Assessing Earth observation techniques for water quality monitoring in Lake Nicaragua

Lake Nicaragua is the largest and most important source of fresh water in Central America, twentieth largest lake in the world and largest tropical lake in the western Hemisphere. Lake Nicaragua's (regional name Lago Cocibolca) has a surface of 8,264 km², and it is located in the central southern part of the country. The oval-shaped lake is relatively uncontaminated, although some serious environmental issues pose a real threat for the lake's future.

Steam rising out of the volcano on the Island Ometepe in Lake Nicaragua.

Hydrology and climate

Lake Nicaragua is part of the largest international drainage basin of Central America, and together with Lake Managua and the San Juan River it forms a tectonic valley with an area of over 41,000 km². The lake itself is relatively shallow with an average depth of 13 meters. Rainfall and inflow from numerous rivers feed Lake Nicaragua; outflow only occurs at the San Juan River. Despite being situated close to the Pacific Ocean (at some places there is only 20 kilometers between them), there is no direct connection between the lake and the Pacific Ocean. The San Juan River, however, connects the lake with the Caribbean Sea, located over 100 kilometers west of Lake Nicaragua.

Precipitation is variable over the basin. In the Pacific region of Nicaragua precipitation ranges is 1000 - 2000mm. Little rainfall takes place during July-August and during the end and beginning of year rains are more abundant (by the action of the trade winds that carry Caribbean humidity). The regional temperatures generally do not vary throughout the year and are at average 20-28°C depending on geographic features.

Currently, there are four main port cities located on the shores of Lake Nicaragua: Granada, San Carlos, San Jorge, and San Miguelito. Despite the lake's size and connections with the Caribbean Sea and the Pacific slope of Nicaragua, the transportation system is rather poorly developed.

A volcanic chain cuts right through Lake Nicaragua, and this has resulted in the creation of many islands and groups of islets. Probably the most famous island is Ometepe, a 276 km² tropical island located 10 kilome-

Landsat image of Lake Nicaragua. Note the two prominent volcanos located in the west central part of lake.

ters off the mainland at the western side of the lake. The island is composed of two volcanoes, Maderas and Concepcion. Another volcanic island, Zapatera, is situated closer to the mainland. Hundreds if not thousands of artifacts have been found here, and pre-Columbian statues and other objects from Zapatera are now on display at several museums. Ometepe Island recently became the third Nicaraguan site in the UNESCO world network of reserves of the biosphere.

Environmental resources in and around Lake Nicaragua

Lake Nicaragua is a dominant feature in the Nicaraguan landscape. Not only does the lake provide a habitat for aquatic species, it is also an important water source for the vegetation located on the banks of the lake. With a perimeter of 425 kilometers there are many types of ecosystems along the lake's shores. To the south and southwest there is moist tropical forest, and tropical dry forest vegetates to the east, north, and west of Lake Nicaragua with parts of the tropical dry forest being replaced by second-growth forest and agricultural land. There is also dense vegetation on most islands and islets and on top of two of the volcanos; there are unique cloud forests.

Thousands of different animal species live within or around Lake Nicaragua. The most easily observable animals are birds, such as egrets, cormorants, herons and birds of prey such as hawks and kites. For hundreds if not thousands of years the lake has provided people living in the area an important source for fish. More than 40 different fish species live in Lake Nicaragua, including 16 species of cichlids. In a 1995 report scientists estimated native cichlids to constitute 58% of the lake's biomass. They also noted that these species were the most heavily exploited. The lake's most famous inhabitant, however, is the so-called freshwater shark. This shark, *Carcharhinus leucas*, is generally known as the Caribbean bull shark. The shark's high tolerance of fresh water enabled the predator to adapt to the water of the San Juan River and eventually Lake Nicaragua. Because of its aggressive behavior (the bull shark is known to attack people) local fishermen and inhabitants often feared this new resident and at one time, a shark-fin processing plant, built on the shores of the San Juan River processed thousands of sharks and the shark population sharply declined. Today, few sharks remain and this fish is no longer a feared predator in Lake Nicaragua. In fact, the animal has become more of a legendary figure and the last media reports of a sighting date back to the year 2000 and the shark population is considered to be virtually extirpated.

Ecological threats

Despite the ecological and economic importance Lake Nicaragua plays in the region, there are severe ecological problems facing the lake today and though many of the problems are recognized there is little institutional support to address them.

One of the main problems for Lake Nicaragua is the amount of raw waterwater discharge entering the lake. Large cities such as Granada, Rivas and Juigalpa and many small towns still discharge their residential and industrial sewage from areas either directly or through a river that terminates in the lake. Consequently, coastal areas close to these urban centers have to deal with the high bacteria and solid waste that is not biodegradable which surfaces in front of the urban areas. The second largest problem comes from the agricultural industry in the coastal areas. The fertile soil next to the lake provides for cattle farming and plantations. Many of these locations don't provide soil and runoff conservation practices places and fertilizers, livestock manure and pesticides end up in the receiving waters. A third problem is the issue related to the recent intro-

Large Tilapia aquaculture cages in Lake Nicaragua.

duction of new Tilapia fish species inside floating cages in the lake. The problem arises from the large waste quantities generated by the aquaculture that has to be assimilated by the lake. Biologists also warn that the Tilapia might bring diseases to the endemic fish population.

A fourth potential issue facing the lake is an interoceanic canal that will run through the southern half of Lake Nicaragua, that has recently begun construction. The canal construction will require the lake to be dredged to a depth of 30 meters for 105 kilometers. Together with ongoing maintenance and traffic, it will impact water quality and it is feared to impair the lake's drinking, irrigation and other ecosystem services. In particular, the canal works could release contaminants and nutrients from the lake sediment into the water, which, in turn, could reduce water quality and affect its rich biodiversity, due to lower light penetration. The increase in oxygen levels of bottom sediments could also lead to an increase in cyanobacteria that can produce toxins that render water undrinkable and possible dead zone. In addition, dredged materials from the lakebed are likely to contain contaminants including heavy metals, oil and grease, with implications for how these will be disposed of or reused.

Another concern is water availability. A proposed 395 square kilometer artificial lake is needed to provide power for the canal's locks and this water will be supplied from Lake Nicaragua. The concern is whether there will be sufficient water for domestic, agricultural and industrial uses as well as base flow for the outflowing rivers to the Caribbean.

Earth observations of water quality

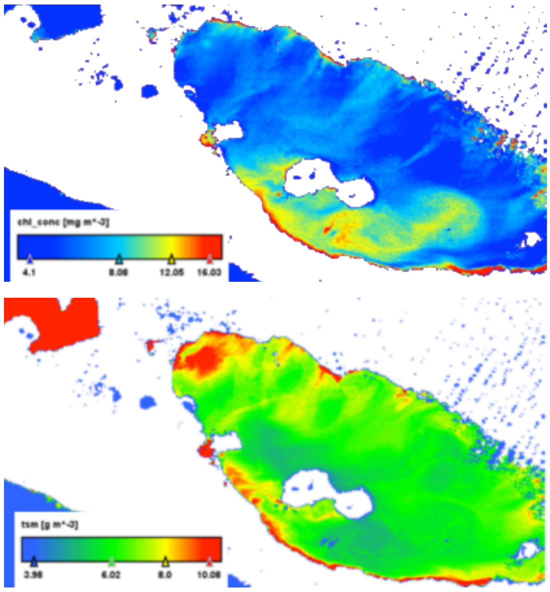
A remote sensing project, funded by IEEE, was initiated in 2011. The project focused on utilizing satellite sensors in combination with recently developed atmospheric and water quality algorithms to examine current conditions in this lake system. This project has also contributed to the global understanding of satellite applications for water quality quantification. In the context of the Group on Earth Observations (GEO, www.earthobservations.org), and its Group on Earth Observations System of Systems (GEOSS), the establishment of regional nodes is needed. This project helps establish this foundation for the American Hemisphere in the Central American region. This pilot project can be seen as building one of the nodes. Lake Nicaragua is viewed as an excellent candidate site to conduct this work and establish a node because it represents a geographic region where as mentioned before water quality information exists sporadically and to-date there has been little application of remote sensing tools. This tropical region (latitude 12° N) provides unique challenges for these techniques in terms of factors such as atmospheric correction (interference due to haze, particulates, etc.) and edge effects (pixels partly touching land and water). The project goal is to improve our capability to use satellite remote sensing for the measurement of freshwater water quality in large freshwater lakes.

Specific Objectives include:

- Demonstrate the efficacy of using satellite remote sensing for monitoring water quality in the Central American lake of Lake Nicaragua.
- Share the operational use of this newly developed tool with local water quality managers for future monitoring of both seasonal and annual water quality conditions and anticipates future problems in the lake.
- Share the data products from this pilot project with the global remote sensing community in an effort to interlink systems and fill the void of Central America regional water quality information.
- Share the developed remote sensing techniques refined in this pilot project with the global community in the hopes that other investigators will use it.

To date, two field campaigns have taken place, December 14 and 15, 2011 and March 21 and 22, 2012 (Greb and Vammen, 2012). Additional fieldwork was scheduled but the unplanned failure of MERIS has temporarily put the project on hold. It is hoped with the launch of Sentinel-3, the project can be completed in 2016. Two clear condition MERIS images were received from ESA to use as a demonstration of the efficacy of remote sensing to estimate spatial patterns of water quality in the lake. These images of December 10, 2011 and March 20, 2012 are acquired within 4-5 and 1-2 days of our field sampling.

All image processing was performed using the BEAM-VISAT software of Brockmann Consult. This software uses MERIS bands of radiation in water leaving radiances after atmospheric correction, derives the inherent optical properties such as backscattering and absorption coefficients from which concentrations of water quality constituents are derived. Very few adjustments are currently allowed in the model simulations. The only calibration parameters allowed are the conversion of backscattering at 443 nm to total suspended matter and pigment absorption to total chlorophyll.

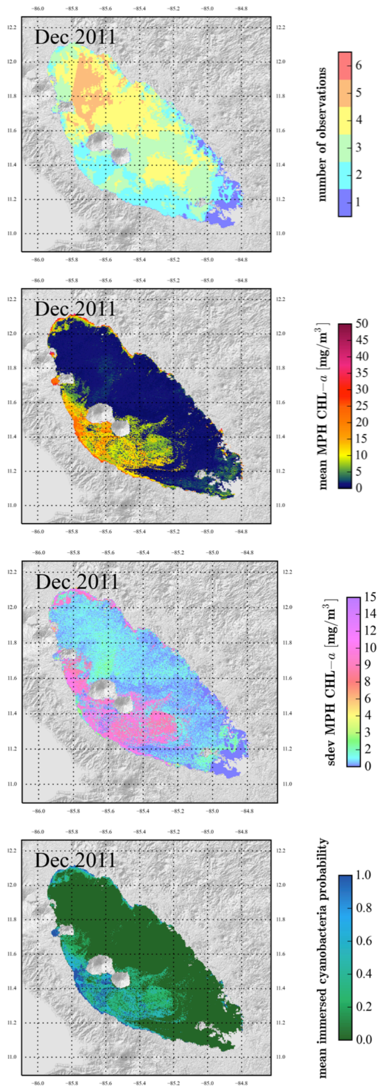


Chlorophyll-*a* (top) and total suspended matter (bottom) concentrations retrieved for December 10, 2011.

The chlorophyll and total suspended matter products for December 10, 2011, show distinct spatial patterns, though different, across the lake. The chlorophyll concentrations are somewhat uniform across the open water but show greater concentrations on the west and southern regions of the lake. This could be explained due to higher input of phosphorus from this specific part of the catchment area (Río Oro which is a highly polluted river from the municipality of Rivas) and the Island of Ometepe (Río Istia another polluted river on the island with high concentrations of domestic and agricultural wastes). In contrast, the total suspended matter concentrations are generally uniform across the lake but with higher concentrations in the north, presumably due to the large input of Rio Tipitapa which brings in water from the highly polluted Lake of Managua. The high TSM concentrations can also be observed in the image of Lake Managua.

Diversity II products

The remote sensing products provided by the Diversity II project represent temporal aggregates for monthly and larger intervals. The aggregation of five available MERIS observations in December 2011 enables almost full coverage of the lake, apart the Río San Juan outlet in the southeast. The spatial distribution of mean Chlorophyll-*a* remains similar to the retrieval for the single acquisition product of December 10. The standard deviation calculated for the temporal aggregates implies however that the Chlorophyll-*a* level has varied strongly in the most productive area. The Maximum Peak Height (MPH) algorithm used in Diversity II identified predominantly cyanobacteria dominated pixels in these areas, and it applies a specific arithmetic model for Chlorophyll-*a* in such cases. For these two reasons, the absolute concentration level is not directly comparable with the one derived in the single acquisition BEAM-VISAT retrievals for the December 10th image. Nevertheless, both sources represent a similar synoptic view on phytoplankton growth dynamics.



Diversity II monthly products composed from all available MERIS acquisitions in December 2011.

Further reading

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