CEER E-35

ECOLOGY OF BIOMPHALARIA GLABRATA AND MARISA CORNUARIETIS IN LAKES OF PUERTO RICO

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Ecology of *Biomphalaria glabrata* and *Marisa cornuarietis* in Lakes of Puerto Rico.

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INTRODUCTION

The ampullarid snail *Marisa cornuarietis* has displaced *Biomphalaria glabrata*, the intermediate snail host of bilharzia, from many of the 28 man-made lakes of Puerto Rico. These lakes were reservoirs created for irrigation, hydroelectric power and domestic water supply (Figure 1). The biological process of displacement was gradual and occurred over a 20 year period. It was the purpose of this study to examine the ecology of these lakes and determine what factors were most important in the competition between the two snails. In addition the information should assist in evaluating the potential for using *M. cornuarietis* in other countries, and in designing or evaluating proposed irrigation and hydroelectric reservoirs in the tropics. This information is especially important in Africa where new reservoirs have invariably resulted in increased bilharzia transmission or caused other health problems (Table 1).

Figure 1. Lake Carraízo in Trujillo Alto, Puerto Rico was constructed as part of the San Juan water supply and also generates electric power. Unfortunately it also receives poorly treated sewage from upstream communities and thus contains heavy aquatic plant populations and other undesirable conditions.

TABLE 1

HYDROELECTRIC RESERVOIRS WITH POTENTIAL IMPACT ON HUMAN HEALTH IN AFRICA

Country	Lake	Dam Location	Health Problems	Lake Area When Full in KM^2	Reference
Egypt	Nasser	Aswan on Nile River	Increased Bilharzia downstream, potential in lake	5000	El-Sayed and El-Kl[illegible] 1964.
Ethiopia	Tana	Gondar on Blue Nile.			Ferguson, Ruiz 1970.
Ghana	Volta	Akosombo on Volta River	Severe outbreak of bilharzia on West Shore.	8500	Paperna. 1969
Ivory Coast	Kossu	Bandama	Potential for bilharzia.		Webbe, 1974
Morocco	Tafilalet				Webbe. 1972
Mozambique	Cabora Bossa	Above Tete on Zambesi River.		2700	Webbe, 1972
Nigeria	Kainji	New Bussa on Niger River	Bilharzia transmission increasing.	1300	Webbe, 1972
Zimbabwe	McIlwaine	Salisbury	Persistent bilharzia focus		Barnish and Shiff, 1970
Sudan	Jebel Auliya Roseires Sennar	On Nile River		600 140 200	Abdel-Malek 1972
Uganda	Victoria	Owens Falls	Onchocerciasis		Waddy, 1975
Zambia	Kariba	On Zambesi River	Bilharzia transmission on Zambian Shore.	5250	Hira, 1969
	Kafue	Kafue Gorge		3100	Dazo and Biles, 1973

MATERIALS AND METHODS

The ecological studies began in 1975 with preliminary reconnaissance surveys of all 28 reservoirs, followed by 3 years of intensive studies on the 6 most important hydroelectric reservoirs, and occasional observations on another 6 reservoirs which represent the wide range in sizes and conditions of man-made lakes in Puerto Rico (Table 2).

The reservoirs were surveyed for snail populations, coliform bacteria, general water quality, algae populations and productivity, dissolved oxygen distribution, temperature, and clarity of the lake waters. Records were obtained on fluctuations in the water level and on incident solar radiation. The sampling methods and analyses used were standard for such ecological surveys and a detailed record of all data is available (1).

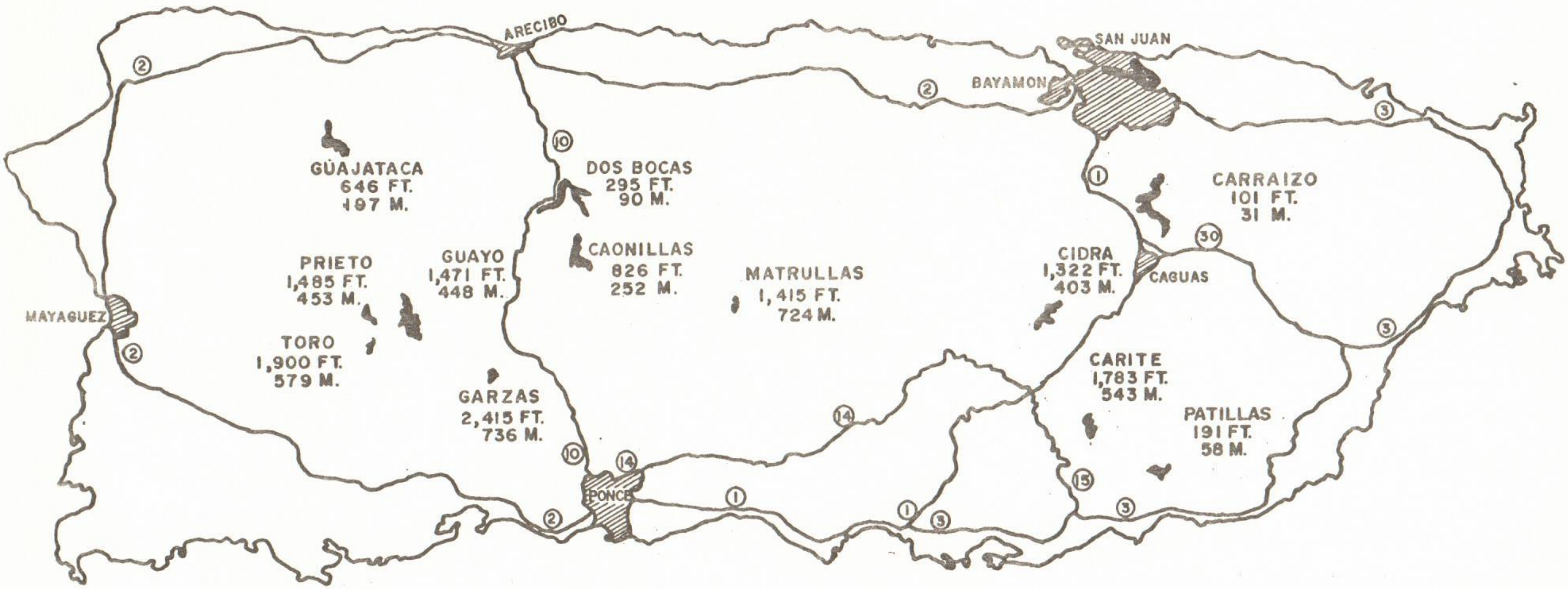
The six hydroelectric reservoirs studied in detail were Lakes Caonillas, Carraízo (Loiza), Dos Bocas, Garzas, Guayo and Prieto (Figure 2). These studies began in January 1976 and ended in September 1978 with a total of 49 separate lake surveys, averaging 2.7 surveys per year, per lake.

The additional six reservoirs, given occasional surveys between December 1975 and October 1978 were Lakes Carite, Cidra, Guajataca, Matrullas, Patillas, and Toro. They were surveyed a total of 16 times in the 3 years, about once a year. The remaining 16 reservoirs not included in these studies were surveyed only once, in 1975 or 1976, collecting information on snail populations and chemical water quality (2).

Table 2. MAJOR LAKES OF PUERTO RICO

Lake	Purpose	Storage Volume in acre-feet	Munici-pality	Tribu-taries	Outlet Rivers	Year constructed	Owner
1. Adjuntas	Power	465	Adjuntas	Vacas River	Tunnel & Arecibo River	1950	AFF
2. Caonillas	Power	49,000	Utuado	Caonillas, Yauco, and Jayuya Rivers	Caonillas River	1948	AFF
3. Carite	Domestic Water Supply and irrigation	11,300	Guayama	La Plata River	La Plata River & penstock	1913	AFF
4. Carraizo	DWS, power	20,000	Trujillo Alto	Valenciana, Loiza, Caguitas and Bairoa River	Loiza River	1954	AAA
5. Cartagena Lagoon	Wildlife Conservation	770	Lajas	Lajas Canal	None	Natural	-
6. Cidra	Domestic Water Supply	5,220	Cidra	Sabana and Bayamon Rivers	Bayamon River	1946	AAA
7. Coamo	Abandoned	200	Santa Isabel	Coamo River	Coamo River and Juana Diaz Canal	1914	AFF
8. Comerio #1	Abandoned	600	Comerio	La Plata River	La Plata River	1913	AFF
9. Comerio #2	Abandoned						
10. Dos Bocas	Power	32,000	Arecibo & Utuado	Caonillas Limon & Arecibo River	Arecibo River	1942	AFF
11. Garzas	Power, Irrigation	4,700	Adjuntas	Garzas and Vacas Rivers	Vacas River	1943	AFF
12. Guajataca	Irrigation	32,600	San Sebastian and Quebradillas	Guajataca River	Guajataca River & Diversion Canal	1929	AFF
13. Guayabal	Irrigation	10,000	Guayabal & Juana Diaz	Toa River Jacaguas River	Guayabal	1913	AFF
14. Guayo	Power, irrigation	17,400	Lares & Adjuntas	Guayo River & Cidra River	Guayo River	1956	AFF
15. Guineo	Power, irrigation	1,860	Ciales and Orocovis	Toro Negro River	Toro Negro River	1931	AFF
16. Jordan	Power		Utuado	Creeks	Tunnel & Rio Vivi	1950	AFF
17. La Plata	Domestic Water Supply		Toa Alta	La Plata River	La Plata	1973	AAA
18. Las Curias	Domestic Water Supply	1,100	Rio Piedras	Rio Piedras	Rio Piedras	1946	AAA
19. Loco	Power, irrigation	1,950	Yauco	Loco River	Loco River & Lajas Canal	1951	AFF
20. Luchetti	Power, irrigation	16,500	Yauco	Yauco River	Yauco River	1952	AFF
21. Matrullas	Power, irrigation	3,000	Orocovis	Matrullas River	Matrullas River	1934	AFF
22. Patillas	Irrigation	14,500	Patillas	Marin River Patillas River	Patillas River & Canal	1914	AFF
23. Pellejas	Power	152	Adjuntas	Pellejas River	Tunnel & Pellejas River	1950	AFF
24. Prieto	Power, irrigation	700	Lares	Prieto River	Prieto River	1955	AFF
25. Rio Blanco	Power		Naguabo	Rio Blanco	Rio Blanco		AFF
26. Toa Vaca	Domestic Water & irrigation	33,124	Villalba	Toa Vaca River	Toa Vaca River	1972	AAA
27. Toro	Power, irrigation	100	Maricao	Toro River	Toro River	1955	AFF
28. Tortuguero Lagoon	Wildlife Conservation		Manati	Canals	Ocean	Natural	Recursos Naturales
29. Vivi	Power	277	Utuado	Vivi River	Tunnel & Vivi River	1950	AFF
30. Yahuecas	Power, irrigation	1,800	Adjuntas	Blanco River	Blanco River	1956	AFF

ELEVATION OF SPILLWAY CREST IN FEET AND METERS



LOCATION OF LAKES IN PUERTO RICO

FIGURE 2

The basic equipment for the surveys included a mobile laboratory with appropriate vehicles and boats for continuous monitoring of the lakes, usually in remote mountain regions. The mobile laboratory used in these surveys included living accomodations for a crew of four as well as laboratory facilities for chemical titration and bacterial analyses (Figure 3).

Two boats were used on the lakes, a 12 foot aluminum Jon boat for shore sampling and an 18 foot fiberglass boat with a small crane and winch for deep-water work (Figure 4). The availability of this equipment and the mobile laboratory made it possible to gather much more information on each lake than had been previously feasible. In the past only one-day expeditions with easily transported row-boats were possible due to the long trips involved from San Juan. With the new equipment the surveys lasted a week and up to 4 men could work full-time on each lake.

Sampling stations were established with marker buoys in each lake, usually at each major tributary, in the main body of the lake near the dam, and in any major branches in the lake.

Each lake survey lasted four days, allowing for three 24 hour photosynthesis rounds using two light and two dark bottles at each station to determine changes in dissolved oxygen due to photosynthesis and respiration. The four bottles were suspended in a wire rack about 0.5 meters from the surface, and the bottles were changed approximately the same time each day. An initial oxygen determination was made at each station every day as well. Also the water temperature

Figure 3. Mobile laboratory on Lake Garzas in Adjuntas, Puerto Rico.

0.1 m below the surface, the depth of visibility of a Secchi disk and the water depth at the station were recorded each day.

One liter samples were taken once during the week at each station for measurement of algae and chemical quality. The parameters measured later in the central laboratory were color, turbidity, hardness, chlorides, nitrogen, phosphates and iron. Algae samples were filtered through millipore paper, fixed and examined microscopically. Coliform samples were filtered and cultivated in the field by the standard Millipore technique and counted visually after 24 hours of incubation in a portable incubator at 34°C.

Snail surveys were conducted from boats and on foot, making a complete shore-line inspection and scooping at 10 or 20 meter intervals with wire mesh dippers. When the bilharzia snails were found they were held in a strong light 3-4 hours to detect cercarial shedding and later crushed and examined microscopically if found negative on the first examination. Water levels in the lakes during the surveys were obtained from records of the Water Resources Authority and the Aqueduct and Sewer Authority. Wind records and cloud cover were obtained from unpublished reports of the federal Weather Bureau.

Figure 4. Small launch on Lake Dos Bocas in Utuado, Puerto Rico. This boat and an aluminum jon boat made it possible to survey the larger lakes fairly quickly.

RESULTS

The initial reconnaisance surveys of 1975 and 1976 were conducted primarily to ascertain the presence or absence of *Biomphalaria glabrata* and to select 6 reservoirs for intensive study in the subsequent 3 years. In this first survey of the 28 reservoirs it was determined that *B. glabrata* was present only in Lakes Carite, Carraízo, Dos Bocas and Garzas. However Lakes Caonillas, Prieto, and Guayo were added to the first 4 since they were interconnected with them by tunnels and overflow spillways. Also Lake Carite was not a hydroelectric reservoir anymore, thus it was placed in the second set of 6 lakes which were selected for occasional study because they typified the many types and purposes of reservoirs throughout the island, giving a general representation of all 28 reservoirs.

Water quality in an additional 14 lakes was estimated from a single set of samples taken from the tributaries and near the dam, usually taken at all points on a given reservoir during the same week. The remaining 2 reservoirs were not sampled for chemical quality as Lake Coamo has been abandoned because it was full of sediment, and Río Blanco reservoir was only a small dam on the Blanco River with virtually no storage volume. Two brackish lagoons, Cartagena and Tortugero were also omitted from the sampling because they were coastal lagoons, not man-made reservoir.

Five Major Reservoirs

The data from the intensive studies on the major reservoirs was analyzed in detail in terms of the Dos Bocas Hydroelectric System (Lakes Caonillas, Dos Bocas and Garzas) and the Lajas Valley System (Lakes Guayo and Prieto). For the sixth reservoir, Lake Carraízo which is part of the San Juan Water Supply System the data will be presented separately.

Lake Caonillas

Conditions in the main body of Lake Caonillas were represented by Stations A, B, and E which generally had no significant differences between them, thus the data was combined (Figures 5 and 6). However the turbidity decreased approaching Station A near the dam, probably due to sedimentation. Thus turbidity at Station A was always lower than at B and E. The number of blue-green algae was comparatively high at Station E in October 1976 while the green algae were few in number. Also in June 1977 high concentrations of iron coming in from the Jayuya River raised the iron concentration at Station E significantly.

Station D represented the inflow from the Jayuya River and C represented the Vivi River, with some minor differences between them. The Jayuya River Station had more algae and diatoms, higher algal productivity, and a higher iron concentration. However the phosphate and nitrate concentrations in the Jayuya River Station were slightly lower than at the Vivi River Station.

Figure 5. Lake Caonillas is the largest lake In Puerto Rico, in volume, and discharges into Lake Dos Bocas as part of a hydroelectric generating system.

Figure 6

Location of Sampling Stations on Lake Caonillas

Grouping the main Stations A, B and E showed the trends with time and lake level (Table 3). The lake dropped to about M.S.L. in the summer of 1977, then rose abruptly from September through November, declining again during the winter of 1978 in a fairly simple pattern (Figure 7). The water quality showed no unusual variations except for a high pH in September 1977 at the low lake level with a low respiration rate. The inflow from September to November diluted the concentration of chlorides, hardness, iron and color, as expected. However nutrients and phyto-plankton did not change very much.

Coliform bacteria counts averaged 4000 per 100 ml for the 4 periods samples, fairly heavy contamination. In January 1978 the water was quite clean however, with a mean of 730 coliform per 100 ml. During the other 3 sampling periods the counts ranged from 3000-5000 per 100 ml.

Table 3

Variations of Water Quality Parameters in Main Stations of Lake Caonillas (A, B and E), 1976-1978.

Parameter	Dates 1976 17 Nov	1977 3 Apr	1977 16 Jun	1977 10 Sep	1977 16 Oct	1978 27 Jan	Mean
Chlorides-mg/l	6	4	8	6	-	4	6
Hardness-mg/l as $MgSO_4$	90	102	133	131	-	82	110
pH	7.30	7.57	7.23	8.20*	-	6.97	7.46
Phosphates as P-mg/l	0.01	0.01	0.01	0.01	-	0.01	0.01
Nitrates and Nitrites as N-mg/l	0.06	0.03	0.04	0.05	-	0.11	0.06
Iron-mg/l	0.15	0.10	0.24	0.12	-	0.03	0.13
Secchi Disk M	1.44	1.54	0.76	0.72	-	-	1.14
Turbidity S.U.	6.0	1.9	3.0	0.33*	-	0.5	2.2
Color S.U	16	18	11	12	-	9	14
Net Productivity mg/l O_2/day	2.1	1.4	1.5	1.5	-	1.2	1.5
Respiration-mg/l O_2/day	1.4	1.3	1.5	0.8*	-	0.9	1.1
Coliform Bacteria per 100 ml	-	5,142	1,951	6,494	-	2,637	3,975
Blue green algae per 100 ml	----	-------	-------	780	1,880	570	1,180
Green algae per 100 ml	----	-------	-------	1,560	570	890	1,160
Diatoms per 100 ml	----	-------	-------	13,130	2,430	3,470	6,700
Flagellates per 100 ml	----	-------	-------	380	10	100	170

*Apparently due to large phytoplankton population.

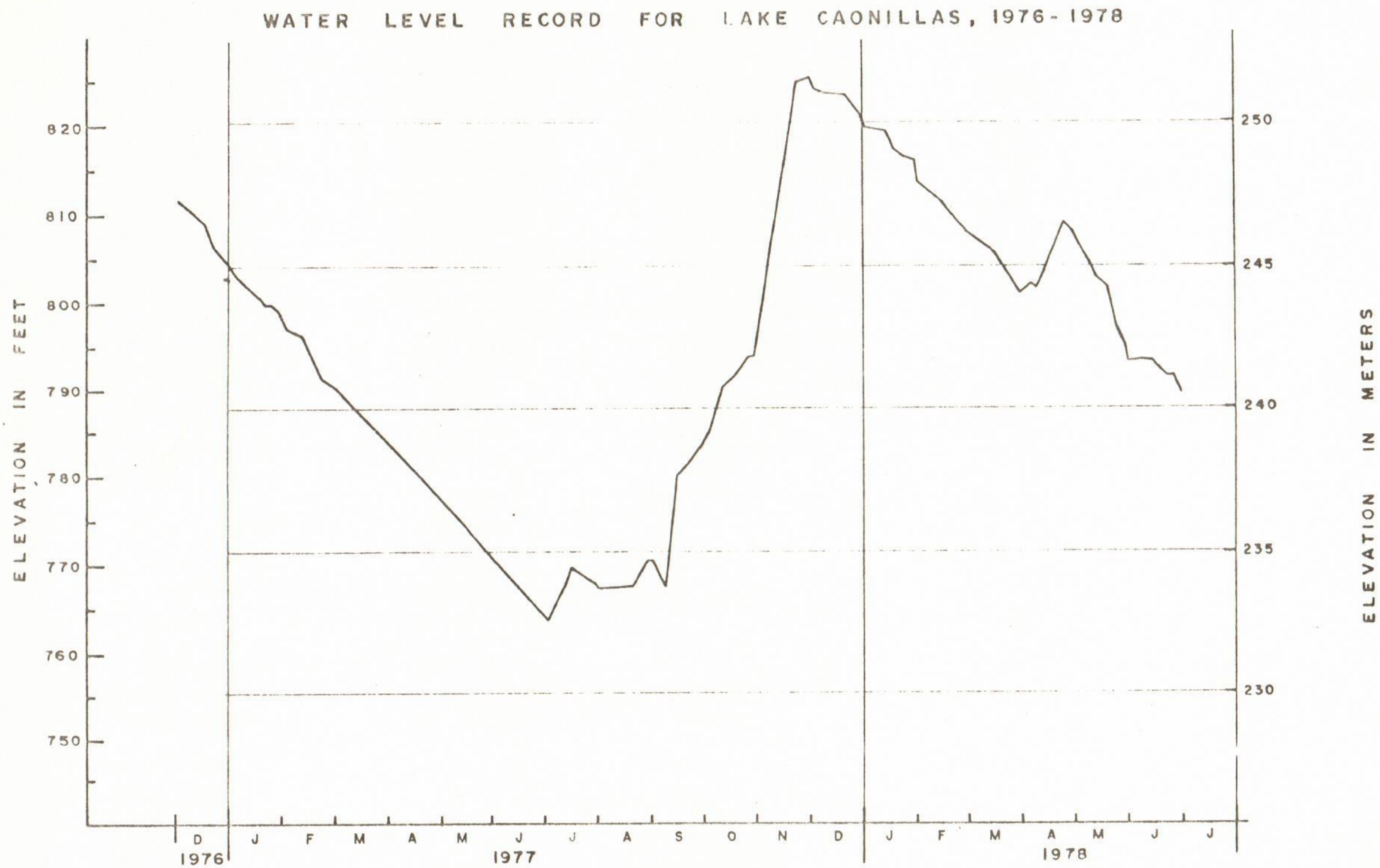

WATER LEVEL RECORD FOR LAKE CAONILLAS, 1976-1978
ELEVATION IN FEET
820
810
800
790
780
770
760
750
ELEVATION IN METERS
250
245
240
235
230
D
1976
J F M A M J J A S O N D
1977
J F M A M J J
1978

Figure 7

Lake Dos Bocas

Lake Dos Bocas is the principal hydroelectric station in Puerto Rico (Figure 8). Although the geographical variation in water quality was not extreme, Station C is the only representative station for the entire lake due to the differences in Station B affected by the Arecibo River and Station D affected by the combined flows from the Limon River and the discharge from the Caonillas turbines (Figure 9).

Seasonal variations in water quality at Station C near the dam were minor, probably affected mainly by large rainstorms. The lake was maintained between 87.8 meters and 90.2 meters above sea level during the two year of observation, a fluctuation range of less than 2.5 meters (Figure 10). This reservoir generates fairly continuously at maximum head, utilizing the upstream reservoirs for storage. At Station C the water was clearest and cleanest with the lowest coliform bacteria counts on the lake and the highest phytoplankton. Apparently the phytoplankton were limited by the very low nutrients (Table 4). The Secchi disk could be read at a mean depth of 1.34 meters, the water being more turbid and colored during the rainy season.

There was a sharp oxygen stratification at 5 meters depth with virtually no oxygen at deeper levels and 6 to 7 mg/l above that depth. However the stratification was not caused by a thermocline, but more likely due to good vertical mixing in the upper layer and a high benthic oxygen demand (Figure 11).

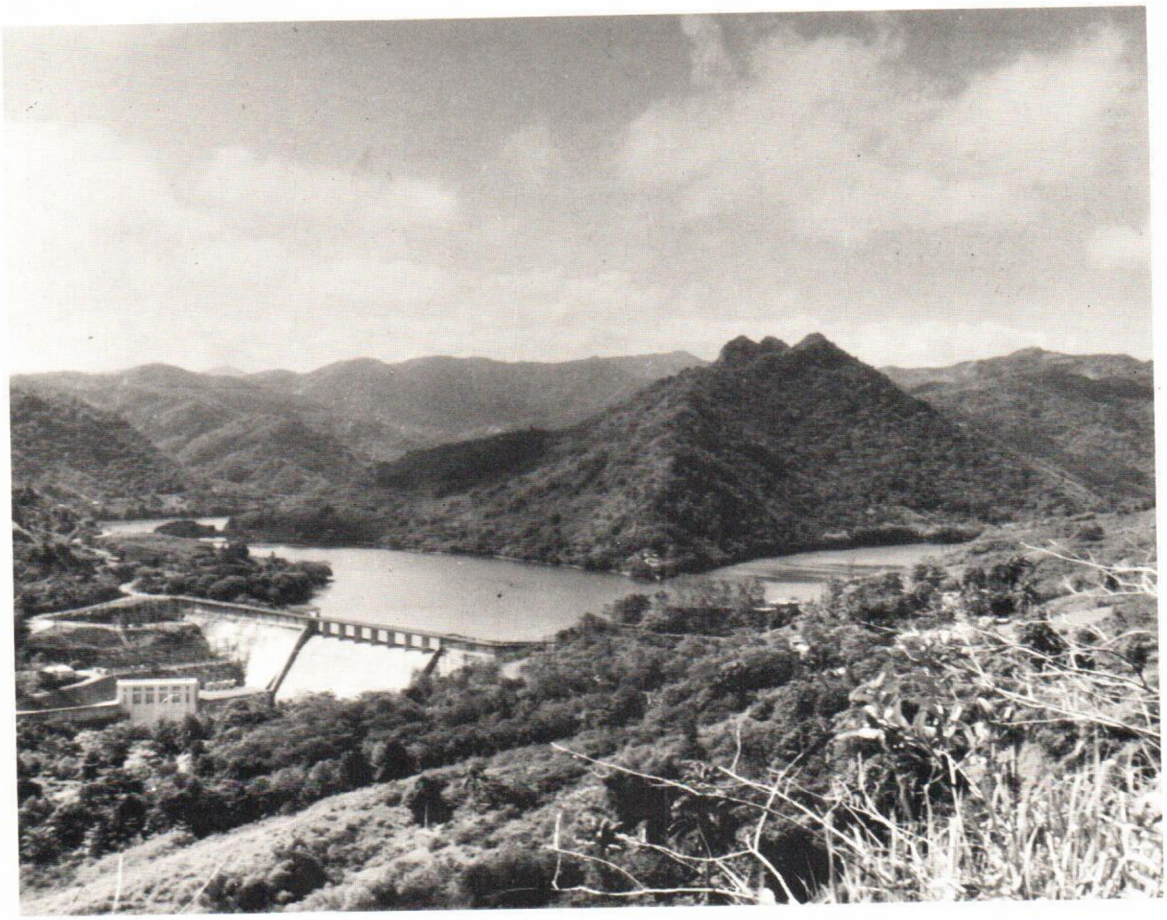


Figure 8. Lake Dos Bocas in Utuado, Puerto Rico is the lowest lake in a system of seven lakes for generating hydroelectric power.

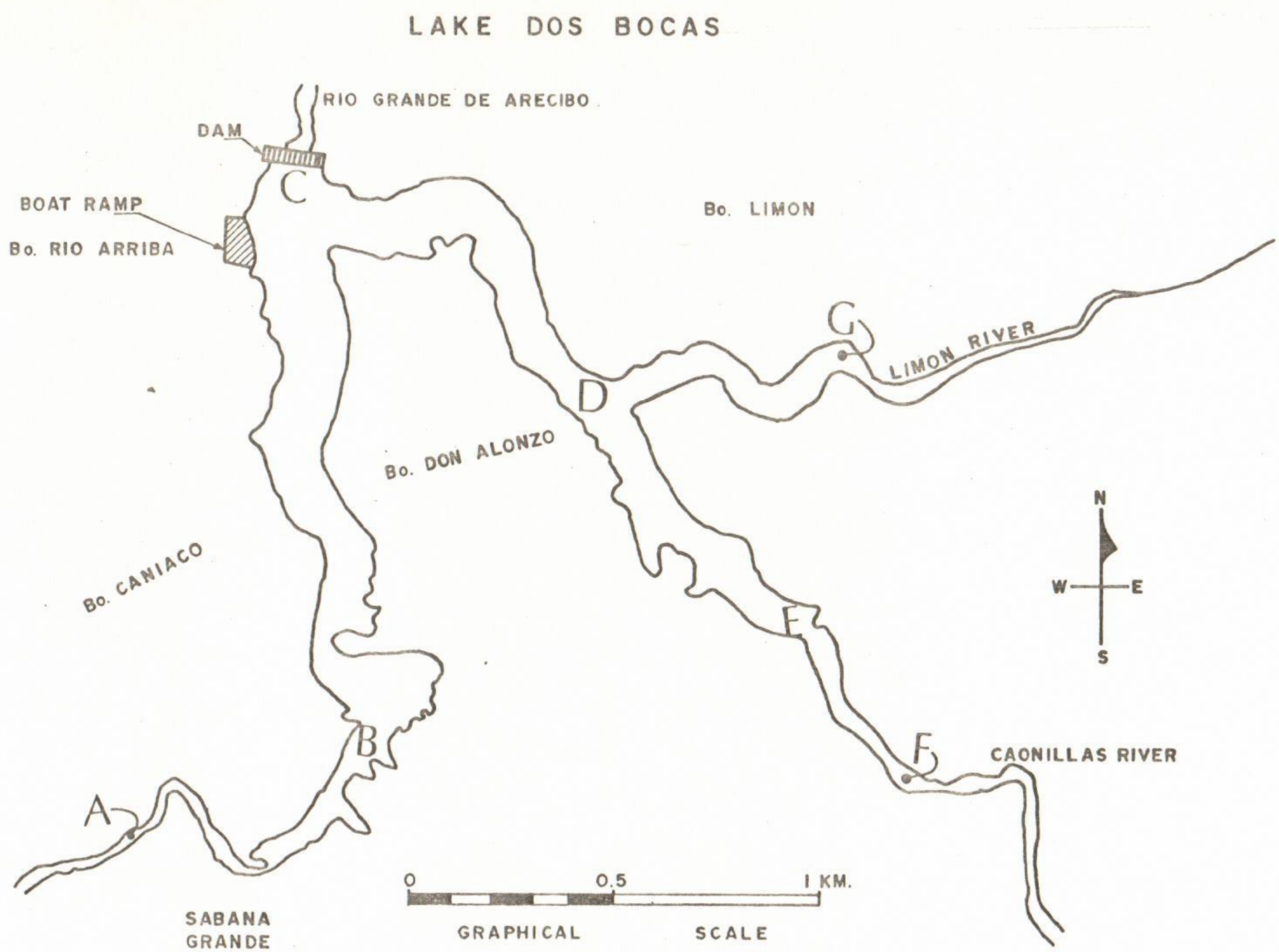


Figure 9. Location of Sampling Stations in Lake Dos Bocas.

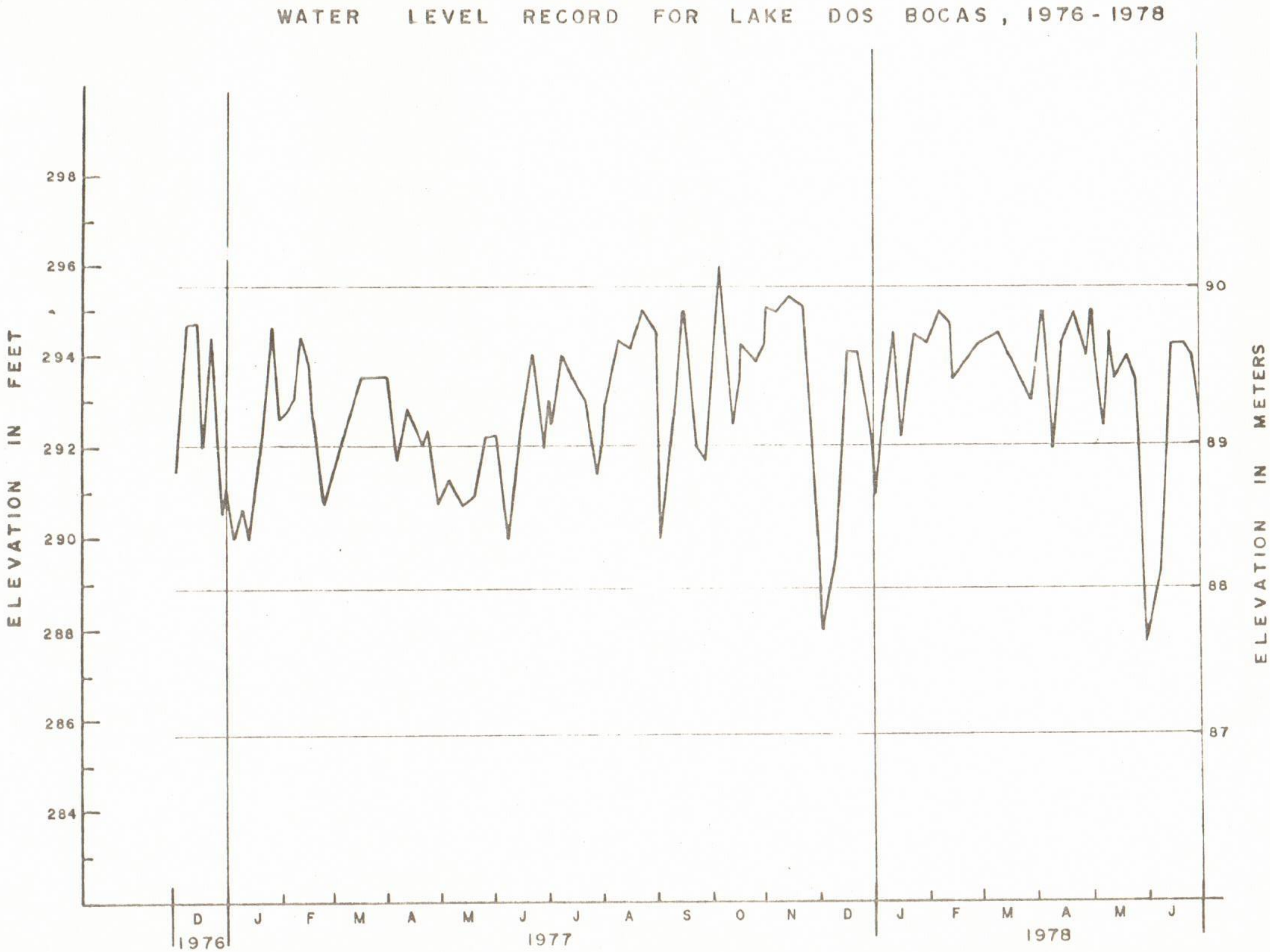
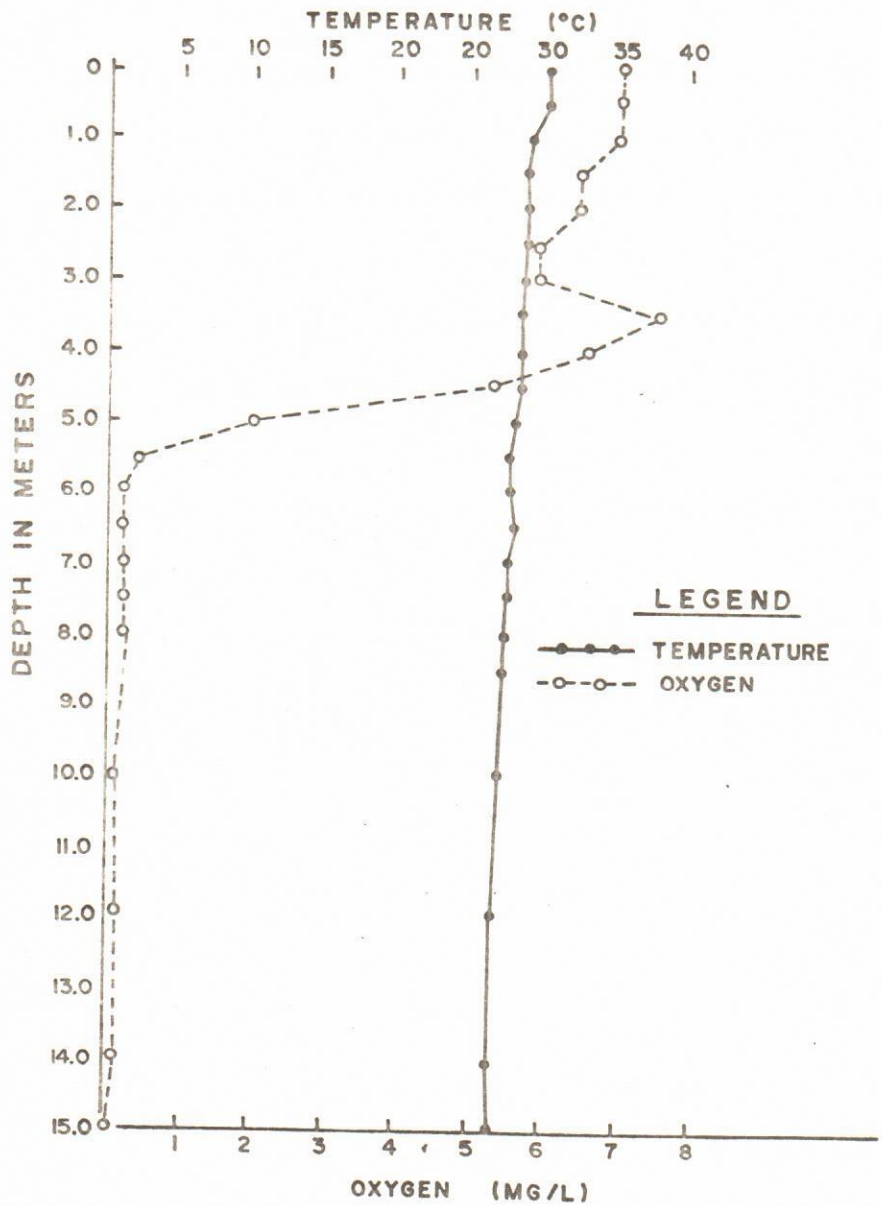

WATER LEVEL RECORD FOR LAKE DOS BOCAS, 1976-1978
ELEVATION IN FEET
298
296
294
292
290
288
286
284
ELEVATION IN METERS
90
89
88
87
D J F M A M J J A S O N D J F M A M J
1976
1977
1978

Figure 10

Table 4

Variations in Water Quality Parameters in Main Station (C) of Lake Dos Bocas, 1976-1978.

Parameters	Dates 1976 9 Nov	1977 1 Feb	1977 20 May	1977 29 Aug	1977 5 Oct	1978 28 Mar	Means
Chlorides-mg/l	7	5	6	7	4	6	6
Hardness-mg/l as $MgSO_4$	76	148	116	119	90	78	104
pH	7.1	7.4	7.9	7.4	7.3	7.7	7.5
Total Phosphates as P-mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Nitrates and Nitrites as N-mg/l	0.20	0.20	0.10	0.00	0.10	0.03	0.06
Iron-mg/l	0.20	0.10	0.10	0.03	0.50	0.20	0.19
Secchi Disk M	0.8	2.0	1.7	1.7	0.5	-	1.3
Turbidity S.U.	6.4	1.9	0.0	0.1	14.8	-	4.6
Color S.U.	15	15	8	10	15	10	12
Net Productivity mg/l O_2/day	3.0	0.8	2.6	1.5	2.3	-	2.0
Respiration-mg/l O_2/day	1.5	-0.2	1.0	0.7	1.8	-	1.0
Coliform Bacteria per 100 ml	-	5	6	-	2,264	0	16
Blue green algae per 100 ml	-	-	-	-	54	54	54
Green algae per 100 ml	-	-	-	-	1,074	430	752
Diatoms per 100 ml	-	-	-	-	537	447	492
Flagellates per 100 ml	-	-	-	-	322	215	268



VERTICAL DISTRIBUTION OF TEMPERATURE AND DISSOLVED OXYGEN AT STATION C NEAR DAM IN LAKE DOS BOCAS AUGUST 8, 1978

FIGURE 11

Lake Garzas

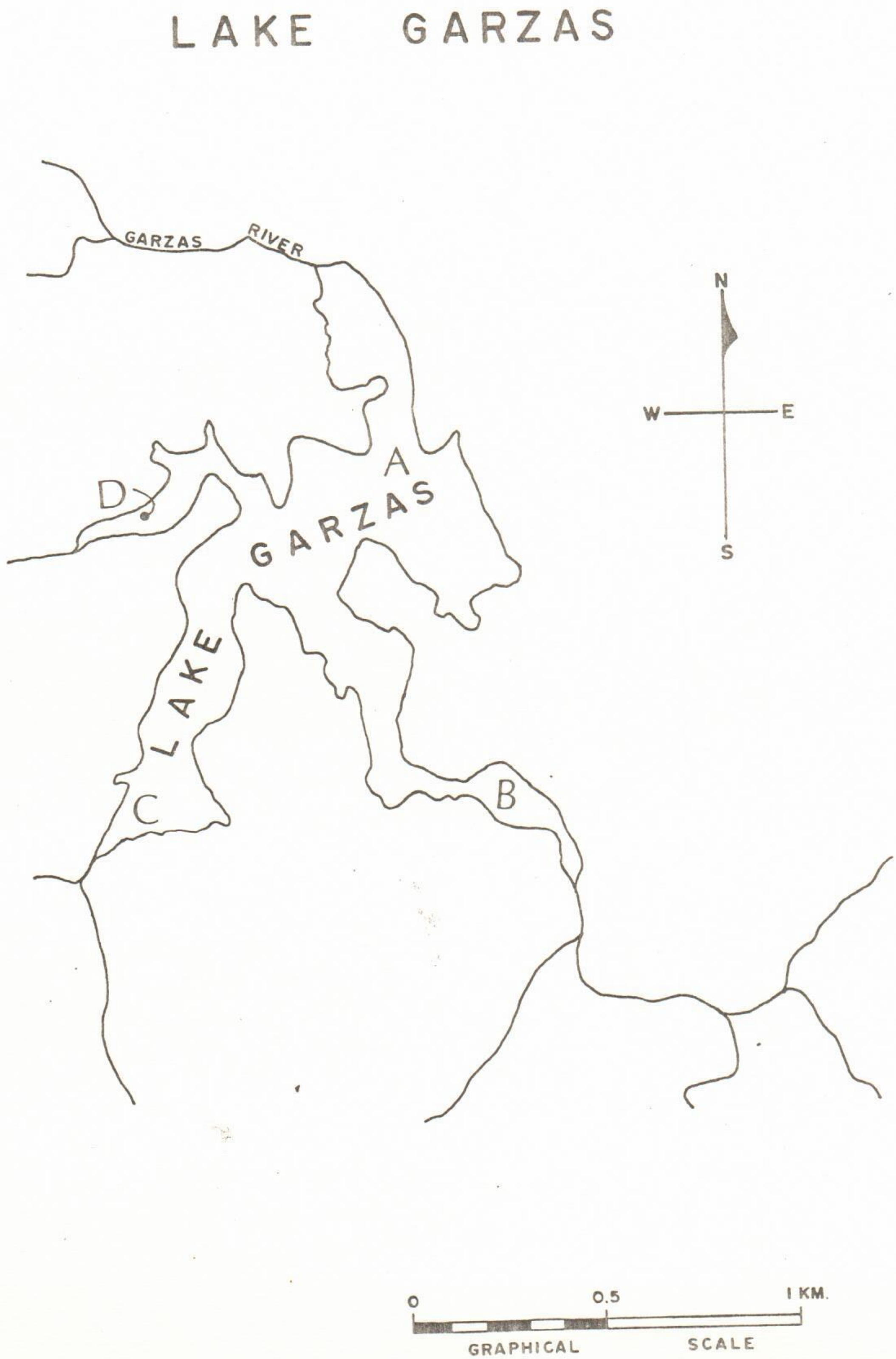
The main body of water was represented by Station A on Lake Garzas near the earth dam (Figure 12 and 13). However the only significant difference between this station and the other 4 was a slightly higher phytoplankton population, more coliform bacteria and slightly higher turbidity at Station A.

Lake Garzas was a fairly clean lake with low nutrients and moderate numbers of phytoplankton. Only in November 1976 did the turbidity go above 6 standard units but color was fairly constant at about 10 standard units (Table 5).

The lake dropped to its lowest level of 723.4 M in July 1976 and rose to its maximum level by November 1976 of 736.1 M, a range of about 13.M. In general the lake was usually full during 1977 and 1978 (Figure 14).

Figure 12

Location of Sampling Station on Lake Garzas.



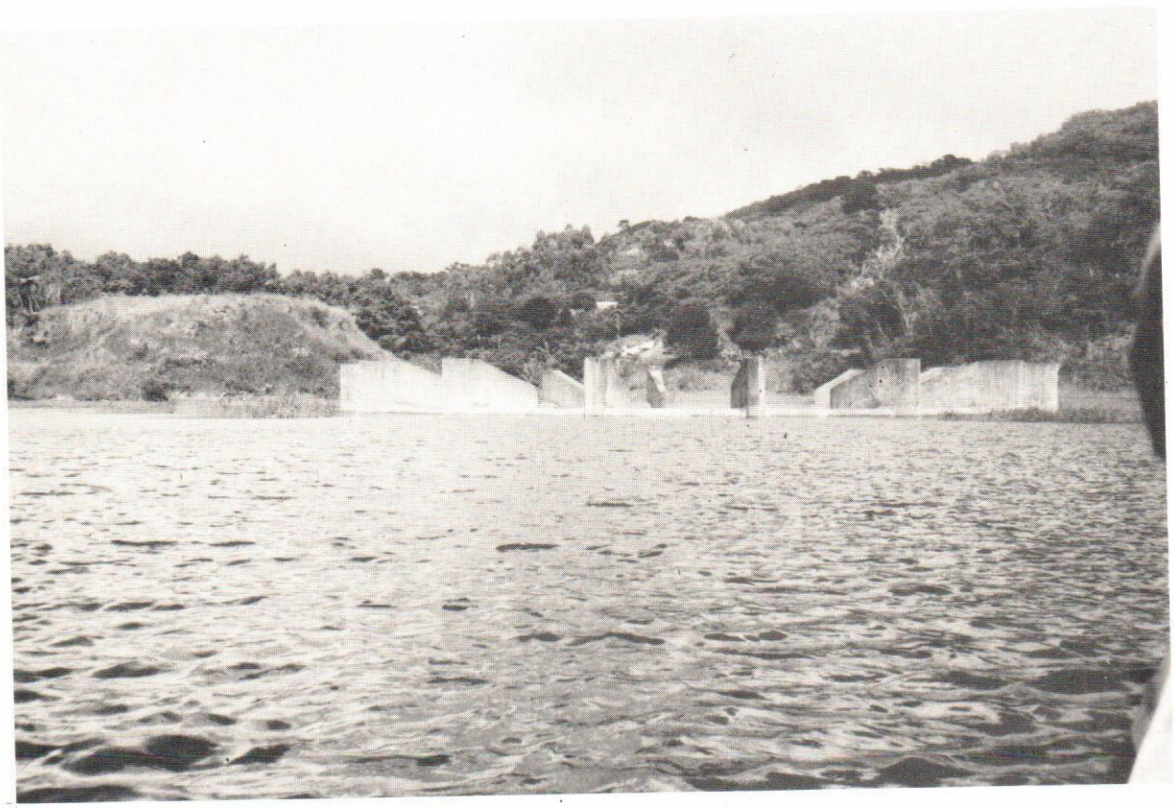


Figure 13. Overflow spillway on Lake Garzas in Adjuntas, Puerto Rico.

Table 5.

Variations in Water Quality Parameters at Main Station (A) of Lake Garzas, 1976-1978.

Parameter	Dates 1976 30 Nov	1977 23 Jun	1977 23 Sep	1978 27 Jan	1978 17 May	Means
Chlorides-mg/1	4	2	2	2	8	4
Hardness-mg/1 as $MgSO_4$	57	96	103	84	77	83
pH	7.5	7.9	8.1	7.5	7.5	7.7
Total Phosphates as P-mg/1	0.00	0.01	0.01	0.01	0.03	0.01
Nitrates and Nitrites as N-mg/1	0.07	0.03	0.06	0.06	0.03	0.05
Iron-mg/1	0.10	0.05	0.03	0.03	0.03	0.05
Secchi Disk M	2.5	1.6	2.1	2.5	-	2.2
Turbidity S.U.	4.4	0.3	0.7	0.0	-	1.4
Color S.U.	10	10	10	5	10	9
Net Productivity mg/1 O_2/day	0.8	0.6	0.7	0.9	-	0.8
Respiration-mg/1 O_2/day	0.2	0.7	0.4	0.4	-	0.4
Coliform Bacteria per 100 ml	3,816	-	-	-	-	3,816
Blue green algae per 100 ml	-	-	501	197	250	316
Green algae per 100 ml	-	-	1,234	680	376	763
Diatoms per 100 ml	-	-	787	680	967	811
Flagellates per 100 ml	-	-	447	18	89	185

WATER LEVEL RECORDS FOR LAKE GARZAS, 1976-78

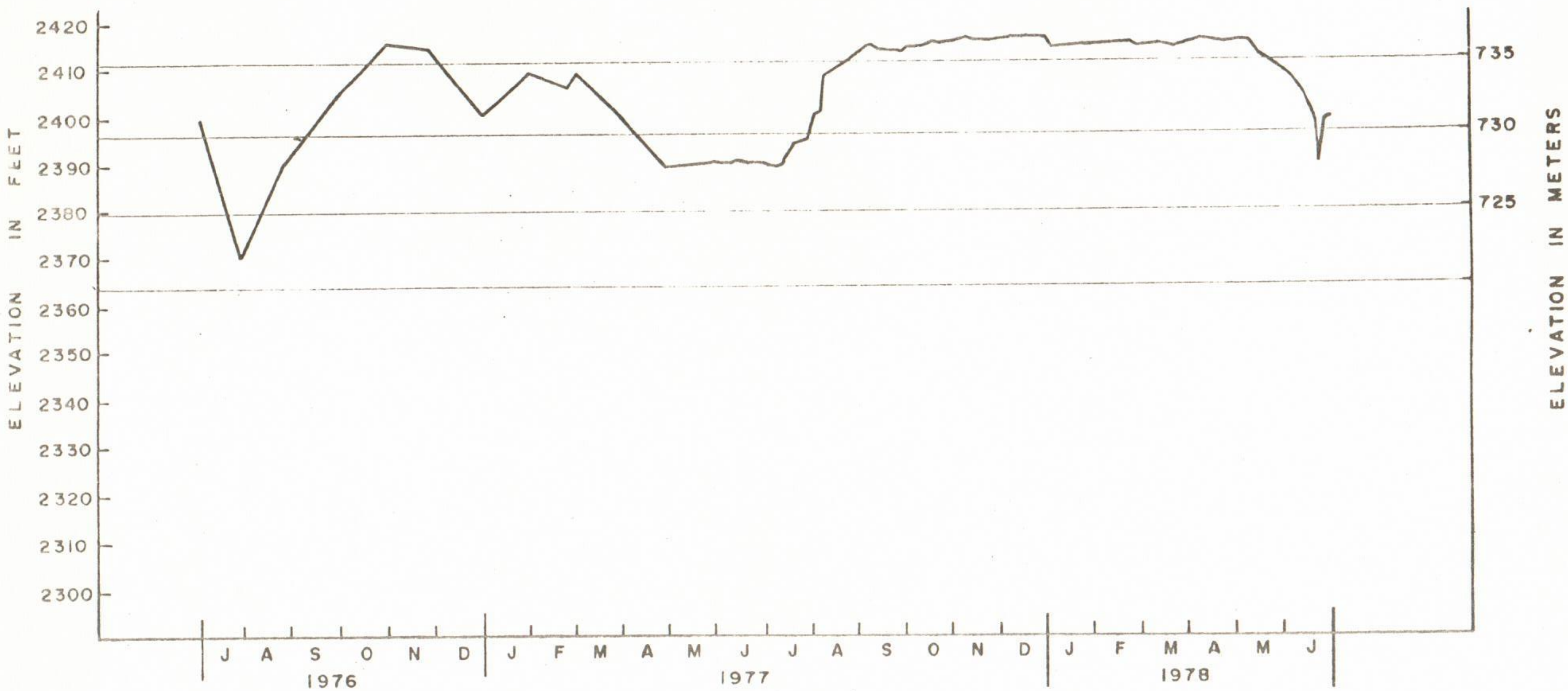


Figure 14

Lake Guayo

Lake Guayo, one of the most attractive lakes in Puerto Rico is located near Castañer. Stations C and D represent the main portion of the lake while Station A was the entrance of the Guayo River and Station B the entrance of the Cidra River. (Figure 15).

Nutrients were generally low except in May 1978 when the Total Phosphates rose to 0.08 mg/l, accompanied by a drop to zero nitrogen. This followed a period of extremely clean water during the Winter of 1978 (Table 6). The lake was quite full with a stable level at about 445 M from September 1977 through June 1978. The previous year however the lake had fluctuated severely dropping to 1410 feet or 430 M in August 1976 and rising to 1460 feet or 445 M in December 1976, a range of 15 M (Figure 16). The level dropped again in July of 1977, but only to about 1430 feet or 436 M.

Figure 15

Location of Sampling Stations on Lake Guayo.

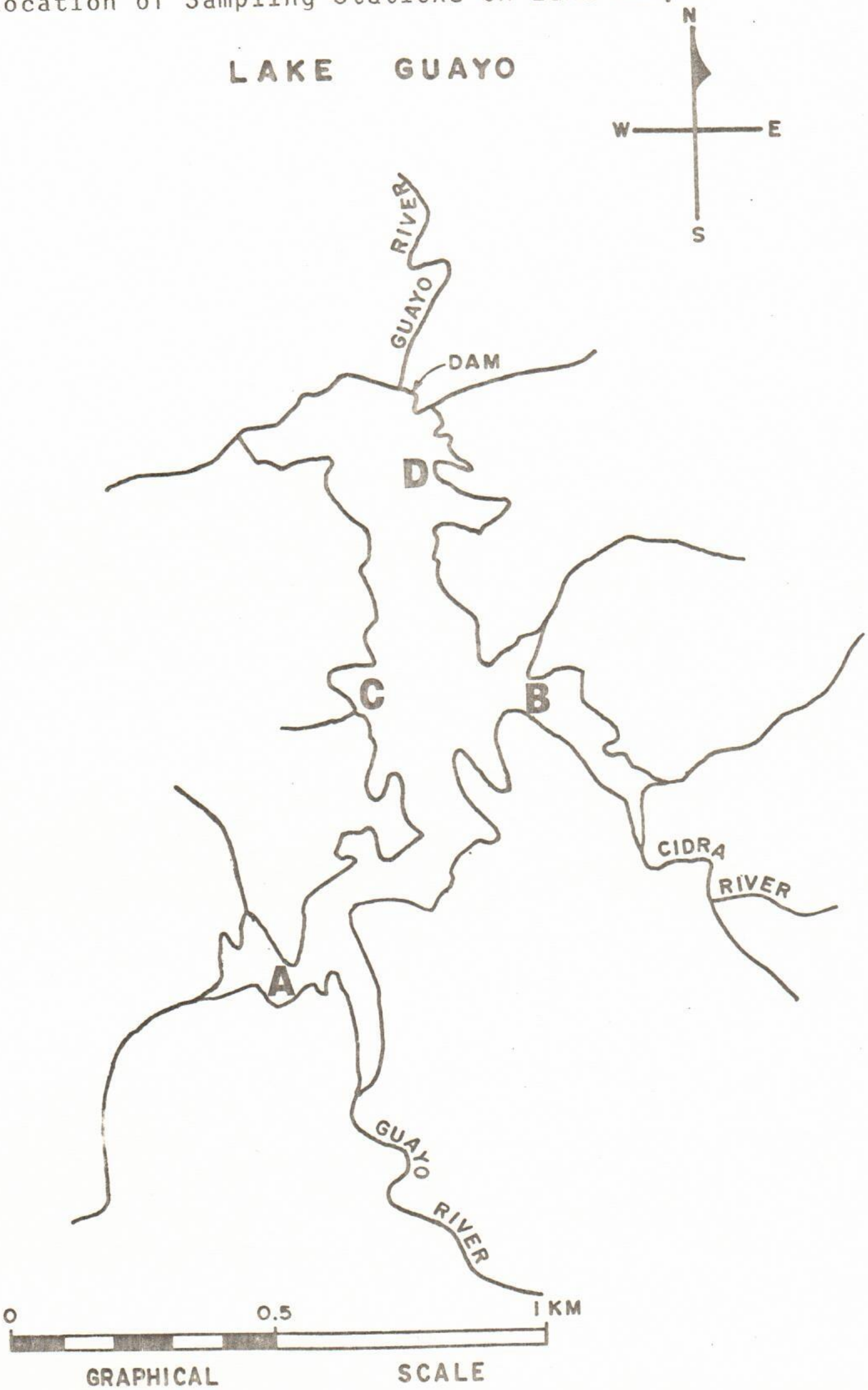


Table 6

Variations in Water Quality Parameters at Main Stations (C and D) in Lake Guayo, 1977-1978.

Parameter	Dates 1977 8 Jul	1977 6 Oct	1978 15 Feb	1978 25 May	Means
Chlorides-mg/l	7	4	4	-	11
Hardness-mg/l as $MgSO_4$	-	126	120	121	122
pH	8.0	7.5	7.8	7.8	7.8
Total Phosphates as P-mg/l	0.00	0.01	0.01	0.08	0.03
Nitrates and Nitrites as N-mg/l	0.2	0.2	0.2	0.0	0.1
Iron-mg/l	0.30	0.04	0.04	0.02	0.06
Secchi Disk M	0.7	3.8	4.4	-	3.6
Turbidity S.U.	2.5	0.3	1.2	-	1.0
Color S.U.	10	12	10	10	11
Net Productivity mg/l O_2/day	0.8	0.6	0.7	-	0.7
Respiration-mg/l O_2/day	0.5	0.4	0.6	-	0.5
Coliform Bacteria per 100 ml	1500	3961	1345	-	2115
Blue green algae per 100 ml	653	376	340	-	456
Green algae per 100 ml	349	233	1038	-	540
Diatoms per 100 ml	250	180	564	-	332
Flagellates per 100 ml	125	188	118	-	178

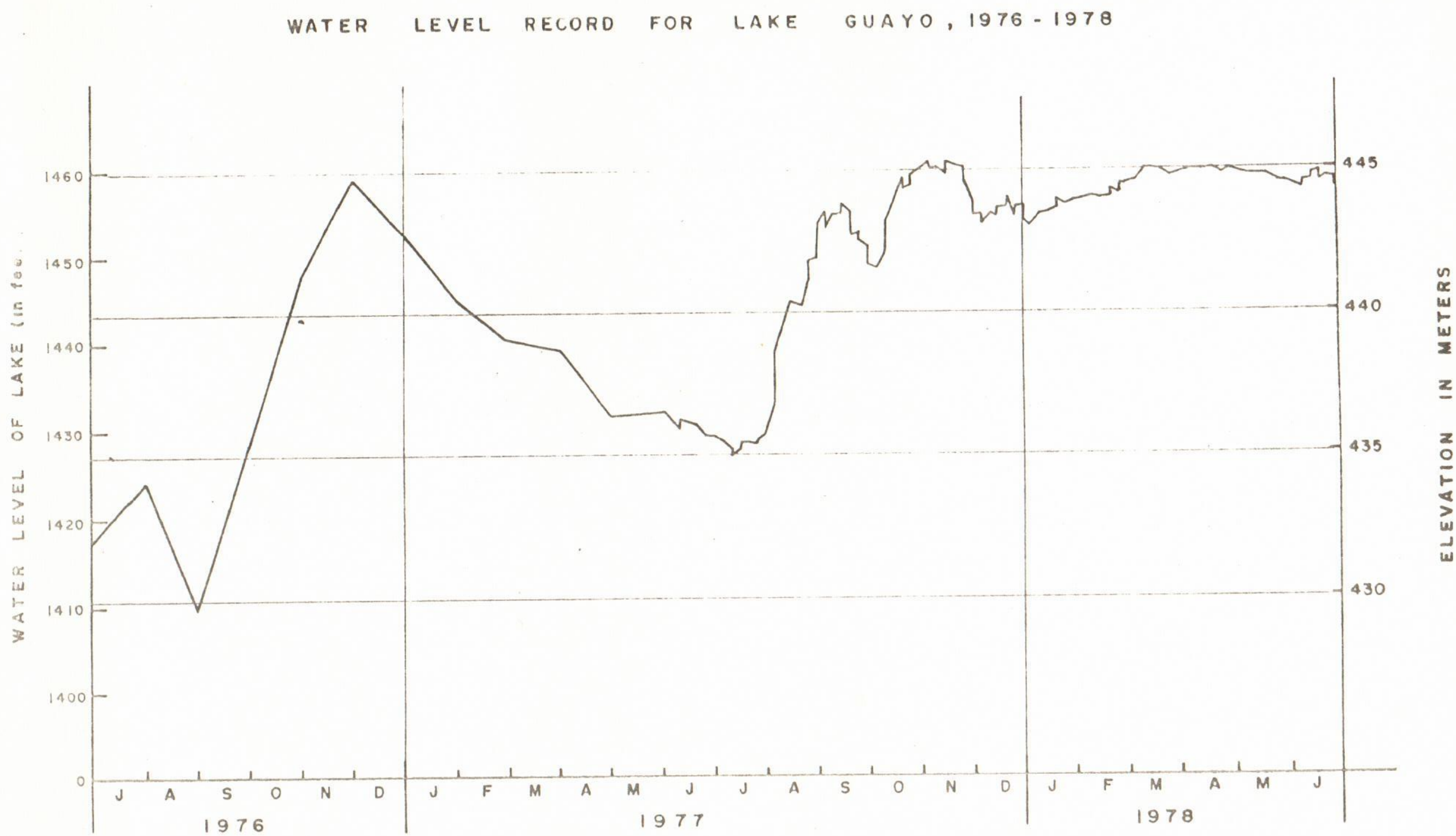

WATER LEVEL RECORD FOR LAKE GUAYO, 1976 - 1978
WATER LEVEL OF LAKE (in fee
1460
1450
1440
1430
1420
1410
1400
0
ELEVATION IN METERS
445
440
435
430
J A S O N D J F M A M J J A S O N D J F M A M J
1976
1977
1978

Figure 16

Lake Prieto

This lake is one of the smallest studied, and was relatively polluted. Station A near the dam was the most representative station (Figure 17). Nutrients were relatively high with a mean total phosphate concentration of 0.02 mg/l, nitrogen of 0.33 mg/l and iron of about 1 mg/l (Table 7). Color and turbidity were also high and the Secchi Disk depth was only 0.5 m. The lake level was quite steady at the level of the overflow to the diversion tunnel, as the overflow has a very large capacity in comparison to the mean flow of the Prieto River, thus lake level was not recorded.

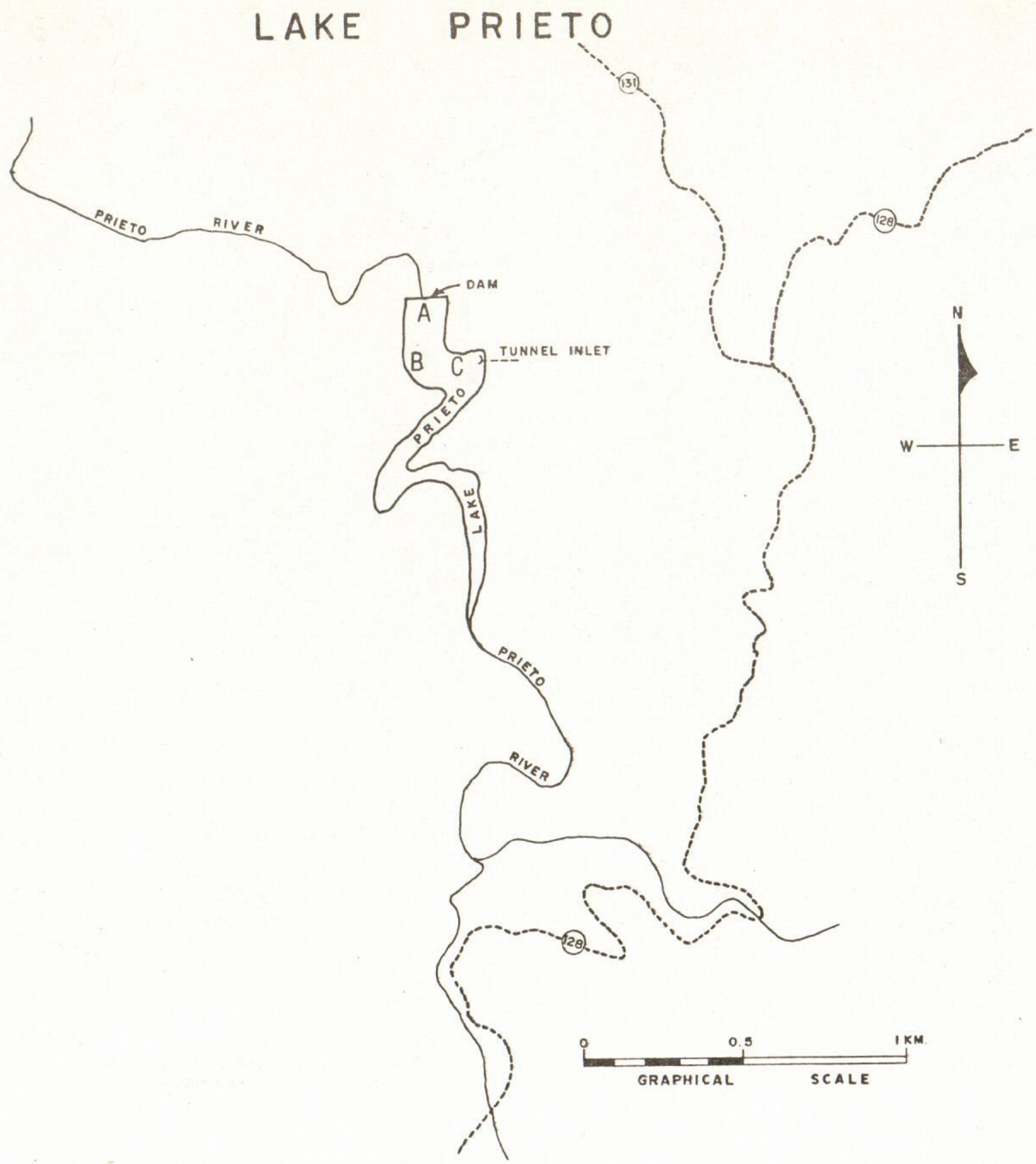


Figure 17. Location of Sampling Stations on Lake Prieto.

Table 7

Variations in Water Quality Parameters of Lake Prieto (Station A), 1977-1978.

Parameter		Dates				
	1977 22 Jul	1977 21 Oct	1978 31 Mar	1978 1 Jun	1978 3 Sep	Means
Chlorides-mg/l	4	1	0	10		4
Hardness-mg/l as $MgSO_4$	157	133	143	226		165
pH	7.1	7.4	7.4	8.2		7.5
Total Phosphates as P-mg/l	0.01	0.06	0.01	0.01		0.02
Nitrates and Nitrites as N-mg/l	0.10	0.10	0.60	0.50		0.33
Iron-mg/l	0.03	3.60	0.10	0.20		0.98
Secchi Disk M	0.2	0.6	0.8	-		0.5
Turbidity S.U.	0.3	65.0	0.1	0.2		16.4
Color S.U.	15	12	10	10		12
Net Productivity mg/l O_2/day	1.4	0.0	0.8	-		0.7
Respiration-mg/l O_2/day	1.3	0.8	0.6	-		0.9
Coliform Bacteria per 100 ml	947	10,323	-	-		3,127
Blue green algae per 100 ml	-	304	340	-	537	394
Green algae per 100 ml	-	984	215	-	418	539
Diatoms per 100 ml	-	1,378	931	-	430	913
Flagellates per 100 ml	-	107	197	-	0	101

Snail Populations

Snail populations in the 5 major hydroelectric reservoirs showed the strong interaction of *Marisa cornuarietis* with *Biomphalaria glabrata*, with the eventual disappearance of the latter from all reservoirs except Lake Prieto (Table 8). By the third and fourth quarters of 1978 only Lake Prieto contained *B. glabrata*, while all 6 contained *M. cornuarietis* (Figure 18). The *B. glabrata* in Lake Prieto were usually infected with *Schistosoma mansoni*.

Table 8

QUARTERLY SURVEYS ON AQUATIC SNAILS IN FIVE HYDROELECTRIC RESERVOIRS OF PUERTO RICO, 1975-1978

Year	1975*		1976*				1977*				1978*			
Quarter	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Lake Caonillas				M T		T L P			T L		T L P		T M	
Lake Dos Bocas	B M T			M T		B M T L P					R M T L P		H T M P L	
Lake Garzas			B M T P					M T L		B M T L P	M T L P	M T P	M T	
Lake Guayo			M					M T L P					M T	M
Lake Prieto			M						B** H M L	M L	B** M P L	M L	B** M T L	B** M P

*B = Biomphalaria glabrata.

M = Marisa cornuarietis.

T = Tarebia granifera

L = Lymnea columella

P = Physa cubensis

A = Pomacea australis

R = Tropicorbis riseii

H = Helisoma caribeum

**infected with Schistosoma mansoni.

Figure 18. This muddy shore on the northern bank of the Limón River was the last habitat of Biomphalaria glabrata in Lake Dos Bocas. Large numbers of Marisa cornuarietis were also present here and B. glabrata was not found again, after late 1976.

Water temperatures

Each day during the photosynthesis surveys the water temperatures were taken at each station 10 centimeters below the surface. These surveys usually occurred during mid-morning, a time when water temperatures approximate the mean daily temperature in Puerto Rican Lakes. The 11 AM temperature has been found to closely approximate the mean daily temperature (Jobin and Ferguson, 1976, PRNC Report #201). Hourly graphs of temperature for each survey make it possible to estimate the mean monthly temperatures for the 5 lakes, using the 11 AM value (Figure 19). As expected the highest mean temperatures occurred in Lake Dos Bocas which is closest to sea level, and the lowest temperatures occurred in Lakes Garzas and Prieto, the highest lakes of the group (Table 9).

The water temperatures in the lakes reached minimums between December and March, the cool dry season, but maximum temperatures occurred any time between June and November (Figure 20).

By using the seasonal curves for water temperature for each lake it was possible to estimate the temperature range for breeding of _M. cornuarietis_ (Table 10). Many eggs of the ampullarid snail were found at temperatures from 23.0°C to 25.0°C, but no eggs were seen at lower temperatures of 18.0° or 19.7° nor were they seen at higher temperatures of 25.2°, or 26.0°, indicating the optimum range for _M. cornuarietis_ may be somewhat lower and narrower than the range for _B. glabrata_ which is 20° to 30° with a maximum at 25°.

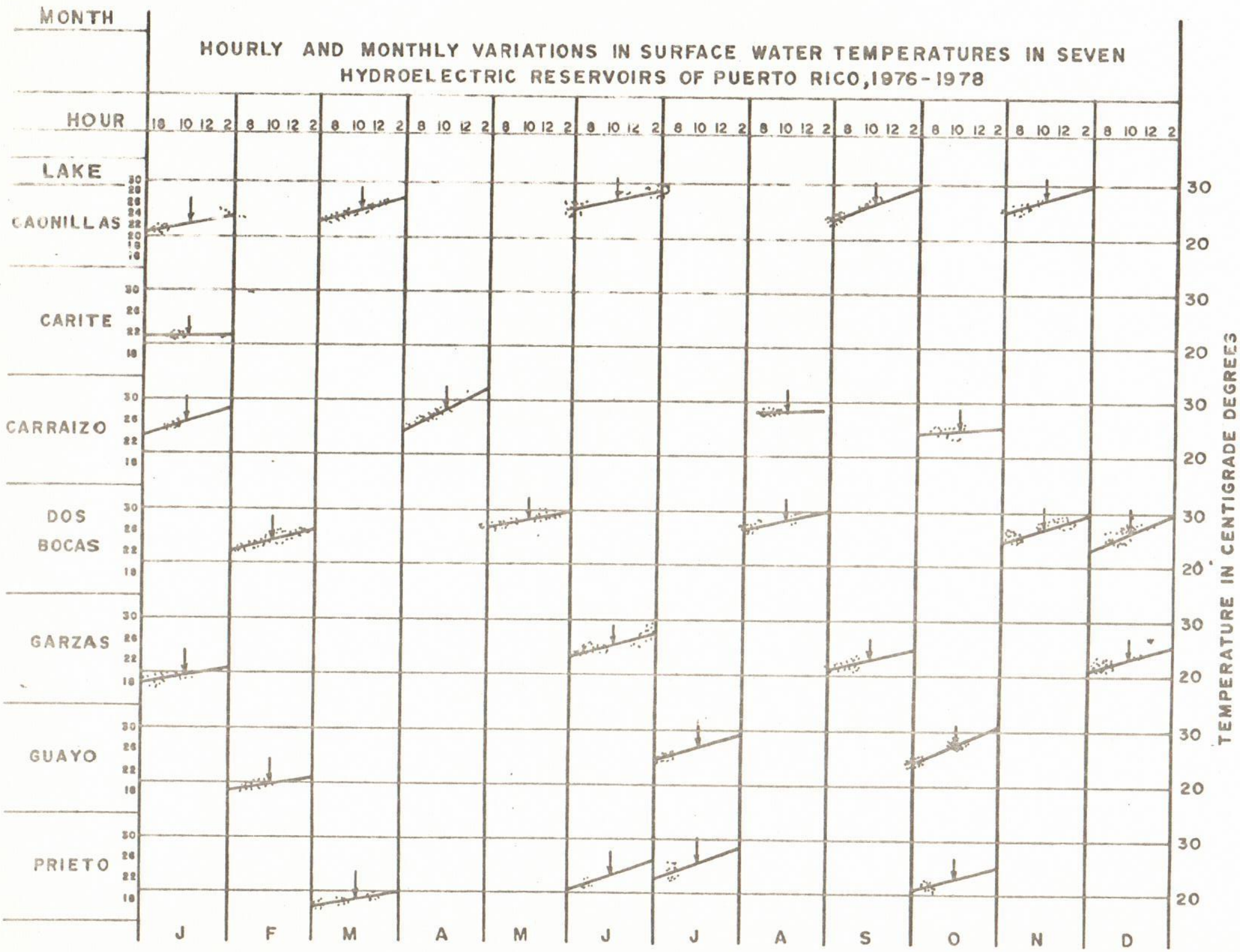

HOURLY AND MONTHLY VARIATIONS IN SURFACE WATER TEMPERATURES IN SEVEN
HYDROELECTRIC RESERVOIRS OF PUERTO RICO, 1976-1978
MONTH
HOUR
LAKE
CAONILLAS
CARITE
CARRAIZO
DOS
BOCAS
GARZAS
GUAYO
PRIETO
8 10 12 2
J
F
M
A
M
J
J
A
S
O
N
D
30
20
TEMPERATURE IN CENTIGRADE DEGREES

Figure 19

Table 9

Annual Mean Temperatures and Spillway Elevation of 5 Major Hydroelectric Reservoir in Puerto Rico.

Lake	Annual Mean Temperature in C°	Spillway Elevation in	
		Feet	Meters
Caonillas	25.5	826	252
Dos Bocas	26.6	295	90
Garzas	22.4	2,415	736
Guayo	24.2	1,471	448
Prieto	22.0	1,485	453

Figure 20. Annual Variations in Normalized Mean Monthly Water Temperature for 5 Major Hydroelectric Reservoirs in Puerto Rico

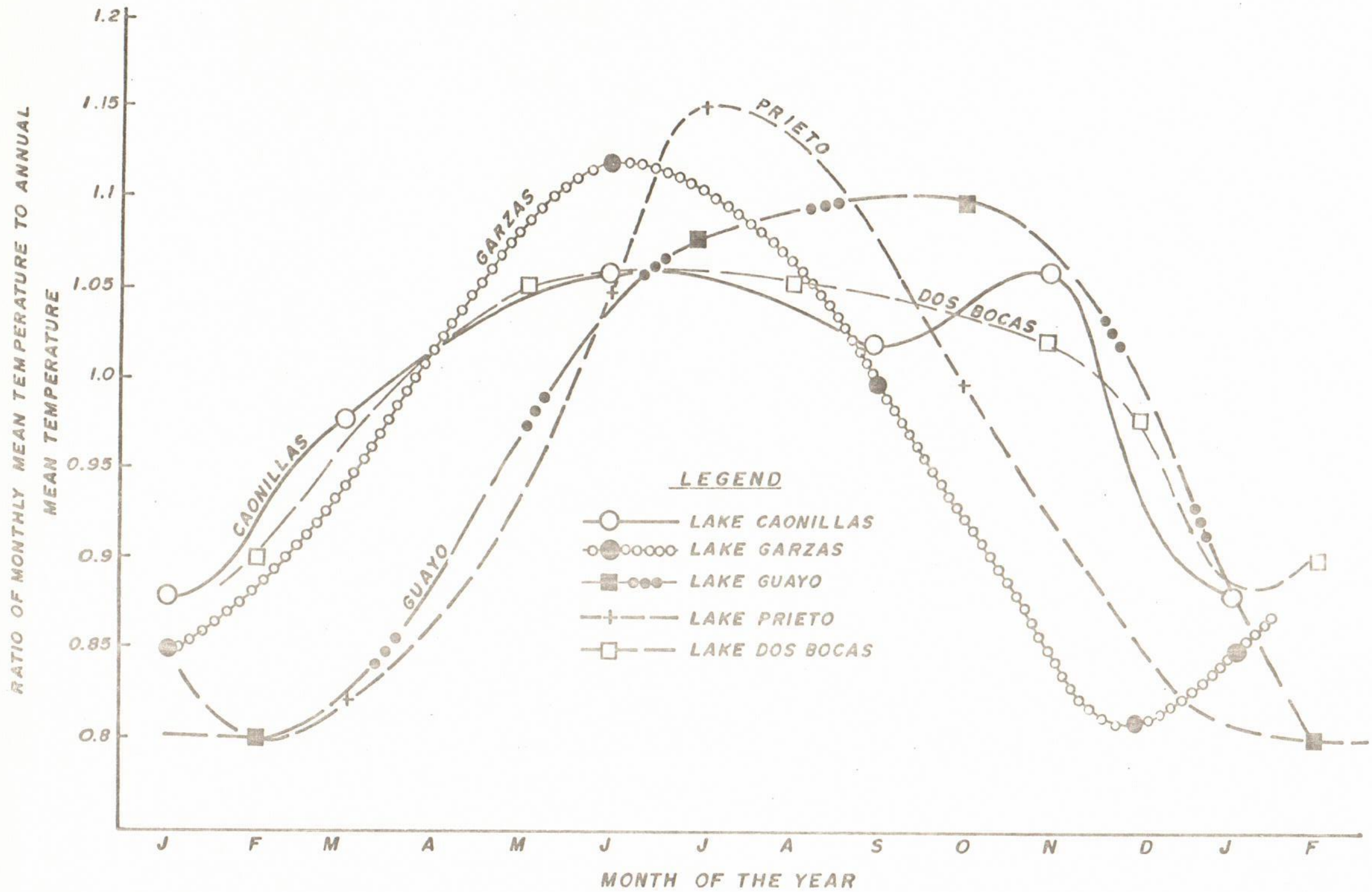


Table 10

Months during which eggs of Marisa cornuarietis were observed in lakes of Puerto Rico, 1975-1978.

Lake	Month	Mean Temperature in Centigrade Degrees (Estimated)	Egg masses of Marisa
Dos Bocas	Mar 78	(25.5)	Not seen
Dos Bocas	Dec 76	26.0	Not seen
Garzas	Feb 78	(19.7)	Not seen
Garzas	May 78	(24.2)	Many
Garzas	Jun 77	25.0	Many
Garzas	Dec 77	23.0	Many
Guayo	Jun 77	(25.2)	Not seen
Prieto	Jun 78	23.0	Many
Prieto	Mar 78	18.0	Not seen
Prieto	Jul 77	25.0	Not seen

Secchi Disk Measurements

The depth at which a secchi disk is no longer visible gives an indication of the depth of the photic zone, the depth which light penetrates significantly to cause algal productivity.

Although there were significant geographical variations in secchi depths between stations, only the average was calculated for each lake survey. The clearest lake was Lake Guayo with visibility up to 3.64 meters (Table 11). However 3 of the lakes had visibilities less than 1 meter, Lakes Caonillas, Dos Bocas and Prieto. The lowest visibility was in Lake Prieto (0.10 m).

Significant variations occurred in the depth of visibility during the various seasons of the year. Minimum visibilities occurred during the Second Quarter (April, May, June) in Lakes Caonillas and Garzas, but during the Fourth Quarter (October, November, December) in Lakes Dos Bocas and Prieto. Maximum visibilities occurred during the Fourth Quarter for Lakes Caonillas and Garzas with no particular pattern in the others. The periods of low visibility correspond to the two rainy seasons but it was not clear why Caonillas and Garzas should have their best visibility during these same rainy periods.

Table 11

SEASONAL VARIATIONS IN MEAN OF SECCHI DEPTH, BY LAKE, 1976-1978.

Year	1976		1977				1978		
Quarter	3rd	4th	1st	2nd	3rd	4th	1st	2nd	Mean
Lake									
Caonillas		1.23	1.21	0.57	0.65		0.92		0.92
Dos Bocas		0.53	1.13		1.22	0.44			0.83
Garzas		2.30		1.69	1.99		2.36		2.08
Guayo						3.64	3.35		3.50
Prieto					0.30	0.10	0.80		0.40

Shore Slope

Flatter shores provide more suitable habitats for aquatic snails since there is usually more vegetation and better protection against wave action. The mean shore slope ranged from 5:1 for the horizontal: vertical slope of Lake Guayo to 1.4:1 for Lake Garzas (Table 12).

One can calculate the maximum potential habitat by using the shore slope information and the depth of the photic zone. This will give the average width of submerged shore which receives light. Multiplied by the shore length this equals the maximum area of potential habitat. Thus Lake Guayo, with a shore slope of 5.1:1 and a photic zone of 3.5 meters had an average illuminated shore width of 17.85 meters. As the shore length was approximately 8 kilometers the total illuminated area was 0.143 square kilometers.

In contrast the larger Lake Caonillas, which had water quality similar to that of Lake Guayo, had a mean shore slope of 2.3:1 and a mean photic zone 0.9 M deep, the width of the illuminated shore was 2 M. As the shore length was about 7.5 kilometers, the total potential habitat was only 0.015 square kilometers, about 10% of the potential habitat in Lake Guayo.

Table 12

Mean Shore Slope at High Water Level of 5 Major Hydroelectric Reservoirs in Puerto Rico.

(Taken from maps at scale of 1:20,000 with 10 meter contour intervals. Slope given is ratio of horizontal:vertical distance).

Lake	Mean Shore Slope	Approximate Kilometers* of Shoreline by class of slope			
		From:0 To :0.9	1.0 4.9	5.0 9.9	10.0 30.0
Caonillas	2.3:1	1.0	10.0	1.0	0.0
Dos Bocas	23:1	3.5	14.0	1.5	0.5
Garzas	1.4:1	0.0	3.5	0.0	0.0
Guayo	5.1:1	0.0	6.5	0.5	0.5
Prieto	3.0:1	0.0	1.0	0.0	0.0

*Straight line distances, ignoring indentations and small projections in shorelines.

Seven Representative Lakes

Results from the annual surveys made on the 6 reservoirs of Lakes Carite, Cidra, Guajataca, Matrullas, Patillas and Toro were combined with data from Lake Carraízo to indicate the general range and variation of conditions in these representative reservoirs (Table 13). In general the water quality conditions are not remarkably different, with Lake Carraízo representing the polluted extreme for Puerto Rico and Lake Matrullas, although highly colored, representing the least contaminated condition.

All of the reservoirs except Lake Matrullas and Lake Toro supported large numbers of snails and usually 3 or 4 species at the same time (Tables 8 and 14). The most ubiquitous snail was the ampullarid *Marisa cornuarietis* which was found in all lakes except Toro. The thiarid snail *Tarebia granifera* was also very common and usually found in such large numbers that they defied counting (Figure 21). *Biomphalaria glabrata*, the planorbid snail which transmits *Schistosoma mansoni* was found in five of the hydroelectric reservoirs, and in Lake Prieto the snails were shedding the cercarial forms of the parasite (Table 8). Another parasite, *Fasciola hepatica* which infects cattle in Puerto Rico, was found in lymnaed snails in Lake Cidra (Table 14).

Table 13

Water quality of Lakes Carite, Carraízo, Cidra, Guajataca, Matrullas, Patillas and Toro, in Puerto Rico, 1975-1978. Samples were taken 0.5 meters below surface

Parameter Unit	Carite	Carraízo	Cidra	Guajataca	Matrullas	Patillas	Toro
Chlorides mg/l	7.7 ± 2.2	16.6 ± 4.1	14.2 ± 0.4	6.6 ± 5.8	2.0 ± 1.4	9.6 ± 3.1	5.0 ± 7.0
Hardness as $MgSO_4$-mg/l	29 ± 16	126 ± 23	76 ± 0	224 ± 64	21 ± 0	29 ± 17	137 ± 2
Total Phosphates as P-mg/l	0.01 ± 0.01	0.28 ± 0.33	0.02 ± 0.02	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.01	0.01 ± 0.00
Nitrates and Nitrites as N-mg/l	0.03 ± 0.03	0.33 ± 0.48	0.20 ± 0.11	0.47 ± 0.53	0.53 ± 0.67	0.14 ± 0.19	0.38 ± 0.09
Iron-mg/l	0.16 ± 0.14	1.02 ± 1.11	0.56 ± 0.27	0.11 ± 0.09	0.22 ± 0.04	0.07 ± 0.10	1.30 ± 0.00
Turbidity-s.u.	3.2 ± 0.6	18.3 ± 15.6	1.7 ± 1.5	7.6 ± 5.5	1.8 ± 0.2	9.6 ± 6.3	10.6 ± 0.0
Color-s.u.	9.8 ± 0.7	23.0 ± 10.1	8.2 ± 2.4	8.4 ± 3.4	17.5 ± 10.6	10.6 ± 2.0	10.0 ± 7.1
pH	7.18 ± 0.16	7.24 ± 0.25	7.30 ± 0.23	7.36 ± 0.49	7.85 ± 0.07	7.72 ± 0.30	7.30 ± 0.71
Dissolved Oxygen-mg/l	7.0 ± 0.7	5.0 ± 2.1	5.4 ± 1.0	7.6 ± 0.3	7.8 ± 1.0	7.4 ± 0.7	6.8 ± 1.0
Coliform Bacteria/100 ml	155	17,604	546	102	64	399	1,229
Secchi Disk M	1.6 ± 0.2	0.5 ± 0.4	----- ± -----	2.2 ± 0.2	----- ± -----	1.8 ± 0.5	----- ± -----
Temperature in °C	23 ± 1.1	26 ± 1.6	23 ± 1.0	26 ± 1.3	----- ± -----	29 ± 1.6	----- ± -----
Net Productivity = P mg/L O_2/day	0.7 ± 0.4	2.4 ± 3.0	1.0 ± 0.5	0.6 ± 0.5	---- ± -----	0.9 ± 0.2	----- ± -----
Respiration = R mg/L O_2/day	0.5 ± 0.3	2.0 ± 1.7	0.6 ± 0.4	0.5 ± 0.1	----- ± -----	0.8 ± 0.6	----- ± -----
P/R	1.4	1.2	1.7	1.2		1.1	
Total Phytoplankton counts/ml	17.5	18.2	26.0		35.6	29.4	20.2

All *Biomphalaria glabrata* recovered in the surveys were examined for schistosome infections, but observations on trematode infections in other snails were made only occasionally. In every instance the numbers of *B. glabrata* recovered were very small and the snails were confined to a single habitat. These habitats were shallow with usually less than 0.1 meters of water, insufficient depth for *M. cornuarietis*. Except for Lake Carite, the habitats were always near the entrance of a tributary stream from a watershed known to contain population of *B. glabrata*, suggesting they were recent arrivals washed in from upstream. In the exception on Lake Carite, the *B. glabrata* were found in a broad swampy overflow which often had only a trickle of water passing over it, insufficient for establishment of a strong population of *M. cornuarietis*. Thus these small habitats served as refuges for the last remnants of the *B. glabrata* populations. The total number of *B. glabrata* found in these places never approached 100 snails and usually fewer than 10 snails were found after intensive searching.

The transitory nature of these remnant populations is further documented by the occasional absence of *B. glabrata* from these lakes during one or more of the surveys before 1978, despite extra searching when they were not encountered. In Lake Garzas the planorbid snails were found only twice in 5 surveys, and in Lake Prieto 2 out of 4 times. This supports the hypothesis that they were snails washed in from upstream and unable to establish strong populations due to pressure from *M. cornuarietis*.

Table 14

Results of Supplemental Snail Surveys in Seven Reservoirs of Puerto Rico, 1975-1978.

Lake	First Survey Date	First Survey Snails*	Second Survey Date	Second Survey Snails	Third Survey Date	Third Survey Snails	Fourth Survey Date	Fourth Survey Snails
Carite	Dec 75	B M P T	Nov 77	M T	May 78	B M T A	Aug 78	M T P
Carraízo	Jul 76	B M P A	Apr 78	M P T A	Aug 78	M T L P A	------	-----
Cidra	Jan 76	M P L A	Jul 76	M A	------	---------	------	-----
Guajataca	Jun 76	M T A	Aug 78	M T	------	---------	------	-----
Matrullas	Feb 75	P T	Nov 75	P	Oct 78	M T P	------	-----
Patillas	Jul 76	M T	May 78	M T A	Jul 78	M T A	------	-----
Toro	Feb 76	None	Mar 78	L P	------	---------	------	-----

B = *Biomphalaria glabrata* P = *Physa cubensis*

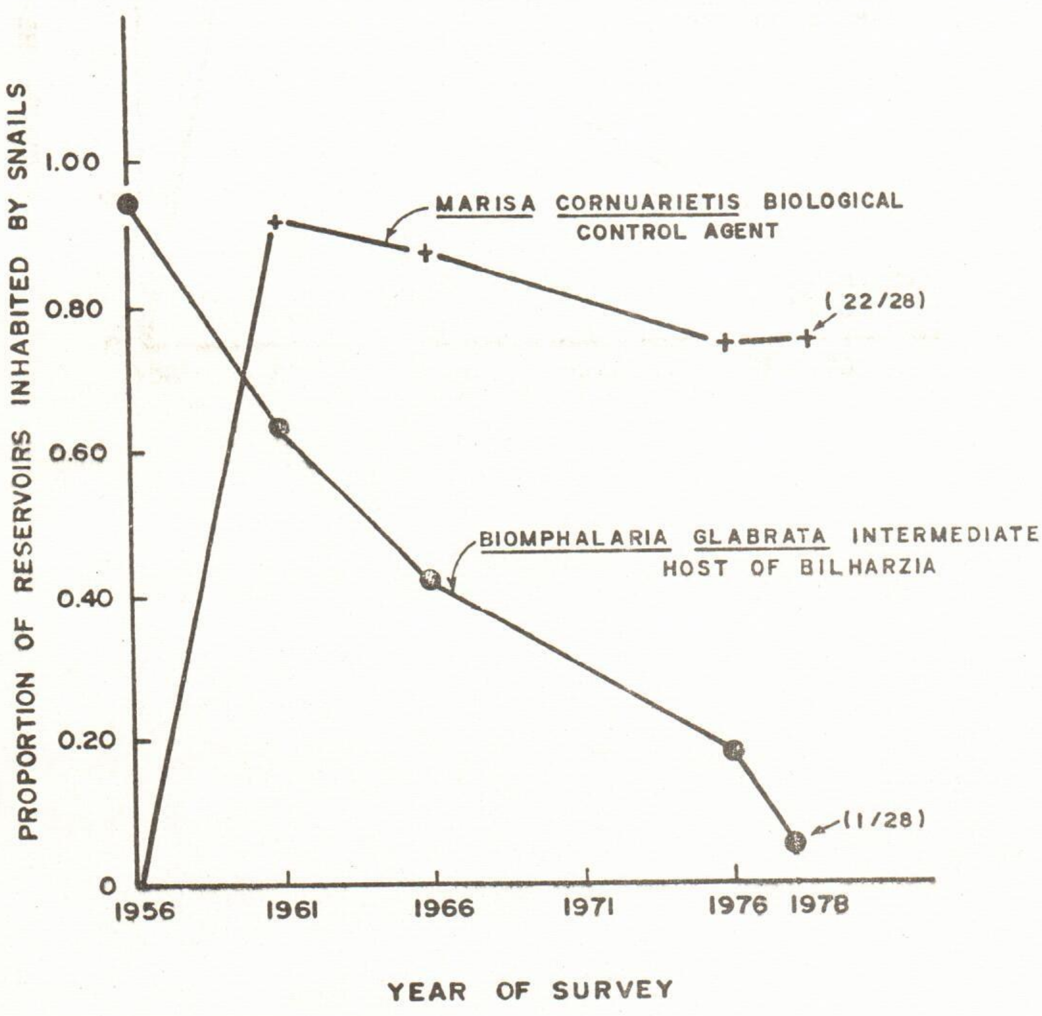
M = *Marisa cornuarietis* A = *Pomacea australis*

T = *Tarebia granifera* L = *Lymnea columella*

Figure 21. *Tarebia granifera* was found in almost every lake, sometimes in uncountable numbers. It usually inhabited highly oxygenated water such as exposed shorelines, whereas *Marisa cornuarietis* and *Biomphalaria glabrata* were found in quiet, protected waters.

The final surveys in 1978 indicated that the long term trend of elimination of *Biomphalaria glabrata* by *Marisa* cornuarietis was continuing. The only lake containing *B. glabrata* at the end of 1978 was Lake Prieto. The planorbids has disappeared from the overflow of Lake Carite, from the bank of the Limón River in Lake Dos Bocas, from the shallow pool at the entrance to Lake Garzas and from the swampy fringes of Lake Carraîzo (Figure 22). In each of these sites large growing populations of *Marisa cornuarietis* were found. However in Lake Prieto the *Marisa cornuarietis* were clearly being limited by shallow water, as the *B. glabrata* occurred in a swamp at the entrance of the river into Lake Prieto, where vegetation was thick, and water level was shallow.

FIGURE 22. BIOLOGICAL CONTROL OF BILHARZIA SNAILS IN RESERVOIRS OF PUERTO RICO, 1956-1978



Remaining 14 Lakes

The remaining 14 lakes showed normal ranges of water quality although the water had less color than the 12 reservoirs studied in detail (Table 15). None of the remaining 14 lakes contained populations of *B. glabrata* although *M. cornuarietis*, *T. granifera* and many others were found (Table 16).

Table 15

Water quality of 14 reservoirs in Puerto Rico
during reconnaissance survey of 1975 and 1976 (3).

Lake	No. of Samples	In Standard Units Color	Turbidity	Chlorides	In mg/liter Total Phosphates as P	Iron	Nitrate and Nitrite	Hardness as mg SO_4
Adjuntas	3	7	1	11	0.2	0.2	0.2	144
Comerio #1	4	12	2	14	0.3	0.1	0.5	266
Comerio #2	4	4	5	15	0.1	0.3	0.4	210
Guayabal	6	12	5	8	0.1	---	0.1	214
Guineo	6	5	2	3	---	0.0	0.0	---
Jordán	2	6	2	14	0.0	0.1	0.0	157
La Plata	5	9	5	16	0.0	0.2	0.2	212
Las Curias	5	8	6	12	0.0	0.1	0.2	94
Loco	6	5	5	8	0.0	0.0	0.1	---
Luchetti	23	5	3	8	0.0	0.2	0.3	157
Pellejas	2	6	15	10	0.0	0.5	0.0	138
Toa Vaca	13	6	2	10	0.1	0.6	0.0	30
Vivi	3	6	2	10	0.0	0.4	0.1	128
Yahuecas	4	10	75	9	0.0	0.2	1.0	121
MEANS		7	9	11	0.1	0.2	0.2	134

Table 16

Snail Species in 14 minor reservoirs of Puerto Rico, 1976 to 1978.

Lake	Snail Species Present						
	Bg	Mc	Tg	Pa	Ph	Ly	Tr
Adjuntas	-	-	-	-	+	-	-
Comerio #1	-	+	+	-	+	+	-
Comerio #2	-	+	+	-	-	-	-
Guayabal	-	+	+	-	-	-	+
Guineo	-	+	+	-	+	-	+
Jordán	-	+	-	-	-	-	-
La Plata	-	+	+	-	-	-	-
Las Curias	-	+	+	-	-	-	-
Loco	-	+	+	-	-	-	-
Luchetti	-	+	+	-	-	-	+
Pellejas	-	-	-	-	-	-	-
Toro	-	+	+	-	-	-	+
Vivi	-	-	-	-	+	-	-
Yahuecas	-	+	-	-	-	-	-

Bg = <u>Biomphalaria glabrata</u>

Mc = <u>Marisa cornuarietis</u>

Tg = <u>Tarebia granifera</u>

Pa = <u>Pomacea australis</u>

Ph = <u>Physa cubensis</u>

Ly = <u>Lymnea columella</u>

Tr = <u>Tropicorbis riseii</u>

Discussion

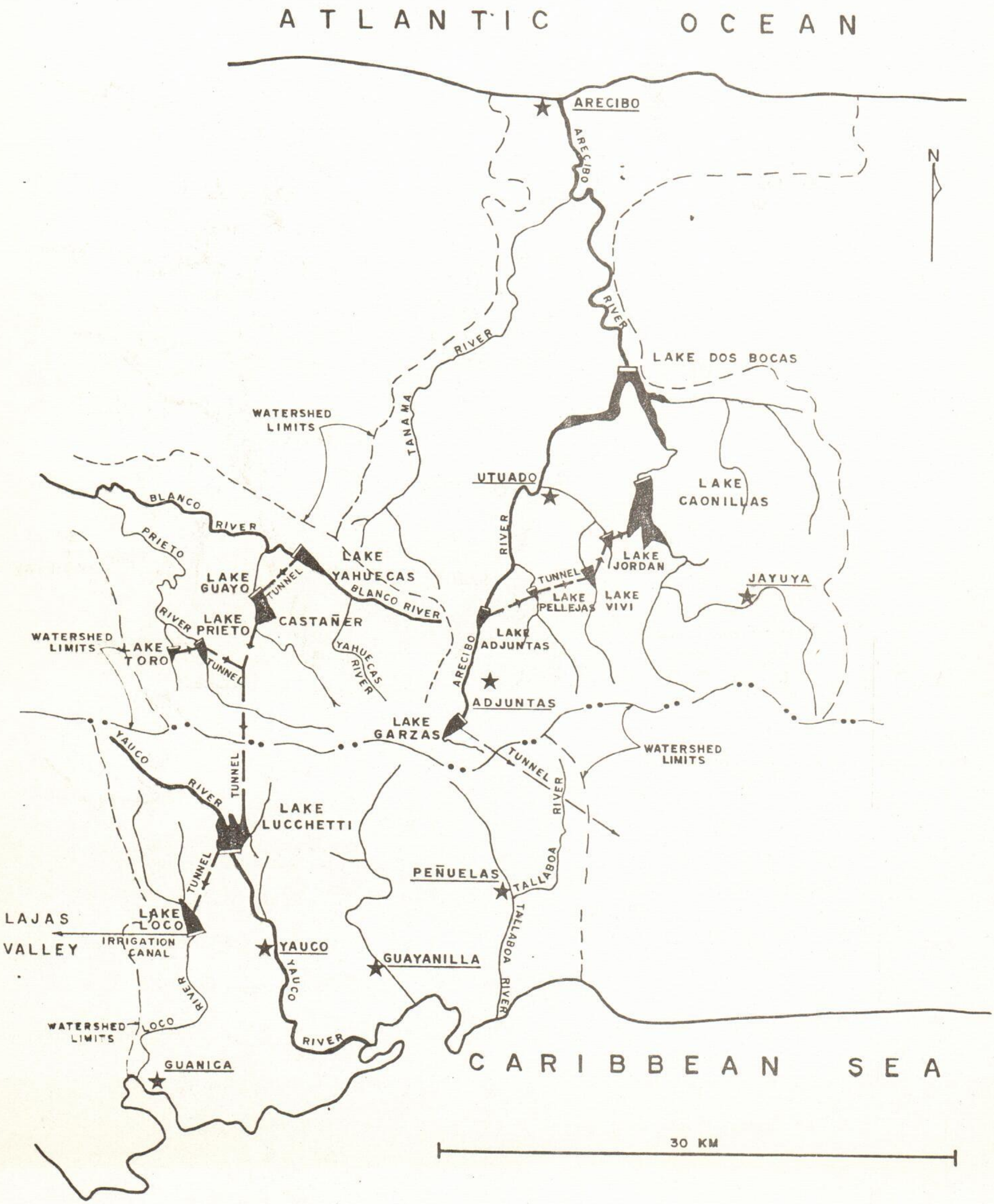
The major portion of the data collected deals with the Lakes of the Dos Bocas Hydroelectric System (Table 17) and the Lajas Valley Irrigation and Hydroelectric System (Figure 23). During the past 15 or 20 years there were general indications that the original focus of bilharzia transmission around the Dos Bocas Reservoir System had decreased significantly while the prevalence by skin test in the population near the reservoirs of the Lajas Valley System had held steady or increased (Table 18).

TABLE 17

HYDROELECTRIC RESERVOIRS IN THE DOS BOCAS SYSTEM

Reservoir	Year of Construction	Municipality
Lake Dos Bocas	1942	Arecibo and Utuado
Lake Caonillas	1948	Utuado
Lake Jordan	1950	Utuado
Lake Pellejas	1950	Adjuntas
Lake Vivi	1950	Utuado
Lake Adjuntas	1950	Adjuntas

Figure 23. The Dos Bocas and Lajas Reservoir System in Puerto Rico.



ADJUSTED POSITIVITY FOR SCHISTOSOMIASIS OBTAINED FROM SKIN TEST OF FIFTH GRADERS IN PUERTO RICO, 1963, 1969, and 1976 FOR THE AREAS SURROUNDING THE DOS BOCAS AND THE LAJAS RESERVOIR SYSTEMS.

	Watershed	1963*	1969**	1976***
Dos Bocas System				
Utuado, Jayuya, Adjuntas	22	34	19.9	5.1
Lajas System				
Yauco, Guayanilla, Peñuelas	24	16	9.3	13.2
Upper Yauco, Castañer	25	6	20.0	10.2

*Adjusted for change in methodology from Kagan et al, 1966 (2).

**Corrected, Ruîz et al, 1973 (3).

***From Negrón and Nazario, 1978 (4).

The Dos Bocas Hydroelectric Complex

During the Second World War construction began on a series of 6 interconnected reservoirs near Utuado, a classical focus of schistosomiasis. Lake Dos Bocas is the largest of the six and receives the flow from turbines at Caonillas which in turn receives the flow from Lakes Jordán, Pellejas, Viví and Adjuntas (Figure 23). The population around Utuado was about 10,000 in 1960.

Because of the relatively large contributing watershed and because it is now used primarily for short-term supplemental power generation, Lake Dos Bocas is maintained at a fairly constant level. The other lakes however are subject to large fluctuations, as was Dos Bocas before 1950. The combined system generates about 63 million kilowatt hours per year. There is very little direct utilization of the water for irrigation.

Although a survey in 1953 did not encounter *B. glabrata* in Lake Dos Bocas or in Lake Caonillas (Harry and Cumbie, 1956) a more detailled survey a few years later discovered a small population in Lake Dos Bocas at the mouth of the Limón River, the eastern tributary, as well as a few small colonies in swamps adjacent to the western tributary, the Arecibo River (Figure 18). The lake was full of floating water hyacinth and the thiarid snail *Tarebia granifera* (Ritchie et al, 1962). A regular inspection system was instituted on Lake Dos Bocas, Lake Caonillas and Lake Adjuntas in 1956, demonstrating the presence of *B. glabrata* in Lake Dos Bocas from 1956 to 1976, primarily in the same small colony on the Limón River (Jobin et al, 1977). The planorbid snail was also found in Lake Caonillas as late as 1966, but it was not found after intensive searching in 1976. The two times Lake Adjuntas was surveyed it did not contain B. glabrata. Lakes Jordán, Viví and Pellejas were not surveyed until 1976 because of their small size and inaccesibility. They did not contain B. glabrata in 1976 (Jobin et al, 1977). Lake Dos Bocas and Lake Caonillas contained enormous numbers of Tarebia granifera in 1976, primarily on exposed redclay shores (Jobin et al, 1976).

In the watersheds contributing to these lakes the snails have been found in many places both upstream and downstream of the lakes, especially on the flood plains of the Viví and Arecibo River near Utuado, in the Jayuya streams which contribute to Lake Caonillas, in the Limón River which contribute to the eastern branch of lake Dos Bocas, and in the lower flood plain of the Arecibo River, below the entire system. Despite the presence of B. glabrata throughout the watershed, it was somewhat surprising that none of the lakes contained significant population of the snails.

The molluscan hervibores in Puerto Rican Lakes are not generally subjected to significant predation by larger forms, thus their population dynamics are regulated by intra-species and inter-species competition for food and habitat space, by suitability of oviposition sites, by water temperatures and in the case of B. glabrata, by predation on eggs and young from M. cornuarietis. Other minor mechanisms of population regulation may be predation by fish, and other larger animals.

Snail death rates are functions of aging, diseases including parasitism, mechanical stress due to wave action, and perhaps chemical deficiencies, primarily oxygen. However most lakes in Puerto Rico seem quite suitable chemically for snail populations.

One snail which is found infrequently is apparently restricted by lack of suitable oviposition sites. Pomacea australis is found in large numbers only along the rocky shores of Lake Patillas, near the entrance of Río Patillas and Río Marín. It is found in small numbers in a few other lakes such as Carraízo, Carite, Cidra, and Guayo. This large snail lays its eggs on vertical faces above the water surface by crawling out at night, thus it needs rocks or other solid vertical surfaces which emerge above the water in lakes with fairly steady levels during the oviposition sites, since B. glabrata and Marisa usually lay their eggs on vegetation or miscellaneous debris. Tarebia granifera is ovoviviparous and coincidentally the most ubiquitous and numerous aquatic snail on the island, found in large numbers in all watersheds.

The factors determining distribution and numbers of Lymnaea and Physa in the lakes are not understood. Their numbers are always few with no discernible patterns to their distribution. Perhaps the amphibious Lymnaea is affected by terrestrial conditions, and perhaps Physa requires high concentration of organic matter. Helisoma is absent from all lakes, apprently being very sensitive to contaminants and a very weak competitor against other snails under Puerto Rican conditions.

The most important determinants to be considered in general analysis of snail populations are thus:

Water temperature

food (peri-phyton)

habitat volume

number of same species

number of other snails.

If one compares the reservoirs in the Dos Bocas System, where bilharzia prevalence has been declining steadily since the reservoirs were constructed, with the reservoirs in the Lajas System where bilharzia prevalence has been increasing since the construction of the reservoirs, it is possible to find some ecological differences which may be responsible. In the Lajas system Biomphalaria populations remained stable in Lake Prieto and they were usually infected with S. mansoni while the planorbids gradully disappeared from the Dos Bocas system and they were never found infected.

The Lakes of the Lajas System had significantly higher concentrations of hardness, phosphates, nitrates and nitrites than had the lakes of the Dos Bocas System (Tables 19 and 20). Also the net productivity and the ratio of net productivity to respiration were lower in the Lajas System. However the other parameters including coliform bacteria and phytoplankton populations showed no significant differences.

A second interesting comparison can be made regarding the suitability of lakes for Marisa cornuarietis, based on a comparison between Lake Guayo which is undoubtedly the lake which supports the largest most productive population of

Table 19

Comparison of Water Quality Parameters between Reservoirs of Dos Bocas System and those of Lajas System.

Parameter	Transmission Decreasing			Transmission steady or increasing	
	Lakes in Dos Bocas System			Lakes in Lajas System	
	Caonillas	Dos Bocas	Garzas	Guayo	Prieto *infected
Chlorides-mg/l	6	6	4	11	4
Hardness-mg/l as $MgSO_4$	110	104	83	122	165*
pH	7.5	7.5	7.7	7.8	7.5
Nitrates and Nitrites as N-mg/l	0.01	0.01	0.01	0.03	0.02*
Iron-mg/l	0.13	0.19	0.05	0.06	0.98
Secchi Disk M	1.1	1.3	2.2	3.6	0.5
Turbidity S.U.	2.2	4.6	1.4	1.0	16.4
Color S.U.	14	12	9	11	12
Net Productivity mg/l O_2/day	1.5	2.0	0.8	0.7	0.7
Respiration-mg/l O_2/day	1.1	1.0	0.4	0.5	0.9
Coliform Bacteria per 100 ml	3975	16	3816	2115	3127
Blue green algae per 100 ml	1180	54	316	456	394
Green algae per 100 ml	1160	752	763	540	539
Diatoms per 100 ml	670	492	811	332	913
Flagellates per 100 ml	170	268	185	178	101

Table 20

Significant differences in Water Quality Parameters between lakes in Dos Bocas System and Lajas System.

Parameters	Lakes in Dos Bocas System				Lakes in Lajas System		
	Caonillas	Dos Bocas	Garzas	Mean	Guayo	Prieto	Mean
Hardness as $MgSO_4$ in mg/l	110	104	83	99.0 ± 14.2	122	165	143.5 ± 30.4
Total Phosphates as P in mg/l	0.01	0.01	0.01	0.010 ± 0	0.03	0.02	0.025 ± 0.007
Nitrates and Nitrites as N in mg/l	0.06	0.06	0.05	0.057 ± 0.006	0.10	0.33	0.225 ± 0.163
Net Productivity in mg/l O_2 per day	1.5	2.0	0.8	1.43 ± 0.60	0.7	0.7	0.70 ± 0
Net Productivity/Respiration	1.36	2.00	2.00	1.787 ± 0.370	1.40	0.78	1.090 ± 0.438

Marisa cornuarietis in Puerto Rico, and Lake Caonillas which is very similar in many respects to Lake Guayo but which contains only a few *M. cornuarietis*, and sometimes none.

While Lake Guayo had more nutrients than Lake Caonillas and a deeper photic zone, the net oxygen productivity at the surface of Lake Caonillas was twice the productivity of Lake Guayo, with similar ratios of oxygen productivity/respiration (Table 21). The higher oxygen productivity was confirmed by the high algae counts in Lake Caonillas.

This suggests that algae is not as important for *M. cornuarietis* as is littoral vegetation. With the flatter shoreline of Lake Guayo, deeper photic zone and higher nutrients, the amount of rooted shoreline vegetation was enormous, while in Lake Caonillas the steep shorelines and low nutrients produced virtually no littoral vegetation, with erosion of most of the shore.

Table 21

Comparisons of lakes as habitats for *Marisa cornuarietis*.

Parameter	Ideal Habitat for *Marisa cornuarietis*	Very poor Habitat for *Marisa cornuarietis*
	Lake Guayo	Lake Caonillas
Chlorides-mg/l	11	6
Hardness-mg/l as $MgSO_4$	122	110
pH	7.8	7.5
Total Phosphates as P	0.03	0.01
Nitrates and Nitrites as N-mg/l	0.10	0.06
Iron-mg/l	0.06	0.13
Secchi Disk M	3.6	1.1
Turbidity S.U.	1.0	2.2
Color S.U.	11	14
Net Productivity mg/l O_2/day	0.7	1.5
Respiration-mg/l O_2/day	0.5	1.1
Coliform bacteria per 100 ml	2115	3975
Blue green algae per 100 ml	456	1180
Green algae per 100 ml	540	1160
Diatoms per 100 ml	332	670
Flagellates per 100 ml	178	170

References

Preliminary data.

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2. Jobin, W. R. et al, 1977 "Biological Control of *Biomphalaria glabrata* in Major Reservoirs in Puerto Rico". *American Journal of Tropical Medicine and Hygiene*, Vol. 26, 1018-1024.