Mapping inland lake water quality across the Lower Peninsula of Michigan using Landsat TM imagery

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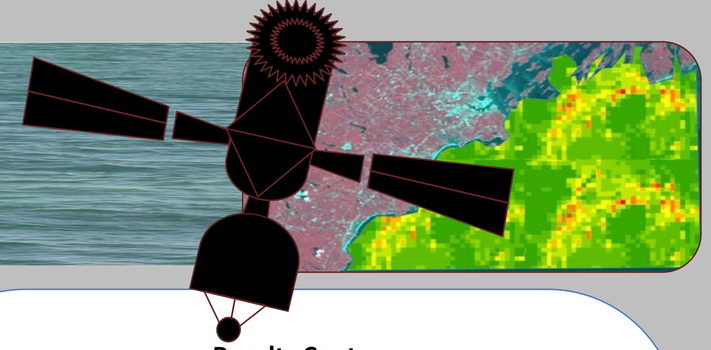
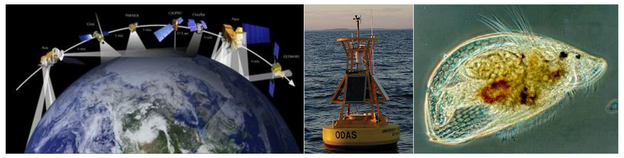


Overview

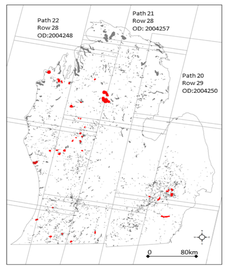
Freshwater quality conditions are under pressure from a range of stressors including land use, pollution, agriculture, and climate change. More than half the world's population lives adjacent to water bodies and carries out activities that increase aquatic stressors such as anthropogenic eutrophication and algal blooms. Pressures on water resources will continue to increase in the future and many studies have recognized declining water quality as one of the most urgent threats to society. However, access to water quality information is limited. Traditional assessment methods are costly and time consuming, limiting the temporal frequency and spatial coverage of these measurements. In addition, scales of existing monitoring strategies do not cover the breadth of temporal and spatial scales to meet demands.

The primary objective of this research application was to 1.) evaluate the ability of Landsat to map nine water quality metrics across diverse lake states over a large geographic area. Follow-on objectives were to 2.) identify the optimal preprocessing routine for this application, 3.) assess whether including landscape pattern metrics in satellite-based water quality models can improve model accuracy and lead to better understanding of the drivers of lake quality, 4.) and to develop a geostatistical approach to map risk uncertainty and hot spot lake regions.

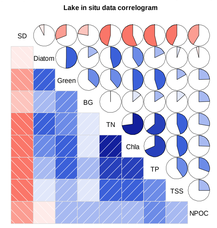


Data

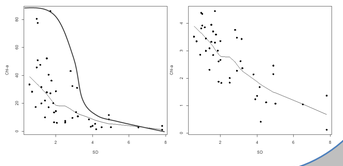
- Landsat 5 TM, 7 ETM+, 8 OLI, and LDCM scale imagery
- 8-day intervals, 30m spatial, 180km swath, broad vis-nir channels



- Map of lakes (>4 hectares) across the Lower Peninsula of Michigan (red shows in situ sampled lakes) and Landsat WRS path row footprints with targeted overpass ("prediction") date.
- Lake water samples and laboratory analyses were carried out for SD, lake depth, light extinction profiles, Dissolved Oxygen, Chl, Total Suspended Solids, Total Nitrogen, Total Phosphorus, Non-Purgable Organic Carbon (NPOC), and phytoplankton types (PFT)
- Correlogram showing relationships among the in situ lake data (blue and clockwise indicate positive relationship with stronger color tone indicating strength).

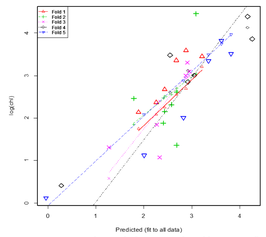


- Secchi Disk vs chlorophyll-a scatterplots (right illustrates log transformed data) show moderately strong relationship (rho: -0.66, p-value<0.000 with lowess line) within the in situ lake data with non-linear trends



Approach & Results

- Target near concordant satellite imagery and field data (+/- 8 days)
- Band ratio regression tested suite of pre-processing routines
- Suite of statistics used to assess model performance (F-stat, adjusted R2, significance values, RMSE, Q-Q plots, Cook's Distance, AIC) along with expert interpretation and logic
- Landscape pattern metrics generated using Fragstats and NLCD
- Moran's I & Local Indicators of Spatial Autocorrelation (LISA) applied to identify "hot spots"



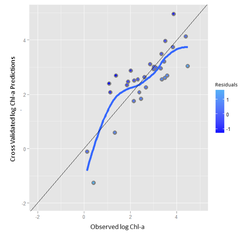
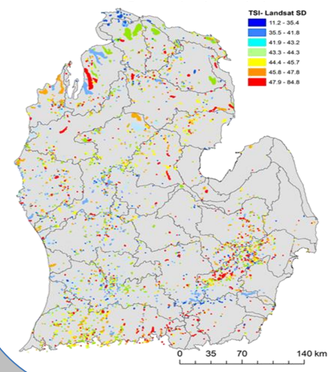


Figure: Example chlorophyll-a n-fold validation (left) used to help determine optimal algorithm. Scatterplot (right) between out of sample predictions and observations for chlorophyll-a concentrations indicating strong relationship (rho:0.80, p-vale<0.000) with rigorous and scalable index across lake states.

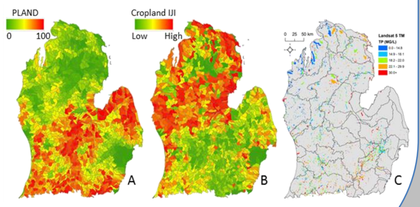
Table: Landsat 5 TM water quality prediction results from multicriteria analysis approach illustrated with DN (brightness) models

Var.	Satellite Model	RS	P-value
sqrt(Secchi)	TM1+TM3	0.82	<0.000
log(Chl)	TM4+TM5+TM3/TM1	0.72	0.001
log(TSS)	TM2+TM3+TM1/TM3	0.35	0.01
log(TP)	TM4+TM1/TM3	0.65	<0.000
log(TN)	TM3+TM3/TM1+TM1/TM2	0.75	<0.000
NPOC	-	-	NS
log(BG)	TM1/TM3	0.37	0.05
Diatom	-	-	NS
log(Green)	TM3/TM1+TM3+TM1 (Spring)	0.66	0.006

- Landsat SD derived Trophic Status Index (TSI) for LP of Michigan displayed by quantile



- Landscape pattern metrics including A.) Cropland Percent of LANDscape (PLAND) and B.) Cropland Interspersion and Juxtaposition (IJI) were significant predictors of C.) Total Phosphorus (MG/L) and chlorophyll-a concentration across the LP of Michigan.



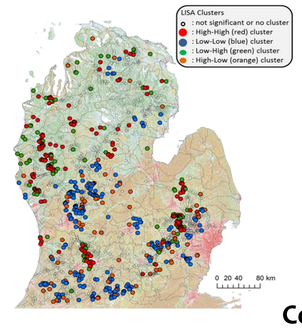
Results Cont.

Table: Summary R2 results for parameter by Landsat processing regime (top) and rank of model preference (bottom).

	Secchi	Chl-a	TSS	TP	TN	NPOC	BG	Diatom	Green
DN	0.56	0.37	0.35	0.54	0.55		0.25		0.55
LEDAPS	0.77	0.41	-	0.48	0.63			0.16	0.26
6S-DOS	0.58	0.21	0.22						
Vol	0.82	0.27		0.47	0.47				0.12
Rad	0.81	0.72	0.37	0.65	0.75		0.37		0.66
	Secchi	Chl-a	TSS	TP	TN	NPOC	BG	Diatom	Green
DN	3	2	2	2	3				2
LEDAPS	5	3		4	2				
6S-DOS	4	5							
Vol	1	4		3	4				
Rad	2	1	1	1	1		1		1

Table: Landscape pattern metrics focused on agricultural, wetland, and urban composition and configuration had some ability to predict lake water quality

Var.	Landscape Model	RS	P-value	Landsat & Landscape Model	RS	P-value
sqrt(Secchi)	CropPLAND+CropIJI+WetPLAND	0.47	<0.000	TM3+TM3/TM1+CropIJI+CropPLAND	0.73	<0.000
log(Chl)	CropPLAND+WetNP+CropNP+CropIJI+Urban	0.62	<0.000	TM3+TM3/TM1+WetNP+CropPLAND+CropIJI+UrbanNP	0.79	<0.000
log(TSS)	CropPLAND+CropIJI+UrbanNP+WetNP	0.37	0.03	TM2+TM3+TM1/TM3+WetNP+CropPLAND+UrbanNP	0.41	0.03
log(TP)	CropPLAND+CropNP+UrbanNP+WetNP	0.61	<0.000	TM3+TM3/TM1+WetNP+CropPLAND+CropNP+UrbanNP	0.76	<0.000
log(TN)	CropPLAND+CropIJI+UrbanNP+WetNP	0.61	<0.000	TM1/TM3+WetPLAND+WetNP+CropPLAND+CropIJI+UrbanNP	0.71	<0.000
NPOC	WetNP+CropPLAND+UrbanNP	0.21	0.06	-	-	NS
log(BG)	-	-	NS	-	-	NS
Diatom	-	-	NS	-	-	NS
log(Green)	-	-	NS	-	-	NS



- Illustrated is hot spot clustering results for mesotrophic lakes based on LISA showing highly variable conditions surrounding the greater metropolitan regions in the southeast and highly variable clusters in the Pere Marquette-White and Muskegon watershed areas.

Conclusions

- Overall, (total) at-sensor radiance generally outperformed the other preprocessing routines according to the multicriteria model selection protocol used in this application
- Of the 4,071 lakes over 4 hectares, approximately two-thirds were identified as mesotrophic (n=2715), with remaining lakes characterized as oligotrophic (23%, n=959), eutrophic (8%, n=346), and hypereutrophic (1%, n=51)
- Landsat radiance models had significant, although relatively weak (R2:0.37), ability to directly map cyanobacteria (BG); cyanobacteria biovolume was primarily made up of Anabaena and Lyngbya followed by Aphanocapsa, Gomphosphaeria, Microcystis, and Oscillatoria
- Inclusion of landscape pattern metrics helps to improve predictive models of water quality
- NPOC and diatom attributes were more challenging to accurately map using Landsat TM