1	3,361	3.6	.5	3.1	21.0	.6	20.3	53.4	.7	52.7
01399500	Lamington River near Pottersville	248.3	76.9	171.4	799.5	105.5	694.0	1,403	115.2	1,288	7.6	2.3	5.2	24.4	3.2	21.2	42.8	3.5	39.3
01399700	Rockaway Creek at Whitehouse	241.0	59.4	181.6	726.3	64.3	662.0	1,416	67.0	1,349	6.5	1.6	4.9	19.6	1.7	17.8	38.2	1.8	36.4
01399780	Lamington River at Burnt Mills	580.2	104.4	475.8	3,062	160.0	2,902	7,423	181.6	7,241	5.8	1.0	4.8	30.6	1.6	29.0	74.2	1.8	72.4
01400500	Raritan River at Manville	4,630	196.1	4,434	13,520	308.0	13,220	34,140	371.0	33,770	9.4	.4	9.0	27.6	.6	27.0	69.7	.8	68.9
01400540	Millstone River near Manalapan	62.1	.0	62.1	268.4	.0	268.4	674.9	.0	674.9	8.4	.0	8.4	36.4	.0	36.4	91.6	.0	91.6
01400650	Millstone River at Grovers Mill	829.7	67.4	762.2	2,700	67.8	2,632	5,672	68.2	5,604	19.1	1.6	17.6	62.2	1.6	60.7	130.7	1.6	129.1
01401000	Stony Brook at Princeton	21.3	5.5	15.8	665.1	5.5	659.7	3,454	5.5	3,449	.5	.1	.4	14.9	.1	14.8	77.6	.1	77.5
01401600	Beden Brook near Rocky Hill	50.2	5.8	44.4	432.6	5.8	426.8	1,175	5.8	1,169	1.8	.2	1.6	15.7	.2	15.5	42.6	.2	42.4
01402000	Millstone River at Blackwells Mills	2,776	238.1	2,538	11,950	239.7	11,710	30,470	259.8	30,210	10.8	.9	9.8	46.3	.9	45.4	118.1	1.0	117.1
01403300	Raritan River at Bound Brook	2,703	799.9	1,903	25,430	1,022	24,400	104,900	1,129	103,800	3.4	1.0	2.4	31.6	1.3	30.4	130.5	1.4	129.1
01405302	Matchaponix Brook at Spotswood	202.6	58.4	144.2	838.7	84.3	754.4	2168	113.7	2,055	4.6	1.3	3.3	19.0	1.9	17.1	49.2	2.6	46.6
01405340	Manalapan Brook near Manalapan	206.8	.0	206.8	600.4	.0	600.4	1266	.0	1,266	9.9	.0	9.9	28.7	.0	28.7	60.6	.0	60.6

land and total undeveloped land increased. TDS also decreased as the percentage of total developed land increased. This appears to be more a function of physiographic province than of land use. Forested land is more prevalent than any other land use in the New England province, and agricultural land is more prevalent in the Piedmont province. Both areas have higher TDS yields than the Coastal Plain because of lithology. Peak concentrations of TDS during runoff during the nongrowing season were greatest at sites in the New England province possibly as a result of a greater amount of frozen precipitation in the region and the subsequent increase in road salt application.

Sources of Constituent Load

The contribution of instream constituent loads from ground-water and permitted surface-water sources was evaluated. The ground-water contribution of load to streams was estimated for three surface-water sampling sites. Constituent loads at 73 permitted facilities (49 municipal and 24 industrial) were compiled and evaluated for the period 1991-97.

Ground-Water Sources

Ground-water discharge (base flow) contributes a significant part of total streamflow in the basin. Base flow provides from 38 to 75 percent of mean annual streamflow at gaging stations in the study area (CH2M Hill and others, 1992). Base flow accounts for an average of 70 percent of mean annual flow at five gages in the New England province, 42 percent of mean annual flow at six gages in the Piedmont province, and 62 percent of mean annual flow at three gages in the inner Coastal Plain part of the Raritan River Basin. Runoff accounts for a higher percentage of total streamflow in the Piedmont province because of the presence of shallow soils with low permeability.

The ground-water contribution to load in streams was estimated at the S.B. Raritan River at Middle Valley, Lamington River at Pottersville, and Millstone River at Grovers Mill sites for 1991-97 (fig. 1). Base flow was computed by separating streamflow into base flow and runoff by use of hydrograph separation techniques. The sliding interval method (Pettyjohn and Henning, 1979), which was designed to estimate base flow from mean daily streamflow, has been used by the USGS and others to estimate the base-flow component of streamflow in New Jersey. The calculation of base flow at a site provides an estimate of ground-water discharge to the stream. Base flow is approximately 71 percent of mean daily streamflow at S.B. Raritan River at Middle Valley, 78 percent at Lamington River at Pottersville, and 66 percent at Millstone River at Grovers Mill.

Hydrograph separation was performed on mean daily streamflows at the Lamington River site for 1922-89 as part of a study to develop the New Jersey Statewide Water Supply Masterplan (CH2M Hill and others, 1992). The percentage of streamflow that consists of base flow determined for the Lamington River site for the masterplan study also was used in this analysis. Average streamflow during 1991-97 was only 6 percent higher than during 1922-89. Mean daily streamflows were not available for the S.B. Raritan River and Millstone River at Grovers Mill sites. Average flow at these sites was estimated from average flow at nearby gaging stations by use of the MOVE1 correlation procedure (see “Statistical Methods” section). The percentage of streamflow that consists of base flow at the nearby gaging stations was applied to the sampling sites. Average flow for S.B. Raritan River at Middle Valley was derived from a correlation with average flow at S.B. Raritan River at High Bridge. Results from hydrograph separation for the High Bridge site for 1919-89 were derived from CH2M Hill and others (1992). Average flow for Millstone River at Grovers Mill was estimated from a correlation with the Crosswicks Creek at Extonville gage. Results from hydrograph separation for the Extonville gage during 1991-96 were obtained from Martha Watt (U.S. Geological Survey, written commun., 2000).

Total instream loads at the S.B. Raritan River at Middle Valley, Lamington River at Pottersville, and Millstone River at Grovers Mill were estimated using the Tobit regression equation relating load to streamflow. The regression equations were used to estimate the constituent load at different streamflows. Constituent loads calculated at the average flow condition for 1991-97 were used to estimate that part of instream load that originates from ground water because the hydrograph separation results are for average flow conditions.

The percentage of instream load contributed by ground-water discharge (base flow) was estimated for three sampling sites at mean daily streamflow conditions during 1991-97. The median concentration of each constituent in samples from wells in the basin (table 23) was used to represent the quality of ground water entering the stream as base flow. The number of wells and the amount of ground-water-quality data available for each basin are limited. The results from this study show that some of the constituents analyzed for receive a significant part of instream load from ground water.

The median ground-water concentration and the base-flow component of streamflow were used to compute the base-flow load at mean daily flow. The ground-water component of mean daily flow was computed by use of the hydrograph separation method. The average point-source flow was subtracted from the ground-water component of mean daily flow before the load in base flow was computed by use of the following equation:

$$\text{Base-flow load (lb/d)} = GWC \times GWF \times (2.20462 \times 10^{-6}\ \text{lb/mg}) \times (86{,}400\ \text{s/d}) \times (28.316\ \text{L/ft}^3), \quad (7)$$

where

Base-flow load = load from base flow component of mean daily flow (1b/d),

GWC = medium shallow ground-water concentration in basin (mg/L), and

GWF = ground-water component of mean daily flow (ft^3/s).

The percentage of instream load contributed by base flow at average flow conditions was estimated at each site for chloride, TDS, NO3+NO2, ammonia plus organic nitrogen, total nitrogen, orthophosphorus, and dissolved organic carbon (fig. 25). The pie charts in figure 25 show the percentages of instream load contributed by ground water and by other sources. The percentages contributed by other sources include loads from runoff and point sources. Load from permitted sources was subtracted from estimated base-flow load to estimate the percentage of load from ground water. Point-source data are not available, however, for chloride and dissolved organic carbon. For these constituents the percentage of base-flow load originating from point sources is not known.

Estimates indicate that ground water contributes most of the mean annual instream load of TDS and TKN at each site while contributing a small percentage of the total phosphorus and dissolved organic carbon load. Chloride load from ground water was small at the Lamington and S.B. Raritan River sites and large at Millstone River. NO3+NO2 load from ground water was slightly less than one-half the instream load at S.B. Raritan and Lamington Rivers and almost three-quarters of the total load at the Millstone River site.

The percentage of TDS load contributed to the three streams by the base-flow component of streamflow is fairly consistent between sites (63-68 percent) (fig. 25). Most of the TDS load at average flow originates from ground water although TDS concentrations were higher in streams than in ground water (table 23). Most of the load originates from ground water because 66 to 78 percent of average flow at the three sites originates from ground water. TKN load from ground water was estimated to be 58, 71, and 79 percent of total instream load at Millstone River, S.B. Raritan River, and Lamington River, respectively. The orthophosphorus part of total phosphorus loads contributed to streams from ground water was estimated to be very low (less than 0.1 percent). Median orthophosphorus concentrations were 0.01 mg/L in the Lamington River subbasin and less than 0.01 mg/L in the S.B. Raritan River and Millstone River subbasins. The percentage of instream phosphorus load contributed by base flow was less than or equal to 0.03 percent at each site. Dissolved organic carbon load in base flow was

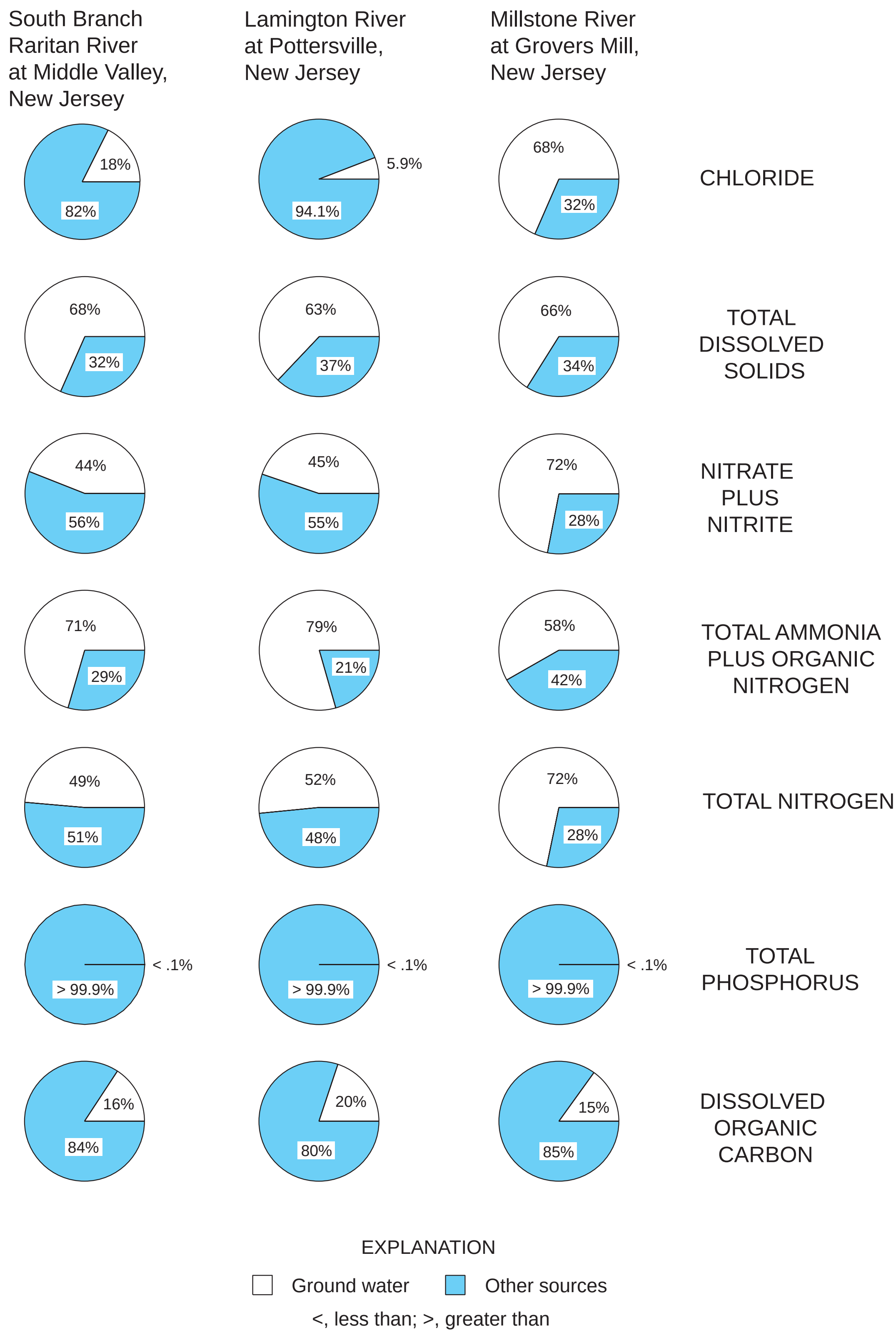


Figure 25. Estimates of percentage of total instream load contributed by ground water at average flow conditions for selected constituents at three sites in the Raritan River Basin, N.J., 1991-97.

estimated to be from 15 to 20 percent of total instream load at the three sites. Chloride load from ground water at base flow ranged from 6 percent of total load at Lamington River to 68 percent at the Millstone River site.

Initial estimates of NO3+NO2 load from ground water were higher than total instream load at the Lamington River and Millstone River sites. NO3+NO2 load from base flow was estimated to be 75, 121, and 208 percent of total instream load at S.B. Raritan River, Millstone River, and Lamington River, respectively. The median concentration of NO3+NO2 in ground water was nearly twice as high as in base flow (table 23). Other studies have reported similar conclusions (Kauffman, 1999). Denitrification and other processes in the near-stream subsurface environment (hyporheic zone) have been shown to substantially reduce the nitrate load in ground-water discharge to streams (Robertson and others, 1991). Aquatic plants also remove a large quantity of nitrite and nitrate nitrogen.

The USGS LINJ NAWQA program used a ground-water flow model along with a particle-tracking program to simulate transport of nitrate from the water table to streams and water-supply wells (Kauffman, 1999). Concentrations of nitrate in three streams at base-flow conditions were compared to concentrations simulated from the model. Nitrate concentrations measured in southern Coastal Plain streams were consistently about 40 percent less than the simulated concentration; however, concentrations in samples from wells were similar to the simulated concentration. The apparent nonconservative behavior in streams is most likely the result of denitrification in the aquifer near the streams and (or) instream processes, usually aquatic plant uptake.

Initial estimates of NO3+NO2 load from base flow were adjusted by subtracting the permitted point source load and 40 percent of the ground-water load estimate (Kauffman, 1999) to get the estimated instream load from ground water. The adjusted NO3+NO2 load from ground water was estimated to be 72, 45, and 44 percent of total instream load at Millstone River, Lamington River, and S.B. Raritan River, respectively. Total nitrogen load was computed by adding NO3+NO2 and TKN loads. Estimates of total nitrogen load from ground water were 72, 52, and 49 percent of total instream load at Millstone River, Lamington River, and S.B. Raritan River, respectively. This estimated reduction in NO3+NO2 load from ground-water discharge to streams was computed using a model calibrated to conditions in a small part of the southern New Jersey Coastal Plain (Kauffman, 1999). This reduction was applied to base flow from ground-water sources in the Millstone River, S.B. Raritan River, and Lamington River basins; however, the model was not calibrated to conditions in those areas.

Permitted Surface-Water Sources

All point source discharges to New Jersey streams are monitored by the NJPDES, a program implemented by NJDEP (New Jersey Department of Environmental Protection, 1997). NJPDES rules were promulgated in 1981, and NJDEP implements the permitting program through the authority of the New Jersey Water Pollution Control Act (State of New Jersey, 1977), the Federal Clean Water Act (U.S. Environmental Protection Agency, 1992), and USEPA's National Pollutant Discharge Elimination System (U.S. Environmental Protection Agency, 2002). Permitted point sources in New Jersey are categorized as minor or major, and as municipal, industrial, non-contact cooling water, or petroleum cleanup. Discharges of non-contact cooling water, stormwater, and temporary hazardous waste cleanup sites were excluded from this study.

A total of 73 facilities --49 municipal and 24 industrial-- discharged effluent to streams in the study area during 1991-97 (fig. 26). The average flow and load discharged by these facilities is listed in table 33. The average total permitted effluent discharged in the study area during 1991-97 was 72 ft^3/s. An average of 65 ft^3/s from 70 facilities was discharged upstream from the Raritan River at Queens Bridge sampling site. Effluent discharged to the three major subbasins in the study area

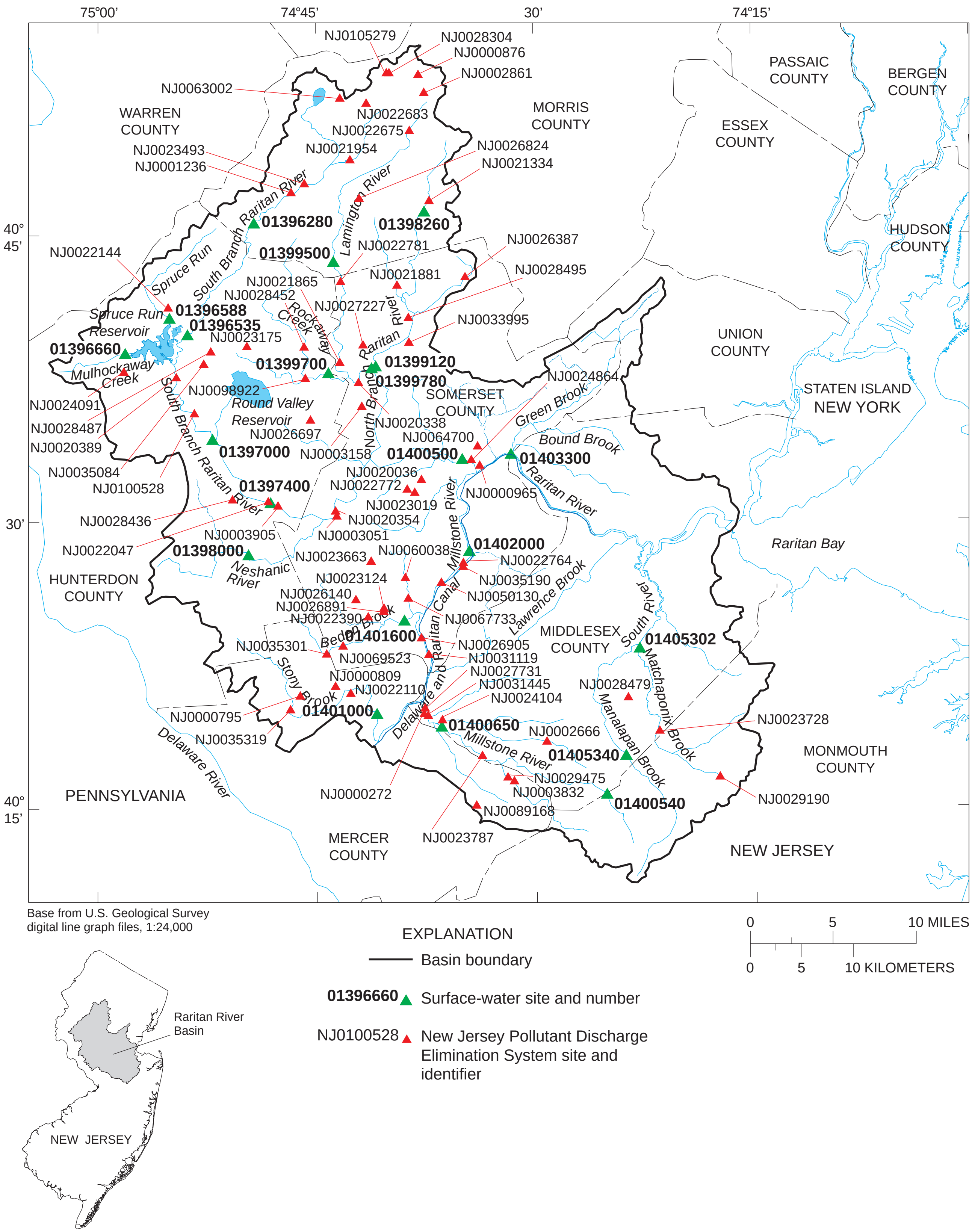


Figure 26. Location of New Jersey Pollutant Discharge elimination system (NJPDES) permitted point sources located upstream from sampling sites, and U.S. Geological Survey/New Jersey Department of Environmental Protection surface-water sampling sites, Raritan River Basin, N.J., 1991-97.

totaled 23 ft^3/s from 32 facilities in the Millstone River subbasin, 8.2 ft^3/s from 19 facilities in the S.B. Raritan River subbasin, and 8.0 ft^3/s from 17 facilities in the N.B. Raritan River subbasin (table 33). Permitted discharges from two facilities on the mainstem of the Raritan River averaged 25.6 ft^3/s, and permitted discharges from three facilities in the South River subbasin to the Matchaponix Brook upstream from the sampling site at Spotswood averaged 7.3 ft^3/s (table 33). The largest point-source facility in the Raritan River Basin discharged an average of 181 ft^3/s from its first pipe and 19.8 ft^3/s from its second pipe to the tidal part of the Raritan River, downstream from the 21 sampling sites.

The Delaware and Raritan Canal is physically located in the study area but affects only the sampling site at Raritan River at Bound Brook. The mean daily flow to the Raritan River Basin from the Delaware River Basin at the basin divide in the Delaware and Raritan Canal at Port Mercer gaging station was 134 ft^3/s during 1990-97. Water is diverted from the canal at Ten Mile Lock into the Millstone River near the confluence of the Millstone and Raritan Rivers. The mean daily flow diverted from the canal to the Millstone River during 1991-97 was 18.9 ft^3/s. The mean daily flow diverted from the canal to the river in the growing season was 11.4 ft^3/s. The remaining flow in the Delaware and Raritan Canal empties into the Raritan River downstream from the Raritan River at Bound Brook site (01403300) at a point outside the study area. The canal is used as a source of raw water for three drinking-water-treatment plants in Middlesex County. A laboratory in Mercer County (NJ0023922) discharged 0.01 ft^3/s to the canal during 1994-97, and a chemical plant in Mercer County (NJ0005541) discharged 0.10 ft^3/s to Duck Pond Run, which empties into the canal, during 1991-97. These two point sources are not shown in figure 26 because the discharge from these facilities bypasses the stream reaches studied in the load analysis. The permitted loads from the two facilities are a small part of the total load in the canal. The quantity of the permitted loads in the canal that is discharged to the Millstone River is considered negligible.

At least one permitted source of wastewater is present upstream from 18 of the 21 water-quality sampling sites studied. The Neshanic River, Manalapan Brook, and Millstone River near Manalapan are the only sites without permitted sources that discharge wastewater upstream. The Millstone River, S.B. Raritan River, N.B. Raritan River, Matchaponix Brook, and the mainstem of the Raritan River receive direct discharges from 31, 19, 17, 3, and 3 facilities, respectively.

Total permitted point-source discharge (table 33) was compared to streamflow statistics for points upstream from sampling sites (table 3). The most significant effect of permitted point sources on a stream occurs at base-flow conditions when the percentage of streamflow consisting of permitted point-source effluent is greatest. Average flow from permitted point sources upstream from the sampling site ranged from 0 to 45 percent of base flow. Permitted point-source flow at five sites --Beden Brook, Matchaponix Brook, Raritan River at Bound Brook, Millstone River at Blackwells Mills, and Millstone River at Grovers Mill--exceeded 25 percent of base flow; the percentages are 45, 40, 36, 32, and 28, respectively.

Approximately 170 ft^3/s is withdrawn from the Raritan River for water supply, 3.1 miles upstream from the sampling site at Raritan River at Bound Brook (01403300). If the 170 ft^3/s was not withdrawn from the river, 24 percent of base flow would consist of permitted effluent at the Raritan River at Bound Brook. Total effluent discharged from permitted sources upstream from the withdrawal point was 39 ft^3/s. It is assumed that permitted sources are evenly mixed with the natural flow in the river at the withdrawal point. The percentages of instream flow at low, median, and high conditions that consist of permitted-source effluent at the point of withdrawal are 12, 5.5 and 3.0, respectively. Therefore, the amounts of permitted effluent removed from the river upstream from Raritan River at Bound Brook at low, median, and high flow are 21, 9.5, and 5.1 ft^3/s, respectively.

Streams in the Piedmont part of the study area have the lowest flows of all streams in the study area at base-flow conditions. (See