U.S. Department of the Interior
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PREPARED IN COOPERATION WITH THE
Puerto Rico Environmental Quality Board for the Conservation Trust of Puerto Rico

Selected Hydrologic, Water-Quality, Biological, and Sedimentation Characteristics of Laguna Grande, Fajardo, Puerto Rico, March 2007-February 2009

Scientific Investigations Report 2010-5071

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Photograph taken from Las Cabezas de San Juan Nature Reserve Lighthouse., of the Laguna Grande, Fajardo Puerto Rico.
(Photograph by Luis R. Soler-López, U.S. Geological Survey.)

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By Luis R. Soler-López and Carlos R. Santos

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Conversion Factors, Datum, Acronyms, and Translations

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
Flow rate		
cubic meter per day (m^3/d)	35.31	cubic foot per day (ft^3/d)
cubic meter per day (m^3/d)	264.2	gallon per day (gal/d)
cubic meter per year (m^3/yr)	35.31	cubic foot per year (ft^3/yr)
	Deposition rate	
centimeter per year (cm/yr)	0.3937	inch per year (in/yr)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram per day (kg/d)	2.205	pound avoirdupois per day (lb/d)
metric ton per year (t/yr)	1.102	ton per year (ton/yr)
	Radioactivity	
miliBecquerel per gram (mBq/g)	27,027	picocurie per gram(pCi/g)

Datum:

Horizontal Datum – Puerto Rico Datum, 1940 Adjustment
Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) – a geodetic datum derived from general adjustments of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

Acronyms used in this report:

ADCP	Acoustic Doppler Current Profiler
BLASS	Bathymetric/land survey system
CTPR	Conservation Trust of Puerto Rico
GIS	Geographic information system
GPS	Global positioning system
NOAA	National Oceanic and Atmospheric Administration
NWQL	National Water Quality Laboratory
PRDNER	Puerto Rico Department of Natural and Environmental Resources
PREQB	Puerto Rico Environmental Quality Board
TIN	Triangulated irregular network
USGS	U.S. Geological Survey

Translations:

Spanish	**English**
Lago	Lake (in Puerto Rico, also reservoir)
Río	River
Municipio	Municipality

Selected Hydrologic, Water-Quality, Biological, and Sedimentation Characteristics of Laguna Grande, Fajardo, Puerto Rico, March 2007-February 2009

By Luis R. Soler-López and Carlos R. Santos

Abstract

Laguna Grande is a 50-hectare lagoon in the municipio of Fajardo, located in the northeasternmost part of Puerto Rico. Hydrologic, water-quality, and biological data were collected in the lagoon between March 2007 and February 2009 to establish baseline conditions and determine the health of Laguna Grande on the basis of preestablished standards. In addition, a core of bottom material was obtained at one site within the lagoon to establish sediment depositional rates.

Water-quality properties measured onsite (temperature, pH, dissolved oxygen, specific conductance, and water transparency) varied temporally rather than areally. All physical properties were in compliance with current regulatory standards established for Puerto Rico. Nutrient concentrations were very low and in compliance with current regulatory standards (less than 5.0 and 1.0 milligrams per liter for total nitrogen and total phosphorus, respectively). The average total nitrogen concentration was 0.28 milligram per liter, and the average total phosphorus concentration was 0.02 milligram per liter. Chlorophyll *a* was the predominant form of photosynthetic pigment in the water. The average chlorophyll-*a* concentration was 6.2 micrograms per liter.

Bottom sediment accumulation rates were determined in sediment cores by modeling the downcore activities of lead-210 and cesium-137. Results indicated a sediment depositional rate of about 0.44 centimeter per year. At this rate of sediment accretion, the lagoon may become a marshland in about 700 to 900 years.

About 86 percent of the community primary productivity in Laguna Grande was generated by periphyton, primarily algal mats and seagrasses, and the remaining 14 percent was generated by phytoplankton in the water column. Based on the diel studies the total average net community productivity equaled 5.7 grams of oxygen per cubic meter per day (2.1 grams of carbon per cubic meter per day). Most of this productivity was ascribed to periphyton and macrophytes, which produced 4.9 grams of oxygen per cubic meter per day (1.8 grams of carbon per cubic meter per day). Phytoplankton, the plant and algal component of plankton, produced about 0.8 gram of oxygen per cubic meter per day (0.3 gram of carbon per cubic meter per day).

The total diel community respiration rate was 23.4 grams of oxygen per cubic meter per day. The respiration rate ascribed to plankton, which consists of all free floating and swimming organisms in the water column, composed 10 percent of this rate (2.9 grams of oxygen per cubic meter per day); respiration by all other organisms composed the remaining 90 percent (20.5 grams of oxygen per cubic meter per day). Plankton gross productivity was 3.7 grams of oxygen per cubic meter per day, equivalent to about 13 percent of the average gross productivity for the entire community (29.1 grams of oxygen per cubic meter per day).

The average phytoplankton biomass values in Laguna Grande ranged from 6.0 to 13.6 milligrams per liter. During the study, Laguna Grande contained a phytoplankton standing crop of approximately 5.8 metric tons. Phytoplankton community had a turnover (renewal) rate of about 153 times per year, or roughly about once every 2.5 days.

Fecal indicator bacteria concentrations ranged from 160 to 60,000 colonies per 100 milliliters. Concentrations generally were greatest in areas near residential and commercial establishments, and frequently exceeded current regulatory standards established for Puerto Rico.

Figure 1. Location of Laguna Grande in eastern Puerto Rico.

Introduction

Laguna Grande is a 50-ha saltwater lagoon located in the municipio of Fajardo, in the northeasternmost part of Puerto Rico (fig. 1). The lagoon is part of the Las Cabezas de San Juan Nature Reserve established in 1986 to protect the natural beauty and ecological integrity of 178 ha of coastal and land resources, and to provide a natural setting for education and scientific research. Although the reserve is owned by the Conservation Trust of Puerto Rico (CTPR; Fideicomiso de Conservación de Puerto Rico), the lagoon is under the jurisdiction of the Puerto Rico Department of Natural and Environmental Resources (PRDNER).

The lagoon is connected to the Atlantic Ocean by a 1.5-km channel (fig. 2).To preserve the aquatic ecosystem at Laguna Grande, the U.S. Forest Service has identified areas of study in need of additional research and data, including lagoon hydrology, morphology, and water quality (Weaver and others, 1999). Of particular importance is the biological productivity of Laguna Grande, and thus, its ability to support higher trophic-level species. Biological productivity is a major indicator of the health of the aquatic ecosystem. The type and degree of the biological productivity provides an indication of the predominant aquatic communities that control the first link of the lagoon's food chain.

Although the Las Cabezas de San Juan Nature Reserve was designated as such in 1986, the water quality and ecological conditions of Laguna Grande have been continously threatened by expanding urban development within its watershed since the mid-1960s. Runoff entering the reserve from the Laguna Grande basin is suspected to contain sewage and other contaminants from nearby substandard housing units and commercial establishments that lack proper sewage infrastructure. During periods of high rainfall, runoff may transport sewage and high nutrient loads into the lagoon, which can be deleterious to its ecological health and impair its homeostatic capacity. In addition, flood tides may contribute pollutants through the channel that are derived from local and distant sources, such as boat marinas and the Río Fajardo, respectively.

In addition to fecal contamination and high nutrient loads, the lagoon is threatened by decreased water transparency and biological change. The lagoon is one of the few remaining habitats of its kind in Puerto Rico that supports bioluminescent dinoflagellates. Of major concern is the conservation of water quality in the lagoon, which if altered, could negatively affect these dinoflagellates. Other similar coastal resources on the island have lost their bioluminescent characteristic, arguably due to a lack of baseline data necessary to establish a resource management plan.

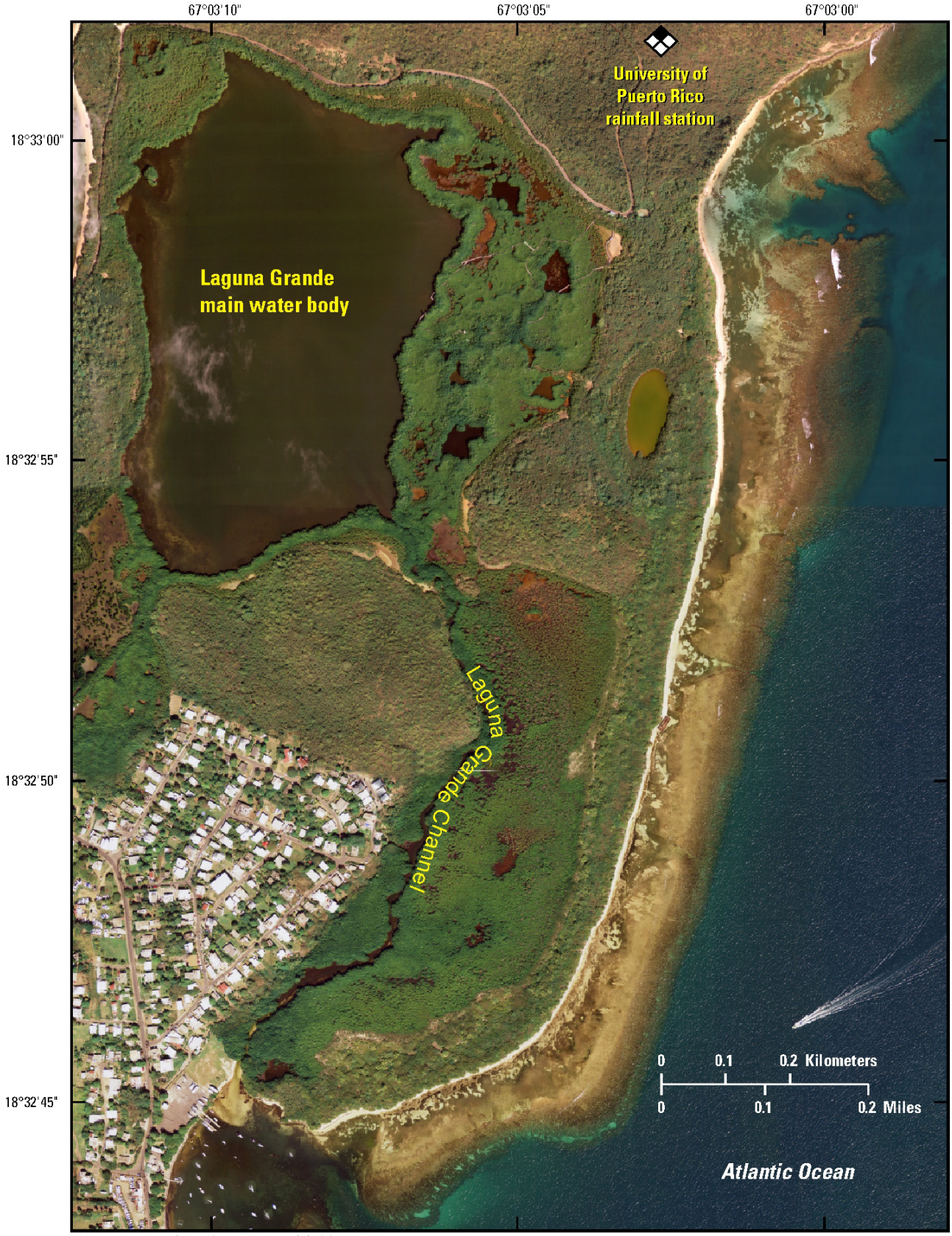
Water-quality standards for surface waters in Puerto Rico have been established by the Puerto Rico Environmental Quality Board (PREQB) on the basis of the designated or intended use, including fishing, swimming, or source for public supply (Puerto Rico Environmental Quality Board, 2003). The PREQB has no established standards for Laguna Grande, however, because baseline data describing its ambient conditions are lacking.

To address the aforementioned issues, the U.S. Geological Survey (USGS) in cooperation with the PREQB, initiated a study in (2007) to determine selected hydrologic, water-quality, biological and sedimentation characteristics of Laguna Grande. Information from this study will be used by the CTPR to establish baseline conditions and to monitor changes in the ecological health of the lagoon. The establishment of baseline conditions will enable the PREQB to establish water-quality criteria for this water body, a requirement prior to including the lagoon and offshore waters to a distance of 500 m under the SA Classification. This categorization is applicable to "bioluminescent lagoons and bays and other estuarine and coastal waters of exceptional water quality or significant ecological or recreational value." The possible classification of Laguna Grande under SA Class waters would need to be designated by the PREQB by enacting a resolution (Puerto Rico Environmental Quality Board, 2003).

Purpose and Scope

The purpose of this report is to document baseline data of the physical, chemical, biological, and bacteriological conditions of Laguna Grande to define its present characteristics. The study included Laguna Grande's main water body, the lagoon's canal, and other adjacent areas with surface and groundwater drainage to the lagoon. The lagoon and drainage area are contained within about 2.3 km^2.

Data collection included 12 sampling trips conducted at approximately 1-month intervals to obtain physical, chemical, biological, and bacteriological data to define seasonal variability over a 13-month period. The study also included the determination of (1) community productivity rates through two diel data collection efforts; (2) diurnal variation of selected water-quality characteristics; (3) surface-water exchange between the lagoon and ocean through the outlet channel; and (4) sediment deposition rates and the expected lifespan of the lagoon. This is the first study to characterize the surface-water hydrology and sedimentation of Laguna Grande. Lagoon flora, fauna, and soil types have been identified and described by Weaver and others (1999) and Boccheciamp (1977).



Photograph from the U.S. Army Corps of Engineers (USACE) 2006-2007 othophotos, 1 meter resolution, for Puerto Rico,

Figure 2. Aerial photograph showing Laguna Grande main water body and inlet/outlet channel.

Description of Study Area

The study area includes Laguna Grande, the lagoon channel, and other adjacent areas with surface-water and groundwater drainage into the lagoon (fig. 2). The Laguna Grande drainage area was estimated to encompass about 2.3 km^2. The 50-ha saltwater lagoon has a mean depth of about 3 m, and a maximum depth of about 5 m in distinct areas located at the southwestern flank of the lagoon, which is connected to the Atlantic Ocean by the shallow Laguna Grande Channel (fig. 2). Laguna Grande contains tidal swamps that are underwater most of the year, and tidal flats that are slightly above mean sea level and only affected by saltwater during high tides. No perennial streams discharge into the lagoon; consequently, it only receives freshwater inflow during intense rainfall/runoff events. The climate is predominantly dry and windy, with an annual long-term average rainfall of about 1,605 mm (National Oceanic and Atmospheric Administration, 1948-1996).

The drainage area is composed largely of volcanic breccias and tuffaceous sandstone and siltstone, which are primarily of marine origin. Basin sediments also include alluvium, sand, and calcium carbonate in the form of limestone (Weaver and others, 1999).

The lagoon is surrounded by a variety physiographic areas, including a headland dominated by a secondary, semi-evergreen forest; rocky and sandy shorelines covered by a secondary woodland; tidal flats; mangrove swamps; and brackish-water lagoons (Weaver and others, 1999). About 50 percent (1.15 km^2) of the Laguna Grande drainage area consists of mangroves and wetlands

The lagoon currently is used primarily for recreational and educational purposes. The Las Cabezas de San Juan Nature Reserve receives about 40,000 visitors every year through the CTPR-organized tours (Elizabeth Padilla, Conservation Trust of Puerto Rico, written commun., 2009), and at least 30,000 visitors per year by non-CTPR organized kayak tours, through the Laguna Grande inlet channel, based on observations made as part of this study. Prior to this study, no water and sediment properties have been described in the literature.

Methods of Investigation

Data for this study were collected at Laguna Grande between March 2007 and February 2009. Hydrologic properties, water-chemistry data, sediment deposition rates, and selected biological characteristics of Laguna Grande were determined from field measurements and sampling following standard USGS methods. Sample volumes, sample containers, and preservation methods used for individual chemical and biological, samples are listed in table 1.

Bathymetric Survey

A bathymetric survey of the Laguna Grande was conducted on August 21, 2008, to contour the lagoon bottom and calculate the water volume of the lagoon at mean sea level. A bathymetric/land survey system (BLASS) interfaced to a depth sounder was used to conduct the survey. The system consists of a Novatel Global Positioning System (GPS) and a digital depth sounder (Intelligent Depth, Specialty Devices Inc.). Geographic location and water depth data were simultaneously collected and stored in a portable computer. The data were then transferred into the USGS GIS for processing and analysis.

After the data reduction process, the lagoon bottom was contoured and converted into a triangulated irregular network (TIN) to calculate the volume. The TIN represents the lagoon bottom surface as thousands of adjoining triangles with x, y, and z coordinates assigned to all vertices (Environmental Systems Research Institute, Inc., 1992).

Surface-Water and Rainfall Data Collection

Water exchange between the Atlantic Ocean and Laguna Grande during low and high tides were determined through a series of discharge measurements at the lagoon inlet channel using USGS standard wading and hydroacoustic methods (Laenen, 1985).

Two tidal stations were installed, one at the lagoon and the other on the seaward side near the inlet channel, to measure tidal fluctuations in the lagoon and Atlantic Ocean, respectively, and to characterize daily and annual tidal cycles. Both stations were referenced to the mean sea level datum and operated continuously from June 5, 2007, to June 16, 2008, with data collected at 15-minute intervals using a data logger. In addition, the tidal stations were also operated selectively during the two tidal exchange cycles (October 21-22, 2008, and February 17-18, 2009) to monitor stage at Laguna Grande and the Atlantic Ocean near the inlet during the tidal cycle discharge measurements. Based on the previously collected yearly tidal fluctuation data analysis, it was determined that the highest tidal cycle occurred on October 26, 2007, and the lowest tidal cycle occurred on February 4, 2008.

To characterize the maximum and minimum flood and ebb flows, the discharge measurements were therefore conducted during October 21-22, 2008, and February 17-18, 2009, to coincide with the typical periods of highest and lowest tides for the year. Discharge measurements were made at hourly intervals starting on October 21st at 8:30 a.m. and ending on October 22nd at 8:30 a.m. An acoustic Doppler current profiler (ADCP) was employed on both days to measure water flow into (flood flow) and out of (ebb flow) the lagoon during a full tidal cycle period of 25 hours. During February 17-18, 2009, flood and ebb tide discharge measurements were made using a SonTek Flow Tracker ® from 11:15 a.m. on the 17th to 11:15 a.m. on the 18th.

Table 1. Sample collection and preservation for selected analytes measured at Laguna Grande, Fajardo, Puerto Rico.

[cm, centimeter; m, meter; mL, milliliter; mm, millimeter; L, liter; °C, degrees Celsius; H_2SO_4, sulfuric acid; N, normality; µm, micron]

Sample matrix	Analyte	Sample volume	Sample container	Method of sample preservation
Water	Total nutrients (nitrogen and phosphorus)	Two 125-mL aliquots	Brown and white polyethylene bottles	Brown bottle: filtered through 0.45-µm , chilled at 4°C White bottle: field rinsed, added 1 mL H_2SO_4 4.5 N, chilled at 4°C
Water	Chlorophyll a	1 L	White polyethylene bottle, field-rinsed	47 -mm glass fiber filter, recorded volume filtered. Placed in vial and wrapped in aluminum foil, frozen
Water	Fecal coliform	125 mL	Sterilized, narrow-mouth bottle	Chilled at 4°C, processed within 6 hours of collection
Water	Phytoplankton biomass	1 L	White polyethylene bottle, field-rinsed	47 -mm glass fiber filter, recorded volume filtered. Placed in vial and wrapped in aluminum foil, frozen
Water	Primary productivity	350 mL	Clear and dark glass dissolved-oxygen bottle	Initial: added 1 pillow of pre-measured manganeous sulfate reagent, 1 pillow of pre-measured alkaline iodide reagent, and 1 pillow of pre-measured sulfamic acid reagent: chilled at 4°C Light: added 1 pillow of pre-measured manganeous sulfate reagent, 1 pillow of pre-measured alkaline iodide reagent, and 1 pillow of pre-measured sulfamic acid reagent. Dark: added 1 pillow of pre-measured manganeous sulfate reagent, 1 pillow of pre-measured alkaline iodide reagent, and 1 pillow of pre-measured sulfamic acid reagent.
Sediment	Age dating by ^{137}Cs, and ^{210}Pb	1-m-long by 5.1-cm-diameter core	Clear polyethylene wide mouth jar with caps.	Collected and capped at both ends and stored vertically

Rainfall data in the drainage area were collected at a meteorological station about 700 m northeast of the center of the lagoon as part of the University of Puerto Rico Long-Term Ecological Research Program (fig. 2). The site is operated and maintained by University of Puerto Rico, Río Piedras Campus.

Water-Quality Sampling and Analysis

Water-quality data were collected and analyzed to determine selected physical and chemical characteristics, as well as fecal coliform indicator bacteria concentrations. Selected physical characteristics of the water in Laguna Grande were measured at eight sites using a YSI multi-parameter water-quality instrument (fig. 3). Meaurements included temperature, turbidity, pH, dissolved oxygen, specific conductance, salinity, and water transparency. At two sites, samples were collected for chemical analysis of nutrients and chlorophyll-*a* concentrations (fig. 3). Table 2 lists the physical and chemical, and biological determinations made at each station. Data collected from March 2007 to June 2008 are listed in appendix 1.

A multiparameter water-quality probe (YSI 650®) was used to measure *in-situ* temperature, pH, dissolved oxygen, specific conductance, and salinity derived from specific conductance on an approximately 1-month basis (during morning hours) from March 2007 to June 2008. Water transparency was also measured during these visits by lowering a 20-cm-diameter Secchi disk into the water and recording the depth at which it disappeared from view. The upper surface of the Secchi disk was divided into four quadrants with alternate black and white areas.

Nitrogen and phosphorus compounds and chlorophyll *a* were sampled on a nearly monthly basis at stations 6 and 8, located in the southern and northern portions of Laguna Grande, respectively (fig. 3), from March 2007 to June 2008. These stations were positioned to represent areas of nutrient input from steep-slope areas within the Laguna Grande drainage basin. Nutrient water samples were collected, filtered onsite as needed, chilled, and sent to the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, for analysis (table 1). The nitrogen species analyzed were organic nitrogen, ammonium, nitrate, and nitrite; total nitrogen is the sum of all of these species. Phosphorus was analyzed for total concentrations only, with no species determinations. Chlorophyll-*a* samples were collected in labeled bottles, filtered onsite, and packed in dry ice, and sent to the NWQL for analysis (table 1). Nutrients results are reported in milligrams per liter and chlorophyll *a* results are reported in micrograms per liter.

Determination of Biological Characteristics

Primary productivity, phytoplankton biomass, and fecal indicator bacteria concentrations for Laguna Grande were determined using standard USGS procedures (Clesceri and others, 1998). In estimating primary productivity rates, respiration and gross productivity rates were also determined.

The most straightforward and inexpensive method for estimating primary productivity in water bodies is the light (translucent) and dark (non-translucent) bottle method, which can be used to determine net changes in the concentration of dissolved oxygen for a given volume of water within a given time interval (Clesceri and others, 1998). This technique was used for the analysis of net primary productivity by phytoplankton in the water column. In addition, two diel (24-hour) studies were conducted to determine the aquatic net community primary productivity, which includes phytoplankton, periphyton, and macrophyte productivity. The productivity associated only with periphyton and macrophytes can therefore be calculated by subtracting phytoplankton net primary productivity from community net primary productivity.

At roughly monthly intervals, productivity measurements were made at stations 6 and 8 by sampling lagoon water in light and dark dissolved oxygen bottles (table 1). These sampling sites correspond to those where nutrient samples were collected (fig. 3). Incubation was typically initiated before 6:00 a.m. and terminated at about 10:00 a.m. The early initial time was selected to avoid high oxygen saturation levels at the time of sample collection so that an increase in dissolved oxygen concentration could be observed at the end of the incubation period. The initial concentration of dissolved oxygen prior to incubation was determined using the Winkler titration method (Clesceri and others, 1998). At both sites, an aluminum rack was deployed that contained two contiguous light bottles and two contiguous dark bottles (Clesceri and others, 1998). The samples of lagoon water were incubated at the depths from which they were collected for at least 4 hours. After incubation, the bottles were removed and their dissolved oxygen concentration was determined by titration. The initial dissolved oxygen concentration was expected to decrease in the dark bottle by respiration, and was expected to increase in the light bottle by photosynthesis. The oxygen production and respiration results, therefore, can be expressed as:

$$\text{Gross productivity (Pg)} = OL - OD;$$
$$\text{Net productivity (Pn)} = OL - OI; \text{ and}$$
$$\text{Respiration (R)} = OI - OD,$$

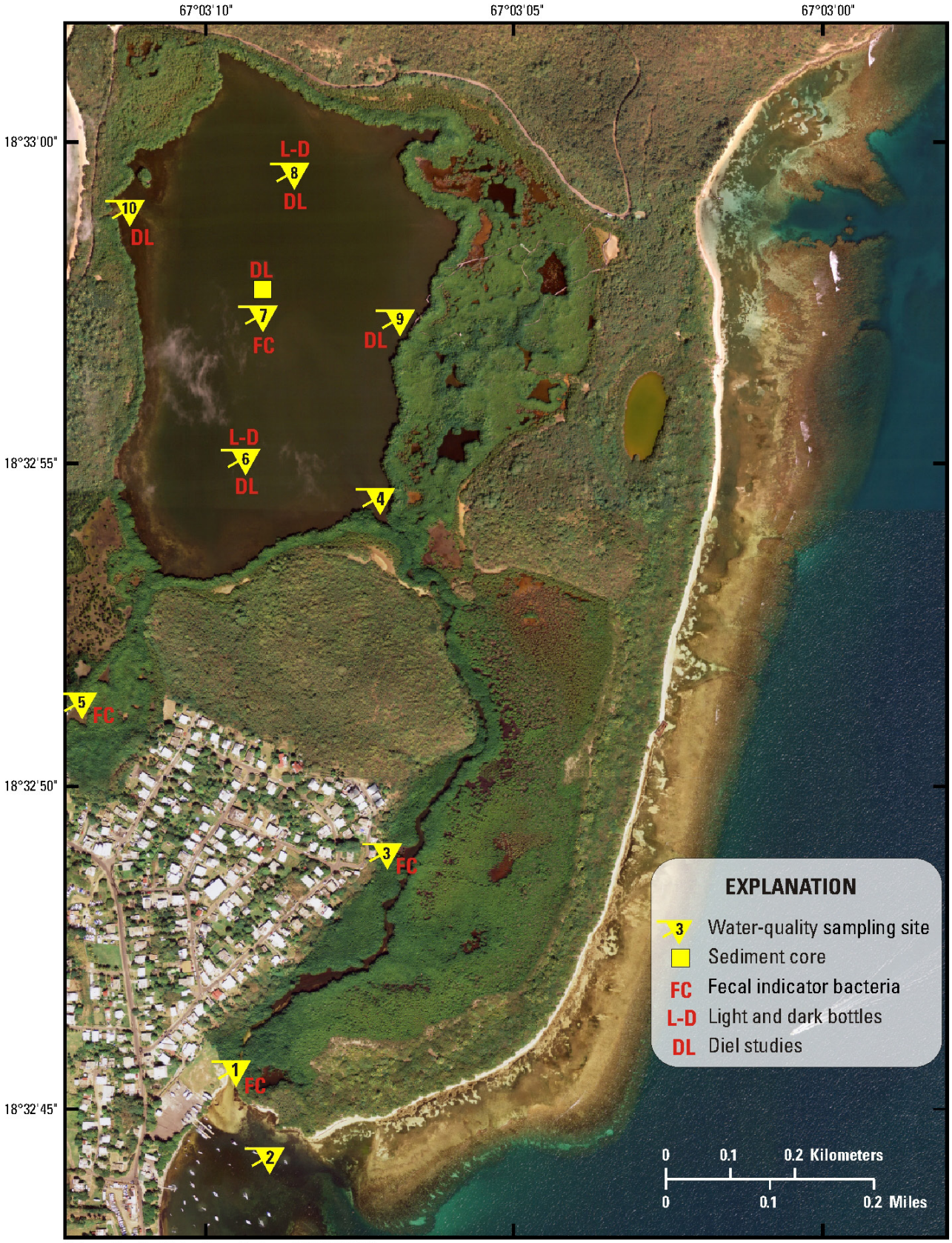
where,

OL is the dissolved oxygen concentration at the end of the incubation period in the light bottle;

OD is the dissolved oxygen concentration at the end of the incubation period in the dark bottle;

and

OI is the initial dissolved oxygen concentration prior to incubation.



Photograph from the U.S. Army Corps of Engineers (USACE) 2006-2007 othophotos, 1 meter resolution, for Puerto Rico,

Figure 3. Aerial photograph showing Laguna Grande water quality, biological, and sediment-core station locations.

Table 2. Laguna Grande sampling stations and applicable determinations.

[Monthly field determinations included measurements of temperature, turbidity, pH, dissolved oxygen, specific conductance, salinity, and water transparency (determined by Secchi disk). USGS, U.S. Geological Survey].

Station name	USGS identification number	Determinations
Laguna Grande no. 1	50069660	Field determinations, fecal indicator bacteria
Laguna Grande no. 2	50069670	Field determinations
Laguna Grande no. 3	50069650	Field determinations, fecal indicator bacteria
Laguna Grande no. 4	50069630	Field determinations
Laguna Grande no. 5	50069640	Field determinations, fecal indicator bacteria
Laguna Grande no. 6	50069620	Field determinations, turbidity, nutrients, primary productivity [1, 2], phytoplankton biomass, chlorophyll-*a*
Laguna Grande no. 7	50069610	Field determinations, primary productivity[2], fecal indicator bacteria, sediment cores for age dating
Laguna Grande no. 8	50069600	Field determinations, turbidity, nutrients, primary productivity[1, 2], phytoplankton biomass, chlorophyll *a*
Laguna Grande no. 9	50069615	Primary productivity[2]
Laguna Grande no. 10	50069605	Primary productivity[2]

[1] Light and dark bottle technique.

[2] Diel study.

As noted earlier, the diel studies were conducted at Laguna Grande to estimate the community net primary productivity, the respiration rate, and the gross productivity rate. These studies involved measuring physical and chemical water properties, such as temperature, pH, and dissolved oxygen, all of which are affected by metabolic processes in a body of water during one complete diurnal cycle. Specific conductance and salinity were also measured because they control the concentration of dissolved oxygen in water. The collected data can be used to define the hourly variation in dissolved oxygen and its saturation levels to calculate the net oxygen production and respiration rates (Odum, 1956).

The diel studies were conducted on March 29, 2007, and November 15, 2008, near the respective annual periods of lowest and highest tides for the eastern coast of Puerto Rico. Data collection began at sunrise and continued until after sunset. Measurements were made at stations 6-10 (fig. 3); stations 9 and 10 were established solely for these studies.

Phytoplankton biomass concentration was measured at stations 6 and 8 by collecting samples in designated bottles, filtering the water onsite, and shipping overnight to the NWQL for analysis. Phytoplankton biomass was determined using the ash-weight/dry-weight ratio method (Clesceri and others, 1998). The samples were collected as sequential replicates within the water column at the same locations where samples were obtained for the light and dark bottle incubation. The water samples were filtered through a glass-fiber (borosilicate) filter, refrigerated, and sent to the NWQL for analysis (table 1). At the laboratory, these filters were dried at 105 °C overnight, cooled to room temperature, and weighed; the samples were then redried at 60 °C for several hours and reweighed. The difference in weight was reported as the ash-free dry phytoplankton biomass, in milligrams per liter.

Water samples were collected for fecal coliform bacteria analysis using the “hand-dip” method, which is applicable to streams and standing waters (Clesceri and others, 1998). Samples were collected at stations 1, 3, 5, and 7, for fecal indicator bacteria concentrations (fig. 3). At each station, two or three sterilized borosilicate 100-mL bottles were immersed in the water to a depth of about 15 cm, leaving a small air pocket to maintain oxygenation and to allow subsequent mixing before analysis (table 1). Samples were passed through a 0.65-µm-pore-size filter using the microfiltration method (Clesceri and others, 1998) within 6 hours of collection. Fecal coliform bacteria were cultured in m-FC agar and incubated at 44.5 °C for 20 to 24 hours; colonies were counted using a magnifying glass (Clesceri and others, 1998). The results were reported as colonies of bacteria per 100 milliliters of sample.

Sediment Core Collection

Sediment cores were collected at one site in Laguna Grande to determine sediment deposition rates. It was determined that the center of the lagoon was a representative location to collect the cores, based on the lagoon-bottom morphology and the TIN generated from the bathymetric survey of Laguna Grande. Ten 1-m-long by 5.1-cm-diameter cores were collected using a WILDCO stainless steel hand corer with transparent polyethylene removable liner and a 3-m extension handle to reach the lagoon bottom. The corer was pushed through the bottom material until refusal—the

point at which the corer cannot be driven further into bottom sediments. Once retrieved, the liner was removed from the stainless steel outer corer, excess water was removed, and the core was capped on the bottom and top (table 1).

The cores were stored vertically until dry enough to be extruded horizontally without losing their integrity. Because the laboratory analysis requires at least 200 g of material, the cores were sectioned at 2-cm intervals from top to bottom (each section weighing about 50 g), composited into a single sample per every 2-cm layer, and placed in a labeled, wide-mouthed polypropylene jar. All composited samples were sent to a USGS NWQL-contracted laboratory (Eberline Laboratories in California, USA) for radioisotope analysis.

Bathymetry

The water volume of Laguna Grande was calculated to be 661,582 m^3 at mean sea level datum. The lagoon bottom had little relief, with a mean water depth of about 3 m and a maximum depth of 5 m below mean sea level in the southwestern part (fig. 4). Most of the lagoon depths ranged from 1 to 4 m, with the shallower areas located along the eastern part of the lagoon. The Laguna Grande flooded area encompassed about 0.3 km^2 (as calculated using GIS), which is about 13 percent of the total drainage area.

Based on this analysis and the resulting bathymetric map, it can be inferred that Laguna Grande was an open bay with its mouth or entrance facing the western flank thousands of years ago, which was gradually closed by wave action and sand deposition (fig. 5). This probably explains why the eastern portion of the lagoon is shallower than the western portion, where the mouth of Laguna Grande was originally located.

Selected Hydrologic Characteristics

Freshwater inflow to Laguna Grande can be characterized as sporadic and relatively minor compared to the amount of seawater inflow to the lagoon. Seawater exchange between Laguna Grande and the Atlantic Ocean is substantially greater during the annual period of highest tides compared to the period of lowest tides.

Rainfall and Runoff

The long-term distribution of monthly rainfall at Laguna Grande was considered similar to that measured at National Oceanic Atmospheric Administration (NOAA) observation station 663657, in Fajardo, Puerto Rico, with a historical period of record from 1948 to 1996 (table 3; National Oceanic and Atmospheric Administration, 1948-1996). The long-term mean annual rainfall in the lagoon drainage area was estimated to be at about 1,605 mm.

To compare rainfall at Laguna Grande during the period of study from March 2007 to February 2008 with long-term mean rainfall, data from the University of Puerto Rico meteorological station were used (fig. 2, table 3). Unfortunately, many months of rainfall data were missing for this site, making comparisons between entire years impossible. Nonetheless, a comparison was made between the two sites for months with common data (May- August, December); long-term rainfall totals for these months range from 120 to 188 mm. The comparison revealed that 2007 was a year with below-normal rainfall during these months (table 3); equaling about 44 percent of the corresponding long-term monthly means for the area.

As noted earlier, the Laguna Grande drainage area has no ephemeral or perennial streams. Runoff in the basin is considered moderate, and occurs predominantly in the form of infrequent, intense rainfall. Freshwater inflow to Laguna Grande is estimated to be 184,575 m^3/yr, or about 28 percent of the water volume in the lagoon, based on: (1) the long-term annual rainfall average of 1,605 mm for the drainage area, (2) the rainfall/runoff ratio of about 5 percent (Giusti and López, 1967), and (3) the 2.3 km^2 extent of the drainage area. This freshwater inflow, however, typically occurs only during infrequent rainfall events with sufficient intensity to produce runoff, and is not considered to represent an effective water-renewal mechanism for Laguna Grande. Such events, however, are of importance in causing a rapid change in water-quality conditions, as was documented during a November 2007 sampling run in this study (app. 1).

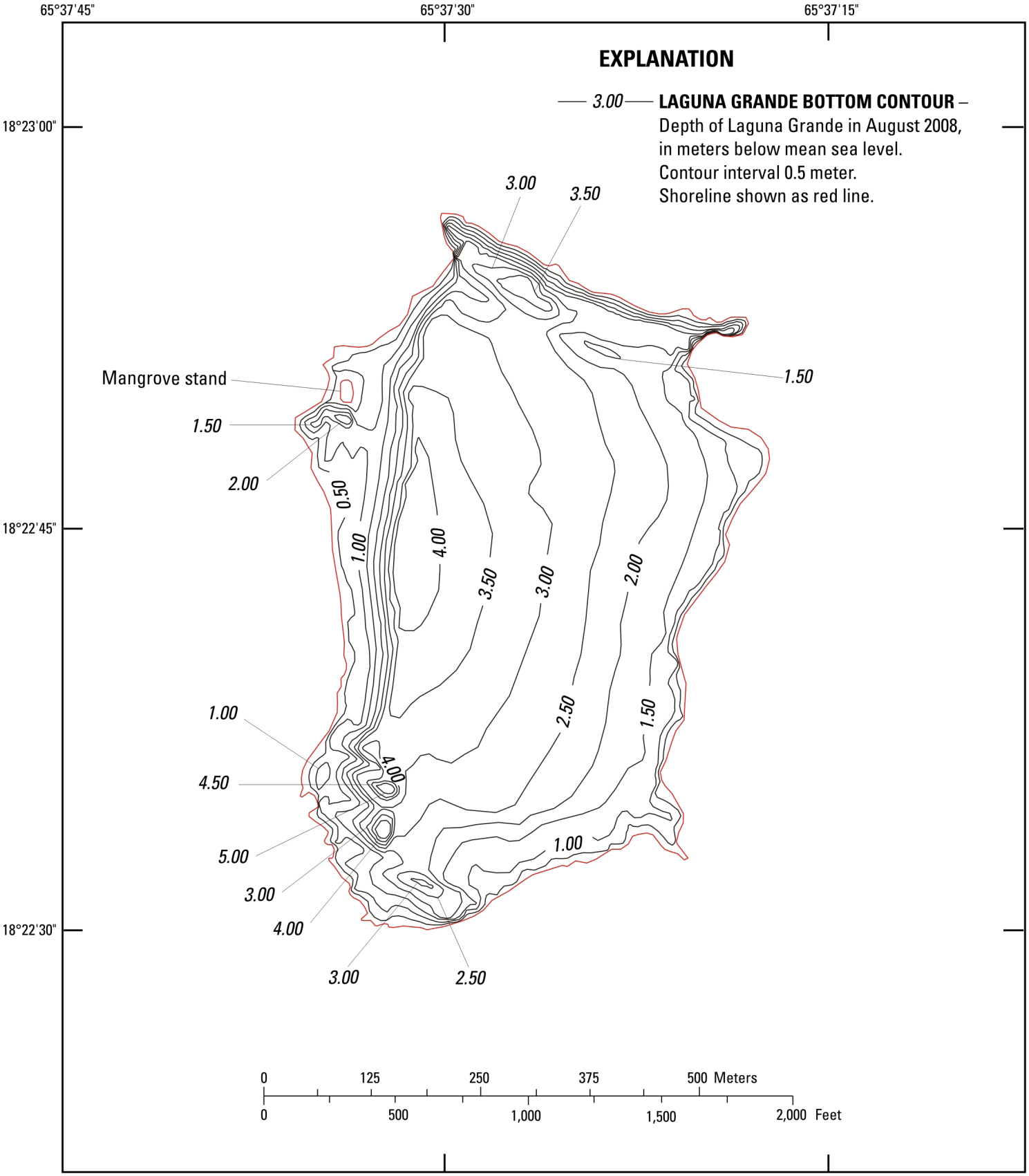


Figure 4. Map showing bathymetry of Laguna Grande main water body, Fajardo, Puerto Rico.

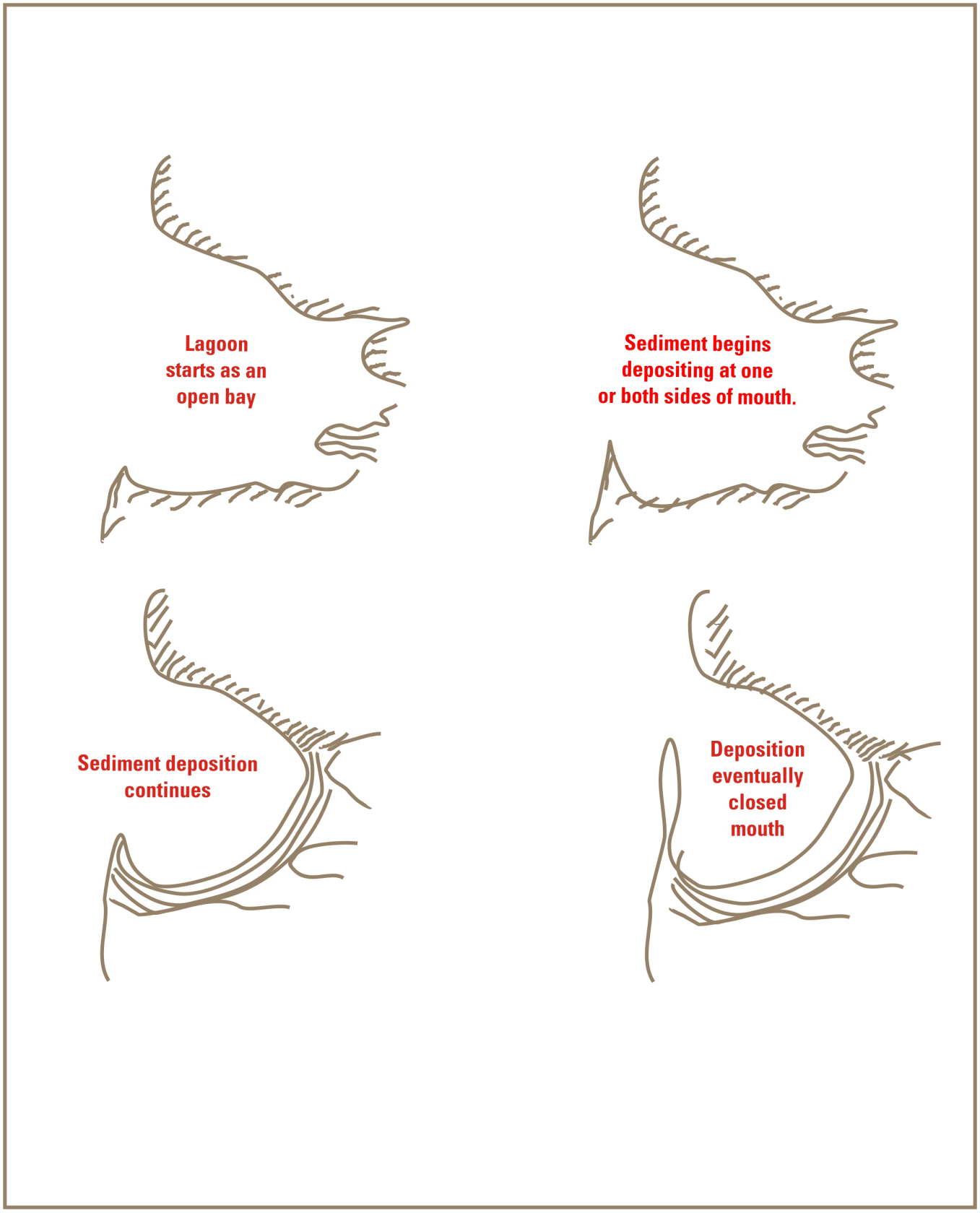


Figure 5. Diagrams showing typical lagoon formation sequence.

Table 3. Comparison between the long-term mean monthly rainfall at the National Weather Service Fajardo rainfall station no. 663657, and monthly rainfall at the University of Puerto Rico rainfall station at Laguna Grande during 2007-2008.

[All values are shown in millimeters; ND, no data; NA, not applicable]

Data type	Month												Annual rainfall
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
Long term (1948-1996) mean	89.15	68.83	75.69	98.30	188.72	126.24	134.11	157.48	166.37	197.89	182.12	120.39	1,604.77
2007-2008 rainfall	ND	ND	ND	ND	91.40	78.09	61.72	49.51	NND	NND	NND	37.78	NNA
Difference					- 34.84	- 48.15	- 72.39	-107.97				-82.61	NA

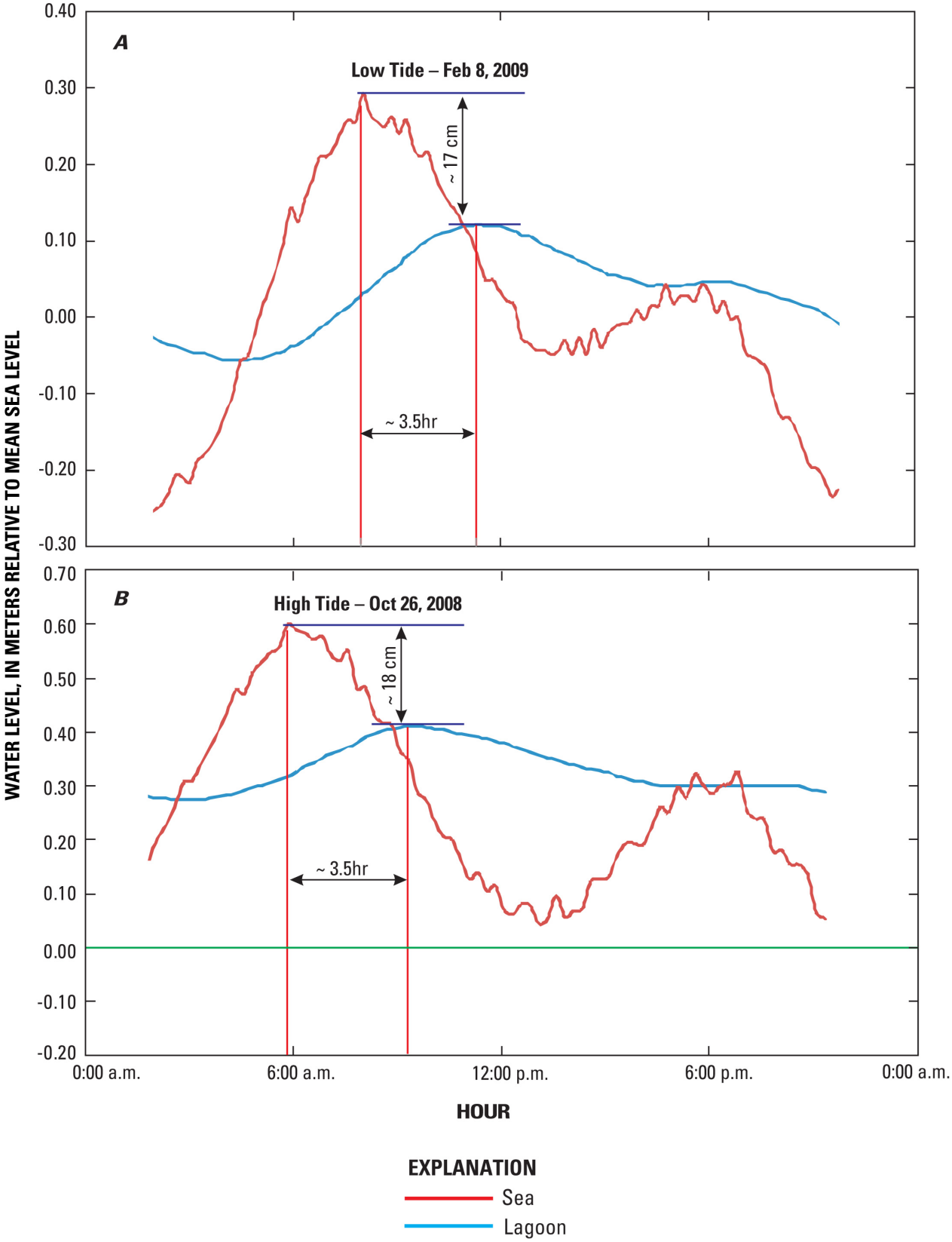


Figure 6. Graph showing typical tidal cycles in Laguna Grande and the nearshore Atlantic Ocean during the periods of *A*, lowest and *B*, highest tides of the year.

Seawater Exchange

Seawater exchange between Laguna Grande and the Atlantic Ocean occurs through the Laguna Grande Channel, which is about 1.5 km long, and 5 m wide and 1 m deep, on average (fig. 2). Flow to (flood) and from (ebb) the lagoon is controlled by oceanic tidal fluctuations, the flooded area of the lagoon, and the resistance to flow that the lagoon-water content exerts over the inflowing water.

The 25-hour tidal measurements made during periods of low and high tides for the year (February and October, respectively), indicate that stage at Laguna Grande peaked about 3.5 to 4 hours after the corresponding oceanic tidal peak (fig. 6). This time period may equal the travel time that a contaminant entering the lagoon through the channel would take to affect Laguna Grande. During February, the lagoon tidal cycle peak amplitude was about 12 cm and the sea tidal cycle was about 30 cm; during October, the lagoon tidal cycle peak amplitude was about 40 cm and the sea tidal cycle peak amplitude was 60 cm (fig. 6).

The maximum water level in Laguna Grande was 18 cm lower than that of the ocean, on average, during the October and February measurements (fig. 6). The corresponding low and high tides for the lagoon and ocean differed by about 30 cm on both occasions (fig. 6), which indicates unrestricted seawater exchange between the Atlantic Ocean and Laguna Grande during the annual periods of lowest and highest tides.

The flushing rate of a lagoon can be determined by calculating its flood (inflow) and ebb (outflow) discharges. High flushing rates are generally associated with good water quality, and healthy lagoon conditions unless the ocean-water quality is substantially impaired. Lagoon water is less susceptible to the effects of point-source contamination originating within the shoreline perimeter due to the relatively rapid dilution with seawater or purging during ebb flows. However, sudden changes in nearshore seawater quality, such as from a fuel or oil spill from nearby marinas or docks, can rapidly affect water quality in a nearby lagoon depending upon the proximity of the lagoon to the contamination source and the degree of connection between the lagoon and ocean.

During the October 21-22 tidal cycle, total outflow during the ebb tide was 94,254 m^3 and total inflow during flood tide was 110,019 m^3 (a 14 percent difference) indicating that 15,765 m^3 of water remained inside the lagoon or its surrounding wetland zone. During flood tides, seawater seeps inland through mangrove stand roots, as observed during the study. Thus, much of the 15,765 m^3 of seawater unaccounted for by ebb flow may have been lost to evapotranspiration within the extensive mangrove stands that border the lagoon and its inlet channel. Based on a water volume of 661,582 m^3, Laguna Grande flushed about 110,000 m^3/d during the October 21-22 tidal cycle, equivalent to 16.6 percent of its entire water volume. Based on this finding, it is estimated that the lagoon flushes its entire water volume every 6 days during the period of annual high tides.

During the February 17-18 tidal cycle, total outflow during the ebb tide was 62,398 m^3 and the total inflow during the flood tide was 60,971 m^3. The difference between the flood and ebb flows was only 2.3 percent, which can be considered within the discharge measurements process accuracy. It can therefore be concluded that an equal amount of water enters and exits the lagoon during the annual period of lowest tides, with insufficient water available to seep inland during this period. Based on a water volume of 661,582 m^3, Laguna Grande flushed about 61,684 m^3/d, or 9.3 percent of its entire water volume during the February 17-18 tidal cycle. Therefore, based on this finding, it is estimated that Laguna Grande flushes its entire water volume every 10.7 days during the period of annual low tides.

Assuming that the average net tidal flux between the annual high and low tides represents the mean annual tidal flux for the lagoon, Laguna Grande flushes 85,852 m^3/d of water, or 13 percent of its entire water volume during every tidal cycle. This flux correponds to a flushing rate of once every 7.7 days, or 47 times per year.

Water Quality

Although Laguna Grande currently has no specific water-quality classification (July 2009), the data collected during this study were analyzed and the water quality of the lagoon characterized using comparable values established for Class SB water. Laguna Grande is believed to satisfy all of the criteria for Class SB waters, which are classified as coastal and estuarine waters intended for use for primary and secondary contact and for the propagation and preservation of desirable species, including those that are threatened or endangered (Puerto Rico Environmental Quality Board, 2003).

Field-measured properties and constituents

As noted earlier, the physical characteristics determined for water at Laguna Grande were temperature, turbidity, pH, dissolved oxygen, specific conductance, salinity, and water transparency. Although data are presented for all sites in appendix 1, the water-quality characteristics of stations 1 and 2 are not discussed in the following analysis because station 1 is at the inlet mouth and thus affected by ebb and flood tides that can modify water-quality properties rapidly, and station 2 is the offshore station established at a navigation marker to represent nearshore conditions in the Atlantic Ocean, which can vary substantially from those inside Laguna Grande (fig. 3). Station 3 is located halfway along the Laguna Grande Channel and adjacent to housing units that may affect local water quality. Station 5 is at another area adjacent to housing units, and the other stations (4, 6, 7, and 8) are within the main water body of Laguna Grande.

Temperature

Temperature exerts a major influence on the biological activity and growth of aquatic organisms. To a point, the higher the water temperature, the greater the biological activity. Temperature is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature, which in turn affects biological activity.

Water temperature varied seasonally, but was areally and vertically uniform within the main water body of the lagoon during each sampling (stations 4, 6, 7, and 8, fig. 3, app. 1). Vertical stratification was not determined at stations 3 and 5 outside the main water body, because the water was too shallow to collect two measurements in the water column.

All temperature measurements at Laguna Grande were within the PREQB standards for SB waters, which establish that water temperature should not increase above 32.2 °C other than for natural causes. The top water column temperature ranged from 24.3 °C on January 29, 2008, at station 5 to 30.4 °C on September 11, 2007, at stations 6 and 8 (app. 1). The bottom water temperature ranged from 25.5 °C on March 4, 2008, at station 7 to 31.3 °C on May 31, 2007, at station 6. The observed temperature ranges can be divided into two general categories. During the winter months (November 2007 to March 2008) the top water column temperature ranged from to 24.3 °C to 29.5 °C. During spring and summer months (March 2007 to October 2007), the temperature range was warmer, ranging from 28.8 °C to 30.4 °C. The bottom water-column temperature during spring and summer ranged from 29.7 °C to 31.3 °C.

Turbidity

Turbidity caused by suspended colloidal particles is a measure of water clarity. The amount of total suspended solids in water is inversely related to clarity and directly related to the measured turbidity. High concentrations of particulate matter can modify light penetration, and can lead to rapid siltation of shallow lakes and bays, effectively smothering benthic habitats.

Turbidity was measured at stations 6 and 8 to account for runoff from parts of the Laguna Grande drainage area where the topography is relatively steep and sediment input to the lagoon is likely to originate. All observed turbidity values were well within the PREQB standard maximum of 10 NTU. Turbidity at station 6 ranged from 2.2 to 5.2 NTU, measured in October 2007 and May 2008, respectively. At station 8, turbidity ranged from 1.2 to 5.4 NTU, with extremes occurring during October 2007 and March 2008 respectively (table 4).

Turbidity values generally were greater at station 6 than station 8 during most of the study, which suggests that the southern part of the Laguna Grande drainage area contributes most of the colloidal particulate matter to the lagoon. It cannot be concluded that the turbidity is generated solely by runoff-derived resuspension of sediments within the basin. Development is greater in the southern part of the drainage area than the northern part and could potentially increase sediment loads and turbidity beyond current levels.

Table 4. Turbidity at stations 6 and 8 from March 2007 to June 2008.

[Values are in nephelometric turbidity units]

Sampling date	Station 6	Station 8
Mar. 28, 2007	2.25	1.42
May 31, 2007	3.87	1.87
June 27, 2007	3.44	3.76
July 24, 2007	4.08	2.93
Sep. 11, 2007	3.02	2.85
Oct. 16, 2007	2.16	1.16
Nov. 14, 2007	2.47	2.23
Jan. 29, 2008	2.83	3.87
Mar. 4, 2008	3.35	5.37
Apr. 1, 2008	3.95	4.41
May 13, 2008	5.21	4.45
June 17, 2008	2.46	4.51
Average	3.26	3.24

pH

The pH is a measure of the activity of hydrogen ions. The pH of water affects the solubility and biological availability of chemical constituents, such as nutrients. In addition, pH reflects biological processes because photosynthesis consumes dissolved carbon dioxide (CO_2). Removal of CO_2 reduces the acidity of the water, thereby increasing water pH. In contrast, respiration of organic matter produces CO_2, which dissolves in water to produce carbonic acid, thus lowering water pH.

The pH values varied seasonally near the top of the water column, but were areally uniform within the lagoon (excluding stations 1 and 2), and ranged from 7.1 to 7.9; seawater pH typically ranges from 7.3 to 8.5. Top and bottom pH values were similar, with no vertical stratification observed during the entire study except on March 28, 2007 at stations 4 and 6, where a marked vertical stratification of one standard unit was observed (app. 1). The lowest value (about 7.1) was obtained on January 29, 2008, and the highest value (about 7.9) was obtained on March 4, 2008 (app. 1). The mean top and bottom water-column pH values ranged from 7.6 to 7.7.

The pH values in Laguna Grande did not show the wide diurnal variations expected in eutrophic waters due to high primary productivity. Rather, the diurnal variation in pH in Laguna Grande was consistent with mesotrophic water bodies. Mesotrophic water bodies have an intermediate level of productivity, with a rough balance of productivity and

decomposition. Diurnal variation in pH can be expected where primary or community biological productivity is substantial. During daylight hours, when primary productivity is high, dissolved carbon dioxide is captured during photosynthesis, increasing pH. During nighttime hours, cellular respiration releases carbon dioxide into the waters, decreasing pH. The diurnal variation in pH in Laguna Grande was within the PREQB standard of 7.3 to 8.5 units.

Dissolved Oxygen

The absolute concentration of dissolved oxygen in an aquatic system is controlled primarily by physical variables, such as water temperature, barometric pressure, salinity, as well as by photosynthetic activity and community respiration. In the presence of high photosynthetic activity, concentrations of oxygen increase monotonically from morning to late afternoon. These increases in dissolved oxygen concentration can be used to estimate the extent of photosynthetic activity. Monthly dissolved oxygen concentration measurements were used to evaluate water quality in terms of pre-established standards and to help establish longer-term trends.

The dissolved oxygen concentrations in the lagoon and channel were generally closer to or slightly lower than, the PREQB standard of 5.0 mg/L; however, these conditions are considered typical for a mesotrophic lagoon. The monthly variation in dissolved oxygen concentrations at Laguna Grande was lowest at stations 6, 7, and 8, near the center of the lagoon. Dissolved oxygen concentrations in top samples ranged from 3.3 to 6.1 mg/L (at station 6), which corresponds to an oxygen saturation range of about 52 to 89 percent. Bottom water column dissolved oxygen concentrations ranged from 0.1 to 4.8 mg/L at stations 8 and 7, respectively, which corresponds to an oxygen saturation range of 2 to 80 percent.

Monthly variation in dissolved oxygen concentration was greatest at stations 3 and 5, located halfway along the Laguna Grande Channel and in the small embayment southwest of the main water body, respectively (fig. 3). Stations 3 and 5 are the closest to developed areas, and may reflect anthropogenic influence. The dissolved oxygen data indicate that this is the most impaired area of Laguna Grande, which is consistent with the fecal coliform data presented later in this report. Dissolved oxygen concentrations ranged from 1.8 to 4.8 mg/L at station 3, and from 0.1 to 2.9 mg/L at station 5. Oxygen saturation values ranged from 32 to 72 percent at station 3, and from 1 to 44 percent at station 5. Dissolved oxygen concentrations were markedly lower at station 5 than at the other stations in the lagoon during all sampling trips.

Supersaturation of dissolved oxygen was not observed during monthly samplings, which is consistent with mesotrophic rather than eutrophic conditions. All monthly samplings occurred between 6:00 a.m. and 9:00 a.m., however, and morning dissolved oxygen values are not good trophic-level indicators because sunlight intensity is low during this period. Supersaturation was not documented during the diel study on March 29, 2007, but was recorded in the afternoon hours during the November 15, 2007, diel study at all stations used for that effort (stations 6-10). This condition was probably a consequence of nutrient-rich runoff that must have occurred days prior to the diel study, as can be inferred from the specific conductance and salinity data presented next in this report.

Specific Conductance

Specific conductance is a measure of the capacity of water (or other substance) to conduct an electrical current. Specific conductance is a function of the types and quantities of dissolved constituents, and can be used to approximate dissolved-solids concentrations in water. The concentration of dissolved solids, expressed in milligrams per liter, is typically 55 to 75 percent of the specific conductance in microsiemens per centimeter at 25 °C (Díaz and others, 2004).

Specific conductance ranged from 11,840 to 60,240 µS/cm near the top of the water column in Laguna Grande; both extremes were measured at station 5. Values of specific conductance varied seasonally, but were areally uniform within the lagoon. Specific conductance was lowest in November 2007, coinciding with high rainfall, and highest in October 2007.

Specific conductance was vertically stratified at stations 6, 7, and 8, and was about 16 percent less at the top of the water column than the bottom (45,000 and 54,000 µS/cm, respectively). As noted earlier, temperature was also vertically stratified at these sites, ranging from about 27 °C at the top of the water column to 30 °C at the bottom. The vertical stratification of specific conductance and temperature at stations 6, 7 and 8, as well as the low measured specific conductance at station 5, indicate a recent rainfall-runoff event. Specific conductance standards have not been established by the PREQB.

Salinity

Water salinity refers to the accumulation of total dissolved salts. Typical salinity values for marine and coastal lagoons with good seawater exchange range from 35 to 40 ppt. Salinity is linearly correlated with specific conductance by the relation described in Clesceri and others (1998). This relation was used to determine salinity indirectly at Laguna Grande using specific conductance measurements.

Salinity in Laguna Grande varied seasonally but not areally, and vertical stratification was minimal except during November 2007, when the vertical stratification of salinity reflected that of specific conductance. Salinity was highest in October 2007 and June 2008 at station 5 (40.4 and 39.9 ppt, respectively) and lowest in May and November 2007, also at station 5 (12.4 and 6.8 ppt, respectively). Salinity in the lagoon was generally comparable to that of coastal seawater (about 35 ppt); a salinity standard has not been established by PREQB.

Table 5. Total nitrogen species concentration by month at stations 6 and 8 from March 2007 to June 2008.

[N, nitrogen; NH_4^+, ammonium; NO_3^-, nitrate nitrogen; NO_2^-, nitrite nitrogen; all concentrations as N, in milligrams per liter].

Sampling date	Total organic N	Total NH_4^+	Total NO_3^-	Total NO_2^-	Total N
Station 6					
Mar. 28, 2007	0.115	0.076	0.00137	0.00963	0.202
May 31, 2007	0.274	0.050	0.00149	0.01051	0.336
June 27, 2007	0.233	0.027	0.00104	0.00796	0.269
July 24, 2007	0.290	0.071	0.00036	0.01664	0.378
Sep. 11, 2007	0.232	0.051	0.00150	0.00550	0.290
Oct. 16, 2007	0.164	0.055	0.00059	0.00741	0.227
Nov. 14, 2007	0.247	0.035	0.00422	0.05378	0.340
Jan. 29, 2008	0.158	0.086	0.00220	0.01180	0.258
Mar. 4, 2008	0.195	0.057	0.00004	0.01596	0.268
Apr. 1, 2008	0.145	0.055	0.00000	0.01300	0.213
May 13, 2008	0.293	0.046	0.00000	0.01100	0.350
June 17, 2008	0.166	0.059	0.00027	0.00873	0.234
Average	0.209	0.056	0.00100	0.01400	0.280
Station 8					
Mar. 28, 2007	0.167	0.067	0.00079	0.00721	0.242
May 31, 2007	0.218	0.040	0.00087	0.00513	0.264
June 27, 2007	0.253	0.024	0.00045	0.01055	0.288
July 24, 2007	0.270	0.063	0.00000	0.01951	0.353
Sep.11, 2007	0.229	0.049	0.00225	0.00575	0.286
Oct. 16, 2007	0.076	0.059	0.00050	0.00750	0.143
Nov. 14, 2007	0.242	0.034	0.00500	0.06600	0.347
Jan. 29, 2008	0.177	0.095	0.00216	0.01184	0.286
Mar. 4, 2008	0.185	0.058	0.00000	0.01800	0.261
Apr. 1, 2008	0.179	0.055	0.00000	0.01100	0.245
May 13, 2008	0.218	0.050	0.00114	0.01386	0.283
June 17, 2008	0.238	0.060	0.01079	0.00021	0.309
Average	0.204	0.055	0.00200	0.01500	0.276

Water Transparency

Water transparency is a physical water property that has ecological and recreational importance. Specifically, water transparency affects sunlight penetration, and thus, photosynthetic activity, and is an aesthetically valuable characteristic. Water transparency and light penetration can be reduced by natural factors, such as inorganic particulate matter, plankton biomass, and humic and fulvic acids produced from decomposing organic matter that can color the water.

As noted earlier, the water transparency of Laguna Grande was measured using a Secchi disk, which provides a means for determining the limit of visibility based on contrast between four quadrants with alternate black and white areas on the disk. Water transparency is roughly twice the Secchi disk depth of dissappearance, because light must travel twice through a water column before it is seen. Biologists consider the depth of the euphotic zone to be roughly three times the measured transparency; the eupthotic zone is defined as the upper layer of a water body into which enough light penetrates to permit the growth of green plants and algae.

Water transparency of Laguna Grande was generally high compared to the lagoon mean water depth of about 3 m, with transparencies ranging between 76 and 201 cm, and a mean depth of 90 cm. Thus, the euphotic zone extended to the lagoon bottom at stations 1, 3, 4, and 5. However, light penetration near the middle of the lagoon (stations 6,

7, and 8) did not reach the bottom in about one third of the measurements (app. 1, values less than 100 cm), which could inhibit plant growth on the Laguna Grande bottom substrate.

Water transparency varied temporally and areally, and was greatest in October 2007 at station 6, when the lagoon bottom was visible (201 cm). Transparency was lowest on four occasions at station 5, when visibility was only 15 cm; however, these low transparencies would not prevent light from reaching the bottom because water is only about 30 cm deep at this station. The PREQB has no established standards for water transparency.

Other Chemical Constituents

Water chemisty determinations for Laguna Grande included nutrient concentrations (nitrogen and phosphorus), and chlorophyll-*a* concentrations. Nutrients are indicators of trophic levels, and chlorophyll *a* is an indicator of photosynthetic activity as well as trophic level.

Nitrogen and Phosphorus

Nutrients are elements and compounds essential to sustain plant and animal life (Hutchinson, 1973). Nitrogen (N) and phosphorus (P) compounds are considered to be the most important in aquatic ecosystems because they are often limiting factors. Waters with ambient nutrient concentrations can become enriched through organic matter decay, autotrophic or heterotrophic processes, and by runoff. Human and animal activities, as well as poor soil conservation practices, can also increase nutrient inputs to waters with background concentrations of these constituents. Several chemical species of nitrogen, such as ammonium, nitrites, nitrates, and orthophosphorus, are the primary anthropogenic contaminants related directly to eutrophication. Excessive concentrations of these constituents can lead to increased densities of planktonic and benthic algae, and substantial daily variation in dissolved oxygen concentrations and pH (Webb and Gómez-Gómez, 1997).

Total nitrogen concentrations in Laguna Grande indicate that total nitrogen appears to be distributed uniformly in Laguna Grande, and were substantially below the PREQB standard of 5 mg/L. Concentrations at station 6 ranged from 0.20 to 0.38 mg/L, with a mean concentration of 0.28 mg/L (table 5). At station 8, total nitrogen concentrations ranged from 0.14 to 0.35 mg/L, with a mean value of 0.28 mg/L.

Most of the nitrogen measured in Laguna Grande was in the form of organic nitrogen, with an average concentration of 0.209 mg/L, and composing roughly 74 percent of the total nitrogen as N present (table 5). The next most predominant nitrogen species was ammonium, although it existed in very low concentrations at both stations. The average ammonium concentration was 0.056 mg/L, or 20 percent of the total nitrogen as N present. Of lesser abundance were nitrite and nitrate, with mean concentrations of 0.014 and 0.002 mg/L N, respectively, and composing 5 and roughly 1 percent of the total nitrogen as N present.

Table 6. Total phosphorus concentration by month at stations 6 and 8 from March 2007 to June 2008.

[P, phosphorus; all concentrations as total P, in milligrams per liter]

Sampling date	Station 6	Station 8
Mar. 28, 2007	0.0299	0.0248
May 31, 2007	0.0268	0.0173
June 27, 2007	0.0211	0.0205
July 24, 2007	0.0088	0.0019
Sep.11, 2007	0.0197	0.0156
Oct. 16, 2007	0.0115	0.0379
Nov. 14, 2007	0.1064	0.0210
Jan. 29, 2008	0.0060	0.0125
Mar. 4, 2008	0.0168	0.0220
Apr. 1, 2008	0.0183	0.0169
May 13, 2008	0.0213	0.0199
June 17, 2008	0.0288	0.0226
Average	0.0260	0.0190

The high proportion of total N accounted for by organic nitrogen and ammonium, compared to that available as nitrate and nitrite, is typical of mesotrophic and eutrophic water bodies because of the rapid uptake of the reduced states of nitrogen by photosynthetic activity. In the absence of regular stream inflow to the lagoon and with the relatively short-duration runoff episodes during the study period, the sources of nitrogen measured were probably internal (decomposition and metabolism), with infrequent, external input from surrounding wetlands. The relatively high observed rates of phytoplankton production (discussed later) support this.

Total phosphorus concentrations in Laguna Grande ranged from 0.01 to 0.11 mg/L as P, well below the PREQB standard of 1 mg/L. The highest concentration was measured in October 2007, and the mean concentration for both stations was 0.02 mg/L (table 6).

The low phosphorus concentrations suggest that available P uptake occurs rapidly through photosynthetic activity by benthic and planktonic flora, and that phosphorus may limit primary production. The total phosphorus concentrations measured at Laguna Grande were substantially lower than those measured in other coastal lagoons in Puerto Rico, where concentrations are greater than 1 mg/L. For example, in Laguna de Las Salinas in Ponce, Puerto Rico, mean total phosphorus concentration was 1.86 mg/L (Soler-López and others, 2005). In addition, mean concentrations in Laguna San José and Laguna de Piñones (both in the San Juan Bay estuary system) ranged between 1.0 and 2.5 mg/L, respectively (U.S. Geological Survey, Caribbean Water Science Center, unpub. data, 2000-2005).

Redfield and others (1963) found that the atomic ratio of carbon (C), nitrogen (N), and phosphorus (P) are related generally by a C:N:P ratio of 106:16:1 in planktonic tissue, which is known as the Redfield's ratio. This ratio can be simplified to the total nitrogen to total phosphorus ratio (TN/TP), which can be used to determine the potential for phytoplankton and plant growth in ambient waters. According to Vollenweider (1968), TN/TP ratios exceeding a value of 15 indicate that phosphorus is the limiting factor for phytoplankton and aquatic plant growth. The TN/TP mean ratio in Laguna Grande was 12.5, indicating that nitrogen could become a limiting factor in primary productivity in Laguna Grande if the ratio were to decrease further. Phosphorus is also a limiting factor in primary productivity at Laguna Grande, because primary production could not occur in its absence. Phosphorus may be a co-limiting nutrient because the N/P ratio is close to 15.

Chlorophyll *a*

Chlorophyll *a* is the principal photosynthetic pigment in vascular plants and algae, converting sunlight into the chemical energy needed to fix CO_2 into carbohydrates. The pigment was sampled at stations 6 and 8, to provide a reasonable estimate of algal biomass in Laguna Grande (fig. 3).

Chlorophyll-*a* data collected during this study indicate that Laguna Grande is mesotrophic. Concentrations were fairly consistent between stations 6 and 8 in Laguna Grande, averaging 6.02 and 6.39 µg/L, respectively. Concentrations ranged from from 2.19 to 13.01 µg/L for both sites. The highest concentrations were measured in September and October 2007 and May 2008, and lowest were measured in January 2008 (table 7). The mean chlorophyll-*a* concentration of 6.2 µg/L for Laguna Grande was well below the concentrations of other coastal lagoons such as Laguna de Las Salinas, where mean concentrations were 14 µg/L (Soler-López and others, 2005). Concentrations ranged between 14 and 23 µg/L in Laguna San José, and in Laguna de Piñones concentrations were about 26 µg/L (U.S. Geological Survey, Caribbean Water Science Center, unpub. data, 2000-2005).

Biological Characteristics

Primary productivity, phytoplankton biomass, and fecal indicator bacteria concentrations were determined at Laguna Grande to characterize biotic conditions within its aquatic ecosystem. Laguna Grande appears to be mesotrophic, with relatively high primary productivity, and constitutes an important food supply for primarily aquatic organisms. Most of the biomass standing crop, however, was found to be generated by benthic organisms in the form of periphyton and macrophytes. Fecal indicator bacteria were present in relatively high concentrations near developed areas compared to concentrations at the center of Laguna Grande.

Primary Productivity

The primary productivity of an ecosystem is defined as the rate at which new organic matter is created by photosynthesis (or chemosynthesis), and is expressed as the production of organic matter per unit of volume (or integrated under a surface area) per unit of time. The principal primary producers in aquatic ecosystems include phytoplankton, periphyton, and macrophytes. Of these, phytoplankton often synthesizes the most organic matter in aquatic systems, although periphyton and macrophytes add substantial amounts. The primary productivity is summarized by the universal equation:

$$6CO_2 + 12H_2O \xrightarrow[\text{Pigment}]{\text{Light}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

In an estuarine system, primary productivity supplies organic matter that supports aquatic and terrestrial food chains. Three processes control the net organic matter created:

1. *Net productivity* (*Pn*)—The net production of organic matter, or stored energy minus the losses per selected time interval. This process involves photosynthetic organisms only.
2. *Respiration* (*R*)—The amount of oxygen consumed by metabolic processes. This process involves all community organisms.
3. *Gross productivity* (*Pg*)—The observed change in biomass, plus all predatory and non-predatory losses per selected time interval. This process involves all community organisms and is the sum of net productivity plus respiration.

Natural systems are affected by many factors that cause rapid, frequent, and variable changes in productivity, such that only average rates can be determined in a typical environment. The annual time period, therefore, is probably the most meaningful interval in comparative quantitative analyses of material and energy fluxes at population, community, and ecosystem levels (Wetzel, 2001).

Table 7. Chlorophyll-a concentration at stations 6 and 8, from March 2007 to June 2008.

[Del, sample damaged; all concentrations are in micrograms per liter].

Sampling date	Station 6	Station 8
Mar. 28, 2007	Del	Del
May 31, 2007	Del	Del
June 27, 2007	8.82	6.34
July 24, 2007	6.93	9.70
Sep. 11, 2007	10.02	7.25
Oct. 16, 2007	3.36	13.01
Nov. 14, 2007	3.61	3.52
Jan. 29, 2008	3.76	2.19
Mar. 4, 2008	3.59	4.79
Apr. 1, 2008	5.26	3.74
May 13, 2008	10.07	6.04
June 17, 2008	4.73	7.33
Average	6.02	6.39

Phytoplankton Net Primary Productivity, Plankton Respiration, and Plankton Gross Productivity

As described earlier, light and dark bottle primary productivity measurements were made to determine the net primary productivity by phytoplankton, and plankton respiration and gross productivity. Table 8 summarizes the primary productivity results obtained using the light and dark bottle method at stations 6 and 8. The dissolved oxygen concentrations shown in table 8 represent the average of two titrations for each of the two light bottles and the average of two titrations for each of the two dark bottles. Therefore, each individual OL, OI, and OD value presented in table 8 is the average of four separate titrations. Although some initial dissolved oxygen values were at or near saturation (or supersaturated), these were not excluded from the calculations because oxygen concentrations continued to increase during incubation, indicating net primary productivity.

On the basis of dissolved oxygen production and consumption as a measure of photosynthetic and respiration rates, results of the light and dark bottle primary productivity studies indicate that the Laguna Grande plankton community is very productive. The phytoplankton yielded an annual average net productivity rate of 0.10 mgO_2/L-hr, and the plankton yielded an annual average respiration rate of 0.12 mgO_2/L-hr (table 8). The average annual plankton gross productivity rate was 0.22 mgO_2/L-hr. Multiplying the average annual net productivity rate by the number of hours for which net primary productivity occurred (typically 8 hours based on the diel study results) yields a daily net productivity of 0.8 mgO_2/L. This value is equivalent to a daily net productivity of about 0.8 gO_2/m^3 for phytoplankton in the uppermost meter in the lagoon (fig. 7), which is considered to be representative of the entire water column based on water transparency values. The same procedure was used to calculate daily respiration, which was 2.9 gO_2/m^3. In this case, however, the hourly respiration rate was multiplied by 24 because respiration can be assumed to remain constant throughout a 24-hour period. The average daily gross productivity for plankton was 3.7 gO_2/m^3 (fig. 7).

Multiplying the daily net productivity by 0.375 provides an estimate of the net organic carbon produced (Fox, 2000). Therefore, phytoplankton in the the Laguna Grande water column had an estimated daily net organic carbon production of about 0.3 g/m^3. In comparison, upwelling coastal zones, where nutrient-rich waters move upward by currents and wind, are considered to be very productive with a primary productivity rate in the range of 0.25 to 0.5 gC/m^3-d (Lecture Notes in Biological Oceanography, 1999). Thus, productivity in Laguna Grande overlaps the lower range of coastal upwelling zones. In addition, the Laguna Grande daily net productivity rate was about half of the rate of 0.5 gC/m^3 calculated for Laguna de Las Salinas (Soler-López and others, 2005).

The productivity of the upper meter layer of the water column at Laguna Grande is representative of the entire water column, considering its shallow depth and substantial wind-induced mixing. Therefore, based on the estimated water volume of the Laguna Grande of about 662,000 m^3, the lagoon phytoplankton community produced an estimated average of about 199 kgC/d, or about 73 tC/yr. This organic carbon production is about 14 percent of the total organic carbon production in the lagoon, which is about 507 tC/yr.

Community Net Primary Productivity, Respiration, and Gross Productivity

As noted earlier, diel studies were conducted in Laguna Grande to estimate the community net primary productivity, the respiration rate, and the gross productivity rate. Appendixes 2 and 3 summarize the dissolved oxygen concentrations for diel studies on March 29, 2007, and November 15, 2007, at stations 6-10, along with temperature, pH, specific conductance, and salinity data.

Dissolved oxygen data were corrected for diffusion, and the net rate of change in dissolved oxygen was calculated. Values above zero indicate a positive rate of change and represent community net primary productivity; values below zero indicate a negative rate and represent community respiration. The net productivity and respiration were calculated by mathematical integration over the water column depth. Figure 8*A* shows the March 29, 2007, dissolved oxygen data collected at station 6. Dissolved oxygen concentration and saturation increased steadily on March 29, 2007, after about 7:00 a.m., reached a maximum from about 2:00 to 5:00 p.m., and subsequently decreased as respiration became more evident (fig. 8*B*).

Table 8. Primary productivity results at Laguna Grande station 6 obtained by the light and dark bottle method, from March 2007 to June 2008.

[All dissolved oxygen values are in milligrams per liter; all productivity and respiration rates are in milligrams of oxygen per cubic meter per hour. DO sat., dissolved oxygen saturation, in percent; OI, initial oxygen; OL, light bottle oxygen; OD, dark bottle oxygen; GP, gross productivity rate; NP, net productivity rate; R, respiration rate; IT, incubation time, in hours; --, Values in bold are at or near saturation]

Month	DO sat.	OI	OL	OD	GP	NP	R	IT	GP rate	NP rate	R rate
Station 6											
Mar. 28, 2007	80	5.20	5.20	4.72	0.48	0.00	0.48	4.00	0.120	0.000	0.120
May 31, 2007	84	5.40	5.60	4.90	0.70	0.20	0.50	5.50	0.127	0.036	0.091
June 27, 2007	96	5.90	5.90	5.40	0.50	0.00	0.50	4.50	0.111	0.000	0.111
July 24, 2007	82	5.00	5.45	4.70	0.75	0.45	0.30	4.50	0.167	0.100	0.067
Sep. 11, 2007	77	4.60	4.65	3.95	0.70	0.05	0.65	3.83	0.183	0.013	0.170
Oct. 16, 2007	83	5.20	5.40	4.80	0.60	0.20	0.40	4.50	0.133	0.044	0.089
Nov. 14, 2007	83	5.60	5.80	5.20	0.60	0.20	0.40	4.17	0.144	0.048	0.096
Jan. 29, 2008	69	4.60	5.10	3.60	1.50	0.50	1.00	4.83	0.311	0.104	0.207
Mar. 4, 2008	98	6.40	7.65	6.20	1.45	1.25	0.20	4.00	0.363	0.313	0.050
Apr. 1, 2008	86	5.60	6.00	3.80	2.20	0.40	1.80	4.00	0.550	0.100	0.450
May 13, 2008	49	3.00	5.20	3.00	2.20	2.20	0.00	4.00	0.550	0.550	0.000
June 17, 2008	91	5.60	5.60	4.90	0.70	0.00	0.70	4.00	0.175	0.000	0.175
Average		5.18	5.63	4.60	1.03	0.45	0.58		0.244	0.109	0.135
Station 8											
Mar. 28, 2007	80	5.20	5.62	5.21	0.41	0.40	0.01	4.00	0.103	0.100	0.002
May 31, 2007	93	6.10	6.30	5.50	0.80	0.20	0.60	5.50	0.145	0.036	0.109
June 27, 2007	**108**	6.60	6.90	6.00	0.90	0.30	0.60	3.58	0.251	0.084	0.168
July 24, 2007	90	5.50	5.50	5.08	0.42	0.00	0.42	4.50	0.093	0.000	0.093
Sep. 11, 2007	82	5.00	5.10	5.00	0.10	0.10	0.00	3.83	0.026	0.026	0.000
Oct. 16, 2007	86	5.40	5.60	5.00	0.60	0.20	0.40	4.42	0.136	0.045	0.090
Nov. 14, 2007	79	5.40	5.80	5.10	0.70	0.40	0.30	4.50	0.156	0.089	0.067
Jan. 29, 2008	69	4.60	5.40	3.60	1.80	0.80	1.00	5.00	0.360	0.160	0.200
Mar. 4, 2008	**101**	6.60	7.40	6.15	1.25	0.80	0.45	4.00	0.313	0.200	0.113
Apr. 1, 2008	92	5.90	6.00	5.00	1.00	0.10	0.90	4.00	0.250	0.025	0.225
May 13, 2008	64	4.00	4.95	4.00	0.95	0.95	0.00	4.00	0.238	0.238	0.000
June 17, 2008	92	5.60	5.60	4.40	1.20	0.00	1.20	4.00	0.300	0.000	0.300
Average		5.49	5.85	5.00	0.84	0.35	0.49		0.198	0.084	0.114

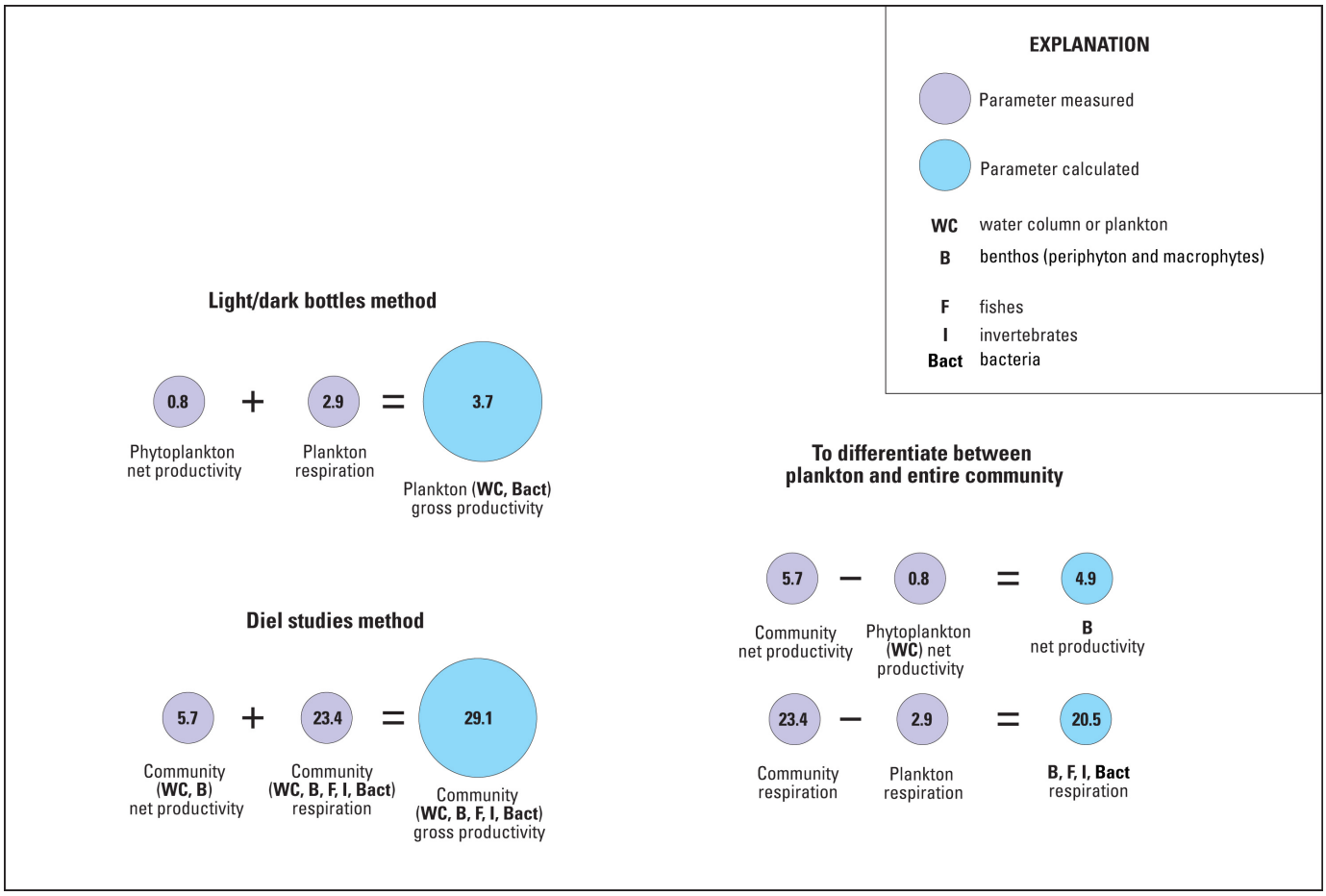


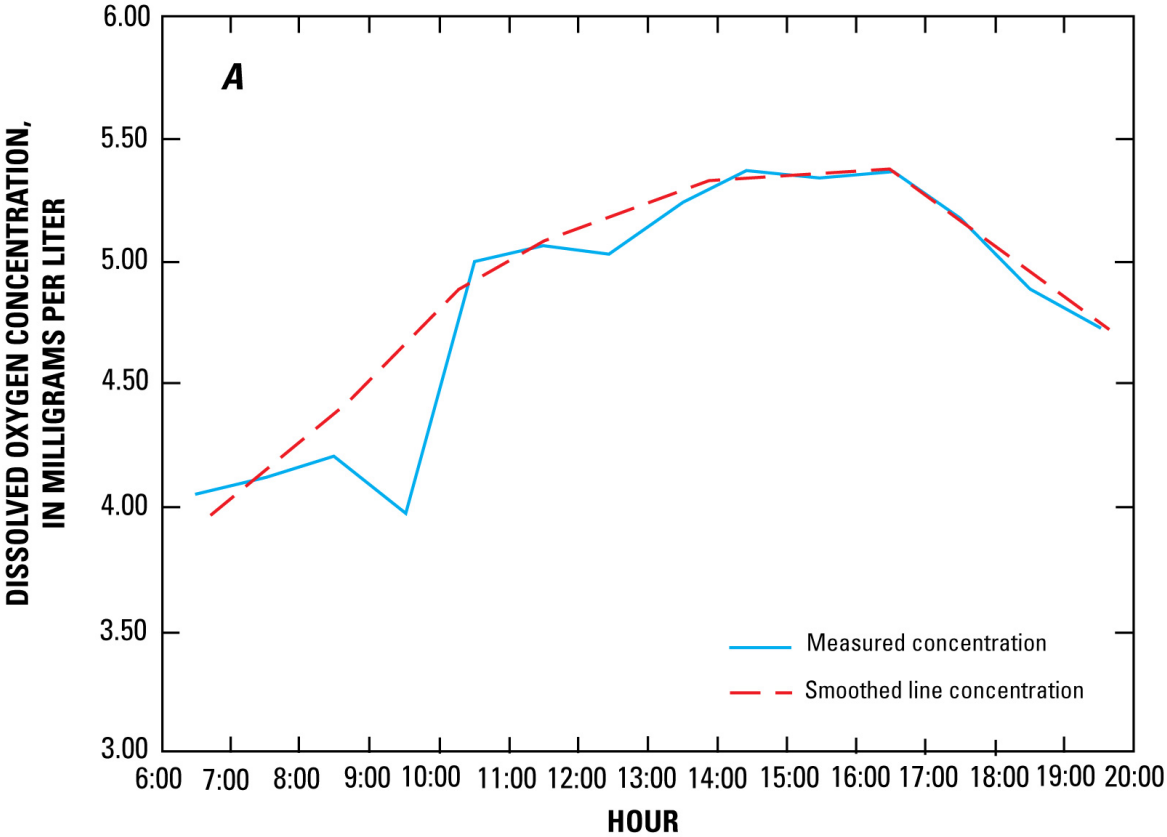
Figure 7. Diagram showing primary productivity categorization for Laguna Grande, Fajardo, Puerto Rico. All values are in grams of oxygen per cubic meter per day.

The average community net primary productivity for the March 29, 2007, study was 2.3 gO_2/m^3-d, the average community respiration was 11.6 gO_2/m^3-d, and the average community gross productivity was 13.9 gO_2/m^3-d (table 9).

Thus, respiration exceeded net primary productivity by a factor of five, on average. The average community net primary productivity for the November 15, 2007, study was 9.1 gO_2/m^3-d (3.4 gC/m^3-d), the average community respiration was 35.3 gO_2/m^3-d, and the average gross community productivity was 44.4 gO_2/m^3-d (table 9). Respiration exceeded net primary productivity by a factor of four, on average.

Averaging the results for the March 29 and November 15, 2007, diel studies yielded a community net primary productivity of 5.7 gO_2/m^3-d (2.1 gC/m^3-d), a community respiration of 23.4 gO_2/m^3-d, and a community gross productivity of 29.1 gO_2/m^3-d (fig. 7). Average net primary productivity was 3.9 times higher in November than in March (9.1 and 2.3 gO_2/m^3-d, respectively), and average respiration was three times as high (35.3 and 11.6 gO_2/m^3-d, respectively); as a result, average gross primary productivity was also higher in November than in March. Net primary productivity in November could have been enhanced by nutrient input from rainfall and runoff, because top conductivity and salinity values in the water column were about 13 percent lower than corresponding bottom values (app. 2). This explanation is consistent with the higher nitrogen concentrations measured in November 2007 compared to March 2007.

The results of light and dark bottle and diel studies indicate that periphyton and macrophyte photosynthesis were the predominant form of net primary productivity in Laguna Grande. Periphyton and macrophytes produced the greatest amount of dissolved oxygen, 4.9 gO_2/m^3-d (1.8 gC/m^3-d) (fig. 7). Approximately 0.8 gO_2/m^3-d (0.3 gC/m^3-d) was estimated to be produced by the phytoplankton. The average overall community net primary productivity, which includes phytoplankton, periphyton, and macrophytes, was 5.7 gO_2/m^3-d (2.1 gC/m^3-d) (fig. 7). Thus, the percentage of net primary productivity in Laguna Grande accounted for by phytoplankton was 14 percent, and the percentage accounted for by periphyton and macrophytes is 86 percent.



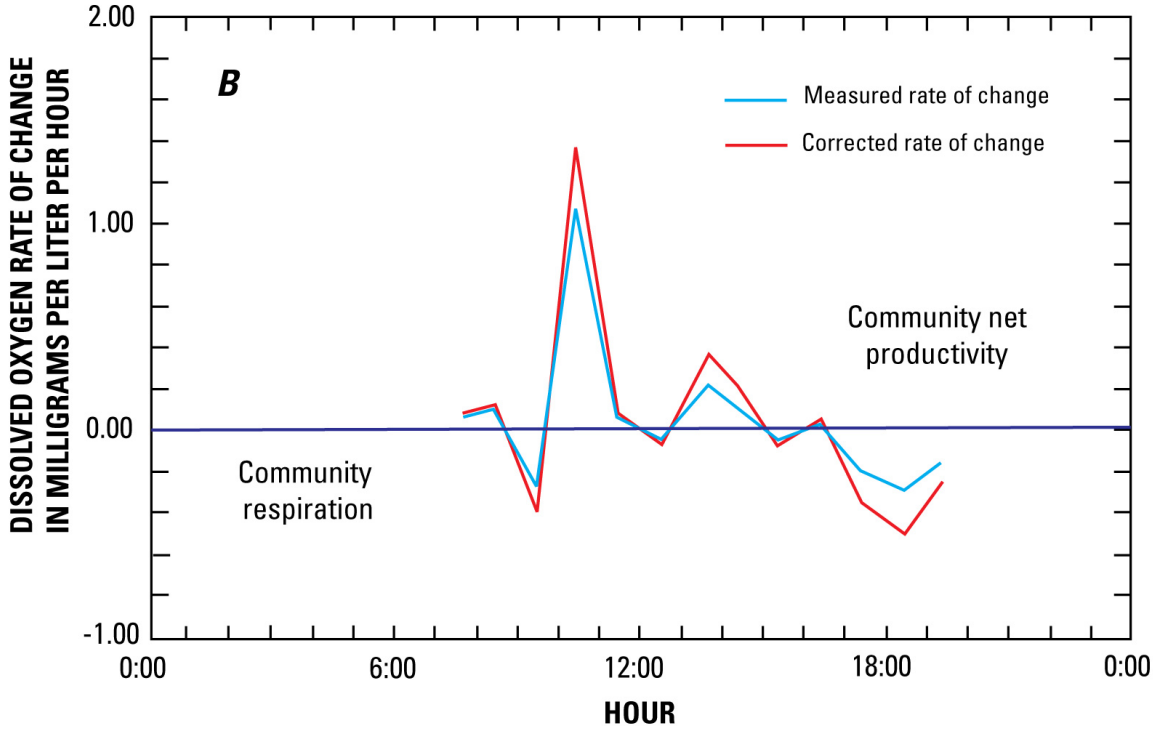


Figure 8. Graph showing *A*, dissolved oxygen concentration, and *B*, rate of change curves for March 29, 2007, at station 6 in Laguna Grande, Fajardo, Puerto Rico.

The net organic carbon production of Laguna Grande is about 507 tC/yr. This value was obtained by multiplying the daily oveall net primary productivity of 2.1 gC/m^3-d by 365 to obtain a yearly value of 766.5 gC/m^3-yr. The yearly value was multiplied by the lagoon water volume of 661,582 m^3 to obtain 507,102,603 gC/yr, or roughly 507 tC/yr.

The respiration rate ascribed to the water column (plankton plus bacteria) averaged about 2.9 gO_2/m³, whereas the respiration rate by all organisms present in Laguna Grande, which include plankton, benthos, bacteria, fish, and invertebrates, averaged 23.4 gO_2/m³-d. Therefore, the respiration rate for benthos, bacteria, fish, and invertebrates alone was 20.5 gO_2/m³-d (fig. 7). About 88 percent of the respiration in Laguna Grande was a function of benthic and non-phytoplankton nektonic organisms (including bacteria).

The gross productivity for water column organisms (plankton) was 3.7 gO_2/m³; the gross productivity for all organisms, which include plankton, periphyton and macrophytes, fish, and invertebrates averaged 29.1 gO_2/m³-d. This finding indicates that at the time of the diel studies, the gross productivity for all organisms excluding plankton was 25.4 gO_2/m³-d. This value is an estimate at the time of data collection, however, and only represents a snapshot of the community dynamics in Laguna Grande, which are complex because higher motile organisms migrate into and out of the lagoon. As with respiration, about 88 percent of the gross productivity in Laguna Grande occurs through the metabolism of benthic and higher organisms.

The highest community net and gross productivity occurred at station 10, located along the western littoral zone, during the November 2007 sampling. The high productivity observed at this site indicates that the algal mats and seagrasses on the western littoral zone of the lagoon are quite prolific. The second highest community net and gross productivity occurred at station 8 near the northern portion of Laguna Grande also during the November 2007 sampling. On the basis of the community productivity results, it is presumed that algal mats and seagrasses could also be present on the lagoon bottom at station 8.

Phytoplankton Biomass

Phytoplankton biomass is defined as the mass or weight of photosynthetic organisms present in the water column per unit of area or volume, at a given instant in time (Wetzel, 2001), and is synonymous with phytoplankton standing crop. As noted earlier, phytoplankton biomass was determined in Laguna Grande at stations 6 and 8 from March 2007 to June 2008, where light and dark bottle primary productivity measurements were made (fig. 3). The average phytoplankton biomass at the two stations in Laguna Grande ranged from 6.0 mg/L in October and November 2007 to 13.6 mg/L in January 2008 (table 10).

The average phytoplankton biomass between March 2007 and June 2008 was 8.8 mg/L, which is equal to 8.8 g/m^3. Assuming that samples from the top of the water column are representative of the entire water column, and an estimated water volume of 662,000 m³, Laguna Grande contained a phytoplankton standing crop of approximately 5.8 t.

The ratio of gross productivity to biomass (P/B) is a weighted mean value of biomass growth rates for all individuals in a population (Benke, 1993); the ratio can be used to estimate the turnover rate of organisms, yielding a general index of the rate of energy flow relative to biomass. The P/B ratio generally decreases as the trophic level increases (Benke, 1993).

Based on the average plankton daily gross productivity of 3.7 gO_2/m³, the annual plankton gross productivity was 1,350.5 gO_2/m³. Using the average annual phytoplankton biomass of 8.8 g/m³, the P/B ratio (1,350.5/8.8) is about 153, which indicates that the phytoplankton community has a turnover rate of about 153 times per year, or about once about every 2.4 days. Phytoplankton gross productivity generally correlates with phytoplankton biomass for most months at both sites (fig. 9), with the exception of July 2007 and January 2008 at station 6, and July 2007 and May 2008 at station 8. The observed correlations indicate that biomass determination, which is a simple and relatively inexpensive method, could probably be used to estimate gross plankton productivity.

Table 9. Primary productivity results for the March 29, 2007 and November 15, 2007diel studies at Laguna Grande, Fajardo, Puerto Rico.

[All values are in grams of oxygen per cubic meter per day. Productivity calculated for a 24-hour period]

Station number	Net productivity	Respiration	Gross productivity
March 29, 2007[1]			
6	1.47	5.76	7.23
7	1.87	6.72	8.59
8	5.13	21.36	26.49
9	1.49	11.33	12.82
10	1.62	12.96	14.58
Average	2.32	11.63	13.94
November 15, 2007[2]			
6	4.01	2.40	6.41
7	3.93	9.60	13.53
8	22.94	62.40	85.34
9	0.27	0.96	1.23
10	14.42	101.04	115.46
Average	9.11	35.28	44.39

[1] Study commenced at 6:00 a.m. and ended at 7:23 p.m.

[2] Study commenced at 5:30 a.m. and ended at 6:46 p.m.

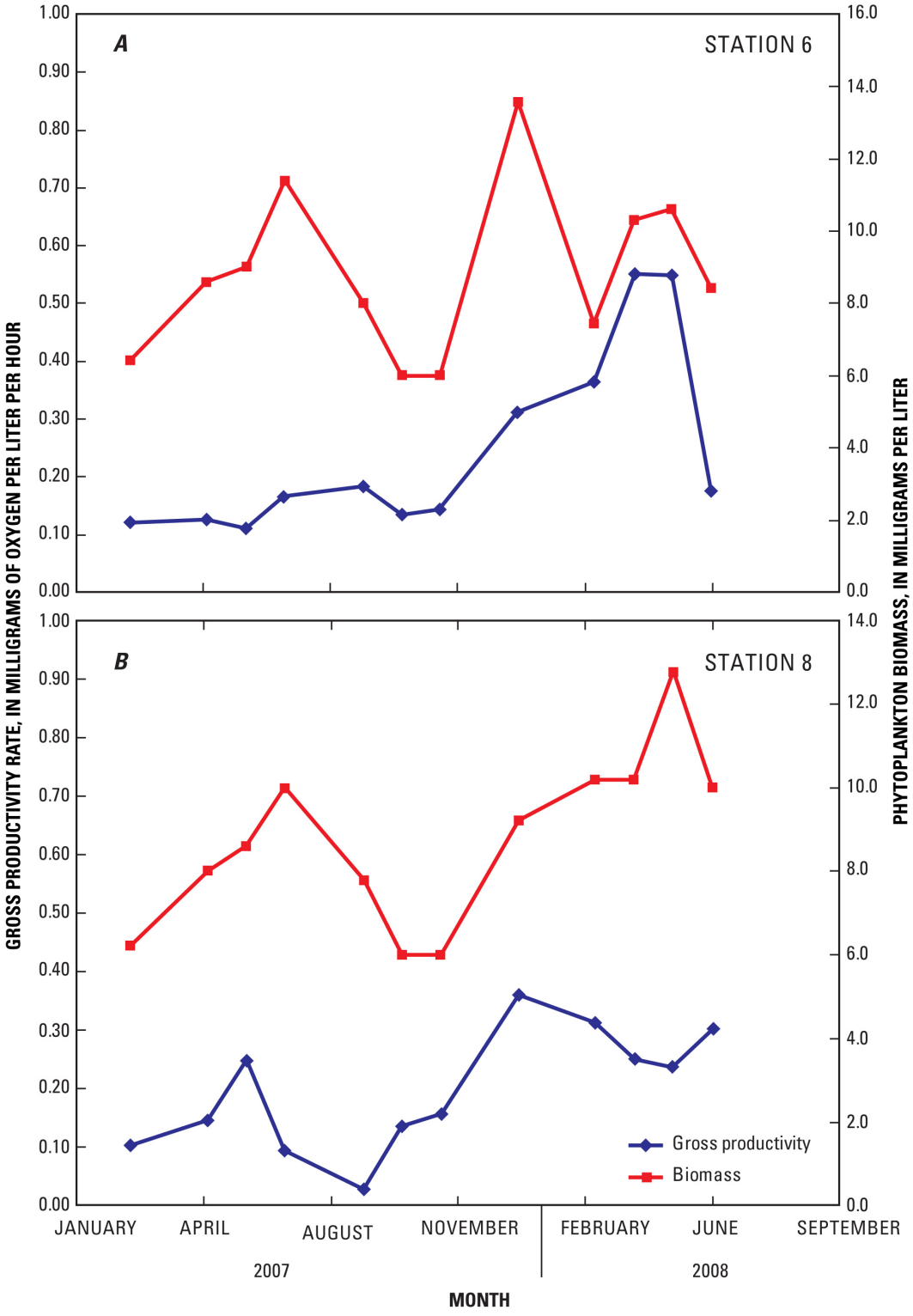


Figure 9. Graphs showing gross productivity rates and phytoplankton biomass at *A*, stations 6, and *B*, station 8 in Laguna Grande, Fajardo, Puerto Rico.

Fecal Indicator Bacteria

Microorganisms such as fecal coliform bacteria can be used to indicate the presence of human and animal waste. Because coliform bacteria cannot live for prolonged periods outside a host organism, a positive test result indicates recent fecal contamination or inappropriate sewer processing.

Fecal indicator bacteria were sampled and analyzed on a roughly monthly basis in Laguna Grande at stations 1, 3, 5, and 7 (fig. 3). Stations 1, 3, and 5 are presumed to be affected by human activity and sewer discharge. Station 7, located in the middle of the lagoon was sampled to document possible sewage dispersion by wind and water currents.

Potential fecal contamination sources to the lagoon include: (1) river discharge that flows by way of longshore ocean currents into the lagoon through the inlet channel during high tide; (2) overflow of a sewer main from the area of Las Croabas south of the lagoon during periods of storm runoff; (3) possible illegal raw sewage discharge from housing units along the western flank of the Laguna Grande Channel; and (4) discharge from unsewered housing units at the end of the southwestern channel in an area known as Soroco.

The PREQB fecal coliform standard for Class SB waters specifies that the geometric mean concentration of at least five samples collected sequentially should not exceed 200 col/100 mL, and not more than 20 percent of the samples should exceed 400 col/100 mL (Puerto Rico Environmental Quality Board, 2003). The regulations do not specify a time period during which the sequential samples must be obtained.

Fecal coliform concentrations often exceeded the 200 col/100 mL PREQB standard (app. 4), mostly at stations 1, 3 and 5, located adjacent to developed/populated areas with possible illegal sewage discharges. In contrast, this limit was exceeded only twice at station 7 on the 12 sampling dates.

The highest concentrations were observed at station 5 near the Soroco area, where the fecal bacteria concentrations exceeded 200 col/100mL on all but two of the sampling dates. Among samples that exceeded the standard, counts ranged from 750 col/100mL, to 60,000 col/100mL, the latter value was observed twice during the study (May 31, 2007, and November 14, 2007). The coliform bacteria count was also high on January 29, 2008, at 39,000 col/100mL.

Fecal bacteria counts exceeded 200 col/100mL in half of the samples at station 3, halfway from the channel mouth to the lagoon and near a developed area; concentrations at this site ranged from 450 to 8,270 col/100mL. At the channel entrance (station 1), fecal bacteria colony counts exceeded 200 col/100mL five times, and ranged from 240 to 860 col/100mL. At station 7, fecal bacteria counts exceeded the standard twice, with 240 col/100mL measured on May 31, 2007, and 970 col/100mL measured on November 14, 2008.

Fecal bacteria colony counts indicate that station 5 at Soroco appears to have the largest fecal coliform input followed by station 3 halfway along the Laguna Grande channel, and station 1 at the channel entrance.

Table 10. Phytoplankton biomass at stations 6 and 8 from March 2007 to June 2008.

[All concentrations are in milligrams per liter]

Sampling date	Station 6	Station 8
Mar. 28, 2007	6.4	6.2
May 31, 2007	8.6	8.0
June 27, 2007	9.0	8.6
July 24, 2007	11.4	10.0
Sep. 11, 2007	8.0	7.8
Oct. 16, 2007	6.0	6.0
Nov. 14, 2007	6.0	6.0
Jan. 29, 2008	13.6	9.2
Mar. 4, 2008	7.4	10.2
Apr. 1, 2008	10.3	10.2
May 13, 2008	10.6	12.8
June 17, 2008	8.4	10.0
Average	8.8	8.8

Sediment Accretion

Coastal lagoons lose depth and water volume as they age, primarily by (1) sedimentation from erosion and runoff transported within the drainage basin, (2) deposition from marine coastal currents, and to a minor extent, (3) atmospheric deposition. As a consequence, coastal lagoons have relatively short life spans that are on the order of thousands of years. To document this process and for future monitoring of sediment deposition in Laguna Grande, 10 sediment cores were collected on October 20, 2008, at station 7 in the center of the lagoon (fig. 3) and analyzed for radioisotopes.

The individual core samples from station 7 were analyzed for ^{137}Cs and ^{210}Pb radioisotopes. The ^{137}Cs radioisotope is primarily a byproduct of atmospheric nuclear-bomb testing and has a half-life of about 30 years. This radioisotope does not occur naturally, and partitions from the atmosphere to fine sediment particles that are then transported to water bodies by runoff. Consequently, sediment layers deposited shortly after periods of major nuclear testing will have relatively high radioisotope activity. The year of first occurrence (1952), along with the year of maximum above-ground testing (1963), are used for dating. The activity peaks in terrestrial sediment may lag a year or two behind the test dates because of the travel time in the atmosphere prior to deposition in bottom sediments. Therefore, the year of first ocurrence is assigned as the year 1954 instead of 1952.

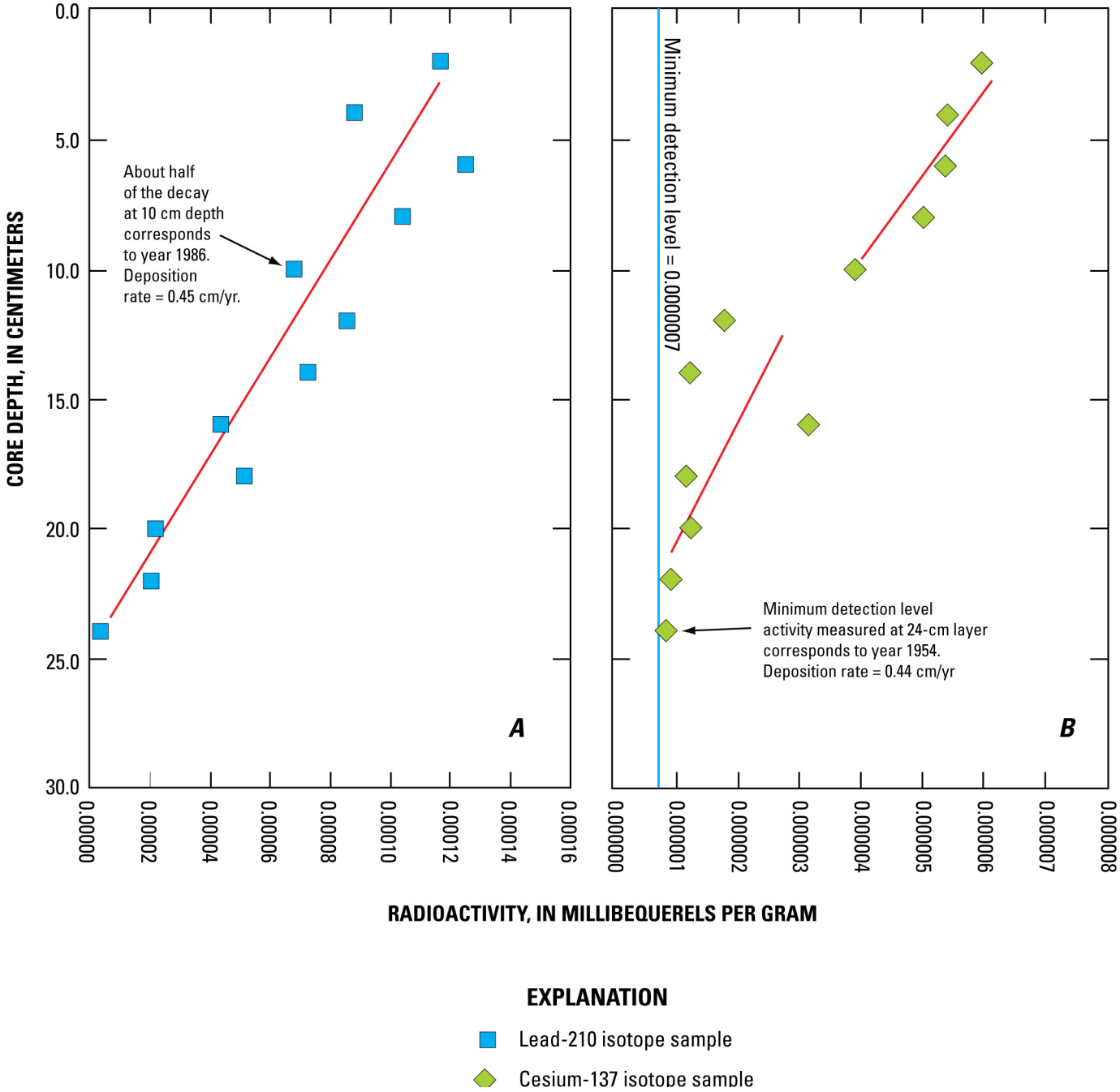


Figure 10. Graphs showing activity of *A*, lead-210, and *B*, cesium-137 compared to depth in the Laguna Grande sediment core.

In contrast to the rapid change in fluxes of ^{137}Cs, the ^{210}Pb method depends on the constant flux of radon gas from the Earth's surface (Krishnaswami and others, 1971). ^{210}Pb has a half-life of 22.3 years, and is a member of the uranium-238 (^{238}U) decay series. Natural ^{238}U decays to radon-222 (^{222}Rn), a natural gas in the atmosphere that has a half-life of 3.8 days, and eventually decays to ^{210}Pb, which precipitates as a solid adsorbed to particles. If the sedimentation rate of a water body and the ^{210}Pb fluxes are constant, the age of the sediment can be determined by assuming the excess ^{210}Pb activity decreases with depth (downcore) by a factor of two every 22.3 years. The excess activity is the total activity minus the activity supported by the *in-situ* decay of radium-226 (^{226}Ra).

To use this ^{210}Pb-based sediment deposition rates method, the radioactivity profile must indicate monotonically decreasing activity downward from the top of the core. Both ^{137}Cs and ^{210}Pb were used and an average rate was estimated from the data, because the ^{210}Pb radioactivity profile exhibited monotonically decreasing activity (fig. 10).

The sediment accretion rate determined using ^{210}Pb was calculated by using the top of the core activity of 1.25 $\times 10^{-4}$ mBq/g, and locating the layer of sediment that had half or nearly half of the top-core activity, which in this case corresponded to the 10-cm layer. Because the radioactivity of ^{210}Pb decreases by a factor of two every 22.3 years, the 10-cm layer was estimated to be deposited during and/or near the year 1986 (2008 - 22.3 = 1985.7). Therefore, an accumulation of 10 cm divided by 22.3 years yields a sediment deposition rate of about 0.45 cm/yr.

The first detectable ^{137}Cs activities were found in the 24-cm layer, which was assigned a year of 1954. Dividing 24 cm by 54 years (2008-1954), the depositional rate using ^{137}Cs as a marker is 0.44 cm/yr, which is in agreement with the rate derived from ^{210}Pb data.

Based on the radioactivity decay for both isotopes, the average and most probable long-term sediment depositional rate in Laguna Grande is approximately 0.44 cm/yr. This sediment accretion rate is in close agreement with other accretion rates estimated for other coastal lagoons in Puerto Rico with similar hydrologic characteristics, such as Laguna Los Corozos (0.49 cm/yr), and Laguna Torrecilla (0.37 cm/yr), located within the San Juan Bay estuary system (Webb and Gómez-Gómez, 1997).

Assuming a long-term sediment accretion rate of about 0.44 cm/yr and a mean water depth of about 3-4 m for Laguna Grande, the lagoon is estimated to have a remaining lifespan on the order of 700 to 900 years before it becomes marshland. This estimate, however, does not consider possible Laguna Grande basin modifications that could increase sediment deposition rates, or any potential future water-level change that could alter the lagoon bathymetry.

Summary and Conclusions

Laguna Grande is a unique ecosystem on the eastern coast of Puerto Rico with ecological and recreational value, and is one of the few remaining coastal lagoons that supports bioluminescent dinoflagellates. Development and human activities, including unregulated ecotourism, are having deleterious effects on the lagoon. Unregulated recreational use of Laguna Grande may already be affecting its ecosystem. Planned construction projects threaten to alter the basin by modifying runoff into the lagoon (and thus, its hydrology), and accelerate sedimentation in the lagoon. To address the aforementioned issues, the U.S. Geological Survey (USGS) in cooperation with the Puerto Rico Environmental Quality Board (PREQB) for the Conservation Trust of Puerto Rico, initiated a study in 2007 to determine selected hydrologic, water-quality, biological and sedimentation characteristics of Laguna Grande.

Historical rainfall data indicate that rainfall was about 44 percent below average for months with available data during the period of study. Because extreme rainfall did not occur in the basin during the period of study, the effect of such an event on the lagoon hydrology and water quality was not documented. Freshwater inflow to Laguna Grande is estimated to be 184,575 m^3/yr, or about 28 percent of the water volume in the lagoon. Seawater exchange between Laguna Grande and the Atlantic Ocean occurs through the 1.5-km Laguna Grande Channel and is driven by tidal fluctuations. During normal wind and tide conditions, the lagoon daily flushing rate is estimated to be 13 percent of its water volume, which corresponds to a flushing rate of once every 7.7 days or about 47 times per year.

A bathymetric survey indicated that Laguna Grande has a water volume of approximately 662,000 m^3. At the time of this study, the maximum water depth was about 5 m and the mean water depth was about 3 m.

The physical and chemical properties of water in Laguna Grande were found to be in compliance with the PREQB standards, except in areas influenced by human development. The lagoon is a generally homogeneous water body, exhibiting temporal rather than spatial variation, with some vertical stratification within the main water body. The water temperature ranged from about 26 to 31 °C, with areas of higher temperatures near developed areas and shallow waters.

The pH of the water ranged from 7.1 to 7.9 and did not exceed PREQB standards. Dissolved oxygen concentrations varied areally and temporally, with vertical stratification in the water column of the lagoon main water body. Dissolved oxygen concentrations varied most at stations along the eastern periphery of the lagoon where sea grasses are abundant and varied less in the center of the lagoon. Dissolved oxygen concentrations were lowest adjacent to an area locally referred to as Soroco, where fecal coliform concentrations exceeded PREQB standards in most samples.

Water transparency was consistently high, with all readings greater than 70 cm. Because the lagoon has no perennial streams, sediment resuspension, high algal counts ("self shading"), as well as runoff from the basin, are presumed to be the principal factors affecting water transparency and light penetration. Specific conductance and salinity varied temporally but not areally, and were directly associated with coastal tides and rainfall runoff.

Total nitrogen and total phosphorus concentrations were below the PREQB standards of 5 and 1 mg/L, respectively. Total nitrogen concentrations ranged from 0.14 to 0.38 mg/L, with a mean of about 0.28 mg/L. Of the nitrogen species present in Laguna Grande, organic nitrogen composed about 75 percent of the total nitrogen, ammonium composed 20 percent, and nitrate and nitrite collectively composed the remaining 5 percent. Total phosphorus concentrations ranged from 0.01 to 0.11, with a mean of 0.02 mg/L. The average concentration of chlorophyll *a* ranged from about 2.2 to 13 µg/L, with a mean concentration of 6.2 µg/L.

Light and dark bottle primary productivity measurements were made at about monthly intervals between March 2007 and June 2008. The average phytoplankton net primary productivity rate was about 0.8 gO_2/m^3-d (0.3 gC/m^3-d), the plankton daily respiration rate was about 2.9 gO_2/m^3, and the mean daily plankton gross productivity was 3.7 gO_2/m^3. Diel primary productivity studies were conducted on March 29, 2007, and November 15, 2008, and the net community primary productivity averaged 5.7 gO_2/m^3-d (2.1 gC/m^3-d). The mean community respiration rate was 23.4 gO_2/m^3-d, and the mean community gross productivity was 29.1 gO_2/m^3-d. Periphyton and macrophytes were responsible for about 86 percent of the total primary productivity, and yielded 4.9 gO_2/m^3-d (1.8 gC/m^3-d). Primary productivity results indicate that Laguna Grande is mesotrophic, with relatively high primary productivity, and constitutes an important food supply for primarily aquatic organisms. Most of the biomass standing crop, however, is generated by benthic organisms (periphyton and macrophytes), indicating that most primary production occurs at the sediment/water interface rather than in the water column.

The average phytoplankton biomass values in Laguna Grande ranged from 6.0 to 13.6 mg/L. During the study, Laguna Grande is estimated to have contained a phytoplankton standing crop of about 5.8 t. Phytoplankton community had a turnover rate of about 153 times per year, equivalent to about once every 2.4 days.

Fecal indicator bacteria samples were collected at about monthly intervals during the study at three locations. Fecal coliform bacteria counts ranged from 160 to 60,000 col/100mL, and often exceeded the 200 col/100mL PREQB standard, particularly in areas near housing units and human activity. Fecal bacteria counts in the Socoro area exceeded the 200 col/100mL standard on all but two samplings, but never exceeded the standard near the center of the lagoon. The distribution of fecal coliform bacteria indicate that water quality is impaired near developed areas in the southern part of Laguna Grande.

Sediment cores collected at the middle of Laguna Grande indicated that sedimentation in the lagoon occurs at a rate of about 0.44 cm/yr. This process will convert Laguna Grande into a marshland in about 700 to 900 years if not altered by human and/or natural causes.

The data obtained from this study will provide reserve managers with a holistic perspective of the local hydrology and its relation to water-quality conditions in Laguna Grande. Specifically, information from this study will be used by the CTPR to establish baseline conditions and to monitor changes in the ecological health of the lagoon. In addition, the data provide stakeholders with a broad understanding of natural processes that can be used effectively to monitor and manage the Las Cabezas de San Juan Natural Reserve watershed and coastal surrounding areas. Protection of the ecological conditions will promote habitat utilization by the indigenous fauna that attract thousands of visitors to the reserve annually.

Continued monitoring of Laguna Grande may be necessary to further document the effects of development in nearby areas. This information will allow timely and informed decisionmaking by resource managers, and help prevent further and potentially irreversible impairment to Laguna Grande.

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APPENDIX

Appendix 1. In situ determination of pH, temperature, specific conductance, dissolved oxygen, salinity, and Secchi disk depth for water-quality sites sampled from March 2007 to June 2008 at Laguna Grande, Fajardo, Puerto Rico.

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. T, temperature, in degrees Celsius; SC, specific conductance, in microsiemens per centimeter; DO, dissolved oxygen, in milligrams per liter; SAL, salinity in parts per thousand; SD, Secchi disk depth in centimeters; -- not collected]

Sample collection		Sample position	Constituent					
Date	Time		pH	T	SC	DO	SAL	SD
Station 1 (50069660)								
Mar. 28, 2007	9:35 a.m.	Top	7.6	26.0	53,700	2.9	35.4	
		Bottom	7.6	26.1	53,700	2.9	35.4	61
May 31, 2007	7:40 a.m.	Top	7.6	29.1	56,010	4.2	37.1	
		Bottom	7.6	29.2	56,000	4.2	37.1	76
June 27, 2007	7:25 a.m.	Top	7.6	29.3	55,200	1.7	36.5	
		Bottom	7.6	29.4	55,300	1.7	36.6	86
July 24, 2007	9:15 a.m.	Top	7.5	29.7	55,300	0.5	36.6	
		Bottom	7.5	29.7	55,300	0.6	36.6	46
Sept. 11, 2007	7:10 a.m.	Top	7.9	29.1	56,010	4.2	37.1	
		Bottom	7.9	29.2	56,000	4.2	37.1	112
Oct. 16, 2007	7:05 a.m.	Top	7.7	29.0	56,860	3.7	37.7	
		Bottom	7.6	29.0	56,860	3.6	37.7	61
Nov. 14, 2007	7:15 a.m.	Top	7.6	27.4	46,650	4.1	30.2	
		Bottom	7.6	27.4	46,650	4.2	30.2	76
Jan. 29, 2008	8:40 a.m.	Top	7.6	25.4	53,220	4.5	35.1	
		Bottom	7.6	25.4	53,220	4.2	35.1	76
Mar. 4, 2008	7:25 a.m.	Top	8.1	25.1	57,250	4.9	38.1	
		Bottom	8.1	25.1	57,250	5.0	38.1	76
Apr. 1, 2008	7:35 a.m.	Top	8.0	25.5	56,330	5.1	37.4	
		Bottom	8.0	25.5	56,310	5.0	37.4	91
May 13, 2008	6:45 a.m.	Top	7.6	27.3	55,080	1.4	36.4	
		Bottom	7.5	27.3	55,100	1.4	36.5	51
June 17, 2008	7:00 a.m.	Top	7.9	28.5	55,970	2.9	37.1	
		Bottom	7.9	28.6	55,950	2.9	37.1	74

Appendix 1. In situ determination of pH, temperature, specific conductance, dissolved oxygen, salinity, and Secchi disk depth for water-quality sites sampled from March 2007 to June 2008 at Laguna Grande, Fajardo, Puerto Rico.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. T, temperature, in degrees Celsius; SC, specific conductance, in microsiemens per centimeter; DO, dissolved oxygen, in milligrams per liter; SAL, salinity in parts per thousand; SD, Secchi disk depth in centimeters; -- not collected]

Sample collection		Sample position	Constituent					
Date	Time		pH	T	SC	DO	SAL	SD
Station 2 (50069670)								
Mar. 28, 2007		Top	--	--	--	--	--	--
		Bottom	--	--	--	--	--	--
May 31, 2007	7:25 a.m.	Top	7.8	28.5	53,200	3.1	35.0	
		Bottom	8.0	28.6	54,000	4.7	35.6	244
June 27, 2007	7:17 a.m.	Top	8.0	28.9	54,100	4.1	35.7	
		Bottom	8.0	28.9	54,100	4.0	35.7	91
July 24, 2007 –	7:00 a.m.	Top	8.0	28.8	55,000	3.8	36.3	
		Bottom	8.0	28.8	55,000	4.1	36.3	137
Sept. 11, 2007	7:00 a.m.	Top	8.1	29.6	55,460	5.5	36.7	
		Bottom	8.1	29.6	55,500	5.5	36.7	213
Oct. 16, 2007	7:00 a.m.	Top	7.9	29.0	55,820	5.0	36.9	
		Bottom	7.9	29.0	55,840	4.9	37.0	213
Nov. 14, 2007	7:05 a.m.	Top	7.8	27.2	50,330	4.5	32.8	
		Bottom	7.9	27.6	53,860	4.3	35.5	94
Jan. 29, 2008	8:30 a.m.	Top	7.8	25.7	55,810	4.5	37.0	
		Bottom	8.0	26.1	56,250	5.5	37.3	221
Mar. 4, 2008	7:14 a.m.	Top	8.1	24.9	57,270	5.0	38.2	
		Bottom	8.0	24.4	57,310	4.7	38.2	91
Apr. 1, 2008	7:25 a.m.	Top	8.1	25.7	56,370	5.5	37.5	
		Bottom	8.1	25.7	56,390	5.4	37.5	89
May 13, 2008	6:35 a.m.	Top	7.9	27.4	54,650	3.5	36.1	
		Bottom	7.9	27.2	54,660	2.8	36.1	203
June 17, 2008	6:55 a.m.	Top	8.0	29.0	55,900	3.9	37.0	
		Bottom	8.0	29.0	55,930	3.6	37.0	183

Appendix 1. In situ determination of pH, temperature, specific conductance, dissolved oxygen, salinity, and Secchi disk depth for water-quality sites sampled from March 2007 to June 2008 at Laguna Grande, Fajardo, Puerto Rico.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. T, temperature, in degrees Celsius; SC, specific conductance, in microsiemens per centimeter; DO, dissolved oxygen, in milligrams per liter; SAL, salinity in parts per thousand; SD, Secchi disk depth in centimeters; -- not collected]

Sample collection		Sample position	Constituent					
Date	Time		pH	T	SC	DO	SAL	SD
Station 3 (50069650)								
Mar. 28, 2007	9:25 a.m.	Top	7.7	26.2	53,800	3.0	35.5	
		Bottom	--	--	--	--	--	7
May 31, 2007	7:25 a.m.	Top	7.6	29.8	51,600	2.7	34.0	
		Bottom	--	--	--	--	--	61
June 27, 2007	7:17 a.m.	Top	7.6	29.6	55,400	2.0	36.6	
		Bottom	--	--	--	--	--	112
July 24, 2007	7:25 a.m.	Top	7.7	29.9	56,200	2.9	37.2	
		Bottom	--	--	--	--	--	8
Sept. 11, 2007	7:20 a.m.	Top	7.8	29.2	56,090	3.4	37.1	
		Bottom	--	--	--	--	--	107
Oct. 16, 2007	7:15 a.m.	Top	7.6	29.0	56,870	4.2	37.7	
		Bottom	--	--	--	--	--	76
Nov. 14, 2007	7:25 a.m.	Top	7.6	27.7	47,310	4.5	30.7	
		Bottom	--	--	--	--	--	53
Jan. 29, 2008	8:45 a.m.	Top	7.6	25.6	53,140	4.8	35.1	
		Bottom	--	--	--	--	--	71
Mar. 4, 2008	7:33 a.m.	Top	8.0	24.9	57,210	4.5	38.1	
		Bottom	--	--	--	--	--	81
Apr. 1, 2008	7:40 a.m.	Top	7.9	25.4	56,500	4.1	37.6	
		Bottom	--	--	--	--	--	61
May 13, 2008	6:55 a.m.	Top	7.6	27.6	54,840	1.8	36.3	
		Bottom	--	--	--	--	--	61
June 17, 2008	7:10 a.m.	Top	7.7	29.6	57,230	2.0	38.0	
		Bottom	--	--	--	--	--	51

Appendix 1. In situ determination of pH, temperature, specific conductance, dissolved oxygen, salinity, and Secchi disk depth for water-quality sites sampled from March 2007 to June 2008 at Laguna Grande, Fajardo, Puerto Rico.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. T, temperature, in degrees Celsius; SC, specific conductance, in microsiemens per centimeter; DO, dissolved oxygen, in milligrams per liter; SAL, salinity in parts per thousand; SD, Secchi disk depth in centimeters; -- not collected]

Sample collection		Sample position	Constituent					
Date	Time		pH	T	SC	DO	SAL	SD
Station 4 (50069630)								
Mar. 28, 2007	9:08 a.m.	Top	7.8	26.7	55,200	3.7	36.5	
		Bottom	6.8	27.4	54,800	3.4	36.4	157
May 31, 2007	8:05 a.m.	Top	7.7	30.2	53,700	3.5	35.3	
		Bottom	7.7	30.6	54,300	3.7	36.0	94
June 27, 2007	8:03 a.m.	Top	7.8	29.8	55,400	4.4	36.6	
		Bottom	7.8	29.8	55,400	3.6	36.6	76
July 24, 2007	7:35 a.m.	Top	7.9	30.0	56,300	4.8	37.3	
		Bottom	7.9	30.0	56,300	5.0	37.3	91
Sept. 11, 2007	7:30 a.m.	Top	7.8	30.3	56,900	4.8	30.3	
		Bottom	7.8	30.3	56,880	4.0	30.3	91
Oct. 16, 2007	7:25 a.m.	Top	7.7	29.1	56,780	4.9	37.7	
		Bottom	7.7	29.1	56,740	4.6	37.6	91
Nov. 14, 2007	7:30 a.m.	Top	7.7	27.5	46,995	4.7	30.6	
		Bottom	7.6	28.4	48,950	4.4	31.9	107
Jan. 29, 2008	8:55 a.m.	Top	7.6	26.0	53,580	5.3	35.4	
		Bottom	7.6	26.0	53,580	5.2	35.4	76
Mar. 4, 2008	7:42 a.m.	Top	7.9	25.5	57,320	4.2	38.2	
		Bottom	7.9	25.3	57,270	4.0	38.1	122
Apr. 1, 2008	7:50 a.m.	Top	7.9	26.1	57,220	4.5	38.1	
		Bottom	7.9	26.3	57,310	4.6	38.1	107
May 13, 2008	7:00 a.m.	Top	7.8	29.1	55,480	3.1	36.7	
		Bottom	7.7	28.9	55,420	2.6	36.6	152
June 17, 2008	7:20 a.m.	Top	7.7	29.7	57,110	3.2	37.9	
		Bottom	7.7	29.7	57,210	2.1	38.0	76

Appendix 1. In situ determination of pH, temperature, specific conductance, dissolved oxygen, salinity, and Secchi disk depth for water-quality sites sampled from March 2007 to June 2008 at Laguna Grande, Fajardo, Puerto Rico.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. T, temperature, in degrees Celsius; SC, specific conductance, in microsiemens per centimeter; DO, dissolved oxygen, in milligrams per liter; SAL, salinity in parts per thousand; SD, Secchi disk depth in centimeters; -- not collected]

Sample collection		Sample position	Constituent					
Date	Time		pH	T	SC	DO	SAL	SD
Station 5 (50069640)								
Mar. 28, 2007	8:50 a.m.	Top	7.5	27.0	49,000	2.3	29.5	
		Bottom	--	--	--	--	--	46
May 31, 2007	8:15 a.m.	Top	7.3	26.9	20,600	0.1	12.4	
		Bottom	--	--	--	--	--	15
June 27, 2007	7:53 a.m.	Top	7.3	26.9	58,800	0.2	39.2	
		Bottom	--	--	--	--	--	30
July 24, 2007	7:50 a.m.	Top	7.4	27.1	50,100	0.1	32.7	
		Bottom	--	--	--	--	--	20
Sept. 11, 2007	7:40 a.m.	Top	7.6	29.1	57,380	2.0	38.1	
		Bottom	--	--	--	--	--	46
Oct. 16, 2007	7:35 a.m.	Top	7.3	26.5	60,240	0.2	40.4	
		Bottom	--	--	--	--	--	46
Nov. 14, 2007	7:45 a.m.	Top	7.4	24.7	11,840	0.8	6.8	
		Bottom	--	--	--	--	--	15
Jan. 29, 2008	9:05 a.m.	Top	7.4	24.3	47,770	2.5	31.1	
		Bottom	--	--	--	--	--	38
Mar. 4, 2008	7:53 a.m.	Top	7.7	25.0	56,600	2.9	37.6	
		Bottom	--	--	--	--	--	23
Apr. 1, 2008	8:00 a.m.	Top	7.7	25.5	58,530	2.7	39.1	
		Bottom	--	--	--	--	--	15
May 13, 2008	7:05 a.m.	Top	7.6	27.7	57,090	1.3	37.9	
		Bottom	--	--	--	--	--	20
June 17, 2008	7:30 a.m.	Top	7.3	26.9	59,870	0.3	39.9	
		Bottom	--	--	--	--	--	15

Appendix 1. In situ determination of pH, temperature, specific conductance, dissolved oxygen, salinity, and Secchi disk depth for water-quality sites sampled from March 2007 to June 2008 at Laguna Grande, Fajardo, Puerto Rico.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. T, temperature, in degrees Celsius; SC, specific conductance, in microsiemens per centimeter; DO, dissolved oxygen, in milligrams per liter; SAL, salinity in parts per thousand; SD, Secchi disk depth in centimeters; -- not collected]

Sample collection		Sample position	Constituent					
Date	Time		pH	T	SC	DO	SAL	SD
Station 6 (50069620)								
Mar. 28, 2007	6:50 a.m.	Top	7.8	26.7	55,300	4.3	36.6	
		Bottom	6.8	27.0	55,800	4.0	37.0	152
May 31, 2007	6:30 a.m.	Top	7.7	29.4	52,400	4.5	34.1	
		Bottom	7.7	31.3	55,300	4.1	36.6	170
June 27, 2007	6:00 a.m.	Top	7.7	29.7	55,600	4.2	36.7	
		Bottom	7.7	29.7	55,600	4.0	36.7	91
July 24, 2007	6:10 a.m.	Top	7.8	30.2	56,200	4.9	37.2	
		Bottom	7.9	30.2	56,300	3.5	37.2	76
Sept. 11, 2007	6:10 a.m.	Top	7.7	30.4	56,850	5.0	37.7	
		Bottom	7.7	30.2	56,810	1.5	37.7	170
Oct. 16, 2007	6:10 a.m.	Top	7.4	29.1	56,740	4.9	37.6	
		Bottom	7.6	29.2	56770	4.5	37.6	201
Nov. 14, 2007	6:05 a.m.	Top	7.6	26.9	45,130	6.1	29.2	
		Bottom	7.4	29.5	53,800	1.0	35.4	122
Jan. 29, 2008	8:05 a.m.	Top	7.6	26.0	53,510	5.3	35.3	
		Bottom	7.7	26.1	53,840	5.0	35.4	122
Mar. 4, 2008	6:25 a.m.	Top	7.7	25.6	57,430	5.3	38.2	
		Bottom	7.6	25.7	57,360	0.3	38.2	91
Apr. 1, 2008	6:30 a.m.	Top	7.8	26.4	57,410	5.6	38.2	
		Bottom	7.9	26.4	57,500	2.8	38.3	122
May 13, 2008	5:55 a.m.	Top	7.7	29.3	55,500	3.3	36.7	
		Bottom	7.3	29.4	48,210	0.1	31.4	122
June 17, 2008	6:05 a.m.	Top	7.4	29.7	56,900	4.2	37.7	
		Bottom	7.6	29.7	56,830	0.6	37.7	107

Appendix 1. In situ determination of pH, temperature, specific conductance, dissolved oxygen, salinity, and Secchi disk depth for water-quality sites sampled from March 2007 to June 2008 at Laguna Grande, Fajardo, Puerto Rico.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. T, temperature, in degrees Celsius; SC, specific conductance, in microsiemens per centimeter; DO, dissolved oxygen, in milligrams per liter; SAL, salinity in parts per thousand; SD, Secchi disk depth in centimeters; -- not collected]

Sample collection		Sample position	Constituent					
Date	Time		pH	T	SC	DO	SAL	SD
Station 7 (50069610)								
Mar. 28, 2007	8:30 a.m.	Top	7.8	26.7	55,500	4.6	36.7	
		Bottom	7.8	27.1	56,000	3.7	37.1	183
May 31, 2007	8:30 a.m.	Top	7.7	30.3	53,700	4.2	35.4	
		Bottom	7.8	31.0	54,300	3.3	35.8	183
June 27, 2007	8:13 a.m.	Top	7.8	29.7	55,400	4.3	36.6	
		Bottom	7.8	29.7	55,400	4.0	36.6	91
July 24, 2007	8:00 a.m.	Top	7.9	29.9	56,300	4.8	37.3	
		Bottom	7.8	30.0	56,300	4.8	37.3	91
Sept. 11, 2007	7:50 a.m.	Top	7.8	30.3	56,930	5.1	37.7	
		Bottom	7.8	30.3	56,850	2.4	37.7	152
Oct. 16, 2007	6:35 a.m.	Top	7.7	29.2	56,480	4.9	37.4	
		Bottom	7.6	29.3	56,860	3.8	37.7	107
Nov. 14, 2007	6:35 a.m.	Top	7.7	26.5	44,410	5.9	28.7	
		Bottom	7.6	29.5	53,800	2.8	29.5	91
Jan. 29, 2008	8:20 a.m.	Top	7.7	25.8	53,370	5.7	35.2	
		Bottom	7.6	26.5	54,700	4.0	36.2	107
Mar. 4, 2008	6:55 a.m.	Top	7.9	25.6	57,440	5.2	38.3	
		Bottom	7.9	25.5	57,430	4.8	38.3	107
Apr. 1, 2008	7:05 a.m.	Top	7.9	26.5	57,640	5.2	38.4	
		Bottom	7.9	26.5	57,630	5.2	38.4	119
May 13, 2008	6:20 a.m.	Top	7.8	29.1	55,400	3.6	36.6	
		Bottom	7.6	29.1	55,220	0.3	36.6	157
June 17, 2008	6:30 a.m.	Top	7.7	29.9	57,030	4.0	37.8	
		Bottom	7.7	30.0	57,160	1.2	37.9	91

Appendix 1. In situ determination of pH, temperature, specific conductance, dissolved oxygen, salinity, and Secchi disk depth for water-quality sites sampled from March 2007 to June 2008 at Laguna Grande, Fajardo, Puerto Rico.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. T, temperature, in degrees Celsius; SC, specific conductance, in microsiemens per centimeter; DO, dissolved oxygen, in milligrams per liter; SAL, salinity in parts per thousand; SD, Secchi disk depth in centimeters; -- not collected]

Sample collection		Sample position	Constituent					
Date	Time		pH	T	SC	DO	SAL	SD
Station 8 (50069600)								
Mar. 28, 2007	8:00 a.m.	Top	7.8	26.4	55,100	4.7	36.4	
		Bottom	7.9	27.1	56,000	4.1	37.2	180
May 31, 2007	8:50 a.m.	Top	7.7	28.2	49,000	4.3	31.4	
		Bottom	7.8	31.2	54,600	3.8	36.0	168
June 27, 2007	5:45 a.m.	Top	7.8	29.8	55,500	4.2	36.7	
		Bottom	7.8	29.8	55,500	4.1	36.7	76
July 24, 2007	6:30 a.m.	Top	7.9	29.9	56,300	5.1	37.3	
		Bottom	7.8	29.9	56,200	0.1	37.2	91
Sept. 11, 2007	6:35 a.m.	Top	7.8	30.4	56,750	5.3	37.6	
		Bottom	7.8	30.3	56,780	4.5	37.6	122
Oct. 16, 2007	6:25 a.m.	Top	7.7	29.1	56,760	5.3	37.6	
		Bottom	7.6	29.2	56,820	3.6	37.7	132
Nov. 14, 2007	6:25 a.m.	Top	7.7	26.3	44,910	5.9	29.0	
		Bottom	7.4	29.5	53,810	0.8	35.4	91
Jan. 29, 2008	7:30 a.m.	Top	7.1	26.0	53,510	5.6	35.3	
		Bottom	7.3	26.5	54,590	1.8	36.1	122
Mar. 4, 2008	6:40 a.m.	Top	7.9	25.6	57,430	5.2	38.3	
		Bottom	7.9	25.6	57,420	4.7	38.2	76
Apr. 1, 2008	6:55 a.m.	Top	7.9	26.6	57,620	5.4	38.4	
		Bottom	7.9	26.7	57,460	0.5	38.3	102
May 13, 2008	6:10 a.m.	Top	7.7	29.2	55,520	4.5	36.7	
		Bottom	7.7	29.2	55,530	0.8	36.7	107
June 17, 2008	6:15 a.m.	Top	7.7	29.8	56,380	4.0	37.3	
		Bottom	7.5	29.9	54,130	0.4	35.6	76

Appendix 2. March 29, 2007, diel study physical properties.

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. Station identification number (STA-ID) is shown on spanner rows. Temp, temperature; SC, specific conductance; DO, dissolved oxygen; SAL, salinity]

TIME	Depth	pH	Temp	SC	DO	SAL
Station 6						
6:46 a.m.	Top	7.8	27.0	54,500	4.0	36.1
	Bottom	7.8	25.5	55,300	3.8	36.6
7:40 a.m.	Top	7.8	26.8	54,300	4.1	35.8
	Bottom	7.8	27.2	54,700	3.8	36.2
8:27 a.m.	Top	7.8	26.9	54,200	4.2	35.8
	Bottom	7.8	27.4	55,100	4.1	36.4
9:27 a.m.	Top	7.8	27.1	54,100	3.9	35.8
	Bottom	7.8	27.4	54,200	4.1	36.3
10:24 a.m.	Top	7.8	27.5	54,200	5.0	35.7
	Bottom	7.9	27.2	54,200	4.3	35.7
11:26 a.m.	Top	7.8	27.8	54,300	5.1	35.8
	Bottom	7.8	27.6	54,300	4.8	35.8
12:30 p.m.	Top	7.8	28.0	54,200	5.0	35.7
	Bottom	7.8	27.9	54,200	4.1	35.8
1:40 p.m.	Top	7.8	28.1	54,100	5.2	35.7
	Bottom	7.8	28.0	54,100	4.1	35.7
2:22 p.m.	Top	7.8	28.1	54,100	5.4	35.7
	Bottom	7.8	28.1	54,200	4.3	35.8
3:21 p.m.	Top	7.8	28.2	54,400	5.3	35.9
	Bottom	7.8	28.2	54,400	4.4	35.9
4:25 p.m.	Top	7.9	28.0	54,100	5.4	35.7
	Bottom	7.9	28.0	54,200	4.2	35.8
5:24 p.m.	Top	7.9	28.2	54,100	5.2	35.7
	Bottom	7.9	28.2	54,400	4.1	35.9
6:28 p.m.	Top	7.8	27.9	53,700	4.9	35.3
	Bottom	7.9	28.1	54,200	3.9	35.7
7:23 p.m.	Top	7.8	27.9	54,000	4.7	35.5
	Bottom	7.8	28.0	55,400	3.2	36.6

Appendix 2. March 29, 2007, diel study physical properties.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. Station identification number (STA-ID) is shown on spanner rows. Temp, temperature; SC, specific conductance; DO, dissolved oxygen; SAL, salinity]

TIME	Depth	pH	Temp	SC	DO	SAL
Station 7						
6:36 a.m.	Top	7.9	26.8	54,500	4.4	36.0
	Bottom	7.9	26.8	54,500	3.6	36.0
7:31 a.m.	Top	7.8	26.9	54,500	4.5	36.0
	Bottom	7.8	26.9	54,600	4.1	36.1
8:20 a.m.	Top	7.8	26.9	54,500	5.2	36.0
	Bottom	7.8	27.0	54,600	4.3	36.1
9:19 a.m.	Top	7.8	27.0	54,300	4.7	35.9
	Bottom	7.9	27.1	54,700	3.6	36.2
10:18 a.m.	Top	7.8	27.4	54,100	4.7	35.6
	Bottom	7.9	27.1	54,300	4.3	35.8
11:20 a.m.	Top	7.8	27.5	54,100	5.2	35.7
	Bottom	7.8	27.4	54,600	4.5	36.1
12:23 p.m.	Top	7.8	27.8	54,300	5.0	35.9
	Bottom	7.8	27.7	54,300	4.4	35.9
1:35 p.m.	Top	7.8	27.9	54,300	5.2	35.8
	Bottom	7.8	27.8	54,300	4.5	35.8
2:17 p.m.	Top	7.9	28.2	54,500	5.5	36.0
	Bottom	7.8	28.0	54,500	4.6	36.0
3:15 p.m.	Top	7.8	27.9	54,500	5.4	36.0
	Bottom	7.8	27.9	54,500	4.6	36.0
4:19 p.m.	Top	7.9	27.9	54,600	5.4	36.0
	Bottom	7.9	27.9	54,600	4.8	36.0
5:14 p.m.	Top	7.9	28.2	54,400	5.3	35.9
	Bottom	7.9	28.0	54,500	4.6	36.0
6:20 p.m.	Top	7.9	28.0	53,800	5.2	35.6
	Bottom	7.9	28.2	54,400	4.2	35.9
7:17 p.m.	Top	7.8	27.8	53,600	4.5	35.3
	Bottom	7.9	27.9	54,700	4.0	36.2

Appendix 2. March 29, 2007, diel study physical properties.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. Station identification number (STA-ID) is shown on spanner rows. Temp, temperature; SC, specific conductance; DO, dissolved oxygen; SAL, salinity]

TIME	Depth	pH	Temp	SC	DO	SAL
Station 8						
6:10 a.m.	Top	7.9	26.7	54,200	4.9	35.8
	Bottom	7.9	27.2	55,000	2.4	36.3
7:12 a.m.	Top	7.8	26.5	53,800	4.7	35.5
	Bottom	7.8	26.7	54,300	4.0	35.9
8:05 a.m.	Top	7.8	26.6	53,500	4.7	35.5
	Bottom	7.8	26.8	54,300	4.5	35.9
9:03 a.m.	Top	7.8	26.7	53,400	4.8	35.2
	Bottom	7.9	26.8	54,300	3.7	35.9
10:03 a.m.	Top	7.8	27.0	53,400	5.1	35.4
	Bottom	7.8	27.1	54,400	3.8	36.0
11:06 a.m.	Top	7.8	27.3	54,200	5.2	35.8
	Bottom	7.8	27.4	54,700	3.9	36.2
12:07 p.m.	Top	7.8	27.6	54,400	5.3	36.0
	Bottom	7.8	27.5	54,800	4.3	36.2
1:02 p.m.	Top	7.8	27.7	54,600	5.1	36.1
	Bottom	7.8	27.7	54,600	4.6	36.1
2:03 p.m.	Top	7.8	27.9	54,500	5.2	36.0
	Bottom	7.8	27.9	54,600	4.6	36.0
3:02 p.m.	Top	7.8	27.8	54,600	5.3	36.0
	Bottom	7.8	27.8	54,700	4.6	36.2
4:04 p.m.	Top	7.9	27.9	54,700	5.6	36.1
	Bottom	7.9	27.9	54,800	4.5	36.2
5:02 p.m.	Top	7.9	28.0	54,700	5.5	36.1
	Bottom	7.9	27.7	54,900	3.8	36.3
6:04 p.m.	Top	7.8	27.9	54,400	5.0	35.9
	Bottom	7.9	27.9	54,800	3.8	36.2
7:03 p.m.	Top	7.8	27.7	53,400	5.2	35.2
	Bottom	7.9	28.0	54,800	1.5	36.3

Appendix 2. March 29, 2007, diel study physical properties.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. Station identification number (STA-ID) is shown on spanner rows. Temp, temperature; SC, specific conductance; DO, dissolved oxygen; SAL, salinity]

TIME	Depth	pH	Temp	SC	DO	SAL
Station 9						
6:00 a.m.	Top	7.8	26.7	54,200	4.6	35.8
	Bottom	7.9	26.8	54,400	4.2	35.9
7:00 a.m.	Top	7.9	26.9	54,400	4.5	35.9
	Bottom	7.8	27.2	54,700	4.5	36.2
8:00 a.m.	Top	7.9	26.6	54,100	4.5	35.7
	Bottom	7.8	26.7	54,200	4.6	35.8
9:00 a.m.	Top	7.8	26.8	54,100	4.6	35.7
	Bottom	7.8	26.7	54,100	4.5	35.7
10:00 a.m.	Top	7.9	27.1	53,700	4.7	35.4
	Bottom	7.8	26.9	54,000	4.2	35.7
11:00 a.m.	Top	7.8	27.5	52,000	4.8	34.2
	Bottom	7.8	27.6	54,600	4.3	36.1
12:00 p.m.	Top	7.7	27.7	52,500	4.5	34.7
	Bottom	7.8	27.8	54,600	4.3	36.1
1:00 p.m.	Top	7.6	27.8	52,700	4.2	34.7
	Bottom	7.6	27.8	53,800	4.6	35.5
2:00 p.m.	Top	7.7	27.9	53,800	4.4	35.1
	Bottom	7.2	28.1	54,500	3.6	35.9
3:00 p.m.	Top	7.7	27.9	53,600	4.0	35.3
	Bottom	7.6	28.1	54,400	4.0	35.9
4:00 p.m.	Top	7.7	27.7	53,100	4.5	34.9
	Bottom	7.6	28.3	54,700	4.3	36.1
5:00 p.m.	Top	7.8	27.9	53,900	4.2	35.6
	Bottom	7.5	28.2	54,600	3.1	36.1
6:00 p.m.	Top	7.8	28.1	54,400	4.0	35.9
	Bottom	7.7	28.2	54,700	3.0	36.2
7:00 p.m.	Top	7.7	28.0	54,600	3.9	36.0
	Bottom	7.74	28.1	54,800	2.6	36.2

Appendix 2. March 29, 2007, diel study physical properties.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. Station identification number (STA-ID) is shown on spanner rows. Temp, temperature; SC, specific conductance; DO, dissolved oxygen; SAL, salinity]

TIME	Depth	pH	Temp	SC	DO	SAL
Station 10						
6:25 a.m.	Top	7.8	26.4	53,400	3.4	35.2
	Bottom	7.8	27.1	54,700	3.4	36.1
7:22 a.m.	Top	7.7	26.6	53,500	3.1	35.1
	Bottom	7.8	27.1	54,400	3.4	35.9
8:13 a.m.	Top	7.7	26.9	53,800	3.3	35.5
	Bottom	7.8	27.3	54,800	4.6	36.2
9:13 a.m.	Top	7.7	27.3	54,400	3.5	36.0
	Bottom	7.8	27.2	54,600	4.9	36.1
10:11 a.m.	Top	7.8	27.6	54,500	4.7	36.0
	Bottom	7.9	27.5	54,500	5.0	36.0
11:13 a.m.	Top	7.8	28.2	54,400	4.9	35.9
	Bottom	7.8	27.6	54,500	5.2	36.0
12:16 p.m.	Top	7.8	28.4	54,600	5.2	36.1
	Bottom	7.8	27.7	54,700	5.2	36.1
1:09 p.m.	Top	8.0	28.9	54,600	6.5	36.0
	Bottom	7.9	28.1	54,800	6.8	36.2
2:10 p.m.	Top	7.8	28.3	54,500	5.2	36.0
	Bottom	7.9	28.3	54,700	5.4	36.1
3:09 p.m.	Top	7.9	28.1	54,600	5.6	36.0
	Bottom	7.9	28.2	54,600	5.7	36.0
4:13 p.m.	Top	7.9	28.3	54,600	6.4	36.1
	Bottom	7.9	28.3	54,700	6.2	36.1
5:08 p.m.	Top	7.9	28.0	54,700	5.7	36.1
	Bottom	7.9	28.2	54,800	4.8	36.2
6:13 p.m.	Top	7.9	28.2	54,400	5.7	35.9
	Bottom	7.9	28.1	54,700	4.5	36.1
7:10 p.m.	Top	7.9	28.1	54,500	6.6	36.1
	Bottom	7.9	28.0	54,900	5.2	36.3

Appendix 3. November 15, 2007, diel study physical properties.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. Station identification number (STA-ID) is shown on spanner rows; Temp, temperature; SC, specific conductance; DO, dissolved oxygen; SAL, salinity]

TIME	Depth	pH	Temp	SC	DO	SAL
Station 6						
5:30 a.m.	Top	7.7	26.8	47,320	6.6	30.7
	Bottom	7.4	29.6	54,340	1.7	35.8
6:30 a.m.	Top	7.8	26.7	47,250	6.4	30.7
	Bottom	7.6	29.7	54,330	1.7	35.8
7:30 a.m.	Top	7.8	26.6	47,310	6.5	30.8
	Bottom	7.6	29.7	54,250	1.8	35.7
8:30 a.m.	Top	7.8	26.8	46,910	6.4	30.4
	Bottom	7.5	29.7	54,290	2.9	35.8
9:30 a.m.	Top	7.8	27.2	47,110	6.6	30.6
	Bottom	7.8	29.7	54,320	2.9	35.8
10:25 a.m.	Top	7.8	27.5	47,370	6.8	30.8
	Bottom	7.5	29.7	54,280	2.8	35.8
11:25 a.m.	Top	7.8	27.5	47,380	7.1	30.8
	Bottom	7.5	29.7	54,280	2.7	35.8
12:25 p.m.	Top	7.8	27.9	47,600	7.3	30.9
	Bottom	7.5	29.7	54,270	2.8	35.8
1:25 p.m.	Top	7.9	28.1	47,600	7.4	30.9
	Bottom	7.5	29.8	54,200	2.8	35.7
2:25 p.m.	Top	7.9	28.3	47,660	7.9	30.9
	Bottom	7.5	29.8	54,240	2.8	35.7
3:25 p.m.	Top	7.9	28.5	47,700	8.2	31.0
	Bottom	7.5	29.8	54,200	2.9	35.7
4:25 p.m.	Top	7.9	28.5	47,710	8.2	31.0
	Bottom	7.5	29.9	54,140	2.4	35.7
5:25 p.m.	Top	7.9	28.4	47,840	8.2	31.1
	Bottom	7.5	29.8	53,330	1.8	35.1
6:25 p.m.	Top	7.9	28.1	47,890	8.0	31.1
	Bottom	7.5	29.8	54,130	1.7	35.7

Appendix 3. November 15, 2007, diel study physical properties.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. Station identification number (STA-ID) is shown on spanner rows; Temp, temperature; SC, specific conductance; DO, dissolved oxygen; SAL, salinity]

TIME	Depth	pH	Temp	SC	DO	SAL
			Station 7			
5:49 a.m.	Top	7.8	26.9	47,260	6.7	30.7
	Bottom	7.5	29.6	54,350	0.7	35.8
6:34 a.m.	Top	7.8	26.8	47,280	6.7	30.7
	Bottom	7.5	29.6	54,370	0.8	35.8
7:35 a.m.	Top	7.8	26.8	47,340	6.8	30.8
	Bottom	7.5	29.6	54,380	2.8	35.8
8:32 a.m.	Top	7.8	26.9	47,430	7.0	30.8
	Bottom	7.5	29.6	54,330	2.9	35.8
9:32 a.m.	Top	7.9	27.1	47,500	7.4	30.9
	Bottom	7.5	29.6	54,260	3.7	35.7
10:30 a.m.	Top	7.9	27.3	47,350	7.4	30.8
	Bottom	7.5	29.6	54,290	3.8	35.8
11:28 a.m.	Top	7.9	27.4	47,430	7.5	30.7
	Bottom	7.5	29.6	54,300	2.6	35.8
12:27 p.m.	Top	7.8	27.7	47,450	7.8	30.8
	Bottom	7.5	29.7	54,260	3.8	35.8
1:28 p.m.	Top	7.9	27.8	47,160	8.2	30.6
	Bottom	7.5	29.7	54,230	3.8	35.7
2:26 p.m.	Top	7.9	28.0	47,230	8.5	30.6
	Bottom	7.5	29.7	54,240	3.8	35.7
3:25 p.m.	Top	8.0	28.1	47,170	8.6	30.6
	Bottom	7.5	29.7	54,210	3.0	35.7
4:30 p.m.	Top	8.0	28.1	47,290	8.8	30.7
	Bottom	7.5	29.7	54,190	3.0	35.7
5:27 p.m.	Top	8.0	28.0	47,390	8.4	30.8
	Bottom	7.4	29.7	53,110	1.9	34.9
6:30 p.m.	Top	8.0	27.8	47,170	8.3	30.6
	Bottom	7.5	29.7	54,150	1.7	35.7

Appendix 3. November 15, 2007, diel study physical properties.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. Station identification number (STA-ID) is shown on spanner rows; Temp, temperature; SC, specific conductance; DO, dissolved oxygen; SAL, salinity]

TIME	Depth	pH	Temp	SC	DO	SAL
			Station 8			
5:55 a.m.	Top	7.8	26.7	46,330	6.6	30.0
	Bottom	7.5	29.7	54,310	0.9	35.8
6:39 a.m.	Top	7.8	26.5	45,950	6.6	29.7
	Bottom	7.4	29.8	54,240	1.8	35.7
7:42 a.m.	Top	7.8	26.7	46,900	6.8	30.4
	Bottom	7.5	29.8	54,160	2.0	35.7
8:34 a.m.	Top	7.8	26.7	46,270	6.8	30.2
	Bottom	7.4	29.7	54,240	2.6	35.7
9:47 a.m.	Top	7.8	26.9	46,700	7.0	30.3
	Bottom	7.6	29.7	54,180	3.4	35.7
10:35 a.m.	Top	7.9	27.0	46,470	7.5	30.1
	Bottom	7.4	29.7	54,230	3.5	35.7
11:34 a.m.	Top	7.9	27.1	46,380	7.5	30.0
	Bottom	7.4	29.8	54,180	3.2	35.7
12:33 p.m.	Top	7.9	27.4	46,700	8.0	30.3
	Bottom	7.5	29.8	54,160	4.1	35.7
1:38 p.m.	Top	7.9	27.7	46,490	8.4	30.1
	Bottom	7.5	29.8	54,150	4.2	35.7
2:34 p.m.	Top	8.0	27.9	46,660	8.6	30.2
	Bottom	7.5	29.8	54,210	7.6	35.7
3:29 p.m.	Top	7.8	28.0	46,360	8.8	30.0
	Bottom	7.5	29.8	54,160	7.5	35.7
4:38 p.m.	Top	8.0	28.1	46,720	9.4	30.3
	Bottom	7.5	29.8	54,180	3.2	35.7
5:36 p.m.	Top	8.0	28.1	47,07	8.9	30.5
	Bottom	7.5	29.8	54,090	1.6	35.6
6:34 p.m.	Top	8.0	27.5	45,130	8.4	29.2
	Bottom	7.5	29.7	54,130	1.1	35.7

Appendix 3. November 15, 2007, diel study physical properties.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. Station identification number (STA-ID) is shown on spanner rows; Temp, temperature; SC, specific conductance; DO, dissolved oxygen; SAL, salinity]

TIME	Depth	pH	Temp	SC	DO	SAL
			Station 9			
6:01 a.m.	Top	7.7	27.3	47,340	5.9	30.7
	Bottom	7.5	29.3	51,480	2.6	33.7
6:46 a.m.	Top	7.8	27.2	47,340	5.8	30.7
	Bottom	7.6	28.7	50,210	4.2	32.7
7:48 a.m.	Top	7.7	27.2	47,460	6.1	30.8
	Bottom	7.5	29.2	51,730	3.6	33.9
8:39 a.m.	Top	7.8	27.2	46,900	6.7	30.4
	Bottom	7.6	29.1	51,580	3.9	33.8
9:52 a.m.	Top	7.8	27.3	47,250	6.5	30.7
	Bottom	7.6	29.0	51,610	3.6	33.8
10:46 a.m.	Top	7.8	27.4	47,090	7.2	30.5
	Bottom	7.6	28.6	49,460	4.7	32.3
11:43 a.m.	Top	7.8	27.6	47,710	6.8	31.0
	Bottom	7.6	28.8	50,540	4.4	33.0
12:40 p.m.	Top	7.8	27.8	47,380	7.3	30.7
	Bottom	7.8	27.9	48,490	6.8	31.6
1:51 p.m.	Top	7.8	28.0	47,800	7.0	31.1
	Bottom	7.6	29.3	51,280	5.3	33.6
2:42 p.m.	Top	7.9	28.2	47,300	8.3	30.7
	Bottom	7.7	29.0	50,160	5.7	32.8
3:36 p.m.	Top	7.9	28.0	47,370	8.3	30.7
	Bottom	7.6	29.5	51,740	4.1	33.9
4:45 p.m.	Top	7.8	28.1	47,530	7.9	30.9
	Bottom	7.7	29.0	50,250	5.1	32.8
5:41 p.m.	Top	7.9	28.0	47,230	8.0	30.6
	Bottom	7.7	29.3	51,020	4.1	33.4
6:40 p.m.	Top	7.9	27.9	47,120	7.8	30.6
	Bottom	7.6	29.3	51,510	3.3	33.8

Appendix 3. November 15, 2007, diel study physical properties.—Continued

[Top values were obtained at about 15 centimeters in depth and bottom values were obtained about 10 centimeters from the lagoon bottom. Station identification number (STA-ID) is shown on spanner rows; Temp, temperature; SC, specific conductance; DO, dissolved oxygen; SAL, salinity]

TIME	Depth	pH	Temp	SC	DO	SAL
Station 10						
6:10 a.m.	Top	7.6	25.7	39,900	3.9	25.4
	Bottom	7.7	26.4	46,220	5.0	28.3
6:53 a.m.	Top	7.6	25.5	39,910	4.0	25.4
	Bottom	7.6	27.1	46,270	2.8	29.8
7:55 a.m.	Top	7.6	25.7	41,170	5.1	26.4
	Bottom	7.6	25.8	41,010	5.2	26.2
8:45 a.m.	Top	7.9	26.2	42,510	7.4	27.3
	Bottom	7.9	26.2	42,750	7.5	27.4
9:57 a.m.	Top	7.8	26.4	41,320	7.7	26.4
	Bottom	7.9	26.5	41,440	8.0	26.5
10:58 a.m.	Top	7.9	26.6	40,900	8.1	26.1
	Bottom	7.9	26.6	40,190	8.1	26.1
11:49 a.m.	Top	8.0	26.9	42,200	9.7	26.9
	Bottom	8.0	26.9	42,110	9.6	27.0
12:49 p.m.	Top	8.1	27.4	42,150	10.4	27.0
	Bottom	8.1	27.4	42,320	10.1	27.1
1:58 p.m.	Top	8.3	28.1	43,300	12.4	27.8
	Bottom	8.2	28.0	43,830	11.9	28.2
2:53 p.m.	Top	8.3	28.3	43,230	12.4	27.7
	Bottom	8.2	28.3	44,000	11.9	28.3
3:48 p.m.	Top	8.2	28.3	43,540	12.7	28.0
	Bottom	8.3	28.3	43,620	12.6	28.0
4:51 p.m.	Top	8.2	28.1	43,530	12.6	28.0
	Bottom	8.2	28.2	43,520	11.5	28.0
5:47 p.m.	Top	8.2	28.0	42,780	13.1	27.5
	Bottom	8.1	28.0	44,030	9.8	28.3
6:46 p.m.	Top	8.1	27.5	42,580	10.1	27.3
	Bottom	8.0	28.0	44,800	5.8	29.1

Appendix 4. Fecal bacteria counts from March 2007 to June 2008.

[All values shown are colonies per 100 milliliters]

Station number	Sample collection date											
	Mar. 28, 2007	May 31, 2007	June 27, 2007	July 24, 2007	Sept. 11, 2007	Oct. 16, 2007	Nov. 14, 2007	Jan. 29, 2008	Mar. 4, 2008	Apr. 1, 2008	May 13, 2008	June 17, 2008
1	240	570	45	64	9	2	860	270	40	720	32	60
3	280	8,270	10	900	34	20	810	600	200	450	33	10
5	600	60,000	2,800	7,000	160	750	60,000	39,000	350	160	1,900	2,000
7	97	240	100	9	4	2	970	8	4	0	5	2