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ECOLOGICAL REVIEW OF HYDROELECTRIC RESERVOIRS IN PUERTO RICO

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ECOLOGICAL REVIEW OF HYDROELECTRIC RESERVOIRS IN PUERTO RICO[1]

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SUMMARY

A review of published literature and available data on the ecology of hydroelectric reservoirs and other lakes in Puerto Rico, yielded various studies on unrelated elements in the aquatic ecology, but very few comprehensive investigations. The majority of the island-wide studies pertained to surveys on snails related to the parasitic disease bilharzia. A survey of 28 major lakes in 1976 showed that *Biomphalaria glabrata* had gradually been displaced from most of the lakes by *Marisa cornuarietis* and *Tarebia granifera*, two foreign snails which do not transmit bilharzia. Of the 17 lakes containing *B. glabrata* in 1956, only 8 remained infested in 1966 and only 5 in 1976, twenty years after the introduction of *Marisa cornuarietis*. Although the trend indicates that the lakes may be safe from transmission a monitoring system is necessary before the lakes could be used for recreation.

ACKNOWLEDGMENTS

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ECOLOGICAL REVIEW OF HYDROELECTRIC RESERVOIRS IN PUERTO RICO

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I. INTRODUCTION

An increase in construction of hydroelectric reservoirs has occurred in the tropics and the large ecological changes caused by these reservoirs have often affected the ecology of local populations, including increases in the parasitic disease, schistosomiasis, also known as bilharzia. The increased trend in hydroelectric projects has been typified by the Aswan Dam in Egypt, Kariba Dam on the Zambesi River and Lake Volta in Ghana (Table 1). Recently, additional emphasis in Latin America was outlined by Mr. Antonio Ortiz Mena, President of the Interamerican Bank on May 19, 1975 in Santo Domingo:

> "... The sectoral distribution of the loans authorized in 1974 reflected a trend determined by the world fuel and food crisis. The increase in hydroelectric capacity and food production within the region is closely connected to the utilization of a common element essential to both sectors-water. For that reason, in financing projects and programs of this type, the Bank is particularly concerned with promoting the rational use of Latin America's vast water resources.
>
> The total of $384.1 million of the Bank's 1974 loan portfolio helped increase power production in the region, making electric power the year's largest individual sector. Loans approved were distributed as follows: $162.5 million to help finance hydroelectric projects that will promote power development, irrigation and other farm improvement facilities in Costa Rica, Chile and Ecuador; $93 million to increase hydroelectric potential, including rural electrification cooperative programs in Argentina and Ecuador; $95 million in binational credit to assist in financing the second stage of construction of the Salto Grande plant on the Uruguay River that will supply energy to Uruguay and to the coastal provinces of Argentina, and $33.6 million to build power distribution systems in Paraguay.
>
> These bring the cumulative value of loans granted in this sector to $1,570 million. Such resources are helping to finance the installation of 19.1 million kilowatts of power, of which 12.5 million kilowatts represent hydroelectric plants. The energy produced by these plants would require the consumption of 89 million barrels of oil a year with a value equal to $623 million. Authorized loans are also helping to install 94,748 additional

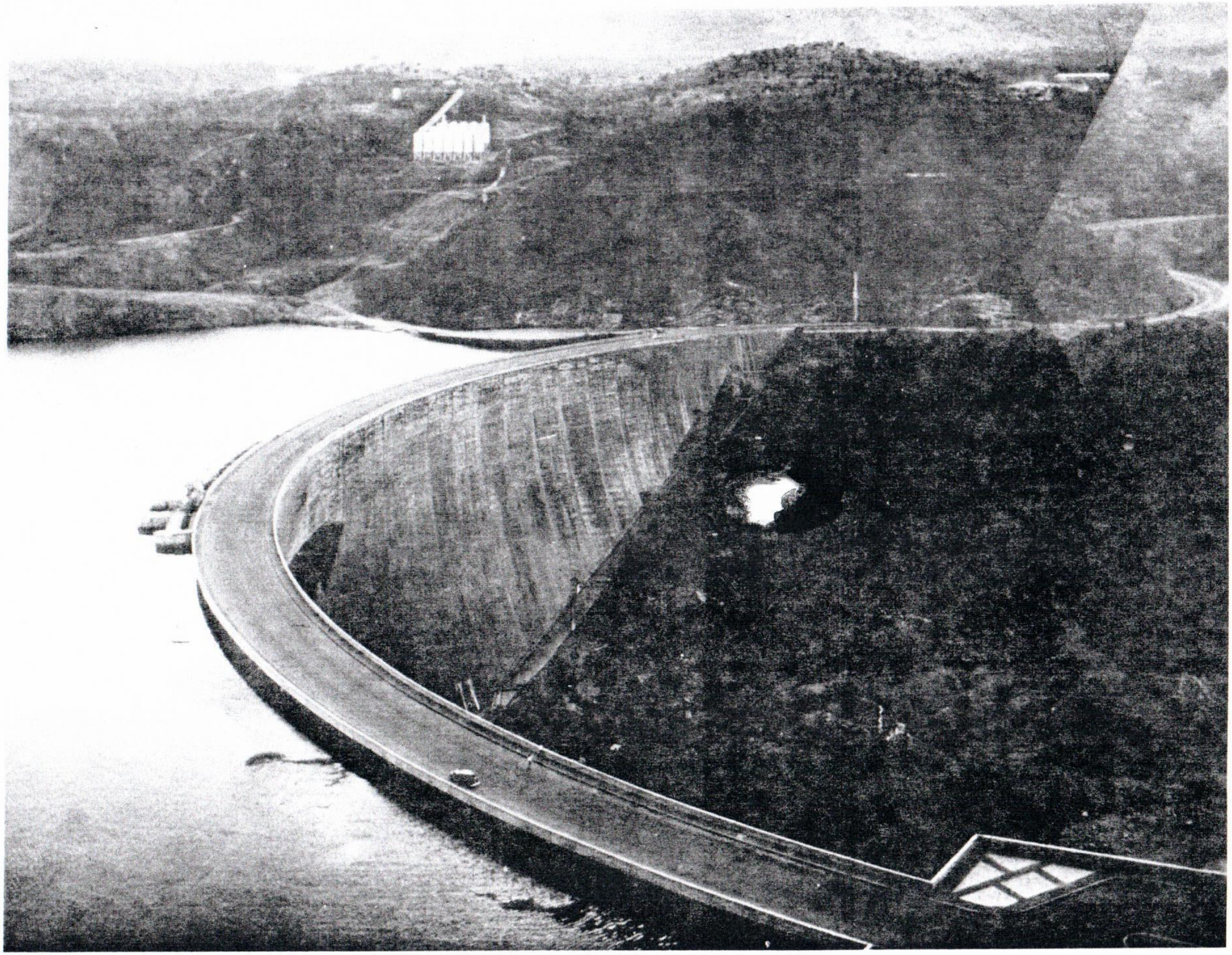

FIGURE 1. KARIBA DAM ON THE ZAMBEZI RIVER, LOOKING TOWARD ZAMBIA. THIS HYDROELECTRIC PROJECT SUPPLIES POWER FOR COPPER PROCESSING IN CENTRAL AFRICA.

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-Kloly, 1964.
Ethiopia	Tana	Gondar on Blue Nile.			Ferguson, Ruiz 1970.
Ghana	Volta	Akosombo on Volta River	Severe outbreak of bilharzia on We . 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
Rhodesia	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

miles of transmission and distribution lines and to improve distribution systems in 2,392 communities."

Our purpose in this report is to review existing data on hydroelectric reservoirs in the tropics, especially those in Puerto Rico, to highlight current problems and to identify future concerns. Our data from Puerto Rico derives from surveys on ecology of bilharzia and from records of Puerto Rican Water Authorities.

A. HYDROELECTRIC RESERVOIRS IN THE TROPICS

The tropical region which has experienced the greatest problems with bilharzia in new hydroelectric impoundments is Africa. (TABLE 1).The bilharzia snails found most commonly in these African lakes have been of the genus Bulinus. Shallow papyrus swamps bordering Lake Victoria pose particular snail control problems. Sennar Reservoir has clear warm water with adequate vegetation for support of Bulinus which was then regularly seeded into the Gezira Irrigation District (Sharaf El Din,1955; Rahman and Sharaf El Din, 1961). At Lake Kariba, the problems of massive floating fern, Salvinia auriculta, threatened navigation and was a suitable habitat for snail vectors (Holm et al, 1969). Bilharzia posed a threat at Siavonga, an area designated for recreation and tourist development on Lake Kariba (Hira,1969). The Volta Reservoir has a growing problem of urinary bilharzia in fishing villages (Paperna, 1969). The same potential exists at Lake Nasser behind the Aswan Dam (Webbe, 1972).

The transmission of bilharzia on these lakes is concentrated at local watering points and village shores; this simplifies control possibilities to some extent but leaves a clouded future because of the vast lengths of shoreline in lakes such as Volta.

In the Western Hemisphere the ecology of Biomphalaria glabrata has received considerable study in the natural lakes of Venezuela and Brazil (Table 2). In Lake Valenciana near Maracay, Venezuela, B. glabrata is not common although there is a massive colonization of Biomphalaria prona, a laboratory host of the schistosomes (Ferguson and Chrosciechowski, 1975). A conservation program

TABLE 2

MAJOR RESERVOIRS IN LATIN AMERICA
WITH POTENTIAL HEALTH PROBLEMS.

Country	Reservoir Name and Locality	Purpose of Reservoirs	Source of Information
Brazil	Furnas in Minas Gerais;	Hydroelectric	Dr. E. Paulini
	Pampulha in Belo Horizonte, M.G.;	Recreation	Dr. E. Paulini
	Tres Marias in M.G.;	Hydroelectric	Dr. E. Paulini
	Jupia-Ilha Solteira Complex in Sao Paulo	4.6 Megawatt Hydroelectric	Interamerican Development Bank, 1975
	Paulo Afonso on Sao Francisco River	3.8 Megawatt Hydroelectric	IDB, 1975
Dominican Republic	Taveras on Yaque del Norte River	Hydroelectric and irrigation	Speech by President Joaquin Balaguer
	Bao in Cibao Valley	Hydroelectric	IDB, 1975
Paraguay	Acaray	Hydroelectric	IDB, 1975
Uruguay	Salto Grande	Regional Hydroelectric	IDB, 1975
Venezuela	Valenciana in Maracay	Natural	Dr. H. Ferrer Faria

protects this lake from pollution. The ecology of Lake Pampulha at Belo Horizonte, Brazil has been studied with regard to possible biological control of B. glabrata. In the Dominican Republic (Etges and Maldonado, 1969) there is special interest in the two hydroelectric reservoirs under construction at Tavares and Cibao. During the past decade, B. glabrata appeared to be absent from lakes of crater origin in Grenada[3], Montserrate, St. Kitts[4] and St. Vincent[5]. Curepe Reservoir has been free of B. glabrata in numerous surveys of St. Croix waterbodies since 1953[6]. The municipal water supply reservoir of St. Kitts contained B. glabrata prior to molluscicidal elimination during 1958 (Sebastian et al., 1960). Several similar units in Grenada lacked the bilharzial snail during 1970 studies but contained large populations of B. straminea (Ferguson and Buckmire, 1974) which is a natural host for schistosomes in parts of Brazil and has proven to be a potential host in Grenada (Richards 1973).

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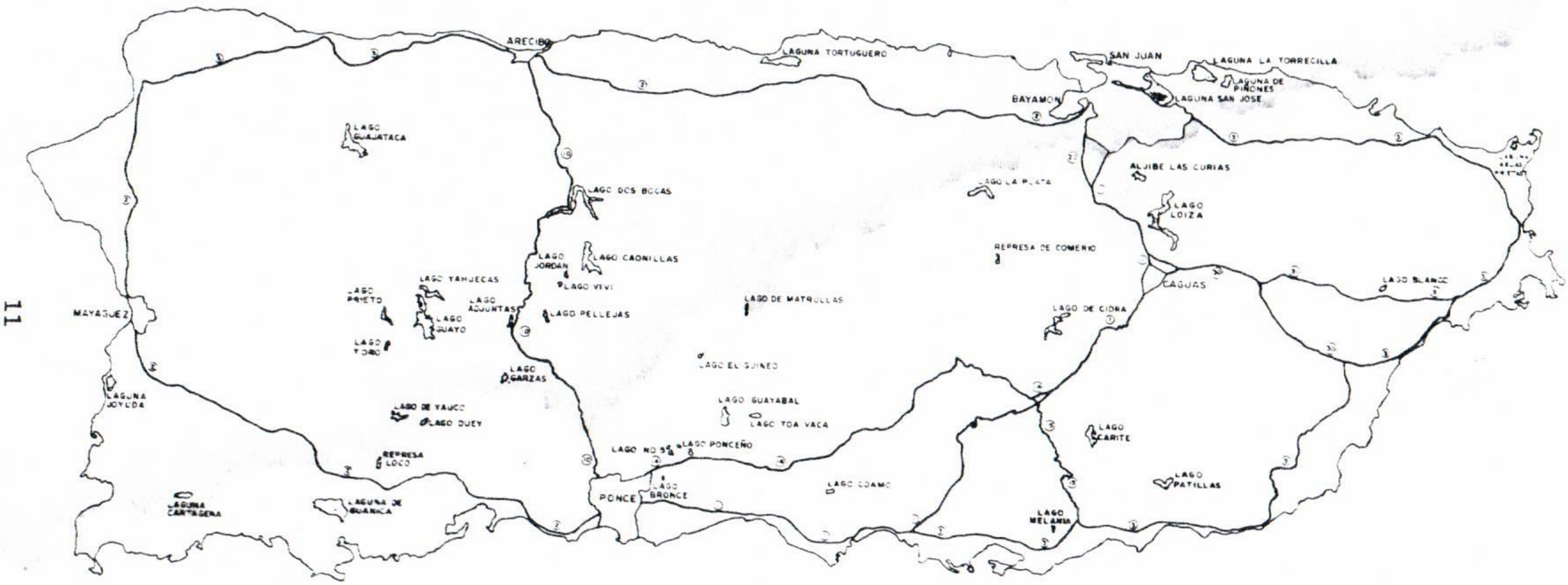
[3] Observations of F.F. Ferguson and K.W. Buckmire;
[4] G.S. Richards; [5] Scotchman; [6] Author's observations

B. General Ecology of Lakes In Puerto Rico

In Puerto Rico there are 28 reservoirs which were constructed during 1913-1976 (Figure 2). Seventeen of these impoundments presently provide hydroelectric power (Table 3 and Figure 3), and some ecological information is available for each lake, generally related to the studies on bilharzia.

There are no natural lakes in Puerto Rico, except for the brackish lagoons of San Jose, Torrecillas, Piñones, and the fresh water lagoons of Cartagena and Tortuguero (Reyes de Ruiz; 1971: Candelas and Candelas, 1964; Harry and Aldrich, 1958; Harry and Cumbie, 1956). In addition to the major lakes there are many small impoundments constructed for agricultural and fishing purposes. More than 800 standard USDA-SCS farm ponds are situated in the drought-prone central portion of the island. About 30 units have been surveyed for B. glabrata, and although the snail was found in about half of the ponds, they are not usually important transmission sites for bilharzia. Specially constructed night-storage ponds are used on the South coast for irrigation and B. glabrata has been controlled in 100 of these ponds using Marisa cornuarietis (Ruiz Tibeń et al, 1969). In comparing ecology of such small impoundments with large man-made reservoirs, extrapolations of ecological parameters must be made with caution.

It is important to understand why bilharzia snails are present or absent from watersheds contributory to hydroelectric impoundments, but perusal of more than 300 titles of various reports on fresh-water bodies in Puerto Rico indicates that ecological considerations affecting molluscan life have been neglected (Cordero, 1969; Bogart et al, 1964). The most relevant reports are the study on lacustrine plankton (Candelas and Candelas,



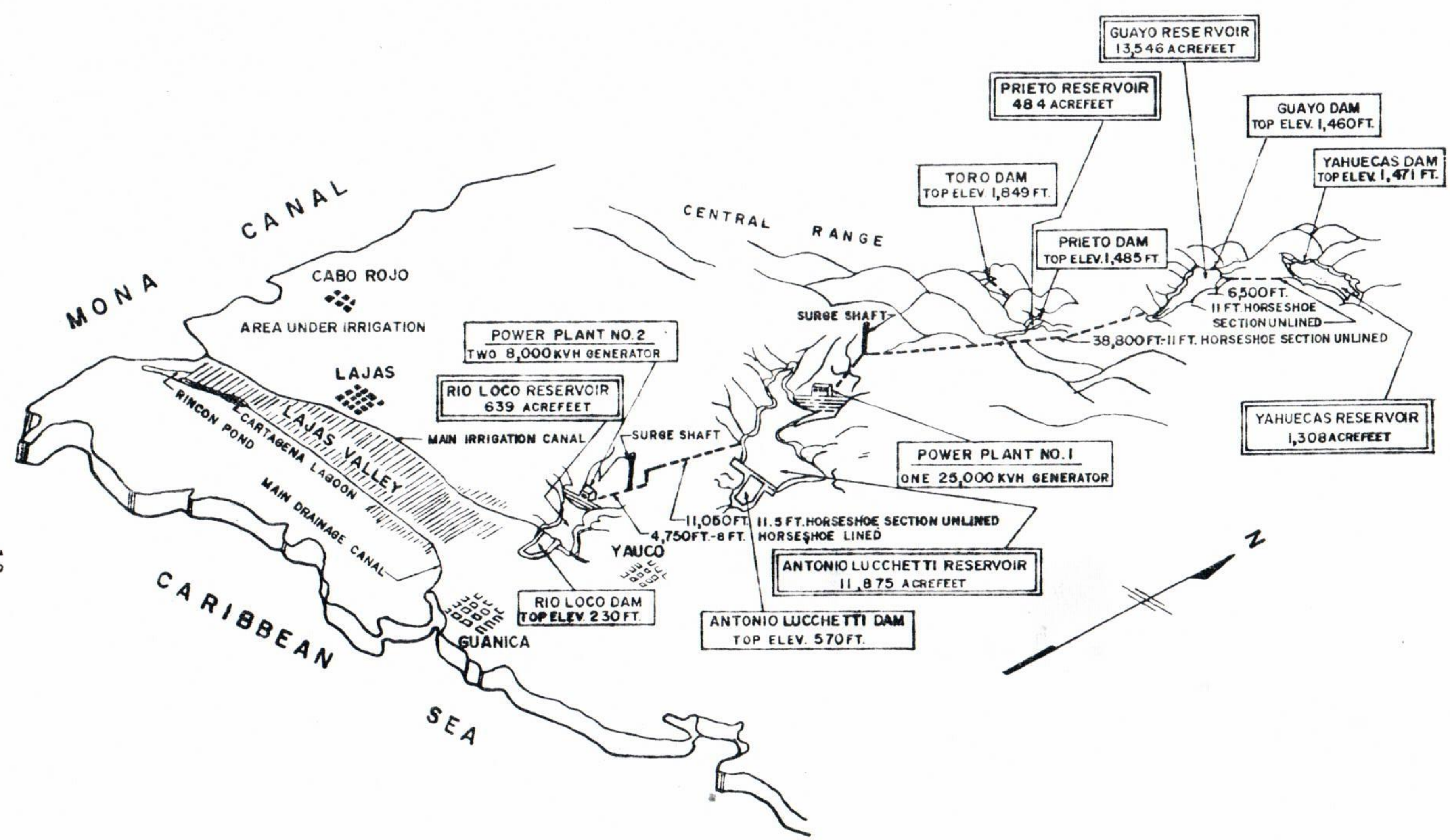
LOCATION OF LAKES IN PUERTO RICO

FIGURE 2

Table 3

MAJOR LAKES OF PUERTO RICO

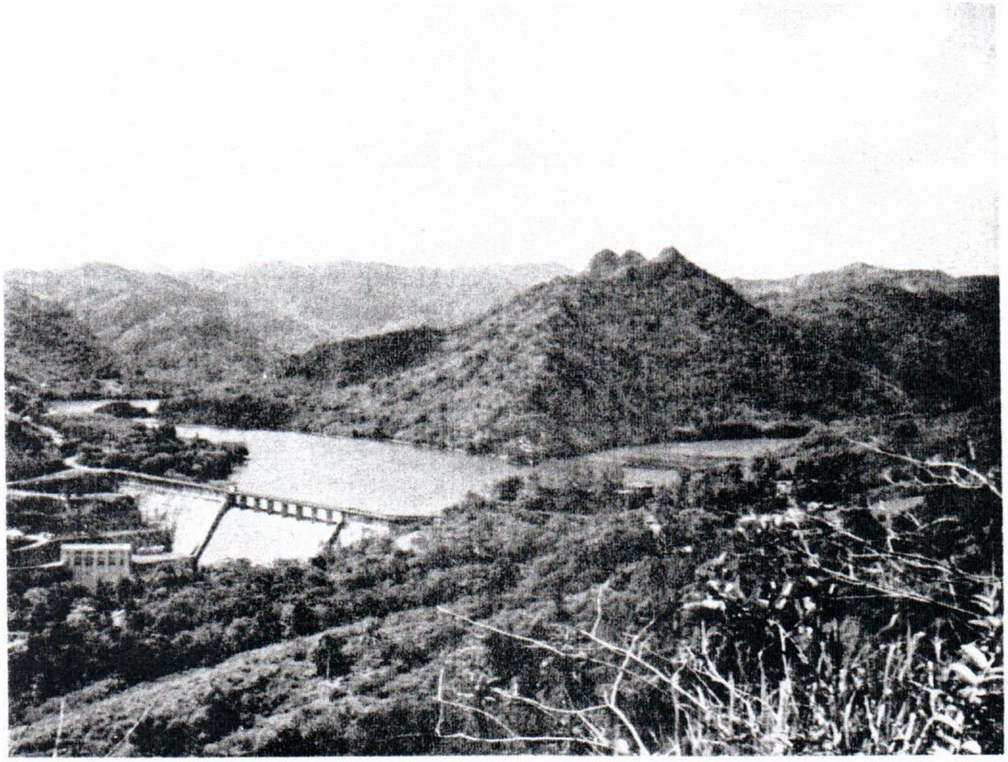
Lake	Purpose	Storage Volume in acre-feet	Munici-pality	Tribu-taries	Outlet Rivers	Year constructed	Owner
1. Adjuntas	Power	465	Adjuntas	Vacas River	Tunnel & Arecibo River	1950	AFF
2. Caonillas	Power	49,000	Utuado	Caonillas, Yauco, and Jayuya Rivers	Caonillas River	1948	AFF
3. Carite	Domestic Water Supply 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 Viví	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



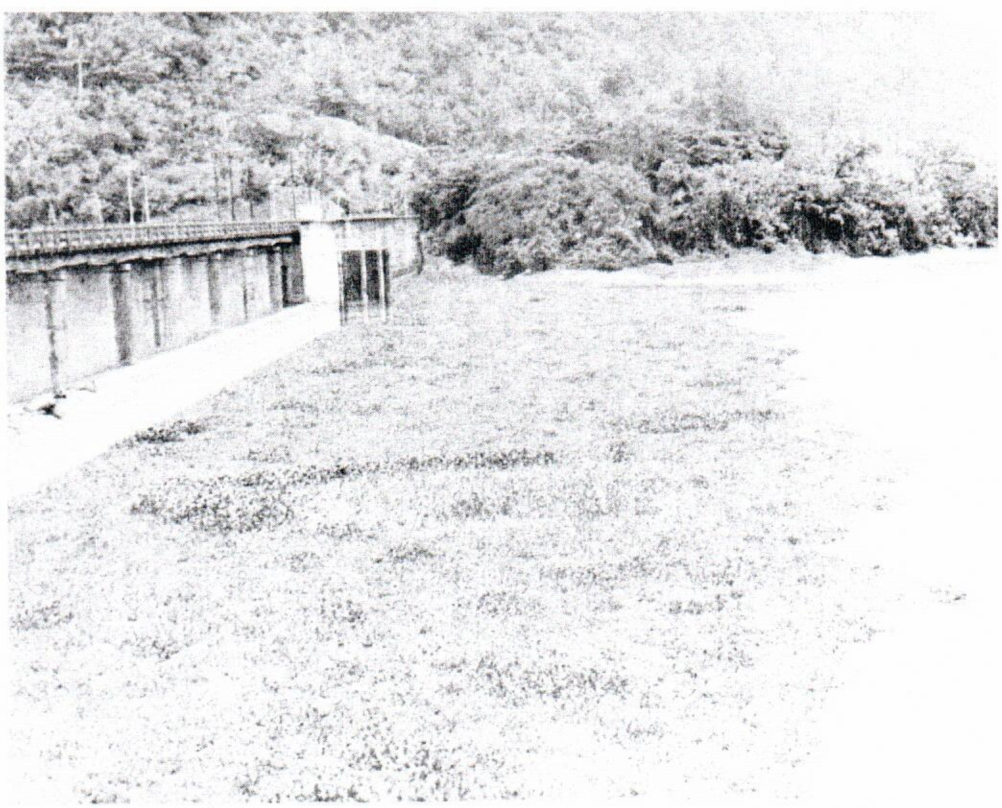
SCHEMATIC DRAWING OF LAJAS VALLEY IRRIGATION AND HYDROELECTRIC POWER SYSTEM

FIGURE 3

1964) and that on hydrography of schistosomiasis (Crooks, 1967). Other reports make general references to richness of the aquatic biota including insects (Garcia, 1938; Klots, 1932; Martorell, 1945; Wolcott, 1948), birds (Biaggi, 1970; Danforth, 1925; Leopold, 1963) and fish (Erdman, 1972; and Ferguson, 1975). Terrestrial plants have been well studied (Odum and Pigeon, 1970; Britten and Wilson, 1930; De Otero et al, 1945; Velez and Van Overbeek, 1950; Little and Wadsworth, 1964), and much is known about aquatic and semi-aquatic plants (Pratt, 1947, 1948; Reyes de Ruiz, 1971). Both terrestrial snails (Aguayo, 1961, 1966; Van der Schalee, 1948) and freshwater snails have received definitive study (Abbott, 1952; Baker, 1945; Ferguson, 1959; Ferguson and Gerhardt, 1956; Ferguson and Richards, 1963; Harry and Hubendich, 1964; Hubendich, 1955; PAHO-WHO, 1968; Reyes de Ruiz, 1971; Richards, 1965; Richards, 1964; Richards and Ferguson, 1962; Watlington, 1955).



HYDROELECTRIC PLANT AT LAKE DOS BOCAS



MASS OF WATER HYACINTH BEHIND DAM AT DOS BOCAS

FIGURE 4

Table 4

RANKING OF HYDROELECTRIC RESERVOIRS IN PUERTO RICO BY POWER PRODUCTION

	Power Production Kilowatts	Present Volume in million cubic meters	Length of Shoreline Kilometers
Yahuecas		1.60	7.1
Guayo	20,000	16.71	22.8
Prieto		0.60	4.0
Toro	Diversion to Prieto	0.12	2.0
Luchetti		14.65	21.2
Dos Bocas	18,000	39.47	
Caonillas	17,600	60.44	
Garzas	12,240	5.80	
Matrullas	8,640	3.58	
Carraizo	2,600	24.67	
Guineo	1,920	2.22	
Rio Blanco			
Loco		0.79	6.8
Jordan	Diversion to Caonillas		
Adjuntas		0.57	
Pellejas		0.19	
Vivi		0.34	

II. IMPACT OF RESERVOIRS ON BILHARZIA SNAILS

In an attempt to assess the role of the major reservoirs in transmission of bilharzia, a complete survey was made of all lakes on the island between July 1975 and June 1976, in cooperation with the Department of Health. A five man crew with a boat inspected the entire shoreline of each lake and identified all live snails. In addition water samples were taken at each tributary and in the main body of the lake near the dam. The samples were analyzed by standard methods (APHA, 1973).

The survey showed that only 5 lakes contained _Biomphalaria glabrata_, while 18 lakes harbored _Marisa cornuarietis_ and 14 lakes contained _Tarebia granifera_ (Table 5). Four other species of aquatic snails were scattered throughout the lakes but in much fewer numbers than the first 3 species mentioned. Seven of the lakes harbored floating water hyacinth and generally large amounts of vegetation, but the other 23 had rather sparse quantities of vegetation.

Although the lakes had fairly high turbidity and color, only 7 of them had significant levels of phosphates, indicative of sewage pollution or eutrophication (Table 6).

A. Previous Snail Surveys

In previous studies only nominal attention was paid to the presence of _B. glabrata_ in reservoirs during 1952-1954 (Harry and Cumbie, 1954; Harry and Aldrich, 1958; Harry et al, 1957; Pimentel and White, 1957, 1959a, 1959b). Cursory searches of Lakes Guajataca, Guineo, Dos Bocas, Patillas, Guayabal and Coamo at a few points failed to locate _B. glabrata_ during 1952-1954. In order to clearly define the presence or absence of the snail in all reservoirs, a comprehensive survey was completed during 1956-58. A two-man team walked accessible shorelines and used a

TABLE 5 MAJOR LAKES OF PUERTO RICO

SNAILS AND VEGETATION, 1976

Lake No.	Name	Bg*	Mc	Tg	Pa	Ph	Ly	Tr	Water Hyacinth	General Vegetation
1	Adjuntas	-				X			-	Sparse
2	Caonillas	-	X						-	Sparse
3	Carite	X	X		X				-	Sparse
4	Carraizo	X	X		X				X	Abundant
5	Cartagena								-	Sparse
6	Cidra	-	X		X				X	Moderate
7	Coamo								X	Abundant
8	Comerio #1	-	X	X		X	X		X	Moderate
9	Comerio #2	-	X	X					X	Moderate
10	Dos Bocas	X	X	X					X	Moderate
11	Garzas	X	X	X		X			-	Sparse
12	Guajataca	-	X	X				X	-	Sparse
13	Guayabal	-	X	X				X	-	
14	Guayo	-	X						-	Sparse
15	Guineo	-	X	X		X		X	-	
16	Jordan	-	X						-	
17	La Plata	-	X	X					X	Moderate
18	Las Curias	-	X	X					-	Sparse
19	Loco	-	X	X					-	
20	Luchetti	-	X	X				X		
21	Matrullas	-				X			-	Sparse
22	Patillas	-	X	X					-	Sparse
23	Pellejas	-							-	
24	Prieto	-	X						-	Sparse
25	Rio Blanco	-							-	
26	Toa Vaca	-	X	X				X	-	Sparse
27	Toro	-								
28	Tortugero	X	X	X						
29	Vivi	-				X				
30	Yahuecas	-								

* Bg= Biomphalaria glabrata

Mc= Marisa cornuarietis

Tg= Tarebia granifera

Pa= Pomacea australis

Ph= Physa sp.

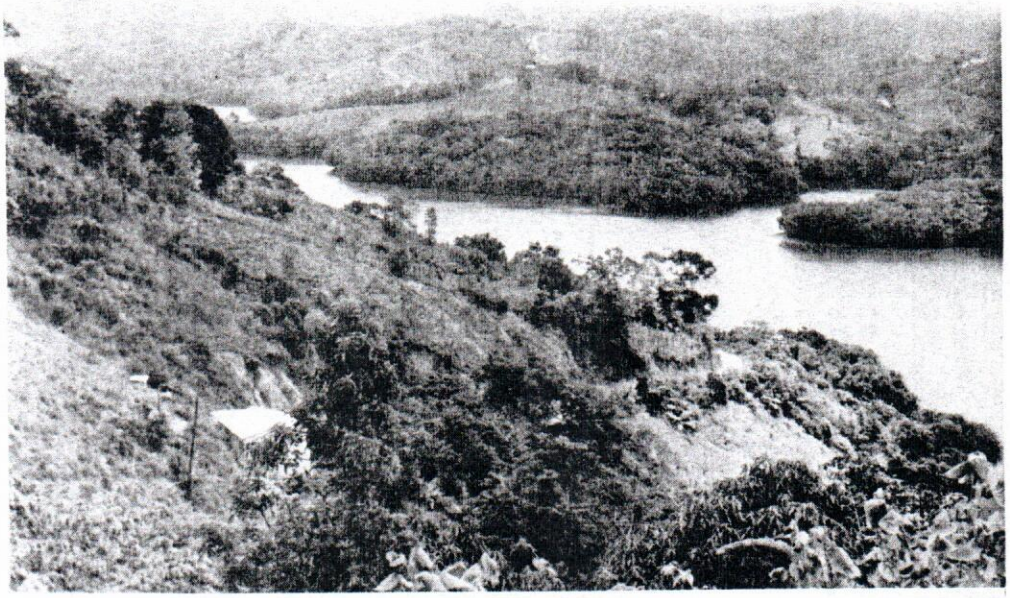
Ly= Lymnaea sp.

Tr= Tropicorbis sp.

TABLE 6. WATER QUALITY IN MAJOR RESERVOIRS OF PUERTO RICO, 1976

	Lake	Number of Samples	Color in Standard Units	Turbidity in Standard Units	Chlorides in Mg/L	Total Phosphates as P in Mg/L	Iron in Mg/L	Nitrite and Nitrate Nitrogen in Mg/L	Hardness as Mg SO_4 in Mg/L
1	Adjuntas	3	6.7±2.1	1.1±0.4	10.7±5.9	0.25±0	0.23±0.15	0.22	144.5±17.3
2	Caonillas	21	8.9±2.0	19.9±2.9	10.8±2.8	0.04±0.04		0.18±0.16	95.7±21.1
3	Carite	5	7.8±2.7	8.0±7.2	7.7±0.5	0.04±0.03	0.78±0.39	0.09±0.05	49.8± 1.2
4	Carraizo	6	21.7±11.7	30.5±58.8	29.3±9.2	0.18±0.10		0.95±0.73	101.1±52.5
5	Cartagena								
6	Cidra	6	8.6±2.0	2.8±2.6	14.1±0.4	0.02±0.02	0.56±0.27	0.17±0.11	76.3± 2.6
7	Coamo								
8	Comerio #1	2	10.0	6.5	22.0	0.27			226.5
9	Comerio #2	2	10.0	10.5	24.1	0.09			81.2
10	Dos Bocas	6	11.3±2.9	6.9±6.7	11.5±3.2	0.08±0.20*		0.54±0.70	127.0±67.7
11	Garzas	16	7.3±2.4	2.2±2.2	4.1±0.7	0.02±0.01	0.31±0.24	0.03±0.02	64.2± 8.5
12	Guajataca	2	6.5	1.4	9.0	0.01			149.5
13	Guayabal	6	11.7±6.1	5.2±5.2	7.8±2.2	0.06±0.02		0.13±0.13	21.4± 4.4
14	Guayo	10	10.0±0	2.7±1.8	4.9±1.8	0.02±0.01	0.17±0.09	0.16±0.14	92.5±18.6
15	Guineo	6	5.0±0	1.6±1.3	2.9±0.5		0.04±0.01	0.03±0.01	
16	Jordan	2	6.0	12	13.6	0.01	0.1	0.02	156.9
17	La Plata	2	9.0	9.2	21.8	0.04			164.3
18	Las Curias	2	9.0	6.8	15.6	0.01			78.5
19	Loco	6	5.3±0.8	5.3±4.7	8.3±3.7	0.04±0.02	0.03±0.01	0.12±0.10	
20	Luchetti	23	5.3±0.8	3.0±2.1	7.7±0.5	0.04±0.05	0.23±0.21	0.30±0.31	156.7±10.4
21	Matrullas	8	5.0±0	2.2±0.7	5.6±2.9		0.03±0	0.04±0.03	
22	Patillas	2	12.5	10.1	11.8	0.02			40.8
23	Pellejas	2	6.5	15.3	9.8	0.01	0.5	0.02	138.3
24	Prieto	1	12	0.4	8.0	0.01	0.4	0.27	203.2
25	Rio Blanco								
26	Toa Vaca	13	6.1±1.7	1.8±1.0	10.1±2.0	0.09±0.08	0.04±0.01	0.04±0.03	30.2±11.0
27	Toro	1	5	10.6	9.9			0.44	138.3
28	Tortuguero								
29	Vivi	3	6.3±0.6	1.9±1.6	10.2±2.4	0.01±0	0.40±0.40	0.08±0.10	127.9±36.2
30	Yahuecas	4	10.5±4.2	75.0±10.8	8.6±2.4	0.04	0.24	1.03±0.45	120.9±14.2

* From 25 Samples



LAKE CARITE IN GUAVATE OF PATILLAS

EMERGENCY SPILLWAY OF LAKE CARITE SHOWING SMALL SWAMP CONTAINING BIOMPHALARIA GLABRATA JULY 1976

FIGURE 5

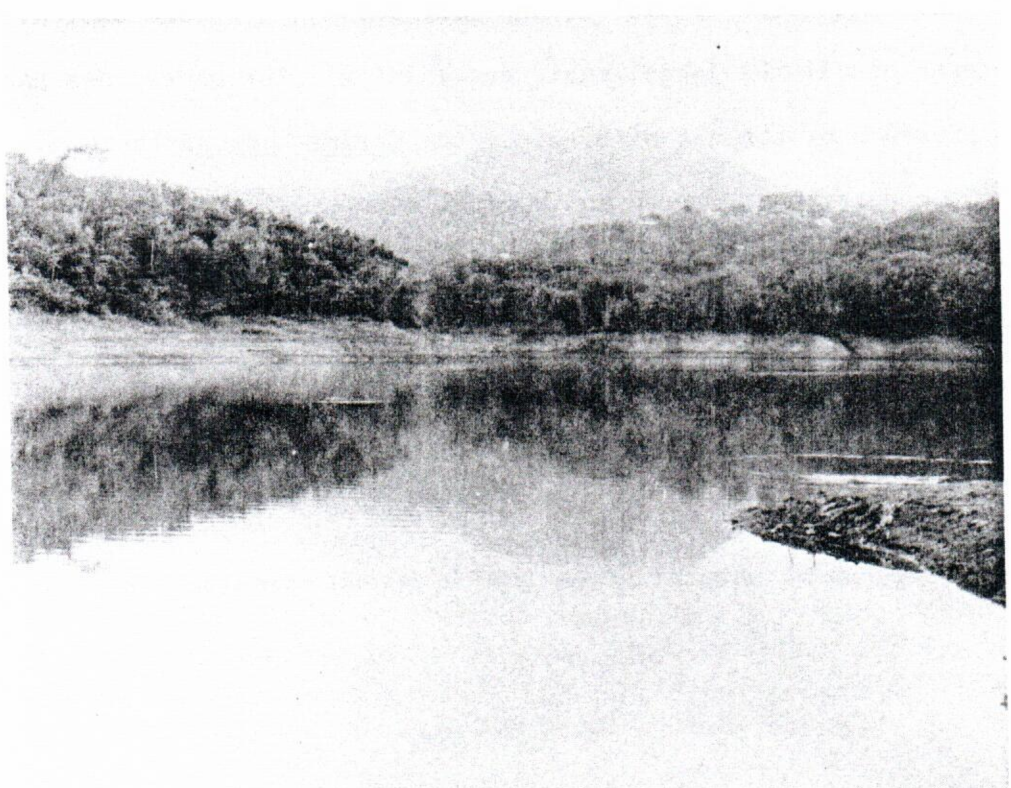
boat to survey the remainder of the shores in all units. From this first island-wide survey it was determined that 17 of the lakes contained populations of B. glabrata (Table 7).

The use of chemical molluscicides for snail control was avoided for these lakes because many of them also serve as drinking water supplies. Thus attempts were made, beginning in 1958 to employ Marisa cornuarietis as a competitor or predator snail and thus reduce the populations of B. glabrata. In addition observations were made on the encroachment of another suspected competitor snail, Tarebia granifera (Ferguson, 1973; Ferguson, 1975). Marisa cornuarietis was hand scattered in batches of 50 or more at several points along the shore of each lake from 1958 to 1961. The concurrent spread of Tarebia granifera was apparently due to natural agents such as birds. Several other species of snails were seen in these reservoirs during this time in much smaller numbers, including Physa cubensis, Helisoma sp., Ferrissia sp., and Ampullaria or Pomacea, an apparent foreign import (Watlington, 1955).

Ten years after the initial island-wide survey, a second similar study was completed on all the lakes, again searching all the shorelines and listing the presence or absence of B. glabrata, Marisa cornuarietis and Tarebia granifera, the three most common and profuse species. Due to the introduction of M. cornuarietis, this snail was established in 15 of the lakes by 1966, while B. glabrata was found in only 8 (Table 7).

Biological control of Biomphalaria glabrata by Marisa cornuarietis is a dynamic process, not an absolute change. Snails are thought to be carried about on the muddy feet of birds and cattle, and the reservoirs are continually becoming reinfested by natural means from upstream colonies. Great losses of

SPILLWAY OF LAKE GARZAS



LAKE GARZAS JUNE 1976

FIGURE 6

Table 7

TWENTY YEAR RECORD OF SNAIL POPULATIONS IN MAJOR LAKES OF PUERTO RICO

1956 - 1976

B= *Biomphalaria glabrata* M= *Marisa cornuarietis* T= *Tarebia granifera*

Lake	Snail Species	1956	1958	1960	1961	1962	1963	1964	1965	1966	1976
1 Adjuntas	B										Absent
	M										Absent
	T										Absent
2 Caonillas	B	Rare			Moderate		Absent			Rare	Absent
	M				Intro		Absent			Rare	Moderate
	T				Intro					Abundant	Moderate
3 Carite	B	Abundant		Rare		Absent			Abundant		Rare
	M		Intro								Moderate
	T								Abundant		Moderate
4 Carraizo	B	Rare			Absent				Rare **		Rare
	M								Rare		Moderate
	T								Abundant		Moderate
5 Cartagena	B	Moderate						Absent		Dry	
	M		Intro					Abundant		Dry	
	T									Dry	
6 Cidra	B	Moderate			Absent			Absent			Absent
	M		Intro					Moderate			Present
	T						Intro	Abundant			Absent
7 Coamo	B	Rare							Absent		
	M										
	T							Intro	Moderate		
8 Comerio #1	B										Absent
	M										Moderate
	T										Moderate
9 Comerio #2	B										Absent
	M										Moderate
	T										Moderate
10 Dos Bocas	B	Rare	Abundant			Rare	Absent				Rare
	M			Intro			Rare			Rare	Moderate
	T			Intro			Abundant			Moderate	Moderate
11 Garzas	B	Rare					Absent				Moderate
	M				Intro		Rare			Moderate	Abundant
	T						Abundant			Rare	Abundant
12 Guajataca	B	Abundant									Absent
	M			Intro							Abundant
	T			Intro							Moderate
13 Guayabal	B	Rare							Absent		Absent
	M										Present
	T							Intro			Present
14 Guayo	B					Abundant		Abundant			Absent
	M					Intro					Abundant
	T										Absent
15 Guineo	B	Rare								Absent	Absent
	M										Present
	T									Intro	Present
16 Jordan	B										Absent
	M										Present
	T										Absent
17 La Plata	B										Absent
	M										Moderate
	T										Abundant
18 Las Curias	B	Rare	Rare			Absent			Absent		Absent
	M			Intro					Rare		Moderate
	T					Intro			Abundant		Moderate
19 Loco	B	Rare					Absent				Absent
	M		Intro				Rare	Moderate			Moderate
	T						Rare				Moderate
20 Luchetti	B	Rare									Absent
	M		Intro		Moderate						Present
	T								Moderate		Present
21 Matrullas	B	Rare								Absent	Absent
	M										Absent
	T									Intro	Rare
22 Patillas	B	Rare	Moderate			Rare				Absent	Absent
	M		Intro							Rare	Moderate
	T		Intro							Abundant	Moderate
23 Pellejas	B										Absent
	M										Absent
	T										Absent
24 Prieto	B							Abundant		Rare	Absent
	M									Intro	Moderate
	T										Absent
25 Rio Blanco	B										Absent
	M										Absent
	T										Absent
26 Toa Vaca	B										Absent
	M										Abundant
	T										Abundant
27 Toro	B									Absent	Absent
	M									Intro	Absent
	T										Absent
28 Tortuguero Lagoon	B	Rare								Absent	Present
	M										Present
	T									Intro	Present
29 Vivi	B										Absent
	M										Absent
	T										Absent
30 Yahuecas	B			Absent					Moderate		Absent
	M			Intro					Abundant		
	T						Intro				

snails occur with constantly shifting water levels, determined by hydroelectric power generation and irrigation usage, as well as drawdowns for urban water supply. However the stranding does not necessarily eliminate all the snails and they soon repopulate the habitat if conditions are favorable. Thus the 20 year record of snail populations, concluding with the final comprehensive survey in 1976, is a summation of the biological interaction of these snail species in response to the dynamic nature of the lake habitats, and the various means of reintroduction of the snails. By 1976 the balance had shifted in favor of M. cornuarietis which was found in 21 lakes, often in very large numbers (Table 7). At the same time B. glabrata was present only in 5 lakes and in 3 of these, less than 100 snails were found after several days of searching by a 5 man crew (Tables 7 and 8).

In studies on small ponds, M. cornuarietis has often eliminated certain types of vegetation due to the large number of snails which have developed. However in these large lakes, although Marisa cornuarietis consumes some of of the types of aquatic vegetation which shelter and feed Biomphalaria glabrata, in general it has had no pronounced effect on weeds in the lakes during the 20 years observation. As in previous studies on farm ponds, the instances in which Biomphalaria glabrata and Marisa cornuarietis co-exist over a long period of time are those waterbodies which contain large quantities of vegetation. This is confirmed by the observations from the lakes in 1976 (Table 5 and 6). The lakes harboring both species either had large masses of floating water hyacinth or high levels of nutrients which indicate extensive algae growths.

B. Fecal Contamination of Lakes

It should be emphasized that snails infected with the bilharzia parasite have been collected from only one lake, at two different sites on Lake Carraizo

TABLE 8 ANALYSIS OF PRESENCE OF <u>BIOMPHALARIA GLABRATA</u> AND <u>MARISA CORNUARIETIS</u> IN MAJOR RESERVOIRS OF PUERTO RICO, 1956-1976.

RESERVOIR	*Biomphalaria glabrata* 1956	1957-61	1962-66	1976	*Marisa cornuarietis* 1956	1957-61	1962-66	1976	Succession
1 Adjuntas	*-	ND	ND	-	-	ND	ND	-	
2 Caonillas	+	+	+	-	-	+	+	+	Yes
3 Carite	+	+	+	+	-	+	ND	+	No
4 Carraizo	+	-	+	+	-	ND	+	+	No
5 Cartagena	+	ND	-	ND	-	+	+	ND	
6 Cidra	+	-	-	-	-	+	+	+	Yes
7 Coamo	+	ND	-	ND	-	-	-	ND	
8 Comerio #1	ND	ND	ND	-	-	ND	ND	+	
9 Comerio #2	ND	ND	ND	-	-	ND	ND	+	
10 Dos Bocas	+	+	+	+	-	+	+	+	No
11 Garzas	+	ND	-	+	-	+	+	+	No
12 Guajataca	+	ND	-	-	-	+	+	+	Yes
13 Guayabal	+	ND	-	-	-	ND	ND	+	Yes
14 Guayo	ND	ND	+	-	-	ND	+	+	Yes
15 Guineo	+	ND	-	-	-	ND	ND	+	Yes
16 Jordan	ND	ND	ND	-	-	ND	ND	+	
17 La Plata	ND	ND	ND	-	ND	ND	ND	+	
18 Las Curias	+	+	-	-	-	+	+	+	Yes
19 Loco	+	ND	-	-	-	+	+	+	Yes
20 Luchetti	+	ND	ND	-	-	+	+	+	Yes
21 Matrullas	+	ND	-	-	-	ND	ND	-	
22 Patillas	+	+	+	-	-	+	+	+	Yes
23 Pellejas	ND	ND	ND	-	-	ND	ND	-	
24 Prieto	ND	ND	+	-	-	ND	+	+	Yes
25 Rio Blanco	ND	ND	ND	-	ND	ND	ND	-	
26 Toa Vaca	ND	ND	ND	-	ND	ND	ND	+	
27 Toro	ND	ND	ND	-	ND	ND	+	-	
28 Tortugero	+	ND	-	+	-	ND	-	+	No
29 Vivi	ND	ND	ND	-	ND	ND	ND	-	
30 Yahuecas	ND	-	+	-	-	+	+	+	Yes
Present/ Surveyed	17/18	5/8	8/19	5/28	0/25	12/13	15/17	21/28	12/17

*

- Snails absent

+ Snails present

ND No data

near Bairoa and near San Antonio. At present this lake is probably the greatest potential hazard in terms of bilharzia transmission since it receives sewage discharges from the Caguas Treatment Plant and from several other communities in the watershed. In addition there are potential problems from the Villalba sewage discharge into Lake Guayabal, the Utuado sewage discharge into Lake Dos Bocas, sewage from Comerio which enters the two Comerio reservoirs and sewage from the Guavate prison colony which enters Lake Carite. There have also been many infected snails collected in the Jayuya river below the town, and there is a possibility that these snails could be carried into Lake Caonillas. Thus the absence of the host snail from most of these reservoirs is a good indication that the lakes could eventually be developed for recreation, but careful monitoring will be required to make sure that the small and sporadic populations of *B. glabrata* which appear in the lakes are not carrying the bilharzia infection.

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APPENDIX

Figures 7 - 31. Maps and photos of lakes in alphabetical order.

Tables A1 - A30. Data Record of water quality samples from lakes in alphabetical order 1975 - 1976.

SPANISH TERMINOLOGY

The maps contain several common spanish words which are translated below:

Lago = Lake

Rio = River

Quebrada = Creek

Afluente = Tributary

Represa - Presa = Dam

N, E, O, S = North, East, West, South

Camino = Road

Ruta = Route

Carretera = Highway

Sifón = Overflow Spillway

Entrada = Entrance

Vertedero = Spillway

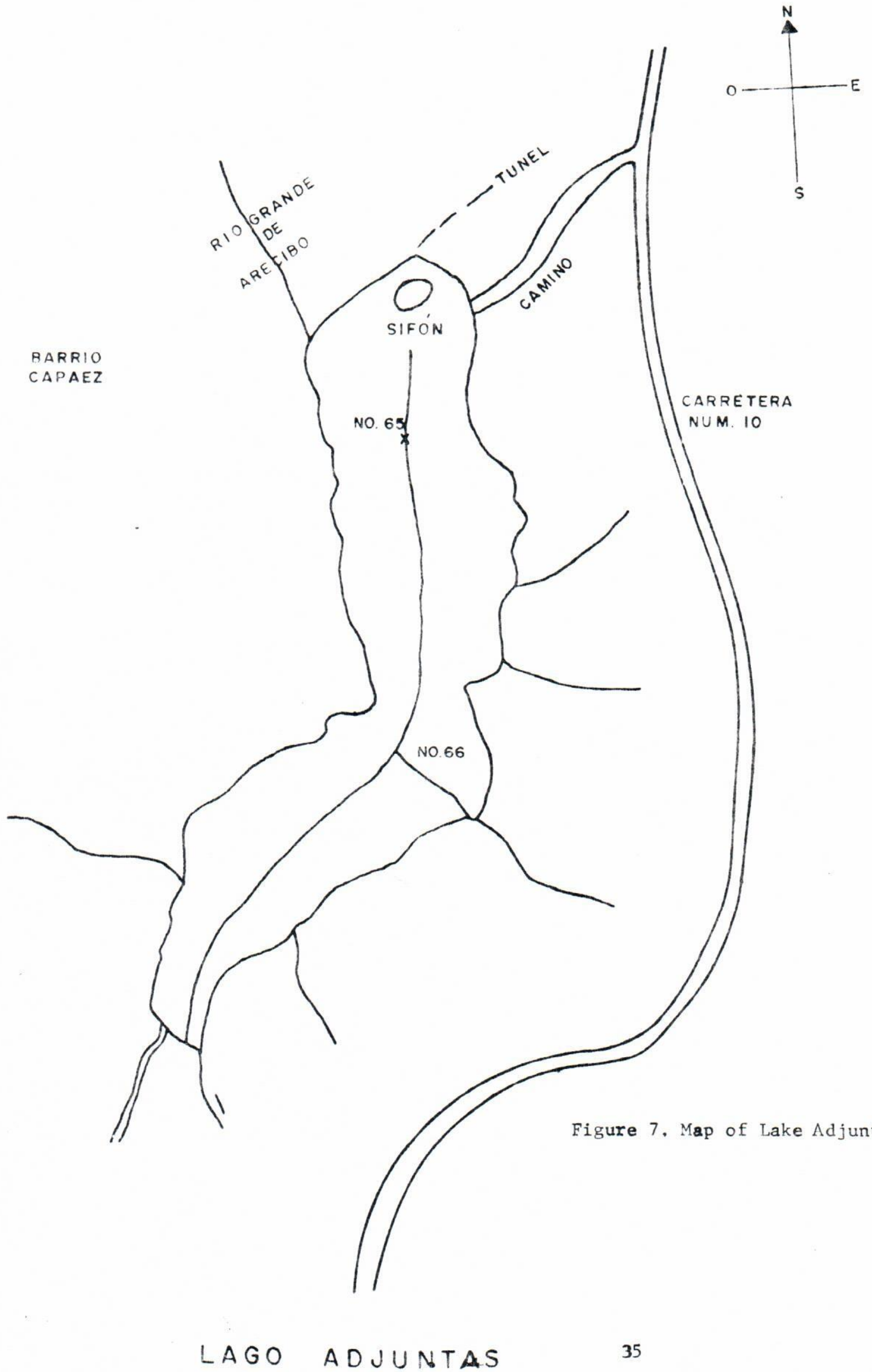


Figure 7. Map of Lake Adjuntas

TABLE A1 . WATER QUALITY SUMMARY FOR LAKE ADJUNTAS , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1. Adjuntas River	1/29/76	-	151	10	1.5	17.5	0.25	0.4	7.0	0.22	139.4
2. Creek on East Side	1/30/76	-	155	5	0.6	7.3	0.25	0.2	7.2	0.21	163.9
3. Creek on East Side	1/30/76	-	156	5	1.1	7.3	0.25	0.1	7.1	-	130.3
TOTAL				20	3.2	32.1	0.75	0.7	21.3	0.43	433.6
Mean of 3 Samples				6.7	1.1	10.7	0.25	0.23	7.1	0.22	144.5
Standard Deviation				±2.1	±0.4	±5.9	±0	±0.15			±17.3

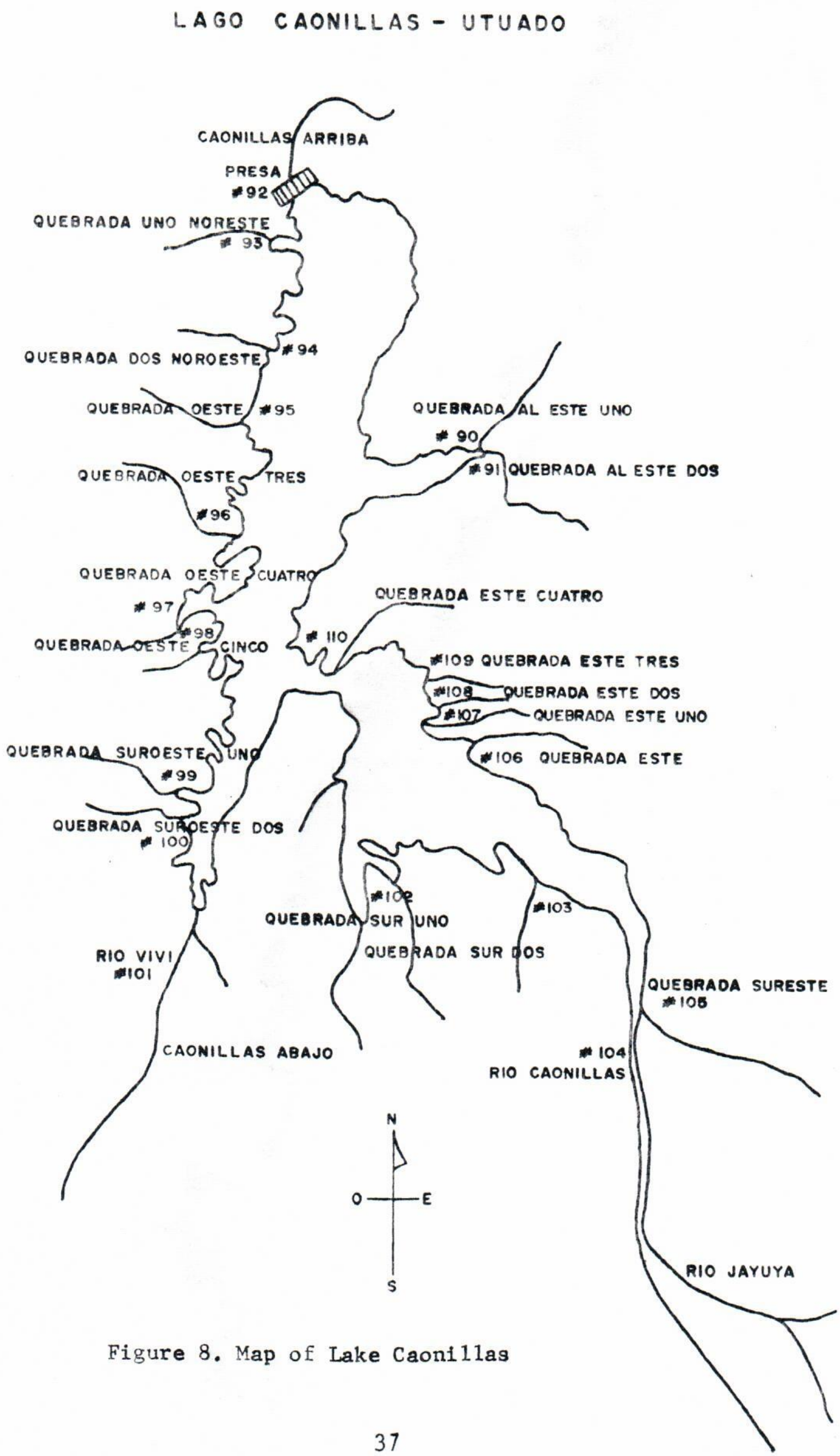


Figure 8. Map of Lake Caonillas

TABLE A2 . WATER QUALITY SUMMARY FOR LAKE CAONILLAS , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1. Creek on East Side	2/26/76	90	208	8	4.5	10.8			7.2	0.52	95.8
2. Creek on East Side	2/26/76	91	209	8	3.6	10.6			7.3	0.45	95.8
3. Reservoir	3/ 8/76	92	210	5	2.1	10.7			7.0	0.07	95.8
4. Creek on NE Side	3/ 9/76	93	211	12	7.6	10.4			6.8	0.11	106.4
5. Creek #2 on NE Side	3/ 9/76	94	212	7	3.0	10.0			6.9	0.11	93.1
6. Creek on West Side	3/ 9/76	95	213	10	6.4	9.5			7.4	0.04	90.4
7. Creek #3 on West Side	3/17/76	96	214	10	14.0	13.5			7.1	0.05	156.9
8. Creek #4 on West Side	3/17/76	97	215	10	7.5	11.1			7.1	0.17	106.4
9. Creek #5 on West Side	3/17/76	98	216	10	3.6	10.3			7.0	0.13	101.1
10. Creek #1 on SW Side	(no date)	99	217		1.3	9.3	0.115		6.9		119.7
11. Creek #2 on SW Side	(" ")	100	218		1.4	10.3	0.120		6.6		82.5
12. Vivi River Mouth	(" ")	101	219		25.5	22.0	0.083		7.0		122.4
13. Creek on South Side	4/26/76	102	220		6.8	9.3	* (.02		6.9		77.1
14. Creek on South Side	"	103	221		8.8	9.3	.048		6.7		103.7
15. Creek on South Side	"	104	222		1.7	9.8	.022		6.9		90.4
16. Creek on South Side	"	105	223		25.0	11.3	.034		6.7		101.1
17. Creek on East Side	5/ 4/76	106	224		11.0	8.3	(.02		6.9		47.9
18. Creek on East Side	"	107	225			9.8	(.02		7.4		93.1
19. Creek on East Side	"	108	226		9.2	8.8	(.02		8.6		77.1
20. Creek on East Side	"	109	227		8.8	8.8	(.02		8.8		79.8
21. Creek on East Side	5/ 5/76	110	228		20.5	12.7	(.02				74.5
Total				80	397.3	223.6	0.482		143.2	1.65	2011.0
Mean of 21 Samples				8.9	19.9	10.8	0.04		7.2	0.18	95.8
Standard Deviation				±2.0	+2.9	+ 2.8	+0.04			±0.16	±21.1

* Less than

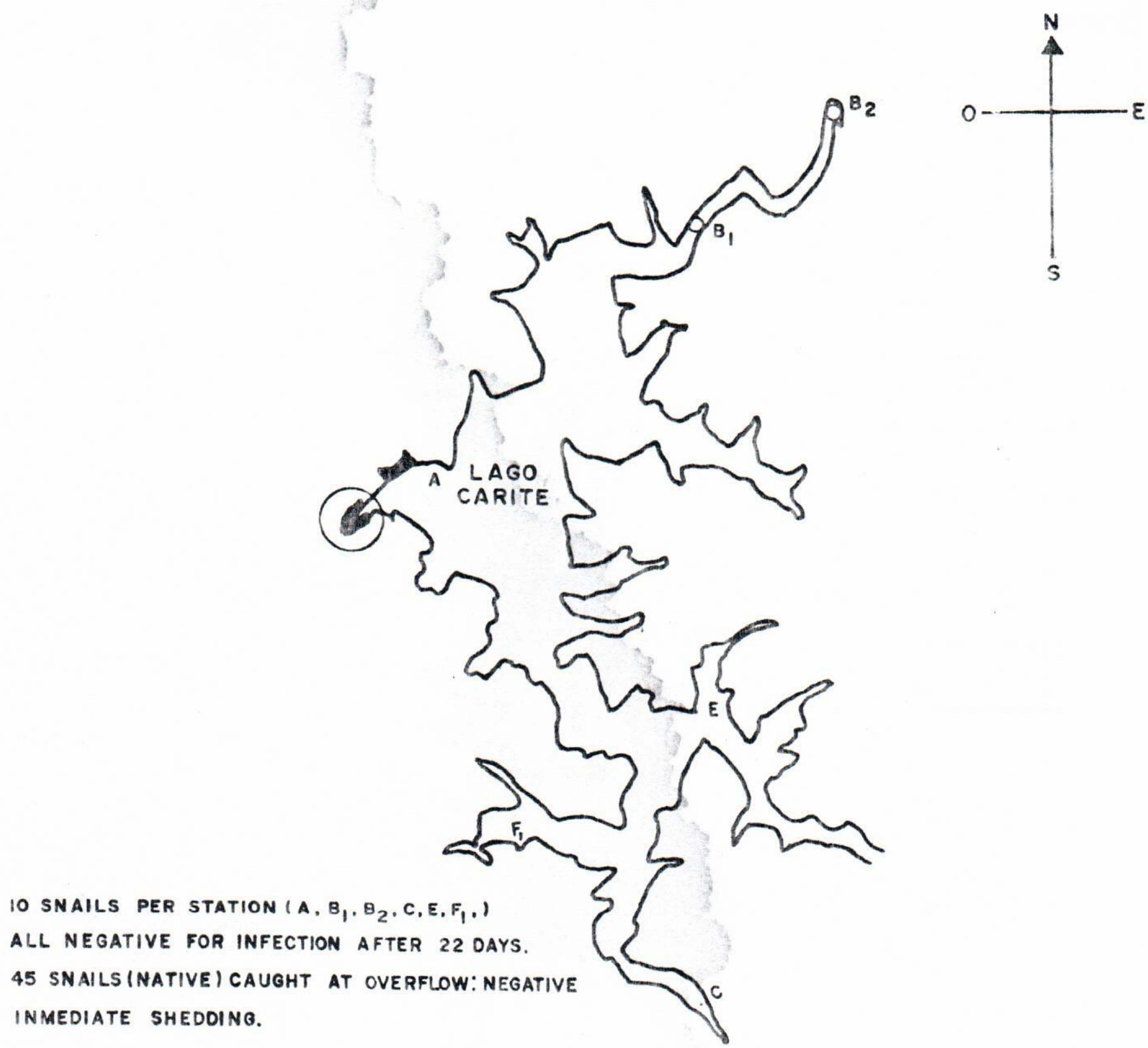
TOTAL COLIFORMS PER 100 ML WATER

STATION	D 16	E 17	C 18
A	362	420	180
B	391	250	280
B_2	—	580	70
E	458	140	160
X	—	100	—
C	210	540	50
F	301	310	180
F_2	—	—	120
Z	—	—	320

CARITE RESERVOIR

TOTAL COLIFORM STUDY DECEMBER 1975

Figure 9



CARITE RESERVOIR

SENTINEL SNAIL STUDY DECEMBER 1975

Figure 10

TABLE A3 . WATER QUALITY SUMMARY FOR LAKE CARITE , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1. Boat Landing	1975	X	1	10	22.0	8.6	0.09	-	-	0.03	-
2. La Plata River Entrance	12/15/75	-	137	4	2.8	7.7	0.025	0.4	6.6	0.10	50.0
3. Q-1	12/15/75	-	138	10	4.8	7.2	0.025	1.0	6.6	0.17	47.9
4. Q-4 Station F	12/15/75	-	139	5	7.8	7.6	0.03	1.2	7.0	0.05	50.0
5. Q-3 Station E	12/16/75	-	140	10	2.8	7.5	0.02	0.5	6.5	0.08	51.1
Total				39	40.2	38.6	0.18	3.1	26.7	0.43	199.0
Mean of 5 Stations				7.8	8.0	7.7	0.04	0.8	6.7	0.09	49.8
Standard Deviation				±2.7	±7.2	±0.5	±0.03	±0.3		±0.05	±1.2

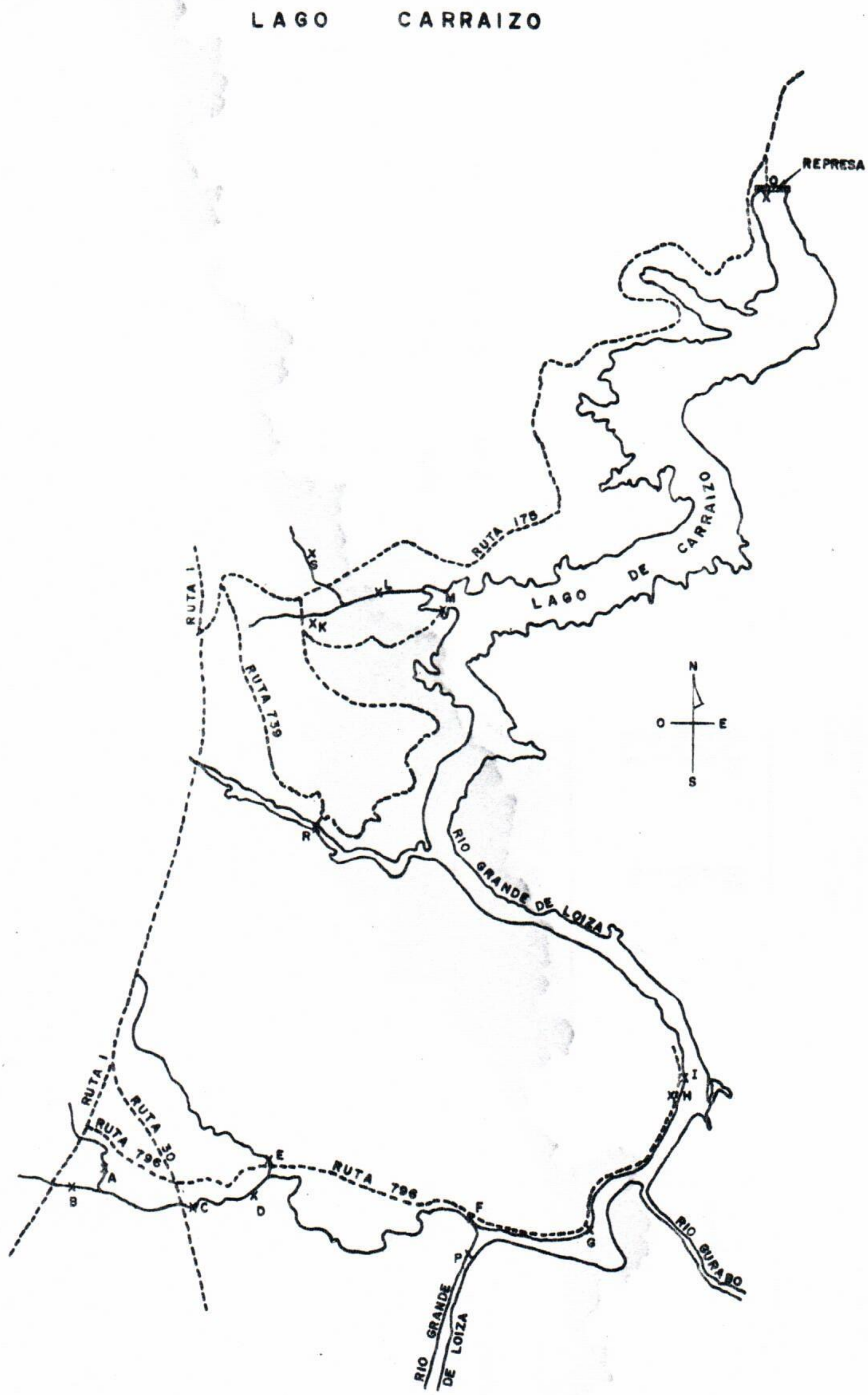


Figure 11. Map of Lake Carraizo

TABLE A4 . WATER QUALITY SUMMARY FOR LAKE CARRAIZO , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/l	Total Phosphates in mg/l as P	Iron in m/l	pH	Nitrates and nitrites in mg/l as N	EDTA hardness in mg/l as $MgSO_4$
1. Bairoa River Station A	6/9/76	157	276	15	1.0	43.8	0.20		7.2	0.34	36.9
2. Bairoa River Station B	"	158	277	15	0.0	37.8	0.20		6.9	1.25	204.5
3. Loiza River at Quarry-P	"	162	281	20	150.0	25.0	0.30		6.5	1.16	80.5
4. Station F	"	163	282	45	12.6	21.4	0.25		6.8	2.08	70.2
5. Near Dam Station O	"	168	287	20	11.0	24.6	0.05		7.4	0.88	118.4
6. Near Trailer Camp-Station M	"	169	288	15	8.2	23.4	0.08		6.6	0.01	95.9
Total				130	182.8	176.0	1.08		41.4	5.72	606.4
Mean of 6 Samples				21.7	30.5	29.3	0.18		6.9	0.95	101.1
Standard Deviation				±11.7	±58.8	±9.2	±0.10			±0.73	±52.5

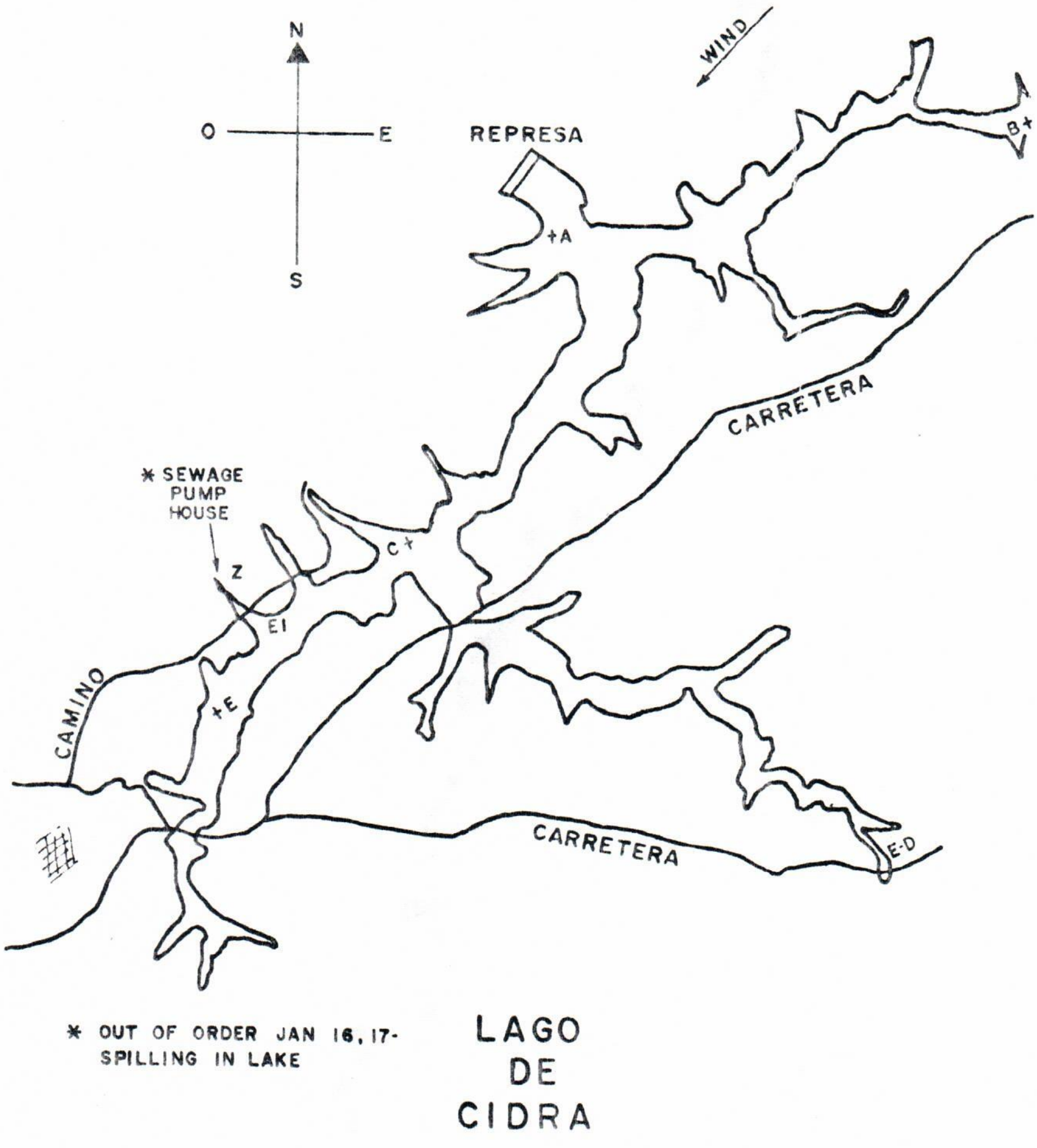


Figure 12. Map of Lake Cidra

TABLE A6 . WATER QUALITY SUMMARY FOR LAKE CIDRA , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1.		C	3	10	8	13.5	0.05	-	-	0.03	-
2. Station A	1/17/76	-	157	10	0.6	14.2	0.01	0.4	7.2	0.39	74.5
3. Station B	1/17/76	-	158	5	0.3	14.1	0.01	0.6	7.5	0.19	72.9
4. Station C	1/17/76	-	159	10	3.5	14.2	* (0.02	0.3	7.1	0.15	76.6
5. Station D	1/17/76	-	160	8	3.2	14.7	(0.02	1.0	7.6	0.11	78.7
6. Station E	1/17/76	-	161	-	1.0	13.7	0.05	0.5	7.1	0.14	78.7
Total				43	16.6	84.4	0.16	2.8	36.5	1.01	381.4
Mean of 6 Samples				8.6	2.8	14.1	0.02	0.56	7.3	0.17	76.3
Standard Deviation				±2.0	±2.6	±0.4	±0.02	±0.27		±0.11	±2.6

* Less Than

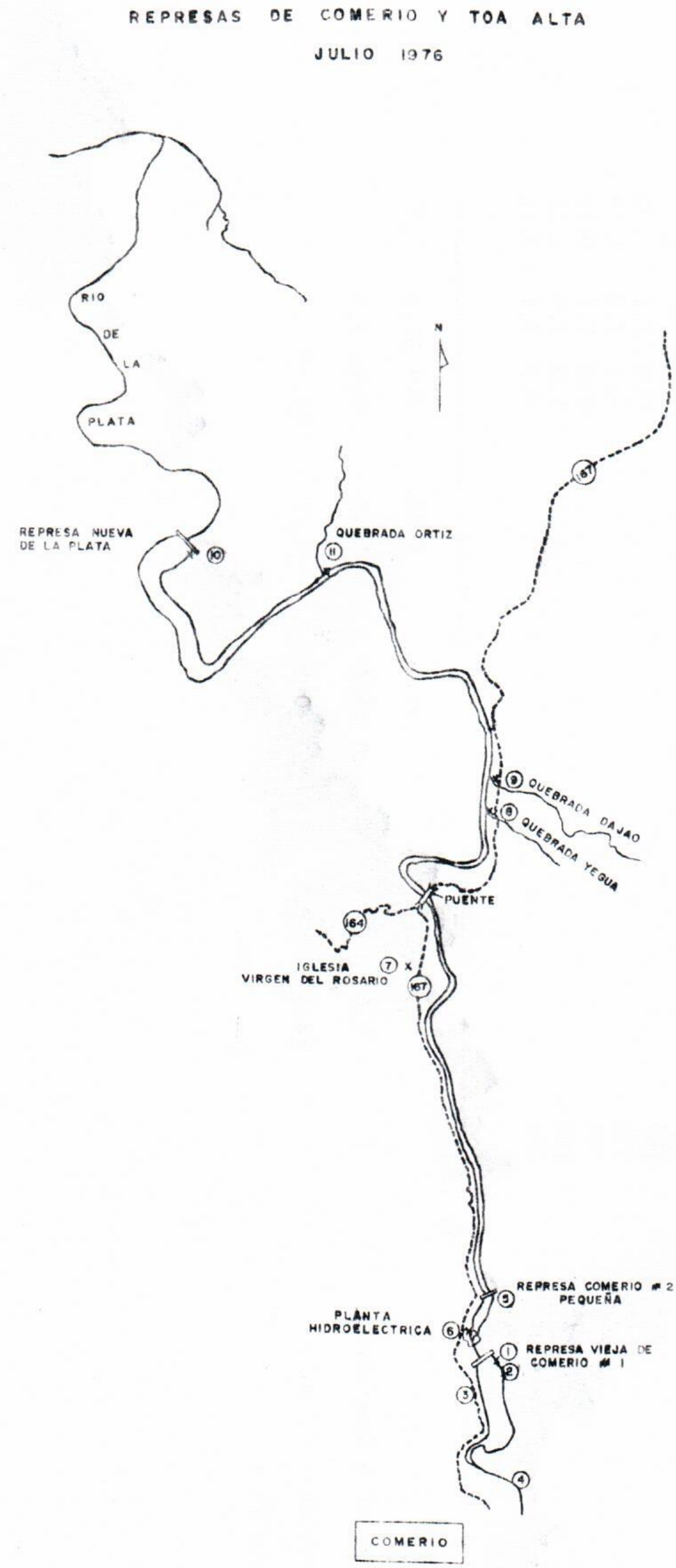
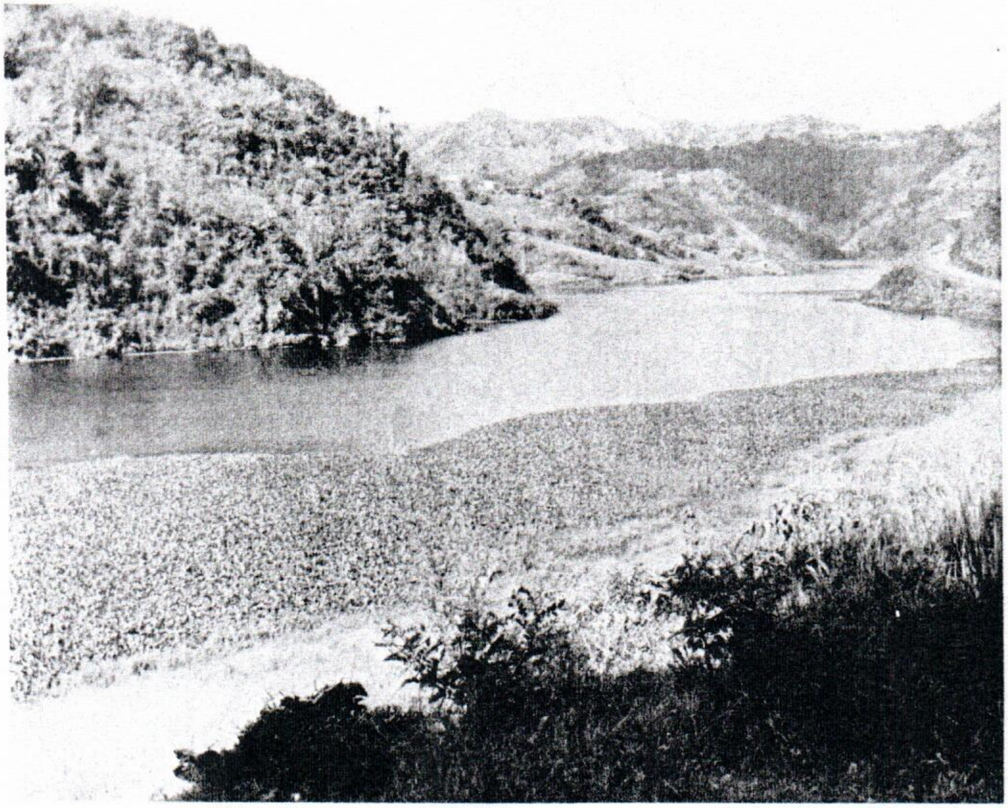


Figure 13. Map of Comerio Reservoirs #1 and #2, and La Plata Lake



WATER HYACINTH ON EASTERN SHORE OF LA PLATA LAKE

SMALL COMERIO RESERVOIR NO. 2

FIGURE 13 A

LAGO DOS BOCAS - ARECIBO

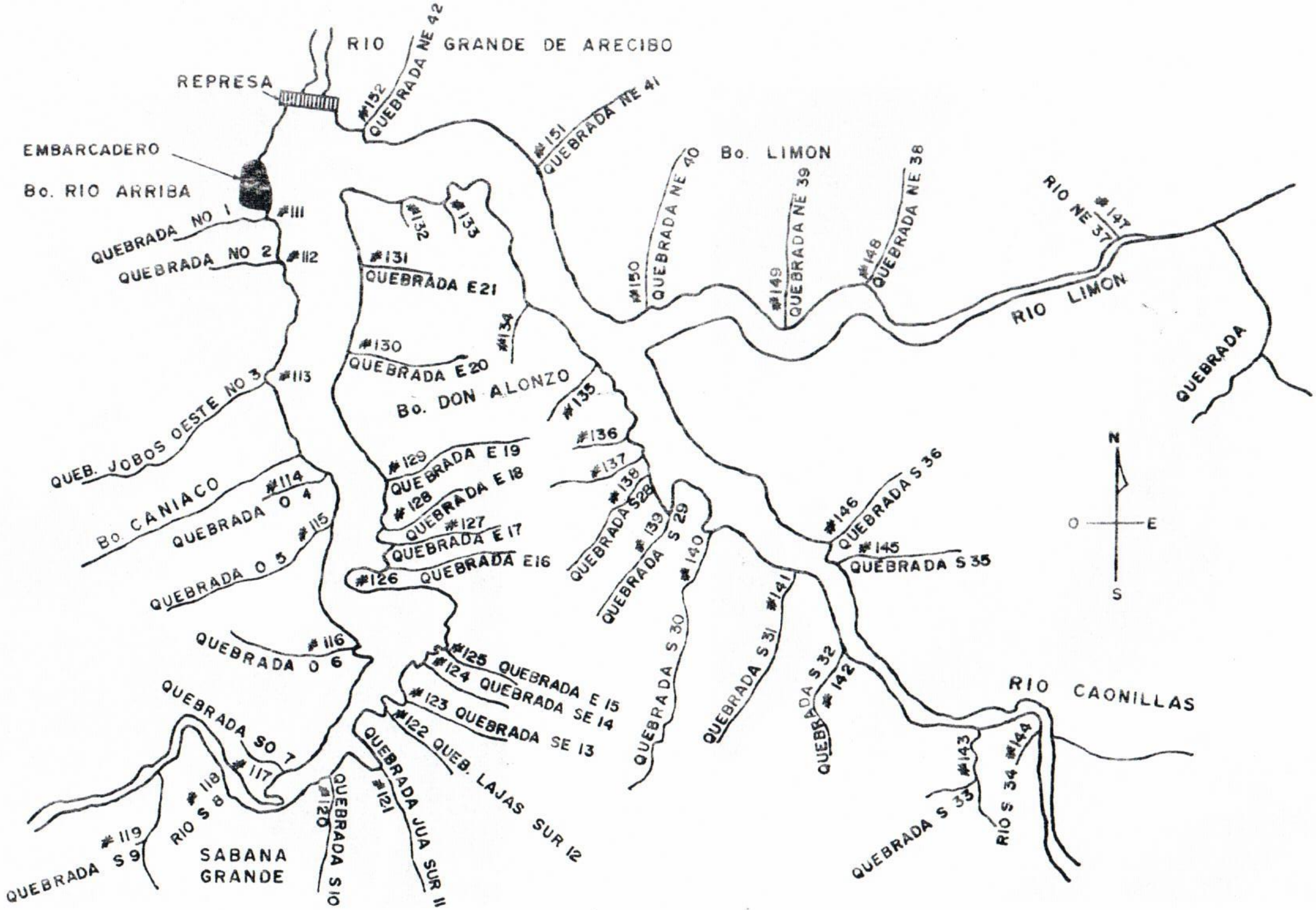


Figure 14. Map of Lake Dos Bocas

TABLE A10. WATER QUALITY SUMMARY FOR LAKE DOS BOCAS , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1.Creek #1 On East Side	5/10/76	111	229	10	1.66	11.7	(0.02		6.5	1.65	87.0
2.Creek #3-Jobos West	"	113	231	15	12.5	16.9	0.10		6.8	0.10	192.8
3.Creek #5 West in Barrio Caniaco	5/12/76	115	233	15	3.5	9.6	*(0.02		7.3	0.05	154.9
4.Creek #7 West	--	117	235	8	2.8	13.2	(0.02		7.1	0.25	208.7
5.Creek #8 South in Barrio Caniaco	5/17/76	119	237	10	18.0	9.0	(0.02		6.4	0.03	45.9
6.Creek #10 South in Barrio Caniaco	"	121	239	10	2.8	8.6	0.025		6.5	1.18	72.5
7.Creek #12 South in Barrio Caniaco	5/19/76	123	241				0.105				
8.Creek #14 South in Barrio Caniaco	"	125	243				0.088				
9.Creek #16 South in Barrio Caniaco	"	127	245				0.042				
10.Creek #18 East in Bo. Don Alonso	5/20/76	129	247				(.02				
11.Creek #20 East in Bo. Don Alonso	"	131	249				(.02				
12.East of Creek in Bo. Don Alonso	5/24/76	133	251				(.02				
13.East of Creek in Bo. Don Alonso	5/24/76	135	253				(.02				
14.East of Creek in Bo. Don Alonso	5/25/76	137	255				(.02				
15.East of Creek in Bo. Don Alonso	5/25/76	139	257				(.02				
16.East of Creek in Bo. Don Alonso	5/26/76	141	259				(.02				
17.East of Creek in Bo. Don Alonso	"	142	260				.025				
18.East of Creek in Bo. Don Alonso	"	143	261				(.02				
19.Caonillas River AFF Plant	"	144	262				.03				

*Less than

TABLE A10. WATER QUALITY SUMMARY FOR LAKE DOS BOCAS, PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
20. Creek on East Side, Bo. Don Alonso	5/27/76	145	263				.05				
21. Creek on East Side	"	146	264				.103				
22. Creek North in Bo. Limon	"	147	265				* (.02				
23. Creek North in Bo. Limon	6/2/76	148	266				1.032				
24. Creek North in Bo. Limon	"	149	267				(.02				
25. Creek North in Bo. Limon	"	150	268				0.20				
Total				68	41.26	69.0	1.935		40.6	3.26	761.8
Mean of 25 Samples				11.3	6.9	11.5	0.08		6.8	0.54	127.0
Standard Deviation				±2.9	±6.7	±3.2	±0.20			±0.70	±67.7

* Less Than

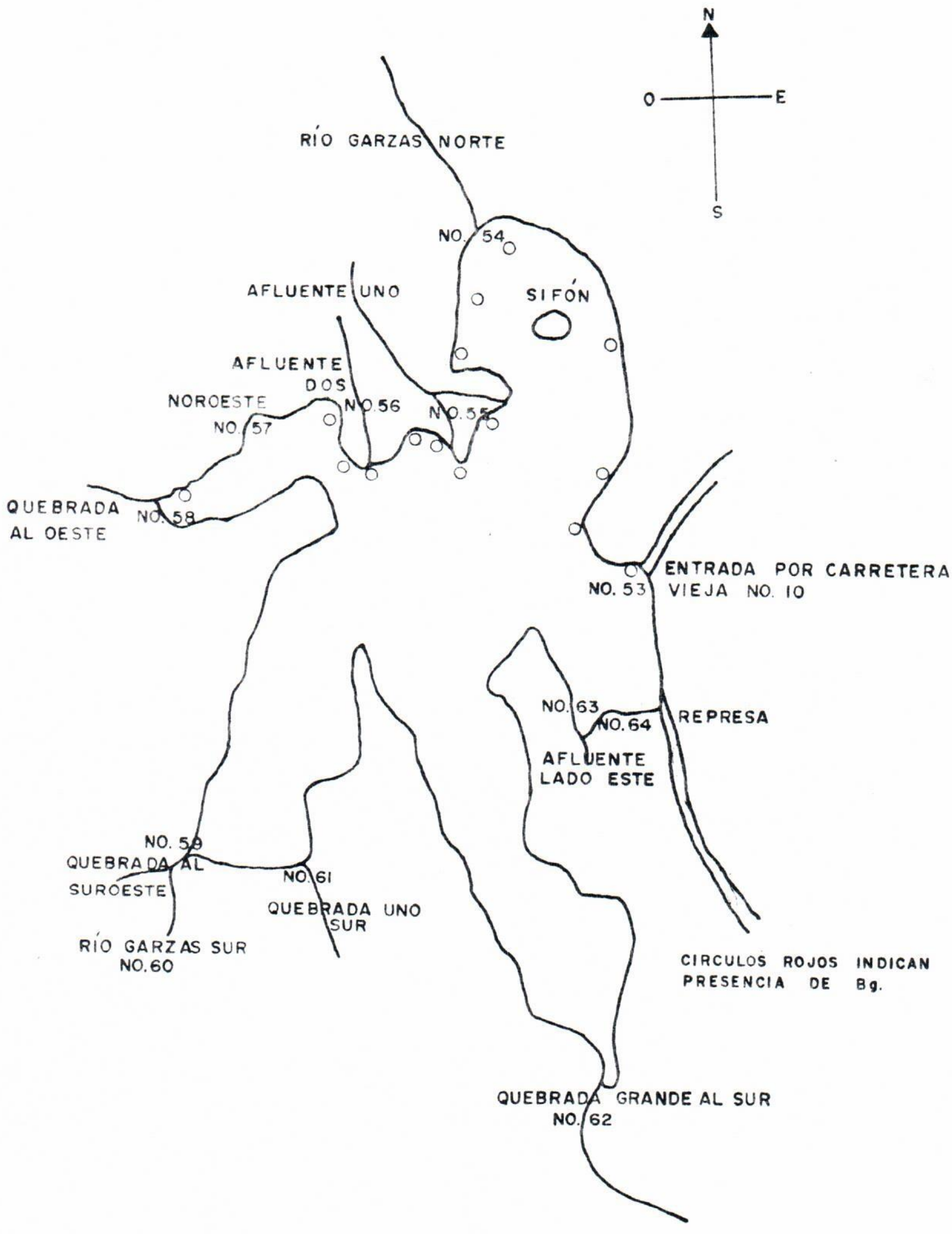


Figure 15. Map of Garzas Lake

REPRESA GARZAS DE ADJUNTAS, P. R.

TABLE A11. WATER QUALITY SUMMARY FOR LAKE GARZAS, PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1. Garzas River	12/3/75	125	-	6	0.6	3.7	0.03	0.10	7.2	0.02	63.8
2. Garzas River	"	126	-	8	0.3	3.8	* <0.02	0.15	7.3	0.04	63.8
3. North Side By Road	"	127	-	10	6.6	4.6	<0.02	0.80	7.3	0.04	61.2
4. North Side By Road	"	128	-	5	6.7	3.7	<0.02	1.00	7.4	0.02	59.6
5. North Creek	12/4/75	129	-	6	0.3	3.7	<0.02	0.15	7.5	0.02	57.5
6. North Creek	"	130	-	4	0.4	3.7	<0.02	0.15	7.6	0.02	58.5
7. Creek Near Garzas River	"	131	-	5	1.8	6.7	<0.02	0.40	7.3	0.02	59.6
8. Creek Near Garzas River	"	132	-	12	4.4	3.9	<0.02	0.40	6.8	-	74.5
9. Creek on West Side	12/5/75	133	-	10	4.3	3.7	0.02	0.3	6.8	0.04	58.5
10. Creek on NW Side	"	135	-	10	4.4	3.7	0.02	0.3	7.2	0.03	55.9
11. Creek on South Side	1/26/76	141	-	8	1.9	4.2	0.02	0.2	6.9	0.02	69.2
12. Creek on South Side	"	143	-	10	0.5	4.0	<0.02	0.2	7.4	0.11	70.2
13. Creek on West Side	1/27/76	145	-	8	1.2	3.9	0.02	0.4	6.9	0.06	63.8
14. Creek on West Side	"	146	-	5	0.8	4.4	0.02	0.2	7.0	0.03	55.9
15. Creek #2 on East Side	1/28/76	148	-	5	0.4	4.2	0.02	0.1	7.1	<0.02	88.8
16. Creek #1 on East Side	"	149	-	5	0.2	4.2	0.02	0.4	7.2	0.04	66.5
Total				117	34.8	66.1	0.33	5.25	114.9	0.53	1027.3
Mean of 16 Stations				7.3	2.2	4.1	0.02	0.31	7.2	0.03	64.2
Standard Deviation				±2.4	±2.2	±0.7	±0.01	±0.24		±0.02	8.5

* Less Than

LAGO GUAJATACA

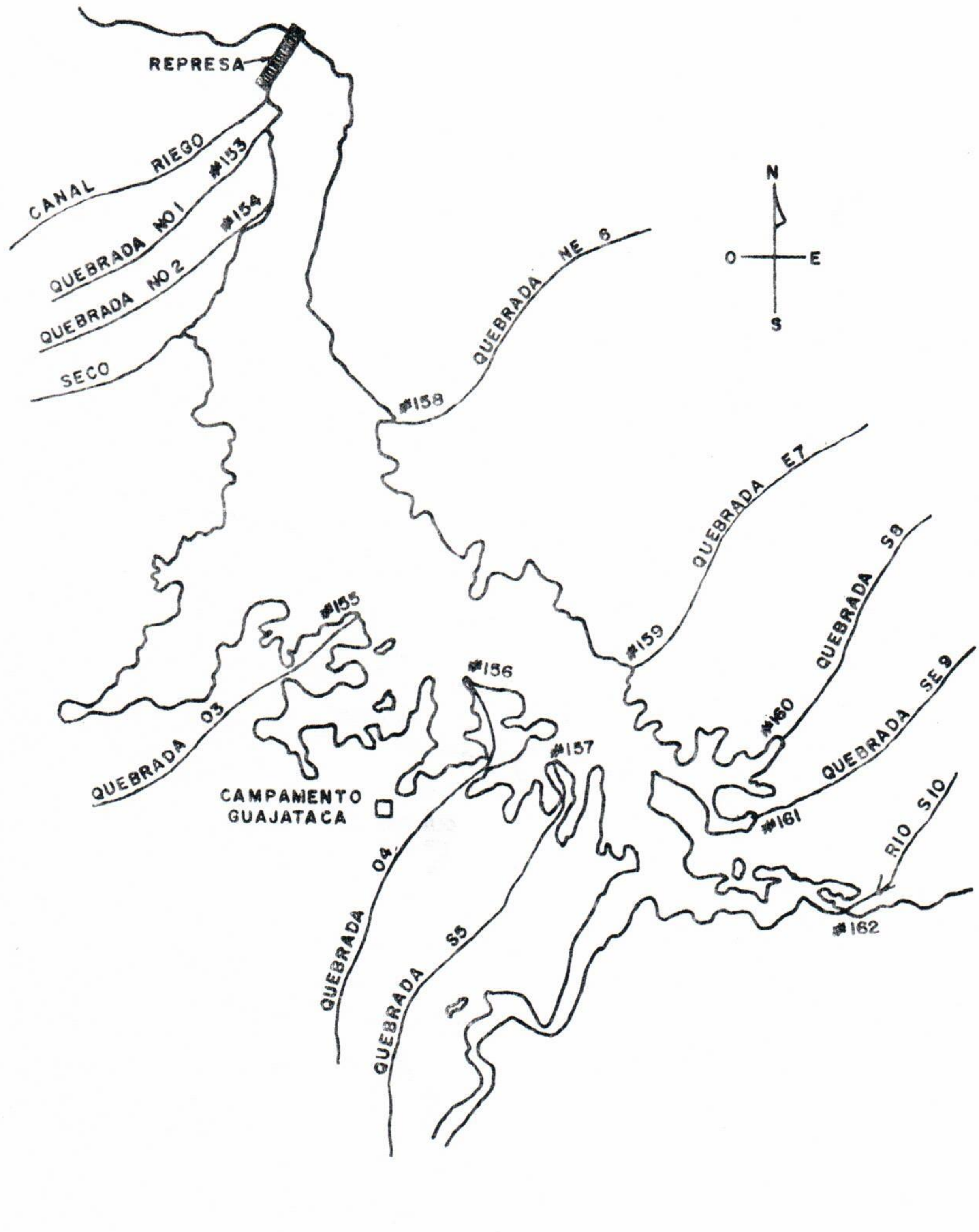


Figure 16. Map of Lake Guajataca

LAGO – GUAYABAL

Figure 17. Map of Lake Cuayabal

TABLE A13. WATER QUALITY SUMMARY FOR LAKE GUAYABAL, PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and Nitrates in mg/1 as N	EDTA hardness in mg/1 as N	Hardness in mg Ca/1
1. East Side, Juana Diaz		G1	4	20	15	4.5	0.07			0.38	-	7.0
2. East Side		G2	5	15	7	8.0	0.04			0.15	-	10.
3. Juana Diaz		G3	6	15	2	11.0	0.09			0.07	-	8.0
4. Villalba, NW Side		G4	7	5	2	7.5	0.06			0.02	-	6.0
5. Luis Rodriguez Creek, West Side		G5	8	10	3	6.7	0.05			0.05	-	7.0
6. Jacaguas River		G6	9	5	2	9.0	0.07			0.12	-	6.0
Total				70	31	46.7	0.38			0.79		44.0
Mean of 6 Samples				11.7	5.2	7.8	0.06			0.13		7.3
Standard Deviation				±6.1	±5.2	±2.2	±0.02			±0.13		+1.5

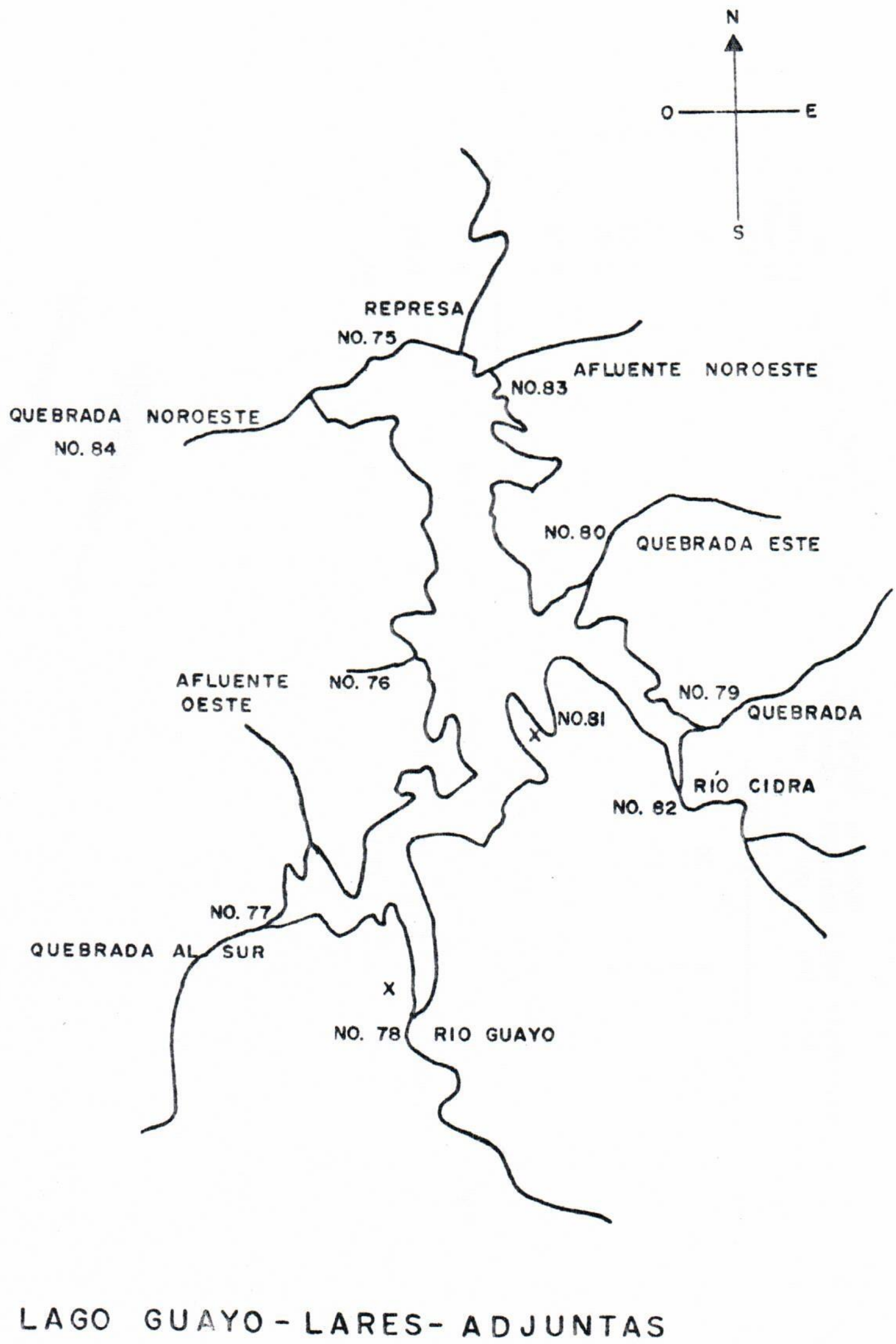
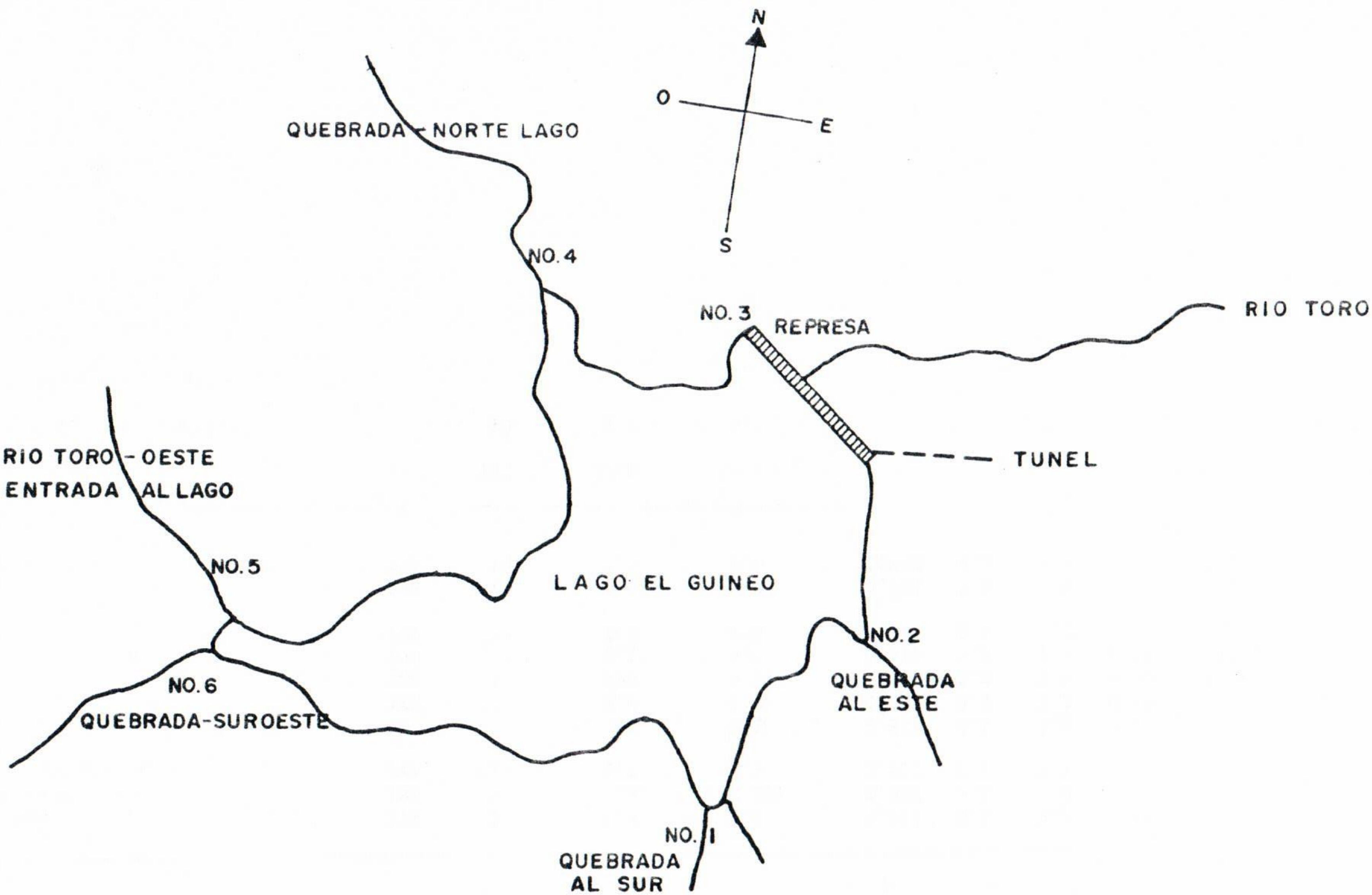


Figure 18. Map of Lake Guayo

TABLE A14. WATER QUALITY SUMMARY FOR LAKE GUAYO, PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1. Near Dam	(No Date)	-	178	10	3.8	6.4	0.012	0.1	7.2	0.19	86.7
2. Creek on NW Side	" "	-	180	10	1.9	(0.12)	0.005	0.1	7.2	0.10	87.8
3. South Side at Guayo River	" "	-	182	10	2.7	5.9	0.017	0.1	7.1	0.08	101.1
4. Creek on South Side	" "	-	184	10	3.0	6.3	0.017	0.1	7.2	0.08	103.7
5. Creek on East Side	" "	-	186	10	1.2	6.0	0.021	0.2	7.2	0.09	104.8
6. Creek on NE Side	" "	-	188	10	7.0	5.2	0.018	0.2	7.0	0.08	107.0
7. Creek on NE Side	" "	-	190	10	1.1	4.6	0.018	0.2	7.2	0.16	97.4
8. Creek on NE Side From Lake Pellejas	" "	-	192	10	0.4	4.5	0.030	0.4	7.1	0.52	62.2
9. Creek on East Side	" "	-	194	10	2.6	4.8	0.020	0.1	7.2	0.13	60.1
10. Creek on NE Side	" "	-	196	10	3.4	5.4	0.040	0.2	7.1	-	115.4
Total				100	27.1	49.2	0.198	1.7	71.5	1.43	926.2
Mean of 10 Samples				10	2.7	4.9	0.020	0.17	7.2	0.16	92.6
Standard Deviation				±0	±1.8	±1.8	±0.01	±0.09		±0.14	+18.7



LAGO EL GUINEO

Figure 19. Lake Guineo

TABLE A15 WATER QUALITY SUMMARY FOR LAKE GUINEO, PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and Nitrates in mg/1 as N	EDTA hardness in mg/1 as N	Hardness in mg Ca/1
1. Creek on East Side	13/11/75	1	29	5	0.2	2.9		0.05		0.02		4.0
2. Creek on NE Side	3/11/75	2	30	5	0.1	3.7		0.04		0.02		2.0
3. Reservoir, North Side	4/11/75	3	31	5	2.0	2.7		0.05		0.04		4.50
4. Reservoir, North Side	4/11/75	4	32	5	1.3	2.5		0.03				
5. Toro River Mouth	4/11/75	5	33	5	3.0	2.4		0.03		0.02		3.0
6. Big Creek, SE	4/11/75	6	34	5	3.0	3.2		0.03		0.04		3.0
Total				30	9.6	17.4		0.23		0.14		16.5
Mean of 6 Samples				5	1.6	2.9		0.04		0.03		3.30
Standard Deviation				± 0	± 1.3	± 0.5		± 0.01		± 0.01		+0.97

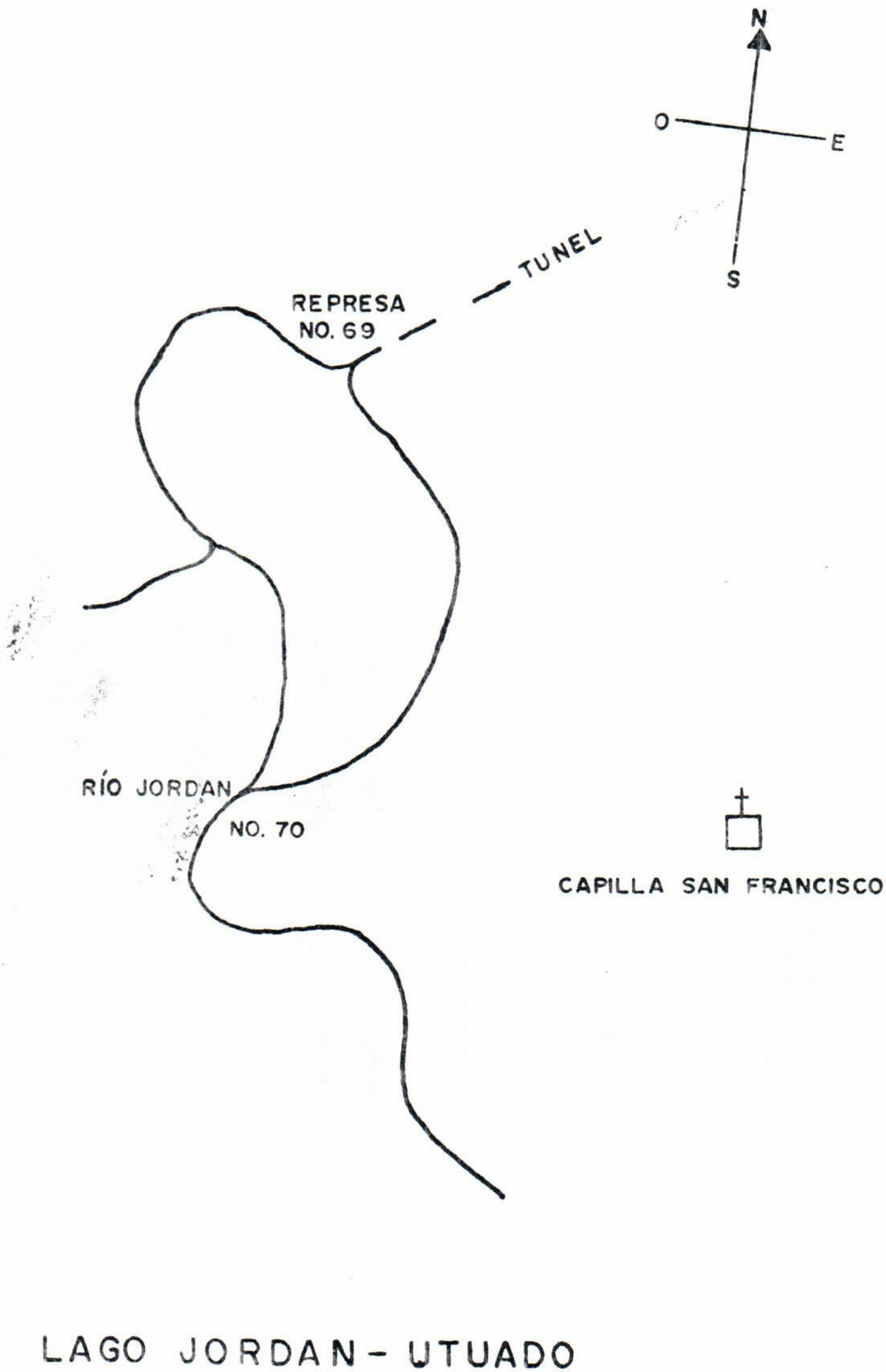


Figure 20. Lake Jordan

TABLE A16 . WATER QUALITY SUMMARY FOR LAKE JORDAN , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/l	Total Phosphates in mg/l as P	Iron in m/l	pH	Nitrates and nitrites in mg/l as N	EDTA hardness in mg/l as $MgSO_4$
1. Reservoir	2/4/76	-	166	7	23.5	18.1	0.01	0.1	6.8	0.02	143.6
2. River	2/4/76	-	168	5	0.0	9.0	*(0.01	0.1	6.8	0.03	170.2
Total				12	23.5	27.1	0.02	0.2	13.6	0.05	313.8
Mean of 2 Samples				6	11.8	13.6	0.01	0.1	6.8	0.025	156.9
Standard Deviation											

* Less than

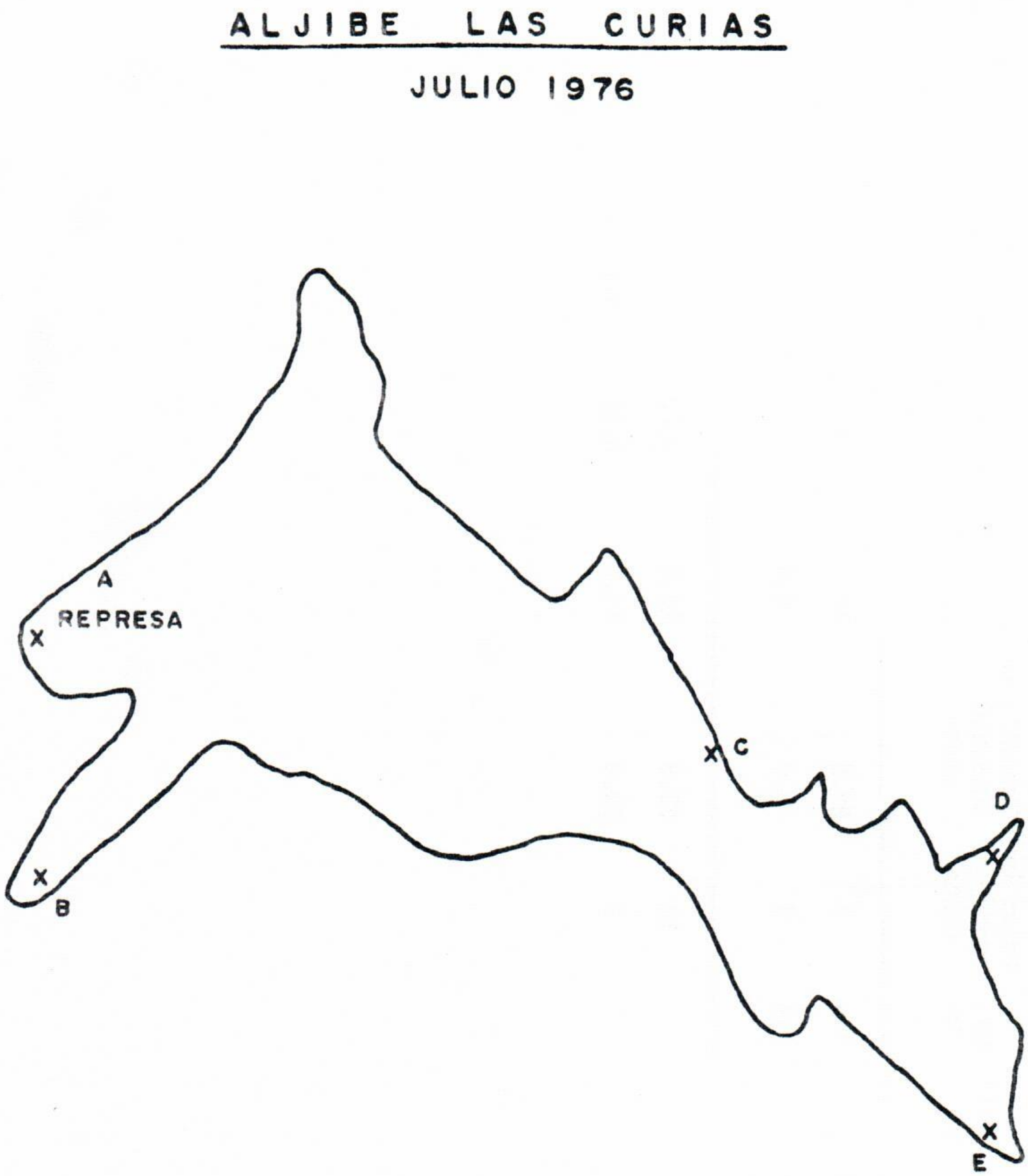


Figure 21. Lake Las Curias

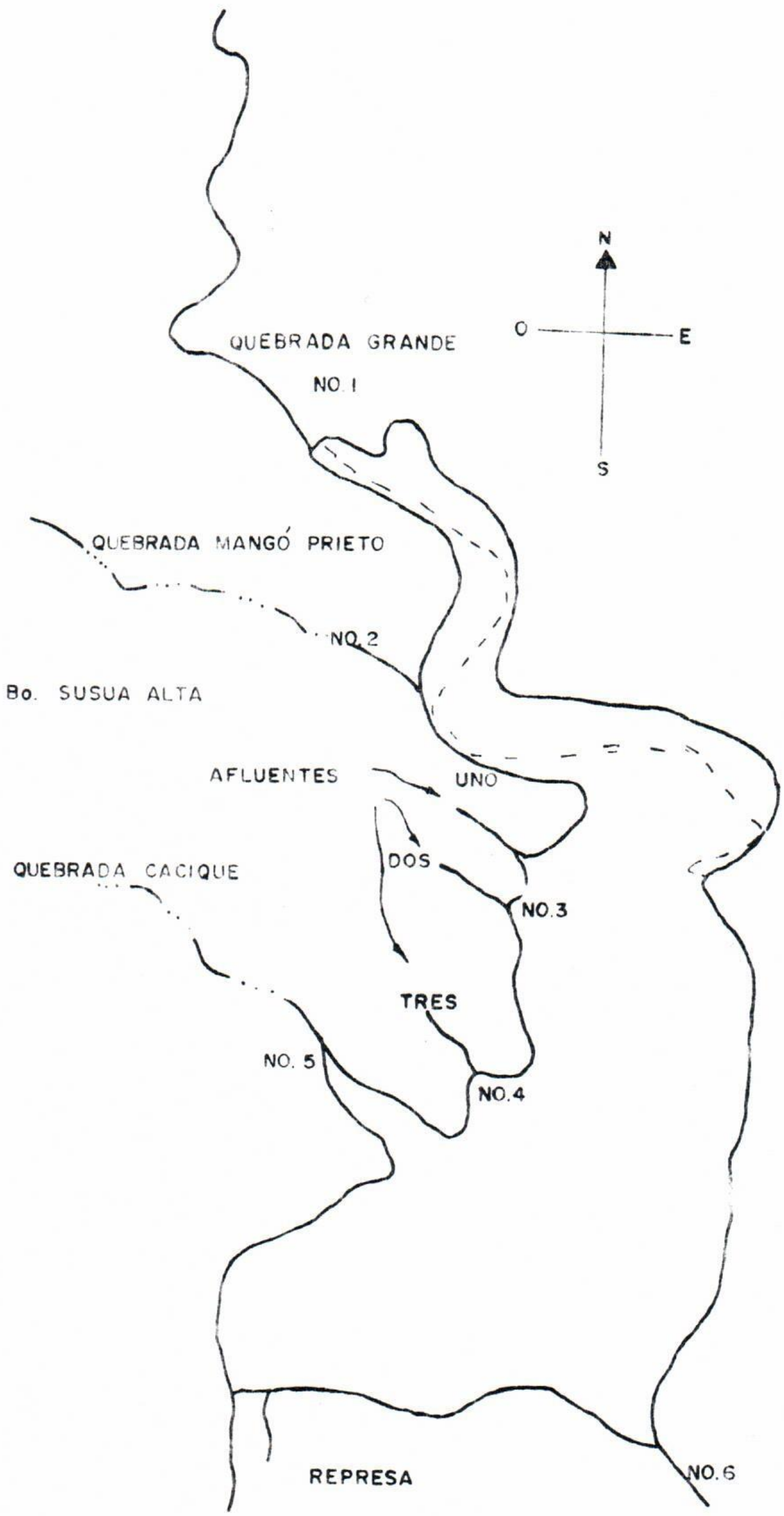


Figure 22. Lake Loco

NOTA: AFLUENTES UNO-DOS Y TRES SON INTERMITENTES. IMPORTANTES POR HABER COMUNIDAD CERCANA.

REPRESA LOCO

TABLE A19 WATER QUALITY SUMMARY FOR LAKE Loco, PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and Nitrates in mg/1 as N	EDTA hardness in mg/1 as N	Hardness in mg Ca/1
1. Rio Loco	(No date)	1	11	5	13	7	0.08	0.03		0.02		7.00
2. Mango Creek	"	2	12	5	9	5	0.05	0.05		0.12		12.00
3. West Side	"	3	13	7	0.3	10	0.03	0.02		0.11		14.0
4. West Side	"	4	14	5	2	8	0.03	0.03		0.11		13.0
5. West Side	"	5	15	5	4	14	0.03	0.02		0.30		16.0
6. East Side	"	6	16	5	3.5	6	0.04	0.04		0.03		11.0
Total				32	31.8	50	0.26	0.19		0.69		73.0
Mean of 6 Samples				5.3	5.3	8.3	0.04	0.03		0.12		12.2
Standard Deviation				±0.8	±4.7	±3.7	±0.02	±0.01		±0.10		3.1

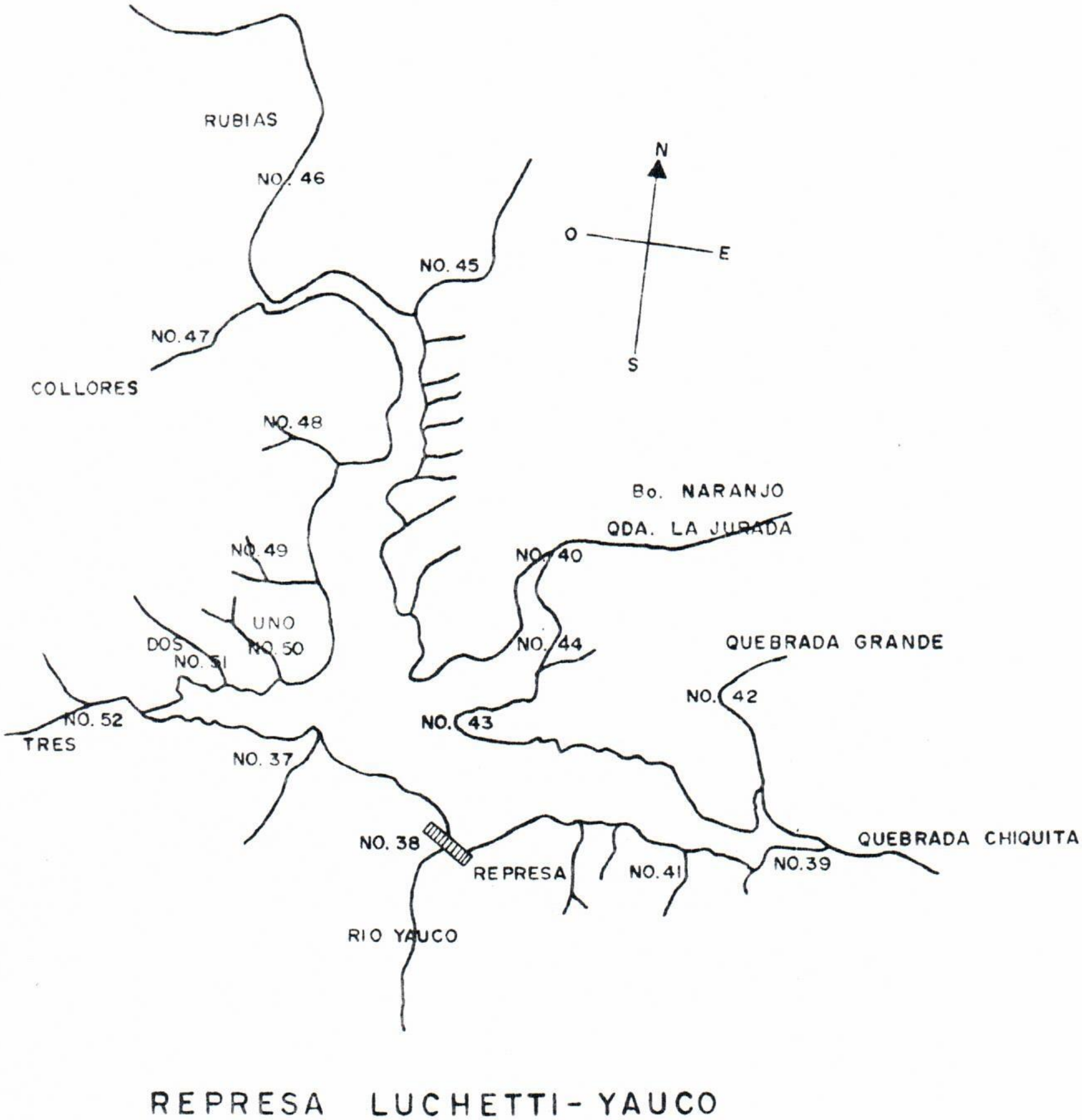


Figure 23. Lake Luchetti

TABLE A 20 WATER QUALITY SUMMARY FOR LAKE LUCHETTI OF YAUCO, PUERTO RICO.

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and Nitrates in mg/1 as N	EDTA hardness in mg/1 as N	Hardness in mg Ca/1
1.Creek on SE Side	11/20/75	-	109	5	1.1	8.0	0.025	0.1	8.2	0.12	153.2	
2.Creek on SE Side	11/20/75	-	110	5	1.9	7.6	0.02	0.2	8.0	0.15	149.0	
3.Creek on Bo.Rubias	11/24/75	-	111	5	1.8	7.3	*0.01	0.3	8.0	0.16	152.2	
4.Mouth of Rio Rubias	11/24/75	-	112	5	1.5	7.3	0.01	0.3	8.1	0.14	152.2	
5.Creek in NE Collores	12/ 1/75	-	113	5	3.9	7.0	0.01	0.4	8.1	0.17	149.0	
6.Creek in NE Collores	"	-	114	4	0.2	7.1	0.02	0.2	8.0	0.14	147.9	
7.Creek in NE Collores	"	-	115	4	7.3	8.1	0.05	1.0	8.2	0.28	143.6	
8.Creek in NE Collores	"	-	116	5	1.8	7.6	0.04	0.5	8.1	0.22	151.1	
9.Tunnel Entrance	"	-	117	6	0.9	8.0	0.05	0.4	8.2	0.28	147.9	
10.Tunnel Entrance	"	-	118	6	3.9	7.6	0.25	0.2	8.0	0.14	149.0	
11.Creek in SW Collores	12/ 2/75	-	119	6	1.1	7.6	0.05	0.1	8.3	0.26	154.3	
12.Creek in SW Collores	"	51	120	5	5.7	7.3	0.05	0.3	8.4	0.96	178.2	
13.Creek in SW Collores	"	51	121	6	4.9	8.3	0.05	0.2	8.1	0.93	174.0	
14.Creek in SW Collores	"	51	122	5	6.6	8.1	0.05	0.2	7.8	1.04	163.9	
15.Creek in SW Collores	"	52	123	6	3.9	8.1	0.05	0.2	8.0	0.77	162.3	
16.Creek in SW Collores	"	52	124	5	3.6	7.5	0.03	0.2	7.6	0.48	162.3	
17.Small Creek on North Side	11/21/75	-	101	8	2.2	7.9	0.0	0.1	8.3	0.04	145.8	
18.Small Creek on NW Side	11/24/75	-	103	5	0.6	7.1	0.0	0.1	8.3	0.05	155.3	
19.Large Creek on East Side	11/20/75	-	105	5	2.4	7.6	0.0	0.1	8.3	0.20	175.6	
20.Small Creek on North Side	11/21/75	-	106	5	2.5	7.0	(0.01	0.2	8.2	0.15	166.0	
21.Reservoir	14/10/75	-	38	5	0.6	7.5		0.02		0.004		10.0
22.Chiquita Creek, Bo. Vega	17/11/75	-	39	5	7.0	8.0		0.03		0.06		10.0
23.La Jurada Creek,Bo. Naranja	17/11/75	-	40	5	3.0	9.0		0.03		0.08		12.0
Total				121	68.4	176.6	0.77	5.38	16.22	6.824	3132.8	
Mean of 23 Samples				5.3	3.0	7.7	0.04	0.23	8.1	0.30	156.7	
Standard Deviation				±0.8	±2.1	±0.5	±0.05	±0.21	0.2	±0.31	10.4	

* Less Than

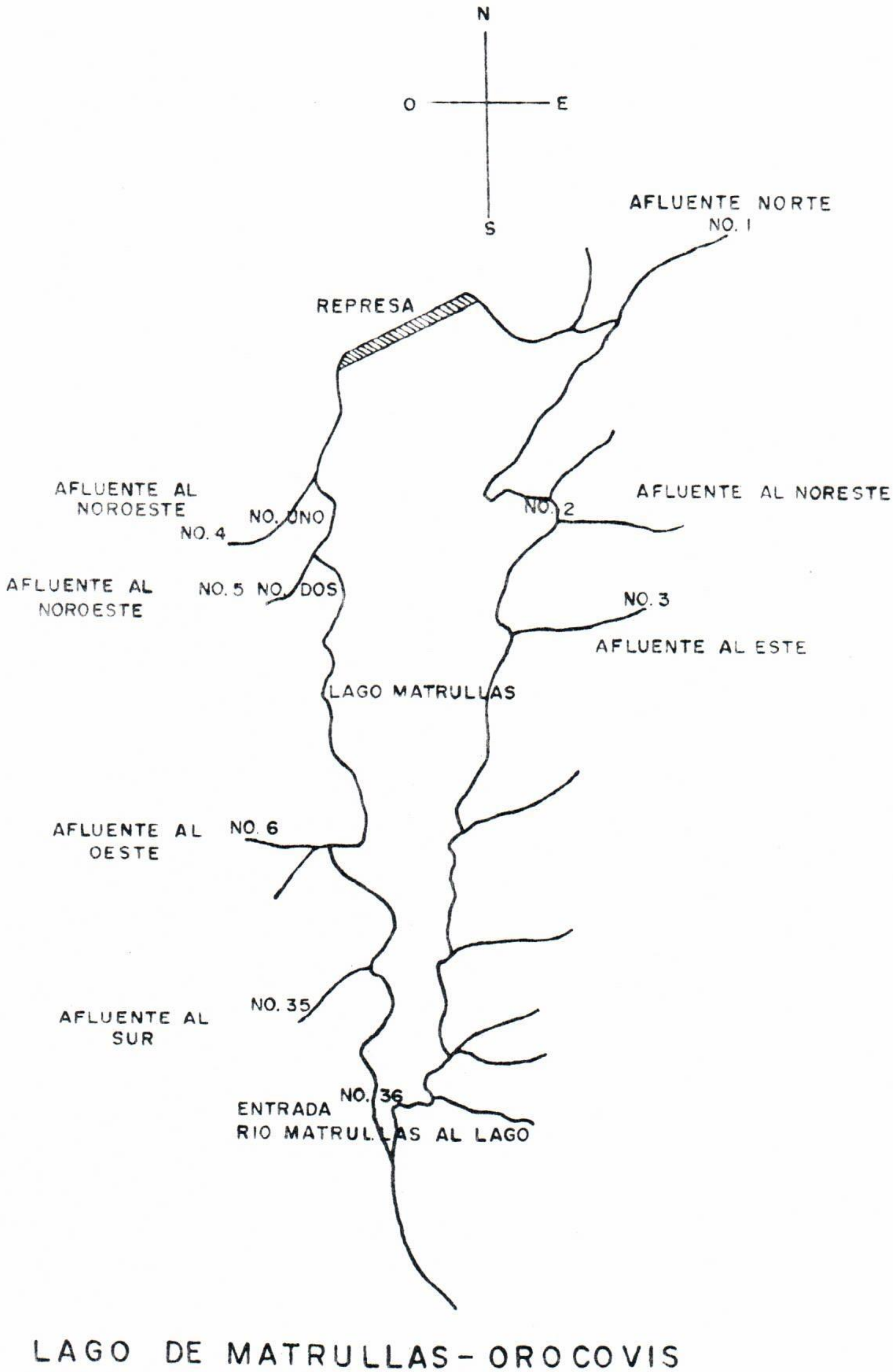


Figure 24. Map of Lake Matrullas

TABLE A21. WATER QUALITY SUMMARY FOR LAKE MATRULLAS, PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and Nitrates in mg/1 as N	EDTA hardness in mg/1 as N	Hardness in mg Ca/1
1.Creek on SE Side	12/11/75	-	35	5	2.0	9.5		0.03		0.06		3.0
2.Creek on NE Side-Bauta Abajo	7/11/75	A1	35	5	2.0	(9.5)		0.03		0.06		3.0
3.Matrullas River	12/11/75	-	36	5	3.0	(0.5)		0.03		0.05		2.0
4.Creek on East Side	7/11/75	B2	36	5	2.0	5.5		0.03		0.07		2.0
5.Creek on East Side	9/11/75	C3	37	5	3.0	4.8		0.03		0.00		2.0
6.Creek on West Side	10/11/75	C4	38	5	2.0	5.5		0.03		0.08		4.0
7.Creek on West Side	10/11/75	E5	39	5	1.0	5.0		0.03		0.004		4.0
8.Creek on West Side	10/11/75	F6	40	5	3.0	4.5		0.02		0.00		3.0
Total				40	18.0	45.8		0.23		0.324		23.0
Mean of 8 Samples				5	2.2	5.6		0.03		0.04		2.88
Standard Deviation				±0	±0.7	±2.9		±0		±0.03		+0.83

SURVEY OF LAKE PATILLAS

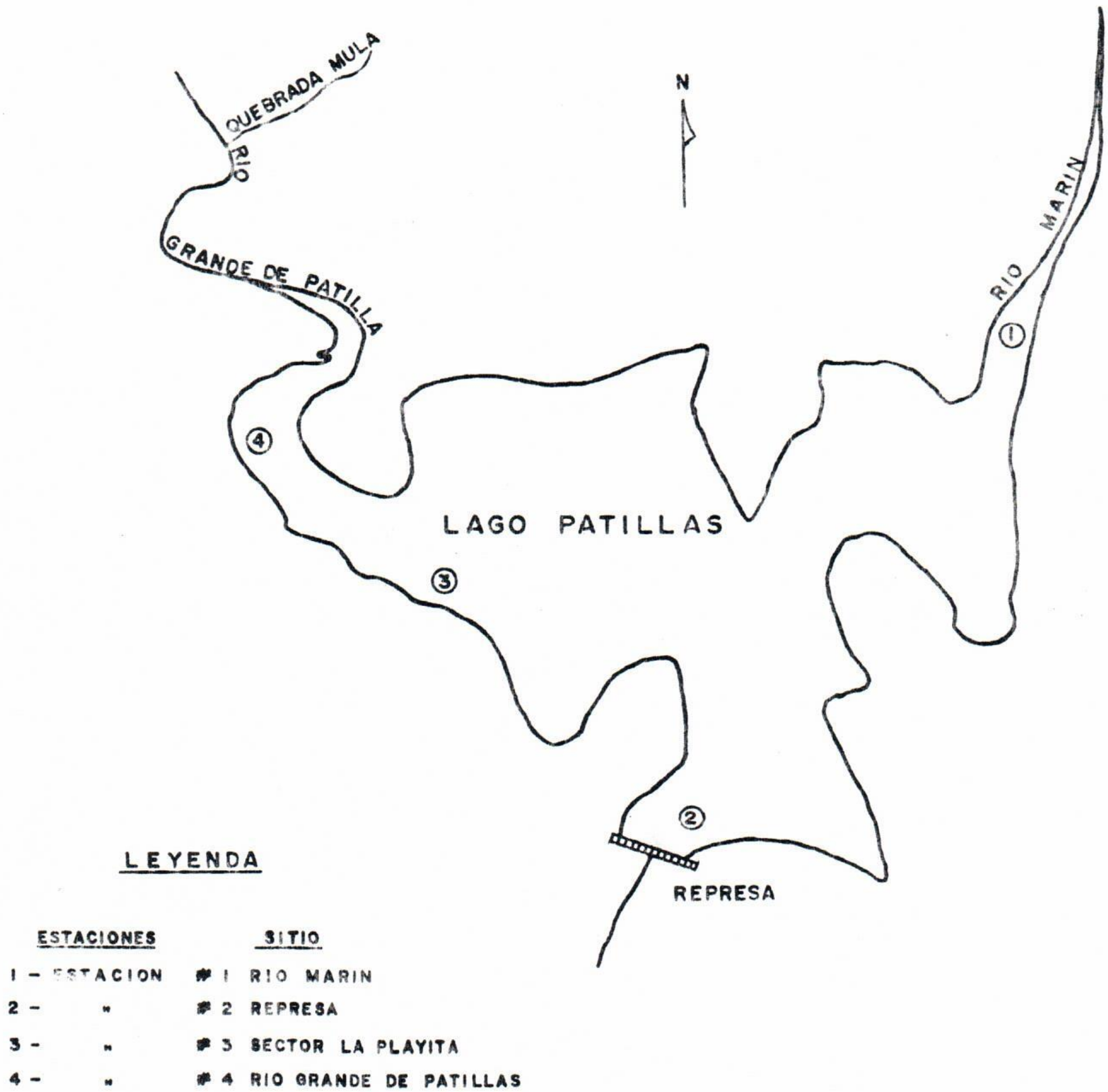


Figure 25. Map of Lake Patillas

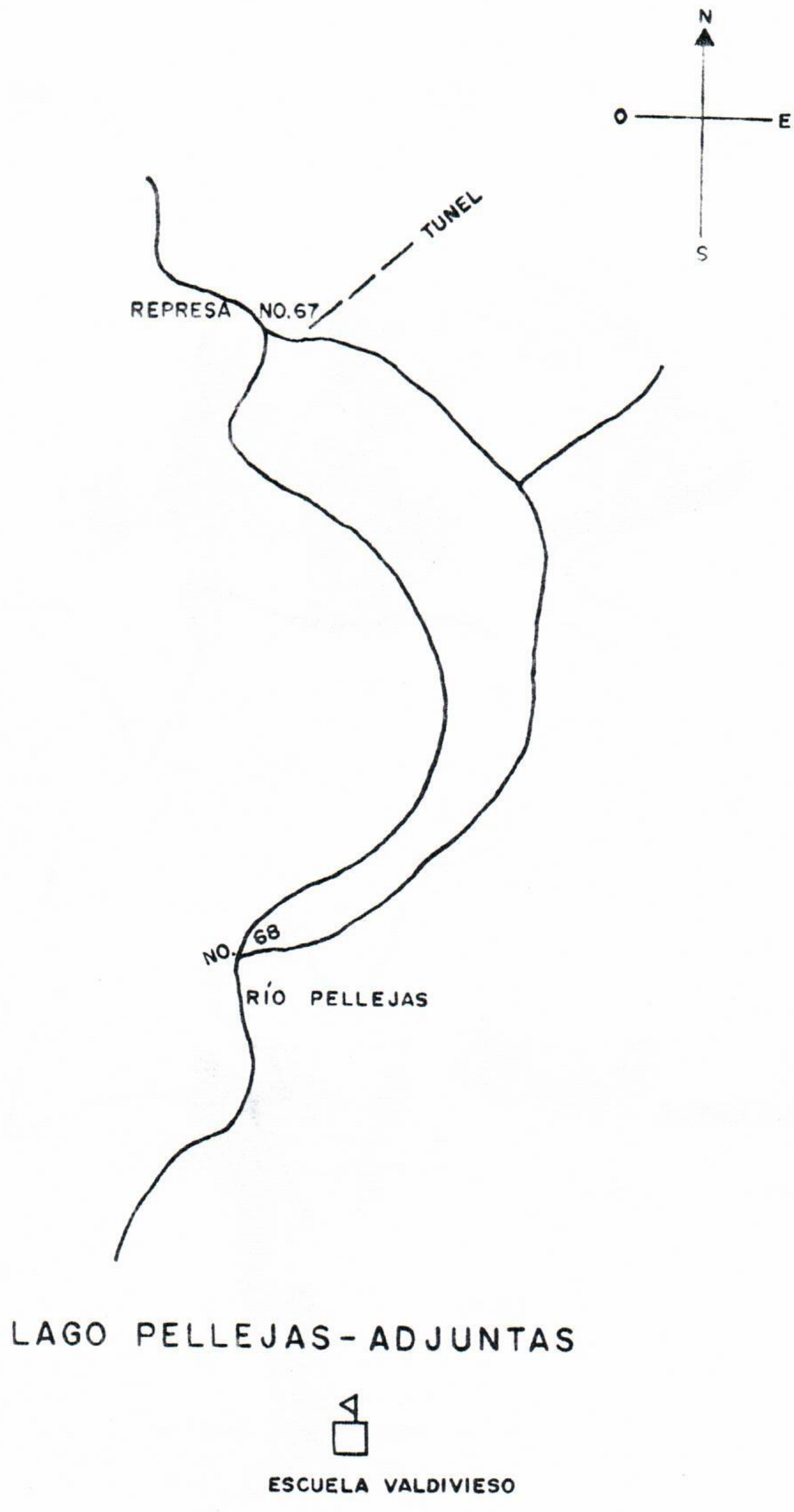


Figure 26. Map of Lake Pellejas

TABLE A23. WATER QUALITY SUMMARY FOR LAKE PELLEJAS , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1. North Side of Reservoir	2/3/76	-	162	5	2.4	9.6	*(0.01	0.8	6.8	0.02	138.3
2. River on South Side	"	-	164	8	28.2	9.9	0.01	0.2	6.8	0.02	138.3
Total				13	30.6	19.5	0.02	1.0	13.6	0.04	276.6
Mean of 2 Samples				6.5	15.3	9.8	0.01	0.5	6.8	0.02	138.3
Standard Deviation											

* Less Than

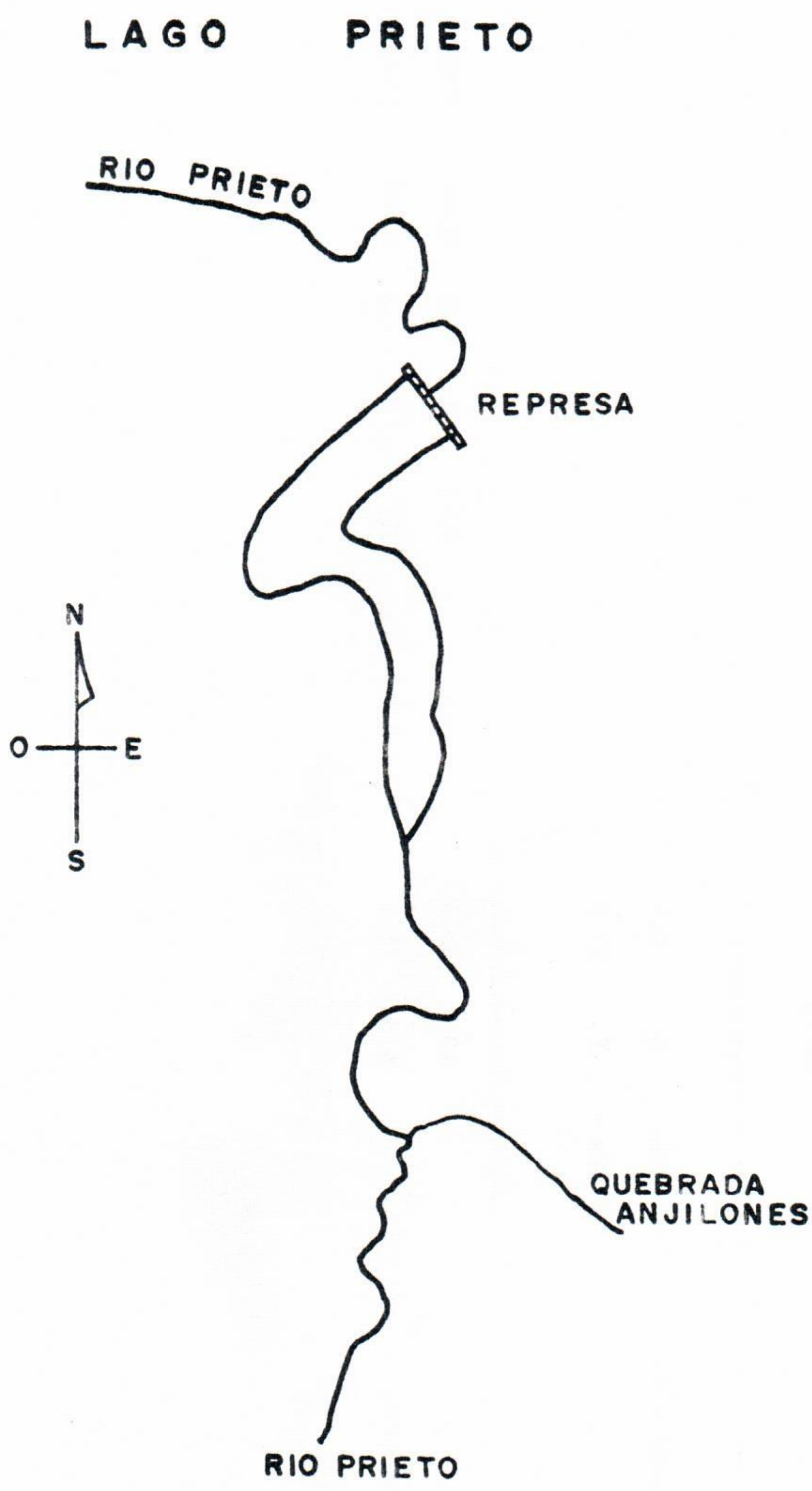


Figure 27. Map of Lake Prieto

TABLE A24 . WATER QUALITY SUMMARY FOR LAKE PRIETO , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1. Near the Dam	2/9/76	-	176	12	0.4	8.0	0.01	0.4	7.0	0.27	203.2

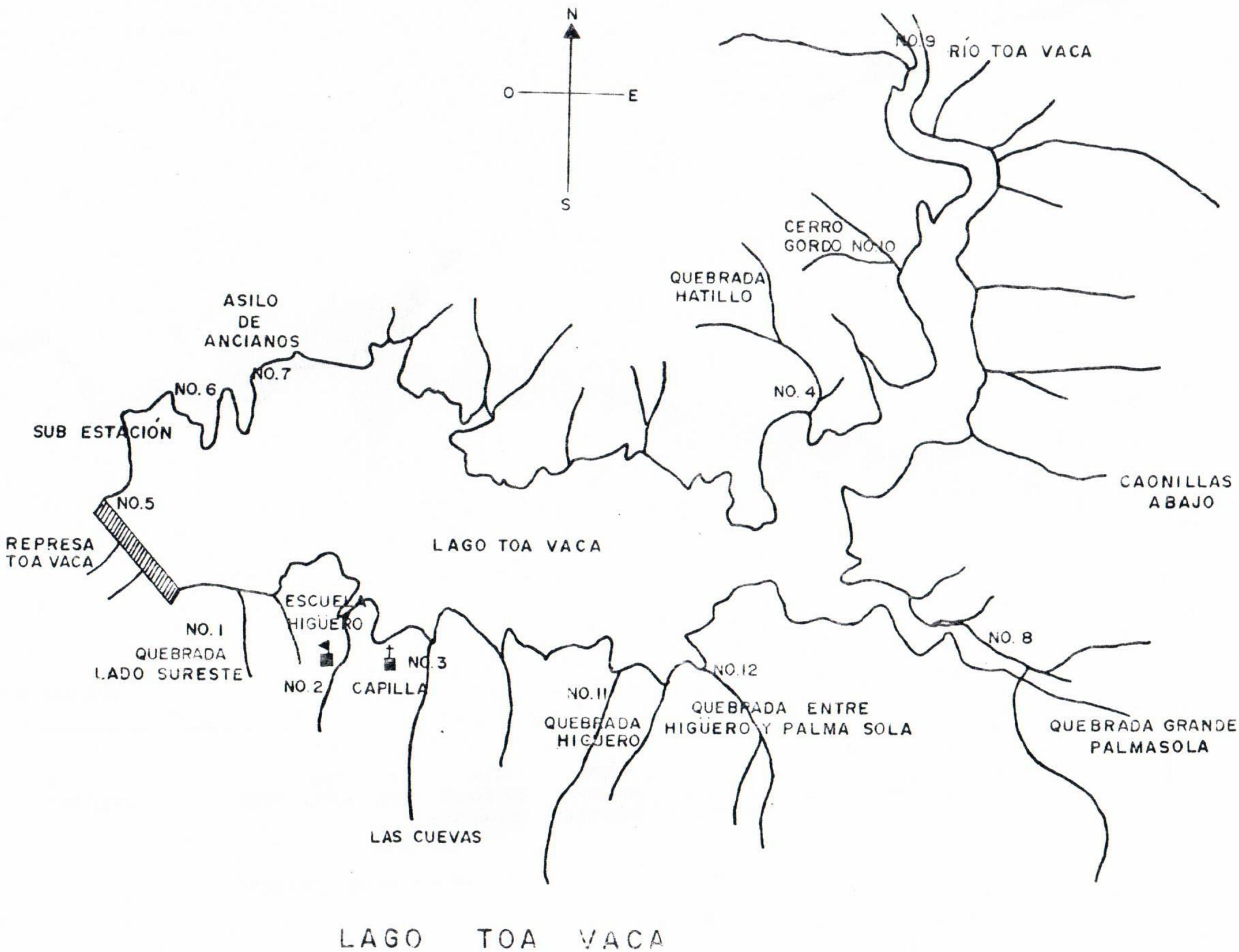


Figure 28. Map of Lake Toa Vaca

TABLE A 26 WATER QUALITY SUMMARY FOR LAKE TOA VACA, PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and Nitrates in mg/1 as N	EDTA hardness in mg/1 as N	Hardness in mg Ca/1
1. Near Outlet	(No Date)	R	10	5	2	7.5	0.04	-		0.03		7.0
2. Ivanol Creek, SE	" "	1	17	5	3	9	0.05	0.05		0.05		8.0
3. Creek Near Chapel East"	"	2	18	6	2.5	11	0.06	0.04		0.02		10.0
4. Creek Near Chapel East"	"	3	19	5	0.8	16	0.25	0.04		0.11		17.0
5. Los Guisos Creek	" "	4	20	7	0.6	9	0.20	0.04		0.03		7.0
6. Reservoir	23/10/75	5	21	9	2	9.5	0.08	0.03		0.05		10.0
7. Creek on West Side	24/10/75	6	22	5	2	10	0.07	0.04		0.02		12.0
8. Creek on West Side	7/11/75	7	23	7	2	10	0.02	0.04		0.05		9.6
9. Bib'Creek-Palmasola	(No Date)	8	24	5	2.5	9	0.07	0.04		0.04		10.0
10. Toa Vaca River North	" "	9	25	5	0.0	11	0.25	0.04		0.08		7.0
11. Creek at North Peak	" "	10	26	10	2.2	9	0.07	0.04		0.04		9.0
12. NE Creek, Sitio Higuera"	"	11	27	5	0.2	10	0.01	0.04		0.04		
13. South Creek Palmasola	" "	12	28	5	3	10	0.06	0.05		0.04		7.0
Total				79	22.8	131.0	1.23	0.49		0.60		
Mean of 13 Samples				6.1	1.8	10.1	0.09	0.04		0.04	30.2	
Standard Deviation				±1.7	±1.0	±2.0	±0.08	±0.01		±0.03	±11.0	

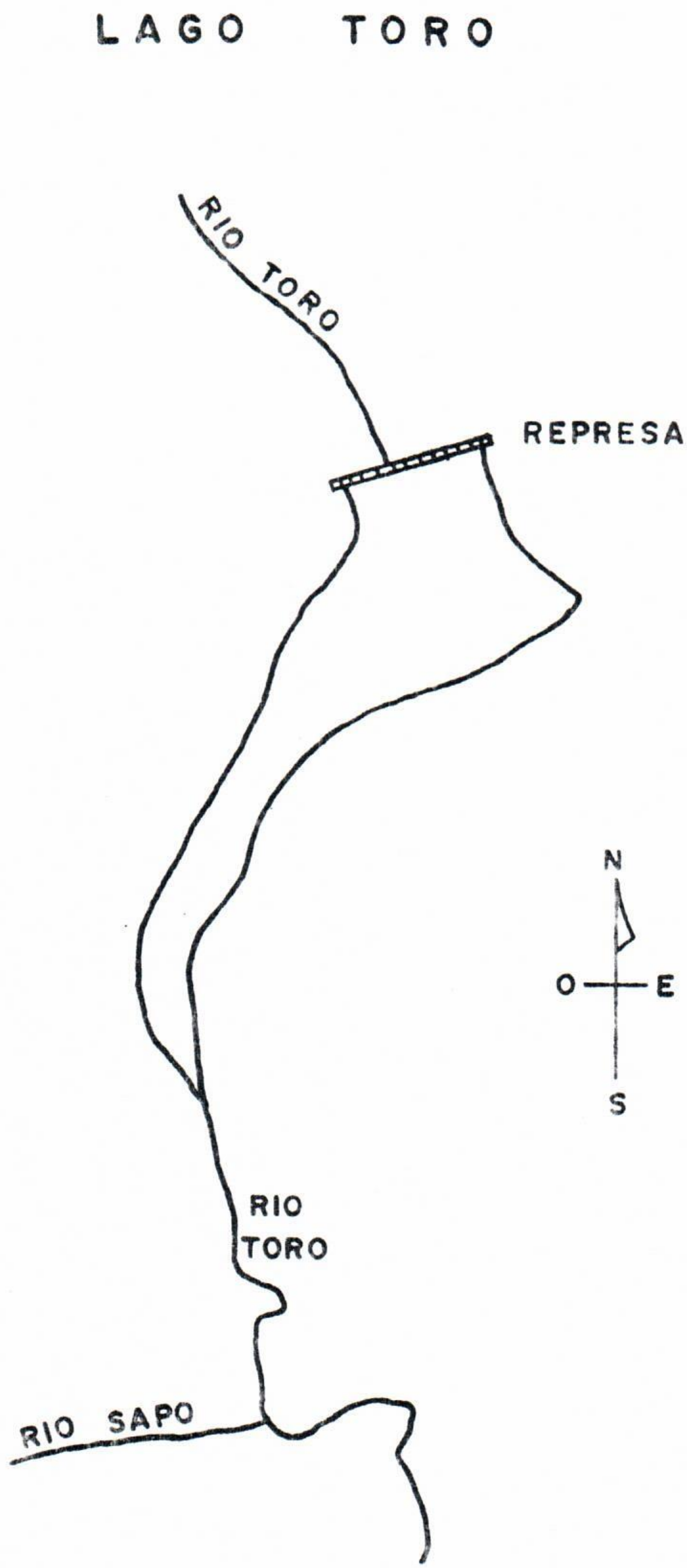


Figure 29. Map of Lake Toro

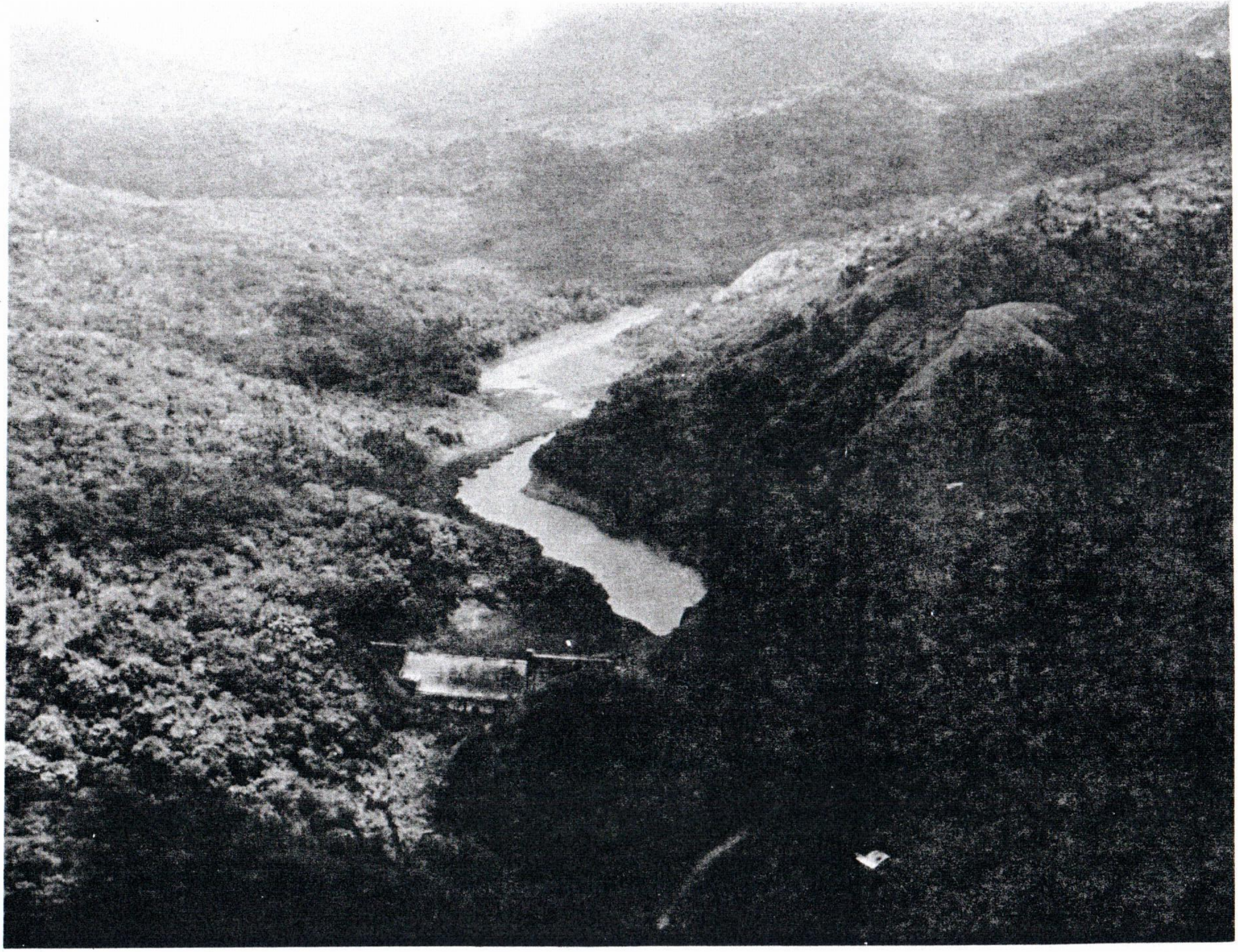


FIGURE 29A. LAKE TORO

TABLE A27 . WATER QUALITY SUMMARY FOR LAKE TORO , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1. River in Barrio Indiera Alta	2/25/76	89	206	5	10.6	9.9			6.8	0.44	138.3

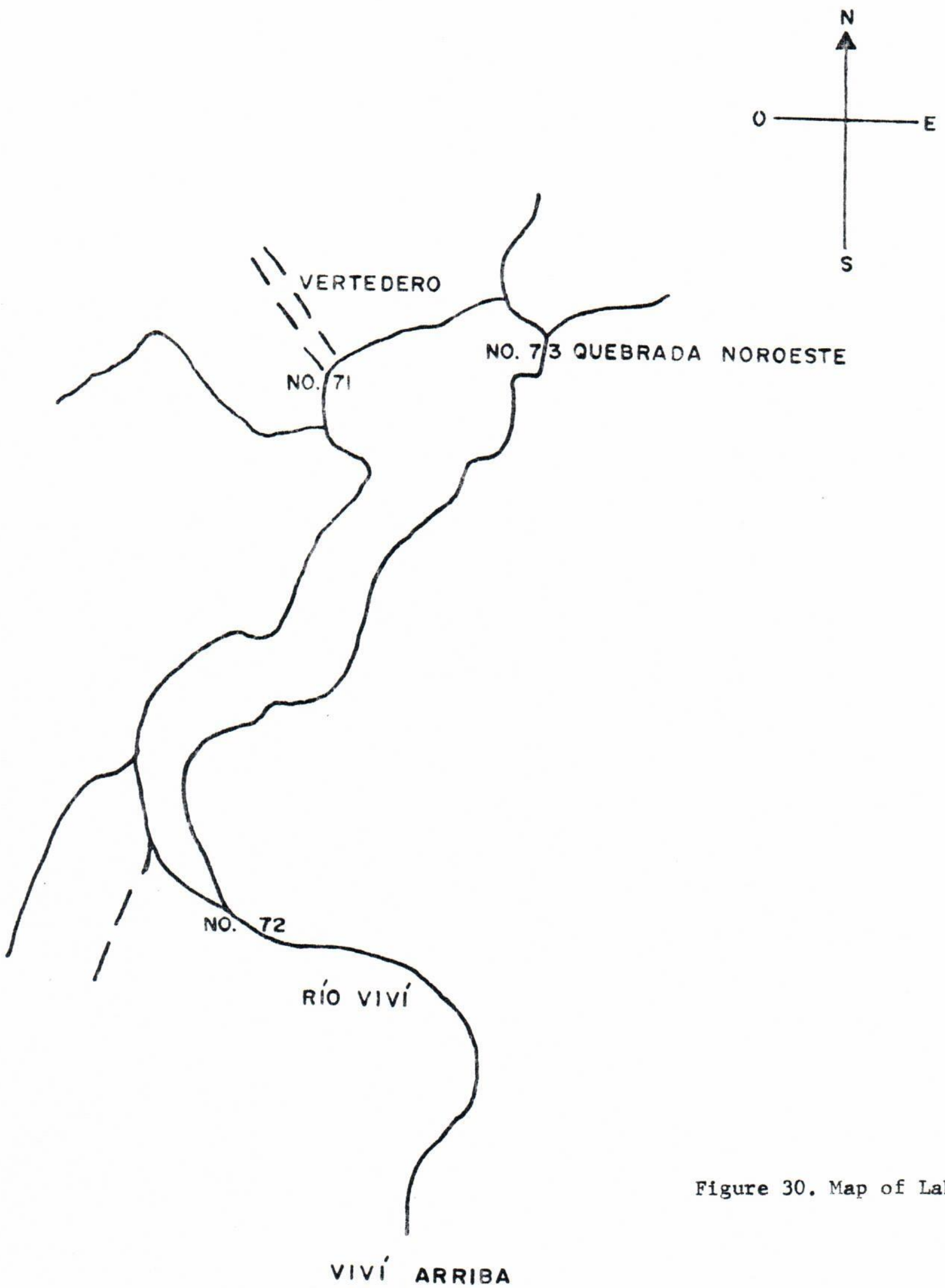


Figure 30. Map of Lake Vivi

LAGO VIVI UTUADO

TABLE A29. WATER QUALITY SUMMARY FOR LAKE VIVI , PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1.South Side Vivi River	2/5/76	-	170	7	0.25	7.5	* (0.01	0.2	6.6	0.02	86.2
2. Creek on East Side	2/5/76	-	172	6	2.04	12.3	0.02	0.1	6.8	0.02	145.8
3. Near the Dam	2/5/76	-	174	6	3.45	10.7	(0.01	0.8	6.6	0.19	151.6
Total				19	5.74	30.5	0.04	1.1	20.0	0.23	383.6
Mean of 3 Samples				6.3	1.9	10.2	0.01	0.4	6.7	0.08	127.9
Standard Deviation				$\pm$0.6	$\pm$1.6	$\pm$2.4		$\pm$0.4	+0.1	+0.10	+36.2

* Less Than

LAGO YAHUECAS

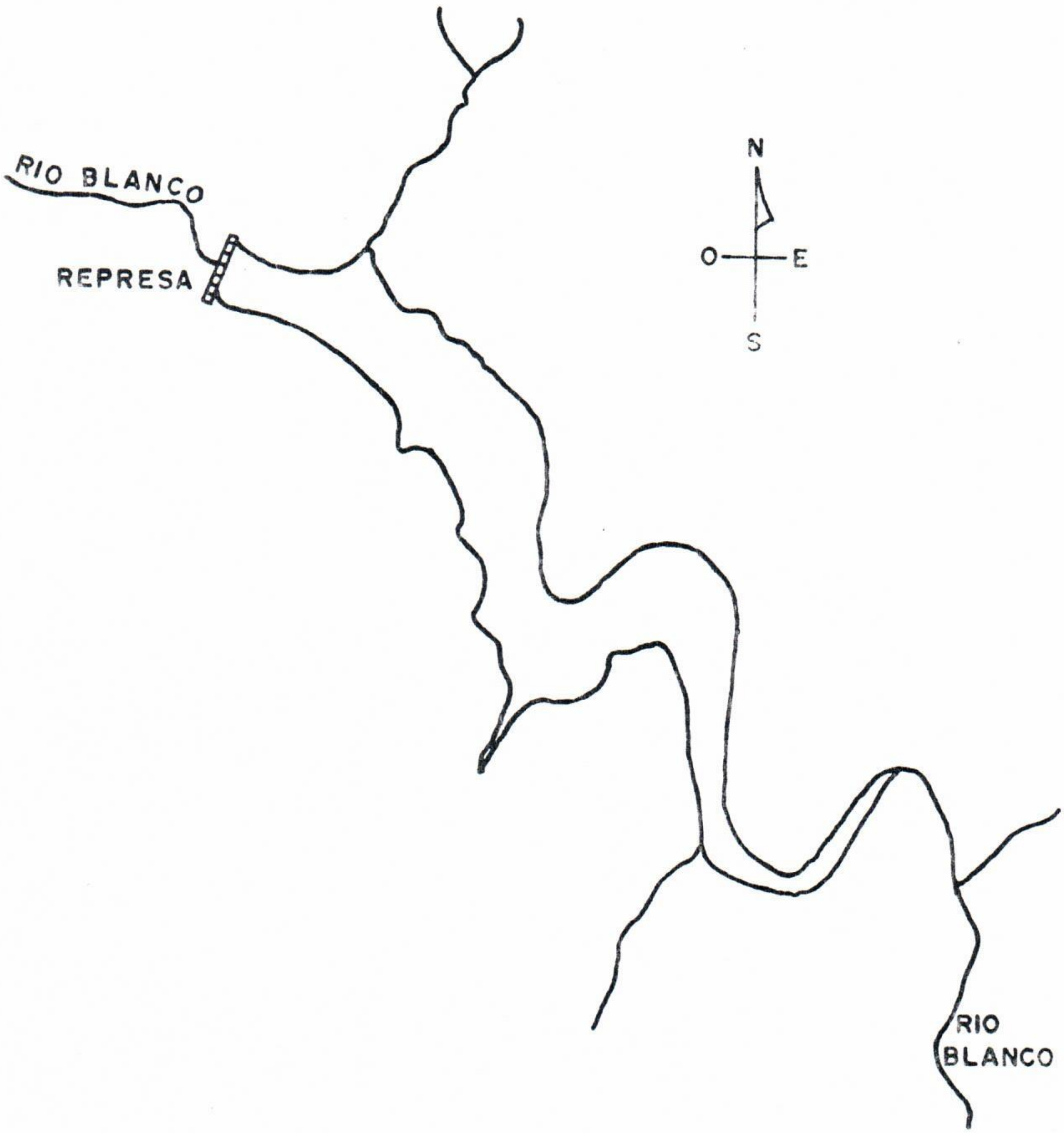


Figure 31. Map of Lake Yahuecas

TABLE A30. WATER QUALITY SUMMARY FOR LAKE YAHUECAS, PUERTO RICO

Sampling Site	Date	Field No.	Lab. No.	Color in standard units	Turbidity in standard units	Chlorides in mg/1	Total Phosphates in mg/1 as P	Iron in m/1	pH	Nitrates and nitrites in mg/1 as N	EDTA hardness in mg/1 as $MgSO_4$
1. NW Side of Reservoir	(No Date)		198	12	120	6.4	0.033	2.4	7.4	0.69	113.3
2. Creek on North Side	" "		200	15	150	6.6	0.056	2.4	7.6	1.55	119.7
3. Creek on East Side	2/24/76	87	202	10	24	10.3			7.7	0.85	137.3
4. Creek on East Side	2/24/76	88	204	5	6.2	10.9			6.9		113.8
Total				42	300	34.2	0.089	4.8	29.6	3.09	483.7
Mean of 4 Stations				10.5	75.0	8.6	0.04	2.4	7.4	1.03	120.9
Standard Deviation				±4.2	±10.8	±2.4			+0.4	+0.45	+14.27