The impact of sewers on the nutrient Budget of Lake George

Completed by

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THE IMPACT OF SEWERS ON THE NUTRIENT BUDGET OF LAKE GEORGE, NY[1]

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ABSTRACT

In order to control eutrophication of lakes the sources and amounts of the principal nutrients, nitrogen and phosphorus, must be determined. Over the past ten years the Rensselaer Fresh Water Institute has been measuring the various sources of nutrients to Lake George. The more populated South Basin of Lake George is the more impacted portion and may already be in the mesotrophic range. Additional development is limited by the present sewer system. In order to reduce suspected nutrient inputs from septic tanks and allow additional development, a proposal has been submitted to expand the sewer system and provide treatment and disposal out of the basin. Estimates were made of the reduction in nutrient inputs of South Lake George from the elimination of septic tanks by the proposed sewer system and the increase due to increased development and subsequent urban runoff. The results indicated that nitrogen inputs to South Lake George would be decreased by about 10%, but phosphorus would be increased by 8% which appears to be sufficient to carry the South Lake into the eutrophic range.

INTRODUCTION

Beautiful, clear recreational lakes are today rare, indeed. Existing lakes are suffering from both natural and anthropogenic eutrophication, and newly created impoundments delayed by litigation. Thus the expanding population with greater mobility and more leisure time is faced with fewer opportunities to enjoy such lakes.

The development around lakes in the USA has followed two general trends. Lakes closer to population centers have become surrounded by summer cottages which over the course of years are being converted to year-round residences. More distant lakes were served by rail transportation and were characterized by several large hotels and a few large estates. With the coming of the automobile and the building of better highways, more people visited these lakes resulting in replacement

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of the old hotels with numerous motels, and dividing the large estates into smaller plots for building individual homes. Here, too, the formerly predominantly summer homes are slowly being winterized for year-round occupancy. Depending upon the accessibility of the lake, many commercial facilities, such as restaurants, theaters, and other recreational facilities, have also grown up around some lakes.

In general, when development began, there was little impact upon the lake. The facilities were used only 2-3 months during the summer. There were few paved roads and no need for extensive parking lots. Few had time to fertilize and groom a lawn. There were a few large (relatively) steam boats and the rest were rowboats, canoes, or sailboats. Sewage was usually adequately handled by septic tanks, although there were instances where a house built on a rock by the edge of a lake had difficulty in treating the wastewaters sufficiently before they reached the lake.

Today many lakes are completely built-up with structures lining the lake front, and with paved driveways and parking areas. Commercial areas survive only with large paved parking lots and construction right to the edge of the lake. Not only does everyone own a motor boat, but also there are many marinas and boat launching ramps encouraging boating. Public beaches and other recreational facilities invite tourists to the area. In some areas in addition to year-round living, winter sports are attracting many more tourists. All these activities are putting more and more strain upon the capabilities of lakes.

For many years, the people have been told that the solution to all their pollution problems, particularly failing septic tank systems, was sewage collection and treatment. The US Environmental Protection Agency (EPA) has encouraged large treatment systems by funding only regional systems encompassing large areas (usually contiguous communities). However, the larger the individual lots and the greater the distance of travel to the final outfall, the higher becomes the cost to the individual homeowner, even with federal and state aid. In some areas, these high costs have caused a second look at the conventional collection and treatment system. Studies of several lakes in the Midwest (Anonymous, 1979; McKinney and Krause, 1979) have shown that at one lake, leachate from only 90 of some 1500 septic tanks reached the lake, and the bulk of the phosphorus load came from precipitation and agricultural and stormwater runoff (and a possible leaking sewer). They were able to control the pollution problem from septic tanks by upgrading the existing systems or installing cluster treatment systems at a much lower cost than a conventional sewage collection and treatment system. No mention was made of the greater degree of treatment achieved in a soil system as compared with a conventional secondary treatment system with discharge back into the lake.

Lake George (NY) Case Study

Lake George is a medium sized lake located in eastern upstate New York (Fig. 1). It was formed by the last glacier from two river valleys about 10,000 years ago. It is known for the clarity of its water and the beauty of its mountainous tree-lined shores. The lake is long and thin, and quite deep for its width. Its morphological characteristics shown in Table 1 also indicate that it consists of two main basins, both quite similar in size, shape and volume, but with considerably greater surface runoff to the South Lake. The island-studded area called The Narrows delineates the South Lake from the North Lake.

TABLE 1. Morphometric comparison of South and North Lake George

	South Lake		North Lake		Total	
Length	22.4 km	13.9 mi	28.6 km	17.8 mi	51 km	32 mi
Mean Breadth	2.6 km	1.6 mi	2.0 km	1.2 mi	2.3 km	1.4 mi
Max. Breadth	4.0 km	2.4 mi	3.2 km	2.0 mi	4.0 km	2.4 mi
Area	57.6 km^2	22.2 mi^2	56.4 km^2	21.8 mi^2	11. km^2	44 mi^2
Max. Depth	58 m	191 ft	53.3 m	175 ft	58 m	191 ft
Mean Depth	15.5 m	50.9 ft	20.5 m	67.3 mi	18 m	59 ft
Length of Shoreline	76 km	47.2 mi	133.6 km	84.5 mi^3	209.6 km	131 mi
Volume	1.02 km^3	0.24 mi^3	1.08 km^3	0.26 mi^3	2.1 km^3	0.5 mi^3
Watershed Area	313.2 km^2	121.0 mi^2	178.8 km^2	69.0 mi^2	492 mi^2	190 mi^2
Watershed Area (including lake)	370.8 km^2	143 mi^2	235.2 km^2	90.6 mi^2	606 km^2	234 mi^2

Due primarily to access by transportation, the major population settlement is in the South Lake. Lake George Village at the southern tip of the lake is the center of population, with lesser concentrations along the western shore to Bolton Landing and along the eastern shore to Pilot Knob (see Fig. 2). The shorelines through The Narrows are completely uninhabited, and there are only a few small centers of populations in the North Lake. Many of the islands, including those in The Narrows, are used for camping.

In the early days, sewage was treated in septic tank systems or even discharged directly into the lake. In order to control sewage discharges to the lake, and in an effort to preserve both the quality and the beauty of Lake George, a group of property owners got together and formed the Lake George Association in 1885.

Today this Association continues an active program to preserve Lake George. In 1936 they supported a sewage collection and treatment system for Lake George Village. This treatment plant was completed in 1939 and has continued to provide the equivalent of tertiary treatment

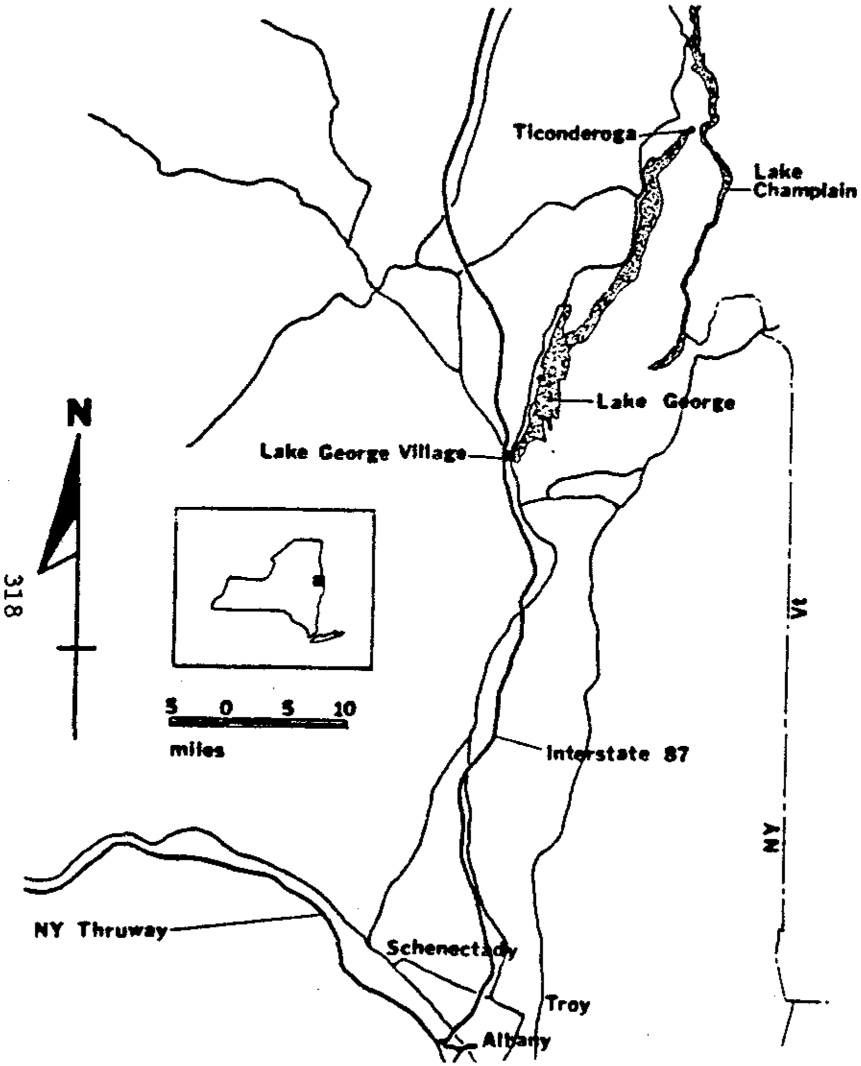

Figure 1. Location of Lake George.

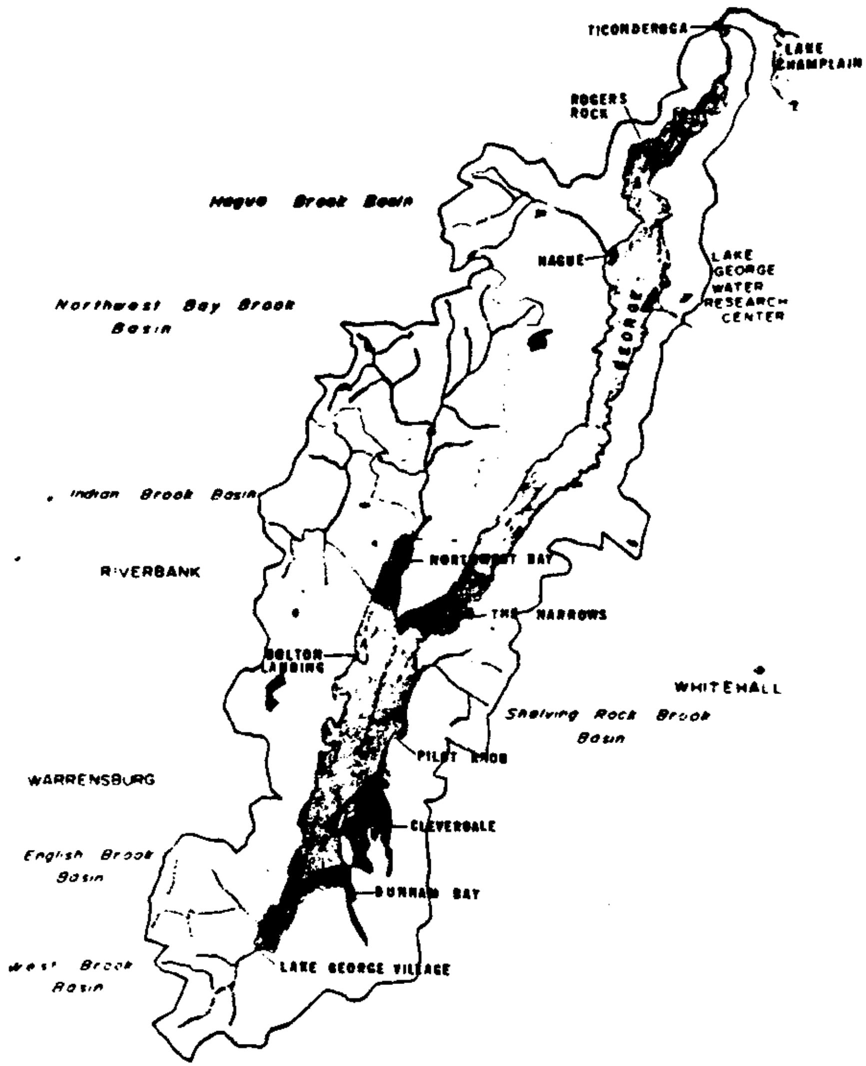

Figure 2. Map of Lake George and its drainage basin.

(complete phosphorus removal and about 50% nitrogen removal) (Aulenbach, 1979b; Aulenbach, Harris and Reach, 1978) by means of a conventional trickling filter system followed by a rapid infiltration land application system for tertiary treatment of the unchlorinated effluent. In 1965 the collection system was expanded to include parts of the surrounding Town of Lake George with a consequent increase in the treatment plant capacity, particularly the area of the infiltration beds. Present flows reach 4,700 m^3/day (1.25 mgd) on peak summer week-ends.

The Village of Bolton Landing also has a sewage collection and treatment system. This system, installed in 1960, also uses rapid infiltration for tertiary treatment. Its operation, however, includes several variables. Due to very low flows (750 m^3/day (100,000 gpd)) and extremely cold temperatures, the trickling filter is not utilized in winter, and the sewage receives only primary sedimentation in a circular Imhoff tank prior to application onto the sand beds. Also, during this time, the original sand beds, constructed using placed sand, are used. Studies (Fillip, 1979) have shown that these sand beds are not performing as well as those at Lake George Village. In 1974 some natural sand was found adjacent to the treatment plant. Rapid infiltration beds were constructed here and have been shown (Fillip, 1979) to provide nitrogen and phosphorus removal similar to the Lake George Village Sewage Treatment Plant. Due to the fact that the pipeline to these beds is partially exposed, they are not used for approximately three months during the winter.

Sewage treatment and disposal throughout the remainder of the lake is primarily by means of septic tank systems. There are a few problem areas where holding tanks with periodic pump-out are used. In some areas there is very little soil cover above the bed rock, and in other areas, particularly in the case of the older homes, the seepage fields are located close to the lake, raising concerns over the effectiveness of the systems to provide adequate treatment and nutrient removal. A study conducted by the New York State Department of Environmental Conservation (NYSDEC) (Frick, 1973) indicated that less than 2% of the septic tank systems observed were failing. Although there have been some questions concerning this study, the results do indicate that only a few septic tank systems exhibit gross failure.

WATER QUALITY OF LAKE GEORGE

Historical studies of the quality of the water in Lake George are almost non-existent. Early reports indicated that the water was sparkling and clear. The first real study of the lake was conducted in 1920 by a team of eminent limnologists (Needham and co-workers, 1922), but this was a very limited study (Aug. 2-9), and was concerned primarily with the quality of fishing. One of their conclusions was that fishing could be improved if the nutrient level of the lake would be increased. They did conduct some water quality measurements, primarily east of

Dome Island, the deepest part of the lake (see Fig. 2).

Numerous detailed studies were conducted as part of the International Biological Program (IBP) from 1969 through 1974. In general, these studies evaluated the quality of the main body of the lake. The results did show greater stresses on the water quality in the south end of the lake, with improvement of the water quality in a northward direction (Aulenbach and Clesceri, 1973, 1977; Clesceri and Williams, 1972; Ferris and Clesceri, 1975, 1977; Hetling, 1974; Schoettle and Friedman, 1972; Stross, 1973). A brief study in 1978 based primarily on chlorophyll a and Secchi disk measurements also showed this south to north trend (Wood and Fuhs, 1979). It is interesting to note, however, that based on chlorophyll a data in this most recent report(not the conclusion of these authors), the water quality in the region of Dome Island has not changed significantly over the past 58 years.

Despite the relatively good quality of the water in the main part of the lake, there are numerous observations that increasing algal growths are occurring in some of the more heavily populated bays. This may represent local conditions where the volume of water for dilution of any added nutrients is insufficient and mixing with the main body of the lake is minimal. In addition, one significant algal bloom did occur in May 1972, shortly after ice-out in the South Lake. The major algae was identified as Volvox, and the occurrence was attributed to heavy rains the previous fall and to above average snow-melt runoff that spring. No similar condition has been observed since that time.

In addition to the nutrient content of the lake, there is concern for the sanitary quality of the water, since the lake is used for the water supply of all the communities around the lake and is consumed with no treatment whatever by most of the individual residents along the lake. Prior to 1977, samples were taken from about 20 locations around the lake and analyzed for total coliform organisms. Since samples were secured by boat, most were in the order of 15 m (50 ft) from the shore, depending upon the depth of the water. Since then the number of sampling sites has been increased, but the samples are secured from the shore. In addition to total coliforms, fecal coliforms and fecal streptococci are also measured. Purportedly these samples are being taken to identify local sources of pollution due to improperly or inadequately treated sanitary wastes. They have helped locate several instances of leaking sanitary sewers, or sanitary drains inadvertantly connected to a storm drain. Whenever such occurrences or septic tank failures are discovered, immediate action is taken to correct the situation.

With the availability of the fecal coli and fecal strep data, some indication of the source of the fecal material is available. In humans the ratio of fecal coli to fecal strep is greater than 4, whereas in animals it is less than 0.75 (Geldrich, 1969). Analysis of the available data (Haas, 1979) shows that in the preponderence of instances the bacterial contamination is of animal (non-human) origin.

In the case of both the nutrients and the bacteria, the poorest quality water was observed at the southernmost part of the lake. This corresponds with the greatest population density and correlates with phosphorus: population relationships found in other lakes (Koenig and Nusch, 1973; Nusch, 1975). It should be pointed out that the entire southern tip of the lake is completely sewered; therefore, the correlation of poorer water quality is with population density, and not with the number of septic tanks.

PROPOSED CONTROL

In an effort to control and/or reduce both the nutrient and the bacterial population of Lake George, a new sewage collection and treatment system has been proposed (Hazen and Sawyer, 1977). This would involve additional sewers to cover the shoreline from Bolton Landing on the west to Pilot Knob on the east (see Fig. 2). With the aid of 23 pumping stations around the lake, the wastewaters would be conveyed to a large central pumping station where they would be pumped out ot the basin through a force main to a central treatment plant at Glens Falls. Here the combined wastewaters would receive conventional secondary treatment by activated sludge with final disposal of the treated effluent into the Hudson River.

According to the design engineer, one of the advantages for this proposal was the removal of all wastewaters from the Lake George basin, thus eliminating any possibility for nutrients or bacteria from the sewage to get back into the lake. (This, of course, assumes no leaky sewers or failure of pumping stations). No estimate was made in the report as to the amount of sewage presently contributing nutrients or bacteria to the lake; therefore, there is no evidence of the necessity for this action. Furthermore, no evaluation was made of the impact of removing this amount of water from the basin. As a matter of fact, Wood and Fuhs (1979) suggest that the present policy of retaining the treated wastewaters within the basin may be an important factor in preventing more acid conditions in Lake George. Lake George is in the region of lakes suffering a severe impact (many lakes in the Adirondacks are now so acid they are devoid of fish (Cronan and Schofield, 1979)) from acid rain, and diversion of the neutralizing wastewaters from the basin may result in the lake's becoming significantly more acidic.

Another selling point for the new sewer proposal was to allow increased commercial development around Lake George. At the present time there can be no additional large commercial development such as hotels, motels, housing developments or shopping centers, in areas which are not presently served by sewers. By extending the sewers, additional development can occur. The new sewer proposal has estimated the extent of this development which might be expected; however, it has not determined the impact of this development upon the lake.

Thus, it may be seen that the design of the proposed sewer system has not taken into consideration the total impact sewers may have upon Lake George. It has not determined how much of the nutrient content of the lake originates from the existing septic tanks, nor how much will be contributed by future increased urban runoff. The remainder of this paper will address these issues.

NUTRIENT LOADINGS TO SOUTH LAKE

A previous paper (Aulenbach, 1979a) has addressed past, present and future nutrient loadings to Lake George. Essentially it showed that the completion of the proposed sewer system would result in reducing the total nitrogen loading to the lake by 4.9%, but would increase the phosphorus loading by 5.5%. Since phosphorus is the critical nutrient, this increase is cause for concern. The present phosphorus loadings based on both mean depth and mean depth and detention time (see Figs. 3 & 4) placed the entire lake in the oligotrophic zone, but very close to mesotrophic conditions. Thus even a slight increase in the phosphorus input could put Lake George into an undesirable condition.

However, all studies have shown that the South Lake of Lake George is suffering from greater stress than the North Lake. Also, the proposed sewer system will serve only the South Lake. Thus to determine the greatest impact, an evaluation must be made to show the impact of the proposed sewer and the concommitant increased development upon South Lake George.

Many sources of inputs to the lake have been measured by various researchers. A brief review of these studies is in order to clarify the final values produced. The measurements of precipitation and runoff were made by Colon (1971,1972). Seepage measurements from the Lake George Village Sewage Treatment Plant were made by Hajas (1975). The nitrogen and phosphorus in the wet precipitation and stream runoff were measured by Gibble (1974), and that in the seepage by Hajas (1975). Nitrogen in the urban runoff was measured by Kasper (1976) and phosphorus by Palladine (1976). The nutrients released by the Bolton Landing Sewage Treatment Plant were measured by Filip (1979) and adjusted for seasonal flow variations by Aulenbach (1979a). The nutrients in the dry fall were measured by Siebecker (1979). The concentrations of nitrogen and phosphorus in the ground water at Lake George have not been measured, but have been estimated on the basis of Gibble's studies (1974). No specific measurements of the nutrient contributions from septic tanks were made. Instead many factors were weighed. Frick (1973) showed the distance of individual septic tanks to the lake. Gibble (1974) obtained estimates for nitrogen and phosphorus removal with distance, but Jones and Lee (1977) did some actual measurements of phosphorus removal in soil systems, so these newer values were used by Mitchell (1978) in calculating phosphorus removals in septic tank systems. The weighted removal efficiencies used in these calculations are 35% for nitrogen and 85% for phosphorus which includes an assumption that as many as 5% of the septic tank/leach field systems may be failing. Lawn fertilizer estimates were based on a survey by Gibble (1974).

Nutrient loading budgets were made on the basis of estimated presettlement values, present values, and possible future values to indicate anthropogenic influences upon the lake. The presettlement budget has all cultural influences removed to provide an estimate of all the natural inputs. The present budget is based on the best information concerning conditions as they exist today. The future budget reflects the maximum cultural development under present Adirondack Park Agency regulations and the development predicted as a result of the construction of the Warren County Sewer System as currently proposed (Hazen and Sawyer, 1977).

The estimated presettlement, present and future nutrient loadings to South Lake George are shown in Tables 2-4, respectively. The presettlement represents natural conditions over which man has little control. Over 90% of the 74,500 kgN/yr derives from wet atmospheric inputs in the form of precipitation which falls directly on the lake and that which falls on the land and ultimately reaches the lake as stream runoff. The 3,400 kgP/yr estimated to reach the lake is almost equally divided among stream runoff, wet fall and dry fall.

TABLE 2. Estimated Presettlement Nutrient Loadings to South Lake of Lake George (Aulenbach, 1979a; Mitchell, 1978, Siebecker, 1979)

Sources	Volume (km^3/yr)	Nitrogen Conc. (ug/L)	Nitrogen Loading (kg/yr)	Nitrogen %	Phosphorus Conc. (ug/L)	Phosphorus Loading (kg/yr)	Phosphorus %
Runoff Stream	0.122	300	36,600	49.1	10	1,220	35.9
Direct Precipitation on Lake Surface							
Wet Fall	0.052	600	31,200	41.9	20	1,040	30.6
Dry Fall		-	3,750	5.0	-	1,040	30.6
Ground Water	0.010	300	3,000	4.0	10	100	2.9
Total	0.184		74,550	100		3,400	100

The present nutrient loading shown in Table 3 reveals the many anthropogenic sources. Wood and Fuhs (1979) even calculated an input from swimmers, but the value was insignificant. The most noticeable difference is the increase in nitrogen input of almost 40,000 kg/yr and the more than doubling of the "natural" phosphorus inputs. The major source of nitrogen is still the wet precipitation and its subsequent stream runoff. Septic tanks may contribute in the order of 6% of the total nitrogen input. As for phosphorus, the largest source is now dry fall, and urban runoff contributes more than stream runoff or precipitation directly on the lake. Less than 5% of the phosphorus loading is attributed to septic tank discharges.

TABLE 3. Estimated Present Nutrient Loadings to South Lake of Lake George (Aulenbach, 1979a; Mitchell, 1978; Siebecker, 1979)

Sources	Volume (km^3/yr)	Nitrogen Conc. (ug/L)	Nitrogen Loading (kg/yr)	Nitrogen %	Phosphorus Conc. (ug/L)	Phosphorus Loading (kg/yr)	Phosphorus %
Runoff							
Stream	0.117	300	35,100	30.9	10	1,170	15.7
Seepage*	0.001	-	4,300	3.8	-	10	0.1
Urban	0.004	-	3,500	3.1	-	1,380	18.5
Bolton Landing Sewage Treatment Plant	0.0002	Variable	1,320	1.2	Variable	26	0.4
Direct Precipitation on Lake Surface							
Wet Fall	0.052	1,000	52,000	45.7	20	1,040	13.9
Dry Fall	-	-	6,300	5.5	-	3,300	44.2
Ground Water	0.010	300	3,000	2.6	10	100	1.3
Septic Tanks	-	-	7,100	6.2	-	330	4.4
Lawn Fertilizer	-	-	1,100	1.0	-	110	1.5
Total	0.184		113,720	100		7,466	100

*Includes contribution from Lake George Village Sewage Treatment Plant.

The proposed Warren County Sewer System will eliminate nearly all septic tank and sewage discharges within the South Lake. There may be a few septic tanks remaining north of Bolton Landing and at some locations fairly distant from the lake. The nutrient contributions from these are considered insignificant, and thus are not even included in Table 4. With the elimination of nitrogen from the seepage, the Bolton Landing

Sewage Treatment Plant and the septic tanks and the lessening of the ground water flow, the total estimated future nitrogen loading would be reduced by about 12,000 kg/yr or about 10%. There would be increased inputs due to the expanded urban areas, and it is predicted that more houses would result in a greater use of lawn fertilizers. However, the phosphorus, which is the limiting nutrient in Lake George, would increase by an estimated 600 kg/yr, an 8% increase. Whereas the dry fall loading would still represent about 40% of the phosphorus input, the urban runoff could contribute twice as much as stream runoff and be a significant source of phosphorus to the lake. The increase due to urban runoff would be greater than the reduction due to elimination of sewage discharges.

TABLE 4. Estimated Future Loadings to South Lake of Lake George (Aulenbach, 1979a; Mitchell, 1978; Siebecker, 1979)

		Nitrogen			Phosphorus		
Sources	Volume (km^3/yr)	Conc. (ug/L)	Loading (kg/yr)	%	Conc. (ug/L)	Loading (kg/yr)	%
Runoff							
Stream	0.114	300	34,200	33.5	10	1,140	14.2
Urban	0.007	-	5,800	5.7	-	2,300	28.6
Direct Precipitation on Lake Surface							
Wet Fall	0.052	1,000	52,000	51.0	20	1,040	12.9
Dry Fall	-	-	6,300	6.2	-	3,300	41.0
Ground Water	0.005	300	1,500	1.5	10	50	0.6
Lawn Fertilizer	-	-	2,200	2.2	-	220	2.7
Total	0.178		102,000	100.1		8,050	100

Attention should be called to the influence of the soil system in reducing nutrients to the lake. Referring to Table 1, it may be seen that the watershed area of the South Lake is about 5.44 times the South Lake surface area. It is assumed that the wet and dry precipitation on the land is the same as on the water. Thus, based on presettlement values the loading to the land and the amount removed before the surface and ground water runoff reaches the lake were calculated as shown in Table 5. It may be seen that in the order of 79% of the nitrogen and 88% of the phosphorus in the precipitation may be removed by the soil system. As development encroaches upon natural land, the area of natural land decreases, resulting in lower nutrient inputs to the lake from runoff as shown in Tables 3 & 4. However, the loading from urban runoff greatly exceeds this reduction.

TABLE 5. Nutrient Removal in Precipitation Which Falls on Land

	Nitrogen	Phosphorus
Precipitation on lake surface, kg/yr		
Wet Fall	31,200	1040
Dry Fall	3,750	1040
Total	34,950	2080
Equivalent amount on watershed, kg/yr	190,058	11,311
Amount reaching lake from land, kg/yr		
Runoff	36,600	1,220
Ground water	3,000	100
Total	39,600	1,320
Amount absorbed (difference) kg/yr	150,458	9,991
% Removed	79.2	88.3

CLASSIFICATION ACCORDING TO PHOSPHORUS LOADING

Vollenweider and Dillon (1974) have shown means of interpreting the trophic nature of a lake on the basis of phosphorus loading. The classification of South Lake George according to phosphorus loading and mean depth is shown in Fig. 3. From this it may be seen that South Lake was originally quite oligotrophic, but anthropogenic influences have forced it over the boundary into the eutrophic range. Any further development, as influenced by the proposed Warren County Sewer System would cause even more eutrophic conditions.

Vollenweider and Dillon (1974) place slightly more reliability on a lake classification also taking into account the lake water retention time. The classification of South Lake George accoridng to this technique is shown in Fig. 4. Here again, the presettlement quality appears quite good. However, the present loading places the South Lake just within the admissible limits, with the additional phosphorus loadings allowed by the proposed new sewer carrying the lake over into the dangerous zone. Inasmuch as South Lake George has not yet exhibited any indications of serious eutrophication, this evaluation seems more representative of the conditions in South Lake George. It must also be pointed out that the proposed diversion of sewage out of the basin would increase the retention time in the South Lake from 5.5 to 5.7 yrs. This, however, would not make a significant change in the future classification.

DISCUSSION

The determination of a nutrient budget for a lake is not a precise calculation. It involves the use of some measured values and some

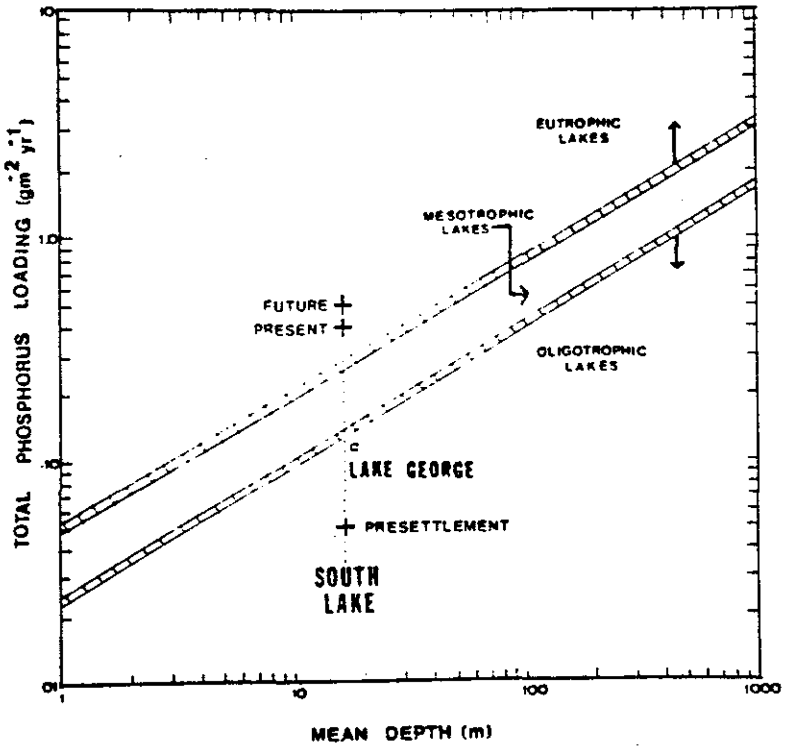

Figure 3. Classification of Lake George and the South Lake of Lake George according to phosphorus loading.

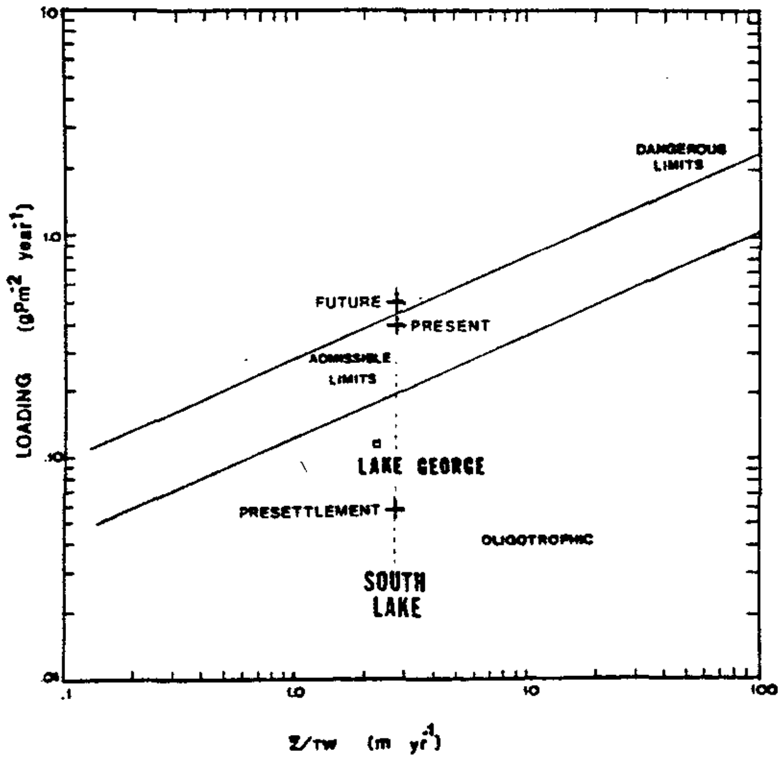

Figure 4. Classification of Lake George and the South Lake of Lake George according to phosphorus loading and water retention time.

reasonable estimates. The more measured values included, the better the estimate. The best measured values relate directly to the lake being evaluated; next would be similar lakes or other nearby areas. When no local data are available, the literature must be searched for appropriate values. Even local measured values may not be precise, as there may be spatial as well as temporal variations in any parameter measured. There have been previous estimated nutrient budgets for Lake George, some of which contained estimates which now appear to be significantly in error. As new data become available, these estimates are revised. The estimates presented here represent all the data available up to the present time.

The results do show the effects of man's activities upon the lake over a long period of time. This is evident in the quality of the water as well as the nutrient budgets. But this presents a problem. The public surely should be able to enjoy the beauty of Lake George, but if every person visited there, it would no longer be beautiful. How to preserve the beauty of Lake George and still make it available to everyone presents a problem which should be considered now. After the lake turns eutrophic is too late to start seeking a solution to the problem.

The results also show that installing the proposed new sewer system will not solve the problem. As a matter of fact, it may encourage greater development in the basin, and therefore contribute to increasing the problem. The lack of a sewer should not be used to replace adequate land use and zoning plans to facilitate orderly development. However, at the present time there are insufficient zoning plans, and the lack of a sewer is preventing excessive development around Lake George.

The important thing revealed by the nutrient budgets shown is the source of the nutrients. With information relating to sources, steps can be taken to reduce inputs from sources which can be controlled. For example, little can be done to reduce the quantity of wet and dry fall onto the lake and the basin. Air pollution controls in distant areas may help reduce the nutrient contents of the precipitation; however, this is not something that can be resolved quickly on a local basis. On the other hand, construction of a sewer system to eliminate the phosphorus inputs from septic tanks would accomplish very little. An in-depth cost-risk-benefit study could provide a more definitive answer to this problem. Looking at the controllable inputs to the lake shows that urban runoff is presently a significant problem, and may become more of a problem in the future. Steps should be taken immediately to develop and adopt a zoning system sensitive to these problems. In addition to controlling (not necessarily stopping) development, this should include setbacks from the lake, establishment of a green belt around the lake and control (possibly collection and treatment) of urban runoff. Some action to control urban runoff could be taken immediately with a little extra cost and effort. However, the people have been led to believe that the proposed Warren County Sewer System will solve all the problems of Lake George, and, therefore, they are not even thinking about any other form of nutrient control. Thus a part of the problem is communicating the proper information to the public.

The results show that the phosphorus loading to the South Lake of Lake George is approaching the critical stage. Any additional loading may be sufficient to carry the lake over into the eutrophic zone, making the lake less desirable and reducing property values. The installation of the proposed sewage collection and treatment system without a concommitant plan to control urban runoff could be sufficient to carry the South Lake into this eutrophic zone.

SUMMARY AND CONCLUSIONS

The nutrient budgets presented here relate directly to the South Lake of Lake George, the most impacted portion of this lake. The temporal scenarios indicate man's impact upon the lake, and his possible future impact. The results also show the sources of the nutrients so that a choice can be made of how best to control the nutrient inputs to the lake. The largest and therefore the most likely source of phosphorus to be controlled is urban runoff. A plan should be commenced now to control this input. The proposed Warren County Sewer System would encourage greater development which would result in even greater inputs from urban runoff.

The South Lake of Lake George is approaching the critical state in terms of eutrophism. Immediate steps should be taken to reduce the phosphorus input to the lake. Inspection of the sources of phosphorus inputs shows that control of urban runoff to the lake would be most effective.

Lake George is still a beautiful recreational lake. It is worth preserving it as long as possible for future use by many people. Should it become eutrophic, it would be much less desirable. Therefore, the public should be informed and every possible effort made to keep Lake George beautiful.

ACKNOWLEDGEMENT

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LITERATURE CITED

Anonymous. 1979. Lower-cost lake protection. Environ. Science & Technol., 13, 909-911.

Aulenbach, D.B. 1979a. Nutrient Budgets and the effects of development on trophic conditions in lakes. Fresh Water Institute Report 79-2, Rensselaer Polytechnic Institute, Troy, NY, 34 pp.

Aulenbach, D.B. 1979b. Long term discharge of trickling filter effluent into sand. EPA-600/2-79-068, Ada, OK, 146 pp.

Aulenbach, D.B., and N.L. Clesceri. 1973. Sources of nitrogen and phosphorus in the Lake George Drainage Basin: a double lake. Fresh Water Institue Report 73-1, Rensselaer Polytechnic Institute, Troy, NY, 23 pp.

Aulenbach, D.B., and N.L. Clesceri. 1977. Means for protecting the drinking water quality of Lake George, New York. In R.B. Pojasek (ED.), Drinking Water Quality Enhancement Through Source Protection. Ann Arbor Science Publ., pp. 545-566.

Aulenbach, D.B., R.R. Harris, and R.C. Reach. 1978. Purification of secondary effluent in a natural sand filter. J. Water Poll. Control Fed., 50, 86-94.

Clesceri, N.L., and S.L. Williams. 1972. Diatom population changes in Lake George (NY). Fresh Water Institute Report 72-1, Rensselaer Polytechnic Institute, NY, 212 pp.

Colon, E.M. 1971. The hydrology of Lake George, New York. Masters Thesis, Rensselaer Polytechnic Institute, NY, 93 pp.

Colon, E.M. 1972. Hydrologic study of Lake George, New York. D. Eng. Thesis, Rensselaer Polytechnic Institute, NY, 190 pp.

Cronan, C.S., and C.L. Schofield. 1979. Aluminum leaching response to acid precipitation: effects on high-elevation watersheds in the Northeast. Science, 204, 304-306.

Ferris, J.J. and N.L. Clesceri. 1975. A description of trophic status and nutrient loading for Lake George, NY, Fresh Water Institute Report 75-1, Rensselaer Polytechnic Institute, NY, 59 pp.

Ferris, J.J. and N.L. Clesceri. 1977. A description of the trophic status and nutrient loading for Lake George, New York. North American Project - a Study of U.S. Water Bodies, EPA-600/3-77-086, Corvallis, OR, 135-181.

Fillip, A. 1979. Masters Thesis, Rensselaer Polytechnic Institute, Troy, NY (in preparation).

Frick, H. 1973. Lake George sanitary survey, June 4, 1973 - September 1, 1973 (Draft). New York State Department of Environmental Conservation, Albany, NY, 32 pp.

Geldrich, E.E., and B.A. Kenner. 1969. Concepts of fecal streptococci in stream pollution. J. Water Poll. Control Fed., 41, R336-R352.

Gibble, E.B. 1974. Phosphorus and nitrogen loading and nutrient budget on Lake George, NY. Masters Thesis, Rensselaer Polytechnic Institute, NY, 104 pp.

Haas, C.N. 1979. Unpublished data, Fresh Water Institute, Rensselaer Polytechnic Institute, Troy, NY.

Hajas, L. 1975. Purification of land applied sewage within the ground water. Masters Thesis, Rensselaer Polytechnic Institute, NY, 242 pp.

Hazen and Sawyer Engineers. 1977. Report No. 3 on wastewater facilities planning for the Lake George - upper Hudson region, Warren County, New York. Project No. C-36-970, Section 201, Step 1, Wastewater Facilities Plan, 328 pp.

Hetling, L.J. 1974. Observations on the rate of phosphorus input into Lake George and its relationship to the lake's trophic state. Technical Report #36, New York State Department of Environmental Conservation, Albany, NY, 20 pp.

Jones, R.A., and G.F. Lee. 1977. Septic tank wastewater disposal systems as phosphorus sources for surface waters. Occasional Paper No. 13, Center for Environmental Studies, University of Texas at Dallas, Richardson, TX.

Kasper, J.R. 1976. Comparison of nitrogen loading in the West Brook and Northwest Bay Brook watersheds, Lake George, NY. Master of Engineering Thesis, Rensselaer Polytechnic Institute, NY, 142 pp.

Koenig, H.W., and E.A. Nusch. 1973. The influence of settlement and recreational activities on reservoirs in the Rhenish-Westphalian industrial area. Proc. Commiss. of Internationale des Grands Barrages, 11, 305-321.

McKinney, N., and A. Krause. 1979. Seven lakes examined in EIS - "septic snooper" plan will save billions of dollars. Land and Water, July, pp. 34-36.

Mitchell, J.R. 1978. Land use influences on the nutrient loadings to Lake George, New York, Master of Engineering Thesis, Rensselaer Polytechnic Institute, Troy, NY, 111 pp.

Needham, J.C., C. Juday, E. Moore, C.K. Sibley, and J.W. Titcomb. 1922. A biological survey of Lake George, NY, State of New York Conservation Commission, Albany, NY, 78 pp.

Nusch, E.A. 1975. Comparative Investigations on extent, causes and effects of eutrophication in western German reservoirs. Verh. Internat. Verein. Limnol., 19, 1871-1879.

Palladine, R. M. 1976. Comparison of phosphorus loading in the West Brook and Northwest Bay Brook watersheds, Lake George, NY. Master of Engineering Thesis, Rensselaer Polytechnic Institute, Troy, NY, 149 pp.

Siebecker, B.G., Masters Thesis, Rensselaer Polytechnic Institute, Troy, NY, (in preparation).

Schoettle, M., and G.M. Friedman. 1972. Sediments and sedimentation in a glacial lake: Lake George, New York. Fresh Water Institute Report 72-11B, Rensselaer Polytechnic Institute, Troy, NY, 24 pp.

Stross, R.G. 1973. Primary productivity of Lake George, New York: its estimation and regulation. International Biological Program Report 73-84, National Academy of Science, Washington, DC.

Vollenweider, R.A., and P.J. Dillon. 1974. The application of the phosphorus loading concept to eutrophication research. Canada Centre for Inland Waters, Burlington, Ontario, 42 pp.

Wood, L.W., and G.W. Fuhs. 1979. An evaluation of the eutrophication process in Lake George based on historical and 1978 limnological data. Environmental Health Report No. 5, New York State Department of Health, Albany, NY, 73 pp.