A STUDY OF EUTROPHICATION AND AQUATIC PLANTS GROWTHS IN SELECTED LAKES AND RIVERS OF PUERTO RICO

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Introduction

The large majority of lakes in Puerto Rico are man-made reservoirs used for the production of energy and for public water supply. Most of these reservoirs have been in operation for periods of time long enough to reach some level of eutrophication. This impairs the chemical quality of the waters, while at the same time introduces in them foul tastes and odors. Aquatic plants such as water lillies, water hyacinths and algal blooms further detract quality, not only by their unsigthliness but also by exerting large oxygen demands and preventing adequate mixing. These growths of aquatic plants are not yet observable in a few lakes. The same applies to rivers in the island, in some of which aquatic plants grow proffusely while in others they are totally absent. Floodprone zones are in some cases a direct result of the presence of large aquatic blooms in the mouths of rivers.

An investigation to identify the physical and chemical parameters which promote eutrophication and aquatic plants growth in the island's bodies of water was undertaken to provide information so as to find effective ways to control the above mentioned adverse effects and to enhance both quality and quantity of the available water resources. The results (findings) of this investigation are presented here.

Description of the Lakes Studied

The Guajataca Reservoir is located in northwestern Puerto Rico on Río Guajataca south of the town of Quebradillas. The reservoir was completed in 1929, with an original capacity of 31,800 acre-feet. The dam is an earth-fill structure with an unregulated spillway. Water stored in the reservoir is currently used for power generation, irrigation and municipal supply.

Yauco Dam, completed in 1952, is located on Río Yauco in southwestern Puerto Rico, about 7 miles north of the town of Yauco. The dam is a unit of the Southwestern Puerto Rico Project and originally provided 16,500 acre-feet of usable storage for power generation and irrigation. The dam is a concrete gravity structure with a total length of 591 feet, a maximum height of 178 feet, and a maximum width at the base of 150 feet.

Toa Vaca. The Toa Vaca Dam, completed in 1972, is located approximately 2 miles south of the town of Villalba on Río Toa Vaca. The storage at the spillway crest is 31,000 acre-feet; with radial gates the storage is 50,900 acre-feet. The dam was originally constructed as part of a major water supply system for importing water from the northern coast. To date, a transfer tunnel from the northern coast has not been constructed. A 66-inch pipeline from the dam is used occasionally to provide raw water to a water treatment plant in Ponce. This line also has sufficient hydraulic capacity to serve agriculture in the vicinity of Ponce, but it is not being used for this purpose at present.

Cidra Dam is located on Río Bayamón about 3 miles northeast of the town of Cidra. The dam is a concrete gravity and earthfill dam with an ungated ogee spillway. The reservoir supplies supplemental water for the San Juan Area. When built in 1946, Cidra provided 4,450 acre-feet of storage. Siltation had reduced the storage capacity to 3,800 acre-feet by 1975. Analysis indicates that it is not economically feasible to increase the storage in Cidra by removing these sediment deposits.

Loiza Dam is located on Río Grande de Loíza about 15 miles southeast of San Juan. When built in 1953, the reservoir provided a capacity of 21,800 acre-feet. Storage has been reduced to 14,400 acre-feet because of siltation. The 1975 effective storage of the reservoir was between an elevation of 40.1 meters and 28.0 meters with a useful capacity of 13,700 acre-feet. Dead storage was contained between elevations of 28.0 meters and 15.2 meters with a capacity of 700 acre-feet. The Loíza Lake is primarily a water supply reservoir. However, it has a built-in power generation capability which can be used during periods when a water surplus is available.

The dam is a concrete gravity structure with a spillway controlled by eight radial gates, each 9.14 meters high. A recent 1-meter extension to the top of existing spillway gates provides an additional 3,000 acre-feet of storage. It increased usable storage to 16,700 acre-feet.

One additional alternative for maintaining or increasing available storage is the removal of sediment by dredging operations. If the present rate of siltation continues, Loíza will be filled with silt between 2010 and 2035. Because of the lack of other large reservoir sites near San Juan, dredging of the lake has been included as a part of the alternative water supply plans considered for San Juan. Dredging operations should be scheduled to begin in 2015.

Materials and methods

Water samples were collected with an Alpha horizontal water sampler (Model 1120-C40 from Wildco, Wildlife Supply Company, Saginaw, Michigan 48602) and for the dissolved oxygen sample a sewage/waste water sampler, in two different sites in each lake at three differents depths: one from the surface, one approximately 1 meter from the bottom, and the third one, half the depth of the lake at that site. Sediments samples were also collected, using the Ekman dredge, Model 196-F10, of Wildco.

The sampling in each lake was done twice, with approximately two months elapsed between sampling. The samples were transfered to acid-rinsed glass or polyethylene bottles and kept in an ice chest until taken to the laboratory for analysis.

The water samples were analyzed for pH, color, turbidity, temperature (in situ), conductivity, total residue, suspended solids, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total phosphorus, dissolved ortho-phosphate, total Kjeldhal nitrogen, ammonia, nitrate, nitrite and some metals (Fe, Cu, Cr, Mn, Zn, Ca, Mg, K, and Na). The sediments samples were analyzed for pH, total solids, total phosphorus, total nitrogen, ammonia, and metals.

The methods used for analysis were those described in the Standard Methods for the Examination of Water and Waste Water (1980), Methods for Chemical Analysis of Water and Wastes (1974), and Methods for the Determination of Inorganic Substances in Water and Fluvial Sediments of the U.S.G.S. (1979).

The sediments samples were passed through a 2 mm sieve before taken for analysis. For the metals analysis the method described in the above mentioned U.S.G.S. publication for sample preparation and pretreatment (Method I-5485-78) was used, but instead of disolving the digestion mixture in HCl, it was dissolved in Aqua regia.

Results and Conclusions

The chemical and physical analysis of the water samples and sediment samples are presented in Tables 1 to 12. In Table 12 are summarized the average of the results of the analysis of total phosphorus, ortho-phosphate, nitrogen-nitrite, nitrogen-nitrate, nitrogen-ammonia, total Kjeldhal nitrogen, and total nitrogen for water samples.

Generally, there was not too much difference between the average of the results obtained in the two different sampling dates. In the sampling of Yauco Lake, the heavy flow observed the second day of sampling indicated there had been many rainy days before. Climatological data confirmed this observation, and so, in certain parameters, such as total solids, suspended solids, color, turbidity and others, there is a great difference between the average results of the first sampling date and the second one.

In Carraizo Lake, the sampling sites were completely different the two sampling days, this due to the presence of water hyacinths which made difficult the collecting of the samples.

The water samples taken are representative of a water column in the lake, so the average results obtained are representative of the characteristics of the lake. The average results found in the middle depth of the water column are nearly equal to the average results of all samples.

Generally, the nutrient concentration (N and P), the solids, the conductivity and the metals were higher in bottom samples than in surface and middle depth samples. The dissolved oxygen (DO) and the biochemical oxygen demand (COD), on the contrary, lowered through the

TABLE 1

Lake Guajataca Water Properties[a]

Parameter[b]	At Surface	At mid depth	Near bottom	Average
pH	8.1	7.1	7.0	7.4
Temperatures, °C	29	25.7	24	26.3
Color, color units	5	9.5	21.2	11.9
Turbidity	1.9	4.8	11.2	5.8
Conductivity, $\frac{\mu \text{ mhos}}{\text{cm}}$	207.0	243.1	254.2	234.8
Dissolved oxygen, mg/l	9.4	2.4	1.4	4.4
Chemical oxygen demand	3.1	8.0	13.2	9.8
Biochemical oxygen demand	.4	.8	.7	.6
Total solids	173.4	189.1	198.5	187
Total Kjedhal nitrogen	.59	0.54	.86	0.66
Ammonia nitrogen	0.5	0.11	.32	0.16
Nitrate nitrogen	.02	.01	.07	.06
Nitrite nitrogen	Nd	<.01	<.01	<.01
Total phosphorus	0.02	.023	.03	.02
Dissolved orthophosphate	.01	.02	.02	.02

a- Values shown for depth are the average ones for the two different dates of observation.

b- All units are mg/l, except where otherwise specified

TABLE 2

Lake Guajataca - Water Properties[a]

Parameter[b]	At Surface	At mid depth	Near bottom	Average
Fe	0.12	0.32	0.75	0.39
Mn	0.01	0.13	0.29	0.15
Cr	<0.01	<0.02	<0.02	<0.02
Zn	0.02	0.01	0.02	0.02
Cu	<0.01	<0.01	<0.01	<0.01
Na	6.13	6.09	5.88	6.03
K	1.60	1.74	1.70	1.68
Mg	3.15	3.24	2.96	3.12
Ca	40.72	51.10	53.11	48.31

a- Values shown for depth are the average ones for the two different dates of observation.

b- All units are mg/l, except where otherwise specified.

TABLE 3

Lake Yauco - Water Properties[a]

Parameter[b]	At Surface	At mid depth	Near bottom	Average
pH	8.1	7.5	7.3	7.6
Temperatures, °C	28.5	26.3	25.8	26.8
Color, color units	4.0	21.3	102.5	42.6
Turbidity	5.3	70.5	165.6	80.5
Conductivity, $\frac{\mu \text{ mhos}}{\text{cm}}$	232.6	201.9	196.2	210.2
Dissolved oxygen, mg/l	9.5	5.2	4.3	6.3
Chemical oxygen demand	8.6	7.5	8.6	8.2
Biochemical oxygen demand	1.6	.8	.9	1.1
Total solids	234.5	167.8	188.1	199.5
Total Kjedhal nitrogen	.34	.32	.45	.37
Ammonia nitrogen	<.05	<.05	<.05	<.05
Nitrate nitrogen	0.08	0.14	0.07	0.10
Nitrite nitrogen	<0.01	<.01	<.02	<0.01
Total phosphorus	0.03	0.03	0.03	0.03
Dissolved orthophosphate	.02	.02	.02	.02

a- Values shown for depth are the average ones for the two different dates of observation.

b- All units are mg/l, except otherwise specified.

TABLE 4

Lake Yauco - Water Properties[a]

Parameter[b]	At Surface	At mid depth	Near bottom	Average
Fe	0.28	2.98	7.07	3.44
Mn	0.01	0.07	0.31	0.13
Cr	0.02	0.04	0.05	0.03
Zn	0.02	0.03	0.03	0.03
Cu	0.01	0.01	0.02	0.02
Na	10.18	9.74	9.59	9.84
K	1.91	2.08	2.57	2.19
Mg	7.94	8.05	8.63	8.21
Ca	29.91	28.88	29.51	29.43

a- Values shown for depth are the average ones for the two different dates of observation.

b- All units are mg/l, except otherwise specified.

TABLE 5

Lake Toa Vaca - Water Properties[a]

Parameter[b]	At Surface	At mid depth	Near bottom	Average
pH	8.05	7.50	7.25	7.60
Temperatures, °C	28.75	25.25	24.50	26.17
Color, color units	4.5	17.50	20.00	14.00
Turbidity	1.80	11.68	14.05	9.18
Conductivity, $\frac{\mu \text{ mhos}}{\text{cm}}$	220.18	223.88	222.40	222.15
Dissolved oxygen, mg/l	7.85	2.33	0.60	3.60
Chemical oxygen demand	8.78	9.35	10.05	9.40
Biochemical oxygen demand	0.71	0.69	0.95	0.79
Total solids	185.13	194.38	186.88	188.79
Total Kjedhal nitrogen	0.33	0.96	1.25	0.84
Ammonia nitrogen	0.04	0.500	0.580	0.37
Nitrate nitrogen	0.01	0.01	0.01	0.01
Nitrite nitrogen	<0.01	<0.010	<0.010	<0.01
Total phosphorus	0.03	0.11	0.17	0.10
Dissolved orthophosphate	0.02	0.09	0.15	0.09

a- Values shown for depth are the average ones for the two different dates of observation.

b- All units are mg/l, except where otherwise specified.

TABLE 6

Lake Toa Vaca - Water Properties[a]

Parameter[b]	At Surface	At mid depth	Near Bottom	Average
Fe	0.16	0.70	1.00	0.62
Mn	0.01	0.92	1.16	0.70
Cr	<0.01	<0.01	<0.01	<0.01
Zn	0.01	0.02	0.02	0.02
Cu	<0.01	0.01	0.01	0.01
Na	12.95	11.47	11.24	11.89
K	1.88	1.95	2.01	1.95
Mg	9.52	9.25	8.63	9.14
Ca	30.09	31.02	29.41	30.17

a- Values shown for depth are the averages ones for the two different dates of observation.

b- All units are mg/l, except where otherwise specified.

TABLE 7

Lake Cidra - Water Properties[a]

Parameter[b]	At Surface	At mid depth	Near bottom	Average
pH	7.4	6.8	6.6	6.9
Temperatures, °C	28	26.	24	26
Color, color units	25	63.8	168.8	85.8
Turbidity	4.1	39.8	75	39.6
Conductivity, $\frac{\mu \text{ mhos}}{\text{cm}}$	153.1	161.5	157.6	157.4
Dissolved oxygen, mg/l	8.2	1.9	.3	3.5
Chemical oxygen demand	16.2	16.3	17.8	16.8
Biochemical oxygen demand	1.2	1.3	0.9	1.1
Total solids	128.8	138.9	153.0	140.2
Total Kjedhal nitrogen	.45	.91	2.35	1.24
Ammonia nitrogen	<.06	.44	1.67	.72
Nitrate nitrogen	0.03	0.05	.19	.09
Nitrite nitrogen	<0.01	<0.01	<0.01	<0.01
Total Phosphorus	.04	.04	.25	.12
Dissolved orthophosphate	.01	.03	.18	.07

a- Values shown for depth are the average ones for the two different dates of observation.

b- All units are mg/l, except where otherwise specified.

TABLE 8

Lake Cidra - Water Properties[a]

Parameter[b]	At Surface	At mid depth	Near bottom	Average
Fe	0.40	5.24	9.49	5.04
Mn	0.17	0.88	0.96	0.67
Cr	0.02	0.02	0.06	0.03
Zn	0.02	0.03	0.03	0.03
Cu	0.01	0.02	0.02	0.02
Na	15.21	14.64	11.39	13.75
K	3.66	3.77	4.02	3.82
Mg	6.25	6.44	5.07	5.92
Ca	11.21	13.03	10.64	11.63

a- Values shown for depth are the average ones for the two different dates of observation.

b- All units are mg/l, except where otherwise specified.

TABLE 9

Lake Loîza - Water Properties[a]

Parameter[b]	At Surface	At mid depth	Near bottom	Average
pH	7.78	6.98	6.80	7.18
Temperatures, °C				
Color, color units	21.25	42.50	80.00	47.92
Turbidity	16.50	30.95	48.75	32.07
Conductivity, $\frac{\mu \text{ mhos}}{\text{cm}}$	223.73	205.08	193.05	207.29
Dissolved oxygen, mg/l	11.78	3.80	3.35	6.31
Chemical oxygen demand	20.33	15.55	17.75	17.88
Biochemical oxygen demand	6.03	2.63	3.40	4.02
Total solids	203.63	203.63	206.50	204.25
Total Kjedhal nitrogen	1.14	0.93	1.06	1.04
Ammonia nitrogen	<0.16	<0.15	<0.25	<0.19
Nitrate nitrogen	0.20	0.45	0.41	0.36
Nitrite nitrogen	0.27	0.13	0.15	0.11
Total phosphorus	0.26	0.32	0.32	0.30
Dissolved orthophosphate	0.18	0.23	0.24	0.22

[a] Values shown for depth are the average ones for the two different dates of observation.

[b] All units are mg/l, except where otherwise specified.

TABLE 10

Lake Loíza - Water Properties[a]

Parameter[b]	Surface	At mid depth	Near bottom	Average
Fe	0.70	1.83	3.15	1.89
Mn	0.12	0.13	0.32	0.20
Cr	0.02	0.03	0.03	0.03
Zn	0.01	0.02	0.02	0.02
Cu	0.01	0.01	0.01	0.01
Na	17.84	16.72	15.83	16.80
K	3.08	3.26	3.48	3.27
Mg	7.82	7.50	7.17	7.50
Ca	20.67	19.72	18.88	19.75

a- Values shown for depth are the average ones for the two different dates of observation.

b- All units are mg/l, except where otherwise specified.

TABLE 11 - Sediment Properties

Parameter	Lake Guajataca	Lake Yauco	Lake Toa Vaca	Lake Cidra	Lake Loíza
pH	7.15	7.0	7.0		
Total nitrogen, μg/g	2929	1228	2,527.475	2973.875	1497.65
Ammonia, μg/g	154	140	122.4	222.775	116.775
Total phosphorus, %	0.054	0.05	0.0515	0.058	0.0623
Fe, %	5.56	6.15	6.615	8.7975	4.975
Mn, μg/g	563	1778	1,385.95	1179.975	1308.7
Cr, μg/g	218	100	156.9	214.55	149.35
Zn, μg/g	96.6	110.4	86.89	186.425	145.85
Cu, μg/g	58.7	109.5	112.425	134.6	123.15
Mg, %	0.54	1.39	2.405	0.532	0.895
Na, μg/g	311.7	349.4	935.1	458.42	478.025
K, μg/g	1870	1992	2,563.575	1556.75	1427.55
Ca, %	7.53	0.76	1.26	0.237	0.7425

a- The values shown are the average ones for the two different sampling dates.

Table 12

Nutrient Concentration in mg/L of N, P of all Samples
Average in each lake or river.

Lake/River	TP	O-PO_4	N-NO_2	N-NO_3	N-NH_3	TKN	TN
Guajataca	0.03	0.02	0.01	0.05	0.16	0.49	0.55
Yauco	0.03	0.02	0.01	0.10	0.05	0.37	0.48
Toa Vaca	0.10	0.09	0.01	0.01	0.37	0.84	0.86
Cidra	0.12	0.07	0.01	0.09	0.72	1.24	1.34
Loíza	0.30	0.22	0.11	0.36	0.19	1.04	1.51
Guajataca River	0.15	0.08	0.08	1.88	0.28	0.75	2.71

water column and many times were almost undetectable (below 1 mg/L).

Bottom ammonia concentrations were consistenly higher for all stations, except in Luchetti Lake, where in all samples it was below 0.05 mg/L. This pattern is most likely due to the extent of organic matter accumulation and decomposition in the sediment. This is supported by dissolved oxygen data showing significant decrease from surface to bottom (Moshiri et al., 1972).

Eutrophic conditions are the consequences or effects of a lake's nutrient enrichment, but there is no way to express this state in simple, quantitative terms (Brezonik and Shannon, 1971).

One of the objectives of this study was to relate the water properties of the lakes and rivers to the presence or absence of water hyacints. Of the water bodies studied, Guajataca, Luchetti and Toa Vaca Lakes didn't have water hyacinths growing on them, but Cidra and Carraízo Lakes and Guajataca river, near the town of Quebradillas did have them.

The presence of algal blooms and water hyacinths in rivers and lakes is directly related to high nutrient concentration in the water bodies. It is generally recognized that the increased nitrogen and phosphorus input to a water body will generate increased plant production (Brezonik and Shannon, 1971).

The amounts of inorganic nitrogen and phosphorus needed to produce abundant algae and rooted aquatic weeds are relatively small. The generally accepted upper concentration limits for lakes free of algal nuisances are 0.3 mg N/L of ammonia plus nitrate nitrogen and 0.02 mgP/L of orthophosphate at the time of spring overturn. Lakes with annual mean total nitrogen and Phosphorus concentrations greater than 0.8 mg/L and 0.1 mg/L, respectively, exhibit algal blooms and nuisance weed growths during most growing season.

Brezonik and Shannon, in a study of Florida lakes, suggest that these lakes can assimilate more nutrients than those studied by R. Vollenweider in Europe and throughout the United States. In their study, they developed a trophic system for Florida lakes using a cation ratio, (Na + K)/Mg + Ca, earlier used by Pearsall, as one of the trophic indicators. They selected Pearsall's cation ratio as a subjective attempt to incorporate information on the major cations into the concept of trophic state. This ratio has not been used to any extent in other investigations, but it has been suggested as a potentially effective parameter for differentiation between lake trophic types. For Florida lakes the cation ratio appears to be a reasonably good indicator of trophic state with high values of the inverse cation ratio being indicative of eutrophic conditions (Brezonik and Shannon, 1971).

In this study done in lakes in Puerto Rico, the inverse was found. The lakes with visible state of eutrophy (presence of water hyacinths) had a cation ratio between 0.74-1.45, and those with no visible state of eutrophy (no water hyacinths present) had a cation ratio of 0.15-0.35. Guajataca Lake had the lowest cation ratio due to the greater concentration of Ca cation compared to the other cations.

Although the relationship between concentration of nutrient level and that of algal growth was established by hindsight observation, the figures must be treated with some caution, because other observations have well established that planktonic algae can flourish in waters containing much lower concentration of phosphorus, they have the ability to store phosphorus in excess of their immediate need (Weiss, 1969).

In Table 12 are summarized the nutrient concentration of the water samples in terms of nitrogen and phosphorus. It is observed that in Guajataca and Luchetti lakes the concentration of total phosphorus and total nitrogen is low compared to the concentration found in Cidra and Carraízo lakes and the Guajataca river. More than 50% of the total phosphorus is in the form of soluble orthophosphate which is the form readily utilized by algae for photosynthesis (Quiñones, 1976). Similar results have been reported recently by Quiñones in the limnology study of Lago Loíza (Quiñones, 1980).

One of the most important findings of the study here presented is the high concentration of total phosphorus and total nitrogen found in Toa Vaca Lake. Toa Vaca Lake is one of the most recently built water reservoirs in Puerto Rico. In this lake, the necessary conditions in terms of total phosphorus and total nitrogen are present to promote accelerated algal growth, but most of the nitrogen present is in the organic form. Looking at the concentration of the inorganic forms of nitrogen ($N\text{-}NO_2$, $N\text{-}NO_3$ and $N\text{-}NH_3$), it is observed that there is a great difference in the amount found in the lakes and the river with no water hyacinth growth (0.16-0.39) and the lakes with a water hyacinth growth (0.66-2.24). NH_3 and NO_3 have been shown to be the most important nitrogen sources for algae and this may play an important role as a limiting factor in the process of eutrophication in the island.

As has been stated earlier, eutrophic conditions are the consequences or effects of lakes nutrient enrichment. The nutrient concentration in the waters of these man-made lakes is mainly due to the intake currents (rivers) and the runoff water entering them, but sedimentation occurs, and, after a while, sediment may exert some influence on the eutrophication process, both as a nutrient source and as nutrient sink. Under aerobic conditions, the sediments act as nutrient sink or trap, but under anaerobic conditions they act as nutrient sources.

About 10 to 15 years ago, there was considerable controversy over the significance of internal (recycling from the sediments) versus external (inputs from land and the atmosphere) phosphate loads, but at present it is well established fact that for many water bodies the internal phosphorus loading is small (Lee, et al., 1978).

The phosphorus in the sediments, in particular, is mostly combined with iron, forming ferric (Fe^{+3}) and ferrous (Fe^{+2}) compounds. The ferric compounds are very insoluble in aerobic conditions, but in anaerobic conditions, the ferric ions are reduced to ferrous ones, which are highly soluble. As a consequence, the phosphates are released and are available to be used by algae (Quiñones, 1976).

The sediments in this study are obviously enriched with nitrogen and phosphorus, as compared to the overlying water; and may represent potential nutrient sources. However, most of the nitrogen present is in the organic form rather than as free ammonia. The phosphorus may also be presumably bound due to the high concentration of iron and manganese found.

Brezonik and Shannon conducted a variety of sediment exchange experiments. Sediment from one Florida lake was incubated in 10 liter bottles under varying conditions, and the ammonia and orthophosphate concentrations present in the overlying water were followed over a period of 20 days. The results obtained showed that, as expected, anoxic conditions allowed the release of more ammonia and phosphate from the sediments. This supports the findings of higher ammonia and phosphate concentrations found in bottom water samples, as compared to middle and surface ones. During periods of high wind or in the rainy season, sufficient currents may be generated in shallow lakes and litoral zones of deeper ones to stir sediments with the water and release considerable amounts of nutrients (Brezonik and Shannon, 1971). It seems that mixing is the most effective mechanism to release sediment nutrients into the water. Resuspension should be greater in shallow lakes, but it likely occurs to some degree in all lakes, particularly in shallow water areas. However, there have been no studies that directly measure the process, and there is little information on the limnological significance of this (Bachman and Canfield, 1979).

As expected, the water bodies with high nutrient concentration were the ones with visible water hyacinths growth. The exception is Toa Vaca Lake, where the minimum phosphorus and total nitrogen concentration necessary to promote algal blooms and nuisance weed growth are present, and there is no visible water hyacinths growth. A possible explanation for these findings is the fact that lakes with high turnover rate tolerate higher loadings of nutrients before eutrophication effects are visible. The water of Toa Vaca lake is an important water reserve already in use, so the quality of the water should be preserved and maintained. A comprehensive study of Toa Vaca Lake and its tributaries should be done, and the principal sources of nutrients, and the flushing and sedimentation rate should be estimated.

The key to the control of excessive fertilization in waters in which P is or can be made to be the limiting aquatic plant nutrient, is the control of available phosphorus from external sources. This has been demostrated in several waterbodies, such as Lake Washington in Seattle, where reducing the external P load resulted in reduced algal growth in the lake to levels proportional to the resulting external P load (Lee, et al., 1978).

As an example of a method used to limit nutrient concentration the diversion of nutrient rich waste water has been used. Construction of a pipeline to convey the treated waste water from the city of Madison, Wisconsin around a chain of lakes was completed in 1959. The rate of eutrophication has been slowed with no further deterioration since the diversion.

Advanced waste water treatment can be used to remove nutrients from waste water where diversion is not possible. Conventional biological treatment provides approximately 30% P removal and 40-50% nitrogen reduction in secondary treatment of domestic waste water. At present, emphasis is being placed on the Phosphorus removal because it is considered the limiting nutrient. There are methods available to precipitate phosphate chemically. Nitrogen compounds are more difficult and more expensive to eliminate.

As clean water for all uses is more difficult to get all the time, and as in this overpopulated island all lakes are man made water reservoirs, something should be done to asses its quality.

One thing is clear, though. High eutrophication and plant growth is already affecting some of the reservoirs,(including rivers and lakes) and the cost to produce clean water is continually rising. Conservation is necessary and it can be done. The study here presented may serve as part of the necessary studies and work to be done. The implicit and explicit recommendations in this report are that a comprehensive study on the principal sources of nutrients and the flushing and sedimentations rates be estimated periodically. The author hopes the work already done may serve not only as a base, but as stimulant in the development of feasible ways to arrest the eutrophication process in the lakes and to enhance the positive usable capabilities of the water bodies in the island.

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