NUTRIENT BUDGETS AND THE EFFECTS OF DEVELOPMENT ON TROPHIC CONDITIONS IN LAKES

BY

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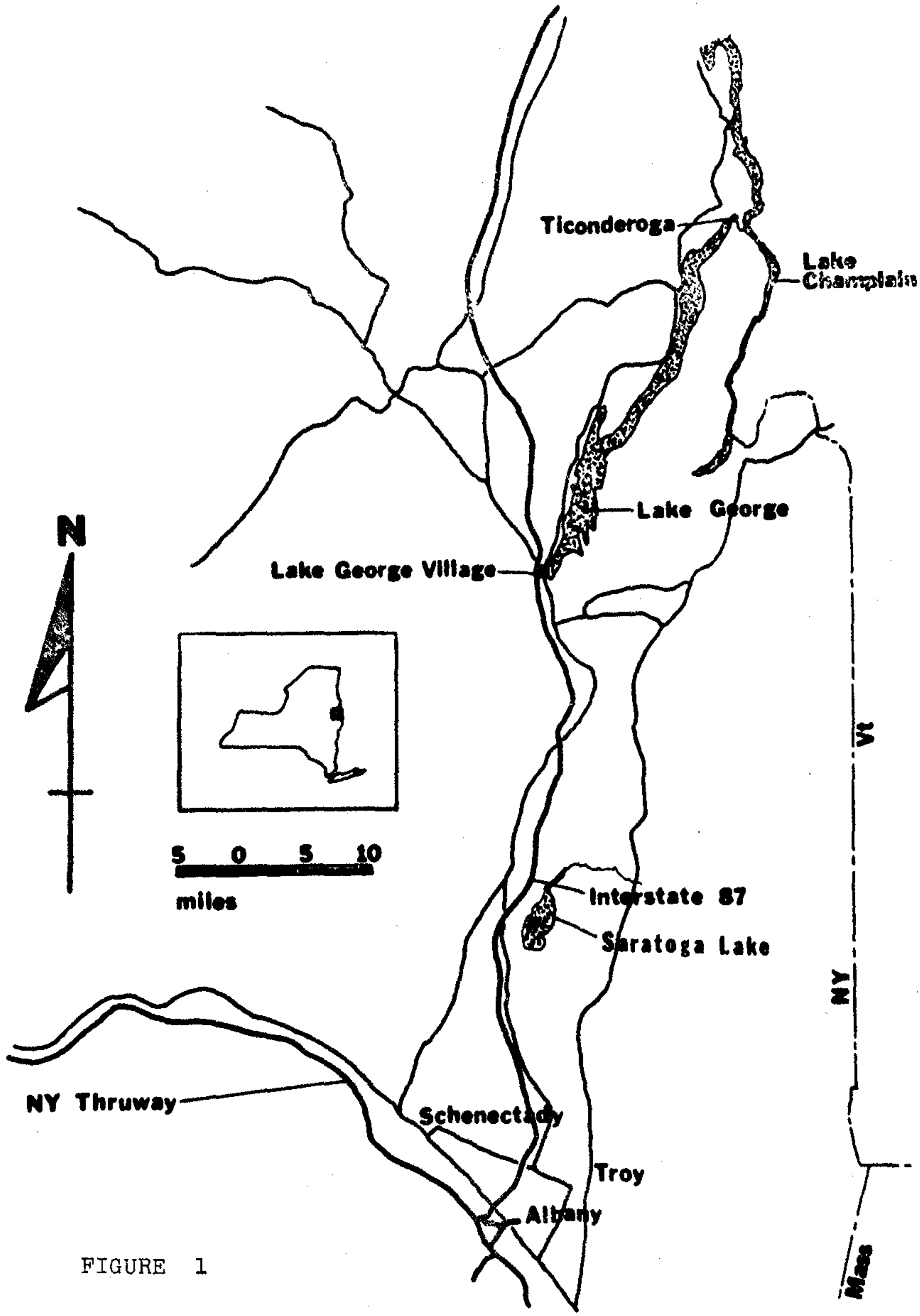
INTRODUCTION

Concern for water pollution has created the largest public works program in the history of the United States. In response to the concern for the poor quality of the lakes and streams within the nation, a massive program of collection and treatment of domestic sewage and industrial wastes was initiated. At the present time, as the result of new waste collection and treatment facilities, we are well on our way towards elimination of all point sources of pollution. There is no question that in many instances our lakes and rivers are showing improvement as the result of the elimination of waste discharges to these bodies of water. However, in our rush to get the job done we may not be taking the time to assess the impacts or the benefits of these waste treatment plants. Even worse, in some instances development, which was restricted due to lack of adequate sewers and sewage treatment facilities, has been allowed to occur, possibly resulting in increasing the nutrient loading to lakes and streams. These possibilities will be evaluated in terms of two case studies of lakes in New York State.

Both Saratoga Lake and Lake George are located along the eastern edge of central New York State (Figure 1). Although they are only about 40 km (25 mi) apart, they are considerably different in their characteristics. The



Ticonderoga
Lake Champlain
Lake George
N
Lake George Village
5 0 5 10
miles
Interstate 87
Saratoga Lake
Vt
NY
NY Thruway
Schenectady
Troy
Albany
Mass

FIGURE 1

morphological characteristics of Saratoga Lake [1] and Lake George [7] are shown in Tables 1 and 2, respectively. Saratoga Lake is the smaller of the two and is also shallower On the other hand, the drainage basin area of Saratoga Lake is larger than that of Lake George. This obviously results in a larger ratio of drainage basin area to lake surface for Saratoga Lake than for Lake George. The hydraulic detention time at the mean flow is only 130 days for Saratoga Lake, whereas it is approximately 8 years for Lake George.

The greatest difference between the two lakes, however, is not their morphological characteristics but their trophic nature. Saratoga Lake is a highly nutrified lake which suffers during the summer from excessive algae and weed growths, depletion of the dissolved oxygen in the hypolimnion and even occasional depletion of oxygen in the lower portions of the epilimnion on calm days during periods of peak algae growth [1]. Lake George, on the other hand, is an oligotrophic to mesotrophic lake which exhibits only minor depletion of the dissolved oxygen in the hypolimnion throughout the summer and is characterized by extremely clear water throughout its entire depth. There are no significant algae blooms in the main body of Lake George and only a few bay areas exhibit aquatic weed growths [7].

Both lakes do have on thing in common, i.e., plans have been set forth to construct sewage treatment plants to eliminate discharge of raw or treated sewage effluents into the lake or its watershed. There is a slight difference in that the sewage treatment plant for the Saratoga Lake area began operation in November of 1977 and since that time there has been no discharge of raw or treated wastes into the Saratoga Lake watershed. On the other hand, at Lake George discussion is still underway as to the need and desirability of the construction of a treatment system which would divert all of the wastewaters out of the Lake George Basin. The results shown in this paper for Saratoga Lake are based on studies which were conducted prior to the completion of the sewage treatment system. Thus, two lakes are compared on an equal basis, that is, the projected benefits or impact of the construction of a sewage treatment system upon the water quality within the lake.

SARATOGA LAKE

A detailed map of the Saratoga Lake Drainage Basin area is shown in Figure 2. This map includes the drainage basin of the outlet of Saratoga Lake and, therefore, actually includes all of the drainage basin area which could be considered the Fish Creek Drainage Basin. The main inlet to Saratoga Lake is the Kayaderosseras Creek and the only outlet is Fish Creek which ultimately flows into the Hudson River at Schuylerville. The major sources of pollutants to the Saratoga Lake Drainage Basin were: 1) the inadequate primary treatment system for the Village of Ballston Spa, 2) a package treatment plant for the development of Geyser Crest, both of which discharged into the

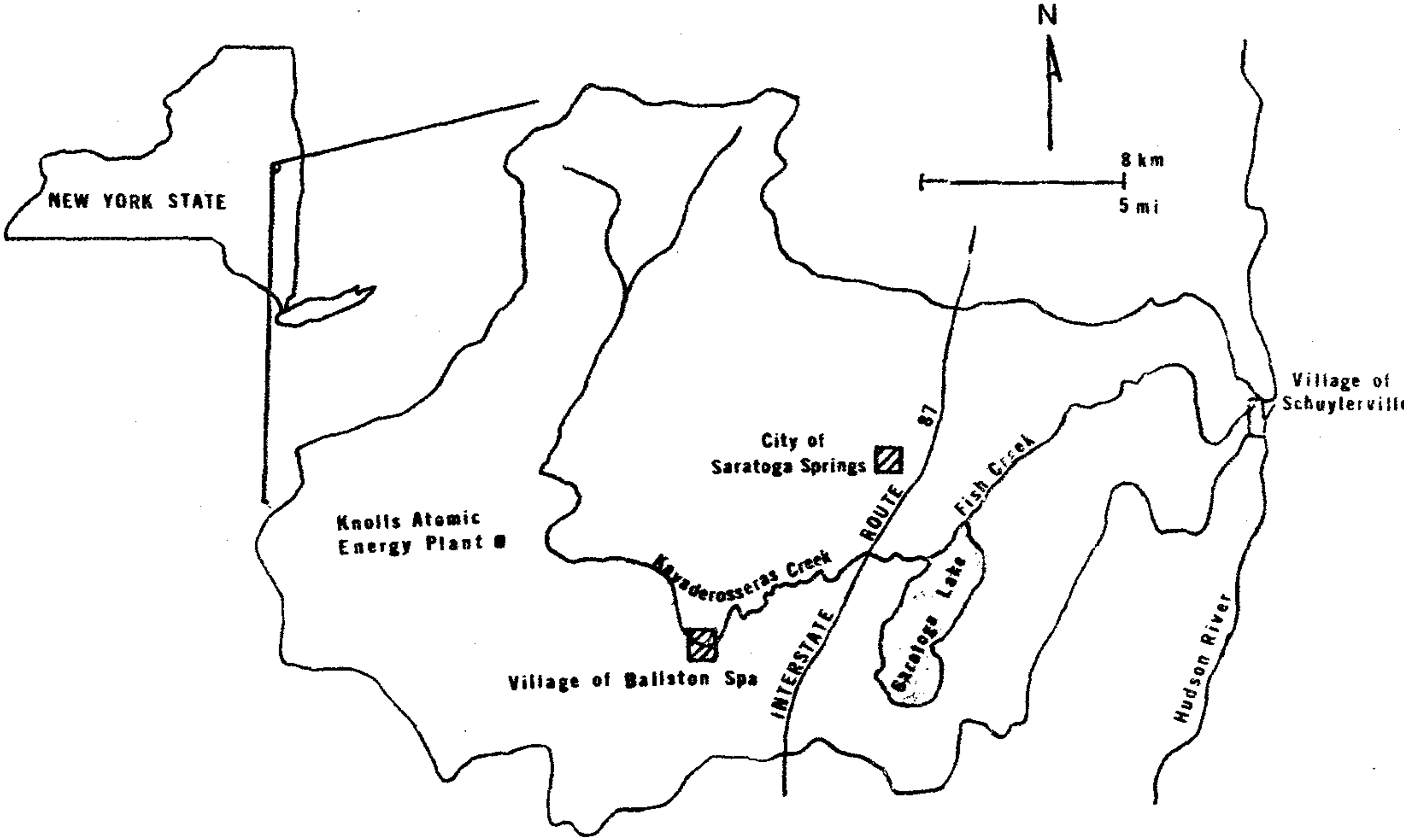


FIGURE 2

SARATOGA LAKE DRAINAGE BASIN

Kayaderosseras Creek, and 3) the high-rate sand filtration system for the City of Saratoga Springs, which actually passed through Lake Lonely before the confluence with the Kayaderosseras Creek just upstream from the discharge into Saratoga Lake. This is shown in Figure 3. Actually Lake Lonely has served as a stabilization pond providing some additional removal of the nutrients from the Saratoga Springs Sewage Treatment Plant prior to their reaching Saratoga Lake itself.

Studies were conducted at Rensselaer Polytechnic Institute (RPI) of the quality of Saratoga Lake during the period of 1971 through 1974 [3,15-17]. At about the same time the Environmental Protection Agency (EPA) also conducted studies of Saratoga Lake as a portion of their lake studies program [18]. Thus, the results of both the RPI and EPA studies are compared in Table 3 showing the nitrogen loadings to Saratoga Lake and Table 4 showing the phosphorus loadings to Saratoga Lake. No claim is made that one study or the other is significantly better, only that different results can be obtained under different circumstances. The RPI data were taken over a more concentrated period of time and more samples were secured. EPA secured samples on approximately a monthly basis and had all its samples analyzed in its central laboratory in Las Vegas. A minor error was found in the original report [18] of the nutrient loadings due to an error in the flow calculation. Thus, the data shown in Tables 3 and 4 for the EPA studies have

SARATOGA LAKE

DEPTH CONTOURS IN FEET

10 FT = 3 M

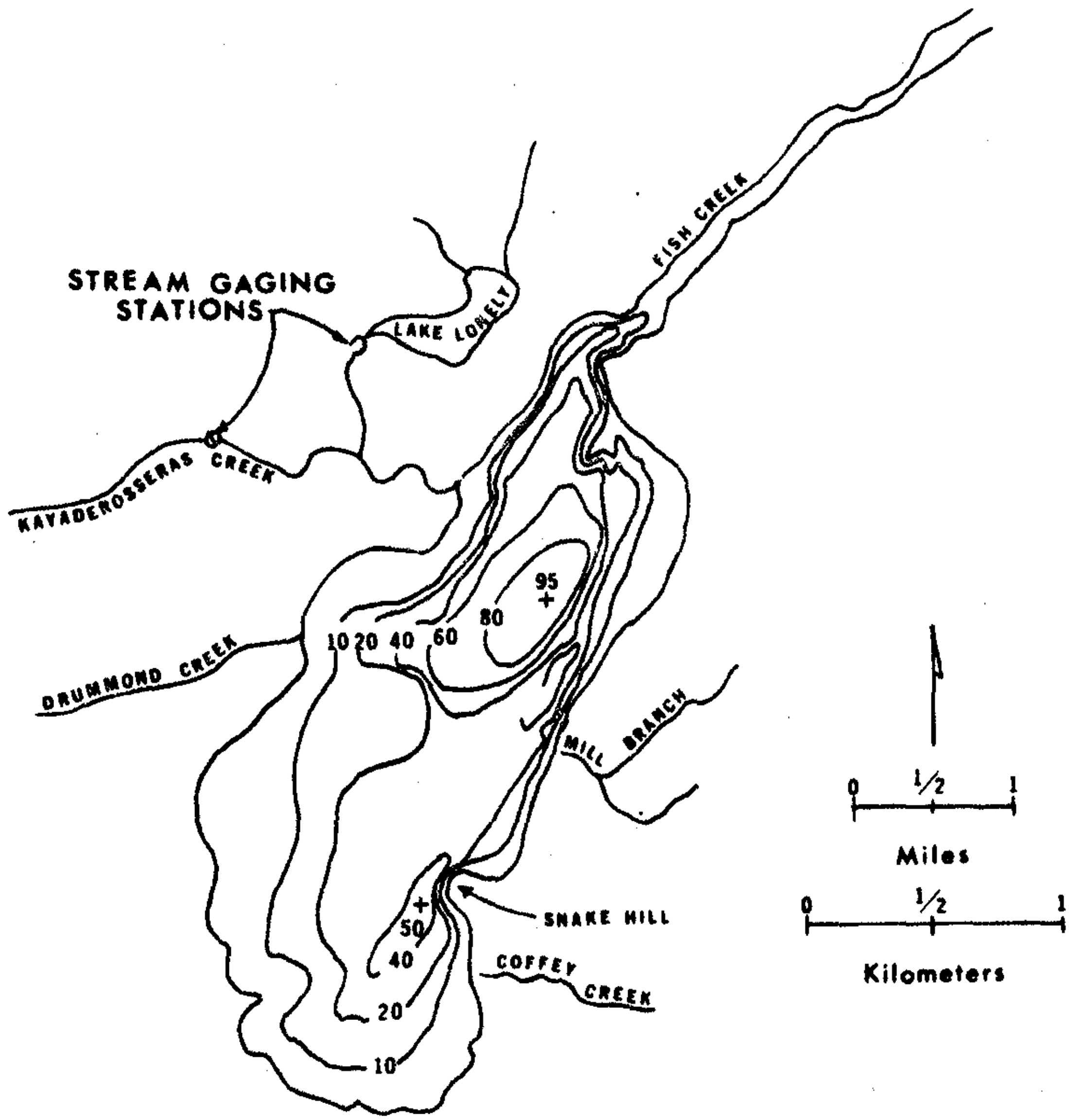


FIGURE 3

SUMMARY OF TOTAL NITROGEN LOADINGS IN SARATOGA LAKE

		EPA Data*(18) Total kg /yr	EPA Data*(18) Total % of Total	Coffey Data (3) Inorganic kg /yr	Coffey Data (3) Inorganic % of Total
1.	Inputs				
	Lake Lonely Basin				
	Saratoga Springs STP	51,678	15.2	75,000	19,7
	Non-point Sources (by difference)	71,887	9.6	(-34,000)	(-9.0)
	Lake Lonely Outlet	185,715	24.8	41,000	10.7
	Kayaderosseros Basin				
	Ballston Spa STP	16,901	5.0	19,800	5.2
	Geyser Crest STP	6,359	1.9	8,000	2.1
	Non-point Sources (by difference)	207,358	60.9	264,200	69.3
	Kayaderosseros above L. L. O.	230,618	67.8	292,000	76.6
	Total Mouth of Kayaderosseros Creek	314,933	92.5	333,000	87.3
	Additional Runoff to Lake	4,640	1.4	28,000	7.3
	Direct Precipitation	17,618	5.2	12,400	3.3
	Septic Tanks	3,166**	0.9	8,000***	2.1
	Total Loading	340,357	100.1	381,400	100.0
2.	Outlet				
	Fish Creek	276,415	77.1	186,000	48.8
3.	Net Annual Accum	82,077	22.8	195,400	51.2

* Revised Data

** Based on 297 lakeside dwelling only.

*** Based on 3000 septic tanks in total basin.

TABLE 4

SUMMARY OF TOTAL PHOSPHORUS LOADINGS IN SARATOGA LAKE

		EPA Data* [18]				Coffey Data [3]			
		kg /yr		% of Total		kg /yr		% of Total	
1.	Inputs								
	Lake Lonely								
	Saratoga Springs STP	16,323		56.4		15,100		12.7	
	Non-point Sources	-7,527		neg.		1,100		0.9	
	Lake Lonely Outlet		8,796		30.4		16,200		13.6
	Kayaderosseras Basin								
	Ballston Spa STP	5,634		19.5		4,000		3.4	
	Geyser Crest STP	2,118		7.3		1,600		1.4	
	Non-point Sources	11,487		39.7		94,200		78.9	
	Kayaderosseras above L. L. O.		19,239		66.5		99,800		83.6
	Total at Mouth of Kayaderosseras Creek				96.9		116,000		97.2
	Additional Runoff to Lake		535		1.8		2,000		1.7
	Direct Precipitation		286		1.0		1,000		0.8
	Septic Tanks		86**		0.3**		400***		0.3***
	Total Loading		28,942		100.0		119,400		100.0
2.	Outlet								
	Fish Creek		12,170		46.6		49,000		41.0
3.	Net Annual Accum		13,920		53.4		70,400		59.0

* Revised Data

** Based on 297 lakeside dwellings only

*** Based on 3000 septic tanks in total basin been corrected for this minor error. RPI's data for the contribution of nitrogen and phosphorus from the Saratoga Springs Treatment Plant were based upon actual measurements in the effluent from the plant, whereas those from EPA were based upon estimates provided by the treatment plant personnel.

The values for the contribution of phosphorus from Saratoga Springs by both studies are quite consistent and the difference in the contribution of nitrogen is not excessive. Significant differences, however, were noted in the nitrogen and phosphorus loadings at the outelt of Lake Lonely. In the case of nitrogen, the RPI data indicated that Lake Lonely actually removed nitrogen from the system, whereas the EPA data indicated that additional nitrogen was contributed by this area. On the other hand, in the phosphorus data the EPA numbers show removal of phosphorus in the Lake Lonely system, whereas the RPI data showed a slight increase in the phosphorus content from this area. In the Kayaderosseras Basin the values of nitrogen by both researchers are quite similar; however, more phosphorus was found at this point in the RPI data. The total nitrogen contributed to Saratoga Lake was similar by both investigators, but greater amounts of phosphorus were shown by the RPI data. However, what is significant is the fraction of the nutrients contributed by each major source. Particularly of interest are the nitrogen and phosphorus contributed by the known sewage treatment plants which were the

TABLE 1

MORPHOLOGICAL CHARACTERISTICS OF SARATOGA LAKE [1]

LAKE SURFACE AREA	15.6 km^2	6.01 mi^2
DRAINAGE AREA	544 km^2	210.04 mi^2
DRAINAGE AREA/SURFACE AREA	34.9	
MEAN LENGTH	7.2 km	4.5 mi
MEAN WIDTH	2.4 km	1.5 mi
LENGTH OF SHORELINE	37 km	23 mi
MEAN ELEVATION	62 km	203 ft
VOLUME AT MEAN ELEVATION	0.12 km^3	4.3×10^9 ft
MAXIMUM DEPTH	29 m	95 ft
AVERAGE DEPTH	8 m	26 ft
THEORETICAL HYDRAULIC DETENTION TIME	130 DAYS	
PERCENT OF SURFACE AREA WITH DEPTH OF 3 m (10 ft) OR LESS	28.6%	

TABLE 2

MORPHOLOGICAL CHARACTERISTICS OF LAKE GEORGE [7]

LAKE SURFACE AREA	114 km^2	44 mi^2
DRAINAGE AREA (land)	492 km^2	190 mi^2
WATERSHED AREA (including lake)	606 km^2	234 mi^2
DRAINAGE AREA/SURFACE AREA	4.3	
LENGTH	51 km	32 mi
MEAN BREADTH	2.3 km	1.4 mi
MAXIMUM BREADTH	4.0 km	2.4 mi
LENGTH OF SHORELINE	209.6 km	131 mi
MEAN ELEVATION	97 m	319 ft
VOLUME	2.1 km^3	0.5 mi^3
MAXIMUM DEPTH	58 m	191 ft
MEAN DEPTH	18 m	59 ft
THEORETICAL HYDRAULIC DETENTION TIME	8.0 YEARS	

point sources to be removed by the Saratoga County Treatment system. Of the total nitrogen loadings to Saratoga Lake, approximately 15-20% originated from the Saratoga Springs Sewage Treatment Plant, approximately 5% from the Balston Spa Sewage Treatment Plant, and approximately 2% from the Geyser Crest Sewage Treatment Plant. Thus, the amount to be removed by the completion of the treatment plant would be somewhere between 22 and 27% of the total nitrogen loading to the lake. Between 60 and 70% of the nitrogen loading is attributed to non-point sources. Small amounts were contributed by additional small streams flowing directly into Saratoga Lake, a small amount of between 3-5% was estimated to be due to precipitation directly onto the lake surface, and an amount between 1-2% was attributed to septic tanks surrounding the lake. At the present time, there is discussion of constructing a sewer to serve the lake area itself to eliminate this last nutrient loading. As for phosphorus there was a significant difference between the RPI and EPA data. The RPI data showed only about 13% of the total phosphorus to Saratoga Lake originated from the Saratoga Springs Sewage Treatment Plant, 3.4% from Balston Spa, and 1.4% from Geyser Crest, or a total of approximately 18% of the total phosphorus originating from these point sources and to be eliminated by the treatment plant. This left approximately 80% of the phosphorus originating from non-point sources. The EPA data on the other hand showed 56% of the phosphorus from the Saratoga Springs Sewage Treatment Plant, 20% from Balston Spa and 7% from Geyser Crest or a total of approximately 84% of the phosphorus to be eliminated with the completion of the treatment plant. The actual amount of the phosphorus to be removed by both estimates was approximately similar. The main difference was in the lower contribution of phosphorus from non-point sources according to the EPA data. An additional 1.8% of the phosphorus is attributed to direct runoff to the lake and approximately 1% is attributed to precipitation falling directly onto the lake. Septic tank contributions of phosphorus were estimated to be negligible by both studies.

It may be seen that the completion of the Saratoga County Sewage Treatment Plant would be expected to reduce the nitrogen and phosphorus inputs to Saratoga Lake by measurable amounts. The actual significance of these removals will be discussed in a forthcoming section.

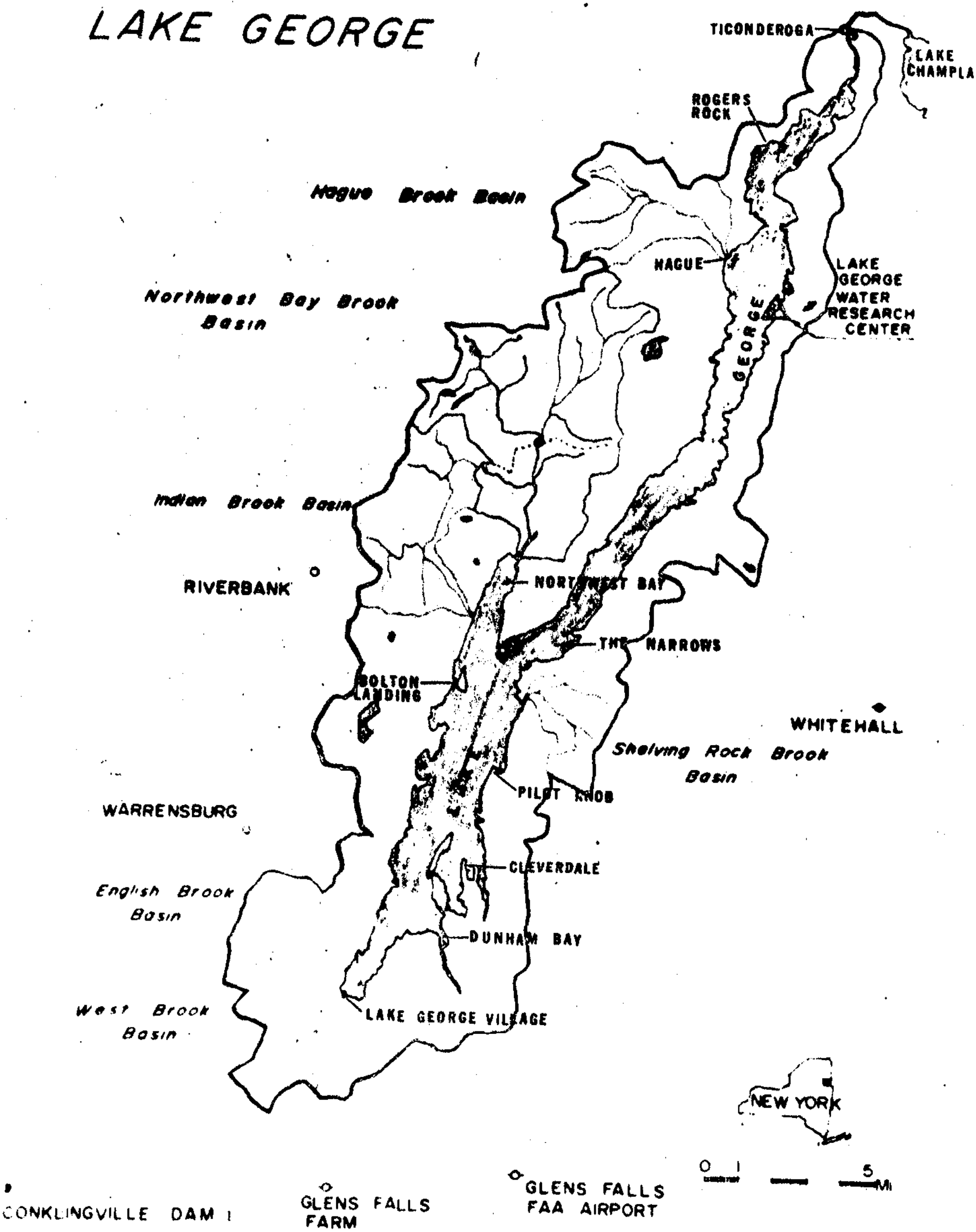
LAKE GEORGE

Somewhat more detailed studies of the nutrient budgets of Lake George have been made. The nutrient budgets shown here were mostly the results of Mitchell's studies [12] who relied on previous studies by numerous other researchers [4,5,9]. Mitchell's values have been modified by some recent data still being conducted by Siebecker [16].

The Lake George Drainage Basin area is shown in Figure 4. It becomes immediately apparent that the drainage

FIGURE 4

LAKE GEORGE



basin area of Lake George is relatively much smaller in relation to the surface area of the lake. The main center of population is around the southern tip of the lake including Lake George Village and the adjacent Town of Lake George. The main population extends up the western shore to Bolton Landing and up the eastern shore to Pilot Knob. The northern half of the lake is sparsely populated with individual homes all being served by septic tanks. At the southern end of the lake all of the Village of Lake George and large portions of the Town of Lake George are sewered, with the wastewater treated in a land application system which results in almost complete removal of all phosphorus and approximately 50% removal of nitrogen [2]. The Village of Bolton Landing is also served by a sewage treatment plant of a design similar to that of Lake George, but with somewhat less efficient operation in the removal of the nutrients. Areas between Lake George and Bolton Landing are served by septic tanks and areas along the east shore are also provided with septic tanks.

Estimates were made for the nutrient loadings to Lake George prior to the coming of the White Man to impact the lake. The values of nitrogen and phosphorus in the runoff and in the ground water were assumed to be the same then as now. However, the nutrients in the precipitation were assumed to be less, due to the fact that present day sources of nitrogen in the atmosphere are attributed to modern combustion practices. As for phosphorus, the classical consideration was that the phosphorus in the dry fall was the same as or about equal to that in the wet fall. On this basis, the presettlement loadings for Lake George were calculated as shown in Table 5. It may be seen that the total nitrogen and phosphorus contributions were significant even without the input from treatment systems, septic tanks and other anthropogenic sources. It must be pointed out in this and all other calculations for nutrient loadings for Lake George that the drainage area of the lake is 4.3 times the lake surface area. Thus, the total nitrogen and phosphorus falling on the drainage basin area would be 4.3 times the amount listed as falling directly on the lake surface. After running across and through the land, the nutrients measured in the runoff and in the ground water represent the amount of these nutrients reaching Lake George. It may be seen that even in presettlement times, 77.5% of both the nitrogen and phosphorus were estimated to have been removed from the precipitation as it ran over and into the ground. Thus, the forest-soil system becomes the absorber of nutrients which would otherwise reach the lake.

The present estimated nutrient loadings for Lake George (Table 6) represent the most accurate data available up to the present time. Extensive studies of stream flow were made by Colon [4,5]. Measurement of the seepage, which is that which occurs in West Brook and includes the

TABLE 5

ESTIMATED PRESETTLEMENT NUTRIENT CONTRIBUTIONS TO LAKE GEORGE, NY [12]

		NITROGEN			PHOSPHORUS		
SOURCES	VOLUME (km^3/yr)	CONC. (ug/l)	LOADING (kg/yr)	PERCENT	CONC. (ug/l)	LOADING (kg/yr)	PERCENT
RUNOFF	0.181	300	54,300	41.7	10	1,810	29.3
DIRECT PRECIPITATION ON LAKE SURFACE							
WET FALL	0.104	600	62,400	47.9	20	2,080	33.7
DRY FALL	----	---	7,500	5.8	--	2,080	33.7
GROUND WATER	0.020	300	6,000	4.6	10	200	3.3
	0.305		130,200			6,170	100.0

TABLE 6

ESTIMATED PRESENT NUTRIENT CONTRIBUTIONS TO LAKE GEORGE, NY

SOURCES	VOLUME (km^3/yr)	NITROGEN CONC. (ug/l)	NITROGEN LOADING (kg/yr)	NITROGEN PERCENT	PHOSPHORUS CONC. (ug/l)	PHOSPHORUS LOADING (kg/yr)	PHOSPHORUS PERCENT
RUNOFF							
STREAM	0.175	300	52,500	26.6	10	1,750	13.4
SEEPAGE*	0.001	4,300	4,300	2.2	10	10	0.08
URBAN	0.005	---	4,100	2.1	--	1,610	12.3
BOLTON LANDING SEWAGE TREATMENT PLANT	0.0002	Variable	1,320	0.6	Variable	26	0.2
DIRECT PRECIPITATION ON LAKE SURFACE							
WET FALL	0.104	1,000	104,000	52.7	20	2,080	15.9
DRY FALL	-----	---	12,600	6.4	--	6,600	50.4
GROUND WATER	0.020	300	6,000	3.0	10	200	1.5
SEPTIC TANKS**	-----	---	10,500	5.3	--	610	4.7
LAWN FERTILIZER	-----	---	2,100	1.1	--	210	1.6
	0.305		197,420	100.0		13,096	100.0

* Includes contribution from Lake George Village Sewage Treatment Plant

** Based on 5% of existing systems failing treated effluent from the Lake George Village Sewage Treatment Plant (LGVSTP), has been studied extensively by Aulenbach et al. [2]; urban runoff was estimated by Kasper [11] and Palladine [14] who measured nitrogen and phosphorus in several gutters and storm drains in Lake George Village during precipitation events. The concentrations of nutrients in the wet fall precipitation were measured by Gibble [9]. Nutrient contributions from the Bolton Landing Sewage Treatment Plant were measured by Fillip [8]; nutrient concentrations in the dry fall were recently determined by Siebecker [16]. The concentrations of nutrients in the ground water were based on the concentrations of these nutrients in Northwest Bay Brook, which is fed primarily by ground water, as well as from measurements made from observation wells in the LGVSTP by Aulenbach et al. [2]. Extensive studies of nutrient contributions from septic tanks were made using estimates of loadings and removals of nutrients based upon known distances of septic tanks to the lakes [9]. These values were modified by Mitchell [12] to represent 5% of existing septic tanks failing. This may be a high number, as a study by the New York State Department of Environmental Conservation (NYSDEC) [13] showed that less than 2% of the septic tanks studied were failing at the time of the study. Lawn fertilizer nutrient loadings were determined by Gibble [9] based on information collected by a survey of individuals within the drainage basin area regarding the amount and types of fertilizers used on their lawns. From Table 6 it may be seen that the major source of the present nutrient loadings for Lake George is direct precipitation of both wet fall and dry fall on the lake. Combined these amount to an estimated 59% of the nitrogen and 66% of the phosphorus which gain access to the lake. Again, based on the area of the watershed, the nitrogen which falls on the drainage basin is reduced 85% while flowing across the surface of the ground to Lake George. This increased reduction under present conditions is primarily the result of a significant increase in the nitrogen loading in the wet fall, which is attributed to modern day combustion practices which have increased the nitrogen content of the atmosphere. On the other hand, the present phosphorus removal is only 60%, due primarily to the relatively constant loadings from the precipitation and the increased phosphorus contributions from urban runoff. Of interest is the fact that the Lake George Village and Bolton Landing sewage treatment plants and the septic tanks in the entire lake contribute only 8.1% of the entire nitrogen loading and 6.8% of the total phosphorus loading to Lake George. The contributions from the two treatment plants and a major portion of those from septic tanks are the ones which would be eliminated by the construction of the sewer system serving the Lake George area.

Estimates were made for the future loadings of nutrients to Lake George based on the removal of both the Lake George Village and Bolton Landing sewage treatment plants and the reduction in numbers of septic tanks. It must be pointed out that not all the septic tanks will be removed from the lake, but only those in the southern portion of the basin from Bolton Landing on the west shore to Pilot Knob on the east shore. There would be no reduction in the number of septic tanks in the northern part of Lake George. At the present time, the lack of sewers is restricting any significant development in the Lake George Basin. No large sub-divisions are being approved nor are new hotels or motels which cannot be served by the existing sewer. The construction of the new sewer system would allow additional development as was predicted in the facilities plan for the treatment system [10]. Based on the numbers provided in this plan, estimates were made of the increase in nutrient loadings from urban runoff. This represents the largest change in the nutrient loadings from the present to the future. It may be seen in Table 7 that the net effect of reducing the treatment plant and septic tank effluents and the increase due to urban runoff would be a reduction of the nitrogen loading to the lake by 4.9%, but a 5.5% increase in the phosphorus loading to the lake. The significance of this increased phosphorus loading will be discussed in the next section. Again, estimating the total nitrogen falling upon the drainage basin, the land system appears to reduce the total nitrogen by 86%. This is essentially the same as

TABLE 7
ESTIMATED FUTURE NUTRIENT CONTRIBUTIONS TO LAKE GEORGE, NY

SOURCES	VOLUME (km^3/yr)	NITROGEN CONC. (ug/l)	NITROGEN LOADING (kg/yr)	NITROGEN PERCENT	PHOSPHORUS CONC. (ug/l)	PHOSPHORUS LOADING (kg/yr)	PHOSPHORUS PERCENT
RUNOFF							
STREAM	0.171	300	51,300	27.3	10	1,710	12.4
SEEPAGE	0.0001	300	30	0.02	10	1	0.01
URBAN	0.009	---	6,900	3.7	--	2,690	19.5
DIRECT PRECIPITATION ON LAKE SURFACE							
WET FALL	0.104	1,000	104,000	55.4	20	2,080	15.1
DRY FALL	-----	---	12,600	6.7	--	6,600	47.8
GROUND WATER	0.015	300	4,500	2.4	10	150	1.1
SEPTIC TANKS	-----	---	4,200	2.2	--	160	1.1
LAWN FERTILIZER	-----	---	4,200	2.2	--	420	3.0
	0.299		187,730	100.0		13,811	100.0

by the present loading due to the fact that the major portion of the nitrogen is in the wet fall and minor changes in other numbers resulted in insignificant changes in the per cent reduction. On the other hand, the phosphorus removal due to flow over the soil is reduced to only 49%. This decrease in reduction is primarily due to the increased nutrients which would reach the lake from urban runoff as a result of increased development around the lake.

CLASSIFICATION OF LAKES ACCORDING TO PHOSPHORUS LOADINGS

Calculations indicate that the limiting nutrient in both Saratoga Lake and Lake George is probably phosphorus [1,7]. Actually, extensive studies in Lake George have shown that phosphorus is limiting most of the year but that at certain times nitrogen may also be limiting. Howeven, phosphorus is usually considered to be the controllable nutrient in a lake. Vollenweider and Dillon have shown means of interpreting the trophic nature of a lake on the basis of phosphorus loadings [19], i.e., gP/m^2-yr versus the mean depth of the lake or versus the mean depth divided by the theoretical water detention time in the lake. The theoretical water detention time of Saratoga Lake is 130 days, whereas for Lake George it is approximately 8 years.

The nutrient states of Saratoga Lake and Lake George based upon the loading and mean depth are shown in Figure 5. The figure shows that both RPI and EPA data indicate that Saratoga Lake is an extremely eutrophic lake.

LAKE CLASSIFICATION ACCORDING TO PHOSPHORUS LOADING

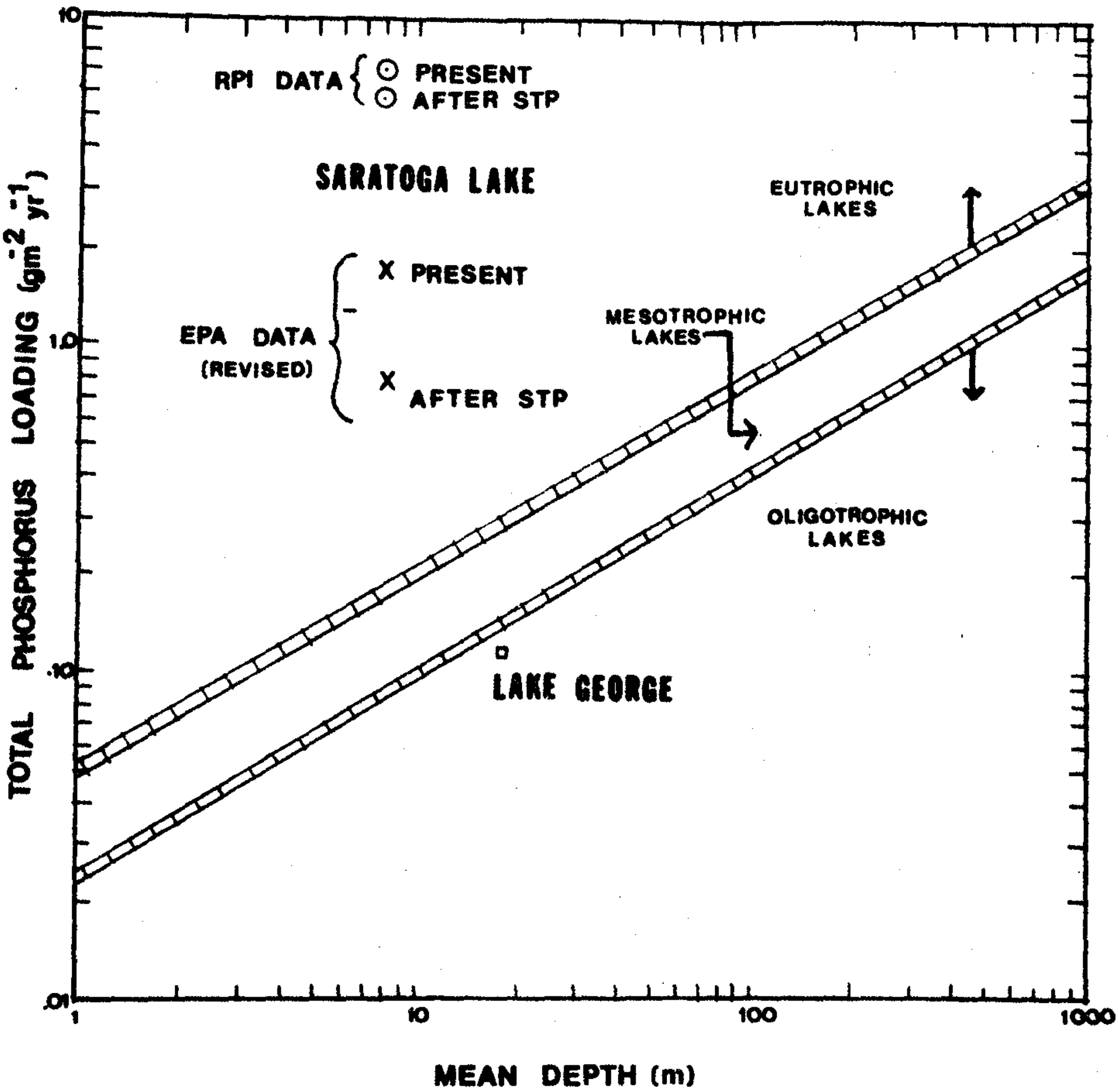


FIGURE 5

Although the RPI data show the lake in poorer condition, even the EPA data indicate that it is in a state of stress. While a greater reduction in phosphorus loading is indicated by the EPA data after the construction of the sewage treatment plant, it may be seen that the quality of the lake will remain in the eutrophic range even with the construction of the sewage treatment plant and subsequent diversion of these nutrients out of the Saratoga Lake Basin. As for Lake George it may be seen that the present loading based on the mean depth is extremely close to the mesotrophic range. Thus, every effort should be made to prevent the phosphorus loading from increasing even a slight bit. The actual estimated nutrient contributions to Saratoga Lake and Lake George for present and future projected condition are summarized in Table 8. It may seen that there is predicted to be a slight increase in the phosphorus loading of Lake George which is estimated to be approximately 4%. While it is impossible to plot this small increase on Figure 5, the result does indicate a slight transformation toward the mesotrophic range.

Based on the loading and the lake retention time (Figure 6), Saratoga Lake appears closer to the admissible limits, and Lake George appears slightly more oliogtrophic; but the point still falls very close to the mesotrophic range. The RPI data show that Saratoga Lake will remain in the eutrophic range even after the construction of the treatment plant; however, the EPA data indicate that the treatment plant may reduce the nutrient loading to

TABLE 8

NUTRIENT LOADINGS TO SARATOGA LAKE AND LAKE GEORGE, g/m^2-yr

	Saratoga Lake				Lake George	
	EPA REVISED		RPI			
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphours
Presettlement	--	--	--	--	1.14	0.054
Before Sewage Treatment Plant Construction	21.8	1.86	24.4	7.65	1.73	0.115
After Sewage Treatment Plant (Plus Development at Lake George)	17.0	0.79	20.0	6.33	1.65	0.12

LAKE CLASSIFICATION ACCORDING TO PHOSPHORUS LOADING AND WATER RETENTION TIME

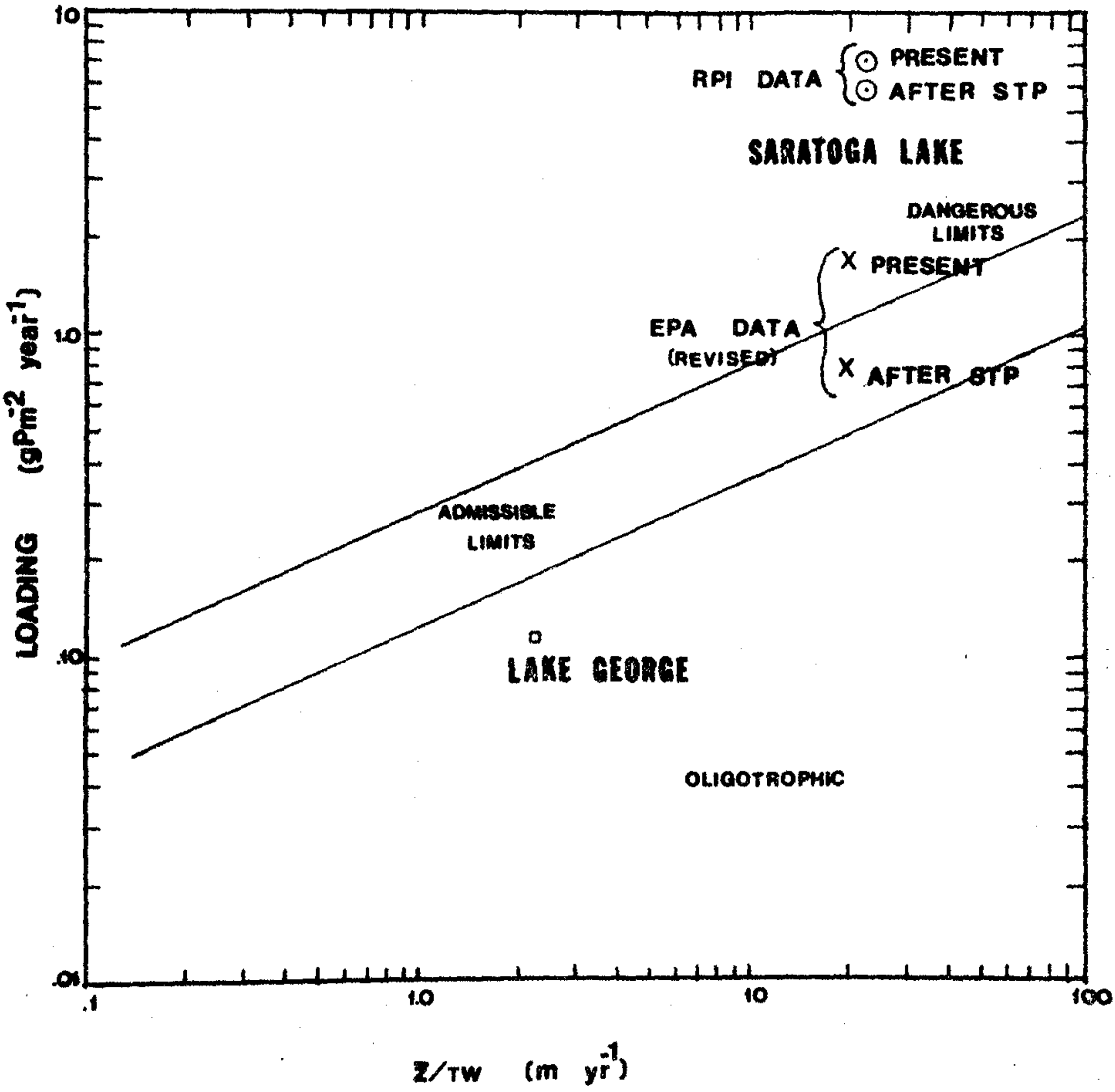


FIGURE 6

approximately the mid-point of the mesotrophic range (admissible limits in Vollenweider's classification). Again Lake George is very close to this level and it would appear unwise to conduct any operation which would result in an increase in the phosphorus level of Lake George.

It must be pointed out that the proposed sewer system around the Lake George are per se is not the caustive factor of increasing the phosphorus loading to the lake. However, the combination of the increase in phosphorus from increased development and the reduction of phosphorus by diversion of the sewage out of the basin results in a net increase in the phosphorus loading to Lake George. In view of the large contribution of both nitrogen and phosphorus to Lake George from non-point sources, it is hardly justified to construct a sewer system around the lake on the basis of removal of nutrients from controllable anthropogenic sources. Further the contribution of phosphorus in the urban runoff, both at the present time and the expanded levels projected for the future, is much greater than the phosphorus concentrations from sewage and septic tank discharges. Thus, any efforts to control the phosphorus input to Lake George should include some form of collection and treatment of the urban runoff. This would represent a greater reduction in the phosphorus contribution to the lake than the construction of a sewer around the lake to divert all wastewater out of the basin. In addition, control of development, not just in terms of quantity, but in terms of runoff control, should be an integral part of the design of the sewage treatment system in the Lake George Basin. Only in this way can the impact of a sewer around Lake George represent a lowering of the loading of phosphorus to Lake George as opposed to an increase in this loading.

SUMMARY

A great deal of effort and considerable time and measurements are involved in the compilation of nutrient budgets to lakes. The various sources of nutrient inputs both natural and anthropogenic must be measured. Very frequently data are not readily available, particularly of the contributions due to precipitation. Measurements of flow and concentrations of nutrients in the flow involve considerable time and effort. However, a comprehensive budget will indicate the major sources of nutrients and will help to indicate the direction of attack in order to provide beneficial reductions of these nutrient contributions to the lake.

Such nutrient budgets were prepared for Saratoga Lake, a eutrophic lake, and Lake George an oliogtrophic lake. In both lakes it was shown that the largest sources of nutrients to the lake are from non-point sources as opposed to direct discharges from sewage treatment plants. Both lakes were presented with plans for construction of sewage treatment plants which would divert from the lake all discharges of nutrients from these sources. In the

case of Saratoga Lake, the treatment plant has been completed and in the case of Lake George it is still under consideration.

It was estimated that the construction of the sewage treatment plant would definitely reduce the nutrient loading to Saratoga Lake; however, not enough to bring it out of the eutrophic range. As for Lake George, the construction of the sewage treatment plant with the ensuing allowable development would actually increase the phosphorus loading to the lake due primarily to the high concentration of phosphorus in urban runoff. Since the present nutrient loading of phosphorus to Lake George places this lake in a precarious balance between oligotrophic and mesotrophic, no actions which would serve to increase the phosphorus loading into Lake George can be recommended. It is suggested that the plan for construction of sewers in the Lake George area should include a plan for prevention of additional phosphorus loadings due to development and additional urban runoff.

In conclusion, it may be seen that the massive input of funds into the wastewater treatment systems of the United States may not necessarily result in pristine pure lakes throughout the country. Whereas the efforts may improve the quality of some lakes, the efforts may not always be enough. In other instances the ensuing development allowed by the construction of sewers and the treatment plant may actually contribute to the eutrophication of a lake. Studies of the nature shown here should be conducted on a lake before the construction of a sewer system and treatment plant to assure that the net result will not be a deterioration of the quality of the lake as would occur at Lake George. Treatment of our wastes is an admirable goal, but we should not go head-long into the construction of treatment facilities without being aware of the total impact that they may have upon a lake.

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