Remote Sensing Calibration of Casey Lake and Silver Lake

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Received: April 27, 2005

Accepted: May 9, 2005

ABSTRACT

This project examines two Iowa lakes to explore the feasibility of using remote sensing technologies for assessing water quality in lieu of actual ground samples. We demonstrate that a principal component analysis of the more than 20,000 remote sensed pixels can be used in a regression analysis to accurately predict total phosphorus levels in Casey Lake on three distinct times in the summer of 2004.

I. INTRODUCTION

The goal of this analysis is to calibrate remote sensing data with ground samples in two local Iowa Lakes, Silver Lake in Delhi, Iowa and Casey Lake in Tama County, Iowa. We examine water quality variables including surface temperature, pH, turbidity, secchi, chlorophyll a, and total phosphorus collected on three occasions during 2004 (June 3, July 8 and July 31) from the two lakes. Remote sensing data taken from aircraft were correspondingly collected for each lake and each of the three times. Variables such as chlorophyll a, turbidity and surface water temperature are traditionally measured from satellite data. However, most of these studies have explored remote sensing applications to large bodies of water such as Lake Michigan [1]. We will address whether the remote sensing variables can be used in lieu of the much more time and labor extensive procedure of collecting ground samples.

We first reduce the number of bands of reflectivity (remote sensed) data from thirty down to a more manageable set without losing much information. We will use tens of thousands of pixels of reflectivity data from each lake at each of the three dates (each pixel having 30 bands) in a principal component analysis. Then the

three to five principal components obtained for the pixel most closely aligned with each ground-sampled location will be used in a regression analysis (using the principal components determined by an analysis of the thousands of pixels from the entire lake) with the observed water quality variables, one at a time, as the dependent variable.

II. REDUCING THE NUMBER OF REMOTE SENSING REFLECTIVITY BANDS

The two lakes being examined are Casey Lake in Tama County, Iowa and Silver Lake in Delhi, Iowa. Figures of each lake were constructed from the 22,522 and 25,708 respective remote sensed pixels (see Figure 1 and Figure 2) that were gathered in June 2004. Similar pixel counts were observed for early July and late July of 2004.

In reviewing the spectral bandwidth summary statistics for June 2004, there were 22,522 pixels obtained with 30 bands each in Casey Lake. The lowest levels for each band (B) ranged from 274 to 1,344 and the highest levels recorded for each band ranged from 1,260 to 2,727. There were 25,708 pixels remote sensed with 30 bands each in Silver Lake. The lowest levels for each band ranged from 638 to 1,664 and the

highest levels recorded for each band ranged from 1,713 to 5,246.

Our first objective is to examine the reflectivity data for correlations to reduce the number of bands with minimal loss of information. Thirty separate regression analyses were performed on Casey and Silver lakes using each of the 30 bands as the dependent variable and the remaining 29 as independent. A table was then made (not shown) showing whether or not each band was a significant predictor of the dependent variable. There was an interesting trend in the R squared values. For Casey, the models with B1, B2, and B3 separately as dependent variables explain less than 80% of the variability using the remaining bands as covariates. For example B1 as the dependent variable would have B2 through B30 as covariates. Specifically, the R squared values for B1, B2 and B3 respectively are 0.5542, 0.7517, and 0.7796. The rest of the bands as dependent variables explain more than 80% of the variability. The results are similar with Silver Lake, except that B1 is the only variable that, when it is dependent, it explains less than 80% or precisely 67.31% of the variability.

We next looked at the five most significant bands when we examined each of the 30 bands as the dependent variable and the rest as independent as before. It also indicates the five bands in which each of the independent bands is most closely related. In comparing the B1 to B30 levels in Casey and Silver Lakes, it is apparent that the bands are more highly correlated with other bands that are within five. For example in Silver Lake, the highest correlations involving B3 are bands B2, B4, B5, B6, and B7. There are a few correlations that do not follow this pattern in Silver Lake, which may be due to floating objects in the water or incorrect readings, etc., but for the most part each band is very closely related to the bands nearest to them.

Table 1 and Table 2 show a summarized version of the regression and correlation analyses. They show the maximum correlation between each of the individual bands, when each band is dependent. They also show the maximum correlation along with the band that corresponds the closest, as well as the total R squared value. These tables visually

Figure 1. 22,522 reflectivity pixels in Casey Lake.

Figure 2. 25,708 pixels in Silver Lake.

show that the highest correlations between the bands are with the bands that are the closest to the variable of interest. For example with Casey Lake in Table 1, B2 is the closest related variable to B1 with a correlation of 0.692, and B5 is the closest related variable to B4 and B6 with correlations of 0.883 and 0.886, respectively. There are a few results that do not comply with the pattern of the rest, for example B10 is the closest related variable to B2, but twenty-five out of the thirty follow this pattern. The R squared values also tend to increase with the band number.

Silver Lake also follows a similar pattern of the higher R squared values associated higher band numbers. For example with Silver Lake in Table 2, B2 is the closest related variable to B1 and B3 is the closest related variable to B2. There are a few more bands with Silver Lake that do

Casey Lake		
Band	Max Corr (Variable)	R squared
B1	0.692 (B2)	0.5542
B2	0.799 (B10)	0.7517
B3	0.814 (B9)	0.7796
B4	0.883 (B5)	0.8500
B5	0.886 (B6)	0.8606
B6	0.886 (B5)	0.8552
B7	0.891 (B8)	0.9018
B8	0.929 (B9)	0.9209
B9	0.932 (B10)	0.9225
B10	0.933 (B11)	0.9274
B11	0.942 (B12)	0.9292
B12	0.946 (B13)	0.9361
B13	0.946 (B12)	0.9350
B14	0.938 (B13)	0.9399
B15	0.918 (B14)	0.9054
B16	0.895 (B17)	0.9143
B17	0.955 (B18)	0.9447
B18	0.968 (B19)	0.9606
B19	0.972 (B20)	0.9697
B20	0.972 (B19)	0.9666
B21	0.978 (B22)	0.9749
B22	0.978 (B21 & B23)	0.9782
B23	0.991 (B25)	0.9878
B24	0.985 (B23)	0.9789
B25	0.991 (B23)	0.9878
B26	0.986 (B23 & B25)	0.9855
B27	0.986 (B26)	0.9822
B28	0.984 (B26 & B27)	0.9811
B29	0.983 (B26 & B28)	0.9786
B30	0.979 (B26)	0.9702

Table 1. Casey Lake bands, maximum correlations, and R squared values.

not comply with the pattern of the rest, but twenty-two out of the thirty follow this pattern. This could be because of the problem mentioned earlier about the possibility of floating objects in the water or incorrect readings. The R squared values tend to increase with the band number for Silver Lake as well.

A Principal Component Analysis (PCA) was conducted on the spectral bandwidth data for both Silver and Casey

Lakes at each of the three times with our objective being to reduce the number of bands from thirty to between two and five with only a minimal loss of information. The results of the PCA for Silver show that the first two principal components explain 90.3% of the total variability and the first three account for 95.1%. The first principal component, which explains 73.1% of the total variability, is a weighted average of all thirty bands, due to the positive correlations amongst all variables. The first two

Silver Lake		
Band	Max Corr (Variable)	R squared
B1	0.722 (B2)	0.6731
B2	0.907 (B3)	0.8934
B3	0.923 (B4)	0.9221
B4	0.985 (B5)	0.9813
B5	0.985 (B4)	0.9822
B6	0.979 (B5)	0.9796
B7	0.963 (B8)	0.9769
B8	0.977 (B9)	0.9785
B9	0.977 (B8)	0.9764
B10	0.976 (B9)	0.9745
B11	0.982 (B12)	0.9801
B12	0.982 (B11)	0.9814
B13	0.975 (B8)	0.9818
B14	0.968 (B10 & B13)	0.9681
B15	0.958 (B12)	0.9498
B16	0.957 (B17)	0.9821
B17	0.975 (B18)	0.9879
B18	0.975 (B17)	0.9893
B19	0.973 (B18)	0.9868
B20	0.851 (B22)	0.9724
B21	0.955 (B19)	0.9804
B22	.0953 (B21)	0.9804
B23	0.990 (B25)	0.9874
B24	0.884 (B25)	0.9801
B25	0.985 (B23)	0.9890
B26	0.985 (B23)	0.9850
B27	0.969 (B26)	0.9782
B28	0.981 (B25)	0.9787
B29	0.971 (B28)	0.9779
B30	0.968 (B29)	0.9717

Table 2. Silver Lake bands, maximum correlations, and R squared values.

principal components explain 94.2% of the total variability in the thirty bands from Casey Lake. The first principal component, which explains 80.5% for the total variability, is a weighted average of only bands 17 through 30. The first 16 bands are not very useful in examining the variability amongst the bands. Thus, the thirty bands from either lake can best be reduced to two or three principal components without much loss of explanatory power.

III. CORROBORATING GROUND DATA

The results of the principal component analyses on the reflectivity data from Casey Lake and Silver Lake were investigated to determine how accurate remote sensing data can predict actually sampled water quality data. The water quality variables: Temperature, Secchi (a measure of water clarity), Chlorophyll a, Turbidity, pH and Total Phosphorus were collected at as many as 20 sites in Silver Lake (see Figure 3) and as many as 21 sites in Casey Lake (see Figure 4) for dates in June, early July and late July. Remote

sensed data were collected for each lake at each corresponding time. The remote sensed pixels most closely associated with the actual sample locations (as many as 20 in Silver and 21 in Casey) were determined and the first three principal components, obtained from the principal component analysis using the pixels from the entire lake (22,522 in June), were separately regressed on each water quality variable (three independent variables and as many as 21 observations or sites). With such relatively small sample sizes, we needed to reduce the number of variables (bands) from thirty to a much smaller number (three) of principal components

Table 3 illustrates the regression results for June 2004 where P (N) represents a positive (negative) parameter estimate and its corresponding significance level is given by the number of asterisks. Ground samples during early July 2004 and late July 2004 were also collected and analyzed in each lake. The first principal component in the June 2004 Silver Lake data explains Temperature, pH and Chlorophyll well, while the first two explain Turbidity. In Casey Lake, the first principal

Silver Lake Sample Sites

Figure 3. Sampled locations in Silver Lake.

Casey Lake Sample Sites

Figure 4. Sampled locations in Casey Lake.

component only explains Temperature. All three principal components are significant in the June 2004 Casey Lake data in explaining the total phosphorus. Note that no principal components explain total phosphorus in Silver Lake. This observation may be due to the quite different water chemistry found in each lake. Silver Lake is more polluted with much higher levels of phosphorus than Casey Lake (see [2, 3]).

We next examine the PCA results for the water quality variable total phosphorus in Casey Lake during the June, early July and late July collection times in Table 4. The first three principal components explain the amount of phosphorus in the lake well. A better illustration of the quality of the remote sensed results for total phosphorus in Casey Lake would compare the actual sampled

	SILVER			CASEY		
	PC1	PC2	PC3	PC1	PC2	PC3
Temperature	P ****			P **		
pH	P *				N ****	
Turbidity	P ***	N *				
Secchi					N **	
Chlorophyll a	N ***					
Total Phosphorus				P **	P *	N **

Table 3. Principal component analysis/regression results for June 2004. * Indicates significance at the alpha = 0.15 level; ** Indicates significance at the alpha = 0.10 level; *** Indicates significance at the alpha = 0.05 level; and **** Indicates significance at the alpha = 0.01 level.

values to the remote sensed fitted or predicted values (see Table 5). For example, the actual value of total phosphorus in Casey Lake in June 2004 at Transect 1, Site 1 (T1S1) was 73.9. The predicted value obtained from regressing the first three principal components, obtained via the principal component analysis of the 25,522 remote sensed pixels from Casey Lake in June, on total phosphorus is 80.6. Similarly, we observed 42.1 in early July and 151.8 in late July, whereas, the corresponding predicted values from the regression model are 47.4 and 120.9, respectively.

Finally, we use the regression results coupled with the principal component analysis to estimate the total phosphorus for each of the 22,522 pixels in Casey Lake. Figure 5 displays the 215 sites in Casey Lake where the total phosphorus levels are predicted to be higher than 390. The highest

	PC1	PC2	PC3
June	P **	P *	N **
Early July	P ***	P ***	P *
Late July	P ***		N ***

Table 4. Significance of the independent variables (principal components) in the regression analysis of Total Phosphorus in Casey Lake for 2004 (for the notation indicating significance at the alpha level, see Table 3).

one percent of the total phosphorus predicted values tend to be located at the inflows to Casey Lake and along the shore, particular the southern portion. Future work will include actual sampling at the lake perimeter to determine if these results are accurate or a direct result of different reflectivity properties along the shore (possibly due to the shallow water depth).

Casey Lake Sites	June Total Phosphorus	June Predicted Values	Early July Total Phosphorus	Early July Predicted Values	Late July Total Phosphorus	Late July Predicted Values
T1S1	73.9	80.62	42.1	47.38	151.8	120.09
T1S2	80.7	76.62	47.8	46.40	126	92.27
T1S3	84.1	78.62	44.3	41.50	100.9	82.42
T1S4	84.1	81.54	40.4	45.50	138.7	103.91
T2S1	70.6	71.71	43.9	41.40	110.5	102.76
T2S2	70.6	70.12	40.4	47.38	88.0	96.70
T2S3	77.3	72.78	43.9	46.85	81.9	90.97
T2S4	80.7	79.41	54.7	55.22	107.7	120.52
T3S1	84.1	76.23	44.3	48.30	92.1	109.71
T3S2	63.8	72.49	45.6	46.26	101.6	102.90
T3S3	70.6	73.54	38.6	31.58	99.6	102.44
T3S4	73.9	79.22	38.6	38.39	98.2	118.08
T4S1	No Data	No Data	38.6	55.55	101.3	146.73
T4S2	No Data	No Data	40.4	40.94	125.1	139.19
T4S3	No Data	No Data	38.6	39.21	81.2	102.18
T4S4	No Data	No Data	45.3	57.73	221.9	175.69
T5S1	No Data	No Data	57.9	49.85	No Data	No Data
T5S2	No Data	No Data	49.1	45.59	No Data	No Data
T5S3	No Data	No Data	45.6	48.07	No Data	No Data
T5S4	No Data	No Data	63.1	65.19	No Data	No Data
Inflow3	84.10	85.59	94.6	59.50	94.7	114.65

Table 5. Actual total phosphorus values together with the modeled phosphorus values from remote sensed data for Casey Lake.

Figure 5. Highest 1% of Phosphorus predicted levels in Casey Lake.

IV. CONCLUSIONS

This project calibrated remote sensing data predictions of water quality variables with results actually obtained on the ground through sampling. The results indicate that the total phosphorus level in Casey Lake was fairly well predicted using only remote sensed reflectivity data. Total phosphorus can be predicted for over 22,000 unsampled sites based on satellite data. Given the high costs, in terms of labor and time, of obtaining and subsequently analyzing these water samples, remote sensing may be a plausible and efficient alternative for total phosphorus in Casey Lake.

ACKNOWLEDGEMENTS

The authors would like to thank Professor Ramanathan Sugumaran and Nathan Green for their assistance in this project.

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