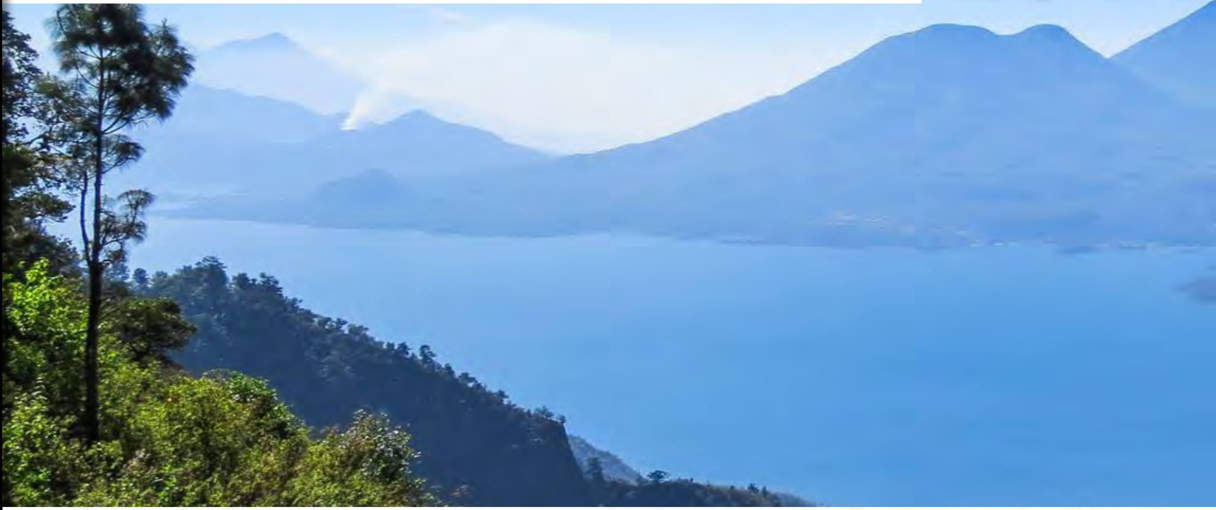
STATE OF THE LAKE
ATITLAN
2014



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ATITLAN

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SUMMARY

We are once again sharing with you the findings and accomplishments of the United for Lake Atitlan project after another year's work in the area. Two aspects that have changed drastically over time have been the transparency or clarity of the water (reduced by approximately 46% since the beginning of the century) and the concentration of available oxygen in deep waters (less than 2 mg/L below 250 m). Bioassays confirmed that sewage and soil from the watershed stimulate bacterial activity which reduces the amount of available oxygen in the bottom of the lake and near shore areas. We have studied changes in lake phytoplankton dominance throughout the year. So far, water samples have shown no toxic blooms of cyanobacteria , but there is concern for the increased concentration of *Microcystis aeruginosa* and *Aphanizomenon sp*. The threat of future cyanobacterial blooms and these changes are relevant not only for the lake ecosystem, but also for human health and the local economy.

Because the lake is a water source for human consumption and recreation, it is important to ensure its water quality. Everything that happens in the terrestrial part of the lake basin impacts lake water quality. For this reason, we collected information that summarizes the situation concerning the dynamics of nutrient discharge to the lake.. Due to the soils' volcanic origin, we studied their phosphorus retention properties. If the soil is eroded and enters the lake, the retained phosphorus can be released into the water and be available for algal growth .

It is known that sewage input to the lake has a great impact on human health and the natural ecosystem, so we believe it is urgent to implement an integrated wastewater management system. The use of residential water filters was studied, but we see as a priority to implement measures to prevent the entry of harmful waters to the lake. As we compare the sustainability of the two best alternatives to this issue, we conclude that it is feasible, effective and in the best interest to the area, the implementation of measures to prevent the entry of polluted waters as a priority. It is concluded that directing the sewage out of the basin is feasible, effective and in the best interests for the area. Directing the sewage out of the lake basin is vital to prevent the spread of diseases and algal blooms, since traditional treatments so far applied in the country have not proven to be a solution.

Throughout this project we maintained an environmental awareness and outreach program aimed at local communities. This program has reached more than 4,000 people in 18 municipalities in the department of Sololá. Our work would not be complete without the collaboration and involvement of multiple volunteers and local actors. Now we have a suitable local laboratory for the lake's water monitoring and sample analysis. Students and managers have been trained to continue the research that will help us better understand the lake and to promote decision making and management based on scientific information. Thanks to all this, we now have the initial answers to our questions, but this is just the beginning. Now is the time to act and to remember that we are all part of the solution!

UNITED FOR LAKE ATITLAN PROJECT OBJECTIVES

1. Train future generations of young Guatemalan scientists to carry out monitoring and communicate results to local people.
2. Develop a long-term scientifically based monitoring framework for the lake to measure the physics (temperature, clarity), chemistry (nutrients and oxygen), and biology (algae, zooplankton and macroinvertebrate composition) to determine the health of the lake and predict future changes.
3. Develop a database of existing lake and river data that will be available to interested parties to understand historical changes to the lake and factors that are driving current conditions.
4. Create a sustainable environmental quality laboratory in the Atitlán watershed capable of measuring critical aspects of lake health, with special instrumentation for measurements of the lake's physics, chemistry, and biology.
5. Share the findings with local stakeholders and policy makers to encourage proper lake management.

DONATIONS

Support student training, outreach programs and on-going research at Lake Atitlán.
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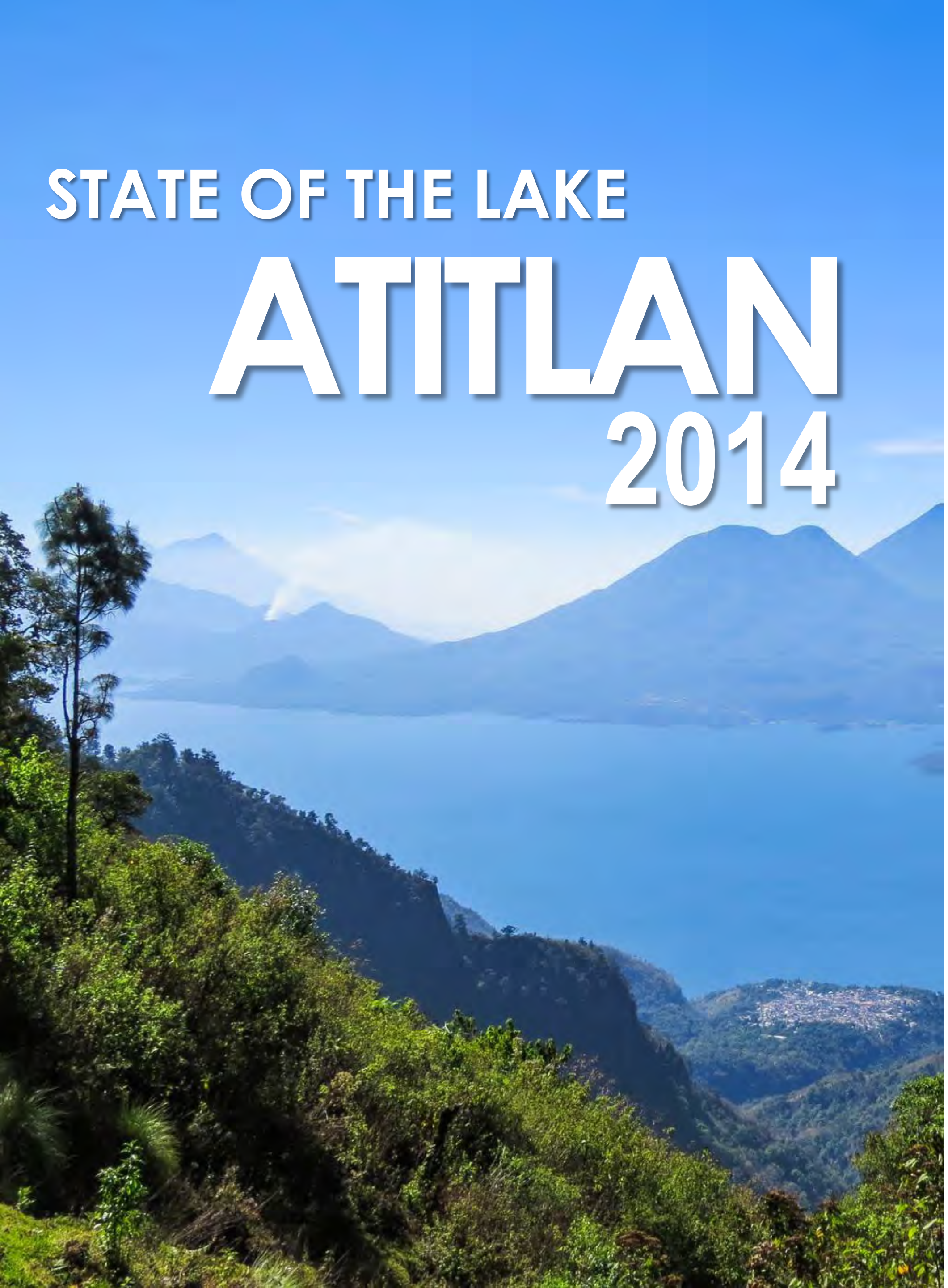
SCIENTIFIC EXPEDITION 2014



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PHYSICAL DYNAMICS

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TRANSPARENCY OF THE LAKE

Lake transparency or clarity is important for a number of physical and chemical factors. First, the transparency dictates the energy budget and temperature structure of the ecosystem. Second, the transparency can dictate where in the water column the biological species including algae may distribute within the lake. The transparency of the lake can change the algal concentrations in the lake, the delivery of sediment particles from the watershed to the lake, and the amount of dissolved matter produced or delivered to the lake. Understanding the changes to the lake transparency can help us understand the state of the ecosystem. Transparency can be measured using a Secchi disc that is lowered into the water until it disappears. The depth where it can no longer be seen is the Secchi transparency. This allows us to compare over time how the lake clarity is changing.

We have compiled the reliable and available information provided to the project to understand change during the rainy and wet season. During the dry season we see oscillating clarity from the 1960s to early 2000s ranging from 10-15 meters. Starting in 2009, there is a strong decline in the clarity to approximately 5.5 meters. We believe the changes during the dry season are attributable to the increase in organic algal production within the lake. There are much fewer observations during the wet season where clarity can range from 7.2 to 15.5 meters until the early 2000s. After this period, clarity is reduced to 5.7 meters which is likely due to a combination of algal production and delivery of sediments from the watershed. Key observations from this analysis suggest that monitoring of clarity should occur during both the dry and wet season followed by collections of algal biomass and particulate organic matter and/ or carbon measurements to understand the mechanisms controlling the loss of clarity.

STATE OF THE LAKE 2014

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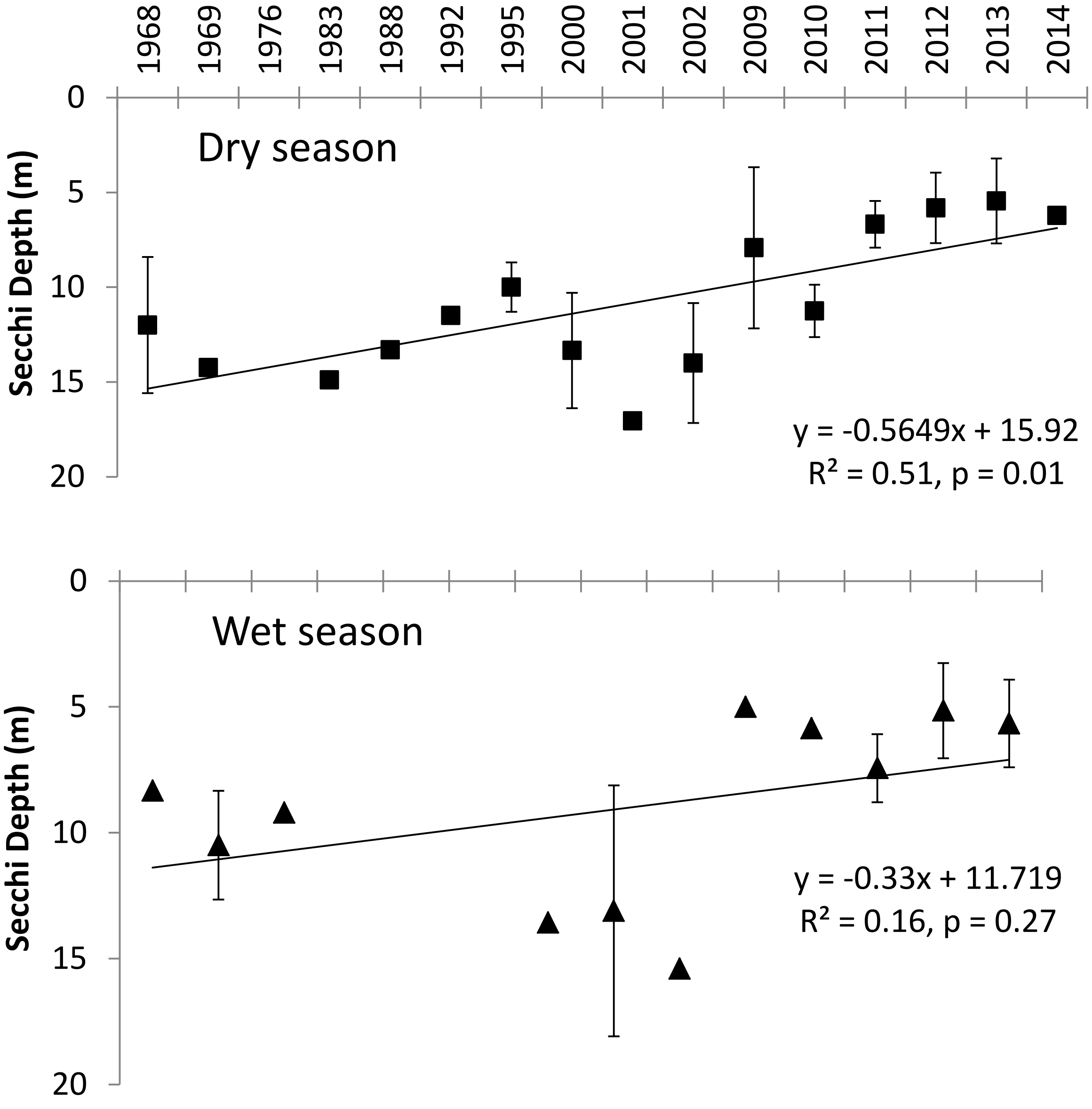

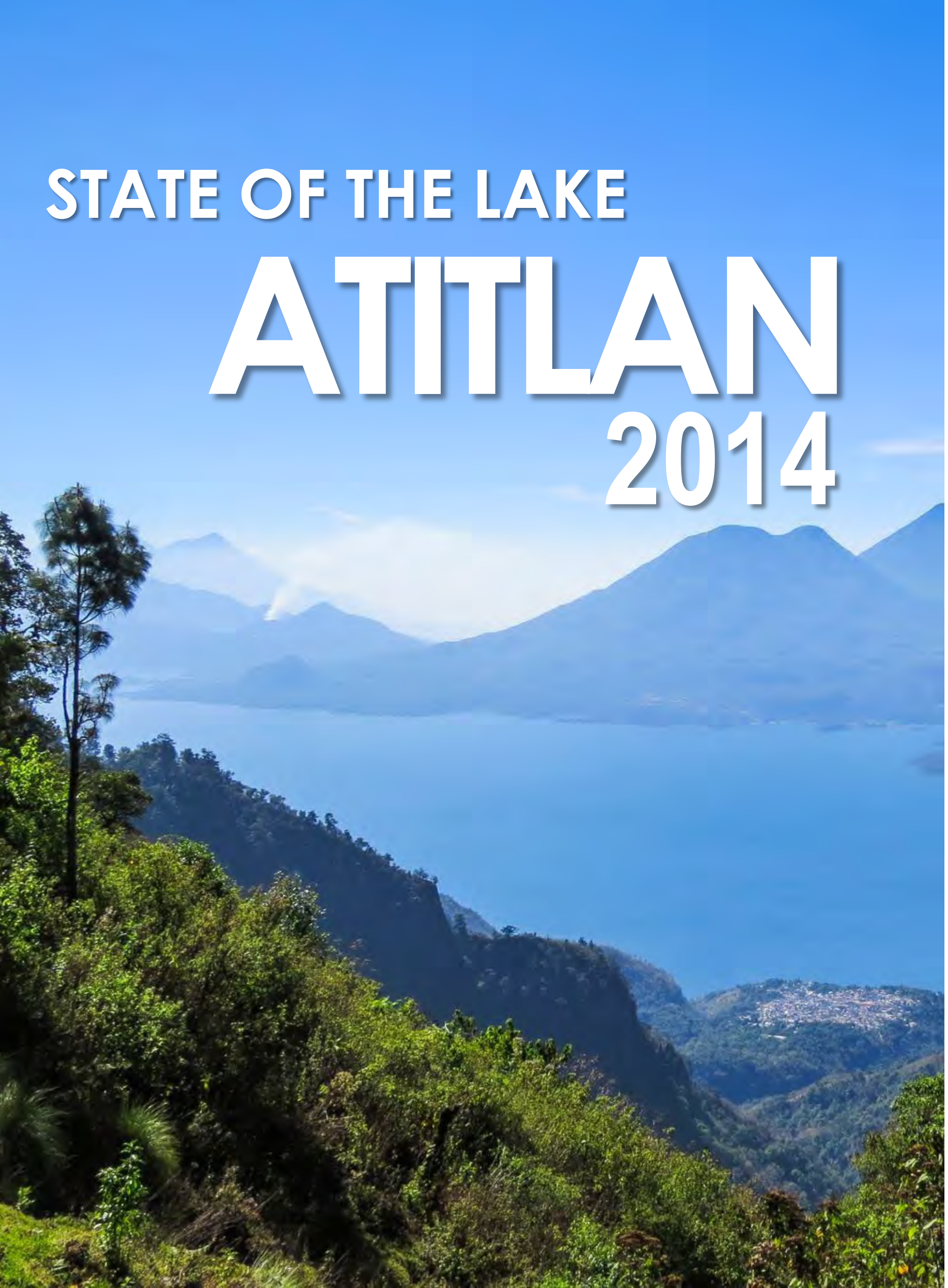

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CHEMICAL DYNAMICS

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NUTRIENTS IN LAKE WATER

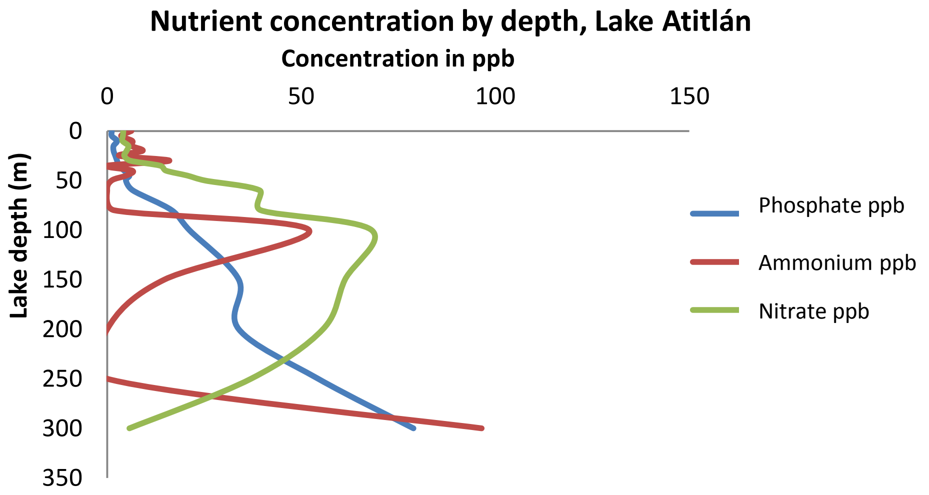
Lake water is composed of many chemicals from various sources- iron and aluminum from rocks, carbon from microscopic plankton, phosphorus from laundry detergents and soils, nitrogen from decomposing vegetation, etc. Life is dependent upon many of these chemical compounds, therefore it is important to know what nutrients are present in the lake water. Two very important elements for life are nitrogen and phosphorus. Nitrogen is found in proteins and muscles and is excreted in waste; phosphorus is found in DNA, cell walls, and is also used for energy by all organisms. But not all nutrients are needed by organisms at the same concentration. In general, much more carbon is needed than nitrogen, and more nitrogen is needed than phosphorus.

Plants and other life forms can't take up these two important chemicals in their elemental form, nor is it always available in nature that way. That is why we test for nitrate (NO_3), ammonium (NH_4), and phosphate (PO_4) - these are the forms of nitrogen (N) and phosphorus (P) that plankton and plants can more readily acquire. We also measure total nitrogen (TN) and total phosphorus (TP). This is a measurement of all of the possible sources of nitrogen and phosphorus in the water and comes from both living and dead sources. Examples include: live plankton, decomposing leaves, sediment particles in the water column, wastewater in the lake, etc. Although many of these sources are composed of larger organic molecules, they can be a source of nutrition to bacteria and other decomposers which can then release an inorganic and more bioavailable form of nitrogen or phosphorus. All of these are measured in parts per billion (ppb): meaning that the value listed is out of every billion particles in the system (water, oxygen, salts, etc.).

NUTRIENTS IN WATER COLUMN

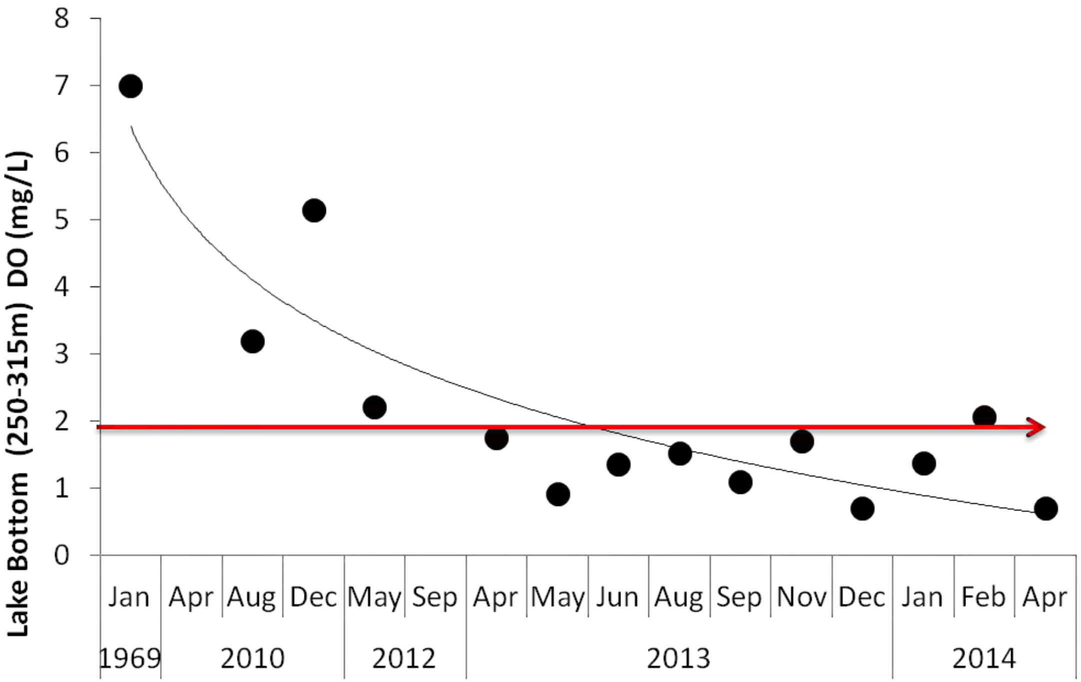
Looking at a snapshot of the nutrients at a single time point can be useful to see the status of the lake at that moment, but there are ways of looking at chemical nutrient data that are more informative. One way is looking at a depth profile- taking samples of water from different depths and comparing their nutrient concentrations. That way we can see how concentrations change with depth. We do this in Atitlan by taking a sample at the surface, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 80, 100, 150, 200, 250, and 300 meters. Another way of looking at nutrient concentrations is by comparing samples taken at different time points. That way we can look at seasonal trends as well as changes over longer periods of time.

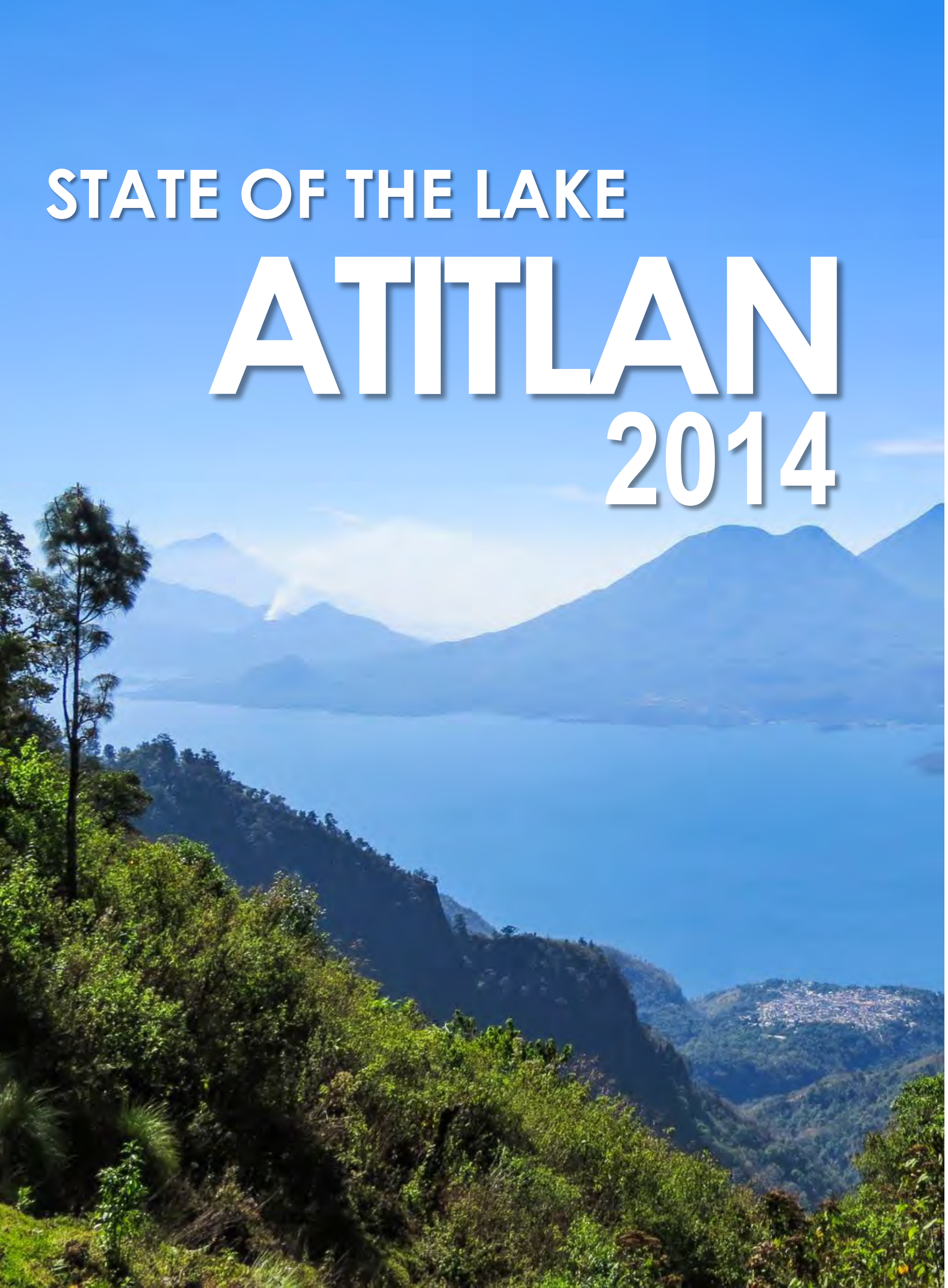
By looking at the graph below, we see that generally the nutrients increase with depth- this is partly because of the rapid utilization of available nutrients by phytoplankton in the upper lake layers, partly due to sinking and accumulation of dead organisms and soil particles in the deeper parts of the lake. We also see the ammonium is close to zero everywhere except for 30-50 meters, 100 meters, and the very bottom. This is because ammonium is generally released as a waste product, thus, we can see a large congregation of plankton in the 30-50m zone and at 100 m releasing ammonium. This is also seen in the nitrate and the phosphate data- the concentrations are lower in these depths than at the surface and in the deeper depths; the plankton is taking up nitrate and phosphate at the 30-50 m depths and releasing it when they die and sink to the bottom.



DISSOLVED OXYGEN WITHIN THE DEEP WATERS OF THE LAKE

Dissolved oxygen plays an important role not only for the survival of fishes and invertebrates within the water column but also controlling the chemical reactions within water. In productive lakes, the oxygen near the bottom of the lake can be low to the consumption of organic matter by bacteria. When oxygen in the water column is reduced below 2 mg/L, fishes can be stressed or killed. In addition, the availability of certain nutrients (phosphorus) can increase due to the “liberation” from iron complexes. There is limited information of oxygen from the deeper depths of the lake. However, this project utilized existing information and conducted measurements with special instruments to determine the levels of dissolved oxygen. Since 1969, there has been a dramatic decline in concentrations within the deeper waters (greater than 250 m) within the lake. This decline is likely leading to the increased bioavailability of phosphorus nutrients within this deep depth which represents a large volume of waters. Thus, if the lake completely mixes and the conditions of light and temperature are favorable, there may be increased possibilities for blooms of algae similar to the late 2000s.





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BIOLOGY

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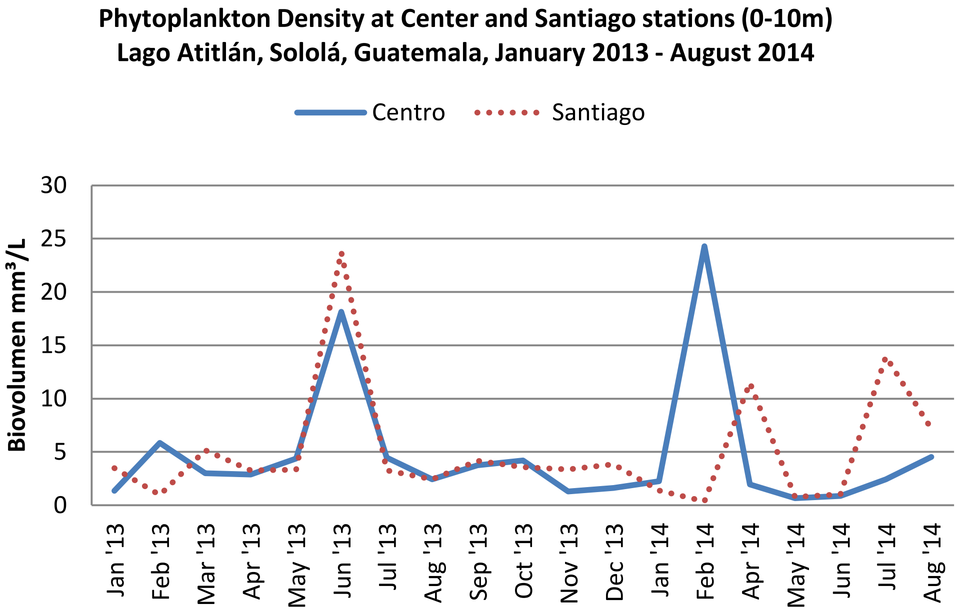
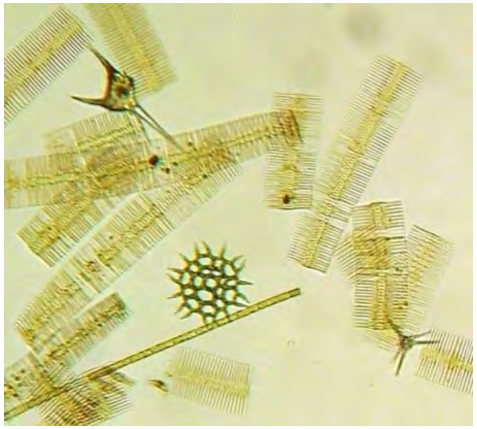
PHYTOPLANKTON DENSITY (BIOVOLUME/LITRE)

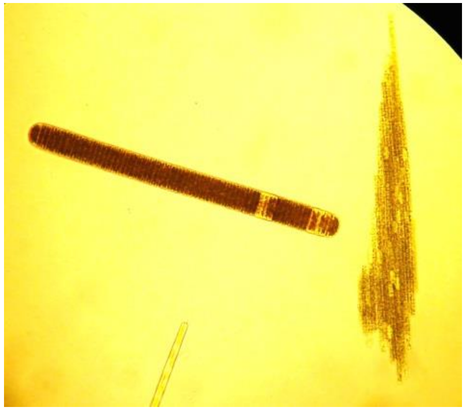
Several peaks of phytoplankton density were observed in the period between January 2013 to August 2014. In 2013, at the Center station in February (5.9 mm³/L) and June (18.3 mm³/L), and for Santiago station in the months of March (5.2 mm³/L) and June (23.8 mm³/L) . In 2014, a peak was reached in February (24.3 mm³/L) at the Center, while for Santiago there was a peak in April (5.1 mm³/L) and another in July (23.7mm³/L). The lowest phytoplankton densities were observed in May (0.8 mm³/L) and June (1.0 mm³/L) 2014.



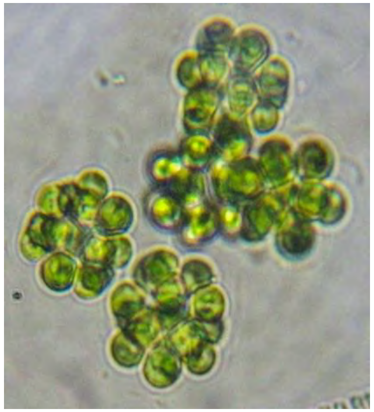
Phytoplankton Density at Center and Santiago stations (0-10m)
Lago Atitlán, Sololá, Guatemala, January 2013 - August 2014



View of phytoplancton dominated by *Fragilaria crotonensis* diatoms



Limnoraphis robusta and Aphanizomenon



Coelastrum

SEASONAL DISTRIBUTION OF PHYTOPLANKTON

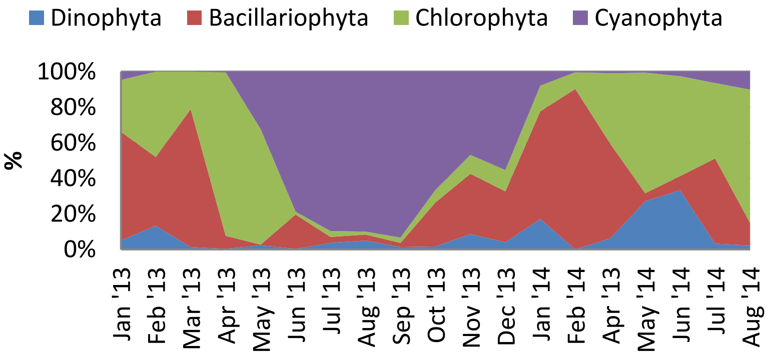
During the period between January 2013 through August 2014, the seasonal distribution of phytoplankton had a similar pattern to that observed in 2012. The figures show that for both stations, Center and Santiago, diatoms were dominant in the lake during the first months of the year (January to March, both in 2013 and 2014). Bacillariophytes were mainly represented by two species *Aulacoseira granulata* and *Fragilaria crotonensis.*

In April and May 2013, green algae (Chlorophyte) were dominant, represented by *Coelastrum* for both sites. Similarly, between April and August 2014, the green algae *Coelastrum* sp, *Oocystis* sp y *Mougeotia* sp dominated in the Center.

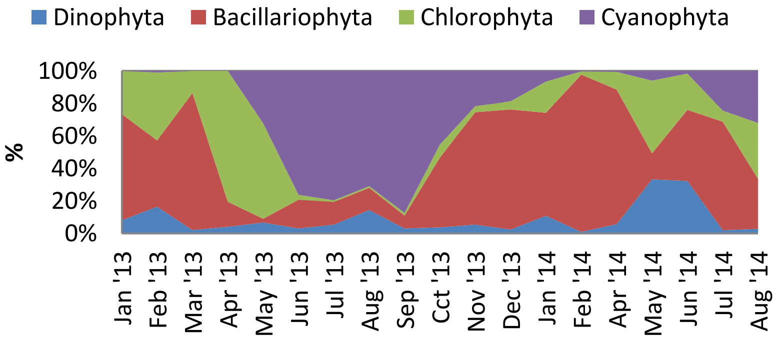
Dinoflagellates (Dinophytes) showed an increase in concentration in the months of May and June 2014 represented by the specie *Ceratium hirundinella*. Cyanobacteria (Cyanophytes) dominated from June to October 2013. The main species were *Limnoraphis robusta*, *Microcystis aeruginosa* and *Aphanizomenon* sp. It is noteworthy that concentrations of *M. aeruginosa* have increased compared to previous years .

During the study period, cyanobacterial blooms in the Center were formed by *L. robusta* (39%), *Aphanizomenon* sp. (48%) and *M. aeruginosa* (13%). In Santiago *L. robusta* (6%) and *Aphanizomenon* sp. (94%) (cell numbers) were predominant. Water analysis showed no presence of cyanotoxins in Lake Atitlan during this period.

Phytoplankton Taxon Relative Density
Centro Weiss G (0-10m) Lago Atitlán, Guatemala,
January 2013 – August 2014

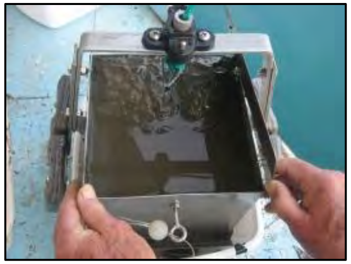


Phytoplankton Taxon Relative Density
Santiago (0-10m) Lago Atitlán, Guatemala,
January 2013 – August 2014



BENTHIC INVERTEBRATES

Changes in benthic invertebrate assemblages over time can indicate how instantaneous measures of the physical and chemical state of a lake are influencing the longer-term biological components of a lake. In Lake Atitlán, benthic invertebrates were collected, enumerated, and identified along a transect from shallow to deep water (5–320 m) in San Juan Bay. The change in the invertebrate assemblage was compared for the years 2010, 2012, 2013, and 2014. Overall, benthic invertebrates (dominated by the order Amphipoda) occurred at higher densities in 2010 and 2012 than in 2013 and 2014 (Figures 1A and 1B). However, another abundant benthic invertebrate, the snail family Thiaridae increased slightly in abundance from 2010 to 2014 (Figure 1C). The decline in benthic invertebrate abundance in recent years at deeper depths may be associated with decreasing oxygen in deep areas of the lake.



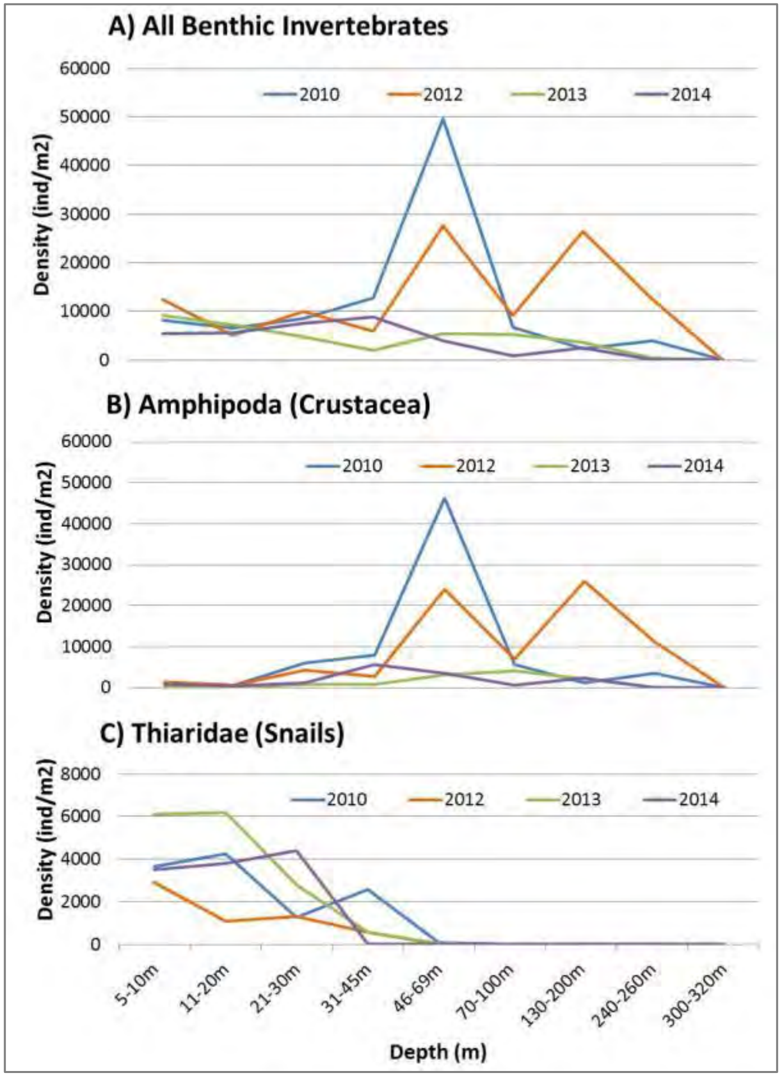
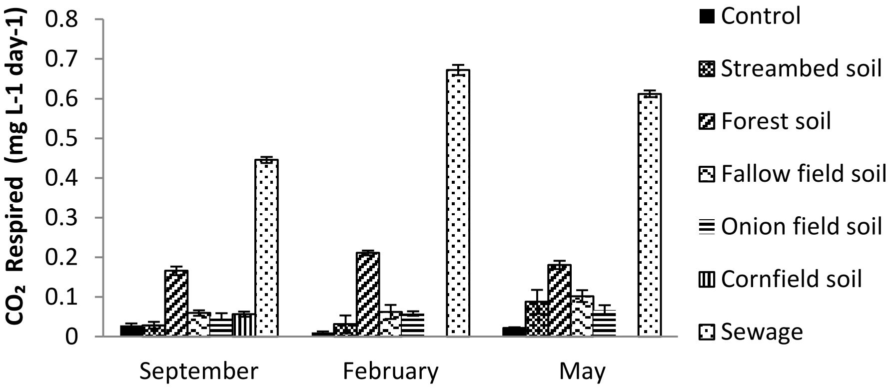


Figure 1. Average density (ind./m^2) of benthic invertebrates collected in samples by depth in 2010, 2012, 2013, and 2014. The total invertebrate assemblage is shown (A), as well as the two most dominant taxa, Amphipoda (B), and Thiaridae (C).

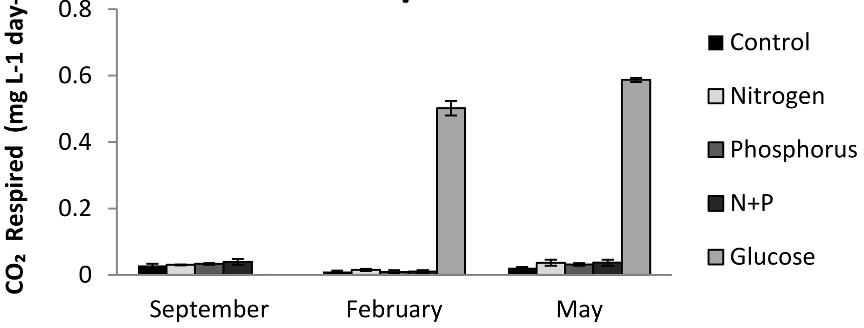
BACTERIAL RESPIRATION

Anoxic zones result from high bacterial respiration rates that deplete surrounding oxygen and produce carbon dioxide (CO_2). Nutrients (carbon, nitrogen, and phosphorus) fuel bacterial respiration, and may limit respiration when scarce in the surrounding environment. In Lake Atitlán, we can determine which nutrients are limiting by adding nutrients to lake water and observing which ones stimulate bacterial respiration. In an incubation experiment, we collected deep water (80, 100, and 150 m) and measured the response of bacterial respiration to nutrient, soil, and sewage additions.

Organic rich sources stimulate bacterial respiration



Organic carbon stimulates bacterial respiration



The figures show results of bacterial respiration in response to treatment additions, displayed as production of CO_2. Glucose, a surrogate for organic carbon, increased respiration 27 and 48 times more than controls in February and May, respectively. Sewage has much higher organic carbon concentrations (40 mg/L) when compared to lake water (1mg/L). Sewage significantly increased respiration in all months (16-64 times more than control). These experiments suggest that organic carbon from nutrient rich sources, such as sewage and soil, stimulates an increase in bacterial respiration, which results in the reduction of oxygen in deep waters of Lake Atitlán.

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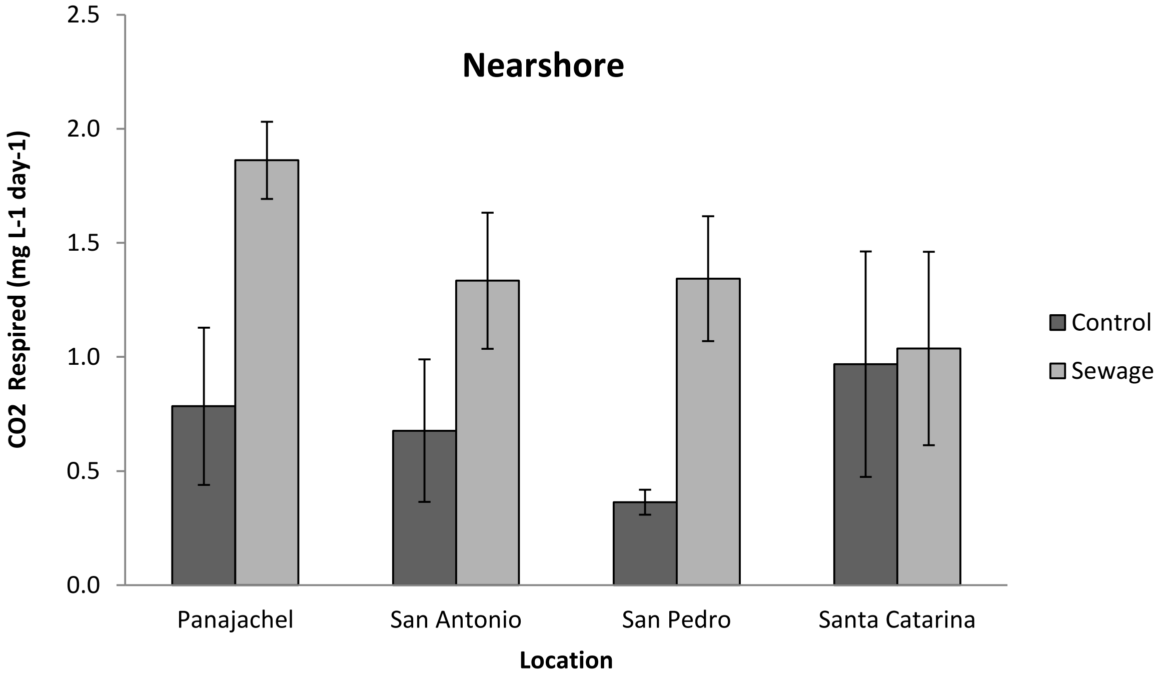
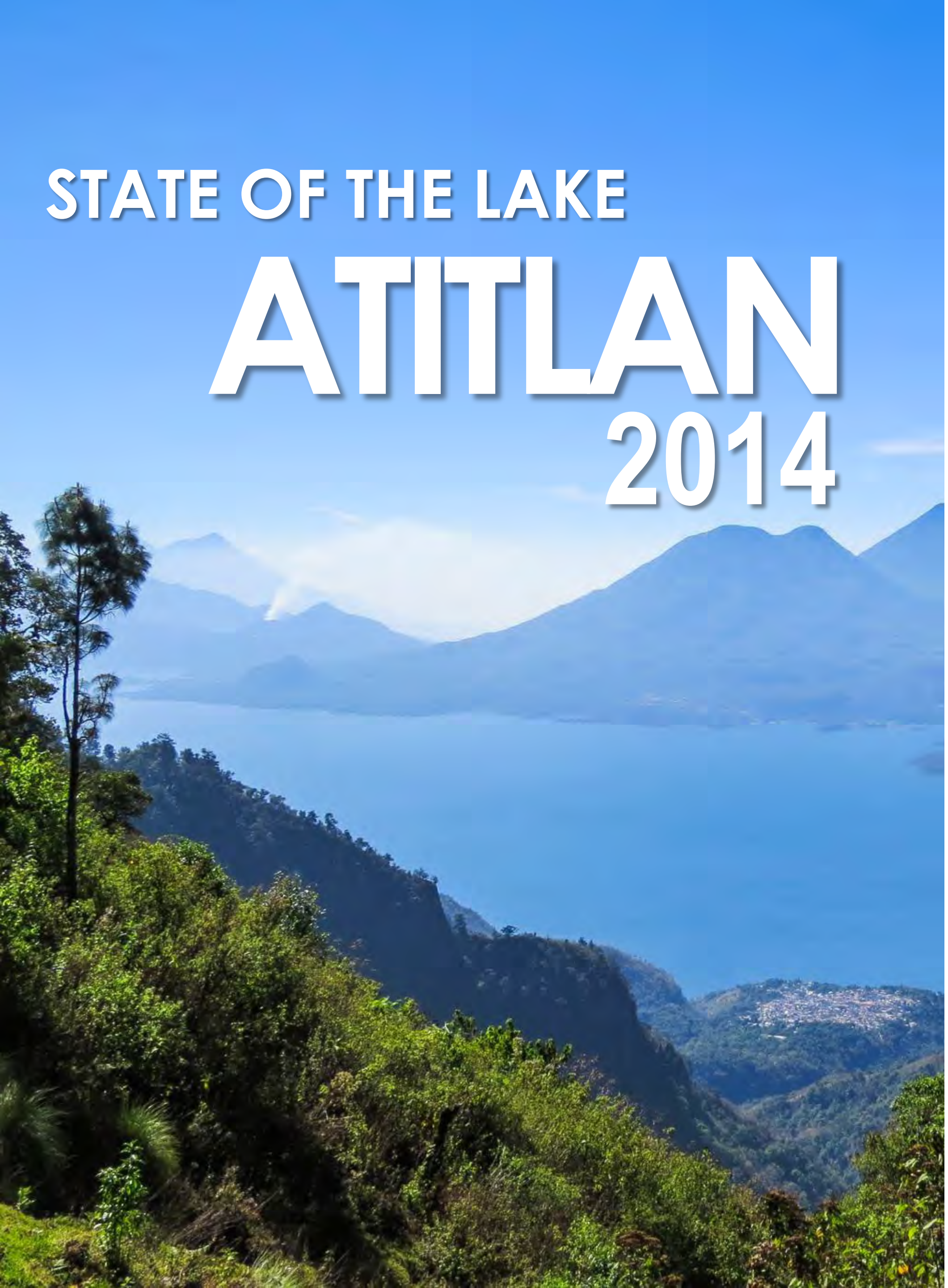
BACTERIAL RESPIRATION (CONT.)

This figure shows bacterial respiration rates in several near-shore sites of Lake Atitlán, with and without sewage additions. The addition of sewage, which stimulated bacterial respiration in the hypolimnion, also stimulated bacterial respiration in the near-shore habitat Additionally, the respiration rates in the near-shore habitat are much higher and more variable than those in the hypolimnion. This shows how productive, yet patchy, the near-shore habitat is when compared with the open water habitat.





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WATERSHED

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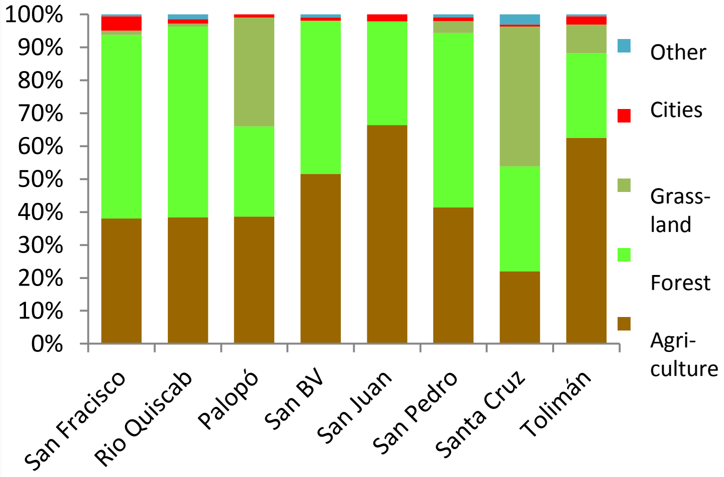
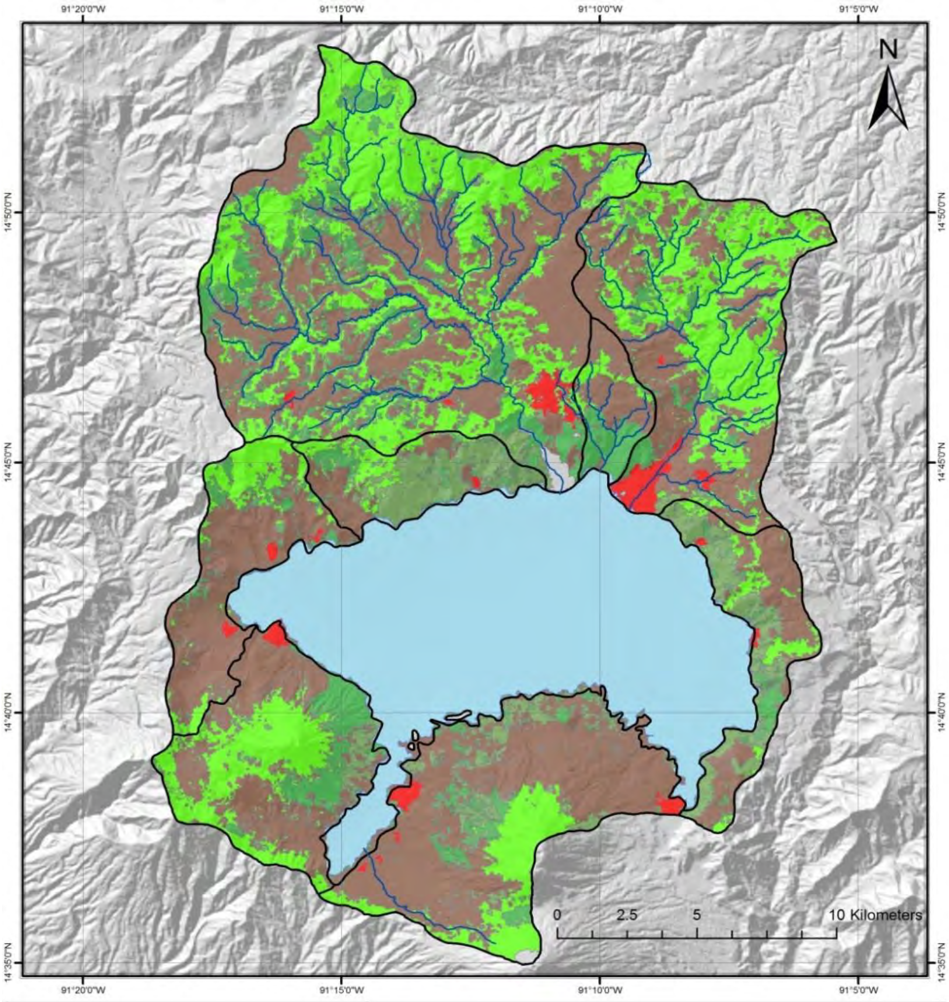
LAKE ATITLÁN'S WATERSHED LAND USE

Land use in Lake Atitlán's watershed is mainly distributed between crops (44%) ,forest (47%), natural pastures (6%), populated centers (2%), and a small portion (1%) for multiple uses.

Analyzing the state of the sub-basins, we see that the forest cover is 58% in the Quixcab basin and 56% in the San Francisco basin, while only 38% is used for crops. Compared to Quixcab (1%), San Francisco has the highest percentage (4%) of populated or developed areas.





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DATUM NAD 27.
Proyección del mapa impreso: Geográfico,
Esferoide de Clarke 1866.
Fuente: MAGA, IGN
Autor: Laboratorio SIG-IARNA
Guatemala, Septiembre 2014.

Leyenda

Uso de la Tierra

☐ SubCuencas Atitlán
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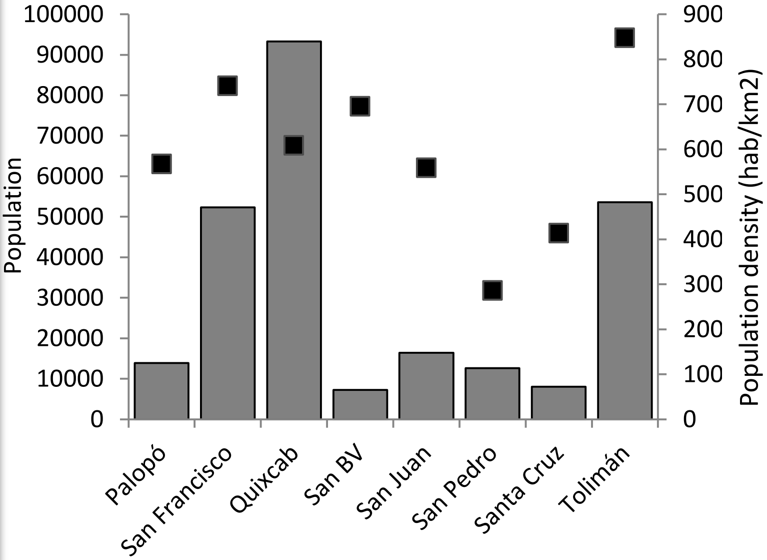
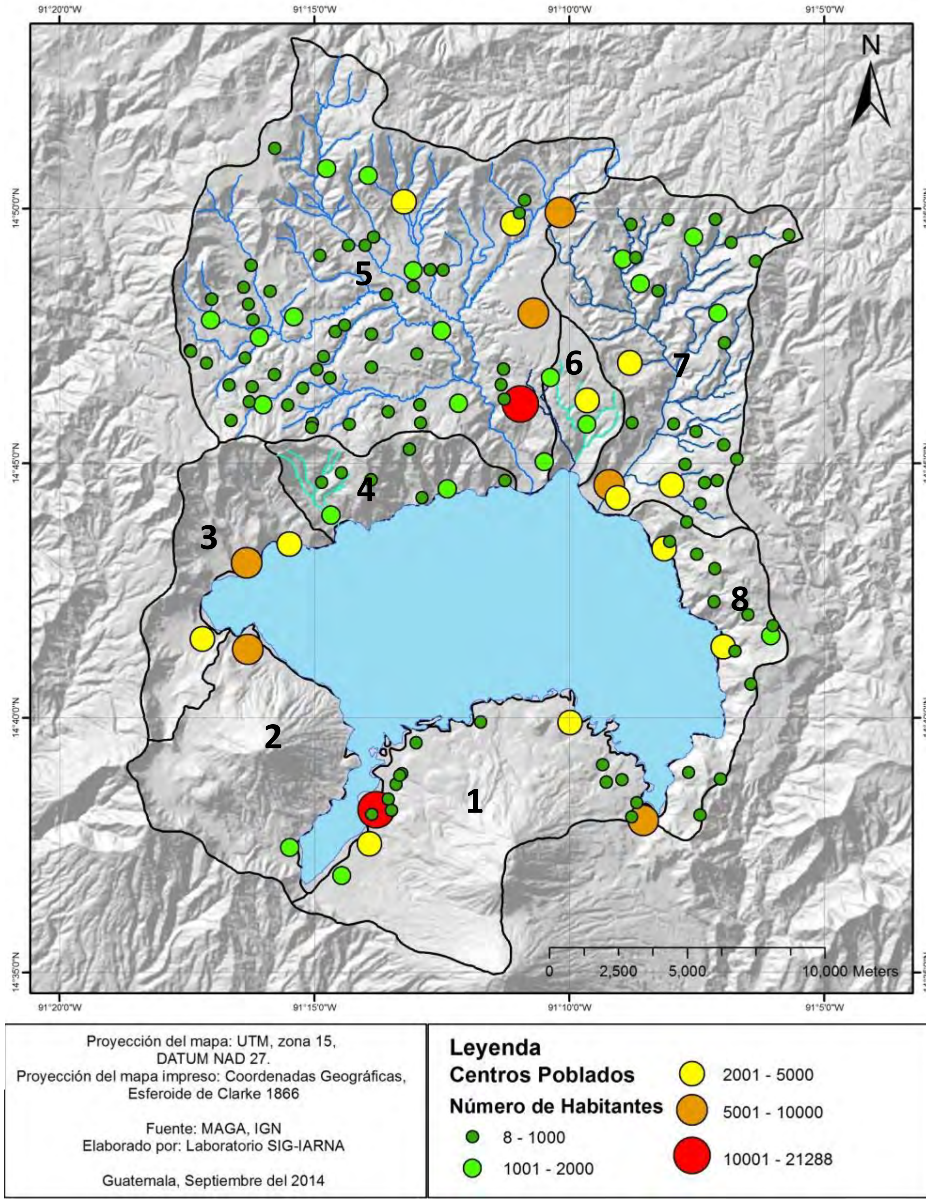
🟫 **Cultivos**
🟩 **Bosque**
🟩 **Arbustos**
🟩 **Pastos naturales**
⬜ **Arena**
🟦 **Lago**
— Rios

LAKE ATITLÁN'S WATERSHED POPULATION

The population of Lake Atitlan has approximately 257,000 habitants. 60% of the population lives in the northern part of the watershed (subbasin of Quixcab, San Francisco, Tzununá, San Buenaventura and Catarata) and 24% of the population (64,000 hab approx.) lives in the shores of Lake Atitlán.

The sub basin with the highest population is Quixcab[5], (93,000 hab aprox), which includes the largest city in the watershed: Sololá and San Buenaventura[6] (smaller town with 7,000 hab aprox). But these are not the more densely populated, the subbasin most densely populated is Tolimán[1], that includes Santiago Atitlán with 850 hab/km² followed by the subbasin of San Francisco[7], that includes the town of Panajachel with 740 hab/km². The less densely populated subbasin is San Pedro[2] with 280 hab/km².



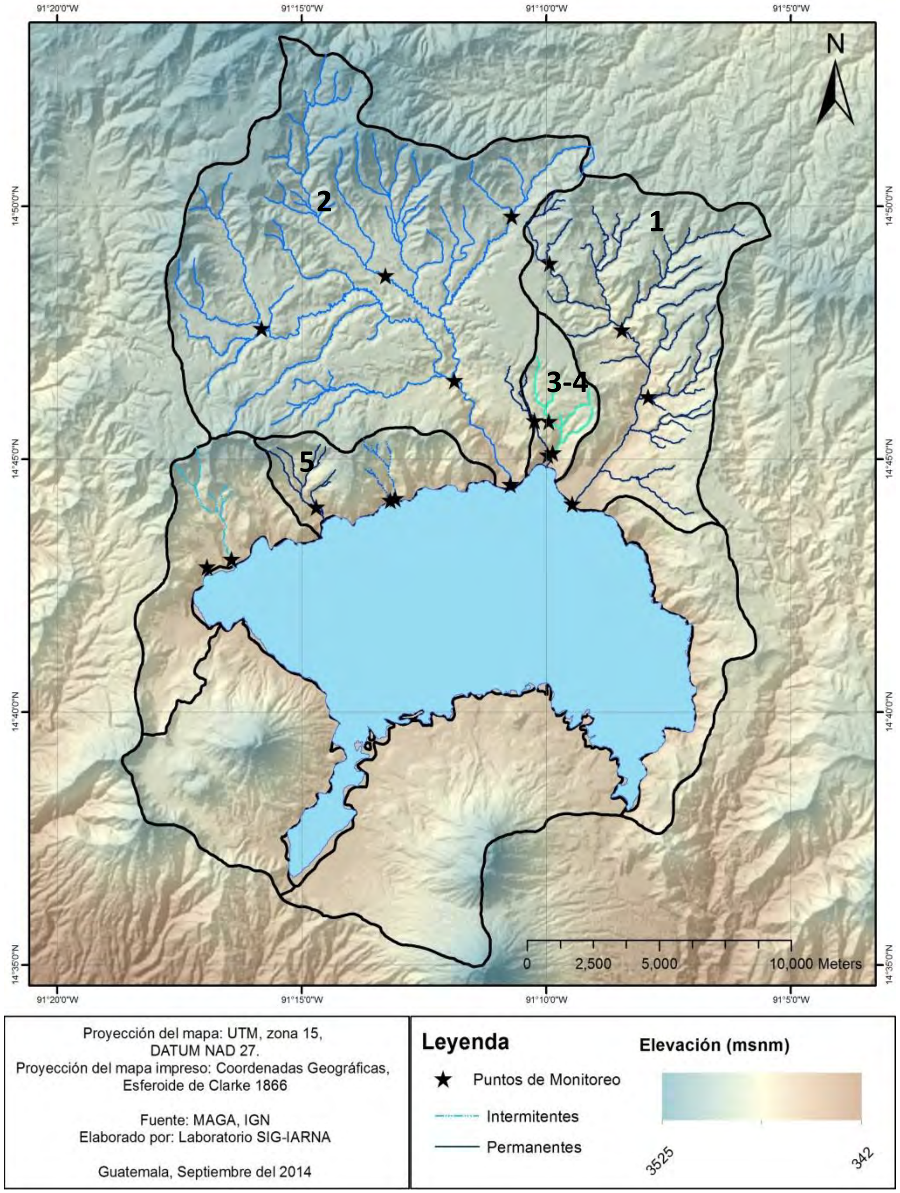


LAKE ATITLÁN WATERSHED HYDROLOGY

Rivers are classified in three categories depending on the river discharge in average conditions: permanent rivers are those that have water all year long, intermittent rivers are those that flow only during rainy season and ephemeral rivers are those that flow only during and immediately after a storm. Lake Atitlan watershed has 5 permanent rivers: San Francisco (1), Quixcab (2), Catarata (3), San Buenaventura (4) and Tzununá (5), at least 5 intermittent rivers, in addition to ephemeral rivers that are not yet quantified but include the river located in Santiago Atitlán.

The river order is another method used to classify rivers giving them a number, the higher the order number the bigger the watershed, channel size y river discharge (Gordon, McMahon, & Finlayson, 2004). The permanent rivers Quixcab, San Francisco, San Buenaventura and Catarata were as classified by order 5, 4, 2 and 2 respectively.

The watershed has a total area of 541 km^2, divided between 414 km^2 of drainage area and 127 km^2 of lake area. The permanent rivers drain 62% of the watershed, 37% from the subbasin of Quixcab, 17% of San Francisco, 3% of Catarata and San Buenaventura and 5% of Tzununá, all located, (see map), in the northern part of the basin. The other 38% of the basin drains through intermittent rivers in rainy season and ephemeral streams during storms.



Proyección del mapa: UTM, zona 15,
DATUM NAD 27.
Proyección del mapa impreso: Coordenadas Geográficas,
Esferoide de Clarke 1866

Fuente: MAGA, IGN
Elaborado por: Laboratorio SIG-IARNA

Guatemala, Septiembre del 2014

Leyenda

★ Puntos de Monitoreo
Intermitentes
Permanentes

Elevación (msnm)

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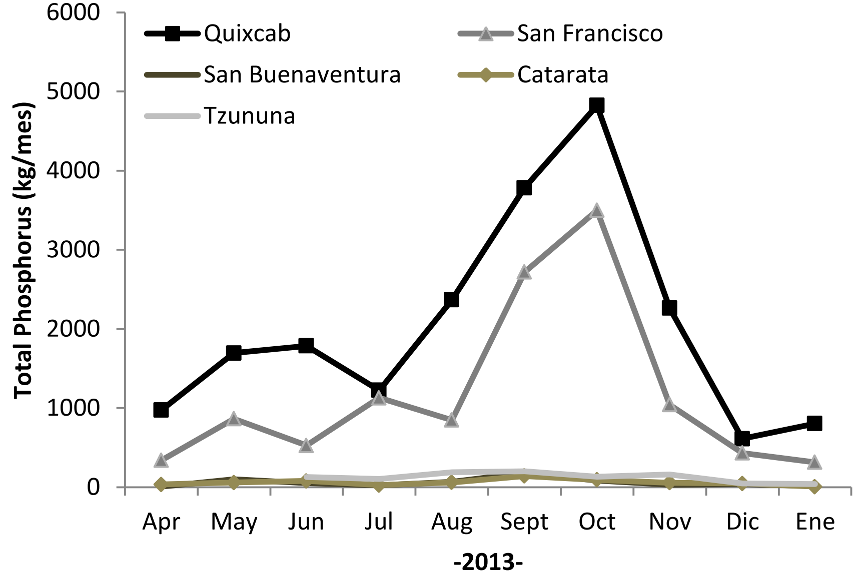
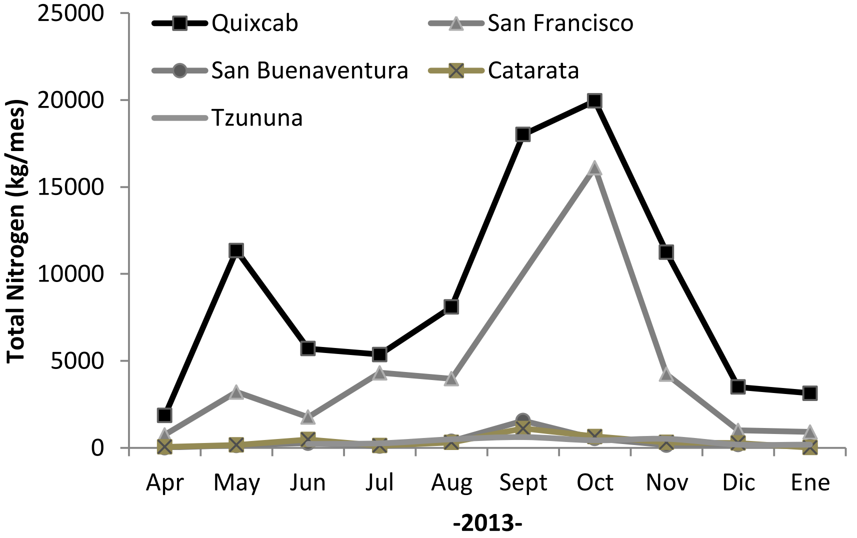
ANNUAL DYNAMICS OF NUTRIENT DISCHARGE –N & P- ENTERING LAKE ATITLÁN

The graphs show the annual dynamics of nutrient discharge contributed by each sub basin. The top graph shows total phosphorus and the bottom graph shows total nitrogen, both in kg/month.

The highest discharge and nutrient input (nitrogen and phosphorus) peak happens in October. Quixcab river discharges 3,474 kg of phosphorus and 19,950 kg of nitrogen; San Francisco river discharges 2,519 kg of phosphorus and 16,108 kg of nitrogen only in the month of October.

April is the month of least river discharge of nitrogen; River Quixcab discharged a total of 748 kg during this month and the Quixcab river discharged 1,853 kg. The lowest phosphorus discharges were later than the nitrogen lows, with a low of 440 kg/month for Quixcab in December and 226 kg/month for San Francisco in January.



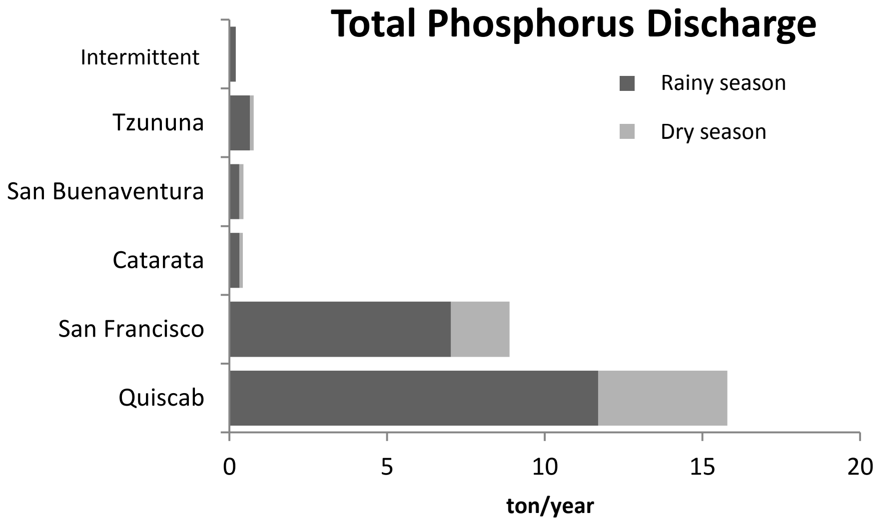


ANNUAL BUDGET -N y P-

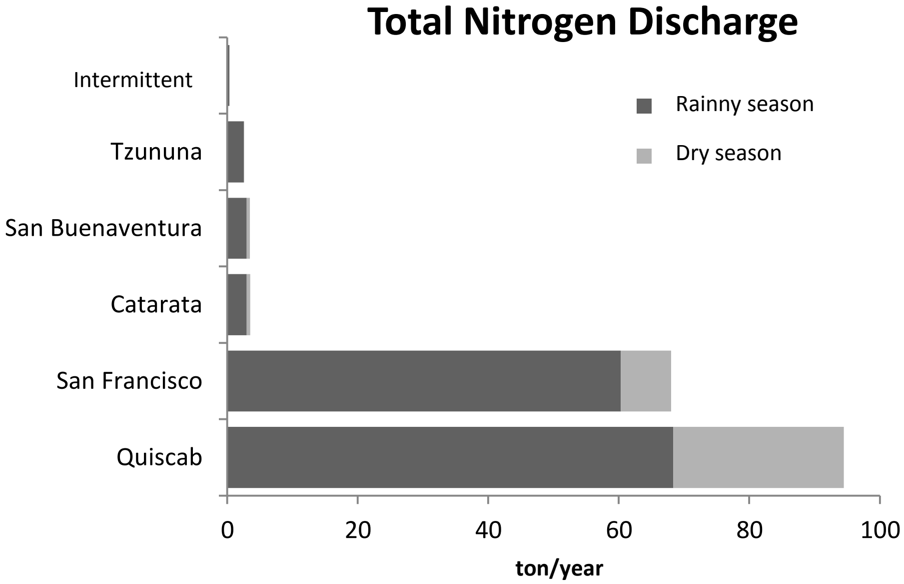
The top and bottom figure show the amount of phosphorus and nitrogen contributed by each river during the year 2013 in tons/year. It can be observed that the subbasins that contributes with the highest amount phosphorus and nitrogen is Quixcab with 59 and 55% respectively; followed by the subbasin of San Francisco contributing with 33% of the total phosphorus and 39% of the total nitrogen.

76% of total phosphorus and 80% of total nitrogen that is discharged into the lake by the river happens during rainy season (from May to October), due to runoff which is able to pick sediments, nutrients, organic matter, etc. from the watershed. Also, during rainy season river discharge of permanent rivers increases and intermittent and ephemeral rivers appear.

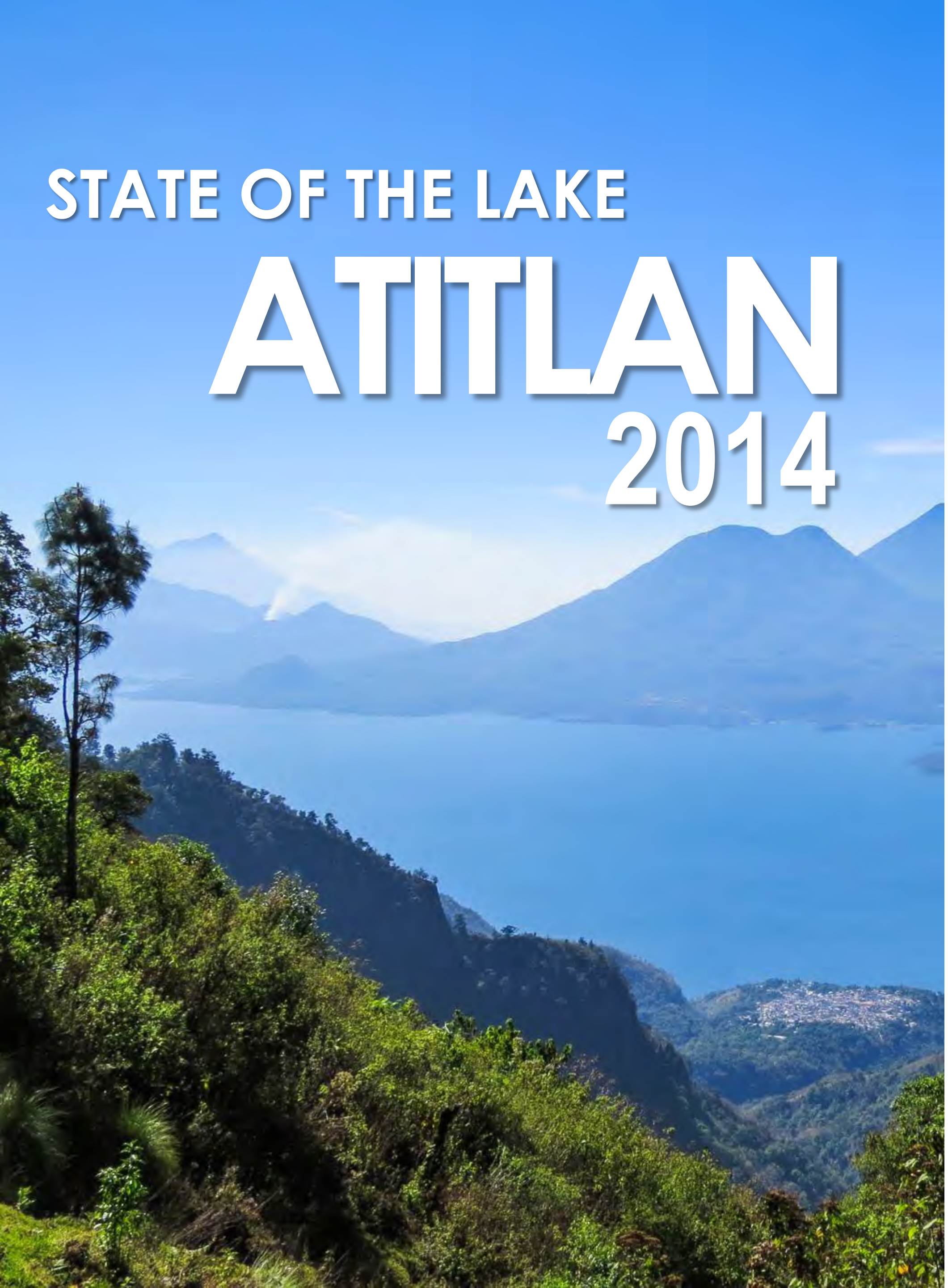
During the rainy season the Quixcab sub-basin contributes 40% of the total nitrogen and 44% of the total phosphorus towards the annual nutrient budget. The San Francisco river contributes 26% of total phosphorus and 35% of total nitrogen.



Total Phosphorus Discharge



Total Nitrogen Discharge



STATE OF THE LAKE

ATITLAN

2014

SOILS

Unidos por el Lago Atitlán

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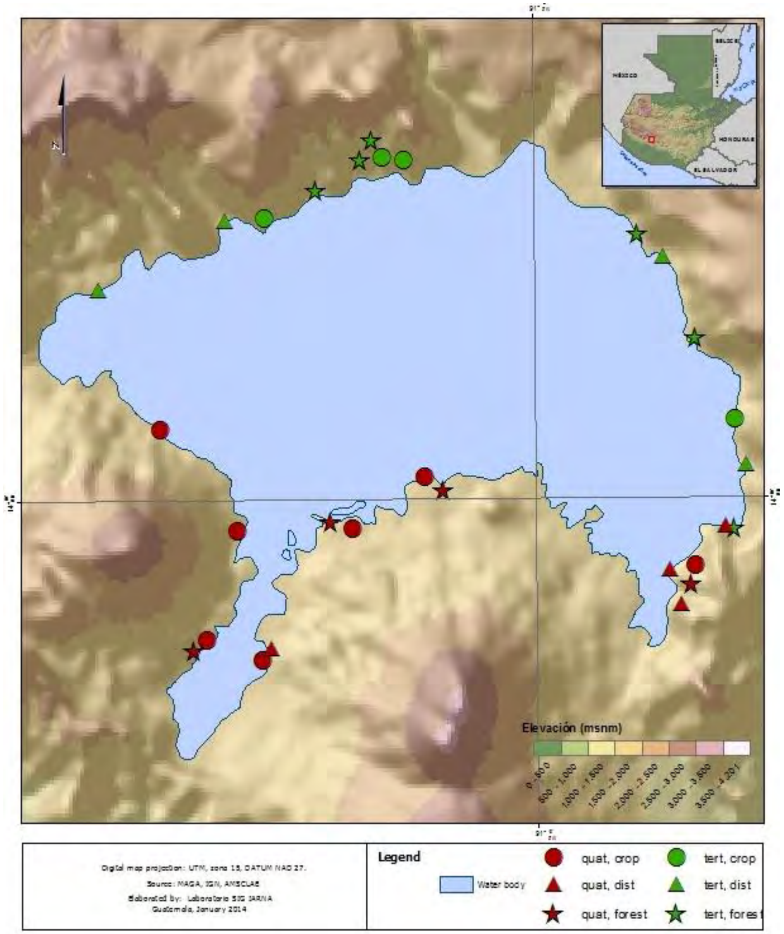
NUTRIENTS IN SOILS

Volcanic soils have many distinct properties that set them apart from other soils. One of the most agriculturally important properties is the high phosphorus sorption capacity. Phosphorus (P) is only available naturally from the rocks that formed the soil, and the decomposition of plants growing in the soil. As the soil ages it loses P available to plants, thus, fertilizers are needed to increase crop yields. Volcanic soils can act as a permanent sponge, taking up P from fertilizer and making it inaccessible to plants. Once this soil is introduced to the lake through landslides, the sorption can be reversed and P is released to the lake, increasing the nutrient load to the lake which causes blooms to occur.

Nitrogen (N) is introduced to the soil by a few mechanisms. Soil microbes can fix atmospheric N, transforming it to more accessible forms in the biologically active zone. But more importantly, N is brought in through atmospheric deposition: rain, gases in the dry air, and lightning. Air pollution from cars, industry, and smoke from fires all act to increase the deposition. Recycling of plant litter returns N to the soil, or in the case of legumes and other N fixing species, introduces new nitrogen to the soil. In the event of a landslide or heavy rain much of the N will easily be released to the lake water column.

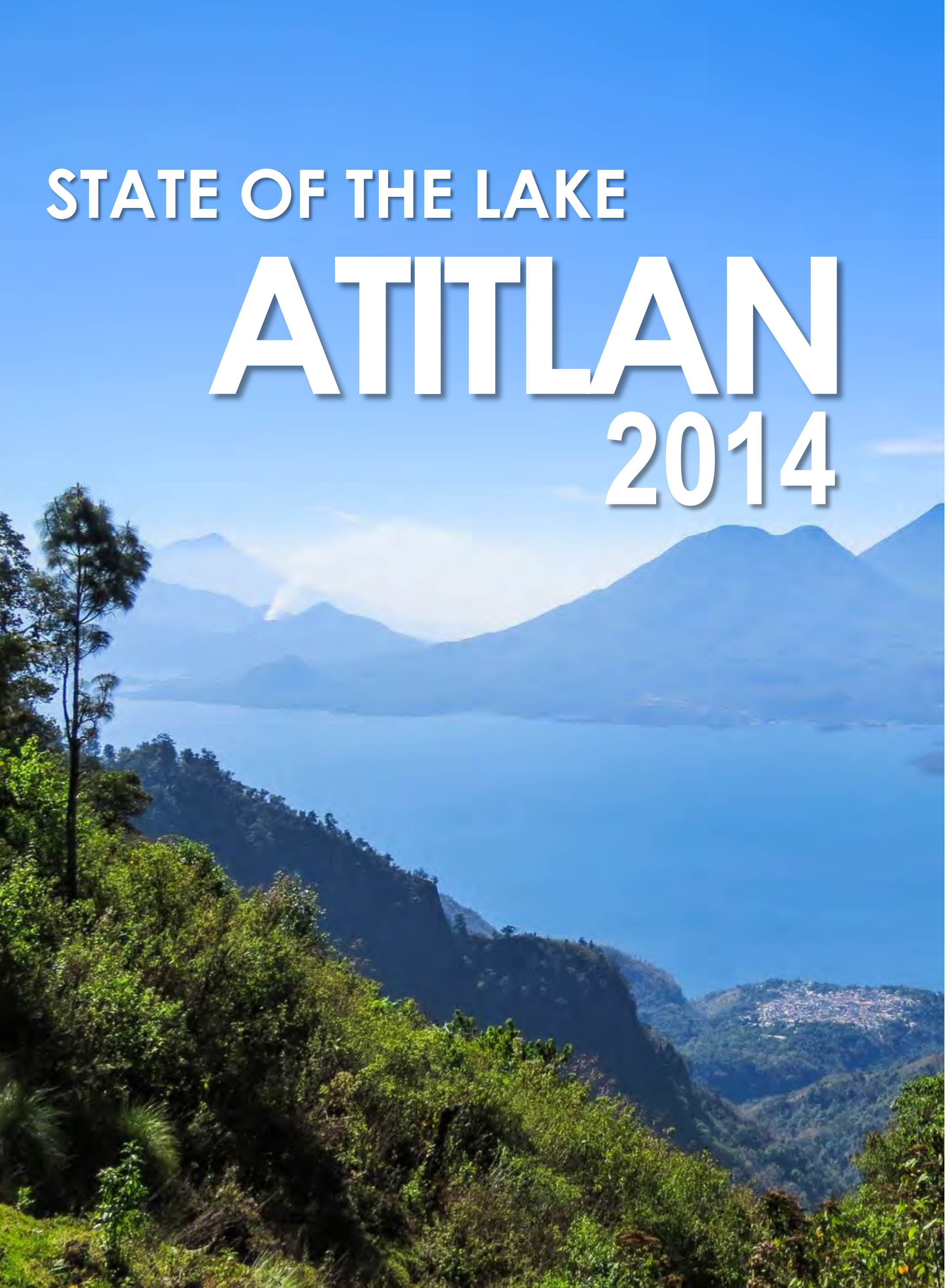
NUTRIENTS IN THE SOILS SURROUNDING LAKE ATITLÁN

A test was done to measure the amount of P sorption in the soils surrounding the lake. The soils were organized by land-use type: crops, landslides, or natural forest. All soils sorbed P, but in different capacities. The crop soils had the highest P sorption capacity (the amount of P the soil is able to hold) with the lowest sorption affinity (how tightly it is able to hold P), due to the slash-and-burn agricultural practices changing the minerals in the soil. The higher sorption maximum means increasing levels of P fertilizer will need to be added to counteract the P sorption, and the lower affinity means runoff from these soils will contain higher levels of P. The landslide soils had the lowest sorption capacity but the highest affinity. This means that old landslides can capture P from runoff, which can then help to boost the fertility of the soil, leading to faster rates of reforestation.



Digital map projection: UTM, zona 15, DATUM NAD 27.
Source: MAGA, IGN, AMSCLAE
Elaborated by: Laboratorio SIG IARNA
Guatemala, January 2014

Any soil used to capture P from runoff needs to be monitored so that it is not washed into the lake. The equilibrium phosphate concentration (EPC) is a calculation of how the soil will act once it reaches the lake. The average EPC for the soils is 0.17 mg P/L, meaning that P will be released from soils in any water with a concentration of P less than 0.17 mg P/L. Because the natural water in Lake Atitlan is usually less than 0.01 mg P/L, the soils will release their P to the lake. Thus, it is important to make sure the soils around the lake are managed to prevent future erosion or landslides



STATE OF THE LAKE

ATITLAN

2014

HUMAN HEALTH

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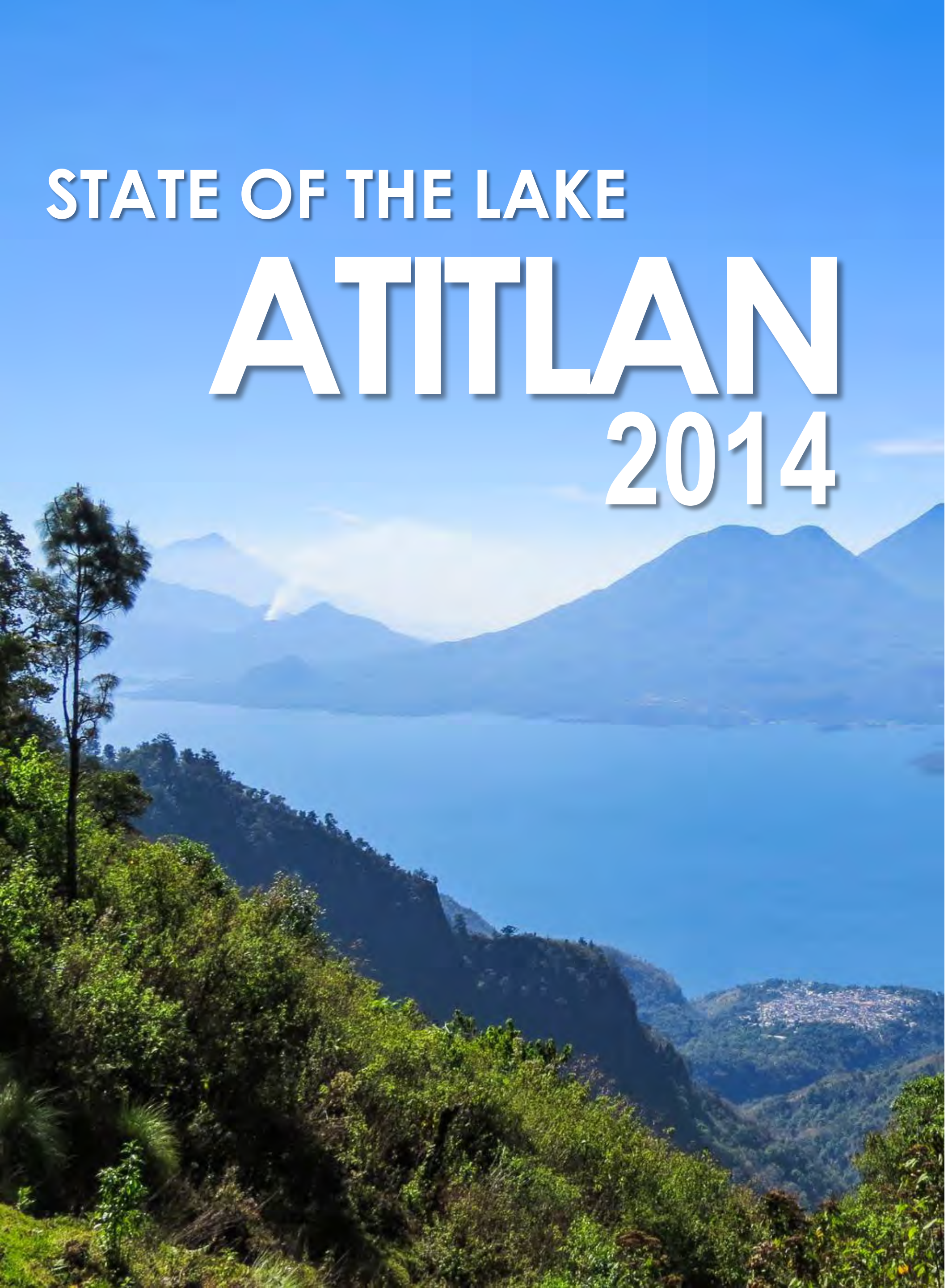
HUMAN HEALTH

Eutrophication of lakes, caused by inflow of untreated or partially treated sewage water, results in direct human health risks due to high pathogen loading. In addition, the increased nutrient input promotes the rapid growth of undesirable algal and cyanobacterial species that leads to blooms often accompanied by cyanotoxin production. Lake Atitlán has recently experienced increasing eutrophication, cyanobacterial blooms and critical values of pathogens in its waters. Over 100,000 people rely on the lake water as their sole drinking water source. Although the diversion of sewage and implementation of natural barriers to non-point source runoff is the best prevention, humans can be protected from pathogens in their water supply by employing point of use (POU) treatment.

Investigators at the University of California, Davis, have partnered with local institutions (Universidad del Valle, Guatemala, AMSCLAE, and La Porta Hotel del Lago) and the town of San Pedro de La Laguna to evaluate efficacy and longevity of filters currently available in country for the removal of bacterial pathogens. Pre- and post-filtration water has been sampled approximately every six weeks over the course of six months in households and tested for coliforms and *Escherichia coli*. Filters have also been evaluated for removal efficiency of bacterial loading in lake source waters and heavily contaminated surface waters in controlled laboratory settings, with some preliminary evaluation of cyanotoxin removal capability.



STATE OF THE LAKE

ATITLAN

2014

INTEGRATED WASTEWATER MANAGEMENT

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INTEGRATED WASTEWATER MANAGEMENT

It is imperative that wastewater management within the basin focus on the elimination of nutrient loadings into the lake. This can only be accomplished through two alternatives:

1) The use of sophisticated wastewater treatment (activated sludge) with tertiary treatment processes for nitrogen and phosphorous removal and lake discharge.
2) Direct wastewater out of the basin with subsequent treatment and reuse in agriculture.

The alternatives were compared in a life cycle analysis that included construction costs, energy consumption for operation, energy production from hydroelectric turbines and methane production, valorization of nutrients and water for reuse in agriculture, and sale of carbon credits from utilization of methane.

The results show that while construction costs for the two alternatives are similar, Alternative 2 is a net producer of energy, allowing the entire system to be energy self-sufficient. In addition, the nutrients that would be removed in expensive treatment processes in Alternative 1, which there is no precedent in Latin America let alone Guatemala, could be valorized in the export alternative and used to irrigate 1,000 ha of farmland outside the basin. This valorization for reuse is a key component of sustainability.

The results clearly demonstrate that wastewater export with agricultural reuse is economically and environmentally superior to wastewater treatment with lake discharge, and is therefore the most appropriate alternative for wastewater management within the Lake Atitlán basin.

Life Cycle Analysis for two alternatives 2016-2036 (Red = Costs)

Parameter	Discharge towards lake	Effluent with Agriculture use	
	Activated sludge	With drilling	Without drilling
I. Construction Costs, US$			
Treatment Plants	($44,134,000)	($11,891,000)	($11,891,000)
Pressure tube	-	($8,374,000)	($8,409,000)
Horizontal drilling	-	($600,000)	-
Pump station	-	($1,821,000)	($1,821,000)
Hydroelectric station	-	($3,608,000)	($3,608,000)
Reservoir	-	($3,320,000)	($3,320,000)
Total Cost	**($44,134,000)**	**($29,614,000)**	**($29,049,000)**
II. Maintenance and operation			
Net Energy cost, US$/year	($2,061,467)	$0	$0
Net Energy value Neta, US$/year	$0	$1,364,808	$1,209,551
Net Cost present, 2016-2036, 6.2%	**($23,265,698)**		
Net Value present, 2016-2036, 6.2%	**$0**	**$15,403,214**	**$13,650,980**
III. Valuation for agricultura reuse			
Value of irrigation water, US$/año	$0	$192,660	$192,660
Value of Nitrogen, US$/año (NT = 30 mg/L)	$0	$517,000	$517,000
Value of Phosphorus, US$/año (FT =10 mg/L)	$0	$472,000	$472,000
Value of Water and Nutrients, US$/year	$0	**$1,181,660**	**$1,181,660**
Net value present: 2016-2036	$0	**$13,336,211**	**$13,336,211**
IV. Carbon credits			
Value of credits/year @ US$10/Bono	$0	$200,700	$200,700
Net value present: 2016-2036	$0	**$2,265,099**	**$2,265,099**
V. Cost/Net Value Total, 2016-2036, US$	**($67,399,698)**	**$1,390,524**	**$203,290**

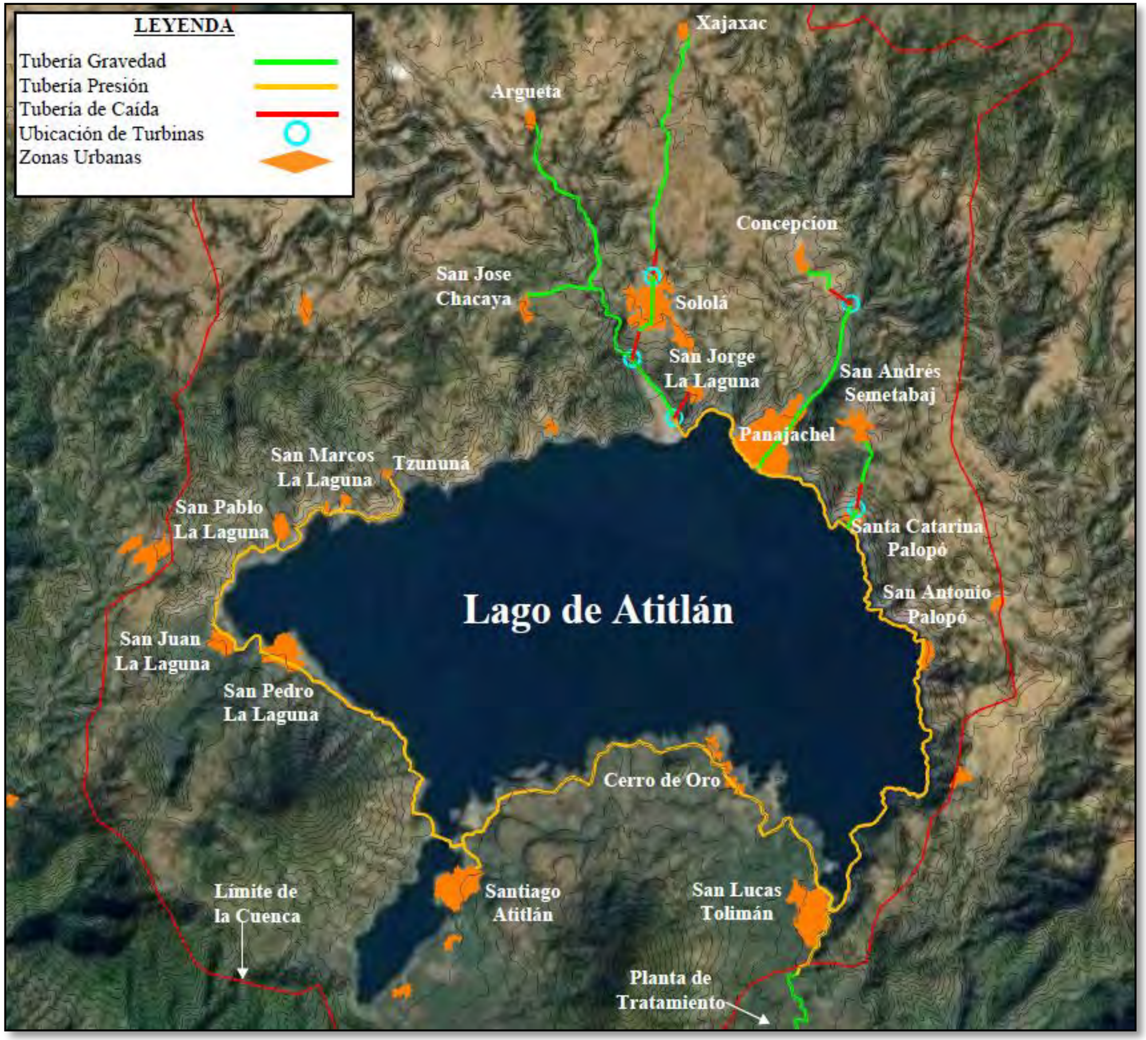
Alternative 2: Wastewater Redirection with Agricultural Reuse

The export alternative has the following components within the basin:

- Wastewater collection and export from the basin with a low pressure sewer. Each municipality would have a pumping station to operate and maintain.

- Generation of hydro-electricity with four turbines, yielding 5,600 kWh/day. This generated electricity will cover all pumping requirements, still leaving a net energy gain after export.

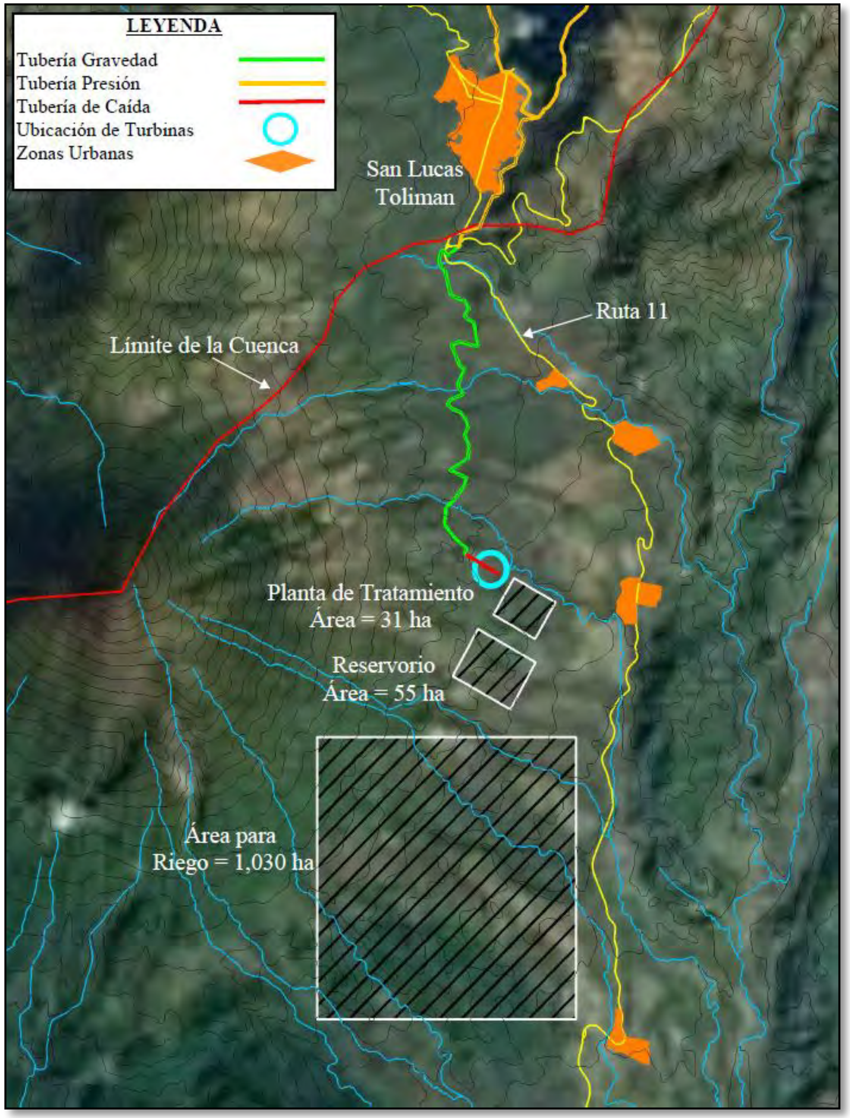
- Export of wastewater at San Lucas Tolimán, which is the lowest point within the basin. The vertical pumping head is 40 m.



Alternative 2: Wastewater Redirection with Agricultural Reuse

The export alternative has the following components outside the basin:

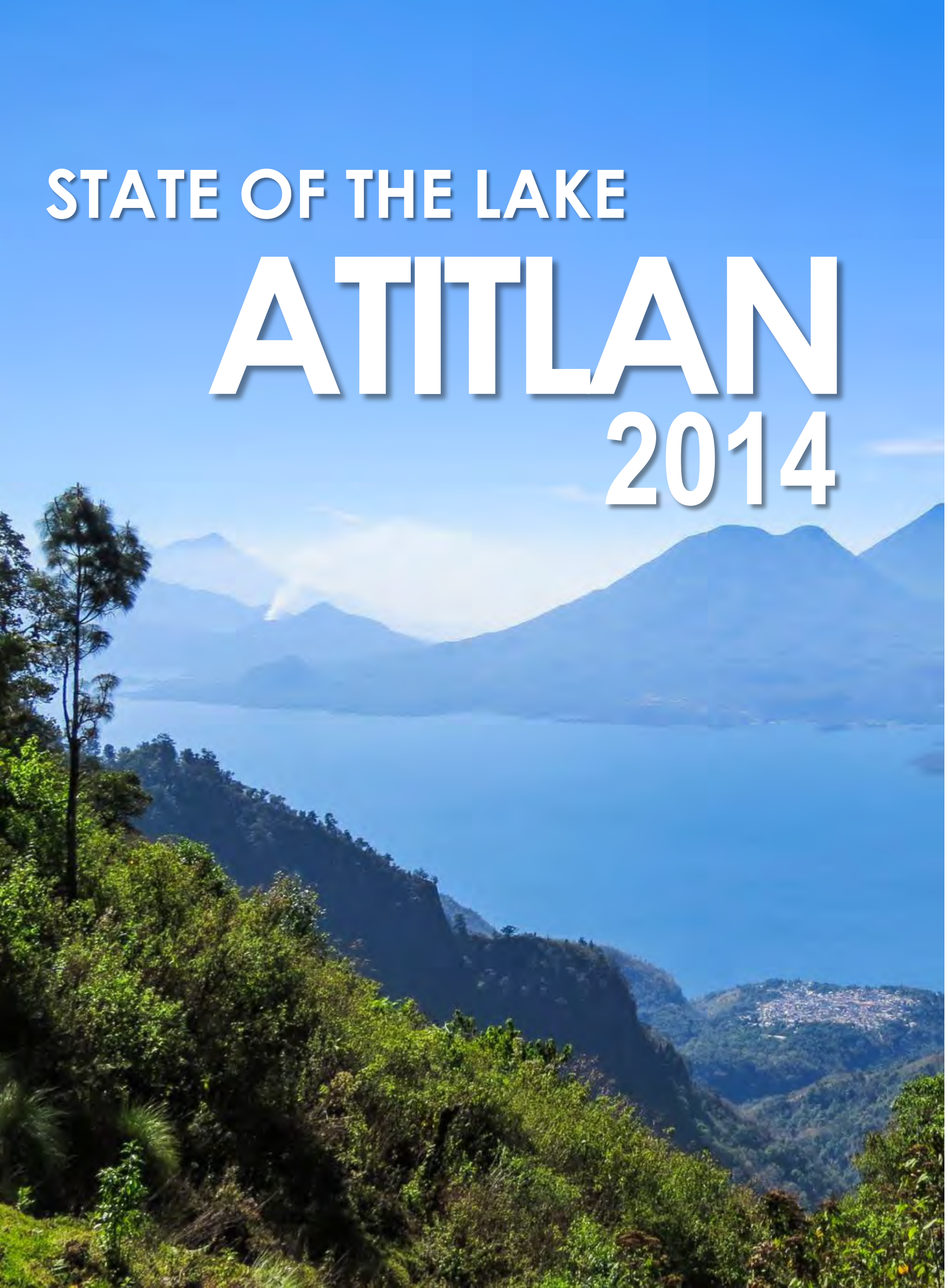
- Gravity flow from the basin export point above San Lucas Tolimán to turbine penstock intake (approximately 5 km).
- Generation of hydroelectricity with the fifth turbine, yielding 9,000 kWh/day.
- Treatment of wastewater in a wastewater stabilization pond system, which includes anaerobic ponds for the generation and capture of methane. Pond area = 31 ha.
- Generation of 8,900 kWh/day of electricity from methane. The use of methane could also lead to the sale of carbon credits.
- Valorization of treated water with nutrients for agriculture. Estimated value = US$900,000/year.
- Irrigation of 1,000 ha of farmland with final treated effluent.



STATE OF THE LAKE

ATITLAN

2014



EDUCATION AND OUTREACH

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DRI Desert Research Institute

EDUCATION AND OUTREACH

The Communication and Sustainability Strategy of the United for Lake Atitlán Project aimed to raise awareness of the problems, causes and solutions to the situation that has caused the deterioration of the lake's ecological state and its increase in cyanobacteria.

Information about the project and scientific research was shared with the communities in 17 municipalities of the department of Solola. Local environmental problems and concerns were identified at each municipality. Nineteen informational meetings were organized regarding the state of the lake. Over 30 educational workshops on solid waste, water, sanitation and soil conservation were also organized. A total of 3271 people were directly trained (1520 men and 1751 women) including community leaders, entrepreneurs, artisans, teachers, students, fishermen, service providers, and the general public. As part of the program, 41 media people and journalists were trained on Environmental Communication for Social Change. The Association of Journalists of Sololá joined the project to design a radio campaign in Spanish and Mayan languages (Kaqchikel and K'ich'e) on issues of water pollution and ways to disinfect it. Information is socialized through local radio, reaching over 30,000 listeners.

Interactive educational workshops were designed for elementary and high school students, where they learned about cyanobacteria and their biology by using microscopes, and also about the causes and consequences of cyanobacterial blooms. This was done to promote measures to reduce nutrients in the lake. Approximately 700 children and young people benefited from this program in the municipalities of Panajachel, Santa Catarina Palopó, San Antonio Palopó, Santa Cruz La Laguna, Sololá, Santa Lucía Utatlán, and Santiago Atitlán.

The first competition and photo exhibition "Atitlán, Alive and Healthy“ was organized as another mechanism to promote environmental awareness and encourage local participation. This exhibition was open to the public and students.

EDUCATION AND OUTREACH (cont.)

We participated in several radio and television interviews and print media for both adult and child groups, in order to expand the knowledge of the lake and its problems in the general Guatemalan public. In collaboration with TV Maya, a series of three programs dedicated to Lake Atitlan were produced. There was an interview on local Channel 3, several publications in print media, and a special publication in the “Chicos” magazine of Prensa Libre news press. These actions helped to share our message with more than 500,000 people.

Another key component was the design and publication of educational materials based on scientific findings about water quality, solid waste, soil conservation, fish, cyanobacteria , aquatic plants and plankton. The material is intended for children, young people and adults living in Lake Atitlán, in order to sensitize them and turn them into multipliers of information in their homes and communities. The materials include: posters, pamphlets, reports on the state of the lake, an educational guide on cyanobacteria, and an educational documentary series of four videos in Kaqchikel, Tz'utujil and Spanish languages. In coordination with the Association of Friends of Lake Atitlan, we also collaborated in the development of a high school workbook for the guide "Educating for Conservation”.

During this period, the fourth Scientific Expedition also took place at Lake Atitlan in order to strengthen the research capacity of local students to help us understand the physical, chemical and biological dynamics of the lake and its basin. There was a total of 80 participants, that included teachers and students from the University of California-Davis, Nevada-Reno, Del Valle of Guatemala, Rafael Landivar and San Carlos de Guatemala, and staff from the Authority for the Sustainable Management of Lake Atitlán Basin - AMSCLAE-.

Our accomplishments are the reflection of a collaborative work with municipalities, communities, organizations, teachers, educational managers, public environmental organizations and civil society, local private companies, local and national media, consultants and the general public.

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