Carbon, Nitrogen, and Phosphorus Loading to the Tidal, Freshwater Portion of the Hudson River Estuary from Point and Non-Point Sources: Preliminary Analyses

Interim Report to the Hudson River Foundation

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INTRODUCTION

The Hudson River drains over 3.4 million hectares in New York, parts of Vermont, Massachusetts, Connecticut, and New Jersey (Figure 1). It flows 507 km from its source in the Adirondack Mountains to New York Bay. The Hudson River basin has three major sub-basins: the upper Hudson, the Mohawk, and the lower Hudson. The Mohawk River joins the upper Hudson River just north of Albany, NY. Our study is focused on the tidal freshwater portion of the lower Hudson River, a stretch of estuary approximately 130 km long running from the estuarine salt wedge north to the Troy Dam near Albany. The salt water wedge is generally confined to the lower one third of the river below Newburgh, NY, although in especially dry years it may extend north to Poughkeepsie.

Our study was undertaken to provide estimates of the inputs of dissolved and particulate forms of N, P, and C to the tidal freshwater portion of the Hudson River from the Hudson River basin using models of water flow, sediment erosion, and sediment transport. The nutrient loading estimates from these models are added to estimates of nutrient loading from point sources in the three sub-basins to provide an estimate of the total loads of N, P, and C to the freshwater tidal portion of the Hudson River estuary. Other work has shown that net primary production by phytoplankton in the tidal freshwater portion of the estuary is low and that respiration often exceeds production. Therefore it is likely that allochthanous inputs of organic matter may play an important role in support of the food webs in this system. Inputs of suspended sediment and nutrients may influence rates of phytoplankton and macrophyte production in the river.

A better accounting and understanding of the nutrient loading patterns to the river in conjunction with our on-going field work on oxygen metabolism and macrophyte production will lead to a better understanding of the controls on primary production and the relationship between organic matter inputs and dissolved oxygen concentrations in the river.

This report describes the methods and the data used to make the nutrient and carbon loading estimates. The first section of the report describes the procedures used to estimate the point source nutrient loading. The second section of the report describes the non-point source model. This work to date has been funded by the Hudson River Foundation.

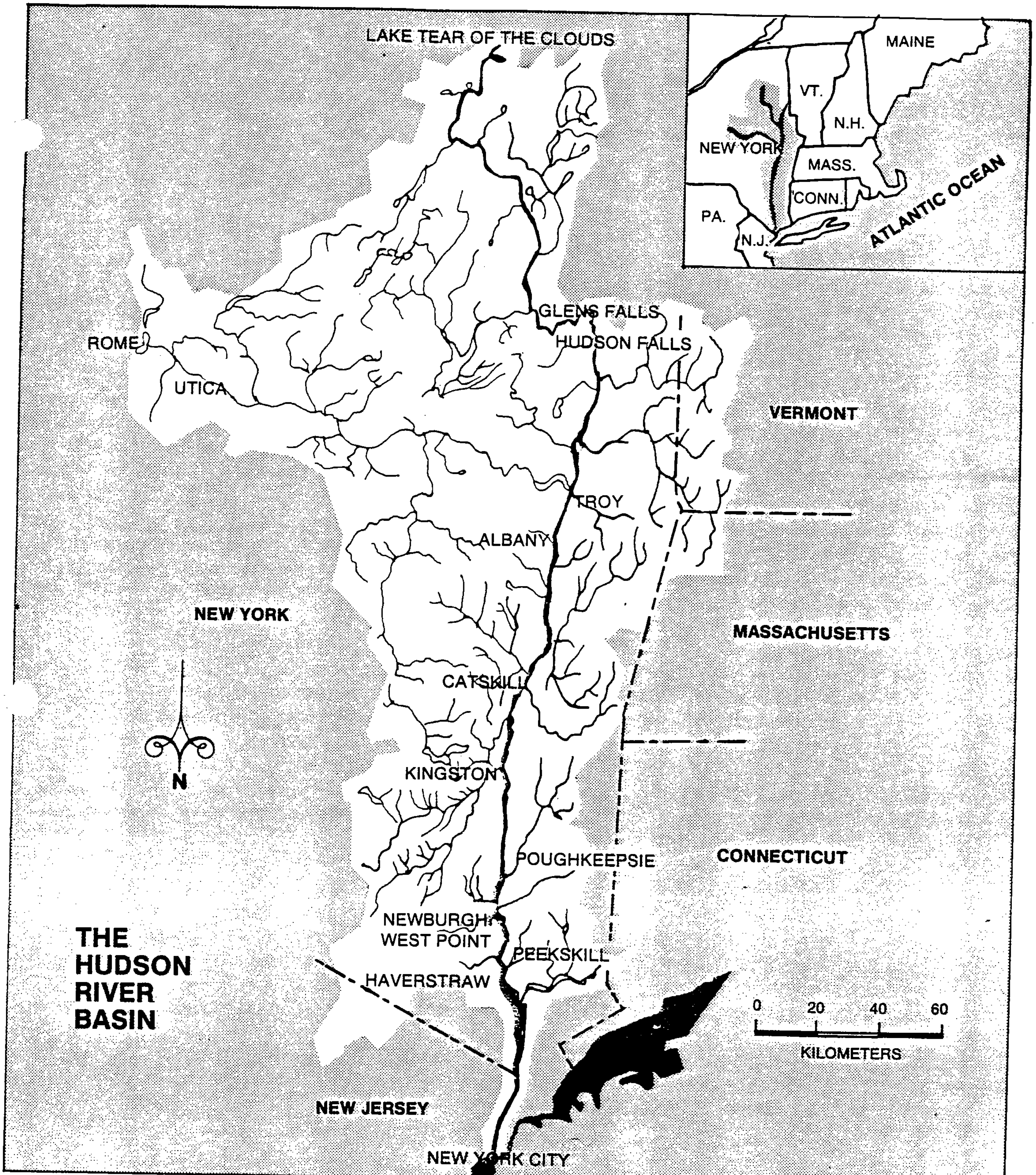

Figure 1. The Hudson River Watershed.

Part I. Point Source Nutrient Inputs to the Hudson River

Two estimates of point source nutrient loading were calculated, one using population data from the 1980 Census of Population for New York State, the other using data from the Department of Environmental Conservation report on sewage treatment systems in New York State (NY DEC 1985).

In order to estimate the input of sewage from point sources, an estimate of the fraction of the total population in the Hudson River basin that is served by a public sewer system is needed. Although there is no direct estimate of the sewered population, there are statistics available on population (Table 1), housing characteristics (Table 2), and sewage disposal for housing units (Table 3), from which an estimate of the sewered population may be derived.

Table 1 lists the total population and the distribution of urban and rural residents of each county in the upper Hudson basin, and Mohawk River basins and that portion of the lower Hudson basin whose watershed feeds into the freshwater estuary (i.e., not New York City, etc.). For the rest of this report, we refer to this as the lower Hudson basin. Rural populations are generally not served by a public sewer system; sewage is commonly disposed of in septic tanks or through direct lines from individual buildings to nearby lakes or streams. The urban population, however, is largely served by a public sewer system. Once the sewage has been treated it is discharged to rivers or other large bodies of water. It is the effluents from the many sewage treatment plants located throughout the Hudson River basin that are the point sources of nutrients to the Hudson and its tributaries. Counties with a high urban population will contribute more point source nutrients than those with a high rural population. About half of the counties in the Hudson River basin have a ratio of urban to rural population greater than 1 (Table 1). The upper Hudson basin has the lowest urban population; the lower Hudson basin has the highest.

Table 1. Population statistics for freshwater Hudson River watersheds (State of NY Dept. of Commerce 1980).

County	Total Population	Urban [a] Population	Rural Population	U/R[b]
LOWER HUDSON				
Albany	285909	246229	39680	6.2
Columbia	59487	7986	51501	0.2
Dutchess	245055	139113	105942	1.3
Greene	40861	7504	33357	0.2
Orange	259603	147157	112446	1.3
Rensselaer	151966	92801	59165	1.6
Ulster	158158	54961	103197	0.5
UPPER HUDSON				
Essex[c]	15888	-0-	15888	0.0
Hamilton[d]	5034	-0-	5034	0.0
Saratoga[e]	153759	71327	82432	0.9
Warren	54854	31616	23238	1.4
Washington[f]	37989	21183	16806	1.3
MOHAWK				
Fulton	55153	27358	27795	1.0
Herkimer[g]	43995	32635	11360	2.9
Montgomery	53439	24427	29012	0.8
Oneida[g]	191475	160480	30995	5.2
Schenectady	149946	133851	16095	8.3
Schoharie	29710	5272	24438	0.2

[a] This definition has 3 components, it includes: 1) the people located in an urban core or "central city", 2) the suburban area surrounding the central city with a density of 1000 persons/sq. mi. (or more), and 3) villages and towns of 2500 persons or more. Rural population is everyone else.

[b] Ratio of urban population to rural population.

[c] Approximately half of this county lies outside of the UHRB. The portion which lies outside is assumed to contain the urban population (along the shore of Lake Champlain). Population in the UHRB is the total population minus the urban population minus half of the rural population.

[d] Approximately half of the area of this county lies outside the UHRB. The portion which lies outside is in Adirondack Park, therefore the total population of this county is assumed to be in the UHRB.

[e] Saratoga county population is assumed to be completely within the UHRB.

[f] Half of this county lies outside the UHRB, however most of the urban areas are within the basin. The population of this county is assumed to be the urban population plus half of the rural population.

[g] Two thirds of the county lies outside of the MRB. Most of the urban population is with the basin. Therefore the basin population is assumed to be the urban population plus one third of the rural population of the county.

Table 2 contains descriptive statistics of housing by county. The sewered population number used in this calculation was obtained by assuming that the population served by the sewer system is a proportion of the urban population. In some counties, the sewered population is estimated to be all of the urban population and some of the rural population. Usually the sewered population is somewhat smaller than the urban population. This is because the urban population, as it is defined (Table 1), includes some of the surrounding suburban area, not all of which is served by the public sewer system.

Table 2. Data on the number of housing units in freshwater Hudson River watersheds by county (State of NY Dept. of Commerce 1980).

County	Housing Units	Urban[a] Units	Rural Units	Seasonal Units	Year-round Units
LOWER HUDSON					
Albany	115733	100738	14995	795	114938
Columbia	25948	3474	22474	1198	24750
Dutchess	86852	49948	36904	1516	85336
Greene	21350	3235	18115	2717	18633
Orange	93274	53673	39601	2998	90276
Rensselaer	57363	35825	21538	1020	56343
Ulster	69280	22016	47264	6110	63170
UPPER HUDSON					
Essex	8669	-0-	8669	2102	6567
Hamilton	7062	-0-	7062	4590	2472
Saratoga	60370	27162	33208	4840	55530
Warren	26825	12317	14508	5136	21689
Washington	14868	7820	7048	1258	13610
MOHAWK					
Fulton	25507	11781	13726	3667	21840
Herkimer	18260	13127	5133	1191	17069
Montgomery	21192	10659	10533	72	21120
Oneida	73803	62788	11015	856	72947
Schenectady	59540	53713	5827	183	59357
Schoharie	12651	1444	11207	1762	10889

[a] Urban housing is defined as: housing units located within the urban population areas (defined in Table 1).

The data used to estimate the sewered population are the number of urban housing units and the urban population. The urban population is divided by the number of urban housing units to obtain an average number of persons per urban housing unit. This number is then multiplied by the number of housing units served by the sewer system (Table 3) to obtain an estimate of the sewered population. The calculation is illustrated below.

$$SP = (UP/UHU) * SHU$$

where:

SP	sewered population
UP	total urban population
UHU	total urban housing units
SHU	total sewered housing units

Table 3. Sewage disposal for housing units in the freshwater Hudson River watersheds.

County	Housing units with public sewer	Housing units with Septic/Cesspool	Housing units using other means[a]	Unaccounted for[b]
LOWER HUDSON				
Albany	98099	15682	1267	685
Columbia	6437	17926	415	1170
Dutchess	39355	45244	846	1407
Greene	5112	13296	368	2574
Orange	55308	34534	595	2837
Rensselaer	34986	20771	724	882
Ulster	21934	40598	989	5759
UPPER HUDSON				
Essex	6346	8270	351	4157
Hamilton	380	2087	71	4524
Saratoga	27736	27182	763	4689
Warren	9283	12016	444	5082
Washington	7136	11707	540	2534
MOHAWK				
Fulton	11932	10073	311	3191
Herkimer	14175	10390	396	3565
Montgomery	14442	6509	184	57
Oneida	66753	26296	604	2181
Schenectady	42421	16729	193	197
Schoharie	2668	7900	394	1689

[a] Other means includes outhouses and individual sewer lines leading to nearby water outlets (streams, marshes, swamps, lakes, etc.).

[b] "Unaccounted for" is the difference between the total number of housing units reported for a county and the total number of housing units reported under the 3 sewage disposal categories. In all cases the number of housing units reported for a county exceeds the number accounted for in the above 3 categories because seasonal housing units have not been categorized. Small discrepancies (after seasonal housing has been accounted for) are due to sampling error.

For those counties that have more housing units served by the sewer system than there are urban housing units (eg. Columbia County), the number of rural persons per rural household is calculated and multiplied by the difference between the total number of units with sewers and the total number of urban housing units.

$$SP = UP + (RP/RHU) * (SHU - UHU)$$

where:

SP	is the sewered population
UP	is the total urban population
RP	is the total rural population
RHU	is the total number of rural housing units
SHU	is the total sewered housing units
UHU	is the total number of urban housing units

The resulting estimates of the sewered population for the counties in each sub-basin of the Hudson River basin are given in Table 4.

Table 4. Estimates of the sewered population by county.

County	Sewered Population	Proportion of Total
LOWER HUDSON		
Albany	235438	.82
Columbia	14805	.25
Dutchess	110194	.45
Greene	11758	.29
Orange	149332	.58
Rensselaer	90964	.60
Ulster	54835	.35
TOTAL	667326	
UPPER HUDSON		
Essex	4104	.26
Hamilton	266	.05
Saratoga	72762	.47
Warren	24136	.44
Washington	19267	.51
TOTAL	120535	
MOHAWK		
Fulton	27660	.50
Herkimer	34941	.79
Montgomery	35019	.66
Oneida	171582	.90
Schenectady	106053	.71
Schoharie	7965	.27
TOTAL	383220	

The estimate of the sewered population was then used to obtain an estimate of the total sewage effluent generated in each county. The sewered population was multiplied by the average amount of waste water produced per person, 100 gal./person/day, (Metcalf and Eddy 1979), converted from gal. to m^3 ($3.8 * 10^{-3}$ m^3/gal), and multiplied by 365 to obtain an annual value of sewage effluent. The estimates of nitrogen, phosphorus, and carbon were then calculated by multiplying the annual effluent for each county by the concentration of N, P, or C in treated effluent. We assumed 40 g N/m3,10 g P/m^3 and 14.5 g organic C/m^3, for our model (Metcalf and Eddy 1979). Results are listed in Table 5.

Table 5. Estimate of total effluent produced annually, by county, estimated from sewered population data.

County	Effluent 10^6m^3/yr	N t/yr	P t/yr	C t/yr
LOWER HUDSON				
Albany	33	1320	333	483
Columbia	2	..80	21	30
Dutchess	15	600	153	222
Greene	2	..80	16	24
Orange	21	840	207	300
Rensselaer	13	520	126	183
Ulster	8	320	76	110
TOTAL	94	3760	932	1352
UPPER HUDSON				
Essex	0.57	22.80	5.7	8.26
Hamilton	0.04	1.60	0.4	0.58
Saratoga	10.09	403.60	100.9	146.30
Warren	3.35	134.0	33.5	48.58
Washington	2.67	106.80	26.7	38.72
TOTAL	16.72	668.80	167.20	242.44
MOHAWK				
Fulton	3.84	153.60	38.4	55.68
Herkimer	4.85	194.00	48.5	70.32
Montgomery	4.86	194.40	48.6	70.47
Oneida	23.80	952.00	238.00	345.10
Schenectady	15	600	147	213
Schoharie	1.10	44.00	11.0	15.95
TOTAL	53.45	2138	531.5	770.52

A second estimate of sewage input to the Hudson River was made using information from all municipally-owned sewage treatment plants (STP) located in New York State. For each treatment plant, information on the county, drainage basin, receiving water body, year that construction began, year that improvements were made, design flow, collection system, and specific information about the treatment plant design are given in a report issued by the New York DEC (NY DEC 1985). An estimate of total effluent produced for each county was obtained by summing the effluent from all treatment plants within a county that discharged into the Hudson and Mohawk Rivers or a major tributary of the these rivers (eg. Fishkill Creek, Wallkill River, Normans Kill Creek, Hoosick River, Roundout Creek, Wappingers Creek, Esopus Creek, and Kinderhook Creek). The resulting estimates of total annual effluent for each county are listed in Table 6.

Table 6. Annual effluent from treatment plants discharging into freshwater portions of the Hudson River and major tributaries. Discharge and effluent is reported in units of $10^6 m^3/yr$.

County	Number of Treatment Plants	Dischg. into main River channel[a]	Dischg. into Tributary	Total Annual Effluent
LOWER HUDSON				
Albany	7 of 9	92.5	10.9	103.4
Columbia	3 of 6	5.1	0.4	5.5
Dutchess	7 of 19	25.0	2.1	27.1
Greene	4 of 5	3.6	-	3.6
Orange	10 of 32	10.8	14.1	24.9
Rensselaer	4 of 4	37.1	1.0	38.1
Ulster	10 of 16	0.9	12.3	13.2
TOTAL	45 of 91	175	40.8	215.8
UPPER HUDSON				
Essex	0 of 2	-	-	-
Hamilton	1 of 2	-	0.4	0.4
Saratoga	4 of 6	19.6	1.4	21.0
Warren	1 of 3	5.0	-	5.0
Washington	2 of 6	1.0	0.3	1.3
TOTAL	8 of 19	25.6	2.1	27.7
MOHAWK				
Fulton	1 of 1	-	13.2	13.2
Herkimer	4 of 5	18.6	1.4	1.4
Montgomery	5 of 6	23.6	-	23.6
Oneida	5 of 8	49.9	3.7	53.6
Saratoga	1 of 1	2.1	-	2.1
Schenectady	4 of 4	26.1	-	26.1
Schoharie	2 of 5	-	0.4	0.4
TOTAL	22 of 30	94.2	44.8	139.0

We have assumed that all treatment plants release effluent at a constant rate given for design flow, ie. that there is no seasonal variation in flow rates. Design flow is the maximum amount of effluent a treatment plant discharges when it reaches its maximum design capacity. We have also assumed that influent = effluent, ie. that no water is lost in the treatment process, and that the level of treatment provided by all of the plants is the same (secondary). Most of the sewage treatment plants in NY State have been upgraded to treat water at the secondary level (NY DEC 1985). The treatment plant statistics that we used do not include treatment plants that are privately owned or municipally-owned plants which provide service to other than the general public (ie. subdivisions and institutions).

Once the total effluent was tabulated for each county, the conversion factors used in the previous section were multiplied by the total annual effluent to estimate the N, P, and C content of effluent from the population estimates. The results are shown in Table 7.

Table 7. Annual nitrogen, phosphorus, and carbon loads from point sources in the three sub-basins of the freshwater Hudson River watersheds estimated from sewage treatment plant data.

Sub-basin	Total Annual Effluent $10^6 m^3/yr$	N t/yr	P t/yr	C t/yr
LOWER HUDSON	215.8	8632	2158	3129
UPPER HUDSON	27.7	1108	277	402
MOHAWK	139.0	5560	1390	2016
TOTAL	382.5	15300	3825	5547

The estimates of total annual effluent derived from population data are consistently lower than those derived from the sewage treatment plant data (56%, 40%, and 62% lower for the lower Hudson, upper Hudson, and Mohawk basins, respectively). The estimates made using the sewage treatment plant data are based on design flow (ie. maximum flow possible for proper functioning of a treatment plant), and the actual flow may well be less than the design flow. Another reason that the sewage treatment plant estimate may be higher than the population-based estimate is that some industries discharge to the municipal sewage treatment systems. The population-based estimate does not account for any industrial effluent.

Limburg et al. (1986) also estimated the input of carbon to the lower Hudson River from point sources. Table 8 shows the annual sewage effluent and the point-source carbon input associated with it, as estimated by our 2 methods and as estimated by Limburg et al. (1986). There are several reasons for the discrepancy between our estimates of the total amount of effluent discharged per day and in the estimates of the amount of carbon contained in the effluent and those of Limburg et al. (1986).

Table 8. Estimates of carbon and effluent flow to the lower Hudson drainage basin.

	Population-Based Estimate	Treatment Plant Estimate	Limburg et al. Estimate
Annual flow ($10^6.m^3.$)	94	215.8	4745[a]
Carbon Input (mtC/yr)	1584	3129	57649

[a] This includes 4097 million m^3 of industrial flow, most of which is cooling water.

The amount of effluent differs because Limburg et al. (1986) include inputs to the lower Hudson south to the Battery in their calculations, as well as discharges from industrial sources. Effluent inputs from Putnam, Westchester, and Rockland counties and from the Manhattan area are not included in our estimates, which are based upon inputs to the freshwater lower Hudson, north of the salt wedge (near Newburg, NY). We excluded inputs to the saline water of the estuary because these cannot influence the functioning of the freshwater portions of the river. We have also excluded inputs from industrial sources that are not processed in municipal treatment systems.

Table 9 gives a breakdown of the total effluent and carbon input as estimated by Limburg et al. (1986). If the municipal flow from the lower Hudson in Table 9 is compared to the two estimates of effluent flow in Table 8, the estimate given by Limburg et al. (1986) is 35 % larger than our sewage treatment estimate and more than double our population-based estimate. If the effluents from Putnam, Rockland, and Westchester counties are added to our estimates, the population-based effluent would be 231 million m^3 per year and the treatment plant-based estimate would be 407 million m^3 per year. The Limburg et al. (1986) estimate lies between these two values. It seems, therefore, that the differences in flow estimates can be accounted for primarily by Limburg et al.'s inclusion of discharge from New York City, Putnam, Rockland, and Westchester counties and industrial discharge.

Table 9. Data from Table 2.1 of Limburg et al. (1986).

	Industrial			Municipal		
	Annual Flow $10^6 m^3$	BOD mt/y	C mt/y	Annual Flow $10^6 m^3$	BOD mt/y	C mt/y
Lower Hudson	3987.2	8116.8[a]	6059	292	20257.5[b]	14709.5
Manhattan area	-	2774[c]	2007.5	365	47997.5[d]	34857.5
Total	3987.2	11096	8066.5	657	68255	49567

[a]Here, the lower Hudson number represents RM 14-152. The values are calculated from data in Table 5 of Hetling (1976).
[b]Calculated from 1974 data in Hetling (1976), Table 3.
[c]1973 data of McFadden et al. (1977) from Table 3.6-2.
[d]Calculated from 1974 data in Appendix Table 4 (p.28) of Hetling (1976).

Table 9 also lists the carbon inputs estimated by Limburg et al. (1986). They did not apply a conversion factor for carbon to their effluent estimates but rather used published estimates of BOD inputs and then estimated the organic carbon equivalents. The estimate of Limburg et al. (1986) corresponded to organic carbon concentrations in the municipal effluant streams of 50-90 g C/m^3. These values are reasonable for untreated sewage (Metcalf and Eddy (1979) but are much higher than the value of 14.5 g C/m^3 we assumed for treated sewage. It is the difference in carbon concentration of effluent that accounts for the large difference in our two point source carbon loading estimates. For inputs to the freshwater portion of the river, our lower assumption seems more reasonable since most sewage input to that stretch is treated.

We use our sewage treatment plant-based estimate of point source nutrient inputs to make our final loading calculations. Over half of the sewage treatment plants are operating at design flow and, these estimates incorporate some of the industrial discharges to the Hudson and Mohawk Rivers and their tributaries. Thus, we feel that this estimate would be more appropriate than the estimate based upon population and housing statistics.

PART II: Non-Point Source Inputs of Carbon, Nitrogen, and Phosphorus

For non-point source inputs, we used a modelling approach developed by Haith and Shoemaker (1987). This technique uses generalized watershed hydrologic functions to compute dissolved and particulate substance exports from different land-use areas within the basin. We used data on soil characteristics, agricultural practices (eg. cropping practices, crop types), and land use of the Hudson River basin to designate uniform source areas. Alternative approaches include: 1) the use of export coefficients for N, P, and C multiplied by the area of the watershed to obtain an annual nutrient load, or 2) the use of a chemical simulation model. The use of export coefficents provides only an annual value of nutrient loading to the watershed. However, by using the watershed loading functions, as we have done here, the seasonal distribution of nutrient loading also can be estimated. While the chemical simulation model would provide a detailed picture of nutrient transport within the basin, the data needed to construct a complex, detailed model such as this are not available at this time. The use of generalized watershed loading functions provides a good compromise between the simplicity of using export coefficients and the complexity of using chemical simulation models (Delwiche and Haith 1983, Haith and Tubbs 1981, Haith and Shoemaker 1987).

INPUT DATA

Precipitation and Temperature Data

Precipitation and temperature data are primary inputs to the model. From these data rainfall, snowfall, evapotranspiration, snow melt, and sediment supply are calculated. It is necessary to use daily weather data to obtain a reasonable estimate of runoff for the watershed. Total monthly precipitation does not adequately represent the dynamics of water movement or of important factors influencing runoff (eg. soil moisture conditions and intensity of precipitation). Hourly data would be preferable to determine the effects of rainfall intensity on runoff and soil erosion. However, manipulation of hourly data is extremely cumbersome and often not available for sufficient areal coverage of a watershed of this size. A daily time step represents a compromise between an extremely rough water balance that could be estimated using monthly averages and a more refined estimate that would reflect specific runoff events.

Data from all NOAA weather stations (53 stations) in each of the 3 sub-basins of the freshwater Hudson River basin (the lower Hudson River basin, the upper Hudson River basin, and the Mohawk River basin) were used to produce daily temperature and precipitation input for 3 years (April 1983 through March 1986, NOAA 1983-1986). The weather stations within each sub-basin are listed in Table 10; locations are shown in Figure 2. A daily temperature and precipitation value is calculated for each of the three sub-basins. To determine a daily precipitation value for a given sub-basin, the arithmetic mean of all data from the stations of the sub-basin for a particular day is calculated. This value is then assumed to be the amount of precipitation falling uniformly throughout the respective sub-basin on that date.

For each date the high and low temperature of the day are recorded at each of the stations in the Hudson River basin. To obtain the daily temperature value used in the model for a given sub-basin, the arithmetic mean of the high and low temperature values for each station within the respective sub-basin is calculated. This value is then assumed to be the daily air temperature throughout the sub-basin.

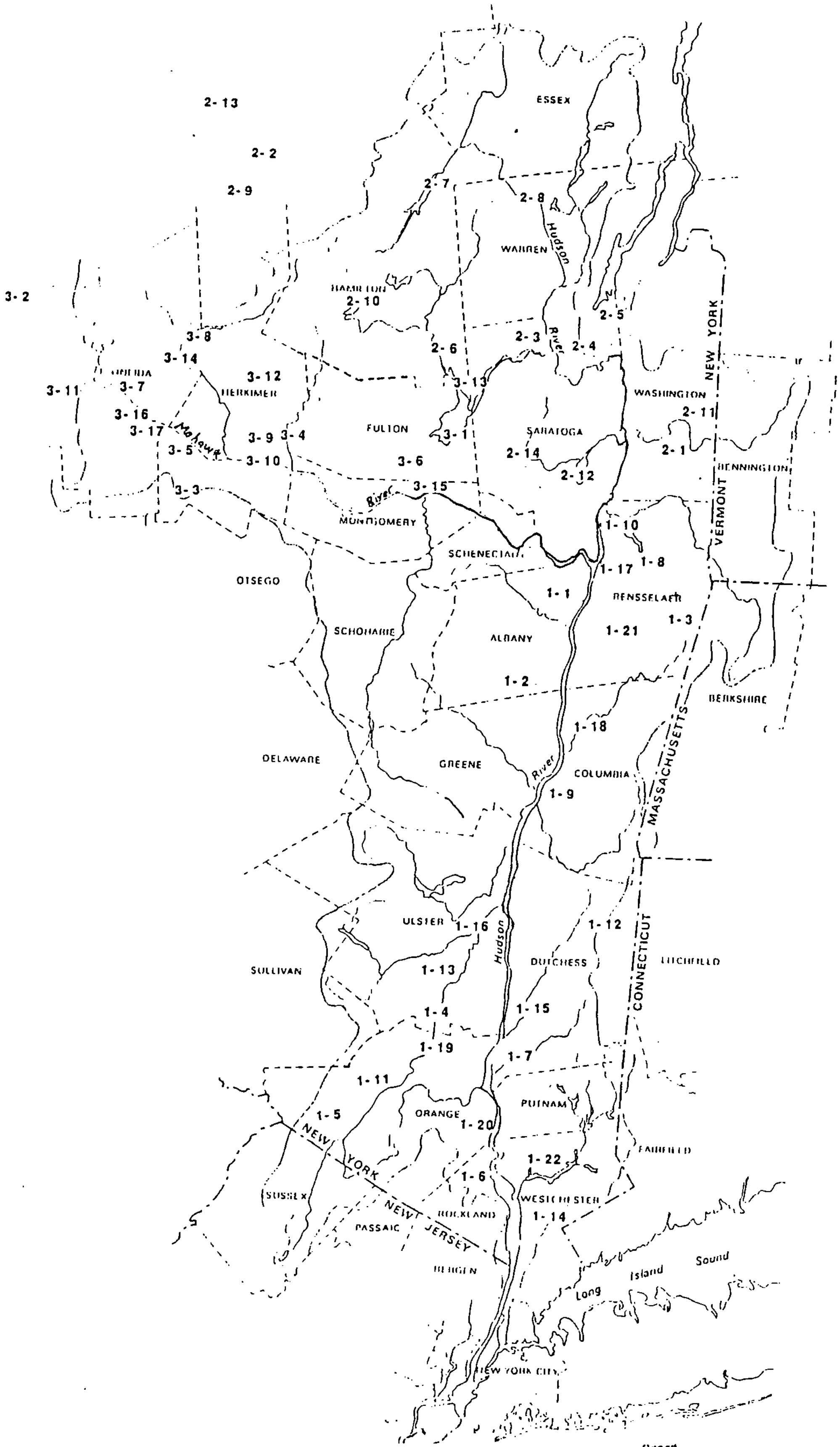

Figure 2. NOAA weather stations in the Hudson River Watershed. Station names corresponding to the numbers shown are listed in Table 10.

Table 10. Precipitation and temperature stations in the Hudson River basin (NOAA 1985, 1986). All stations listed record precipitation data. Those marked with an asterisk are stations that record temperature and precipitation.

* Albany WSFO AP (1-1)	* Middletown 2 NW (1-11)
* Alcove Dam (1-2)	* Millbrook (1-12)
Battenville (2-1)	* Mohonk Lake (1-13)
Berlin 5S (1-3)	New London Lock 22 (3-11)
Big Moose 3 SE (2-2)	Newport 6, NE (3-12)
Broadalbin (3-1)	North Creek 5 SE (2-8)
* Camden 2 NW (3-2)	Northville (3-13)
Chepachet (3-3)	* Old Forge (2-9)
* Conklingville Dam (2-3)	Piseco (2-10)
Dolgeville (3-4)	* Pleasantville (1-14)
Frankfort Lock 19 (3-5)	Poughkeepsie FAA AP (1-15)
Gardiner (1-4)	Rosendale 2 E (1-16)
Gardinerville (1-5)	* Salem (2-11)
* Garnerville (1-6)	* Saratoga Springs 4 SW (2-12)
* Glenham (1-7)	* Stillwater Reservoir (2-13)
* Glens Falls Farm (2-4)	Trenton Falls (3-14)
* Glens Falls FAA AP (2-5)	Tribes Hill (3-15)
* Gloversville (3-6)	* Troy Lock & Dam 2 (1-17)
* Grafton (1-8)	* Utica FAA AP (3-16)
* Griffiss AFB (3-7)	* Utica 3 W (3-17)
Hinckley 1 SE (3-8)	* Valatie 1 N (1-18)
Hope (2-6)	* Walden 1 ESE (1-19)
* Hudson Correctional FAC (1-9)	West Milton (2-14)
* Indian Lake 2 SW (2-7)	* West Point (1-20)
* Little Falls City RES (3-9)	West Sand Lake 2 S (1-21)
* Little Falls Mill St (3-10)	* Yorktown Heights (1-22)
Melrose 1 NE (1-10)	

1 = Lower Hudson River basin
2 = Upper Hudson River basin
3 = Mohawk River basin

Land Use

The entire Hudson River basin (3,054,258 ha) is assumed to be characterized by four land uses: forest, row crop agriculture, pasture, and urban/suburban area. In order to facilitate the calculation of areal distribution of the land uses, the Lower Hudson basin (freshwater) is considered to fall within the boundaries of the counties in this area (Table 11). The upper Hudson and Mohawk basins both have partial areas of some counties. In these cases, all statistics were apportioned to reflect the proportion of the county within the respective basin (Table 11). Land-use statistics from the neighboring states of Vermont, Massachusetts, and Connecticut were not incorporated into the calculations. We have assumed that since most of the areas of these states that fall within the hydrologic boundary of the Hudson River basin are forested, they would not be significant contributors of nutrients or Carbon to the River in any case.

Data on forest areas were obtained from the NY Department of Conservation (1981) report on forest resources, and data on agricultural area were obtained from the NY Crop Reporting Service (1985). These are reported in Tables 11 and 12. Data on total land area by county were taken from the forest reports. Area of urban/suburban use is not reported in either of the above-mentioned sources and was calculated by difference. The sum of cropland, pasture and forest subtracted from the total land area yields hectares of urban/suburban area. For the lower Hudson, upper Hudson, and Mohawk basins, the areas of suburban/urban land are 323436, 82860, and 91809 hectares, respectively. The total area under cultivation for the five crop categories shown in Table 12 was subtracted from the total area of cropland shown in Table 11 to obtain an estimate of inactive agricultural area for each of the three sub-basins. This value is needed to calculate a runoff curve number from agricultural areas (see below).

Table 11. Land use data for the Hudson River basin in hectares (NY State DEC 1981, Table 2a; NY Crop Reporting Service 1985).

County	Total Land Area	Cropland	Pasture	Forest	
LOWER HUDSON					
Albany	136238	21490	2630	6613	
Columbia	167060	40227	4937	89722	
Dutchess	210574	31728	6273	122179	
Greene	169132	12100	4047	126792	
Orange	215754	35330	5504	117565	
Rensselaer	172240	28127	2995	103563	
Ulster	295528	21570	2307	231246	
TOTAL	1366526	156554	29341	857195	
Percent		11	2	63	
UPPER HUDSON					
Essex[a]	236082	6617	648	216778	
Hamilton[a]	224689	-	-	219712	
Saratoga	211860	23027	2711	151398	
Warren	229748	1093	202	211901	
Washington[a]		108257	32801	4958	55930
TOTAL	1010636	63538	8519	855719	
Percent		6	1	85	
MOHAWK					
Fulton	128979	10320	1012	102956	
Herkimer[b]	122664	17389	3467	92284	
Montgomery	105667	51518	3845	33145	
Oneida[b]	104534	25051	5140	56519	
Schenectady	53615	6192	728	26993	
Schoharie	161637	38123	6678	103927	
TOTAL	677096	148593	20870	415824	
Percent		22	3	61	

a 50 % of the area of this county falls within the basin.
b 33% of the area of this county falls within the basin.

Table 12. Crop area data for the Hudson River basin (NY Crop Reporting Service 1985) in hectares.

County	Oats[a]	Corn[a,b]	Wheat[a]	Alfalfa[c]	Other[c]
LOWER HUDSON					
Albany	364	2630	*	3764	7366
Columbia	971	11372	162	7811	6637
Dutchess	890	8013	121	7649	5949
Greene	*	1538	*	2590	5747
Orange	*	7730	*	4128	9956
Rensselaer	445	6070	*	5504	6799
Ulster	*	2064	*	1174	5747
Total	2671	39417	283	32619	48199
Percent	2	32	>1	26	39
UPPER HUDSON					
Essex	81	1538	243	1396	2307
Hamilton	-	-	-	*	*
Saratoga	567	5059	*	4330	5909
Warren	-	81	-	162	607
Washington	364	8438	*	5018	7973
Total	1012	15116	243	10906	16796
Percent	2	34	<1	25	38
MOHAWK					
Fulton	567	1862	*	2185	3845
Herkimer	1518	4270	*	4748	3575
Montgomery	1497	11655	324	13679	13679
Oneida	1376	5666	283	5356	5045
Schenectady	162	809	*	688	3238
Schoharie	1416	6839	*	9227	12222
Total	6536	31101	607	35883	41604
Percent	6	27	<1	31	36

* included in other counties

[a]oats, corn, and wheat statistics are for hectares planted.
[b]corn includes both grain and silage.
[c]the sum of Alfalfa and Other is equal to Hay, reported here as hectares harvested.

WATER BALANCE

Calculation of Runoff

The method used to calculate runoff in this study was originally developed by the Soil Conservation Service (Mockus 1972) to estimate direct runoff, including channel runoff, surface runoff, and subsurface flow. Channel runoff is assumed to be negligible. The proportions of surface runoff and subsurface flow are evaluated by using runoff curve numbers.

The first steps in calculating runoff are: 1) to determine the daily rate of evapotranspiration, and 2) to determine if precipitation occurs as snow or rain, and if there is snow, to determine whether it melts or accumulates.

The equation used to calculate runoff from rural areas is :

$$Q_t = \frac{(R_t + M_t - 0.2W_t)^2}{(R_t + M_t + 0.8W_t)} \quad \text{for } (R_t + M_t) >= 0.2W_t \qquad \text{(eq. 1)}$$

where
Q_t is the runoff on day t
R_t is the precipitation as rain on day t
M_t is the snow melt on day t
W_t is the detention parameter of the watershed on day t

R_t is determined by examining the daily precipitation and the daily temperature. If the temperature on day t is less than or equal to 0^{o} C, then R_t is zero. If the temperature on day t is greater than 0^{o} C, then R_t is equal to the total precipitation occurring on day t.

If precipitation occurs on day t and the temperature on day t is less than or equal to 0^{o} C, the total precipitation for that day is assumed to fall as snow (SN_t). The total amount of snow is accounted for with the following equation:

$$SN_{(t+1)} = SN_t + \Delta SN_t - M_t \qquad \text{(eq. 2)}$$

where
$SN_{(t+1)}$ is the accumulated snow present on day t+1
SN_t is the accumulated snow present on day t
ΔSN_t is the new snow falling on day t
M_t is the accumulated snow that melts on day t

The amount of snow melting on a given day is proportional to temperature when T_t is greater than zero. For all temperatures 0^{o} C and below, there is no snow melt. This is obviously a simplification since factors such as rain and radiation also generate snowmelt. The equation for snow melt is: