Lake Elsinore and Canyon Lake, CA

Chlorophyll-*a* Data Report

1997-2009

Submitted July 23, 2010

Presented to:

Lake Elsinore and San Jacinto Watersheds Authority

Contents

Executive Summary

Introduction

Blue Water Satellite, Inc. used satellite imagery to measure Chlorophyll-a (Ch-*a*) concentrations in Lake Elsinore and Canyon Lake in California, for the period of 1997 to 2009. Blue Water Satellite uses proprietary image processing algorithms and satellite images from the Landsat series of satellites.

Blue Water Satellite processed 102 images for specific dates between February 19, 1997, and November 19, 2009, for dates specified by The Lake Elsinore and San Jacinto Watersheds Authority. These processed images show Ch-*a* concentrations and locations throughout Lake Elsinore and Canyon Lake. A measurement is made for every 30m X 30 m satellite picture element (pixel) for the entire lake. This 30 x 30 m resolution produces 5 measurement points per acre or approximately 15,000 measurements for each satellite overpass of Lake Elsinore. Lake wide averages were also determined for the lake.

Correlation Analysis

Blue Water Satellite has run a regression analysis showing a comparison of data collected by Lake Elsinore with data measured from Blue Water Satellite's image processing. This correlation study was performed for the 11 days where Lake Elsinore data was collected on dates of satellite overpass. A review of the correlation data and regression analysis indicates the processed image data correlates well with the values obtained from field data collected on date of satellite overpass. A calculated R^2 adjusted of .83 indicates this high level of correlation. Therefore, there is statistical evidencethat the image data is representative of the Ch-*a* concentrations measured in Lake Elsinore. A detailed regression analysis is shown in the body of the report.

Observations

A significant difference noted in the images is the amount of water surface area in Lake Elsinore. We interpreted the images to depict the following relative lake level levels:

Median lake levels-July 1997-January 1998

High lake levels-March 1998-May 1999

Median lake levels-June 1999-November 2001

Low lake levels-August 2001-September 2004

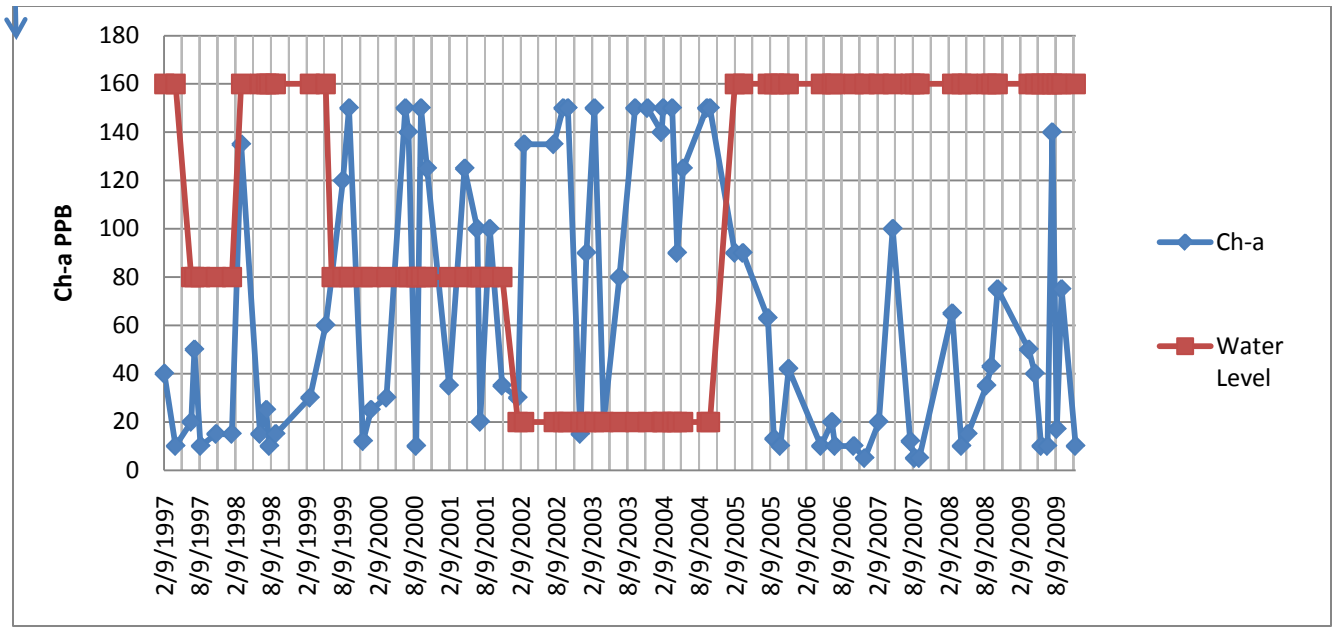
High lake levels-February 2005-November 2009

1. **We noted a strong correlation between lake level and lake wide average Ch-*a* concentration (as shown in the graph below).**

2. **We also noted that September of most years seems to be a peak in Ch-*a*.**

Graph Chlorophyll-*a* vs. Lake Level Data for Lake Elsinore, CA[1]

1997-2009



Patterns

In our limited review, we have identified 3 groups of representative patterns in the images provided. Identifying these patterns may help in the identification of future sampling locations and present an approach to evaluating the reasons for Ch-*a* concentration variability in Lake Elsinore.

- **Lake Wide** (concentrations distributed evenly across the entire lake) as in the 9/2/2001 image.
- **Shoreline dominated** (average concentrations along the shoreline are significantly higher or lower than the concentrations in the center of the lake) as in the 8/22/2000 image.
- **Concentrated** (elevated levels of Ch-*a* are concentrated in one or two specific areas) as in the 10/1/1997 image.

[1] The data on lake level is relative data based on observation of satellite frames, see note in report.

As an example of how the images can be used, we have put together the following chronological patterns based upon our interpretations. Please note, that no significant correlation has been established between these patterns and the Ch-*a* concentrations. Additional review, beyond the scope of this report would be necessary for any further evaluation.

- **February 1997 – July 2000 .** The dominant Ch-*a* pattern was **Lake Wide.**
- **August 2000 to November 2001.** The dominant Ch-*a* pattern was **Shoreline.**
- **January 2002 to February 2005.** The dominant Ch-*a* pattern was **Lake Wide.**
- **June 2005 to August 2007.** The dominant Ch-*a* pattern was **Shoreline and Concentrated**.
- **September 2007 to November 2009.** The dominant Ch-*a* pattern was **Lake Wide.**

Conclusions

- General Ch-*a* concentrations in Lake Elsinore range from 0 to greater than 150 ppb and are distributed throughout the entire surface water area.
- For 1997-1998 Lake Elsinore Ch-*a* values were relatively low.
- Beginning in 1999 Lake Elsinore levels for Ch-*a* began to elevate.
- **There appears to be a strong correlation between the lake wide average of Ch-*a* and lake level with high lake levels producing the lowest lake wide average Ch-*a*.**
- **Canyon Lake levels of Ch-*a* mirror those of Lake Elsinore. Peaks of Ch-*a* in Lake Elsinore correlate with peak levels in Canyon Lake (examples: 9/13/99, 6/27/00, 9/15/00)**
- September of a number of years was a peak month for Ch-*a* In Lake Elsinore and Canyon Lake.
- Three patterns were noted in the Ch-*a* images: **Shoreline, Lake Wide, and Concentrated.**
- In 2005 there was a very significant level of rainfall (15.52" according to published data) which appears to have driven lake levels up and driven Ch-*a* down in subsequent years.

Questions for further study

- What changes led to the increase in Ch-*a* in Lake Elsinore from 1997-1999?
- What are levels of Cyanobacteria are in the lake? Blue Water Satellite can scan for Cyanobacteria and a few sample scans showed high Cyanobacteria in Lake Elsinore.
- Is there any information from the patterning seen in the lake; **Lake Wide, Concentrated, or Shoreline dominated** and what can explain the patterning?
- What effects do meteorological and climatic changes have on the lake?
- What effect does lake temperature have?
- What is the change in lake volume over time?
- What percentage of time is Lake Elsinore in TMDL compliance?

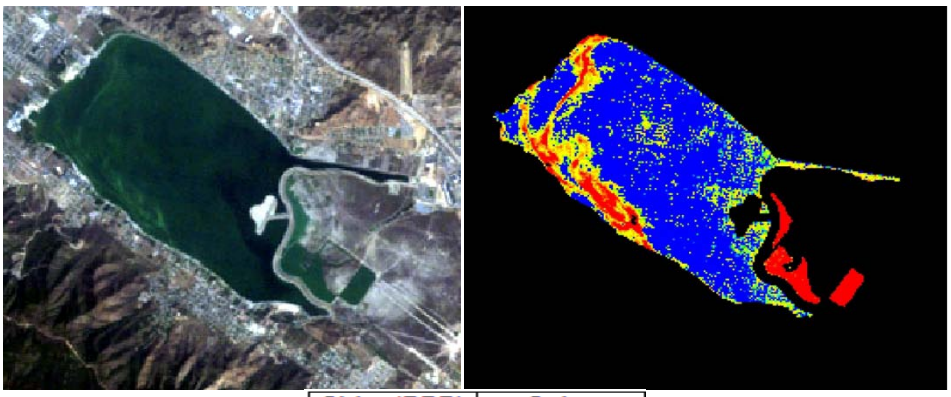
Report

Methodology

Blue Water Satellite, Inc. uses the government's Landsat satellites (Landsat 5 & 7) along with proprietary and patented algorithms to detect Chlorophyll-*a* in rivers, lakes, streams, ponds, and water bodies around the world.

Blue Water Satellite detects Ch-*a* based on the reflectance spectrum of Chlorophyll-a. The Landsat satellites contain sensors that measure reflected light in 7 spectral bands. Chlorophyll-*a* produces a unique set of ratios in the Blue Water Satellite algorithm which sense the unique "fingerprint" produced by Chlorophyll-*a*.

An example of the satellite image is shown below:



Chl-a (PPB)	Color
0 – 5	
6 – 10	
11 – 15	
16 – 20	
21 – 30	
31 – 40	
41 – 50	
51 – 75	
76 – 100	
101 – 125	
126 – 150	
>150	

Figure 1

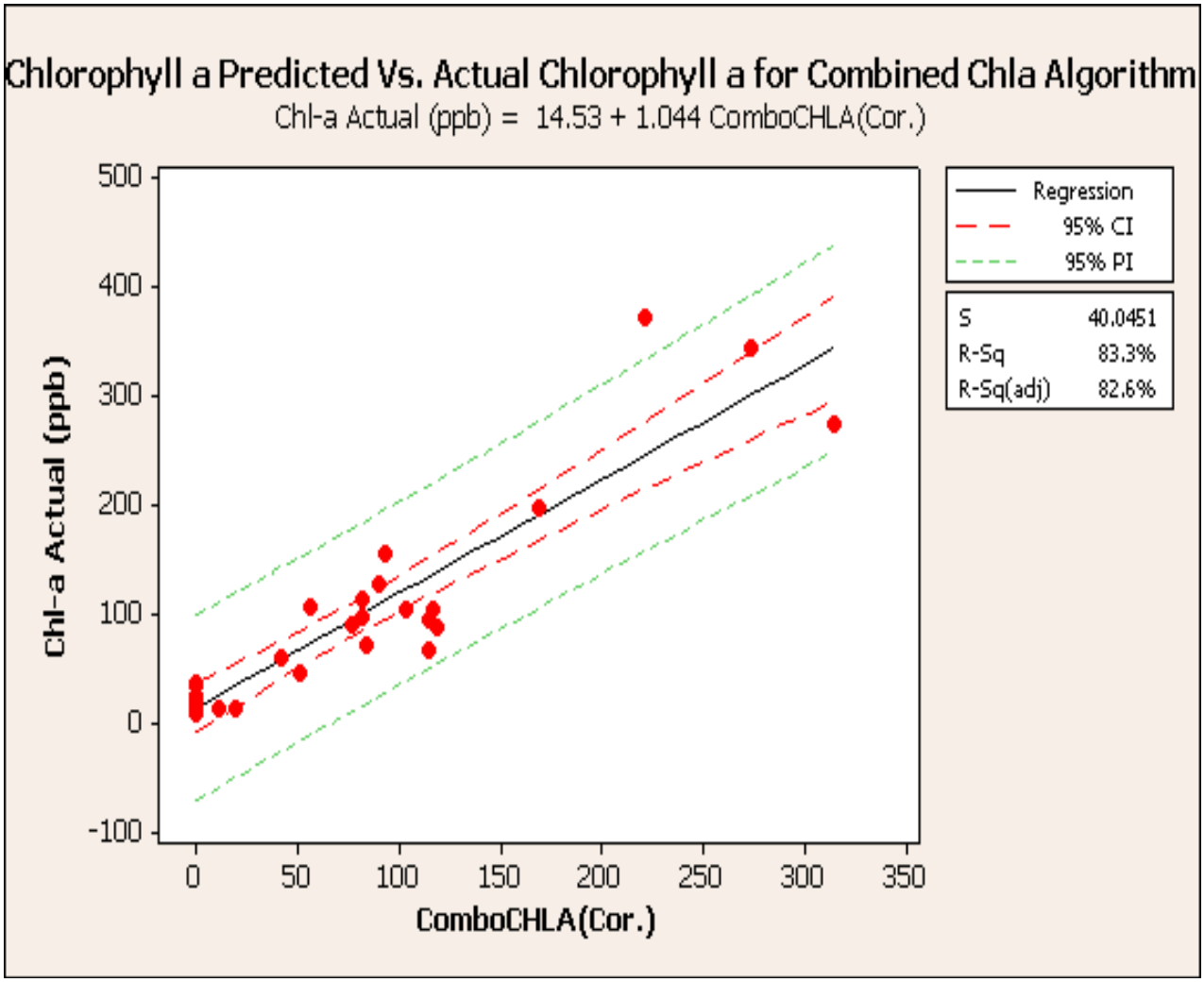
Figure 1-The image on the left is the natural color image from the satellite for Lake Elsinore October 1, 1997. On the right is the processed image showing the levels of Chlorophyll-*a* in the lake in parts per billion (ppb).

Correlation

Lake Elsinore provided Blue Water Satellite with data on 11 satellite overpass dates for correlation studies. It is important to note that due to water movement, ground correlation data must be taken as close as possible to satellite overpass in order to determine correlation. With a one mile per hour current, the water will drift 1 satellite pixel (approximately 100 feet) each minute.

Blue Water satellite performed a regression analysis comparing data provided by Lake Elsinore on the 11 satellite overpass dates with data measured by Blue Water satellite for the same dates.

The result of the regression analysis is shown below:



For this data the R^2 adjusted is .83. The standard deviation of the data is as follows:

For Ch-*a* range in the range of 0-40 ppb the standard deviation is 5ppb. For 40-150 ppb Ch-*a* standard deviation is 25 ppb. The standard deviation can be made much tighter if samples are collected closer to satellite overpass time. If this is done the results can be applied retroactively to all the images to improve accuracy.

Data ranges

In satellite imaging data is sampled using algorithms with certain discrete ranges. Satellite imagery can saturate if the samples are higher in concentration than the range maximum for the range. This is very similar to ground based chemistry where saturation requires sample dilution and re-test. When saturation occurs a new higher range algorithm must be used.

For the Lake Elsinore and Canyon Lake data two ranges were used: 0-40 ppb Ch-*a*, and 40-150 ppb Ch-*a*. These are currently the two ranges that Blue Water Satellite has developed for Ch-*a*.

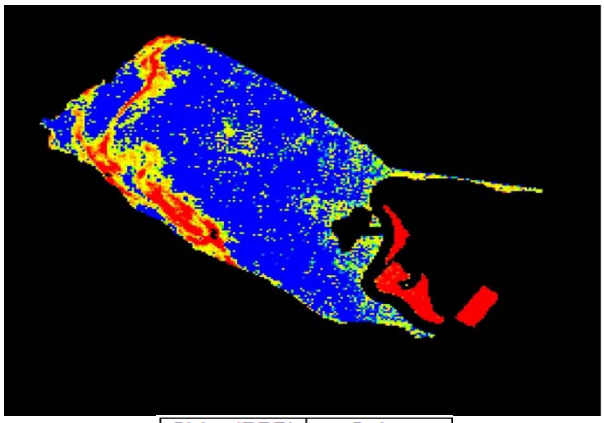
Higher Data Ranges

If The Lake Elsinore and San Jacinto Watersheds Authority is interested in higher ranges for Ch-*a*, Blue Water Satellite can develop a higher range model. This would be done by taking ground based data from Lake Elsinore simultaneously with satellite overpass on a date where the lake levels of Ch-*a* exceed 150 ppb. This can be done on a one time basis and then applied retroactively to all the images processed to date.

Lake Wide Compliance Monitoring

It is possible to calculate a lake wide average for of Ch-*a.* Often the lake wide average will be very different from the data obtained from individual sampling points. From satellite imaging Blue Water Satellite can determine the percentage of the lake that is at certain levels of Ch-*a.*

An example of this is shown in figure 2 and figure 3 below.



Chl-a (PPB)	Color
0 – 5	
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31 – 40	
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76 – 100	
101 – 125	
126 – 150	
>150	

Figure2

Figure 2 Lake Elsinore data from October 1, 1997, showing significant variation of Ch-*a* across the surface of the water body.

From the Satellite data a pie chart can be calculated showing the percentage of area that has various concentrations of Ch-*a*.

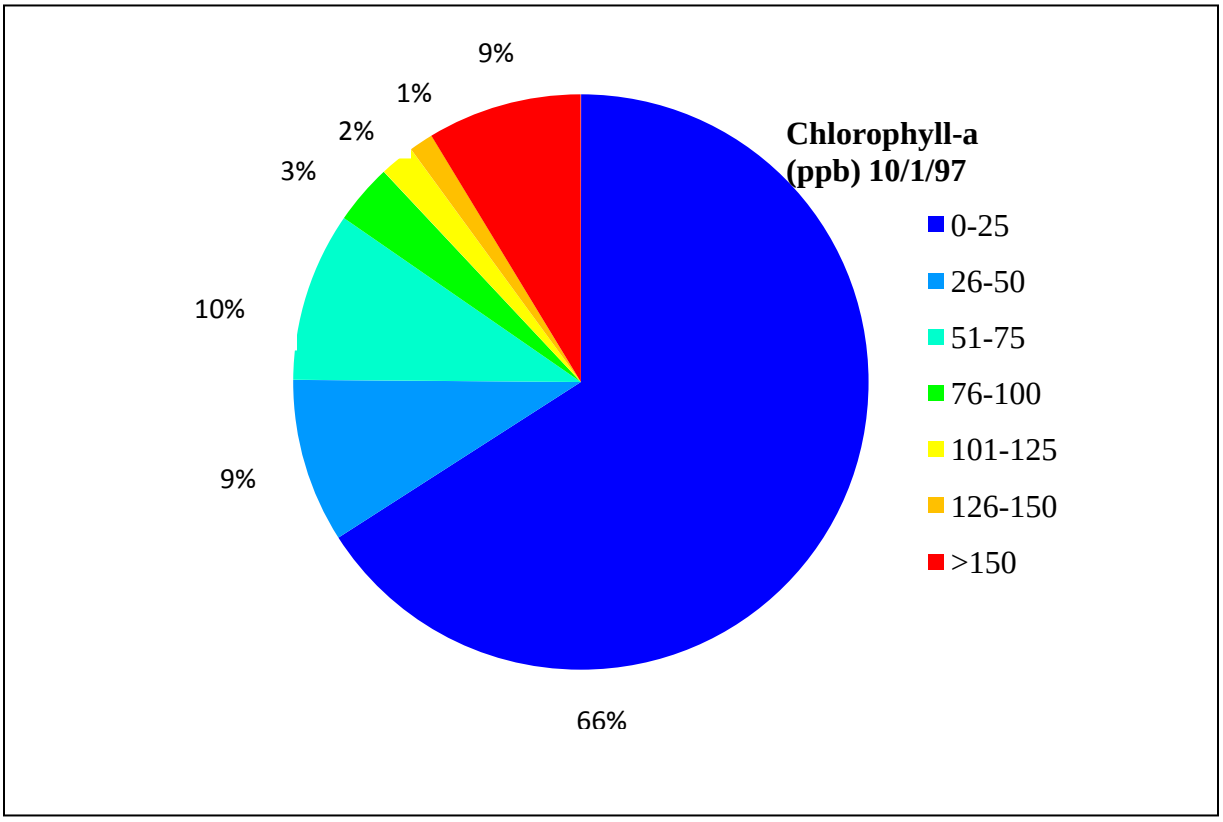

Figure 3

Figure 3 showing the percentage of Lake Elsinore with various levels of Ch-*a* on October 1, 1997.

From the above data the lake wide average concentration is calculated to be 38 ppb Cha-*a*.

TMDL Compliance Monitoring

For total maximum daily load (TMDL) compliance the satellite imagery can be configured to show areas of the lake which are above and below statutory limits. An option would be to provide Ch-*a* data calibrated up to the TMDL limit and then indicate in red all areas that are out of compliance.

A Note on Satellite Imagery "Venetian Blind" Effect

Blue Water Satellite uses two of the US Government's satellites: Landsat 5 and Landsat 7. In 2003, Landsat 7 had a partial failure of its scan converter. What this means is there are drop out lines in the Landsat 7 images. These lines in no way affect the processed images but do produce the "venetian blind" effect seen in the image below. The failure of the scan converter affects about 10% of the image. The Landsat 5 satellite has no such failure and this situation will be rectified in July of 2011 with the launch of Landsat 8. This effect is shown in figure 4 below.

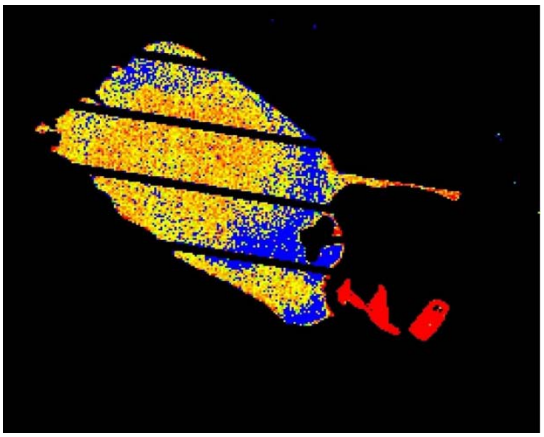

Figure 4

Figure 4 showing a Landsat image of Lake Elsinore for August 23, 2003, showing the effect of Landsat 7's scan converter problem. This corresponds to a 10% reduction in image data.

Note on Lake Level Data

In the graph of Chlorophyll-*a* vs. Lake Level data, the levels of the lake were estimated to be Low, Median, and High as defined on page 2 of the report. For the purposes of the graph a low lake level was assigned a relative value of 20, a median lake level was assigned a relative value of 80 and a high lake level was assigned a relative value of 160. Blue Water satellite is capable of making precise measurements of lake level surface area but the graph data was approximated.

For Further Information

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