Relationship Between Landsat 8 Spectral Reflectance and Chlorophyll-a in Grand Lake, Oklahoma

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Funding Provided by Grand River Dam Authority (GRDA)
Dr. Darrell Townsend, Steve Nikolai, and Dr. Rich Zamor
Grand Lake o’ the Cherokees

- Located in Northeast Oklahoma in the foothills of the Ozark Mountain Range
- Administered by Grand River Dam Authority, an Oklahoma State Agency
- Pensacola Dam completed 1940
- 46,500 surface acres
- Designated Uses
  - Hydroelectric power
  - Flood control
  - Water supply
  - Recreation

http://mygrandlakehomes.com/
Grand Lake Water Quality Issues

• Blue-Green Algae Bloom, 2011
• Elevated Microsystin levels up to over 350 µg/l
• WHO – Adverse Health Effects when over >20 µg/l
• DEQ issued alert
• GRDA shut down the lake on July 4th 2011
• Monitoring Program has grown significantly (Townsend, OCLWA, 2014)
Grand Lake Project Objectives

- Relate *in situ* water quality data to spectral reflectance data
- Develop algorithms to predict water quality parameters based on an empirical model and semi-analytical shape derivative approach
- Spectral Data
  - Temporally and spatially corresponding Landsat satellite imagery
  - Landsat 8 OLI (Operational Land Imager) and historical Landsat 5 TM (Thematic Mapper) 30-meter resolution multispectral satellite imagery.
  - Proba CHRIS satellite observations
  - Develop semi-analytical algorithms for hyperspectral instruments

Water Quality Data               Remotely Sensed Data

Temporally & Spatially Coincident
Presentation Objective

- Determine which Landsat 8 Surface Reflectance (SR) bands better predict CHL-a in Grand Lake, using the following datasets
  - 8 bands of Landsat 8 SR values for Aug. 14\textsuperscript{th} and Sept. 15\textsuperscript{th} 2015
  - Temporally coincident \textit{In situ} CHL-a data from 13 sampling points in the Grand Lake, Oklahoma
Literature Review

- **Han & Rundquist (1997)**
  - NIR/RED (Band 5/Band 4) comparison
  - NIR/Red ratio not an effective algal-chlorophyll concentration predictor

- **Arenz Jr. & Saunders III (1996)**
  - NIR/Green (Band 5/Band 3) comparison
  - Strong relationship ($R^2 = 0.98$)

- **Pattiaratchi, Wyllie & Hick (2007)**
  - Combined Band 1 & Band 3
  - High predictive confidence

- **Torbick et al. (2013)**
  - Lake water Quality Mapping
  - Band ratio radiance models performed well ($R^2 = 0.65-0.81$)
Data Acquisition

- USGS Earth Explorer – downloaded Landsat 8 images in GeoTIFF format
- Created ArcMap project
- ESRI Image Classification tool
  - Created polygons at Sampling sites
  - Calculated mean reflectance per selected pixel
- Export analysis to MS Excel and combine with In-situ CHL-a data
## Landsat Download Bands

<table>
<thead>
<tr>
<th>Bands</th>
<th>Wavelength (nm)</th>
<th>Resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1 - Coastal aerosol</td>
<td>430 - 450</td>
<td>30</td>
</tr>
<tr>
<td>Band 2 - Blue</td>
<td>450 - 510</td>
<td>30</td>
</tr>
<tr>
<td>Band 3 - Green</td>
<td>530 - 590</td>
<td>30</td>
</tr>
<tr>
<td>Band 4 - Red</td>
<td>640 - 670</td>
<td>30</td>
</tr>
<tr>
<td>Band 5 - Near Infrared (NIR)</td>
<td>850 - 880</td>
<td>30</td>
</tr>
<tr>
<td>Band 6 - SWIR 1</td>
<td>1570 - 1650</td>
<td>30</td>
</tr>
<tr>
<td>Band 7 - SWIR 2</td>
<td>2110 - 2290</td>
<td>30</td>
</tr>
<tr>
<td>Band 8 - Panchromatic</td>
<td>0.50 - 0.68</td>
<td>15</td>
</tr>
</tbody>
</table>


1. Seasons
   - Spring, Summer, Fall
   - Capture spatial and temporal variability in water quality

2. Sample dates
   - Temporally coincident satellite overpass
   - Sampling begins just prior to satellite overpass and continues for a short period after

3. Alternative
   - +/- 2 days of individual satellite overpasses (acceptable)
   - Assumes no rainfall/runoff event
GRDA Designated 13 Sampling Sites

http://www.oclwa.org/pdf/2015Presentations
Field Sampling

- Boat (GPS enhanced, bathymetry)
- YSI multi-parameter Sampler
- Secchi Disc
- Van Dorn Sampler
- Sample bottles & Ice Chest
- Water sampling Hose
- Laboratory Analysis for QA/QC Conducted
Statistical Analysis of Data

- Regression
  - Chlorophyll $a$ vs spectral bands
  - Stepwise elimination of bands
  - Band 2 (Blue) and Band 3 (Green) linear relationship

- Equations
  1. $\text{CHL-a} = 0.05456 \text{ Band 3}$
  2. $\text{CHL-a} = -33.1 + 0.2105 \text{ Band 2}$
  3. $\text{CHL-a} = -40.1 + 0.4138 \text{ Band 2} - 0.1349 \text{ Band 3}$
  4. $\text{CHL-a} = 20.32 \text{ Band2/Band3}$

- ANOVA
  - Different combinations of Bands 2 and 3 with CHL-a
Plot of CHL-a vs. Band 2, Band 3
Plot of CHL-a vs. Band 2, Band 3
Hypothesis

- Null Hypothesis (Ho): Selected bands cannot be used to predict CHL-a (non-significant relationship)

- Alternative Hypothesis (Ha): Selected bands are good predictors of CHL-a (significant relationship)

- Test: Reject Ho if P–Value < 0.05
### Results of Regression Analysis

<table>
<thead>
<tr>
<th>Equation</th>
<th>$R^2$ (%)</th>
<th>RMSE</th>
<th>$b_0$</th>
<th>$b_1$</th>
<th>$b_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chl a = $b_0$ + $b_1$Band 2</td>
<td>40.00</td>
<td>11.05</td>
<td>33.10</td>
<td>0.211</td>
<td>-</td>
</tr>
<tr>
<td>Chl a = $b_0$ + $b_1$Band 3</td>
<td>63.40</td>
<td>12.99</td>
<td>0</td>
<td>0.055</td>
<td>-</td>
</tr>
<tr>
<td>Chl a = $b_0$ + $b_1$Band 2 + $b_2$Band 3</td>
<td>51.83</td>
<td>10.10</td>
<td>-40.1</td>
<td>0.414</td>
<td>-0.135</td>
</tr>
<tr>
<td>Chl a = $b_0$ + $b_1$Band 2 / Band 3</td>
<td>57.57</td>
<td>13.72</td>
<td>0</td>
<td>12.16</td>
<td>-</td>
</tr>
</tbody>
</table>

**RMSE:** Root Mean Square Error

**Desired outcome:** High R-squared, Low RMSE
Summary of Regression Results

- Band 3 is a good predictor of CHL-a (p-Value < 0.05).
  - The equation accounts for 63% of the data

- Band 2 is a good predictor of CHL-a (P-Value < 0.05)
  - The equation accounts for 40% of the data

- Combining them gives a predictive potential in-between, with less RMSE
### Results of the ANOVA

<table>
<thead>
<tr>
<th>Response variable</th>
<th>Treatment</th>
<th>Significant</th>
<th>p-value (α = 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHL-a (µg/L)</td>
<td>Date</td>
<td>Yes</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Sample site</td>
<td>No</td>
<td>0.997</td>
</tr>
<tr>
<td></td>
<td>Date, Sample site</td>
<td>No</td>
<td>&lt;0.001, 0.077</td>
</tr>
<tr>
<td>Band 2 (nm)</td>
<td>Date</td>
<td>Yes</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td>Sample site</td>
<td>No</td>
<td>0.274</td>
</tr>
<tr>
<td>Band 3 (nm)</td>
<td>Date</td>
<td>No</td>
<td>0.437</td>
</tr>
<tr>
<td></td>
<td>Sample site</td>
<td>Yes</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Desired trend: change in SR values reflects change in CHL-a conc.
Conclusions

- Different Combinations of Landsat 8 SR values in Bands 2 and 3 enhance prediction of CHL-a in Grand Lake, Oklahoma

- The predictive equations account for at least 40% of the data

- Few data points were utilized, relationships will change with more data points

- No processing of SR data was done; relationships might improve with pre-processing
Next steps

- Collect more *in situ* data in 2016
- Pre-process spectral data and combine with *in situ* data
- Re-run the tests using more data points, with a more robust software
- Build predictive models
Thank you!