**NASA DEVELOP National Program**



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Lake Tahoe Water Resources

Creating an Algorithm for Global Continuous Detection Lake Level Monitoring Using Landsat Imagery

 **Technical Report**

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# I. Abstract

[Placeholder - do not put anything here until the final draft submission. The abstract in the project summary is where the working draft of the abstract should “live”]

**Keywords**

Remote Sensing, Landsat, Continuous Detection, Python, Lake Level, Google Earth Engine.

# II. Introduction

Drought is one of the most common threats to populations worldwide as weather and climate patterns continually shift. According to the World Meteorological Organization of the United Nations, of the 2.8 billion people who encountered weather-related disasters from 1967 to 1991, approximately 50% of the individuals suffered due to drought. Likewise, in 1988, severe drought cost the United States economy nearly $40 billion (Kogan, 1997). The consequences of drought are still a concern for many as droughts worldwide have increased in their frequency, duration, and severity (Allen et al., 2009), particularly in the state of California where water levels are exceptionally low in 2015.

Lake Tahoe, along with many other water bodies in California, is now in jeopardy as the state faces one of the most severe droughts on record. Lake Tahoe is an important water feature for it has an exceptional impact on local residents, economies, and ecological factors. Many residents rely on the lake for drinking water (North Tahoe Public Utility District, 2014), and it supports one of the state's largest tourism industries, drawing 23 million visitor days per year (Kocher & Cobourn, Date) and generating over $300 million in revenue annually. Furthermore, the lake also has a diverse ecosystem and is home to Tahoe Yellow Cress, an endangered species that can only be found growing along the shoreline of Lake Tahoe. For these reasons, declining water levels are now a major concern for Tahoe’s local residents, economies, and endangered species; the need to consistently monitor lake levels is essential in preserving future water resources and protecting local counterparts.

The Lake Tahoe Basin Management Unit (LTBMU) of the USDA Forest Service was the primary end-user of this project. As Lake Tahoe falls in their regional jurisdiction, the LTBMU is responsible for managing the water resources in the area, including relatively small water bodies such as Fallen Leaf Lake. The LTBMU does not currently have a consistent timeframe for monitoring lake level and, as a result, their measurements are sporadic, infrequent, and difficult to analyze (Joey Keely, Personal Communication). Both the USGS and the University of California-Davis Tahoe Environmental Research Center (TERC) have *in situ* data for specific locations throughout Lake Tahoe, but the current methods have yet to assess the lake as a whole. As California’s water supplies are decreasing rapidly, the LTBMU has a vested interest in having access to near real-time monitoring of Tahoe Basin water levels in order to improve current and future management.

This project developed the Continuous Lake Area Detection (CLAD) tool, for continually monitoring lake levels in near real-time using Landsat imagery. From 1984 to present, the Landsat program has provided consistent imagery acquisition at a 30 meter spatial resolution with a return interval of 16 days; this high temporal resolution makes it a powerful tool for continuous change detection monitoring. In conjunction with the cloud-based geospatial tool Google Earth Engine, CLAD provides a means of lake level monitoring that automatically updates with the latest set of Landsat imagery. In addition to lake level monitoring, CLAD will be able to provide simple estimates of water quality and…Algal blooms? The goal is to give water managers the ability to have accurate, continuous, and on-demand, lake level measurements for use in their decision-making.

The original lake measurement algorithm, from which CLAD is based upon, was calibrated to output the lake level of Mono Lake via a series of density slices from a Landsat Standard Terrain Correction (L1T) product. The chief purpose of this project is to adjust the algorithm so that it can provide near real-time lake level monitoring for Lake Tahoe, CA, and be a useful tool for the Lake Tahoe Basin Management Unit. The secondary purpose, and ultimate goal, is to then further modify this tool so it scales globally—so any water manager can monitor the level of any lake or terrestrial water body of sufficient size.

# III. Methodology

**3.1 Modifications to Existing Lake Level Measurement Algorithm**

**3.1.1 Google Earth Engine Landsat TOA Image Collections**

The original algorithm used Landsat L1T products, which come with pixel values in digital numbers (DN). Given the change in water body delineation method (section 3.1.4), pixel values needed to be converted to reflectance rather than the scaled radiance that DN represents. Converting from the Landsat L1T DN values would add complexity and processing time to CLAD. Rather than add a conversion step, CLAD uses image collections from Google Earth Engine that come in values of Top Of Atmosphere (TOA) reflectance. The Landsat TM collection is complete, as neither Landsat 4 nor 5 is currently in operation. The Landsat OLI collection is updated as new images are acquired by Landsat 8. Landsat 7 (ETM+) was not utilized in this project due to the complication of scan line errors. A water body with a scan line going through it would return a decreased water pixel count, potentially confusing a water manager or other CLAD user. Therefore, no measurements from 2012 were incorporated into this project.

**3.1.2 Cloud Mask and Cloud Shadow Masking**

The original lake measuring algorithm used a cloud mask derived from a series of density slices, which involves computer value thresholds based on the DN of TM bands 3 and 6 of a Landsat L1T product. The original thresholds are >35 for band 3 and <120 for band 6. The cloud mask capitalizes on the high DN’s in Landsat’s visible bands. While the cloud mask in the original algorithm performed well in identifying clouds, there was no method of identifying cloud shadows.

Cloud shadows can make pixel classification difficult. Land cover features (particularly water, given its dark spectral qualities) can often be misclassified when in shadow (Zhu & Woodcock, 2011). To mask cloud shadows, CLAD employs a temporal dark pixel identifier (citation). This cloud shadow mask, which locates pixels that are only temporarily dark, was provided by the USDA Forest Service’s Remote Sensing Applications Center. Pixels that are consistently dark are left out of the mask, as they likely belong to a dark land cover classification, such as a water body. Pixels that decrease in reflectance for a brief period of time are likely in shadow, and are therefore added to the mask.

**3.1.3 Snow Masking**

CLAD uses a spectral water index to delineate water pixels (see section 3.1.4). This index has also been used in the past to detect snow (Immerzeel et al., 2008). CLAD assigns very high values to snow-covered pixels, which adds snowy banks of a water body to the water pixel count in the winter months.

To allow for continuous lake level monitoring in the presence of snow, a simple method for masking snow is included in CLAD. Similar to the algorithm’s original cloud mask, the snow mask capitalizes on the high reflectance of snow in Landsat’s visible bands. A simple thresholding algorithm is applied to TM bands 1, 2, and 3, and OLI bands 2, 3, and 4. Any pixel in these bands with a reflectance greater than 0.2 is included in the snow mask and therefore excluded in lake level analysis. This also includes land cover with relatively high reflectance such as bare rock. Given that CLAD is monitoring only water bodies, this does not present a problem.

**3.1.4 Water Body Delineation**

CLAD identifies water using the Modified Normalized Difference Water Index (MNDWI). Contrary to the Normalized Difference Water Index (NDWI), which uses a green band and a near infrared band, the MNDWI uses a green band and a mid or shortwave infrared band. MNDWI assigns a higher value to water and a lower value to vegetation than the NDWI (Xu, 2006).

CLAD loads a vector boundary of the selected water body, and applies a buffer of 1km. Within this area, it calculates the MNDWI algorithm (See appendix 1). Any pixel not included in the cloud or snow mask that has an MNDWI value of >0.2 is classified as water and therefore added to the water pixel count.

**3.1.5 *In situ* Validation**

For validation purposes, remotely-sensed lake level measurements were compared to *in situ* measurements taken by the USGS gauge station located near Tahoe City. To process and analyze *in situ* data, the same methods used in CLAD were used for lake level validation, but the calculations were manually analyzed in ENVI rather than automatically calculated through Google Earth Engine. Using one image per year from 1984 to 2015 (with the exception of 2012), the pixel values were converted to reflectance (as mentioned in section 3.1.1). In order to apply the MNDWI, the band math tool was used (shown in Figure 1), assuming band 2 was equal to the green band and band 5 was equal to the first shortwave infrared band.

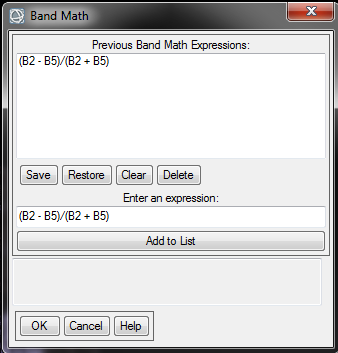


Figure 1. Equation used in ENVI to develop MNDWI.

The same shapefile used in CLAD that creates a vector boundary around Lake Tahoe (section 3.1.4) was also used in ENVI to mask pixels beyond the study area. In order to determine the water pixels within the region of interest, a band threshold was applied with the values ranging from 0.40 to 1.00. Water pixels then became identifiable as shown in Figure 2. After calculating the statistics for each region of interest within each image, a graph was created in order to compare the results with the *in situ* data.

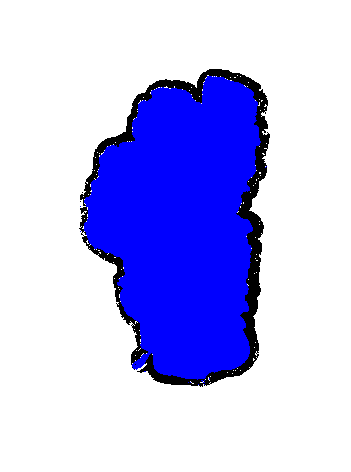


Figure 2. Water pixels highlighted in blue after determining the band threshold within the ROI.

**3.2 Incorporating Water Quality Measurements**

**3.2.1 NDTI**

**3.2.2 FAI?**

# IV. Results & Discussion

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* Future Work: If this project was to be selected for another term, what would be the focus? What other areas would be of interest?

# V. Conclusions

Final conclusions. Word count: 200-600 (~a page).

# VI. Acknowledgments

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