Table 33. Wastewater discharge and unattenuated constituent loads from permitted point sources listed in downstream order in the Raritan River Basin, N.J., study area, 1991-97 water years

[Loads are in pounds per day; flow is in cubic feet per second; NJPDES, New Jersey Pollutant Elimination Discharge System]

				Average discharge		Load, in pounds per day						
						Ammonia plus organic nitrogen, total	Bio-chemical oxygen demand	Dissolved solids, total	Nitrate plus nitrite	Organic carbon, total	Phos-phorus, total	Suspended solids, total
NJPDES number	Facility name	Receiving water	Period of discharge analyzed	1991-97	Period of discharge analyzed	1991-97	1991-97	1991-97	1991-97	1991-97	1991-97	1991-97
			South Branch Raritan River									
NJ0063002	Gold Mine Estates Water Systems	Budd Lake via unnamed trib	1991-96	0.0003	0.0003	0.003	0.008	0.831	0.008	0.008	0.002	0.004
NJ0105279	Hi-Speed Checkweigher Co Inc	Drakes Brook	1994-97	.05	.10	.59	.56	147.5	6.79	.18	.88	.56
NJ0028304	Days Inn	Ledgewood Brook	1991-97	.02	.02	.18	.20	45.2	2.08	.18	.02	.53
NJ0022683	Skyview STP	Flanders Brook	1991-97	.12	.12	5.54	4.00	337	11.3	4.00	.48	3.81
NJ0021954	Clover Hill STP	Drakes Brook	1991-97	.52	.52	5.93	10.8	1,413	64.7	10.8	1.01	17.2
NJ0023493	Washington Township MUA WTP	S.B. Raritan River	1991-97	.63	.63	10.9	17.3	1,692	73.7	17.3	10.2	14.0
NJ0001236	Parmalat Welsh Farms Inc	S.B. Raritan River	1991-97	.11	.11	1.32	4.13	302.9	.30	4.17	2.85	3.86
NJ0022144	Hagadorn Center For Geriatrics	Rocky Run via unnamed trib	1991-97	.04	.04	.53	1.11	110.5	4.99	1.21	.18	1.17
NJ0024091	Union Twp Elementary School	Mulhockaway Creek	1991-97	.004	.004	.02	.07	10	.48	.07	.01	.07
NJ0028487	Mountainview Correctional Inst	Beaver Brook	1991-97	.26	.26	12.1	22.8	691	30.8	22.8	2.48	27.3
NJ0035084	Exxon Research & Eng Co	Beaver Brook	1991-97	.05	.05	.24	.65	159	6.44	.26	.03	.39
NJ0020389	Clinton WTP	S.B. Raritan River	1991-97	1.76	1.76	101	55.8	3,801	123	53.4	9.51	61.4
NJ0100528	Glen Meadows/Twin Oaks STP	S.B. Raritan River	1996-97	.003	.008	.04	.03	9.53	.44	.04	.06	.04
NJ0028436	Raritan Twp MUA-Flemington	S.B. Raritan River	1991-97	.59	.59	70.0	87.2	1,592	9.55	87.2	15.9	60.3
NJ0022047	Raritan Township STP	S.B. Raritan River	1991-97	3.90	3.90	48.9	64.4	10,520	179	64.4	44.1	107
NJ0003905	Merck & Co Inc	S.B. Raritan River	1991-97	.02	.02	.15	.19	59	2.80	.55	.35	.73
NJ0020354	Neshanic Station STP	S.B. Raritan River	1991-97	.04	.04	.24	.52	102	4.68	.41	.61	.84
NJ0003051	Wilson Color Inc	S.B. Raritan River	1991-96	.04	.04	.40	1.01	101	4.66	2.66	.61	1.31
NJ0026697	Readington Twp Public School	Holland Brook via unnamed tributary	1991-97	.004	.004	.14	.15	11.8	.45	.14	.07	.14
			North Branch Raritan River									
NJ0021334	Borough Of Mendham STP`	India Brook	1991-97	.66	.66	10.2	18.2	1,773	78.6	18.2	2.09	24.5
NJ0021881	Peapack & Gladstone STP	Peapack Brook	1991-96	.66	.66	15.6	12.5	588	13.8	12.5	3.53	10.3
NJ0026387	Bernardsville STP	Mine Brook	1991-97	.89	.89	10.4	13.1	2,393	110	9.57	1.12	7.70
NJ0028495	Bedminster STP	N.B. Raritan River	1991-94	.09	.16	2.03	2.20	81.00	8.95	2.26	.48	2.52
NJ0033995	Environmental Disposal Corp	N.B. Raritan River via unnamed trib	1991-97	1.29	1.29	6.26	11.7	2,262.9	14	6.96	.88	11.0
NJ0027227	John Z Delorean	Middle Brook	1991-97	.002	.002	.05	.08	4.36	.17	.08	.03	.05
NJ0003158	Agfa Corporation	Chambers Brook	1991-97	.14	.14	1.48	3.70	370	17.0	3.70	2.22	3.33

Table 33. Wastewater discharge and unattenuated constituent loads from permitted point sources listed in downstream order in the Raritan River Basin, N.J., study area, 1991-97 water years--Continued

NJPDES number	Facility name	Receiving water	Period of discharge analyzed	Average discharge 1991-97	Average discharge Period of discharge analyzed	Load, in pounds per day: Ammonia plus organic nitrogen, total 1991-97	Bio-chemical oxygen demand 1991-97	Dissolved solids, total 1991-97	Nitrate plus nitrite 1991-97	Organic carbon, total 1991-97	Phos-phorus, total 1991-97	Suspended solids, total 1991-97
			Lamington River									
NJ0000876	Hercules Kenvil	Lamington River from drainage ditch	1991-97	0.09	0.09	0.61	1.62	265	11.78	0.99	0.07	3.83
NJ0002861	County Concrete Corp	Lamington River	1991-97	1.52	1.52	16.4	41.0	4,100	189	41.00	24.6	64.6
NJ0022675	Roxbury Township Of	Lamington River	1991-97	2.09	2.09	10.0	42.0	5,636	140	22.6	7.21	73.2
NJ0026824	Chester Shopping Center STP	Tiger Brook	1991-97	.01	.01	.09	.77	33.22	1.57	.78	.20	.87
NJ0022781	Pottersville STP	Lamington River	1991-97	.04	.04	.32	1.19	99.82	4.72	1.20	.60	1.54
NJ0021865	Fiddler's Elbow Ctry Club STP	Lamington River	1991-97	.01	.01	.21	.60	38.73	.03	.61	.42	.61
NJ0028452	Best A M Co Inc	N.B. Rockaway Creek from unnamed trib	1991-97	.005	.005	.17	.24	14.09	.54	.27	.08	.11
NJ0023175	Round Valley Middle School	S.B. Rockaway Creek from unnamed trib	1991-97	.002	.002	.02	.11	6.30	.30	.06	.04	.07
NJ0098922	Readington-Lebanon Sa	Rockaway Creek	1991-97	.86	.86	17.3	48.1	2,783	23.6	28.3	17.8	40.7
NJ0020338	Fox Hollow STP	Lamington River	1991-97	.04	.04	.22	.59	102	4.69	.41	.61	.87
			Millstone River									
NJ0004243	Rheox Inc	Millstone River from unnamed trib	1991-97	.01	.01	.08	.13	27.8	1.31	.11	.02	.07
NJ0003832	Hightstown WTP	Rocky Brook	1991-95	.06	.06	.63	1.58	158.3	1.59	1.58	.32	.47
NJ0029475	Hightstown Advanced WWTP	Rocky Brook	1991-97	1.13	1.13	5.83	10.7	2,520	213	10.9	2.43	11.6
NJ0023787	East Windsor Water Pollution	Millstone River	1991-97	3.86	3.86	91.5	55	4,161	277	58.8	16.2	81.9
NJ0002666	Carter-Wallace Inc	Cranbury Brook	1991-94	.10	.17	1.07	2.69	269	12.4	2.69	1.61	3.25
NJ0024104	United Water Princeton	Cranbury Brook	1991-97	1.69	1.69	112	47.5	2,918	38.8	48.8	5.50	79.0
NJ0089168	Fina Oil & Chemical Co (Former)	Bear Brook from storm sewer	1997	.0002	.0009	.00	.00	0.11	.02	.00	.00	.01
NJ0027731	FMC Corporation	Millstone River	1991-92, 95-97	.12	.21	1.23	3.09	308	3.09	3.08	.16	.00
NJ0000272	Sarnoff Corporation	Millstone River	1995-97	.05	.12	.55	1.37	137	6.31	1.37	.14	.83
NJ0031445	Firmenich Incorporated	Millstone River	1992-97	.005	.006	.15	.09	33.0	.78	.05	.01	.09
NJ0000795	Bristol-Myers Squibb Company	Stony Brook from unnamed trib	1991-93, 97	.06	.11	.36	.42	205	7.00	.59	1.44	.45
NJ0035319	Stony Brook RSA - Pennington	Stony Brook	1991-97	.37	.37	2.81	6.04	1,053	36.1	4.01	8.42	4.16
NJ0000809	Hopewell Business Center	Cleveland Brook	1991-97	.03	.03	.18	6.54	81.8	3.32	.36	.04	.30
NJ0022110	Educational Testing Service	Stony Brook	1991-97	.035	.035	.25	.41	94.9	4.49	.38	.05	.55
NJ0031119	Stony Brook RSA	Millstone River	1991-97	13.1	13.1	141	131	35,280	1,412	141	168	80.9

Table 33. Wastewater discharge and unattenuated constituent loads from permitted point sources listed in downstream order in the Raritan River Basin, N.J., study area, 1991-97 water years--Continued

				Average discharge		Load, in pounds per day						
						Ammonia plus organic nitrogen, total	Bio-chemical oxygen demand	Dissolved solids, total	Nitrate plus nitrite	Organic carbon, total	Phos-phorus, total	Suspended solids, total
NJPDES number	Facility name	Receiving water	Period of discharge analyzed	1991-97	Period of discharge analyzed	1991-97	1991-97	1991-97	1991-97	1991-97	1991-97	1991-97
			Millstone River--Continued									
NJ0026905	Stage II Treatment Plant	Millstone River	1991-97	0.48	0.48	4.53	6.64	855	43.6	5.18	8.20	4.75
NJ0035301	Stony Brook RSA - Hopewell	Beden Brook	1991-97	.70	.70	4.18	4.55	1,046	22.68	3.49	6.93	2.71
NJ0069523	Cherry Valley STP	Beden Brook	1993-97	.06	.09	.22	.59	135	1.40	.70	.10	.45
NJ0022390	North Princeton Developmental Ctr	Rock Brook	1991-97	.45	.45	5.24	14.2	1,214	55.46	14.7	1.62	8.96
NJ0023663	Carrier Foundation STP	Cruser Brook	1991-97	.05	.05	.37	.70	140	6.65	.56	.06	1.45
NJ0060038	Pike Brook Treatment Plant	Pike Run	1991-97	.20	.20	1.10	2.14	438	4.35	2.17	.09	2.11
NJ0026140	Johnson & Johnson Consumer	Back Brook	1991-94	.09	.06	.39	1.04	119	.86	1.76	.10	1.36
NJ0067733	Oxbridge Treatment Plant	Pike Run	1995-97	.01	.03	.08	.14	28.00	.48	.12	.02	.08
NJ0023124	Montgomery High School	Back Brook	1991-97	.02	.02	.03	.23	31.5	1.58	.16	.47	.11
NJ0026891	Burnt Hill Treatment Plant #1	Back Brook	1991-97	.01	.01	.01	.22	23.1	.72	.24	.12	.22
NJ0050130	Riverside Farms STP	Millstone River	1991-97	.09	.09	.90	1.51	204	11.58	1.00	.58	1.19
NJ0035190	North Brunswick Twp-WTP	Millstone River	1991-97	.02	.02	.19	.47	47.0	.47	.47	.09	.15
NJ0022764	River Road STP	Millstone River	1991-97	.16	.16	5.19	5.92	433	11.26	5.99	2.60	6.14
NJ0023019	Industrial Tube Corp	Royce Brook	1991-97	.02	.02	.17	.42	51	1.75	.42	.25	.10
NJ0022772	Fieldhedge Drive STP	Royce Brook	1991-97	.08	.08	1.61	1.93	201	6.83	1.67	1.21	2.39
NJ0020036	Dept Of Veterans Affairs	Roycefield Brook	1991-97	.04	.04	.48	.36	120	5.51	.48	.72	.32
			Raritan River mainstem									
NJ0000965	Raritan-Millestone WTP	Raritan River	1991-94	.06	.06	.59	1.49	148	1.49	1.39	.89	2.17
NJ0024864	Somerset Raritan Valley Sa	Cuckels Brook	1991-97	25.6	25.6	408	547	66,800	2,130	547	335	597
NJ0064700	Gibson Tube Inc	Cuckels Brook	1991-94	.03	.05	.31	.78	77.9	3.58	.78	.47	.10
			South River									
NJ0029190	Freehold Borough WTP	McGellairds Brook	1993-97	.0005	.0006	.01	.04	1.49	.01	.01	.00	.04
NJ0023728	Pine Brook STP	Pine Brook	1991-97	7.08	7.08	20.9	86.7	18,935	978	38.2	30.3	138
NJ0028479	Jamesburg School For Boys	Matchaponix Brook	1991-97	.17	.17	6.68	10.3	466	6.54	10.3	.92	9.25

"Evaluation of Streamflow" section.) The stream reach upstream from the Beden Brook site has one of the lowest flows at base-flow conditions; therefore, point sources constitute a relatively high percentage of streamflow. Studies of streamflow in the Beden Brook subbasin by TRC Omni Environmental Corporation (2001) have found that the stream loses flow to ground water at base-flow conditions.

Three small facilities discharge to streams that drain into large impoundments. The Hagadorn Center for Geriatrics (NJ0022144) discharged 0.04 ft^3/s to Spruce Run, and Union Township Elementary School (NJ0024091) discharged 0.004 ft^3/s to Mulhockaway Creek during the study period (table 25). Both of these streams drain into Spruce Run Reservoir. Gold Mine Estates Water System (NJ0063002) discharged 0.0003 ft^3/s to an unnamed tributary that drains into Budd Lake (TRC Omni Environmental Corporation, 2001).

During the study period three municipal facilities, four industrial facilities, and two water-treatment plants did not report discharges (table 33). Discharge from Peapack & Gladstone STP (NJ0021881) and Bedminster STP (NJ0028495) was transferred to Environmental Disposal Corporation (NJ0033995). All three of these facilities are in the N.B. Raritan River subbasin upstream from the Burnt Mills sampling site and continued to discharge to N.B. Raritan River upstream from the sampling site. Gold Mine Estates Water System (NJ0063002) stopped discharging (0.0003 ft^3/s) to Budd Lake in 1997 (TRC Omni Environmental Corporation, 2001).

No discharges were reported for three industrial facilities after 1994. Carter Wallace (NJ0002666) and Johnson & Johnson (NJ0026140) are upstream from the Millstone River at Blackwells Mills site, and Gibson Tube Co (NJ0064700) is upstream from the Raritan River at Bound Brook site. The average discharges before 1994 were 0.17, 0.10, and 0.05 ft^3/s at the three facilities, respectively. No discharges were reported for the Raritan-Millstone (NJ0000965) and Hightstown (NJ0003832) water-treatment plants in 1994 and 1995, respectively. Previously, discharges of 0.06 ft^3/s had been reported.

During the study period, four municipal and three industrial facilities began discharging effluent (table 33). Sarnoff Corporation (NJ0000272) began reporting 0.10 ft^3/s discharge to the Millstone River upstream from the Blackwells Mills sampling site in 1995. Fina Oil and Chemical Co. (NJ0089168) did not report any discharge until 1997 when 0.001 ft^3/s was reported. Hi-Speed Checkweigher Co. Inc. (NJ0105279) began discharging an average of 0.1 ft^3/s to Drakes Brook, upstream from S.B. Raritan River at Middle Valley in 1994. Freehold Water Treatment Plant (NJ0029190) began reporting an average discharge of 0.0005 ft^3/s in 1993, which was released upstream from the Matchaponix Brook sampling site. Oxbridge Treatment Plant (NJ0067733) discharged an average of 0.03 ft^3/s to Pike Run upstream from Millstone River at Grovers Mill. Cherry Valley STP (NJ0069523) began discharging an average of 0.09 ft^3/s to Beden Brook, upstream from the sampling site, in 1993. Glen Meadows/Twin Oaks STP (NJ0100528) began discharging an average of 0.01 ft^3/s to S.B. Raritan River in 1995 (TRC Omni Environmental Corporation, 2001).

Average annual discharges at some facilities varied from year to year. Discharges from the water-treatment plants, as a group, were the most variable. Discharge from two facilities ranged from 0 to 0.2 ft^3/s in any given year. Average annual discharge at another three water-treatment plants varied by orders of magnitude from less than 0.001 ft^3/s to 0.1 ft^3/s during the study period. Average annual discharge from other facilities, such as the Raritan Township MUA's Flemington Peak Flow facility (NJ0028436), ranged from 0.0005 to 1.4 ft^3/s. Wilson Color Inc. (NJ0003051) did not report any discharge in 1997. Bristol Meyers Squibb (NJ0000795) reported discharges of 0.08 ft^3/s from 1991 to 1993 but did not report discharge again until 1997. FMC Corporation (NJ0027731) did not report any discharge in 1993 or 1994. In addition, Firmenich Inc. (NJ0031445) did not report discharge in 1991 or 1995 (TRC Omni Environmental Corporation, 2001).

EVALUATION OF LOAD FROM PERMITTED SOURCES

The point-source constituent load discharged from permitted facilities was computed primarily from discharge quantity and quality data obtained from the NJDEP Discharge Monitoring Report database. The database, however, does not contain data for all constituents at all the facilities. Some facilities collect additional data that is not included in the NJDEP database. Additional data from these facilities were obtained by TRC Omni Environmental Corporation (2001). When no data were available, constituent concentrations were estimated from data for similar facilities or from scientific literature. Monthly data were used to compute an average annual load at each facility for each year and for the 1991-97 period (TRC Omni Environmental Corporation, 2001) (table 33).

Permitted load is defined as the load discharged to a stream by a permitted facility. The permitted load is not necessarily the maximum design load of the facility. Total instream loads were computed from water-quality and streamflow data at surface-water sampling sites. The part of total instream load that originates from permitted point sources was computed from (1) effluent-quality and -quantity data reported for permitted point sources (TRC Omni Environmental Corporation, 2001) and (2) water-quality and streamflow data from USGS/NJDEP water-quality sites in the basin. Travel time and attenuation rates were used to estimate the amount of permitted point-source loads that contribute to total instream load at sampling sites at low, median, and high flows.

The average annual daily constituent loads in effluent remained constant from 1991-97 at most of the permitted facilities. Changes occurred at the 17 facilities listed in the section "Permitted Surface-Water Sources" that did not report discharge each year and at 6 other facilities believed, on the basis of substantial changes in reported concentration, to have upgraded treatment of effluent. The effluent from two facilities in the N.B. Raritan River subbasin was transferred to a third facility, resulting in improved treatment and a decrease in constituent loads discharged to the stream. Some facilities also showed an increase in average annual daily load over the study period caused by an increase in streamflow. Some of these changes in effluent quality resulted in changes in the total instream constituent load at some sampling sites.

Some constituent loads in effluent from six facilities changed as a result of upgrades in treatment. Loads of BOD, TKN, TOC, total phosphorus, and TSS in effluent decreased. Loads of NO3+NO2 increased, whereas TDS loads generally remained unchanged. The six facilities with upgraded treatment and the year of upgrade are Town of Clinton WWTP (NJ0020389), Hagadorn Center for Geriatrics (NJ0022144), and East Windsor Water Pollution (NJ0023787) in 1993; North Princeton Developmental Center (NJ0022390) in 1994; Bernardsville STP (NJ0026387) in 1992; and Mountain View Correctional Institution (NJ0028479) in 1992 and again in 1997 (TRC Omni Environmental Corporation, 2001) (table 33). Hagadorn Center for Geriatrics (NJ0022144) discharges effluent to Rocky Run upstream from the Spruce Run sampling site. Town of Clinton WWTP (NJ0020389) and Mountain View Correctional Institution (NJ0028479) discharge to S.B. Raritan River and Beaver Brook upstream from the S.B. Raritan River samplng sites at Stanton and Three Bridges. Bernardsville STP discharges to Mine Brook upstream from the N.B. Raritan River at Burnt Mills sampling site. North Princeton Development Center (NJ0022390) discharges to Rock Brook upstream from the Beden Brook sampling site, and East Windsor Water Pollution (NJ0023787) discharges to Millstone River upstream from the Grovers Mill sampling site. Effluent from Bernardsville STP (NJ0028495) and Peapack/Gladstone STP (NJ0021881) was transferred to Environmental Disposal Corporation (NJ0033995) in 1994 and 1996, respectively. The effluent is discharged to the same stream; however, upgraded treatment at Environmental Disposal Corporation (EDC) has lead to a reduction in permitted loads to the stream.

Constituent loads from two facilities increased substantially toward the end of the study period. Loads from Readington-Lebanon STP (NJ0098922) increased as a result of a steady increase in effluent flow during 1991-95 and a more substantial increase in flow during 1995-96. Loads for most constituents more than doubled during 1991-95 and 1996-97. The facility discharges effluent to Rockaway Creek upstream from the Rockaway Creek sampling site (01399700). Loads of TSS, BOD, and TOC from Union Township Elementary School (NJ0024091) doubled from 1991-94 to 1995-97. The loads were small, however, and did not have a significant effect on total constituent load at the Mulhockaway Creek sampling site.

The contribution of permitted constituent load to total instream load was computed for each sampling site each year. The permitted component of instream load at the sampling site is dependent on four factors, which are (1) the amount of load discharged to the stream; time of travel which consists of (2) the distance between the discharge point and the sampling site; (3) the average velocity throughout the stream reach; and (4) the attenuation rate of the constituent. The USGS computed the velocities and distances along stream reaches, and TRC Omni Environmental Corporation (2001) provided the constituent attenuation rates. The chemical and physical reactions of a constituent in the water column affect the attenuation rate. Attenuation rates increase for most constituents as water temperatures increase. Permitted loads were computed at both 20 ^{o}C and 5 ^{o}C for this study by use of the following equation.

$$Load_{site} = Load_{pt}\ e^{(-kt)}, \qquad (8)$$

where

$Load_{site}$ = load at sampling site (lbs/d),

$Load_{pt}$ = load discharged by the point source (lbs/d),

k = first order decay rate coefficient (1/d),

e = the exponent of the k and t terms, and

t = time of travel from upstream to downstream location (days).

Attenuation rates for both growing and nongrowing seasons were analyzed in this study. Attenuation rates at 20 ^{o}C were provided by Omni (TRC Omni Environmental Corporation, 2001). The attenuation rates at 20 ^{o}C were used for the primary calculation and evaluation of permitted load for the growing season. The median water temperature at sampling sites in the Raritan River Basin is highest in July. The median of the median water temperatures for the 21 sites from data collected from the beginning of the period of record through 1993 was 22.2 ^{o}C (Reed and Hunchak-Kariouk, 1995). The results of the load analysis in this report are for the growing season unless stated otherwise. A nongrowing season attenuation rate calculated at 5 ^{o}C also was applied to the permitted loads for comparative purposes. The median of the median water temperatures for the 21 sites from data collected from the beginning of the period of record through 1993 was 4.1 ^{o}C for the nongrowing season (Reed and Hunchak-Kariouk, 1995).

Average annual effluent loads from the permitted facilities were used to compute the permitted part of instream load at a surface-water sampling site for each year and for the entire 1991-97 period. The permitted part of total instream load was computed at three flow conditions--90th, 50th, and 25th percentile flows. The average permitted load for each year was evaluated to identify changes during the study period. The permitted load for most of the constituents at most sampling sites did not change noticeably. When changes occurred, the permitted load representing the most recent period was used in the analysis.

Criteria were established for determining whether the permitted load during 1991-97 or during a recent subset of this period was used in the analysis. The permitted part of total instream load in 1991 was compared to the permitted load in 1997. When the change in permitted load was at least 50 percent, the data were evaluated to determine whether a sudden change in effluent discharge occurred. When a sudden change occurred, the average permitted load during the years before the change was compared to the average permitted load after the change. The average permitted load for the later period was used when the change was at least 50 percent and the permitted load accounted for more than 10 to 15 percent of total instream load, depending on the constituent. When a gradual change occurred in permitted load, an average permitted load for the entire period (1991-97) was used.

Analysis of variance (ANOVA) conducted on the ranks of total instream loads was used to test for significant differences in sampled loads at sites before and after the upgrades. If a significant difference exists, the relation of total instream load to streamflow will vary. Test results indicated that the differences in total instream load for one or two constituents at four sites were significant. Total instream loads of TKN and total phosphorus at N.B. Raritan River at Burnt Mills were significantly lower after treatment plant upgrades at Bernardsville STP (NJ0026387) and after transfer of effluent discharge from Bernardsville STP (NJ0028495) and Peapack/Gladstone STP (NJ0021881) to EDC (NJ0033995) in 1994 and 1996, respectively. Upgraded treatment at EDC also may have contributed to the reduction in permitted loads to the stream. Total instream phosphorus loads at S.B. Raritan River at Stanton were significantly lower after upgrades in treatment at Town of Clinton Waste Water Treatment Plant (WWTP) (NJ0020389), Hagadorn Center for Geriatrics (NJ0022144), and Mountainview Correctional Institution (NJ0028479).

Total instream BOD loads were significantly greater at Rockaway Creek at Whitehouse during 1996-97 than during 1991-95. Increases in BOD loads discharged to the creek by Readington-Lebanon STP (NJ0098922) as a result of a steady increase in volume of flow during 1991-97 could have contributed to the increase in total instream BOD load. TKN and TOC loads at Lamington River at Burnt Mills (01399780) were significantly greater during 1996-97 than during 1991-95. These increases also can be attributed to increases in loads discharged to Rockaway Creek by Readington-Lebanon STP (NJ0098922) (TRC Omni Environmental Corporation, 2001).

Tobit regression analysis of total instream load in relation to flow was conducted for the four sites with significant changes in sampled loads after treatment facility upgrades. The analysis was run on data collected before and on data collected after the treatment plant upgrades. Total instream loads of total phosphorus at S.B. Raritan River at Stanton and N.B. Raritan River at Burnt Mills and of TKN at N.B. Raritan River at Burnt Mills were lower during 1995-97 than during 1991-94. Total instream load of BOD at Rockaway Creek at Whitehouse was greater during 1996-97 than during 1991-95. Values for BOD during 1996-97 are shown in table 26. The ANOVA results for loads of TKN and TOC at N.B. Raritan River at Burnt Mills indicate a significant increase occurred in total instream load from 1991-95 to 1996-97. The Tobit regression analysis of TOC load as a function of streamflow conducted using the 10 samples available for the 1996-97 period, however, did not produce a valid result. The total instream TOC load and yield at N.B. Raritan River at Burnt Mills listed in table 26 are for 1991-95 and are somewhat less than the total instream load and yield for 1996-97. Therefore, the part of total TOC load originating from permitted sources for the most recent period (1996-97) is actually higher than the amount shown in table D-6.

Effects of Upgraded Effluent Treatment

Surface-water sampling sites, for which constituent trends had been determined from data collected during 1991-97, were further studied for a relation between the trends and changes in effluent discharged upstream from the sampling site. Changes in constituent loads in effluent were determined to be caused by upgraded effluent treatment and by increases in the volume of effluent discharged. The constituent concentrations in instream samples collected before the change were compared to those collected after the change by use of an ANOVA test on the ranked data.

Significant trends observed in instream concentrations and loads of TKN and total phosphorus during 1991-97 at some sampling sites (table 3) were determined to be related to upgraded treatment of effluent during the period. Substantial decreases in total phosphorus loads in effluent discharged by Clinton Township STP (NJ0020389), 6.3 mi upstream from the sampling site, and Mountainview Correctional Institution (NJ0028487), 3.1 mi upstream from the sampling site, that began in 1994 and 1992, respectively, were found to be related to significant decreases in instream loads of total phosphorus at S.B. Raritan River at Stanton. Data on total phosphorus load in effluent from Mountainview Correctional Institution indicate that treatment upgrades were made in 1992 and in 1997 (fig. 26). Significant decreases in total phosphorus and TKN concentrations at N.B. Raritan River at Burnt Mills were related to changes at three facilities in the subbasin. The treatment at Bernardsville STP (NJ0026387) was upgraded in 1992. Effluent from Bedminster STP (NJ0028495) and Peapack/ Gladstone STP (NJ0021881) was transferred to EDC (NJ0033995) in 1994 and 1996, respectively. Loads of total phosphorus and TKN in effluent discharged to the stream decreased as a result of the transfer. Negative trends in TKN and total phosphorus loads at Beden Brook and Millstone River at Grovers Mill were not attributed to upgrades at facilities upstream from these sites.

Trends in instream constituent concentrations at other sites were observed but were not statistically related to changes in the quality of effluent discharged to the stream (table 4). The trends observed during 1991-97 were not found to be significantly related to changes in the quality of effluent discharged to the stream but still could be a contributing factor to the trend. A significant downward trend in total phosphorus concentrations at Millstone River at Grovers Mill could be the result of decreases in loads in effluent discharged by East Windsor Water Pollution (NJ0023787) and Hightstown Advanced Water Treatment Plant (NJ0029475) beginning in 1992. Significant downward trends in total phosphorus, TKN, and TOC at the Beden Brook sampling site could be related to upgraded treatment at the North Princeton Developmental Center (NJ0022390) in 1993, but the relations are not statistically significant.

Adjustment for Withdrawals

The Elizabethtown Water Company withdraws water for public supply from intakes on the Raritan and Millstone Rivers near the confluence of these two rivers. During 1991-97, an average of 170 ft^3/s or 110 million gallons per day was withdrawn. This withdrawal affects the streamflow and constituent loads observed at the Raritan River at Bound Brook sampling site, located 3.1 miles downstream from the withdrawal site. The streamflow just upstream from the withdrawal site is supplemented by a mean daily flow (1991-97) of 18.9 ft^3/s which is diverted from the Delaware and Raritan Canal to the Millstone River. The diversion represents 14 percent of the flow in the canal, including a small percentage of the 0.11 ft^3/s discharged to the canal by two permitted source facilities in the Princeton area. The amount of the permitted load diverted to the Millstone River is considered insignificant and is not considered in the estimate of permitted load in the river at the Elizabethtown Water Company withdrawal site.

Total instream flows on the Raritan River just downstream from the confluence with the Millstone River at the 90^{th}, 50^{th}, and 25^{th} percentile flow duration were 314 ft^3/s, 694 ft^3/s and 1,310 ft^3/s, respectively. Withdrawals by the Elizabethtown Water Company accounted for 54 percent, 24 percent, and 13 percent of the streamflow at the 90^{th}, 50^{th}, and 25^{th} percentile flow durations. A part of the total constituent load, consisting of load from both permitted and nonpermitted sources, is removed from the stream by this withdrawal. It is assumed that load from permitted sources is evenly mixed with the natural flow in the river at the withdrawal point.

The total instream load, including load from permitted and nonpermitted sources, was estimated for the sites at the mouth of the Millstone River and at the Raritan River just upstream from the Millstone River at each flow condition. Permitted and nonpermitted loads were estimated from loads at the Millstone River at Blackwell’s Mill and the Raritan River at Manville sampling sites. Permitted loads were adjusted by use of time-of-travel and attenuation rates between the sampling sites and the confluence.

The permitted point-source load at the Raritan River at Bound Brook sampling site was adjusted for the permitted load removed from the river by withdrawals for the Elizabethtown Water Company. The permitted point-source part of total instream load removed from the river by the withdrawals was omitted from the estimated permitted load at the sampling site. The adjustment was made under the assumption that load in the river was evenly mixed at the point of withdrawal. Some of the total instream load also is removed when water is withdrawn from the river. Given the flow and load in the river, load per unit of flow was estimated at the point of withdrawal. The amount of load removed from the river was calculated by use of the average flow withdrawn from the river and the load per unit flow. Using the assumption that the river is well mixed, the percentage of total load consisting of permitted load was used to estimate the amount of permitted load removed from the river.

Adjustment for Time of Travel

The time required for the effluent discharged from permitted facilities to reach the sampling site downstream is an important factor in determining the amount of load contributed by the facility. The time of travel between sampling sites depends on the distance and velocity of the water through the stream reach. The water velocity depends on many factors, including volume of streamflow, general morphology of the river, and in particular, the amount of ponding caused by dams or other manmade works (Jobsen, 1996). The best estimates of travel time use actual data collected by timing the transport of a tracer along a stream reach (fig. 27). When no data are available, however, a prediction equation can be developed from base characteristics (Jobsen, 1996).

Velocities and TOT along stream reaches with multiple TOT studies were compared between subbasins and flow conditions (table 34). Velocities and TOT at high flow (25th percentile flow duration) were 2.4 to 3.5 times as great as velocities and TOT at low flow (90th percentile flow duration). Average velocity at low flow was lowest, 0.24 ft/s, along the Millstone River and highest, 0.55 to 0.56 ft/s, along the S.B. Raritan and mainstem Raritan Rivers. At median flow (50th percentile flow duration), velocities were more than 0.90 ft/s in the mainstem Raritan, S.B. Raritan, and Lamington River subbasins. The lowest average velocity was 0.52 ft/s on the Millstone River. At high-flow conditions, average velocities were from 1.27 to 1.44 ft/s in the N.B. Raritan, S.B. Raritan, mainstem Raritan, and Lamington River subbasins. The average velocity at high flow on the Millstone River was 0.83 ft/s.

Distances along stream reaches in the study area were derived from the National Hydrologic Dataset GIS coverage. Distances from permitted point sources to sampling sites and between sampling sites were needed to compute TOT. The longest stream reach in the study area is 65.2 mi. This stream reach extends from the most upstream permitted source on the Drakes Brook, a tributary to the S.B. Raritan River, to the most downstream sampling site on the Raritan River at Bound Brook. The longest distances from permitted sources in other subbasins to the Raritan River at Bound Brook sampling site are 47.4 miles, 38.3 miles, 33.4 miles, and 30.6 miles in the Lamington, Stony Brook-lower Millstone, N.B. Raritan River, and the upper Millstone River drainage basins, respectively.

Travel times at all three flow conditions are longest for the Stony Brook-lower Millstone River reach and are shortest for the N.B. Raritan River reach. At low-flow conditions, TOT from the most upstream permitted point source on the Stony Brook to the Raritan River at Bound Brook is 19 days. Average velocity along the Stony Brook is 0.1 ft/s, and the average velocity through Carnegie Lake is 0.04 ft/s at low flow. The TOT at low flow along the N.B. Raritan River reach was 5.0 days. At high-flow conditions, TOT along the Stony Brook-lower Millstone River reach was 5.2 days and along the N.B. Raritan River reach, 1.5 days.

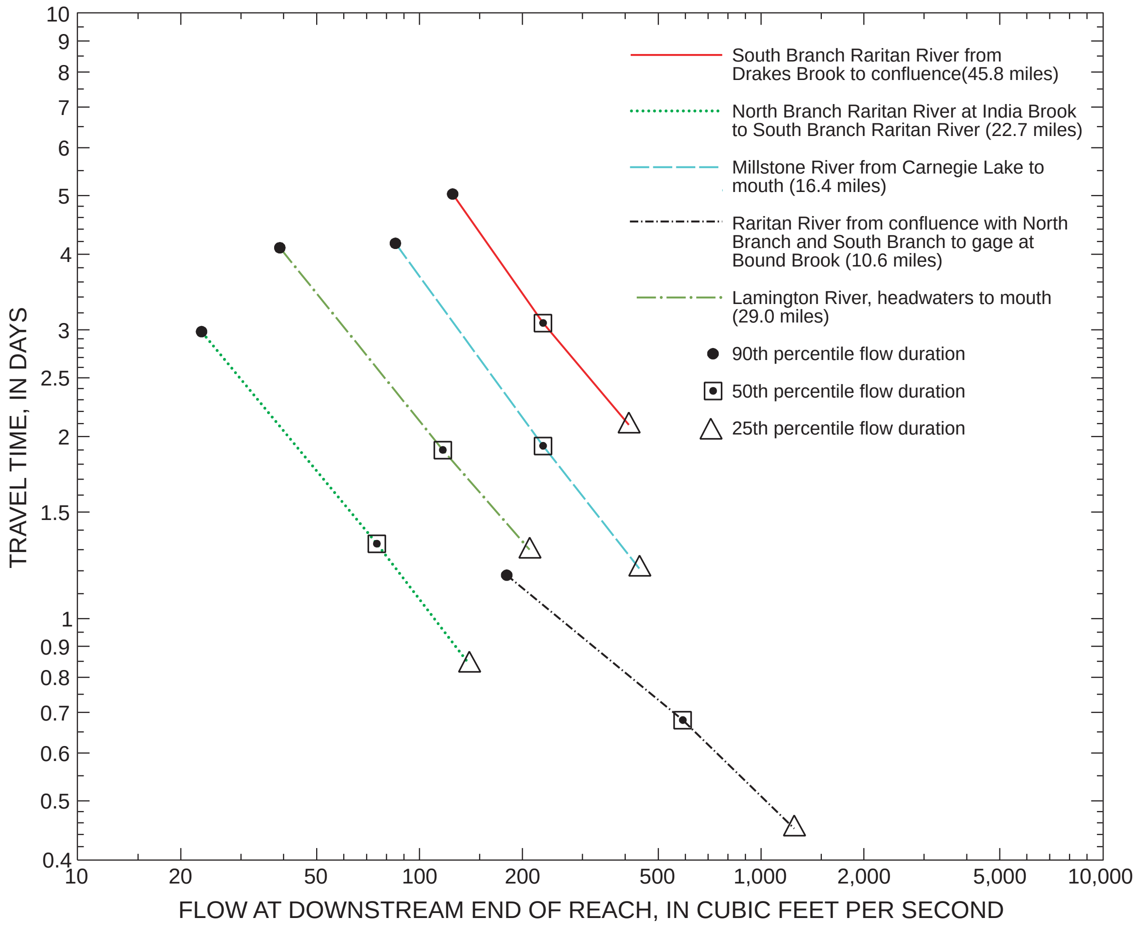

Figure 27. Travel times at 25th, 50th, and 90th percentile flow durations along stream reaches with multiple time-of-travel studies, Raritan River Basin, N.J.

Table 34. Estimates of time of travel at three flow conditions along stream reaches with multiple time-of-travel measurements, Raritan River Basin, N.J.

[Q90, 90th percentile flow duration; Q50, 50th percentile flow duration; Q25, 25th percentile flow duration]

Stream	Reach	Stream reach		Velocity (feet/second)			Time of travel (days)		
		Length (miles)	Slope (feet/ mile)	Q90	Q50	Q25	Q90	Q50	Q25
S.B. Raritan River	Drakes Brook to confluence with N.B. Raritan River	45.8	11.6	0.56	0.91	1.33	5.0	3.1	2.1
N.B. Raritan River	India Brook to confluence with S.B. Raritan River	22.7	2.2	.36	.82	1.27	3.9	1.7	1.1
Millstone River	Carnegie Lake to Raritan River	16.4	1.8	.24	.52	.83	4.2	1.9	1.2
Raritan River	Confluence of N.B. and S.B. Raritan Rivers to 01403300	10.6	2.9	.55	.95	1.44	1.2	.7	.4
Lamington River	Headwaters to confluence with N.B. Raritan River	29.0	22.6	.43	.94	1.35	4.1	1.9	1.3

Time-of-travel studies.--The USGS conducted TOT studies along stream reaches in the Raritan River basin in the 1960’s and 1970’s. Fluorescent Rhodamine dye was used as a water tracer to quantify transport and dispersion along the Drakes Brook, S.B. and N.B. Raritan Rivers, Lamington River, Millstone River, and Raritan River mainstem (Edward Pustay, U.S. Geological Survey, written commun., 1975). Fifty of the 62 stream reaches studied for TOT were studied more than once at two or more flow conditions. Some of the reaches studied, however, are sub-reaches. The lowest flow conditions studied in a reach were typically between the 80th and 50th percentiles, and the highest flow was typically between the 50th and 25th percentiles. Regression equations were developed for reaches with multiple studies to predict velocity at different flow conditions. Ordinary least squares (OLS) regression was performed on the log base-10 transformed discharges and velocities.

Two to four time-of-travel studies were conducted along stream reaches on Drakes Brook, S.B. and N.B. Raritan Rivers, Lamington River, the Raritan River mainstem, and the Millstone River downstream from Carnegie Lake. Stream velocity was estimated at the 90th, 50th, and 25th flow durations along these stream reaches with the OLS regression equations (fig. 27). Average distance-weighted velocities were used between a point source and a sampling site, and between sampling sites when more than one sub-reach along the stream reach had been studied for TOT. If the point source and sampling site were present within one TOT study sub-reach, the velocity computed for the entire TOT study reach was used as the velocity between the point source and the sampling site.

A single time-of-travel study is available for the upper Millstone River, two reaches along Matchaponix Brook, and through Carnegie Lake on the Millstone River. For these reaches, estimates of velocity at the three flow conditions were calculated with a procedure developed by Jobson (2000). The velocity, flow, and average channel width from the TOT study and the slope (S) of the reach are needed to predict velocities at other flow conditions in the reach. The Mannings resistance equation is used as a basis for computing velocity through a stream reach. The Manning equation relates discharge, Q, to measurable quantities as:

$$Q = \frac{1.486}{n} A(A/P)^{0.667} S^{0.5}, \qquad (9)$$

where Q = streamflow,

n = Mannings resistance coefficient,

A = active flow area,

P = wetted perimeter, and

S = slope.

This equation is used to solve for the active flow area of the reach during the TOT study, and another equation is used to estimate channel width during the TOT study, if it is not available. The method developed by Jobson (2000) defines an inactive flow area that does not change as flow changes. The inactive area is computed by subtracting the total area (Q/velocity) from the active area. The width and active area are recomputed for any flow event, and an estimated velocity is calculated by dividing the event flow by the total area (active + inactive area).

Time of travel through lakes.--Round Valley Reservoir, Spruce Run Reservoir, and Budd Lake are the largest water bodies in the study area. No TOT data are available for these lakes. Round Valley and Spruce Run Reservoirs are the only water-supply reservoirs in the study area. Round Valley is a pump-storage reservoir with a maximum capacity of 55.4 Ggal (billion gallons); no streams flow into it. Water is pumped into the reservoir from S.B. Raritan River at Hamden and released to the S.B. Raritan River and Rockaway Creek to supplement releases from Spruce Run Reservoir during periods of low flow. Spruce Run Reservoir is fed by Mulhockaway Creek and Spruce Run. Its maximum capacity is 11.82 Ggal; contents ranged from 4.28 to 11.82 Ggal during 1991-97. Releases from Spruce Run constitute most of the water needed to supplement flow in the S.B. Raritan River for water purveyors downstream. Budd Lake is located at the headwaters of the S.B. Raritan River and is used for recreation. There are no regulated releases for water supply from Budd Lake.

Time of travel through Spruce Run Reservoir is slow enough that the constituent load entering the reservoir from two point sources, discharging a total of 0.044 ft^3/s, will be insignificant by the time the discharge reaches the reservoir outlet. (See "Permitted Surface-Water Sources" for a description of these permitted sources.) The volume of water in the reservoir allows for sufficient dilution of conservative constituents. A combination of the capacity of the reservoir and TOT from point of entry to the outlet of the reservoir makes the point-source-load contribution insignificant to the total load that leaves the reservoir. The assumption that a small point-source load entering a large lake will be insignificant at the outlet also is made for the 0.0003 ft^3/s and the small load discharged from a permitted source to an unnamed tributary entering Budd Lake. Carnegie Lake, Lake Solitude, and Ravine Lake (fig. 1) are located along the Millstone, S.B. Raritan, and N.B. Raritan Rivers, respectively. A single TOT study was done through Carnegie Lake, and two TOT studies were done at two different flow conditions through Lake Solitude. No TOT data are available for Ravine Lake (Edward Pustay, U.S. Geological Survey, written commun., 1975).

Three small permitted facilities discharge to streams that drain into large impoundments. The Hagadorn Center for Geriatrics (NJ0022144) discharged 0.04 ft^3/s to Spruce Run, and Union Township Elementary School (NJ0024091) discharged 0.004 ft^3/s to Mulhockaway Creek during the study period. Both of these streams drain into Spruce Run Reservoir. One small permitted point source, Gold Mine Estates Water System (NJ0063002), discharges 0.0003 ft^3/s to an unnamed tributary that drains into Budd Lake.

Carnegie Lake from its upstream end on the Millstone River to the dam is 2.2 miles long with an approximate average width of more than 600 feet. Results of the single study of TOT through Lake Carnegie indicated that the average velocity was 0.04 ft/s at approximately the 60th percentile flow. The velocity through Carnegie Lake was not included in the regression analysis because it is much lower than the velocities in the stream reaches. The prediction of velocity from the regression equation was an order of magnitude higher (0.4 in contrast to 0.04) than the actual velocity measured. The 0.04 ft/s velocity was used to compute TOT through Carnegie Lake at both the 50th and 90th percentile flow conditions. A velocity of 0.07 ft/s was computed for the 25th percentile flow from the method described in Jobson (2000).

Lake Solitude, located downstream from the S.B. Raritan River at High Bridge site, is 0.5 miles long and has an average width of approximately 200 feet. Two TOT studies were conducted at approximately the 60th and 40th percentile flows. OLS regression was used to estimate velocities through the lake at the 90th, 50th, and 25th percentile flows. Average velocities ranged from 0.08 ft/s at 90th percentile flow to 0.45 ft/s at 25th percentile flow.

Ravine Lake is 1.04 mi long and approximately 300 ft wide. No TOT data are available for this reach through the lake. Estimates of velocity were based on studies of TOT through Lake Solitude. The drainage area and flow through Ravine Lake is one-third that of Lake Solitude. Velocities were estimated to be 0.04, 0.10, and 0.2 ft/s at 90th, 50th, and 25th percentile flows, respectively.

Adjustments for Attenuation Rates

For most of the constituents studied, the load discharged to a stream from a permitted point source is attenuated as the effluent travels downstream. Chloride and TDS do not attenuate. Loads were evaluated and found to behave conservatively in this basin. Loads of chloride and TDS were found to increase as flow moved to sampling sites farther downstream in the basin. The other six constituents studied-- BOD, NO3+NO2, TKN, TOC, total phosphorus, and TSS--attenuate as a result of biological, chemical, and physical processes in the stream. The reduction of constituent loads between point sources and surface-water sampling sites is a function of time of travel and the average attenuation rate through the stream reach.

No attenuation rates for TOC were available from the study by TRC Omni Environmental Corporation (2001) or from a literature review by Omni. Particulate organic carbon rates from a literature review ranged by 2 orders of magnitude from 0.001/d to 0.1/ day (TRC Omni Environmental Corporation, 2001). TOC was considered conservative for this study.

Attenuation rates for BOD, NO3+NO2, TKN, total phosphorus, and TSS are used in this study. First order attenuation rate coefficients were established from the results of modeling studies completed by Omni. Omni provided average first order decay rates for all stream reaches studied (TRC Omni Environmental Corporation, 2001). The attenuation rate coefficients were spatially averaged, then applied to long stream reaches. The attenuation rates usually vary along each reach and these average rates cannot be used appropriately for short distances (less than 10 mi) along the reach. One of the goals of this project was to evaluate the effects of load from permitted sources on total instream load at specific surface-water sampling sites. The average attentuation rates for long stream reaches are appropriate for this type of study.

Attenuation rates for both growing and nongrowing seasons were evaluated in this study. For the growing season, an attenuation rate calculated at 20 ^{o}C was used for the primary calculation and analysis of permitted loads. The results of the load analysis in this report are for the growing season, unless stated otherwise. A nongrowing season attenuation rate calculated at 5 ^{o}C also was applied to some permitted loads for comparative purposes (table 35). No attenuation rate was applied to loads of TDS and TOC from permitted sources. The rate for TSS does not vary with changes in water temperature (TRC Omni Environmental Corporation, 2001); therefore, the loads from permitted sources are identical in the growing and nongrowing seasons.

Table 35. Percentage increase in attenuated permitted point-source load from growing season to nongrowing season at three flow conditions, Raritan River Basin, N.J., 1991-97 water years

[90th is low flow, 50th is median flow, 25th is high flow; TDS and TOC are not attenuated; TSS attenuation does not vary with season; NA, no permitted sources upstream from the sampling site. Values are in percent.]

Station number	Total ammonia plus organic nitrogen			Biochemical oxygen demand			Nitrate plus nitrite			Total phosphorus		
	90th	50th	25th	90th	50th	25th	90th	50th	25th	90th	50th	25th
01396280	19.4	12.1	8.4	30.1	19.8	14.5	17.2	11.0	7.9	21.2	14.5	10.8
01396535	45.4	30.4	22.0	73.6	55.2	42.7	43.9	29.5	21.5	50.0	34.8	26.1
01396588	2.0	.9	.5	.9	.4	.2	.7	.3	.2	1.6	.7	.4
01396660	5.8	2.5	1.7	7.6	3.3	2.3	5.8	2.5	1.7	13.0	5.8	4.0
01397000	22.4	17.0	13.0	37.7	34.9	30.5	16.6	13.6	10.9	41.2	31.9	25.1
01397400	17.2	12.5	9.5	17.9	16.6	15.4	13.1	10.6	8.4	16.4	12.1	9.3
01398000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01398260	7.5	3.7	2.4	4.2	2.1	1.3	3.4	1.7	1.1	6.7	3.3	2.1
01399120	17.1	8.7	5.7	39.5	20.8	13.6	34.1	19.5	13.2	32.0	18.8	12.7
01399500	48.1	27.4	20.3	78.4	53.5	41.9	47.8	27.2	20.1	54.4	31.9	23.8
01399700	4.1	2.0	1.0	9.8	5.0	2.5	.3	.2	.1	9.8	5.0	2.5
01399780	39.1	24.9	18.2	57.8	47.4	38.4	58.2	36.1	27.0	46.2	30.5	22.4
01400500	49.5	35.6	26.2	79.7	63.5	50.3	41.6	30.9	23.3	58.3	42.3	31.5
01400540	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01400650	12.3	9.3	6.7	6.9	5.1	3.6	4.1	3.1	2.1	5.2	3.9	2.8
01401000	56.9	16.9	8.4	64.5	21.6	11.1	83.6	37.7	20.4	95.1	48.3	26.8
01401600	50.4	12.6	5.9	32.2	7.2	3.3	33.0	9.0	4.4	46.4	11.3	5.2
01402000	28.0	19.2	21.5	50.8	33.3	25.7	15.5	10.8	7.3	72.6	52.0	36.8
01403300	19.9	17.9	15.7	19.0	21.2	19.4	24.6	16.2	11.4	29.4	26.4	22.5
01405302	43.7	29.7	15.2	25.3	16.2	7.8	22.0	13.8	6.7	59.7	42.2	22.5
01405340	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Attenuation rates for BOD generally were lower on smaller streams than on larger streams in the basin. The average first order decay rate for BOD at 20 ^{o}C ranged from 0.4 per day in samples from tributaries to the S.B. Raritan River to 1.5 per day along the mainstem of the S.B. Raritan, N.B. Raritan, and Lamington Rivers. Growing season attenuation rates for NO3+NO2 ranged from 0.1 per day along parts of the S.B. Raritan, N.B. Raritan, and Millstone Rivers to 1.0 per day on small tributaries to these rivers. Growing season attenuation rates for TKN ranged from 0.0 per day along the downstream part of the N.B. Raritan River to 1.0 per day on the Millstone River, 1.1 per day on the mainstem Raritan River, and 1.2 per day on Cranbury Brook tributary to the Millstone River. Growing season attenuation rates for total phosphorus ranged from 0.1 per day along the N.B. Raritan River to 1.6 per day on Cranbury Brook and 1.5 per day on the Millstone River downstream from Carnegie Lake and on tributaries to the S.B. Raritan River. Growing season attenuation rates for TSS were 0.0 per day along the S.B. Raritan River, the Millstone River downstream from Carnegie Lake, and selected tributaries to the S.B. Raritan, N.B. Raritan, and Millstone Rivers. The attenuation rate was as high as 2.1 per day on Pike Run, a tributary to the Millstone River in the growing season.

Attenuation rates were lower in the nongrowing season than in the growing season. A water temperature of 20 ^{o}C was used for the growing season. The following equation was used to adjust the attenuation rates received from Omni for a change in water temperature.

$$K_t = K_{20} \; C^{(T-20)}, \qquad (10)$$

where

K_t = attenuation rate coefficient, at water temperature T;

K_{20} = attenuation rate coefficient, at 20 degrees Celsius;

T = water temperature, in degrees Celsius; and

C = temperature correction coefficient (1.0 for TSS, 1.05 for other constituents).

Attenuation rates at 5 ^{o}C were approximately 50 percent lower than rates at 20 ^{o}C for BOD, NO3+NO2, TKN, and total phosphorus. At 5 ^{o}C, the attenuation rate for BOD ranged from 0.2 to 0.7 per day. The attenuation rates for NO3+NO2, TKN, and total phosphorus ranged from 0.05 to 0.77, 0 to 0.58, and 0.05 to 0.77 per day, respectively. The attenuation rates for TSS were the same at 5 ^{o}C as at 20 ^{o}C when the recommended temperature correction coefficient of 1.0 was used.

Loads and Yields from Permitted Sources

Attenuated permitted yields computed at each flow condition at the sampling sites and the percentage of total instream yield that originated from permitted sources in the growing season are summarized in this section. For each constituent, the summary focuses on the effects of permitted yields on total instream yield at the seven sites with the highest total instream yields and at the seven sites with the highest permitted yields. Loads and yields of selected constituents from permitted sources are summarized for each of the three flow conditions in tables 25-32.

Permitted yields account for a higher percentage of total instream yields at low flow than at high flow for all constituents. The proportions of permitted and nonpermitted yield of NO3+NO2 shown in figure 28 are similar to those for the other constituents. The permitted yield of nonconservative constituents is higher at high flow than at low flow at each of the sampling sites. This is caused by higher velocities at high flow, leading to a shorter travel time from the point of discharge to the sampling site and, therefore, less time for attenuation to occur. Nonpermitted yields of all constituents increased at a faster rate than permitted yields as flows increased from low to high.

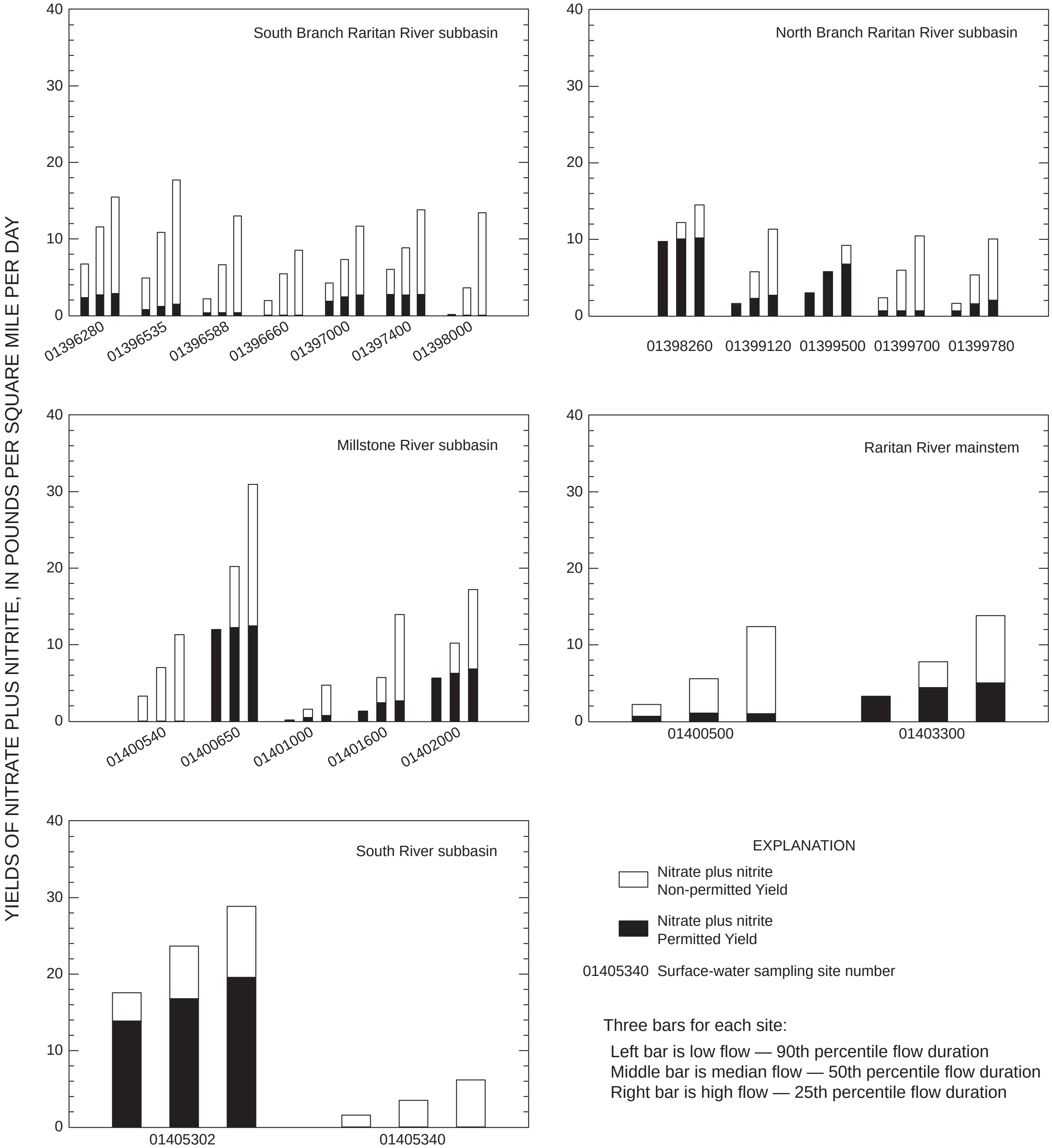

Figure 28. Permitted and nonpermitted components of nitrate plus nitrite yield at low-, median-, and high-flow conditions, Raritan River Basin, N.J., 1991-97.

Ammonia Plus Organic Nitrogen, Total

Yield of TKN from permitted sources at the seven sites with the highest permitted yield and at the sites with the highest total instream yields are discussed in this section. Less than 25 percent of the TKN yields at median and high flows at the seven sites with highest permitted yields were from nonpermitted sources. At low flow, however, from 17 to 48 percent of the total instream yield of TKN at the seven sites was from permitted sources. The seven sites with the highest total instream yields are not the same as the seven sites with the highest attenuated permitted yields (table 25). The highest attenuated permitted TKN yields were in samples from N.B. Raritan River near Chester, Rockaway Creek, and Millstone River at Grovers Mill.

Attenuated permitted source loads accounted for more than 80 percent of total instream TKN load at low flow at the N.B. Raritan River sites and at the Rockaway Creek and Raritan River at Bound Brook sites (table 25). At median flows, attenuated permitted loads accounted for more than 50 percent of total instream load at N.B. Raritan River near Chester and Rockaway Creek. At high flows, the highest percentage of total instream load from attenuated permitted sources (45 percent) was at N.B. Raritan River near Chester.

At low flows, the sites with the highest total instream yields were the Millstone River sites at Grovers Mill and Blackwells Mill; the S.B. Raritan River sites at Three Bridges, Stanton, and Middle Valley; Lamington River at Pottersville; and Raritan River at Manville (table 25). The attenuated permitted yields at these sites ranged from 0.2 to 0.7 (lb/d)/mi^2. The Millstone River sites and S.B. Raritan River at Middle Valley site had the highest percentage of total instream yield that originated from permitted sources (44-48 percent). The attenuated permitted yields at the other sites ranged from 17 to 33 percent of total instream yield. At low-flow conditions, more than 33 percent of the total instream yield originated from permitted sources at 10 of the 21 sites studied. The Millstone River sites at Grovers Mill and Blackwells Mill, and S.B. Raritan River at Three Bridges were among the seven sites with the highest permitted TKN yields at each flow condition. At median and high flows, the Raritan River at Bound Brook also was among the seven sites with the highest permitted TKN yields.

At median flows, the seven sites with the highest total instream yields were the same as at low flow, except the Raritan River at Bound Brook replaced the Raritan River at Manville. The attenuated permitted yields at these sites ranged from 0.3 to 0.7 (lb/d)/mi^2 or 15 to 23 percent of total instream yields at median flow. The highest attenuated permitted yield at median flow was at N.B. Raritan River near Chester (1.2 (lb/d)/mi^2), a site not among those with the highest total instream yield. More than 33 percent of the total instream yield originated from permitted sources at 4 of the 21 sites studied.

At high flow, Matchaponix Brook replaced S.B. Raritan River at Middle Valley as one of the seven sites with the highest yields. The attenuated permitted yields at these sites ranged from 0.3 to 0.8 lb/d/mi^2 at high flow or 9 to 18 percent of total instream yields at high flow (table 25). The highest attenuated permitted yield at high flow was at N.B. Raritan River near Chester (1.3 (lb/d)/mi^2), a site not among those with the highest total instream yield. At high flow, more than 33 percent of the total instream yield originated from permitted sources at 2 of the 21 sites studied.

Biochemical Oxygen Demand

Yields of BOD from permitted sources at the sites with the highest total instream yields and at the seven sites with the highest attenuated permitted yields are discussed in this section. Most of the yield at these sites was from nonpermitted sources; however, yield from permitted sources at two sites at low-flow conditions accounted for 59 to 60 percent of total instream yield. Ninety percent or more of instream yield at median- and high-flow conditions originated from nonpermitted sources at each of the seven sites with highest total instream yields. The seven sites with the highest total instream yields are not the same as the seven sites with the highest attenuated permitted yields (table 26). The attenuated permitted yields of BOD at N.B. Raritan River near Chester, Matchaponix Brook, and Rockaway Creek were the highest in the study area**.**

At low flows, the sites with the highest total instream yield of BOD were the S.B. Raritan River sites at Stanton, Three Bridges, Middle Valley, and High Bridge; Raritan River at Manville; and N.B. Raritan River at Chester and Rockaway Creek (table 26). The attenuated permitted yields at these sites ranged from 0.03 lb/d/mi^2 at Raritan River at Manville to 2.21 lb/d/mi^2 at N.B. Raritan River at Chester or 0.7 to 59 percent of total instream yield. The attenuated permitted yield recorded at N.B. Raritan River at Chester (2.21 lb/d/mi^2) was the highest observed at low flow. At low flow, Matchaponix Brook (1.25 lb/d/mi^2), Millstone River at Grovers Mill (0.88 lb/d/mi^2), and Raritan River at Bound Brook (0.66 lb/d/mi^2) were among the seven sites with the highest attenuated permitted yield but were not among those sites with the highest total instream yield. At low flow, more than 33 percent of the total instream yield originated from permitted sources at 10 of the 21 sites studied, and more than 50 percent of the total instream load measured for sites at N.B. Raritan River near Chester and Matchaponix Brook originated from permitted sources.

At median flow, the seven sites with the highest BOD yields were the four S.B. Raritan River sites, the two Lamington River sites, and the Millstone River at Grovers Mill site. The attenuated permitted yields at these sites ranged from 0.11 to 0.91 lb/d/mi^2 or 1 to 10 percent of total instream yields at median flow. The highest attenuated permitted yield at median flow was at N.B. Raritan River near Chester (2.3 lb/d/mi^2), a site not among those with the highest total instream yield. At median flow, more than 30 percent of the total instream yield originated from permitted sources at 2 of the 21 sites studied, N.B. Raritan River near Chester and Matchaponix Brook.

At high flow, Stony Brook replaced Lamington River at Burnt Mills as one of the seven sites with the highest yields of BOD. The attenuated permitted yields of BOD at these sites ranged from 0.18 to 0.94 lb/d/mi^2 or 1.0 to 6.0 percent of total instream yields at high flow (table 26). The highest attenuated permitted yield at high flow was at N.B. Raritan River near Chester (2.3 lb/d/mi^2), a site not among those with the highest total instream yield. The Millstone River at Grovers Mill site had the highest attenuated permitted yield in the study area. At high flow, less than 22 percent of the total instream yield of BOD originated from permitted sources at all 21 sites studied.

Chloride

Values for total instream loads and yields of chloride are presented in table 27. Permitted and nonpermitted chloride load and yield could not be determined because no permitted point-source data for chloride were available. Chloride and TDS are both conservative constituents, and there is a relation between concentrations of these constituents (Hem, 1985). The following section on TDS may offer insights on the behavior of chloride at specific surface-water sampling sites. Total instream loads and yields of chloride are discussed in the section “Total Loads and Yields by Constituent.”

Dissolved Solids, Total

TDS is a conservative constituent; therefore, the permitted yield remains the same at each flow condition. TDS yields from permitted sources at the sites with the highest permitted yield and at the seven sites with the highest total instream yields are discussed in this section. The attenuation rate used for TDS load and yield from permitted sources was zero. At median and high flows less than one-third of the yields were from permitted sources at six of the seven sites with highest total instream yields. One-half of the yield at Matchaponix Brook at median flow was from permitted sources. More than 60 percent of instream yield at low-flow conditions was from permitted sources at three sites. Less than 20 percent of the total instream yield at the other four sites was from permitted sources. The seven sites with the highest total instream yields are not the same sites as those with the highest attenuated permitted yields (table 28). The permitted yields at Matchaponix Brook (440 lb/d/mi^2), Lamington River at Pottersville (306 lb/d/mi^2), and N.B. Raritan River near Chester (234 lb/d/mi^2) were the highest permitted TDS yields in the study area**.**

At low flow, the sites with the highest total instream yields of TDS were the S.B. Raritan River sites at Three Bridges, Middle Valley, Stanton, and High Bridge; N.B. Raritan River near Chester; Lamington River at Pottersville; and Matchaponix Brook (table 28). More than 60 percent of total instream yields at Matchaponix Brook, Lamington River at Pottersville, and N.B. Raritan River near Chester were from permitted sources. The permitted yields at the other sites ranged from 6 to 17 percent of total instream yield. Permitted yields at these sites ranged from 440 lb/d/mi^2 at Matchaponix Brook, the highest in the study area, to 31.5 lb/d/mi^2 at S.B. Raritan River at Stanton. At low flow, more than 50 percent of the total instream yield originated from permitted sources at 8 of the 21 sites studied.

At median flow, the seven sites with the highest TDS yields were the three S.B. Raritan River sites at Three Bridges, Middle Valley, and High Bridge; the two N.B. Raritan River sites; Lamington River at Potterville; and Matchaponix Brook. Permitted sources contributed 50 percent of total instream yield at Matchaponix Brook, 30 percent at Lamington River at Pottersville, 20 percent at N.B. Raritan River near Chester, and less than 10 percent at the other sites. Attenuated permitted yields at these sites ranged from 57.2 to 440 lb/d/mi^2. At median flow, more than 33 percent of the total instream yield originated from permitted sources at 2 of the 21 sites studied.

The sites with the highest yields at high flow were the four S.B. Raritan River sites, the two N.B. Raritan River sites, and Lamington River at Pottersville. Contributions to total instream yield from permitted sources ranged from 2 percent at S.B. Raritan River at Stanton to 20 percent at Lamington River at Pottersville. Permitted yields at these sites ranged from 31.5 to 306 lb/d/mi^2. At high flow, less than 20 percent of the total instream yield originated from permitted sources at 20 of the sites studied; at Matchaponix Brook, 53 percent originated from permitted sources. The seven sites with the highest attenuated permitted yield were Matchaponix Brook (440 lb/d/mi^2), Lamington River at Pottersville (306 lb/d/mi^2), N.B. Raritan River near Chester (234 lb/d/mi^2), Millstone River at Blackwells Mill (201 lb/d/mi^2), Millstone River at Grovers Mill (158 lb/d/mi^2), Raritan River at Bound Brook (132 lb/d/mi^2), and Lamington River at Burnt Mills (131 lb/d/mi^2).

Nitrate Plus Nitrite

This section summarizes the percentage of NO3+NO2 yields from permitted sources at the sites with the highest attenuated permitted yield and at the seven sites with the highest total instream yields. Most of the yield of NO3+NO2 at low and median flows was from permitted sources at four of the seven sites. At high flow, most of the yield at two sites was from permitted sources. The attenuated permitted yields at low and median flow were the highest in the study area at six of the seven sites. The attenuated permitted yields at high flow were the highest in the study area at five of the seven sites. The seven sites with the highest total instream yields were not all the same as those with the highest attenuated permitted yields (table 29). The yields at Matchaponix Brook, Millstone River at Grovers Mill, and N.B. Raritan River near Chester were the highest attenuated permitted NO3+NO2 yields in the study area (fig. 28)**.**

At low flow, the sites with the highest total instream yields were Matchaponix Brook, the Millstone River sites at Grovers Mill and Blackwells Mill, N.B. Raritan River near Chester, and the S.B. Raritan River sites at Middle Valley, Three Bridges and High Bridge (table 29). Attenuated permitted yields at these sites ranged from 0.8 lb/d/mi^2 at S.B. Raritan River at High Bridge to 13.9 lb/d/mi^2 at Matchaponix Brook, the highest in the study area. At low-flow conditions, more than 75 percent of the total instream yield originated from permitted sources at 8 of the 21 sites studied, including 4 of the 7 with highest total instream yield--N.B. Raritan River near Chester, the Millstone River sites at Grovers Mill and Blackwells Mill, and Matchaponix Brook. The attenuated permitted yields of NO3+NO2 at the other three sites ranged from 15 to 34 percent of total instream yield. All seven sites with highest total instream yields, except S.B. Raritan River at High Bridge, were the same as those with the highest permitted NO3+NO2 yields at low- and median-flow conditions (table 29). At low flow, more than 50 percent of the total instream yield originated from permitted sources at 9 of the 21 sites studied (fig. 28).

At median flow, the seven sites with the highest total instream yields were the same as those with the highest total instream yields at low flow. Attenuated permitted yields at these sites ranged from 1.2 lb/d/mi^2 at S.B. Raritan River at High Bridge to 16.8 lb/d/mi^2 at Matchaponix Brook, the highest yield in the study area. At the same four sites, most of the total instream yield originated from permitted sources (57 to 82 percent) at low and median flows. Attenuated permitted yields accounted for 10 to 24 percent of total instream yield at median flow at the three S.B. Raritan River sites. At median flow, more than 50 percent of the total instream yield originated from permitted sources at 6 of the 21 sites studied.

The seven sites with the highest total instream yields at high flow are the same as those at median flow, except Beden Brook replaces S.B. Raritan River at Three Bridges as one of the seven sites with the highest instream yields. Attenuated permitted yields at these sites ranged from 1.4 lb/d/mi^2 at S.B. Raritan River at High Bridge to 19.6 lb/d/mi^2 at Matchaponix Brook, the highest in the study area. Instream yield from permitted sources accounted for 70 percent of total instream yield at N.B. Raritan River near Chester and at Matchaponix Brook. Total instream yield from permitted sources at the other five sites ranged from 8 percent at S.B. Raritan River at High Bridge to 37 percent at Millstone River at Grover Mill. All sites among those with the highest total instream yields at median flow, except S.B. Raritan River at High Bridge and Beden Brook, are among the seven sites with the highest permitted NO3+NO2 yields at high flow. At high flow, more than 30 percent of the total instream yield originated from permitted sources at 6 of the 21 sites studied; yields at N.B. Raritan River near Chester, Lamington River near Pottersville, and Matchaponix Brook exceeded 60 percent.

Organic Carbon, Total

TOC was assumed to be a conservative constituent; therefore, the attenuated permitted yield remained the same at each flow condition. The amount of TOC yield from permitted sources at the sites with the highest attenuated permitted yield and at the seven sites with the highest total instream yields is discussed in this section. No sampling site studied received more than 33 percent of total instream yields from permitted point sources. The total instream yields at all sites were received mainly from nonpermitted sources. More than 80 percent of total instream yield at low-flow conditions came from nonpermitted sources at each of the seven sites with highest total instream yields. At median and high flows, from 93 to 99.7 percent of instream load came from nonpermitted sources at the seven sites with highest total instream yields. The seven sites with the highest total instream yields are not the same sites as those with the highest attenuated permitted yields (table 30). The attenuated permitted yields at N.B. Raritan River near Chester (2.4 lb/d/mi^2), Lamington River near Pottersville (2.0 lb/d/mi^2), and Lamington River at Burnt Mills (1.5 lb/d/mi^2) were the highest permitted TOC yields in the study area.

At low flow, the sites with the highest yields were Lamington River at Pottersville; Millstone River at Grovers Mill; Raritan River at Manville; and the S.B. Raritan River sites at Stanton, Three Bridges, Middle Valley, and High Bridge (table 30). Attenuated permitted yields at Lamington River at Pottersville and Millstone River at Grovers Mill accounted for 14 to 17 percent of total instream yields. The attenuated permitted yields at the other five sites ranged from 4 to 9 percent of total instream yield. At low flow, only the attenuated permitted yields at Lamington River at Pottersville and Millstone River at Grovers Mill were among the seven highest permitted TOC yields in the study area (table 30). At low flow, more than 30 percent of the total instream yield originated from permitted sources at 2 of the 21 sites studied--Raritan River at Bound Brook and N.B. Raritan River at Burnt Mills.

Five of seven sites with the highest total instream yields at median flow were the same as those with the highest yields at low flow; Millstone River at Blackwells Mill replaced the S.B. Raritan River at Stanton and Lamington River at Burnt Mills replaced Raritan River at Manville. The percentage of total instream yield that originated from permitted sources was lower at median flow than at low flow. Permitted sources of instream yields ranged from 2.5 to 6 percent of the total instream yield. At median and high flows, the attenuated permitted yields at the Millstone River sites at Grovers Mill and Blackwells Mill, the Lamington River sites at Pottersville and Burnt Mills near Pottersville, and Raritan River at Bound Brook were among the highest in the study area. At median flow, less than 13 percent of the total instream yield originated from permitted sources at all sites studied, except Millstone River at Grovers Mill (27 percent).

At high flow, the sites with the highest yields were the S.B. Raritan River sites at Middle Valley and High Bridge, the Lamington River sites at Pottersville and Burnt Mills, the Millstone River sites at Grovers Mill and Blackwells Mills, and Raritan River at Bound Brook. Total instream yield from permitted sources ranged from 0.3 to 3.8 percent at high flow at these sites. At high flow, less than 8 percent of the total instream yield originated from permitted sources at all 21 sites studied.

Phosphorus, Total

Yields of attenuated total phosphorus from permitted sources at the sites with the highest attenuated permitted yield and at the sites with the highest total instream yields are discussed in this section. At low flow, more than 60 percent of the total instream yield was from permitted sources at seven of the nine sites with highest total instream yields. At median flow, more than one-half of the total instream yield originated from permitted sources at four of eight sites with highest total instream yields. At high flow, from 24 to 47 percent of the total instream yield originated from permitted sources at the seven sites with the highest total instream yields. The seven sites with the highest total instream yields are not all the same as those with the highest attenuated permitted yields (table 31). The sampling sites at Rockaway Creek, Raritan River at Bound Brook, Millstone River at Grovers Mill, and S.B. Raritan River at Three Bridges had the highest permitted total phosphorus yields in the study area.

At low flow, the nine sites with the highest total instream yields of total phosphorus were the S.B. Raritan River sites at Middle Valley and Three Bridges, the Millstone River sites at Grover Mill and Blackwells Mill, the Raritan River sites at Manville and Bound Brook, the N.B. Raritan River near Chester site, and the Lamington River near Pottersville and Rockaway Creek sites (table 31). Attenuated permitted yields at these sites ranged from 0.2 to 0.4 lb/d/mi^2 and accounted for greater than 50 percent of total instream yields at seven of the nine sites. The attenuated permitted yield at Raritan River at Manville was 23 percent of total instream yield and at Millstone River at Blackwells Mill, 10 percent of total instream yield. Seven of the nine sites with highest total instream yields had the highest permitted total phosphorus yields at low flow; the exceptions were Raritan River at Manville and Millstone River at Blackwells Mill (table 31). At low flow, more than 50 percent of the total instream yield originated from permitted sources at 10 of the 21 sites studied; 7 of the10 sites had approximately 100 percent attenuated permitted yield.

At median flow, the sites with the highest total instream yields were S.B. Raritan River at Middle Valley and Three Bridges; Millstone River at Grovers Mill, Blackwells Mill, and Manalapan; Raritan River at Bound Brook; Lamington River at Burnt Mills; and N.B. Raritan River near Chester, and at low flow, the sites with the highest total instream yields were Millstone River at Blackwells Mill, S.B. Raritan River at Three Bridges, Raritan River at Bound Brook, and Millstone River at

Grovers Mill. Attenuated permitted yields at median flow at these eight sites ranged from 0.3 to 0.4 lb/d/mi^2 and accounted for greater than 50 percent of total instream yield at S.B. Raritan River sites at Middle Valley and Three Bridges, Rockaway Creek, and Lamington River at Burnt Mills. Attenuated permitted yields at the other four sites ranged from 0 to 46 percent of the total instream yield. Attenuated permitted yields at the S.B. Raritan River at Three Bridges, Rockaway Creek, Millstone River at Grovers Mill, and Raritan River at Bound Brook were among the highest in the study area. At median flow, more than 50 percent of the total instream yield originated from permitted sources at 7 of the 21 sites studied.

At high flow, the seven sites with the highest yields were the Millstone River sites at Manalapan, Grovers Mill, and Blackwells Mills; Raritan River at Bound Brook; S.B. Raritan River site at Three Bridges; Lamington River at Burnt Mills; and Beden Brook. Total instream yield from permitted sources ranged from 24 to 47 percent at these sites. The highest permitted total phosphorus yields in the study area were at Raritan River at Bound Brook, Rockaway Creek, Lamington River at Pottersville, and S.B. Raritan River at Three Bridges. At high flow, more than 50 percent of the total instream yield originated from permitted sources at 4 of the 21 sites studied--Matchaponix Brook, Rockaway Creek, N.B. Raritan River near Chester, and Lamington River at Pottersville.

Total Suspended Solids

Yields of TSS from permitted sources at the sites with the highest attenuated permitted yields and at the seven sites with the highest total instream yields are discussed in this section. Attenuated permitted yields of TSS generally account for a small percentage of total instream yield at all of the sampling sites. The seven sites with the highest total instream yields are not all the same as those with the highest attenuated permitted yields (table 32). The sites at Lamington River near Pottersville, N.B. Raritan River near Chester, Rockaway Creek, and Millstone River at Grovers Mill had the highest attenuated permitted TSS yields in the study area.

At low flow, permitted sources were not a major contributor to instream TSS yields at the seven sites with the highest total instream yields. The seven sites with the highest total instream yields were the S.B. Raritan River sites at High Bridge and Three Bridges; the Millstone River sites at Grovers Mill, Blackwells Mill, and Manalapan; Manalapan Brook; and Raritan River at Manville (table 32). At low-flow conditions, 0 to 8 percent of total instream yield originated from permitted sources at these sites. Millstone River at Grovers Mill was the only site among the seven sites with highest total instream yields that was also among the seven sites with the highest attenuated permitted yield.

Permitted sources of TSS yield are major contributors to total instream TSS yields at low flow at one site. At the seven sites with the highest amounts of attenuated permitted yield, total instream yield ranged from 8 to 100 percent. Essentially all total instream TSS yield originated from permitted sources at N.B. Raritan River near Chester. The site with the second highest percentage of total instream yield from permitted sources is Matchaponix Brook with 28 percent.

Permitted sources are not major contributors to TSS yields at median- and high-flow conditions. Only 0 to 5 percent of total instream yield originated from permitted sources at the seven sites with the highest total instream yields. The eight sites with the highest total instream yields at median flow were the same as those with highest yields at low flow, except S.B. Raritan River at Three Bridges, Lamington River near Pottersville, and Raritan River at Manville replaced Lamington River at Burnt Mills, Raritan River at Bound Brook, and S.B. Raritan River at Middle Valley.

At high flow, the sites with the highest total instream yields were the Millstone River sites at Grovers Mill and Blackwells Mills, Raritan River at Bound Brook, S.B. Raritan River sites at Middle Valley and Three Bridges, Lamington River at Burnt Mills, and Beden Brook. Total instream yield from permitted sources at these sites ranged from 0 to 2.4 percent of total instream yield at high flows.

EVALUATION OF LOADS AND YIELDS FROM NONPERMITTED SOURCES

Nonpermitted load is defined as the part of instream load not attributable to permitted point sources. Nonpermitted loads were computed at three flow conditions by subtracting either attenuated or non-attenuated permitted load, depending on constituent, from the total instream load at the sampling sites.

Estimates of nonpermitted yields were computed from nonpermitted loads. Nonpermitted yields were used to compare stream quality between sites and to investigate the relation of basin characteristics to stream quality. Nonpermitted chloride load could not be estimated because chloride data from permitted sources were not available and could not be accurately estimated (James Cosgrove, TRC Omni Environmental Corporation, written commun., 2001).

Nonpermitted loads were normalized by drainage area to compute nonpermitted yield. Nonpermitted yields were used in this analysis because they allow for direct comparison between sites. This method of comparison does not eliminate all the differences in loads between sites caused by differences in drainage-area size because the flow per unit area varies across the study area. Flow per unit area is highest in streams in the New England province and lowest in streams in the Piedmont province. A separate analysis of nonpermitted yields in each physiographic province was not possible because of the limited number of sampling sites. Nonpermitted loads at the confluence of the Millstone and Raritan Rivers were estimated by applying the observed nonpermitted load per square mile at the sampling sites to the intervening area.

The nonpermitted yields discussed in this report were estimated for growing-season conditions by use of attenuation rates at 20 ^{o}C, unless otherwise stated. Nonpermitted yields of BOD, NO3+NO2, TKN, and total phosphorus calculated for the growing season account for a higher percentage of total instream yield than the nonpermitted yields calculated for the nongrowing season. The attenuation rates applied to the permitted yield in the nongrowing season were approximately one-half the rates used for the growing season. Nonpermitted yields of TDS, TOC, and TSS do not vary with changes in water temperature. A summary of the percentage increases in permitted yields from the growing season to the nongrowing season at low, median, and high flows is presented in table 35.

In the nongrowing season, attenuated permitted yields account for a higher percentage of the total instream yield for TKN, BOD, NO3+NO2, and total phosphorus because of changes in attenuation rates. The percentage increase was greatest at low flow when the travel time was longest (table 35). The percentage difference in attenuated permitted yield from growing season to nongrowing season also varied by site on the basis of the travel time of effluent from the discharge point to the sampling site. At low flow, attenuated permitted yields of TKN, BOD, NO3+NO2, and total phosphorus in the nongrowing season were as much as 56, 80, 84, and 95 percent greater, respectively, at some sites than in the growing season.

The estimates of nonpermitted loads at some sites with high percentages of permitted sources were biased low. Estimates of nonpermitted loads at some sites at low-flow conditions were estimated to be approximately zero. This typically happens at sampling sites near a permitted source. The permitted source can be the dominant contributor to instream load at these sites at low flow. The cumulative uncertainty involved in estimating time of travel, attenuation rates, streamflows and total instream load at a particular flow condition from the regression equation relating load to streamflow can lead to obvious underestimates in nonpermitted load and, perhaps, less obvious overestimates. Estimated nonpermitted loads at sites with more than 50 percent of total instream load originating from permitted sources were not included in the regression analysis of loads in relation to basin characteristics.

Nonpermitted Loads and Yields by Constituent

Ammonia Plus Organic Nitrogen, Total

Estimates of nonpermitted yields of TKN at the N.B. Raritan River, Rockaway Creek, and Raritan River at Bound Brook sites could be biased low because of the predominance of permitted sources at these sites and the uncertainties involved in the estimation of the attenuated permitted load. Nonpermitted yields of TKN at low-flow conditions were highest (0.8 - 0.9 lb/d/mi^2) at the S.B. Raritan River at Three Bridges, Raritan River at Manville, and Millstone River at Grovers Mill sites (table 25). Nonpermitted yields were lowest (0.1 lb/d/mi^2) at low flow at Neshanic River and Stony Brook. Nonpermitted yields of TKN at median flow were highest at the Millstone River at Grovers Mill and Blackwells Mill sites and at S.B. Raritan River at Three Bridges (1.8 - 3.1 lb/d/mi^2). Lowest nonpermitted yields at median flow were 0.4 to 0.9 lb/d/mi^2 at N.B. Raritan River at Burnt Mills, Mulhockaway Creek, and Spruce Run.

Nonpermitted yields of TKN at high flow were highest at Millstone River at Grovers Mill (6.3 lb/d/mi^2), Raritan River at Bound Brook (3.9 lb/d/mi^2), Millstone River at Blackwells Mill (3.8 lb/d/mi^2), and Stony Brook (3.8 lb/d/mi^2). Lowest nonpermitted yields at high flow were 1.4 to 1.6 lb/d/mi^2 at Mulhockaway Creek, Spruce Run, Rockaway Creek, and N.B. Raritan River near Chester.

No significant differences in nonpermitted yields were found among the three physiographic provinces when sites were aggregated by physiographic province. A comparison of sites by subbasin showed that at low-flow conditions sites on the Raritan River had significantly higher nonpermitted yields than sites on tributaries to the Millstone River. No other significant differences were observed.

Most of the total TKN yields at the seven sites with the highest total instream yields were from nonpermitted sources (table 25). At low flow, 52 to 83 percent of the total instream yield at the seven sites was from nonpermitted sources. The percentages of total instream yield that originated from nonpermitted sources increased at higher flows. At high flow, 86 to 90 percent of total instream yields were from nonpermitted sources. The seven sites with the highest total instream yields of TKN were not all the same as the sites with the highest nonpermitted yields (table 25).

Biochemical Oxygen Demand

Estimates of nonpermitted yield of BOD at low-flow conditions at the N.B. Raritan River near Chester and Matchaponix Brook could be biased low because of the predominance of permitted sources at these sites and the uncertainties involved in the estimation of the attenuated permitted load. Nonpermitted yields of BOD at low flow were highest at the S.B. Raritan River sites at Stanton and Three Bridges (5.0 - 5.5 lb/d/mi^2). Lowest nonpermitted yields were 0.4 to 0.5 lb/d/mi^2 at Stony Brook, Beden Brook, and Millstone River near Manalapan (table 26).

Nonpermitted yields of BOD at median-flow conditions were highest (9.1-9.5 lb/d/mi^2) at the S.B. Raritan River sites at Three Bridges, Stanton, and Middle Valley. Lowest nonpermitted yields at median flow were 0.96 lb/d/mi^2 at Millstone River near Manalapan, 3.46 lb/d/mi^2 at Matchaponix Brook, and 4.26 lb/d/mi^2 at Stony Brook.

Nonpermitted yields of BOD at high flow were highest at S.B. Raritan River at High Bridge (18.0 lb/d/mi^2), S.B. Raritan River at Three Bridges (16.5 lb/d/mi^2), Millstone River at Grovers Mill (16.4 lb/d/mi^2), and S.B. Raritan River at Middle Valley (15.0 lb/d/mi^2). Lowest nonpermitted yields were 1.5 lb/d/mi^2 at Millstone River near Manalapan and 7.2 lb/d/mi^2 at Matchaponix Brook and Manalapan Brook.

Nonpermitted yields of BOD were significantly higher at sites in the New England province than at sites in the Coastal Plain at median-flow conditions. A comparison of sites by subbasin showed that at median and low flows, nonpermitted yields of BOD at all S.B. Raritan River sites were significantly higher than those at all sites on Millstone River tributaries and along the mainstem of the Raritan River.

Total BOD instream yields at the seven sites with the highest total instream yields originated mainly from nonpermitted sources (table 26). More than 90 percent of total instream yield at median- and high-flow conditions was from nonpermitted sources at each of the seven sites. At low flow, however, less than 50 percent of instream load was from nonpermitted sources at N.B. Raritan River at Chester and Matchaponix Brook, 13 and 40 percent, respectively. The seven sites with the highest total instream yields were not all the same as the sites with the highest nonpermitted yields (table 26).

Chloride

Total instream loads and yields are summarized for chloride in the section “Total Loads and Yields by Constituent” (table 27). Permitted and nonpermitted chloride load and yield could not be evaluated because no permitted point-source data were available for chloride in the study area, and estimates of load could not be made accurately from a literature search (TRC Omni Environmental Corporation, 2001).

Dissolved Solids, Total

Sites with more than 50 percent of total instream load of TDS that originated from permitted sources are not included in the following discussion of the lowest nonpermitted yields observed. At low-flow conditions, more than 50 percent of the total instream yield originated from nonpermitted sources at all sites, except N.B. Raritan River near Chester, Lamington River near Pottersville, Millstone River sites at Grovers Mill and Blackwells Mill, Stony Brook, Beden Brook, Raritan River at Bound Brook, and Matchaponix Brook. Estimates of nonpermitted yield could be biased low at these eight sites because of the predominance of permitted sources.

Nonpermitted yields of TDS at low-flow conditions are highest (459-463 lb/d/mi^2) at the S.B. Raritan River sites at Three Bridges and Middle Valley (table 28). Lowest nonpermitted yields (25-69 lb/d/mi^2) at low flow were at Neshanic River and Stony Brook.

Nonpermitted yields of TDS at median flow were highest at the S.B. Raritan River sites at Middle Valley and High Bridge (948-974 lb/d/mi^2). The lowest nonpermitted yields were 327 and 330 lb/d/mi^2 at Stony Brook and Manalapan Brook, respectively.

Nonpermitted yields of TDS at high flow were highest at N.B. Raritan River at Burnt Mills (1,450 lb/d/mi^2), S.B. Raritan River at Middle Valley (1,364 lb/d/mi^2), and S.B. Raritan River at Three Bridges (1,310 lb/d/mi^2). Lowest nonpermitted yields were 508 and 592 lb/d/mi^2 at Manalapan Brook and Millstone River near Manalapan, respectively.

No significant differences in nonpermitted yields of TDS at the three flow conditions were observed when sites were aggregated by physiographic province. A comparison of sites by subbasin at high flow indicated that nonpermitted yields were significantly higher at sites on the S.B. Raritan River than at sites on the Millstone River, Matchaponix Brook, and Manalapan River. At median flow, nonpermitted yields at sites on the S.B. Raritan River were significantly higher than at sites on the Millstone River, Matchaponix Brook, Manalapan Brook, Raritan River, and Millstone River tributaries. No significant differences were observed in yields between subbasins at low flow.

Total instream TDS yields at the seven sites with the highest total instream yields were mainly from nonpermitted sources, except at N.B. Raritan River near Chester, Lamington River at Pottersville, and Matchaponix Brook (table 28). At these three sites, less than 40 percent of instream yield at low-flow conditions was from nonpermitted sources. More than 80 percent of the total instream yield at the other four sites was from nonpermitted sources. The seven sites with the highest total instream yields were not the same as the sites with the highest nonpermitted yields (table 28).

Nitrate Plus Nitrite

Sites where more than 50 percent of total instream load of NO3+NO2 originated from permitted sources are not included in the following discussion of the lowest nonpermitted yields observed. At low-flow conditions, more than 50 percent of the total instream yield originated from permitted sources at the N.B. Raritan River sites; Lamington River; the Millstone River sites at Grovers Mill and Blackwells Mill; Beden Brook; Raritan River at Bound Brook; and Matchaponix Brook. A large amount of uncertainty is associated with estimates of nonpermitted yield at these sites; the estimates could be biased low because of the predominance of permitted sources at these sites.

Nonpermitted yields of NO3+NO2 at low flow were highest (3.7–4.4 lb/d/mi^2) at the S.B. Raritan River sites at Middle Valley and High Bridge and at Matchaponix Brook (table 29). Lowest nonpermitted yields (0.1 lb/d/mi^2) at low flow were at Neshanic River and Stony Brook.

Nonpermitted yields of NO3+NO2 at median flow were highest (8.0–9.7 lb/d/mi^2) at the S.B. Raritan River sites at Middle Valley and High Bridge and at Millstone River at Grovers Mill. The lowest nonpermitted yields were 1.1 lb/d/mi^2 at Stony Brook at Princeton and 3.3 lb/d/mi^2 at Beden Brook. Nonpermitted yields of NO3+NO2 at high flow were highest at Millstone River at Grovers Mill (18.1 lb/d/mi^2) and S.B. Raritan River at High Bridge (16.3 lb/d/mi^2). The lowest nonpermitted yields were 4.0 lb/d/mi^2 at Stony Brook and 6.2 lb/d/mi^2 at Manalapan Brook.

No significant differences in nonpermitted yields were observed among the three physiographic provinces when sites were aggregated by physiographic province. When sites were compared by subbasin, no significant differences were observed in nonpermitted yields.

At low and median flows, total NO3+NO2 instream yields at the seven sites with the highest total instream yields did not originate primarily from nonpermitted sources (table 29). Less than 50 percent of the yield at four of these sites at low and median flows was from nonpermitted sources. At high flow, less than 50 percent of the total instream yield at two sites was from nonpermitted sources. The seven sites with the highest total instream yields are not all the same as the sites with the highest nonpermitted yields (table 29). Three of the sites have essentially no nonpermitted yield because of the predominance of permitted sources.

Organic Carbon, Total

No more than 33 percent of total instream yields of TOC originated from permitted point sources at any site. All 21 sites are included in this discussion of the lowest nonpermitted yields observed. Nonpermitted yields of TOC at low flow were highest at the S.B. Raritan River sites at Stanton and Three Bridges and at the Lamington River at Pottersville (9.8–10.3 lb/d/mi^2). The lowest nonpermitted yields were 0.9 lb/d/mi^2 at Stony Brook and 1.1 lb/d/mi^2 Neshanic River (table 30).

Nonpermitted yields of TOC at median-flow conditions were highest (21-30 lb/d/mi^2) at the Lamington River at Pottersville and the S.B. Raritan River sites at Middle Valley and High Bridge. Lowest nonpermitted yields at median flow were 10.0 lb/d/mi^2 at Neshanic River, 11.9 lb/d/mi^2 at Mulhockaway Creek, and 12.1 lb/d/mi^2 at Stony Brook.

Nonpermitted yields of TOC at high flow were highest at Lamington River at Pottersville (50.6 lb/d/mi^2), Millstone River at Grovers Mill (44.7 lb/d/mi^2), and S.B. Raritan River at High Bridge (40.0 lb/d/mi^2). The lowest nonpermitted yields were 21.1 lb/d/mi^2 at Manalapan Brook, 21.7 lb/d/mi^2 at Mulhockaway Creek, and 22.0 lb/d/mi^2 at Rockaway Creek.

No significant differences in nonpermitted yields were observed when sites were aggregated by physiographic province. When sites were compared by subbasin, significant differences were observed at low- and median-flow conditions. Nonpermitted yields at sites on the S.B. Raritan River were significantly higher than those at sites on tributaries to the S.B. Raritan River and tributaries to the Millstone River.

Total TOC instream yields at the seven sites with the highest total instream yields were mainly from nonpermitted sources. (table 30). More than 80 percent of total instream yield at low-flow conditions originated from nonpermitted sources at each of the seven sites. At median and high flows, from 93 to 99.7 percent of instream load was from nonpermitted sources at the seven sites with highest total instream yields. The seven sites with the highest total instream yields were the same sites as those with the highest nonpermitted yields (table 30).

Phosphorus, Total

The nine sites where more than 50 percent of total instream load of total phosphorus originated from permitted sources are not included in the following discussion of the lowest nonpermitted yields. At low-flow conditions, more than 50 percent of the total instream yield originated from nonpermitted sources at 9 of the 21 sampling sites --the S.B. Raritan River sites at High Bridge and Stanton, Spruce Run, Mulhockaway Creek, Neshanic River, Raritan River at Manville, N.B. Raritan River near Chester, and the Millstone River sites at Manalapan and Blackwells Mills. Nonpermitted yield of total phosphorus at low flow was highest at Millstone River at Blackwells Mills (0.5 lb/d/mi^2). Nonpermitted yields at low flow were lowest, less than 0.1 lb/d/mi^2, at Beden Brook, Mulhockaway Creek, and Neshanic River (table 31).

Nonpermitted yields of total phosphorus at median-flow conditions were highest, 0.8 lb/d/mi^2, at the Millstone River at Blackwells Mills and, 0.5 lb/d/mi^2, at Millstone River at Grover Mill and Raritan River at Bound Brook. Nonpermitted yields at median flow were lowest, 0.1 lb/d/mi^2, at Lamington River at Burnt Mills, Mulhockaway Creek, Neshanic River, the N.B. Raritan River sites at Burnt Mills and Chester, S.B. Raritan River at Stanton, and Stony Brook.

Nonpermitted yields of total phosphorus at high flow were highest at Millstone River at Blackwells Mills (1.2 lb/d/mi^2), Millstone River at Grovers Mill (1.0 lb/d/mi^2), and Raritan River at Bound Brook (1.0 lb/d/mi^2). The lowest nonpermitted yield at high flow was 0.1 lb/d/mi^2 at S.B. Raritan River at Stanton and N.B. Raritan River at Burnt Mills.

Significant differences in nonpermitted yields were observed when sites were aggregated by physiographic province. Nonpermitted yields at high flow were significantly higher at sites in the Coastal Plain than at sites in the New England province. Nonpermitted yields at the Piedmont sites did not differ significantly. When compared by subbasin, significant differences were observed among sites at high-flow conditions. Nonpermitted yields at sites on the Millstone River were significantly higher than at sites on the Lamington River at high-flow conditions.

More than 50 percent of total phosphorus yield originated from nonpermitted sources at only two of the nine sites with the highest total instream yields at low flow (table 31). At median flow, more than 50 percent of total instream load at five sites originated from nonpermitted sources. Nonpermitted yields at high flow accounted for 53 to 76 percent of total instream load at the seven sites with highest total instream yields. The seven sites with the highest total instream yields were the same as those with the highest nonpermitted yields (table 31).

Total Suspended Solids

At low-flow conditions, more than 50 percent of the total instream yield of TSS originated from permitted sources at N.B. Raritan River near Chester. This site is not included in the discussion of the lowest nonpermitted yields because of a possible bias in the estimate of nonpermitted yield caused by the predominance of a permitted source. Nonpermitted yields of TSS at low flow were highest at Millstone River at Grovers Mill (17.6 lb/d/mi^2), S.B. Raritan River at High Bridge (10.5 lb/d/mi^2), and Manalapan Brook (9.9 lb/d/mi^2). The highest yields at low flow were observed in the summer during periods of algal growth. The lowest nonpermitted yield was 0.4 lb/d/mi^2 at Neshanic River and Stony Brook (table 32).

Nonpermitted yields of TSS at median-flow conditions were highest at the Millstone River at Grovers Mill (60.7 lb/d/mi^2), Millstone River at Blackwells Mills (45.4 lb/d/mi^2), and Millstone River near Manalapan (36.4 lb/d/mi^2). The lowest nonpermitted yields at median flow were at N.B. Raritan River near Chester (6.3 lb/d/mi^2), Neshanic River (12.4 lb/d/mi^2), and Stony Brook (14.8 lb/d/mi^2).

Nonpermitted yields of TSS at high flow were highest at Millstone River at Grovers Mill, Raritan River at Bound Brook (129 lb/d/mi^2), and Millstone River at Blackwells Mill (117 lb/d/mi^2). Nonpermitted yields were lowest at N.B. Raritan River near Chester (20.3 lb/d/mi^2), Mulhockaway Creek (29.2 lb/d/mi^2), and Spruce Run (29.8 lb/d/mi^2).

No significant differences in nonpermitted yields of TSS were observed when sites were aggregated by physiographic province. When sites were compared by subbasin, significant differences in nonpermitted yields were observed at median-flow conditions. Nonpermitted yields at sites on the Millstone River were significantly higher than at sites on tributaries to the S.B. Raritan River at median-flow conditions. Nonpermitted yields at high-flow conditions increased significantly with an increase in the size of the contributing drainage basin. Nonpermitted yields at low and median flows did not increase or decrease with increases in basin size.

Total TSS yields at the seven sites with the highest total instream yields mainly originated from nonpermitted sources (table 32). At low-flow conditions, 92 to 100 percent of instream yield at all seven sites was from nonpermitted sources. At median- and high-flow conditions, 95 to 100 percent of instream yields originated from nonpermitted sources. Permitted sources were not a major contributor to TSS yields in the study area. The seven sites with the highest total instream yields were the same as those with the highest nonpermitted yields (table 32).

Relation of Nonpermitted Yields Among Sites

Values of nonpermitted yields of selected constituents at all the study sites are presented in tables 25 to 26 and 28 to 32. Only total instream yields of chloride are listed in table 27. The nonpermitted part of instream yield could not be computed for chloride because permitted point-source data were not available. Estimated total instream yield, and the permitted and nonpermitted parts of load and yield, at each site at the three flow conditions are listed in tables 25 to 32. An example of the stacked bar charts used to visually represent the estimated yields and to make comparisons among sites is shown in figure 28. The bar charts show the total instream permitted and nonpermitted components of the NO3+NO2 yield at the low-, median-, and high-flow conditions listed in table 29.

Comparisons were made among sites at each of the three flow conditions by use of the ANOVA test on ranks of nonpermitted yield and the Tukey's test. Comparisons also were made among sites grouped by physiographic province and by subbasin. Permitted point-source yield dominated the total instream yield of a few constituents at some sites at low flow. When estimates of attenuated permitted point-source yield exceeded 80 percent of total instream yield, the nonpermitted yield at that site was not included in the ANOVA statistical test.

Significant differences ($p<0.05$) in nonpermitted yields between sites in the different physiographic provinces were observed for three constituents. Yields of TDS (table 28) were significantly higher at sites located in the New England province than at sites located in the Coastal Plain. The differences occurred at low- and median-flow conditions. Nonpermitted yields of phosphorus (table 31) at high-flow conditions were significantly higher at sites in the Coastal Plain than at sites in the New England province. Nonpermitted yields of BOD (table 26) were significantly higher at sites in the New England province than at sites in the Coastal Plain at median-flow conditions. No significant differences occurred at low- or high-flow conditions. No significant differences in nonpermitted yields of nitrate, TKN, TOC, and TSS were observed among provinces.

Significant differences in nonpermitted yields of six of the seven constituents were observed when sites were grouped by subbasins at one or more flow conditions. Sites were divided into eight subbasins--S.B. Raritan River mainstem, S.B. Raritan River tributaries, N.B. Raritan River, Lamington River, Millstone River mainstem, Millstone River tributaries, Raritan River mainstem, and South River. No significant differences in NO3+NO2 yields were observed (table 29). Yields of BOD at low and median flow were significantly higher at the mainstem S.B. Raritan River sites than at the mainstem Raritan River and Millstone River tributaries sites (table 26). Nonpermitted yields of TKN at low flow at the mainstem Raritan River sites were significantly higher than in the Millstone River tributaries (table 25).

Nonpermitted yields of TOC at low and median flows at the S.B. Raritan River sites were significantly higher than nonpermitted yields at S.B. Raritan and Millstone River tributaries sites (table 30). Nonpermitted yields of total phosphorus at high flows were significantly higher at the Millstone River sites than at the Lamington River sites (table 31). Nonpermitted yields of TSS at median flows at Millstone River sites were significantly higher than at those sites on S.B. Raritan River tributaries (table 32). Nonpermitted yields of TDS at high flows at S.B. Raritan River sites were significantly higher than those at Millstone River, Matchaponix Brook, and Manalapan Brook sites. Nonpermitted yields of TDS at median flows at S.B. Raritan River sites were significantly higher than those at sites on the Raritan River, Millstone River mainstem and tributaries, Matchaponix Brook, and Manalapan Brook (table 28).

Nonpermitted yields in relation to basin characteristics at each flow condition were evaluated by using correlation analysis and multiple regression analysis. Total instream yield at some sites originated primarily from permitted sources. Nonpermitted yields at sites where more than 50 percent of total instream yield originated from permitted sources were removed from the data set. The estimated nonpermitted yields at these sites were not included in the correlation or regression analysis. The lack of variability in nonpermitted yields between sites with more than 50 percent of total instream yield originating from permitted sources, for most constituents, limited the number of significant relations between basin characteristics and nonpermitted yields.

Correlation analysis was conducted initially on all variables, including those variables that could not be transformed to a normal distribution. Five variables--the percentages of Coastal Plain, New England and Piedmont provinces and the percentages of metamorphic and unconsolidated bedrock--were dropped from the multiple regression analysis because the data could not be transformed to a normal distribution. The percentages of barren land and open water were removed from the discussion of results because percentages of these land uses are small at all sites, and results may lead to spurious conclusions.

The density of private septic systems, the percentage of land area in the Coastal Plain, the percentage of area underlain by unconsolidated sediments, and the percentage of area covered by water correlated with the most constituents at most flow conditions. The density of septic systems was related to six of the seven constituents at one or more flow conditions. The percentage of land area in the Coastal Plain and the land area underlain by unconsolidated sediments were related to the nonpermitted yield of five of the seven constituents at one or more flow conditions. Four basin characteristics--total urban land use, commercial/

industrial land use, total undeveloped land, and stream density--did not correlate with nonpermitted yields of any constituent at any flow condition.

Streamflows per unit of drainage area were highest at base flow and median flow in streams in the New England province and lowest in streams in the Piedmont province. In the Piedmont province, a relatively high proportion of streamflow is derived from direct runoff. In the Piedmont, streamflow consists of a larger percentage of runoff and a smaller percentage of base flow than in streams in other provinces. Shallow soils, rich in clay with low permeability, do not allow as much precipitation to infiltrate as deeper soils with a higher permeability. The combination of shallow soils and sloping topography enhances runoff to streams in the Piedmont province.

Differences in flow per unit area among physiographic provinces have an effect on constituent yields, which are computed by dividing load by drainage area. Yields normalize the load among sites with various sizes of drainage area. When the flow per square mile differs among sites with similar drainage areas, yields will differ as a function of flow. Constituent yields at low flow (90^{th} percentile flow duration) were found to be influenced more by differences in flow per square mile than constituent yields at high flow.

Ammonia Plus Organic Nitrogen, Total

The relation of nonpermitted yields of TKN (table 25) to 17 basin characteristics was evaluated. At high flow and at median flow, nonpermitted yields most strongly correlated with slope and land use. Nonpermitted yields increased with decreases in slope and forested land use, and with increases in population density and wetlands. At low flow, nonpermitted yields most strongly correlated with flashiness, a measure of variability in streamflow. The lower the base flow in the stream, the lower the yield. Small streams in the Piedmont province had significantly lower nonpermitted yields at low flow than small streams in other areas because streamflow was significantly lower at these sites. Streamflows were most variable in streams in the Piedmont province.

At high flow, nonpermitted yields correlated with eight explanatory variables. Nonpermitted yields increased as three basin characteristics associated with the Coastal Plain--hydrologic soils class-A, percentage of wetlands, and unconsolidated sediments--increased. Nonpermitted yields at high flows significantly decreased at sites as five variables increased. Each of the five variables--slope, forested land use, excessively well-drained soil, igneous bedrock, and metamorphic bedrock-- is associated with the New England province. Population density and housing density also increased as nonpermitted yields increased. At high flows, nonpermitted yields were generally higher at Coastal Plain sites than at other sites and lower at New England province sites than at other sites. Results of the best fit regression model indicated that the variation in nonpermitted yields of TKN at high flows was a function of slope. Slope accounted for 60 percent of the variability in nonpermitted yields of TKN in the study area.

At median flows, nonpermitted yields of TKN were highest along the S.B. Raritan and Millstone Rivers (fig. 29). Nonpermitted yields of TKN at median flows correlated with increases in seven variables. Five of these variables are indicators of urban land use--population density, housing density, impervious surface area, septic-system density, and hydrologic soils class D. Basin elongation and soil permeability also increased as nonpermitted yields increased. Flashiness, slope, and clay in the soil increased at sites as yields at median flow increased. Results of the best fit regression model indicated that the variation in nonpermitted yields of TKN was a function of septic-system density and slope. Septic-system density and slope accounted for 66 percent of the variability in nonpermitted yields of TKN at median flow in the study area. The highest nonpermitted yields were at sites on the mainstem of the S.B. Raritan and Millstone Rivers (fig. 29).

Increases in nonpermitted yields of TKN at low flow correlated with increases in basin elongation and hydrologic soils class D, and with

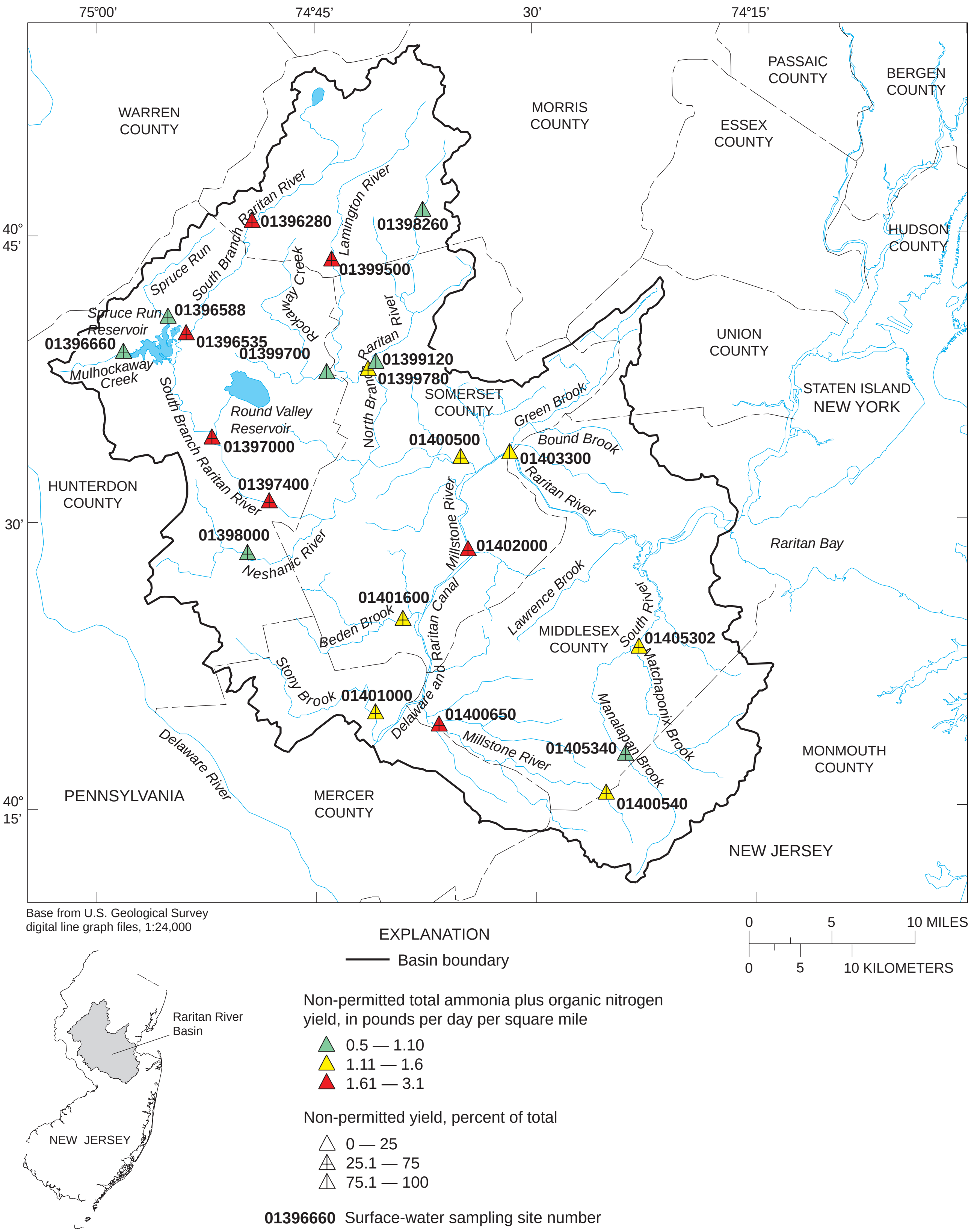

Figure 29. Nonpermitted yields of total ammonia plus organic nitrogen and percentage of total load from nonpermitted sources at median-flow conditions in the Raritan River Basin, N.J., 1991-97.

decreases in flashiness. These variables are associated with the New England province, urban areas, and the Piedmont province, respectively. Yields were higher at low flow at sites with a higher volume of flow per unit drainage area. Results of the best fit regression model indicated that at low flow variability of nonpermitted yields was a function of flashiness.

Biochemical Oxygen Demand

Nonpermitted yields of BOD (table 26) correlated with 15 basin characteristics. At high flow, nonpermitted yields correlated with soil and lithology. At median flow, yields most strongly correlated with septic-system density and excessively well-drained soils. Yields increased with increases in both factors. At low flow, nonpermitted yields most strongly correlated with septic-system density, flashiness, and agriculture. Nonpermitted yields increased with increases in septic-system density and flashiness, and decreased with increases in agricultural land.

At high flow, only two basin characteristics correlated with nonpermitted yields. Variables associated with the Coastal Plain--well-drained soils and unconsolidated sediments--decreased as nonpermitted yields at sites increased. Results of the best fit regression model indicated that the variation in nonpermitted yields of BOD were a function of well-drained soil. Well-drained soil accounted for 26 percent of the variability in nonpermitted yields of BOD in the study area.

At median flow, nonpermitted yields of BOD were highest at sites along the S.B. Raritan River, Lamington River, and Millstone River at Grovers Mill (fig. 30). Increases in nonpermitted yields of BOD at median flow correlated with increases in six environmental variables. The variables are basin elongation, forested land, septic-system density, excessively well-drained soils, and igneous and metamorphic bedrock; all of these variables were greater in the New England province (fig. 30) than in other provinces. Nonpermitted yields decreased as amounts of well-drained soils, unconsolidated sediments, and total developed land use in a subbasin increased. These three variables correlated with the Coastal Plain province. Results of the best fit regression model indicated that the variation in nonpermitted yields of BOD at median flow was a function of excessively well-drained soil. Excessively well-drained soil accounted for 36 percent of the variability in the study area. The highest nonpermitted yields of BOD were at sites on the mainstem of the S.B. Raritan and Lamington Rivers (fig. 30).

Nonpermitted yields of BOD at low flow correlated with seven variables. The variables include five measures of urban land use--population density, housing density, impervious surface area, septic-system density, and agriculture--in addition to flashiness and excessively well-drained soils. Septic-system density is the only urban land-use indicator that correlated with a physiographic province. Septic-system density is highest in the New England province. Flashiness correlated with the Piedmont province, and excessively well-drained soils correlated with the New England province. Results of the best fit regression model indicated that the variation in nonpermitted yields of BOD at low flow was a function of septic-system density. Septic-system density accounted for 39 percent of the variability in the study area. The highest nonpermitted yields were at sites on the mainstem of the S.B. Raritan River.

Dissolved Solids, Total

Nonpermitted yields of TDS (table 28) correlated with 19 basin characteristics. At high and median flows, nonpermitted yields most strongly correlated with lithology, soils, and septic-system density. Nonpermitted yields increased with increases in soils and the lithology characteristic of the New England province and decreased with increases in soils and the lithology characteristic of the Coastal Plain province. At low flow, nonpermitted yields most strongly correlated with population density, septic-system density, and agriculture. Nonpermitted yields increased with increases in population density and septic-system density and decreased with increases in agricultural land.

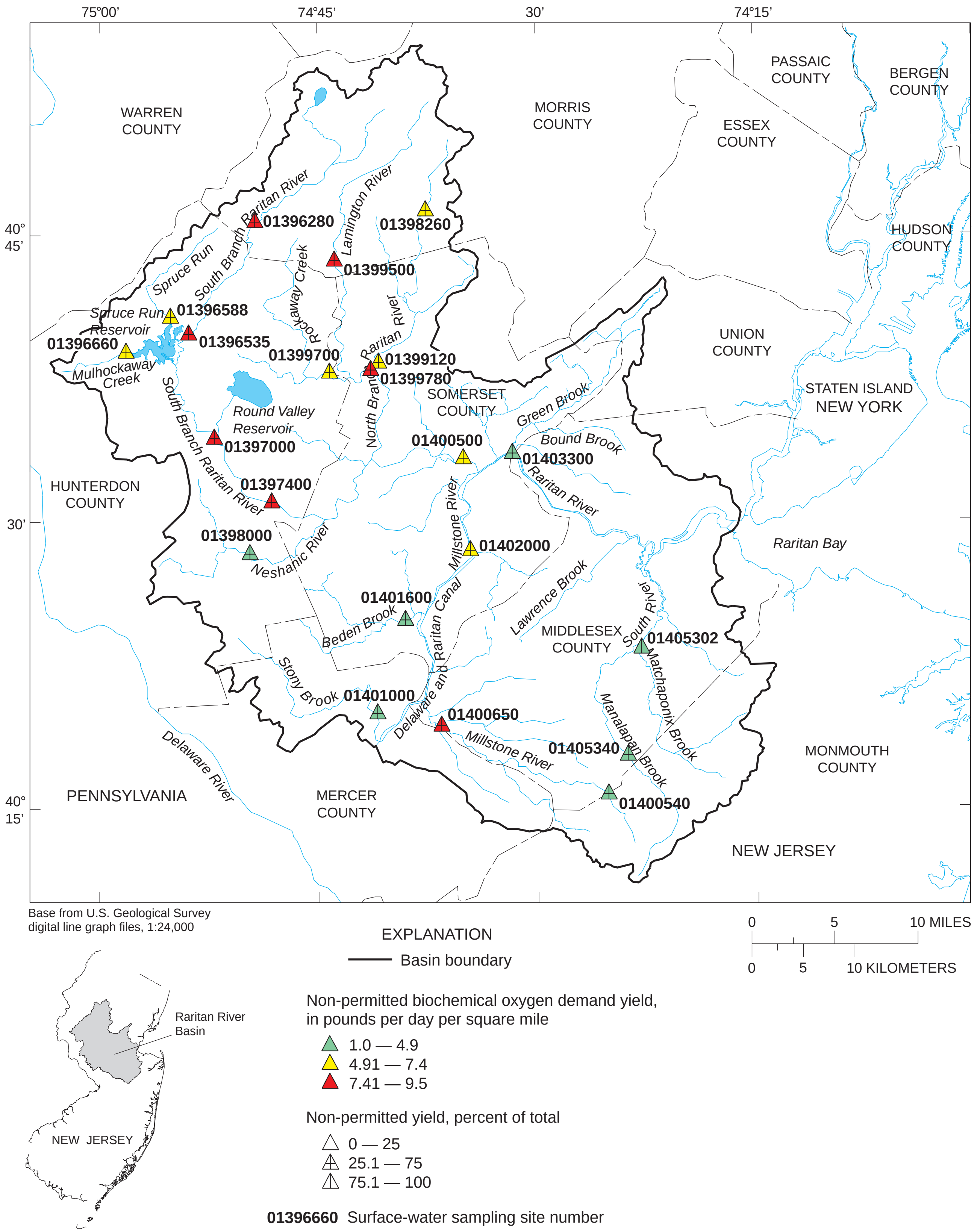

Figure 30. Nonpermitted yields of biochemical oxygen demand and percentage of total load from nonpermitted sources at median-flow conditions in the Raritan River Basin, N.J., 1991-97.

At high flow, increases in nonpermitted yields correlated with increases in five explanatory variables. All five variables--septic-system density, forested land, excessively well-drained soil, and igneous and metamorphic bedrock--correlated with increases in percentage of land in the New England province. Increases in nonpermitted yields correlated with decreases in five variables. All five variables--well-drained soil, hydrologic soil group A, sand, unconsolidated sediments, and wetlands--are associated with the Coastal Plain. Results of the best fit regression model indicated that the variation in nonpermitted yields of TDS at high flows was a function of septic-system density, hydrologic soil group C, and silt content of the soil. Hydrologic soil group C and silt in the soil are characteristic of the New England province. The three variables accounted for 68 percent of the variability of nonpermitted yield of TDS in the study area.

At median flow, nonpermitted yields of TDS were highest at sites in the N.B. and S.B. Raritan River subbasins (fig. 31). At median flow, nonpermitted yields of TDS correlated with 13 variables. Increases in nonpermitted yields correlated with increases in eight variables, including three indicators of urban land use--population density, road density, and septic system density--along with forested land and four indicators of soil and bedrock in the New England province (fig. 31). Increases in nonpermitted yields correlated with decreases in five variables. Three of the variables describe soils and lithology in the Coastal Plain. Total developed land use and agriculture correlated with the Coastal Plain and Piedmont provinces, respectively. Results of the best fit regression model indicated that the variation in nonpermitted yields of TDS at median flow was a function of septic-system density. Septic-system density accounted for 62 percent of the variability in the study area. The highest nonpermitted yields were at sites on the mainstem of the S.B. Raritan and N.B. Raritan Rivers.

Nonpermitted yields of TDS at low flow correlated with 11 variables. Increases in nonpermitted yields correlated with increases in seven variables, including four indicators of urban land use--population density, septic-system density, housing density, and impervious surface--and hydrologic soils group D, which correlated with urban indicators. Increases in two other variables correlated with increases in nonpermitted yield. Excessively well-drained soil and igneous bedrock are associated with the New England province. The four variables that decreased as nonpermitted yields increased were total developed land, well-drained Class A soils, which are associated with the Coastal Plain, and agriculture and flashiness, which are associated with the Piedmont province.

Results of the best fit regression model indicated that the variation in nonpermitted yields of TDS at low flow was a function of agricultural land and flashiness. TDS yield increased as agricultural land use and flashiness decreased. Agricultural land use and flashiness accounted for 90 percent of the variability in the study area. The highest nonpermitted yields were at sites on the mainstem of the S.B. Raritan River. The lowest nonpermitted yields were at sites on small streams in the Piedmont province. Small streams in the Piedmont province had very low flows (less than 0.10 $ft^3/s/mi^2$ at the 90th percentile flow duration) during the driest times of the year; therefore, sites on these small streams had the highest flashiness value. The land use in those areas consists of higher percentages of agricultural land than at other sites in the study area.

Nitrate Plus Nitrite

Nonpermitted yields of NO3+NO2 correlated with seven basin characteristics at low and median flows (table 29). No variables correlated with nonpermitted yield at high-flow conditions. At median flows, nonpermitted yields most strongly correlated with lithology and soils. Yields decreased with increases in clay content of the soil and sedimentary bedrock, both characteristics of the Piedmont province. At low flow, nonpermitted yields most strongly correlated with the clay content of the soil and septic-system density. Nonpermitted yields increased with increases in septic-system density and decreased with increases in clay content in the soil.

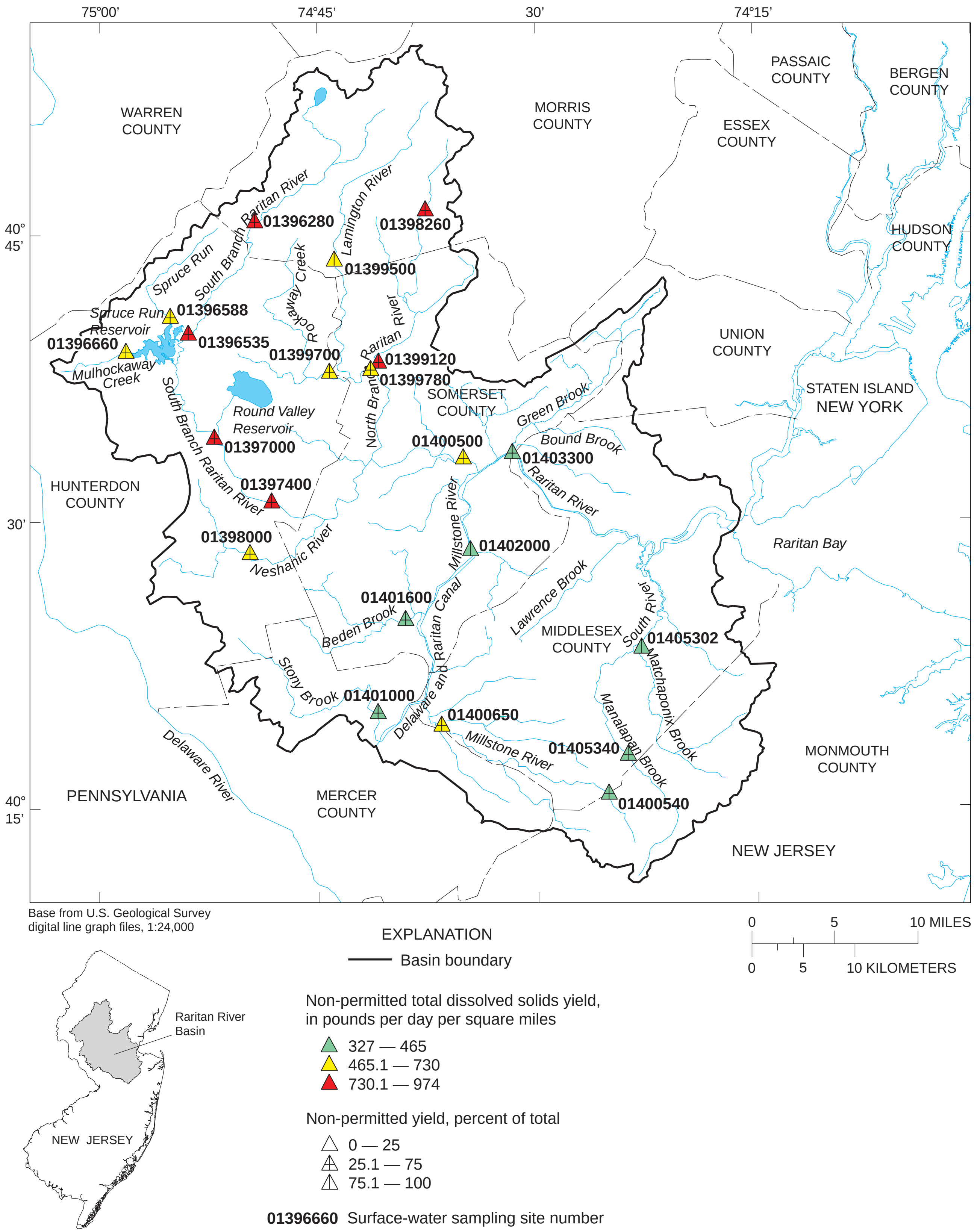

Figure 31. Nonpermitted yields of total dissolved solids and percentage of total load from nonpermitted sources at median-flow conditions in the Raritan River Basin, N.J., 1991-97.

Nonpermitted yields of NO3+NO2 at median flow were highest at sites on the Millstone and S.B. Raritan Rivers and Matchaponix Brook (fig. 32). Nonpermitted yields of NO3+NO2 at median flow correlated with four variables. Nonpermitted yields increased with increases in poorly drained soil and hydrologic soils group D. Both of these soil characteristics are associated with urban land use. Increases in nonpermitted yields correlated with decreases in clay and sedimentary bedrock. Both variables are associated with the Piedmont province (fig. 32). Results of the best fit regression model indicated that the variation in nonpermitted yields of NO3+NO2 at median flow was a function of clay content of the soil and urban land use. These variables accounted for 74 percent of the variability of NO3+NO2 in the study area. The highest nonpermitted yields were at sites in the upper part of the S.B. Raritan River and in the Coastal Plain.

Nonpermitted yields of NO3+NO2 at low flow correlated with five variables. The clay content of the soil and the flashiness of a stream decreased as yields increased. Both variables are characteristics of soil and hydrology associated with the Piedmont province. Increases in nonpermitted yield correlated with increases in septic-system density, permeability, and hydrologic soil group D. Septic-system density and hydrologic soil group D are associated with urban land uses. Permeability correlated with soil properties in the Coastal Plain province. Results of the best fit regression model indicated that the variation in nonpermitted yields of NO3+NO2 at low flow was a function of septic-system density and sandy soil. These two variables accounted for 83 percent of the variability in the study area; however, only 11 sites were used in the model. The highest nonpermitted yields were at sites along the S.B. Raritan River and at selected Coastal Plain sites.

Organic Carbon, Total

Nonpermitted yields of TOC correlated with 14 basin characteristics (table 30). At high-flow conditions, nonpermitted yields most strongly correlated with factors that define urban land use. Yields increased with increases in population density and housing density. At median flows, nonpermitted yields most strongly correlated with basin shape and septic-system density. Yields increased with increases in basin elongation and septic-system density, characteristics associated with the New England province. At low flows, nonpermitted yields most strongly correlated with hydrology, soils, and basin shape. Nonpermitted yields increased with increases in basin elongation and decreased with increases in flashiness and clay content in the soil.

At high flows, three variables correlated with nonpermitted yield of TOC. Increases in nonpermitted yields correlated with increases in population density and housing density. Increases also correlated with decreases in slope, which are associated with the Coastal Plain province. Results of the best fit regression model indicated that the variation in nonpermitted yields of TOC at high flow was a function of population density. Population density accounted for 21 percent of the variability of TOC in the study area.

Nonpermitted yields of TOC at median flows were highest on the S.B. Raritan, N.B. Raritan, and Lamington Rivers (fig. 33). Nonpermitted yields of TOC at median flows correlated with nine variables. Seven of the nine variables correlated positively with nonpermitted yield. Four of these variables--population density, housing density, impervious surface area, and septic-system density--are indicators of urban land use. Basin elongation, hydrologic soils group D, and soil permeability are associated with the New England province (fig. 33). The two variables that negatively correlated with nonpermitted yields were agricultural land use and clay content of the soil. Both of these factors are associated with the Piedmont province. Results of the best fit regression model indicated that the variation in nonpermitted yields of TOC at median flow was a function of basin elongation and impervious surface area. Basin elongation and impervious surface area accounted for 60 percent of the variability of TOC in the study area.

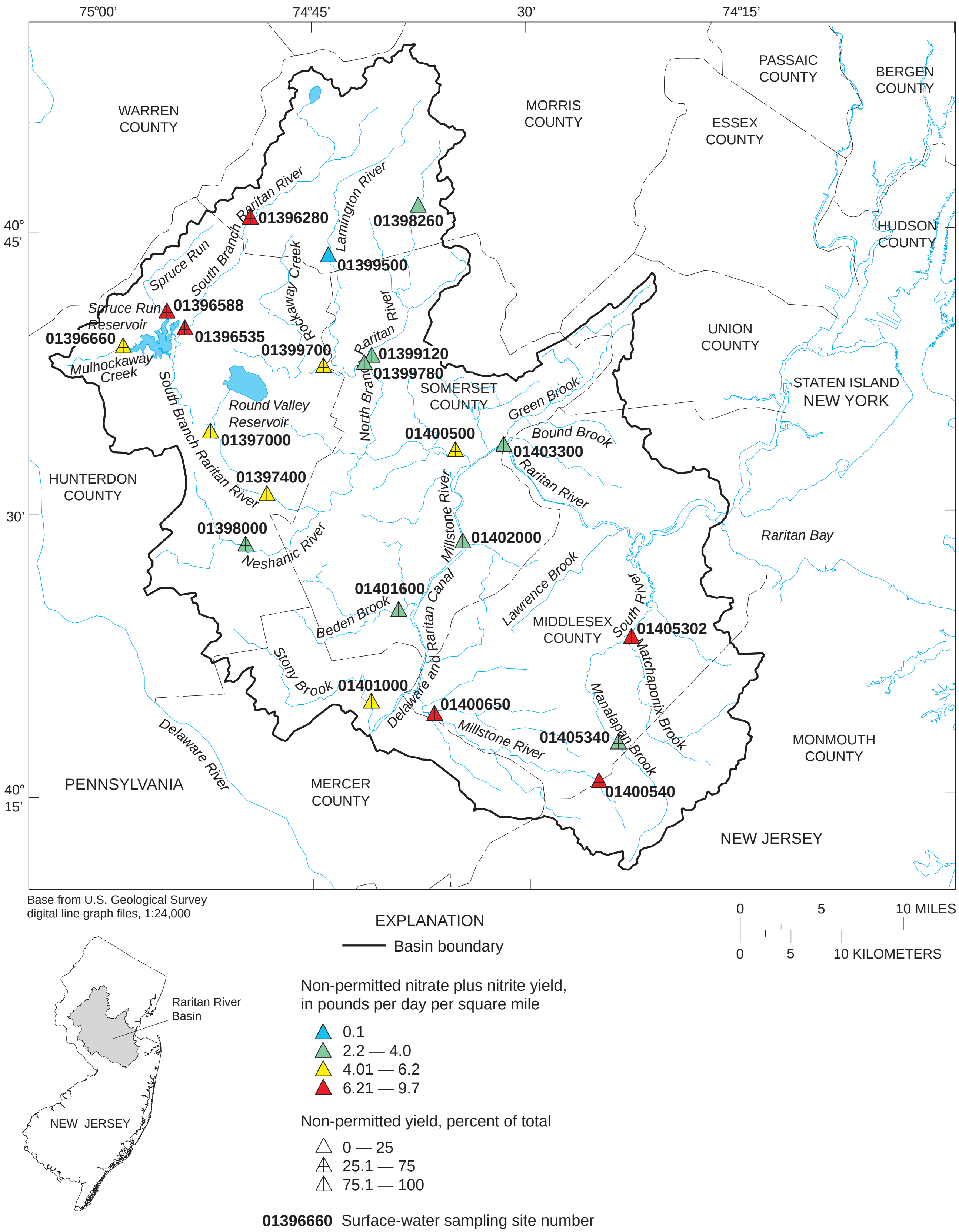

Figure 32. Nonpermitted yields of nitrate plus nitrite and percentage of total load form nonpermitted sources at median-flow conditions in the Raritan River Basin, N.J., 1991-97.

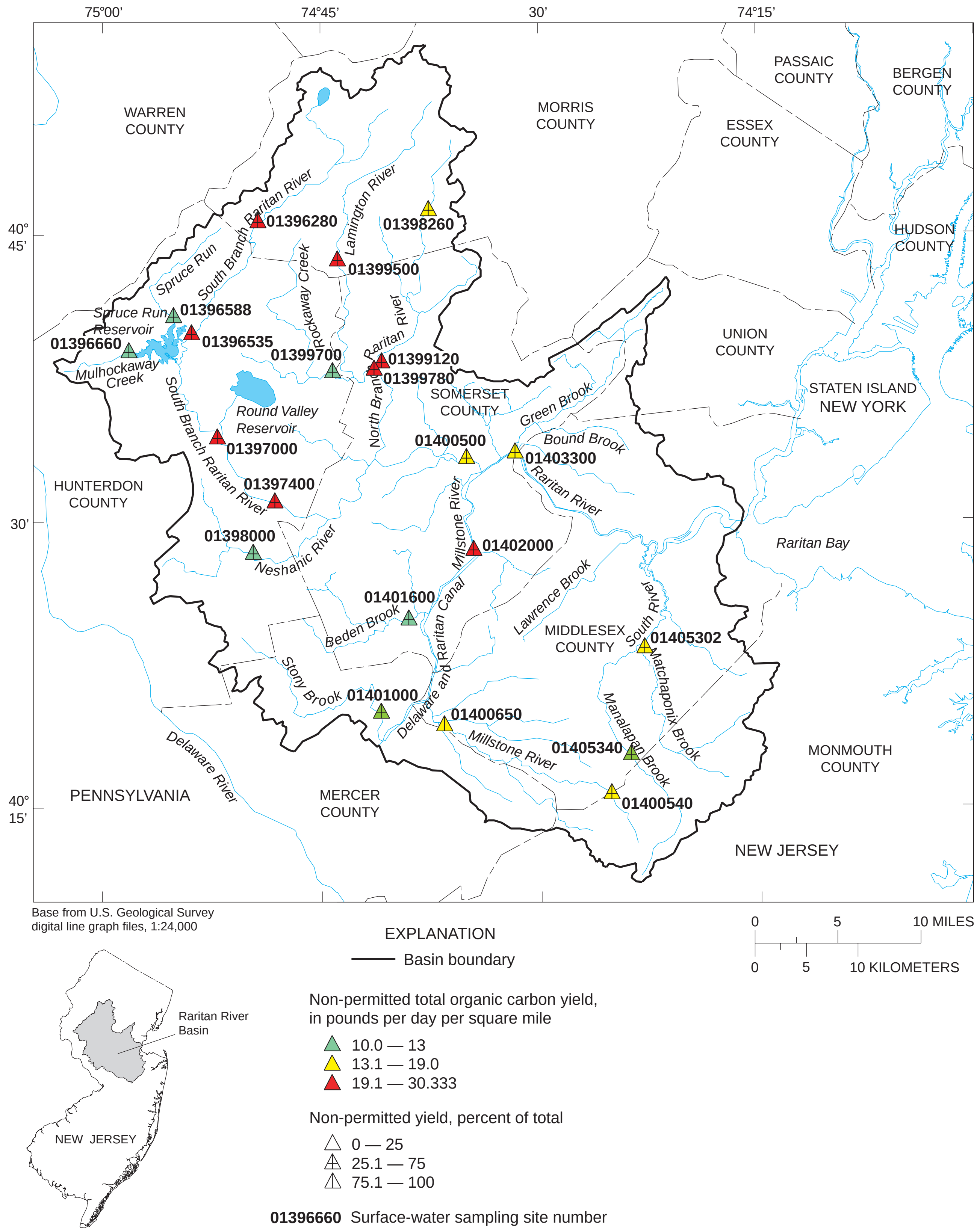

Figure 33. Nonpermitted yields of total organic carbon and percentage of total load from nonpermitted sources at median-flow conditions in the Raritan River Basin, N.J., 1991-97.

Nonpermitted yields of TOC at low flows correlated with eight variables. Five of the eight variables correlated positively with nonpermitted yield. The variables are basin elongation; septic-system density; hydrologic soil group B; silt, which is associated with the New England province; and permeability, which is associated with the Coastal Plain. The three variables that negatively correlated with nonpermitted yield of TOC are hydrologic soils group B, clay content of the soil, and flashiness. These variables are associated with soils and hydrology in the Piedmont province. Results of the best fit regression model indicated that the variation in nonpermitted yields of TOC at low flow was a function of flashiness and basin elongation. Flashiness and basin elongation accounted for 71 percent of the variability in the study area.

Phosphorus, Total

Nonpermitted yields of total phosphorus correlated with 14 basin characteristics (table 31). At high-flow conditions, nonpermitted yields most strongly correlated with factors of slope, lithology, and forested land. Yields increased with decreases in the percentages of slope, forested land, and metamorphic bedrock. At median flows, nonpermitted yields most strongly correlated with hydrologic soils groups and lithology. Yields increased with increases in hydrologic soils groups A and D and unconsolidated sediments, characteristics associated with the Coastal Plain province and urban land use. At low flow, nonpermitted yields most strongly correlated with hydrology, soils, and basin shape. Nonpermitted yields increased with increases in basin elongation and decreased with increases in flashiness and clay content in the soil.

At high flow, three basin characteristics associated with the Coastal Plain--hydrologic soils group A, percentage of wetlands, and consolidated sediments--positively correlated with nonpermitted yields of total phosphorus. Increases in nonpermitted yields at high flows correlated with decreases in four variables--slope, forested land, igneous bedrock, and metamorphic bedrock. Increases in each of the four variables correlated with the New England province. At high flows, nonpermitted yields generally were higher at Coastal Plain sites than at other sites and lower in the New England province than other provinces. Results of the best fit regression model indicated that the variation in nonpermitted yields of total phosphorus at high flows was a function of slope. Slope accounted for 54 percent of the variability in the study area. Nonpermitted yields of total phosphorus increased at the sites with flatter slopes. Increases in slope correlated with forested land and total undeveloped land. Decreases in slope correlated with increases in the percentage of area that is sewered, an indicator of urban land use.

Nonpermitted yields of total phosphorus at median flows were highest at sites on the Millstone River, mainstem Raritan River, and S.B. Raritan River at Three Bridges (fig. 34). Increases in nonpermitted yields of total phosphorus at median flows correlated with increases in four variables associated with either the Coastal Plain province (fig. 34) or urban land use. Increases in total phosphorus yields correlated with increases in hydrologic soils class D, hydrologic soils class A, unconsolidated sediments, and sand. Increases in hydrologic soils class D correlated with increases in urban land use. Increases in total phosphorus yields also correlated with decreases in slope. Results of the best fit regression model indicated that the variation in nonpermitted yields of total phosphorus at median flow was a function of hydrologic soils class D.

Increases in nonpermitted yields of total phosphorus at low flow correlated with increases in basin elongation, percentage of sand in the soil, and soil permeability. The highest values of basin elongation were associated with the New England province. The soils with the highest percentage of sand and highest permeability are in the Coastal Plain province. Decreases in nonpermitted yields of total phosphorus correlated with hydrologic soils group B, clay content of the soil, and sedimentary bedrock. All three variables are associated with the Piedmont province. Results of the best fit regression model indicated that at low flow variations in nonpermitted yields were a function of basin elongation. Only 11 sites,

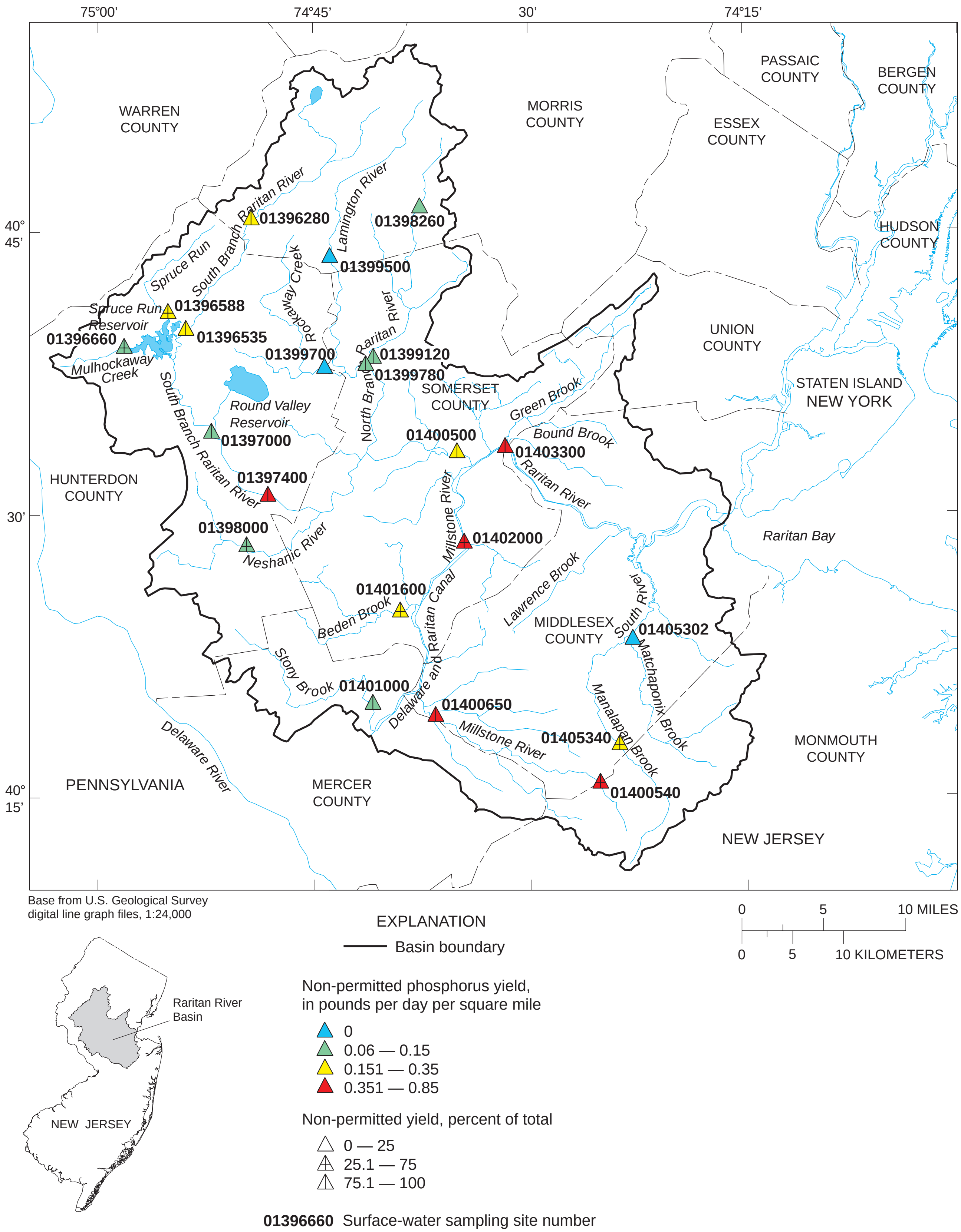

Figure 34. Nonpermitted yields of total phosphorus and percentage of total load from nonpermitted sources at median-flow conditions in the Raritan River Basin, N.J., 1991-97.

however, were included in the regression analysis at low flow because at the other 9 sites greater than 50 percent of total instream yield originated from permitted sources.

Total Suspended Solids

Nonpermitted yields of TSS (table 32) correlated with 18 basin characteristics. At high-flow conditions, nonpermitted yields most strongly correlated with slope, forested land, and soils. Nonpermitted yields increased with decreases in slope and forested land and increased with increases in hydrologic soil group A. At median flows, nonpermitted yields most strongly correlated with slope, hydrologic soils group A, and unconsolidated sediments. Yields increased with decreases in slope and increased with increases in hydrologic soils group A and unconsolidated sediments, all characteristics associated with the Coastal Plain province. At low flow, nonpermitted yields most strongly correlated with slope, soils, and lithology. Nonpermitted yields increased with decreases in slope, sedimentary bedrock, and clay and with increases in permeability and sandy soil.

At high flows, increases in nonpermitted yields correlated with decreases in six basin characteristics associated with the New England province--slope, septic-system density, forested land, excessively well-drained soil, and igneous and metamorphic bedrock. Nonpermitted yields at high flows increased as the five variables increased. Four of the five variables--hydrologic soil group A, well-drained soil, unconsolidated sediments, and total developed land--correlated with the Coastal Plain province. Agricultural land correlated with total developed land, well-drained soil, and the Piedmont province. At high flows, nonpermitted yields were generally higher at Coastal Plain sites than at other sites and lower at New England province sites than at other sites. Results of the best fit regression model indicated that the variation in nonpermitted yields of TSS at high flows was a function of slope and flashiness. Slope and flashiness accounted for 62 percent of the variability in the study area. Nonpermitted yields of TSS increased at the sites with flatter slopes and sites with higher variability in flow. Flatter slopes are characteristic of sites in the Coastal Plain, and higher variability in streamflow is characteristic of sites in the Piedmont province.

Nonpermitted yields of TSS at median flows were highest at Millstone River sites and Raritan River at Bound Brook (fig. 35). Increases in nonpermitted yields of TSS at median flows correlated with increases in four variables--wetlands, hydrologic soil class A, sandy soil, and unconsolidated sediments-- that are associated with the Coastal Plain province (fig. 35). Increases in nonpermitted yields at median flows correlated with decreases in three variables--slope, forested land, and igneous rock--that are associated with the New England province. Results of the best fit regression model indicated that the variation in nonpermitted yields of TSS at median flows was a function of urban land use and slope. Urban land use and slope accounted for 63 percent of the variability in the study area. Nonpermitted yields of TSS generally increased at the sites with flatter slopes and higher amounts of urban land use.

Increases in nonpermitted yields of TSS at low flows correlated with increases in six basin characteristics. Wetlands, hydrologic soil group A, sandy soil, permeability, and unconsolidated sediments are associated with the Coastal Plain province, and silt content of the soil is associated with the New England province. Decreases in nonpermitted yields of TSS correlated with clay content of the soil, sedimentary bedrock, and slope. Clay and sedimentary rock are found primarily in the Piedmont province. Increases in slope are associated with the New England province. Results of the best fit regression model indicated that the variation in nonpermitted yields of TSS at low flows was a function of sandy soil and housing density. Sandy soil and housing density accounted for 71 percent of the variability in the study area. Nonpermitted yields of TSS increased at the sites with sandier soil and higher housing density.

SUMMARY AND CONCLUSIONS

Seventeen water-quality constituents in samples from 21 surface-water sampling sites in the Raritan River Basin, New Jersey, were studied in an investigation conducted by the U.S. Geological survey (USGS), in cooperation with the New Jersey Water Supply Authority. Water-quality data from 801 samples collected during water years 1991 through 1997 were used for the investigation. The water quality at these sites was evaluated by comparing the concentrations of 13 constituents to New Jersey instream standards and drinking-water standards and by comparing concentrations among sites. Water-quality and streamflow data were used to compute instream loads and yields (load per unit area) for eight constituents. Instantaneous yields were computed by dividing load by drainage area. The area-normalized load was used to compare loads between drainage basins of different sizes. The part of total instream load that originated from permitted point sources and from nonpermitted point sources was computed from (1) data on effluent quality and quantity reported for permitted point sources, and (2) data on water quality and streamflow at USGS and New Jersey Department of Environmental Protection (NJDEP) sampling sites in the basin.

Instream water-quality standards and (or) drinking-water standards have been established by the New Jersey Department of Environmental Protection and the U.S. Environmental Protection Agency for 13 of the 17 constituents studied. The standards were used as reference levels for evaluating water quality in the Raritan River Basin.

The sites with the greatest number of samples that meet the references levels and sites with the greatest number of samples that do not meet the reference levels are summarized. The most desirable rating is given to the three sites with the most samples that meet the reference levels or have the largest number of lowest median values for each constituent. The least desirable rating is given to the three sites with the most samples that do not meet the reference levels or that have the highest median values. The sites with the most desirable rating for the most 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.

Nine of the 13 constituents studied did not meet reference levels at one or more sites in the basin. The constituents that most commonly did not meet the reference levels are total phosphorus (greater than 0.1 mg/L in 32 percent of samples), fecal coliform bacteria (greater than 400 counts/100mL in 29 percent), hardness (greater than 50 mg/L in 21 percent), pH (greater than 8.5 or less than 6.5 in 17 percent), and water temperature in designated trout waters (greater than 20 ^{o}C in 12 percent). Chloride, total dissolved solids (TDS), nitrate plus nitrite (NO3+NO2), and sulfate did not exceed the reference levels in any samples. Total phosphorus was greater than the standard of 0.1 mg/L in all but one sample at Millstone River at Blackwells Mills and in more than one-half the samples at Raritan River at Bound Brook, Millstone River at Grovers Mills, and South Branch (S.B.) Raritan River at Three Bridges. The concentrations of nine pesticides infrequently exceeded established water-quality criteria at sites on Bound Brook, Raritan River, Stony Brook, and Neshanic River.

Fecal coliform bacteria were greater than 400 counts/100mL in more than 50 percent of samples at the site on the Neshanic River. Geometric means for counts of fecal coliform bacteria were greater than the surface-water-quality reference level of 200 counts/100mL at six sites. Geometric means for low-flow samples were higher than those for high-flow samples at 14 of the 21 sites. The geometric mean for low-flow samples exceeded the reference level at seven sites and for high-flow samples at four sites. Only sites at S.B. Raritan River at Three Bridges and Lamington River at Burnt Mills had geometric means that exceeded 200 counts/100mL at high flow only.

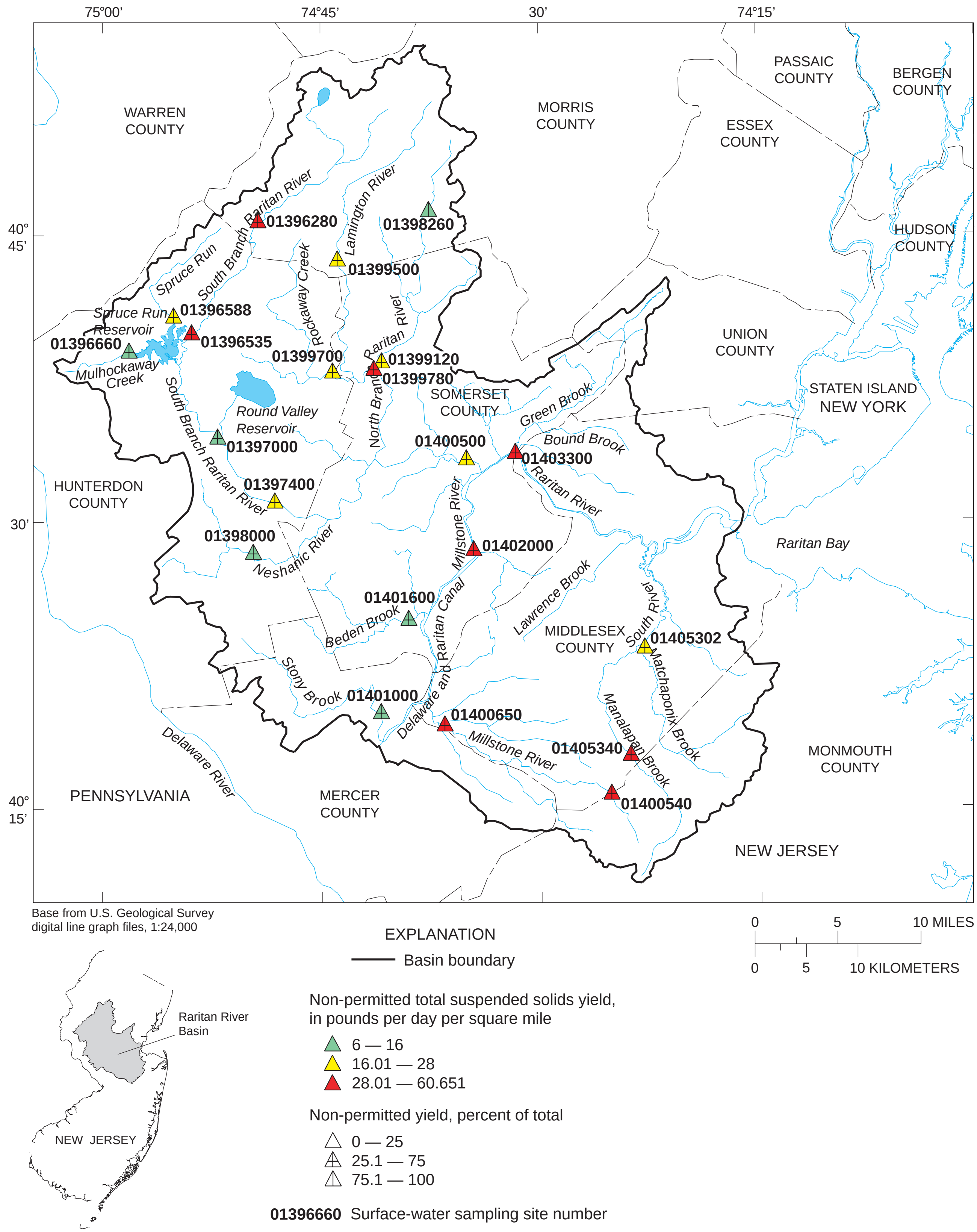

Figure 35. Nonpermitted yields of total suspended solids and percentage of total load from nonpermitted sources at median-flow conditions in the Raritan River Basin, N.J., 1991-97.

Concentrations of all constituents at one or more sites changed significantly as streamflow changed. All significant relations between alkalinity, un-ionized ammonia, TDS, hardness, pH, and water temperature decreased with increased streamflow. All significant relations between biochemical oxygen demand (BOD), dissolved oxygen, total organic carbon, and total suspended solids (TSS) increased with increased streamflow. Total ammonia, total ammonia plus organic nitrogen (TKN), chloride, NO3+NO2, total phosphorus, sodium, and sulfate increased with increased flow at 1 to 3 sites and decreased with increased flow at 1 to 13 sites. Increases in TSS concentrations at approximately one-half the sites studied corresponded significantly with increases in total phosphorus, TKN, and total organic carbon. Chloride concentrations at some sites increased significantly with increased flow in the nongrowing season and decreased with decreased flow in the growing season.

Data on constituent concentrations were grouped by the flow condition in which the samples were collected. The groups of samples collected at flows less than the median and those collected at flows greater than the median were significantly different for all constituents, except BOD, at multiple sites. Concentrations or values of the following constituents were significantly greater in low-flow samples than in other samples at one or more sites: alkalinity, TDS, fecal coliform bacteria, hardness, pH, total phosphorus, un-ionized ammonia, and water temperature. Concentrations of dissolved oxygen and TSS were significantly greater in samples at high flow at one or more sites. Concentrations of ammonia plus organic nitrogen, chloride, NO3+NO2, total organic carbon, sodium, and sulfate were significantly greater at some sites at low flow and significantly greater at other sites at high flow.

Concentrations of constituents were observed to differ significantly between seasons at multiple sites. Values for the following constituents were significantly greater during the growing season than the nongrowing season at multiple sites: alkalinity, ammonia plus organic nitrogen, BOD, fecal coliform bacteria, hardness, total organic carbon, pH, total phosphorus, un-ionized ammonia, and water temperature. Concentrations of the following constituents were significantly greater during the nongrowing season at one or more sites: chloride, dissolved oxygen, TDS, NO3+NO2, and sodium. Concentrations of sulfate were significantly greater during the nongrowing season at four sites and during the growing season at one site. Concentrations of TSS were significantly greater in the growing season at five sites and in the nongrowing season at one site.

Concentrations of seven constituents in streams were related to ground-water quality in three subbasins. Most of the TDS and TKN load at mean flow was from ground water in each subbasin. Most of dissolved organic carbon and total phosphorus load was from runoff (nonpermitted sources), and most of chloride load was from runoff in two of the three subbasins. Ground water was a major contributor of NO3+NO2 loads in the three subbasins studied; slightly less than 50 percent in two subbasins and nearly 75 percent of the total load in the third subbasin were contributed by ground water.

Trends determined in a previous study using data collected during 1986-95 were available for 16 of the 17 constituents studied for loads at one or more sites in the basin. All trends for concentrations of total ammonia, organic nitrogen, fecal coliform bacteria, total organic carbon, total phosphorus, sulfate, and water temperature were downward over time. All observed trends for values of alkalinity, chloride, TDS, hardness, NO3+NO2, pH, and sodium were upward over time. Trends in BOD were downward at two sites and upward at one site.

In the same study that used data collected during 1986-95, trends were observed at one or more sites for 10 of the 13 constituents evaluated at high flows and at one or more sites for 8 of 13 constituents at low flows. All trends observed for TKN and total organic carbon concentrations decreased at one or more sites during high flow and (or) low flow. All trends observed for concentrations of chloride, dissolved oxygen, TDS, hardness, NO3+NO2, total phosphorus, and sodium increased at one or more sites during either high flow or low flow.

Trend tests were conducted on data collected during 1991-97 for the eight constituents used in load analysis. Results from trend tests performed for this study showed similar but fewer significant trends for seven of the eight constituents than results from the other studies. The only exception was NO3+NO2. The other two studies showed upward trends for concentrations of NO3+NO2 at two and at four sites studied with no significant downward trends. In this study, four sites showed a significant downward trend in NO3+NO2, and no sites showed an upward trend. All significant trends for NO3+NO2, TKN, total phosphorus, and total organic carbon (TOC) were downward. The trends for chloride and TDS were upward, except at Neshanic River where the trend was downward. The trend was upward for BOD at one site, and TSS did not change significantly at any site.

Pesticides were detected frequently in the Raritan River Basin; however, concentrations were generally low. Pesticide concentrations were highest during the growing season and were related to land use. Concentrations of atrazine, alachlor, and cyanazine exceeded the NJDEP maximum contaminant levels and health advisory levels at high-flow conditions in the May and June at sites with agricultural land use. Concentrations of chlorpyrifos, chlorthalonil, diazinon, and ethyl-parathion exceeded U.S. Environmental Protection Agency chronic life criteria for the protection of aquatic life. Dieldrin was detected in one sample and 1.1-dichloro-2,2-bis(p-dichlorodiphenyl) ethylene (DDE) was detected in one sample at concentrations that exceeded NJDEP health advisory levels.

Volatile organic compounds (VOCs) were frequently detected in the Raritan River Basin; however, concentrations were generally low. No VOCs exceeded NJDEP maximum contaminant levels or NJDEP health advisory levels. VOC concentrations were generally higher during the nongrowing season than the growing season. Concentrations of some VOCs decreased significantly with increased streamflow. The number of VOCs and total concentrations increased during storm runoff at urban sites. The number of VOCs and total concentrations decreased at a site with little development. 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 basins with predominantly forested land use.

Instantaneous loads and yields were computed from sampled concentrations and flows. Tobit regression analysis was used to develop a relation between total instream load and streamflow. Instream loads were studied at low, median, and high flows, as defined by the 90th, 50th, and 25th percentile flows, respectively. The parts of total instream load that originated from permitted point sources and from nonpermitted point sources were computed from (1) effluent-quality and -quantity data reported for permitted point sources and (2) water-quality and streamflow data from USGS and NJDEP water-quality sites in the basin.

Travel time and attenuation rates were used to estimate the amount of permitted point-source loads in total instream load at the sampling sites at high-, median-, and low-flow conditions. Nonpermitted load was estimated by subtracting the estimated permitted load at the sampling site from the total instream load. Nonpermitted yields were correlated with environmental variables and were evaluated by regression analysis to study the relation between basin characteristics and water quality.

Loads of total organic carbon and TSS were contributed mainly by nonpermitted sources. Permitted loads accounted for less than one-third of the load at all but one site at low flow. Loads from permitted sources accounted for more than a one-third of total phosphorus and NO3+NO2 loads at low- and median-flow conditions at more than one-third of the sites. Permitted sources of TKN accounted for more than one-third of the load at low flow at most sites. Permitted sources accounted for more than one-third of the BOD load at low-flow conditions at a few sites. Loads from permitted sources accounted for more than a one-third of TDS load at low flow at nearly half the sites. TDS loads at median and high flows were contributed primarily by nonpermitted sources.

Samples from the Raritan River site at Bound Brook represented a composite of the water draining from nearly three-quarters of the Raritan River Basin that included the effluent from 70 permitted point sources. The percentage of total annual instream load at the Bound Brook sampling site that was contributed by permitted sources ranged from 4 to 56 percent for seven constituents. Permitted sources accounted for 4 percent of TSS, 10 percent of total organic carbon, 14 percent of BOD, 22 percent of TDS, 35 percent of TKN, 45 percent of total phosphorus, and 56 percent of NO3+NO2.

Nonpermitted yields were related to environmental factors such as land use, soils, lithology, basin shape, and hydrology. Increases in nonpermitted yields of TKN generally increased most strongly with increases in factors that characterize both urban areas and the Coastal Plain at high and median flows and with increases in factors that characterize the New England Province at low flow. Nonpermitted yields of BOD generally increased most significantly with increases in factors that characterize urban areas at low flow and with deceases in factors that characterize soils and lithology in the Coastal Plain at high flow. At high flows, nonpermitted yields of TDS generally increased most significantly at sites that drain areas with the highest percentages of lithology and soil types associated with the Coastal Plain Province. This probably is caused by a greater abundance of frozen precipitation in the province than in other provinces and the subsequent increase in road-salt application, which results in higher concentrations of TDS in runoff. At low flow, nonpermitted yields most strongly correlated with factors that characterize urban and agricultural land use and flow.

Nonpermitted yields of NO3+NO2 generally increased most significantly with increases in septic-system density, flow per unit area, and soil permeability at low flow. Yields at high flow did not correlate with any variables except flow per unit area. Increases in nonpermitted yields of TOC generally were associated most significantly with increases in factors that characterize urban areas, flow per unit area, and permeability. Nonpermitted yields of total phosphorus and TSS generally increased most significantly with factors that characterize the Coastal Plain.

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