Research and Monitoring of Lake Water Quality Using Remote Sensing

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WISCONSIN DEPT. OF NATURAL RESOURCES

USGS science for a changing world

Citizen Lake Monitoring Network

Outline

1. Annual Satellite Monitoring of Inland Lake Water Clarity
   - Concepts and Procedure
   - Some initial findings
2. Current Collaboration with UW-Madison
   - Landscape and Climate Effects on Lake Water Clarity
3. New Remote Sensing Research

Lakes in Wisconsin

- Between 9,000 - 15,000 lakes in WI
  - Unique in morphometry, chemistry, aquatic community, size and landscape structure of watershed.
- Important resource for state and local economy
- Monitoring lake health is integral to long term sustainability

Public Trust Doctrine

- WI lakes and streams are held in public trust
  - Originally meant protecting public rights to transportation on navigable waterways
  - Supreme Court broadened to include public rights to “water quality and quantity, recreational activities, and scenic beauty.”
  - DNR responsible for protecting this public resource which includes monitoring health of all waterbodies in WI

Monitoring Lake Water Quality

- Water quality monitoring is expensive
  - Transportation/vehicle costs
  - Salary
  - Lab supplies/shipping costs/analysis
- Approach 1: Citizen Lake Monitoring Network
  - Started in 1986 with 126 lakes; grown to over 850 lakes and >1100 volunteers
  - Collect data on water chemistry, clarity, and invasive species.
  - Water clarity is the easiest and most common water quality measurement collected.

Monitoring Lake Water Quality

- Approach 2: Water Quality Monitoring through Satellite Remote Sensing
- Advantages
  - Large spatial coverage (Landsat 185 km x 185 km)
  - Continuity of historical records (40 years of Landsat)
  - Simultaneous sampling of many lakes
  - Cheap (< $1/lake)

Monitoring Lake Water Quality

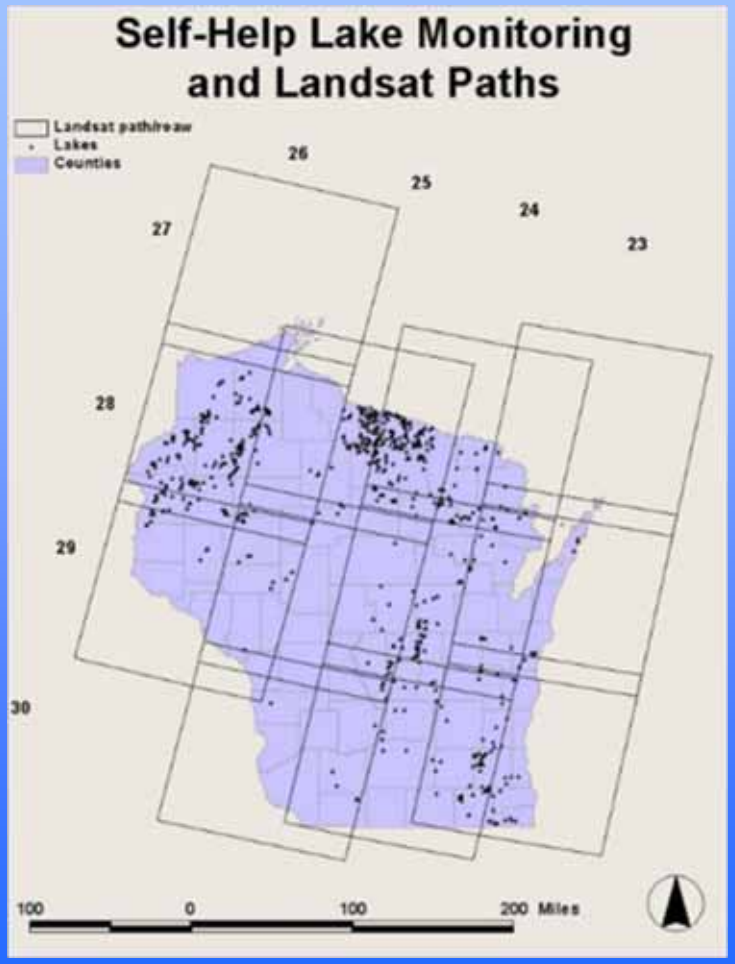
- Approach 2: Water Quality Monitoring through Satellite Remote Sensing
- Disadvantages:
  - Freshwater is complex mixture of algae, suspended solids, color… Not all constituents can be monitored
  - Shallow/very small lakes <5 acres can't be monitored.
  - Dynamic water quality changes, spatial heterogeneity in large lakes
  - Cloud cover/haze prevent some images from being used

Satellite Monitoring of Lake Water Clarity

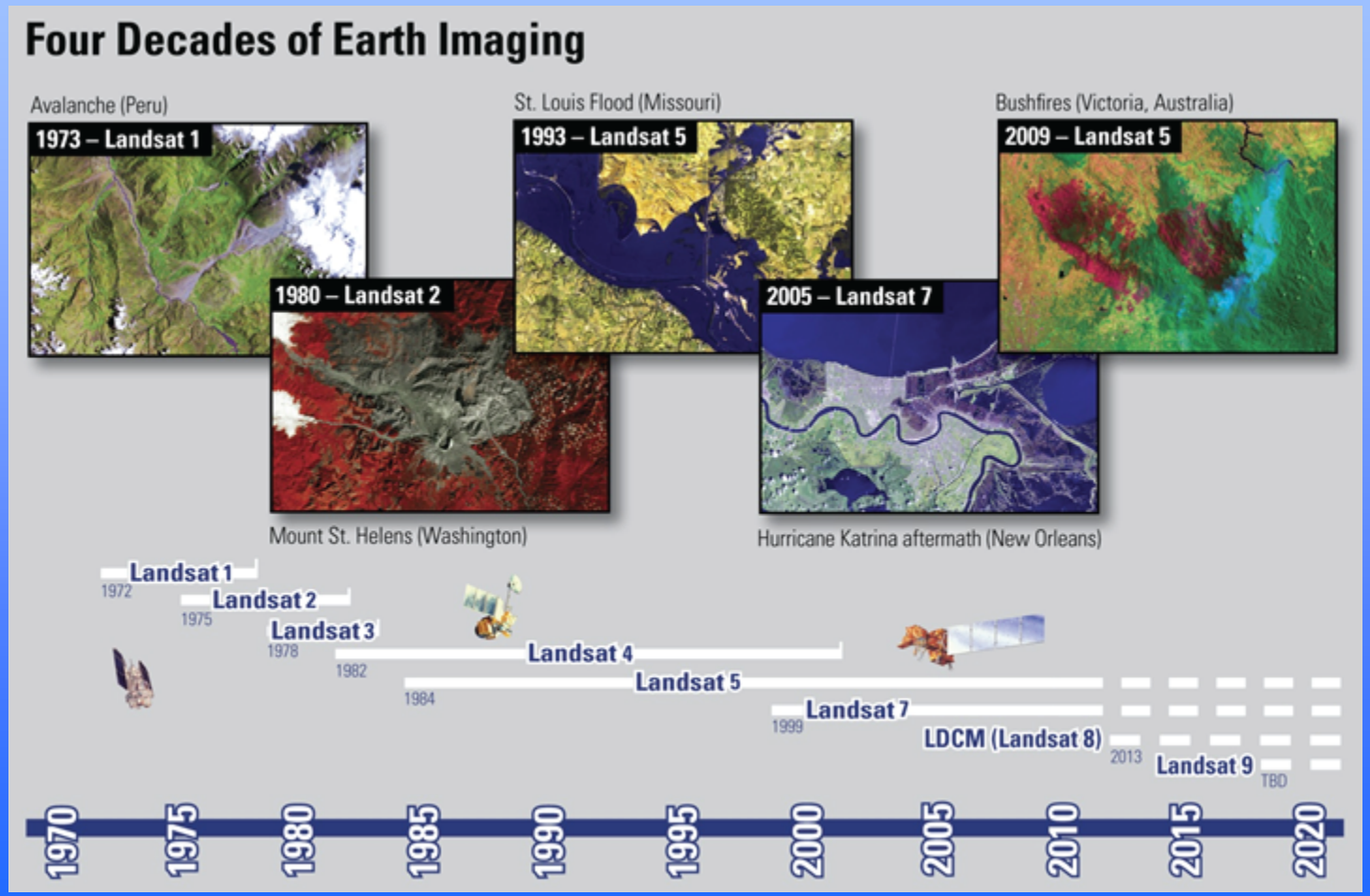
- WDNR successfully monitored inland lake water clarity using Landsat satellite imagery annually since 2003.
- Program relies heavily on participation by the Citizen Lake Monitoring Program volunteers.
- Secchi disk is a simple yet very important monitoring tool to measure water clarity.

Satellite Monitoring of Lake Water Clarity Procedure

- Landsat 5 and 7 both used.
  - 12 scenes required to cover the entire state
  - Satellites pass over every 16 days
  - Volunteers asked to collect secchi disk transparency (SDT) depths on or close to overpass date
  - Cloud/haze in a scene can be a problem

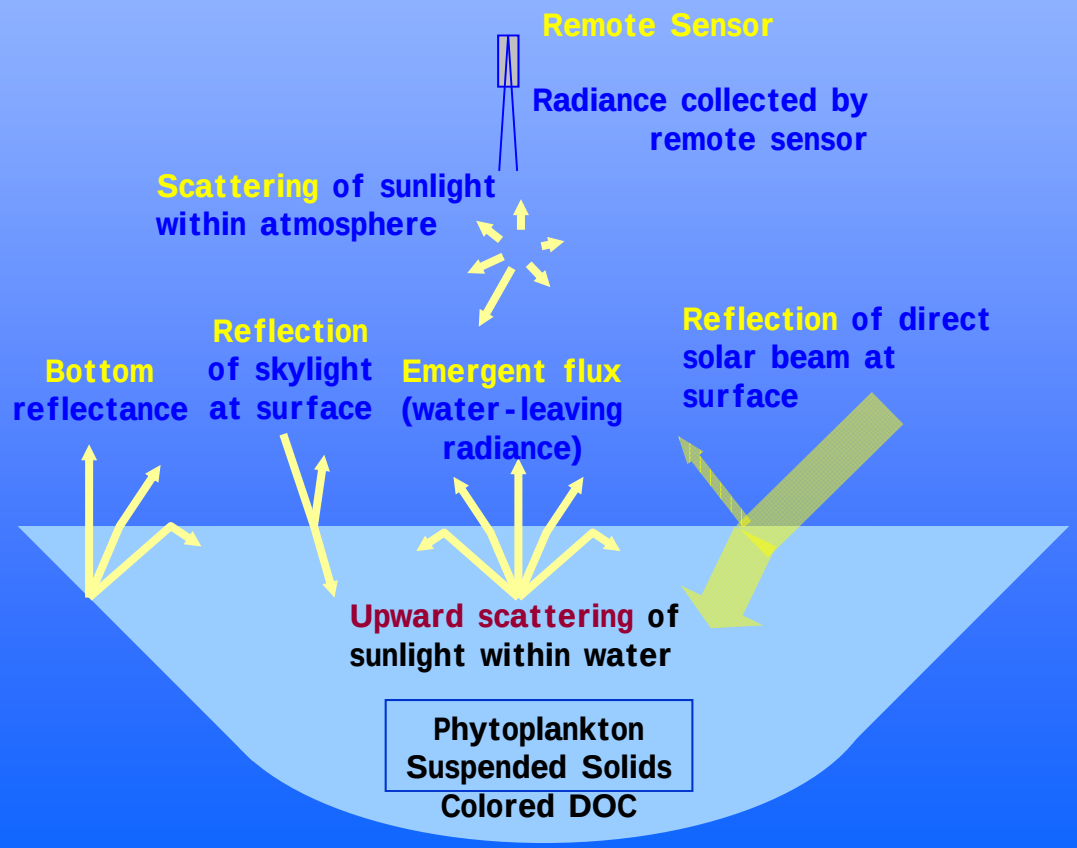


Satellite Monitoring of Lake Water Clarity Procedure: Landsat Satellites

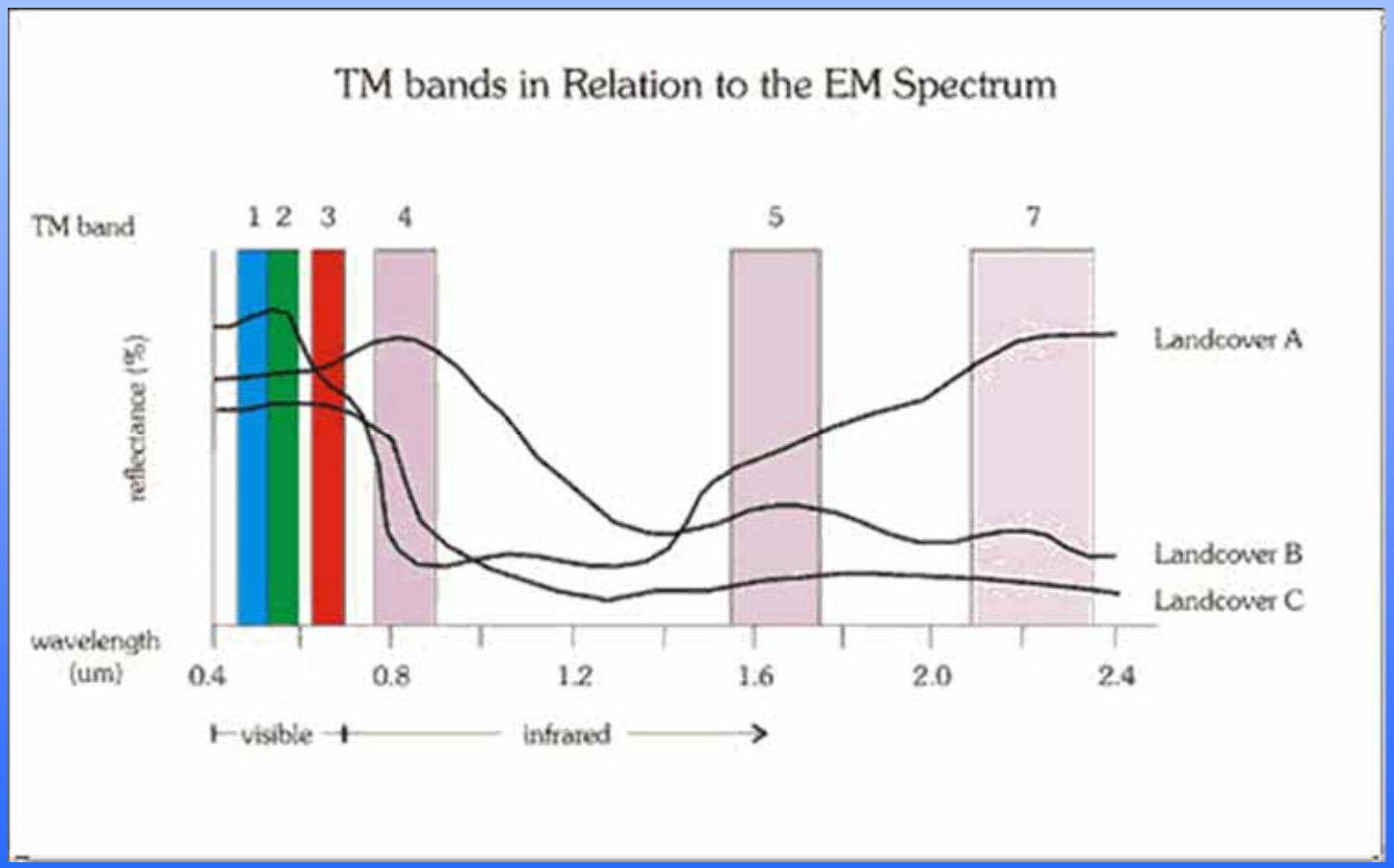


Important Concepts of Remote Sensing

- Sensors collect “radiance” or “brightness” values reflected off the landscape.



Landsat Bands

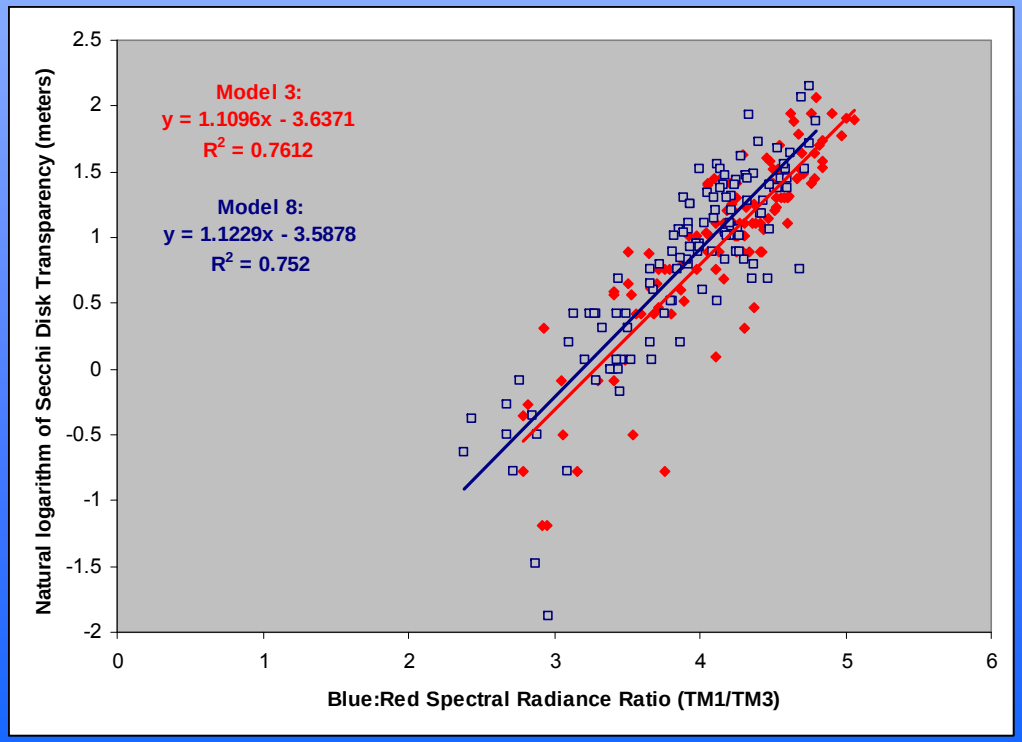


http://www.satelliteimpressions.com/landsat.html

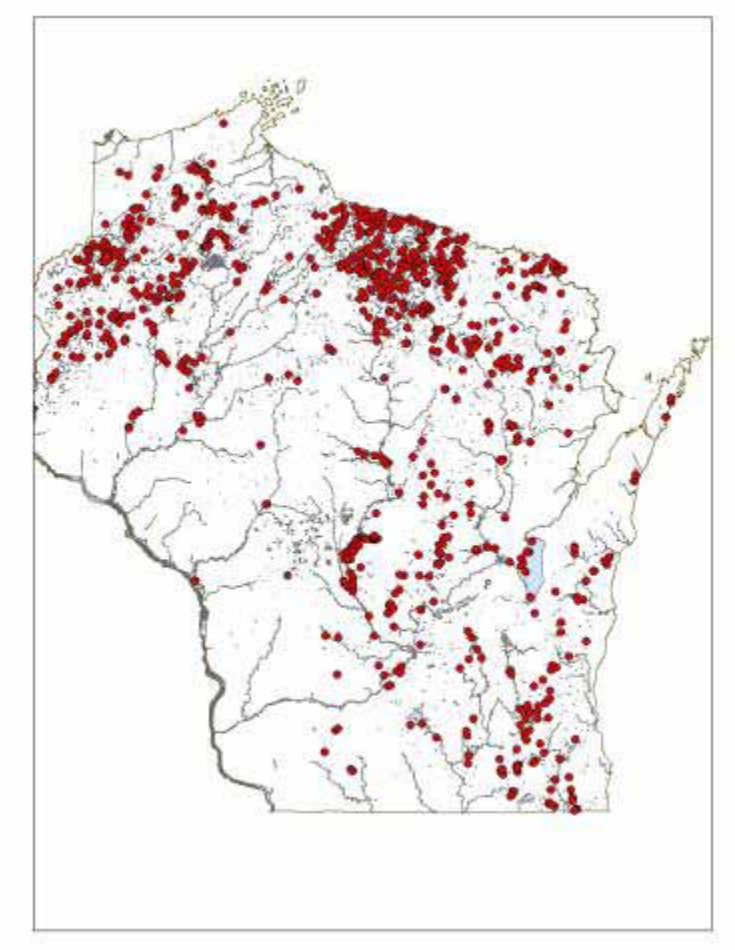
Multiple regression is used to relate the field observations and the image data:

$$\ln(\text{Secchi}) = b_0 + b_1\left(\frac{TM1}{TM3}\right) + b_2(TM1)$$

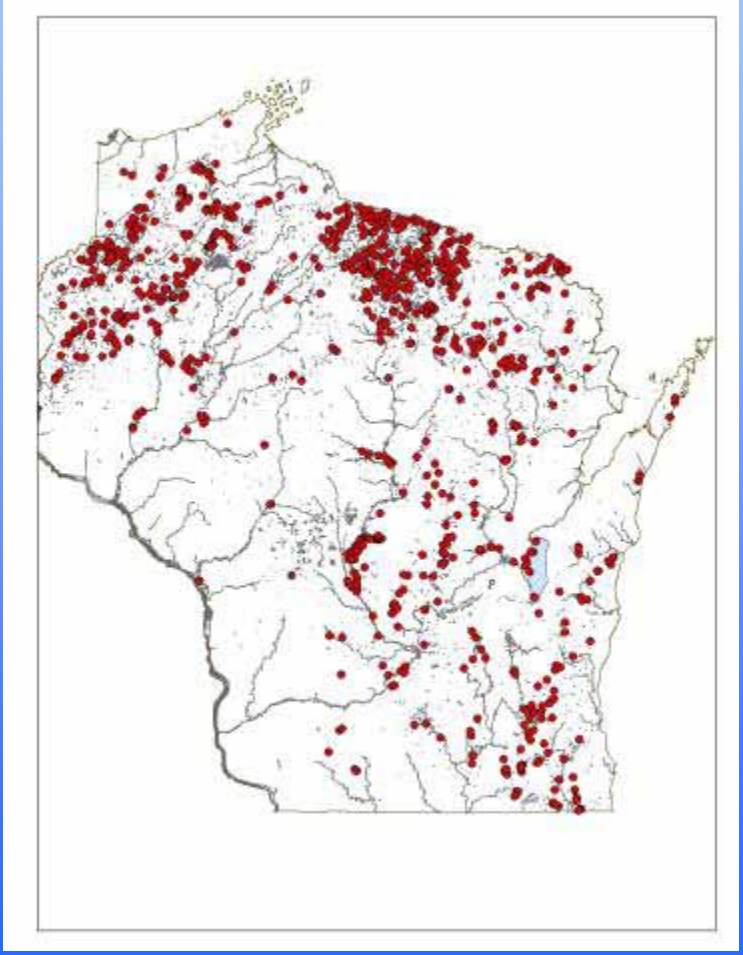
with the most important parameter being the TM1/TM3 ratio (blue/red ratio):

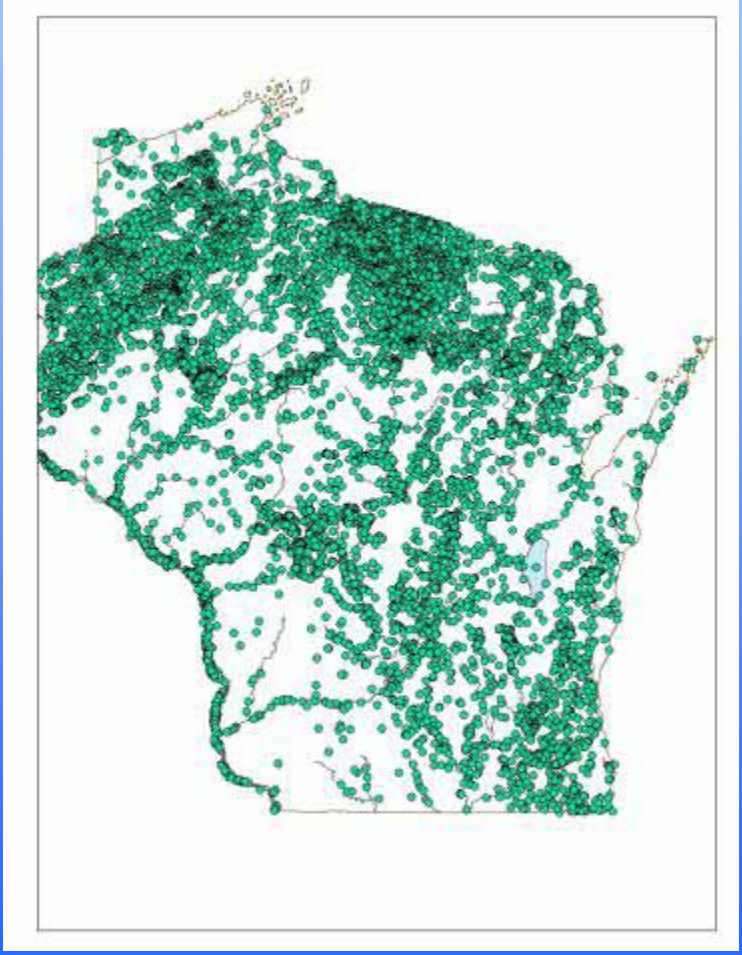


Lakes with Water Clarity Data



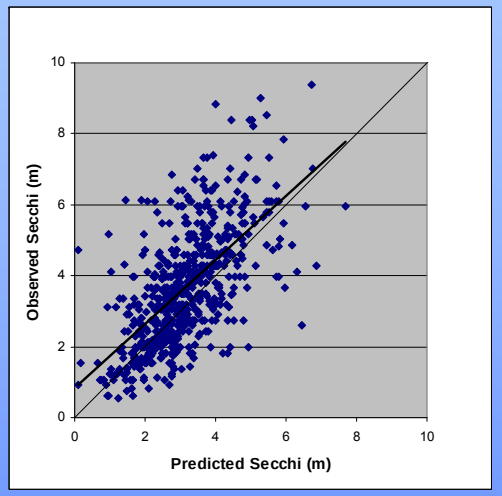
Lakes with Water Clarity Data

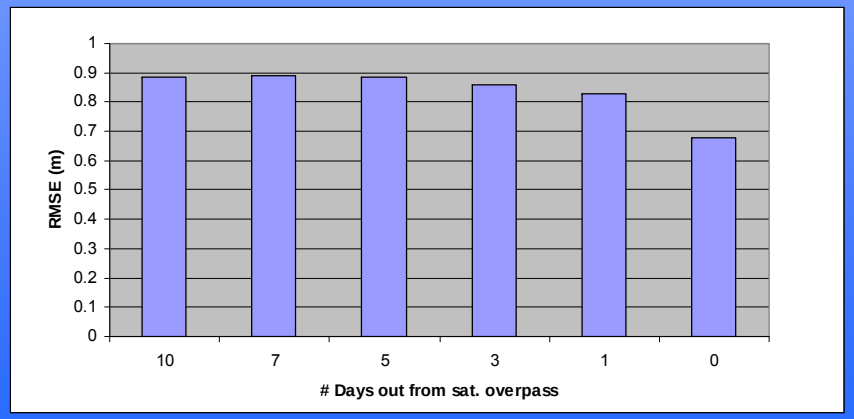




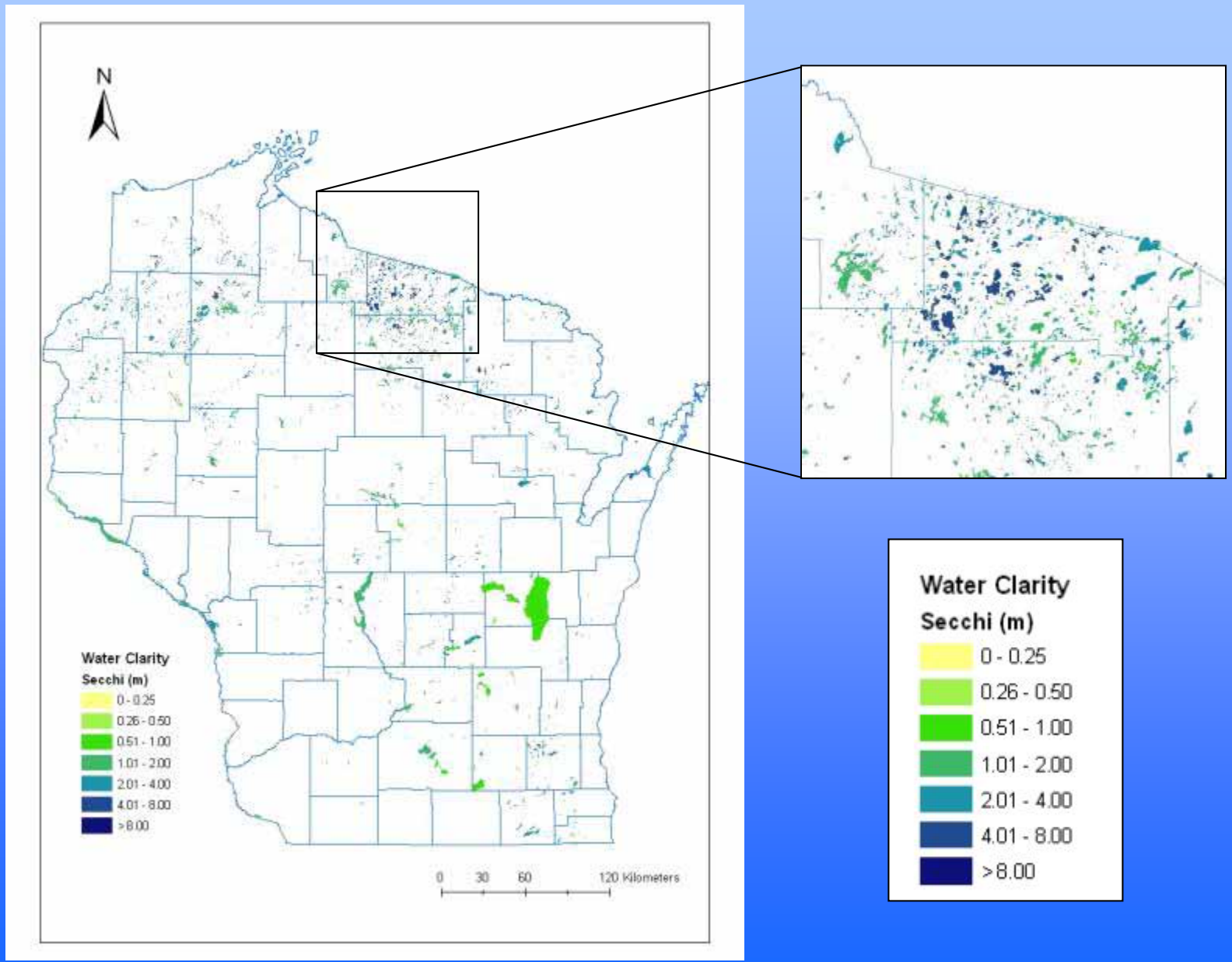
Lakes with Water Clarity Data

- Annually, generate estimates for 6000-8000 lakes, with ~800 *in situ* measurements.
- Accuracy best when *in situ* measurements taken on day of satellite overpass, but measurements ±10 days are acceptable.



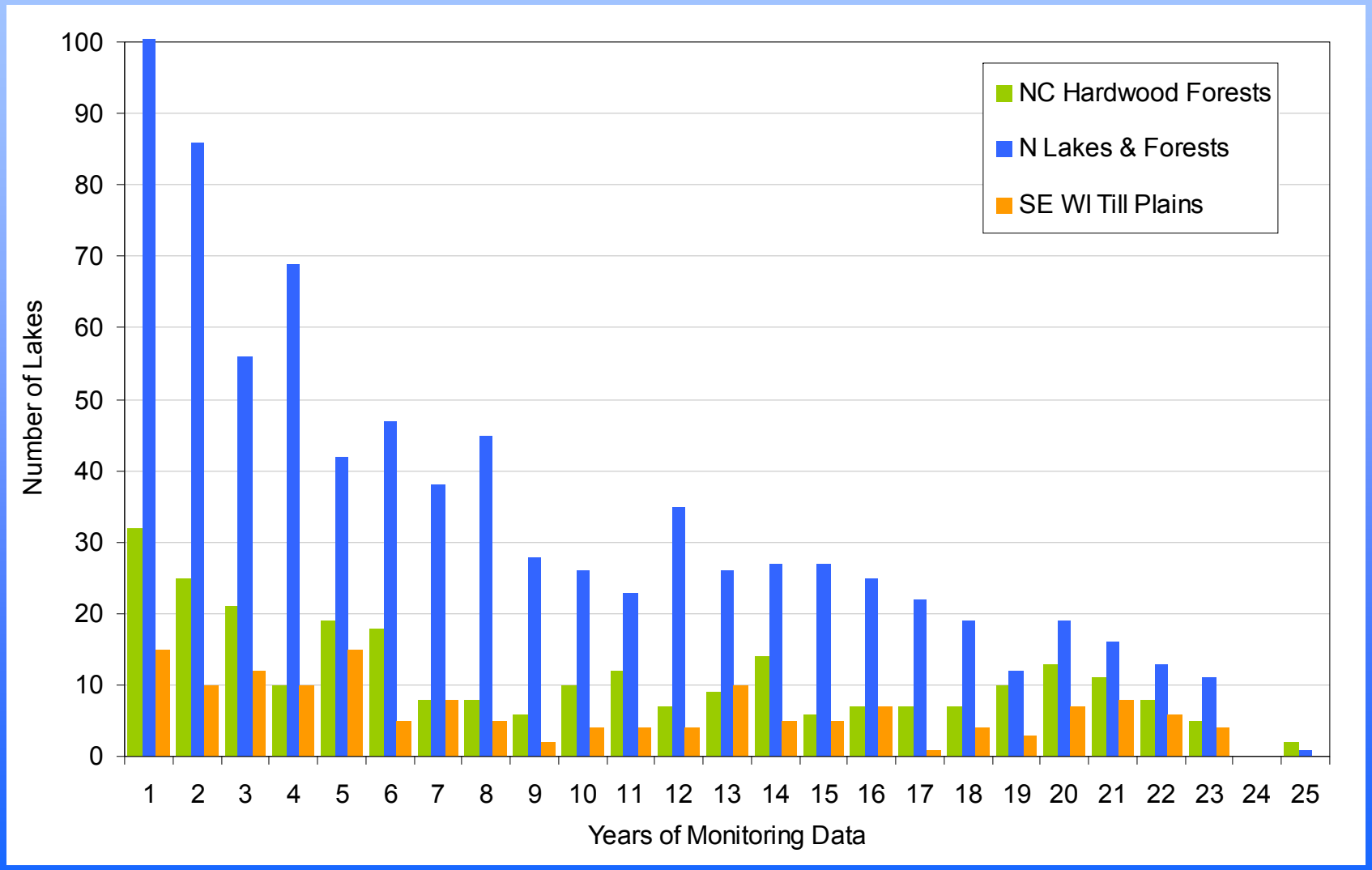


Statewide Lake Water Clarity Map



2010

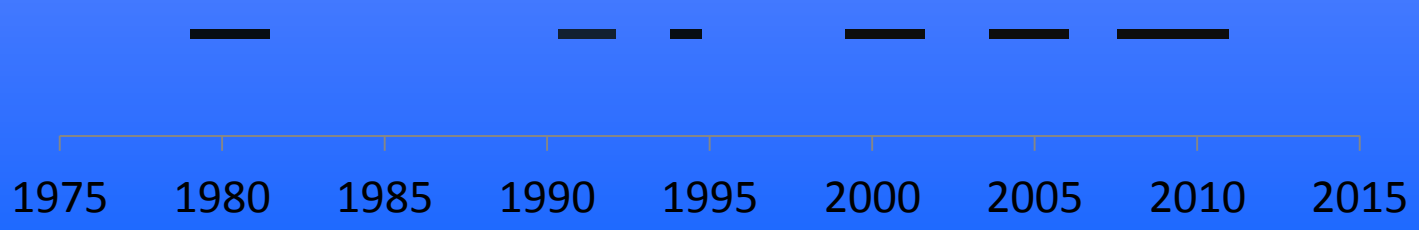
Lake Water Clarity Database



Lake Water Clarity Database

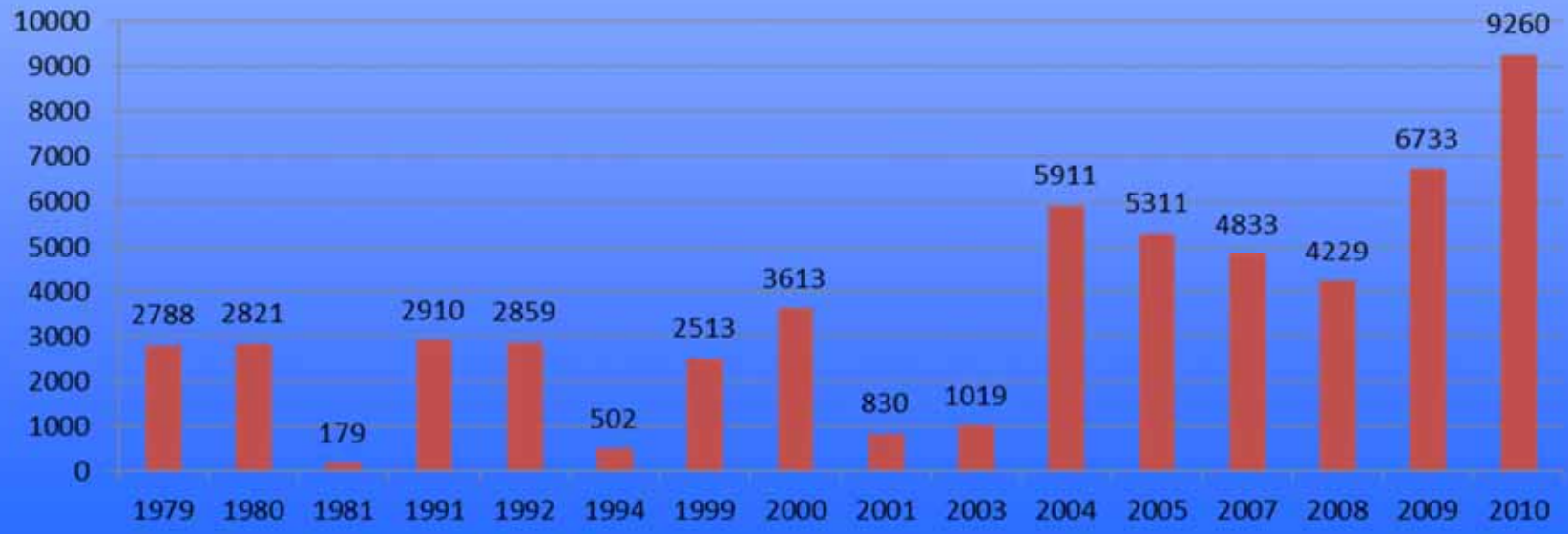
Years when satellite data was collected/processed

1979	2001
1980	2003
1981	2004
1991	2005
1992	2007
1994	2008
1999	2009
2000	2010



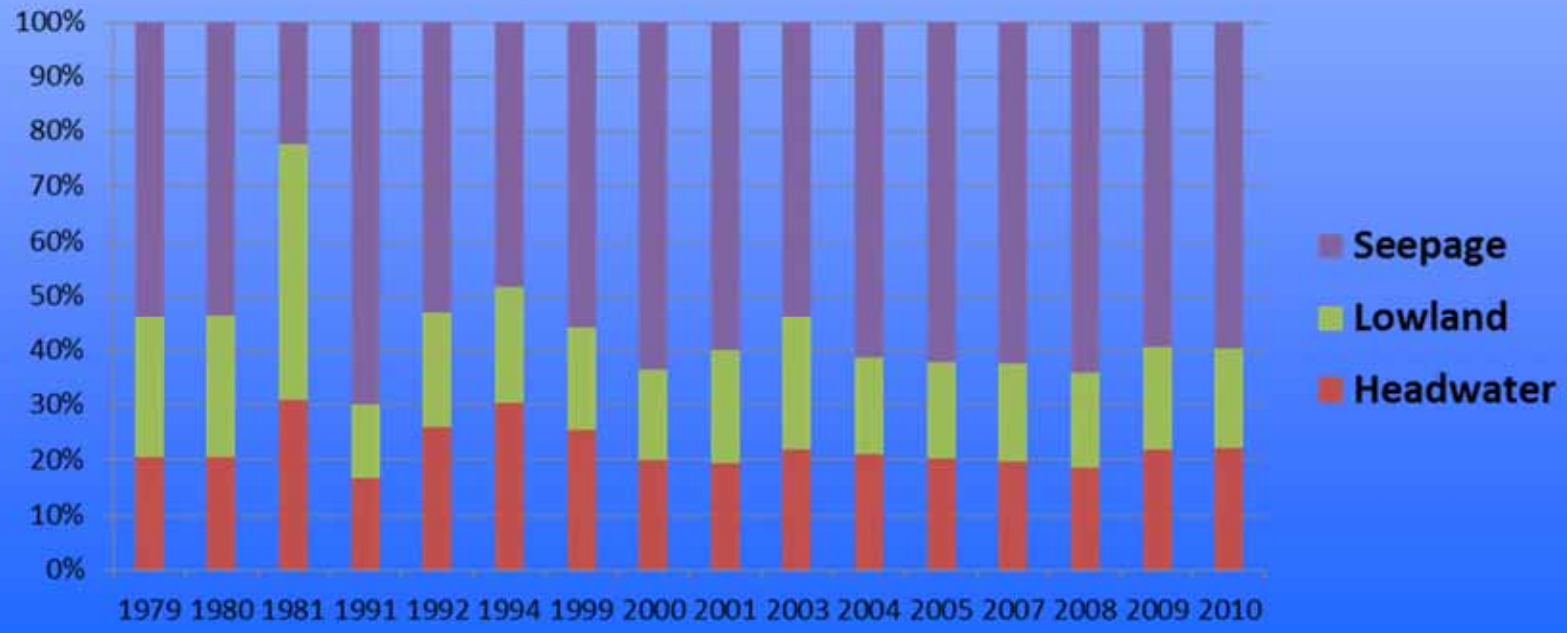
Lake Water Clarity Database

Number of Lakes with Water Clarity Measurements Estimated by Satellite



Lake Water Clarity Database

Lake Types with Water Clarity Measurements Estimated by Satellite



Trend Analysis Approach

Annual (summer) mean for each lake (One value for each year for each lake)

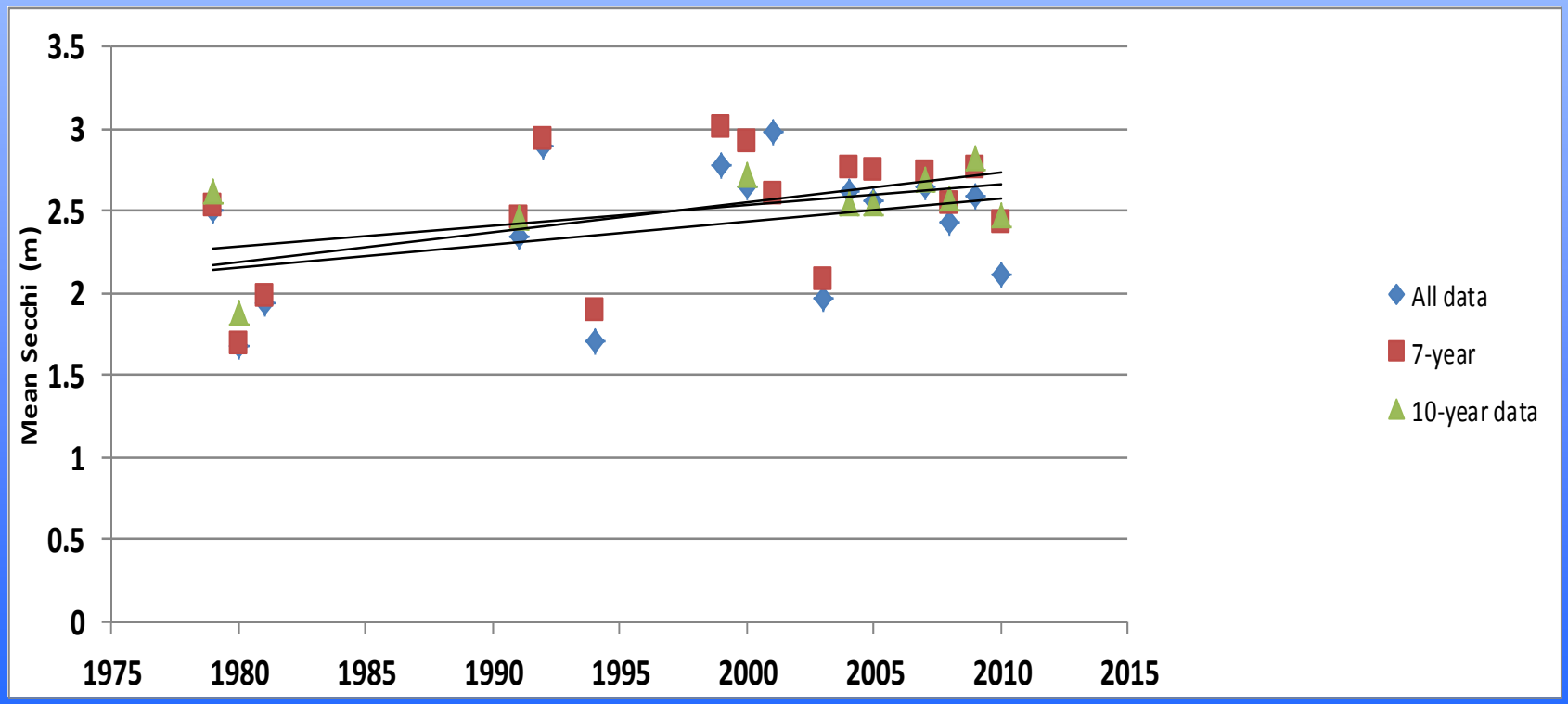
Three data sets

- All data, all years (n= 179 to 9200)
- Only lakes with 7 yr. record (any 7+ of 16 yrs, w/ one before 1985 and one after 2005. n≈3483)
- Only lakes with data for each of 10 specified yrs. (n=430)
- Additional subcategories i.e. Depth, Lake class, position

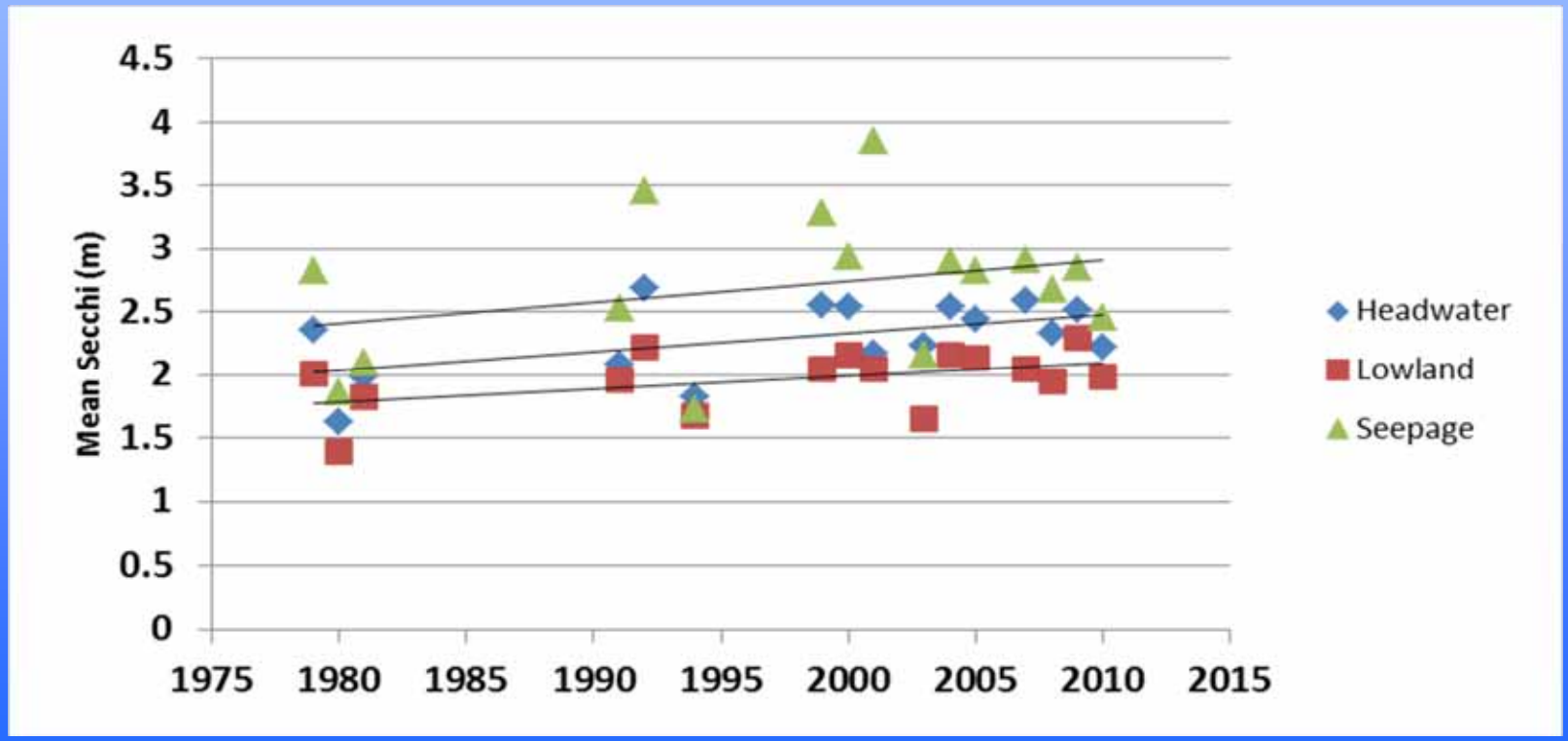
Statistical Analysis

- Regression
- Mixed effects model

Trends in Estimate Water Clarity

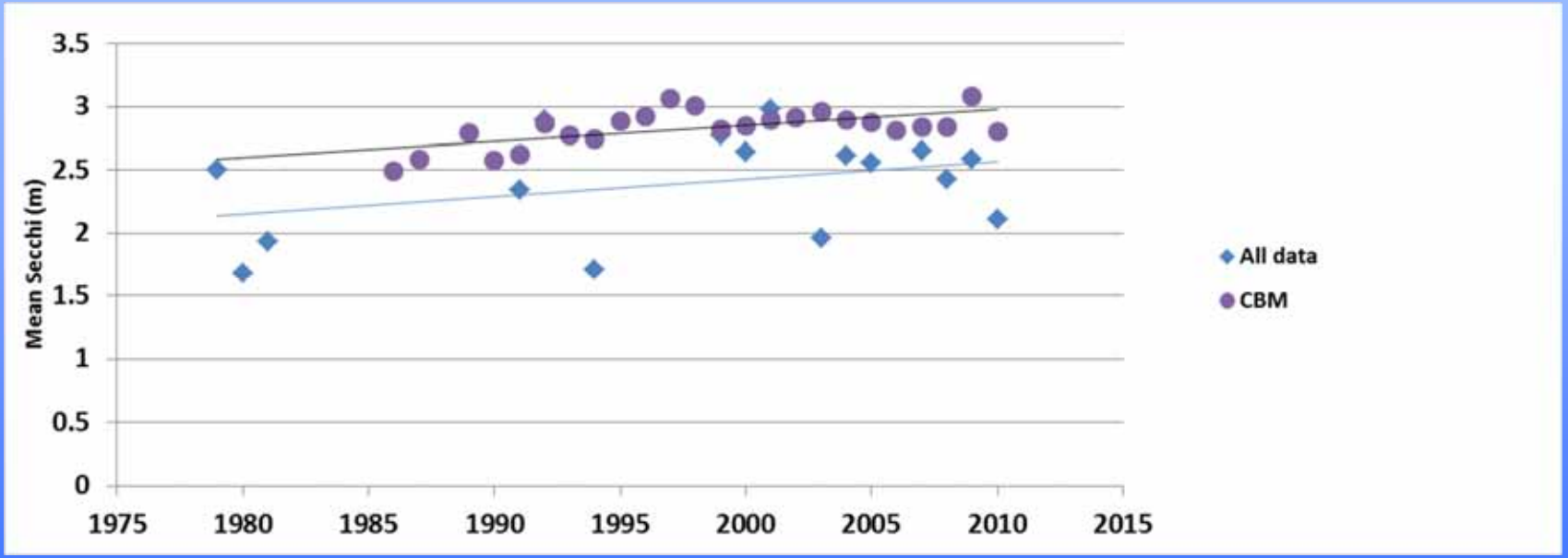


Trends in Estimated Water Clarity Categories = Lake Position



Trends in Estimated Water Clarity with CBM *in situ* Data

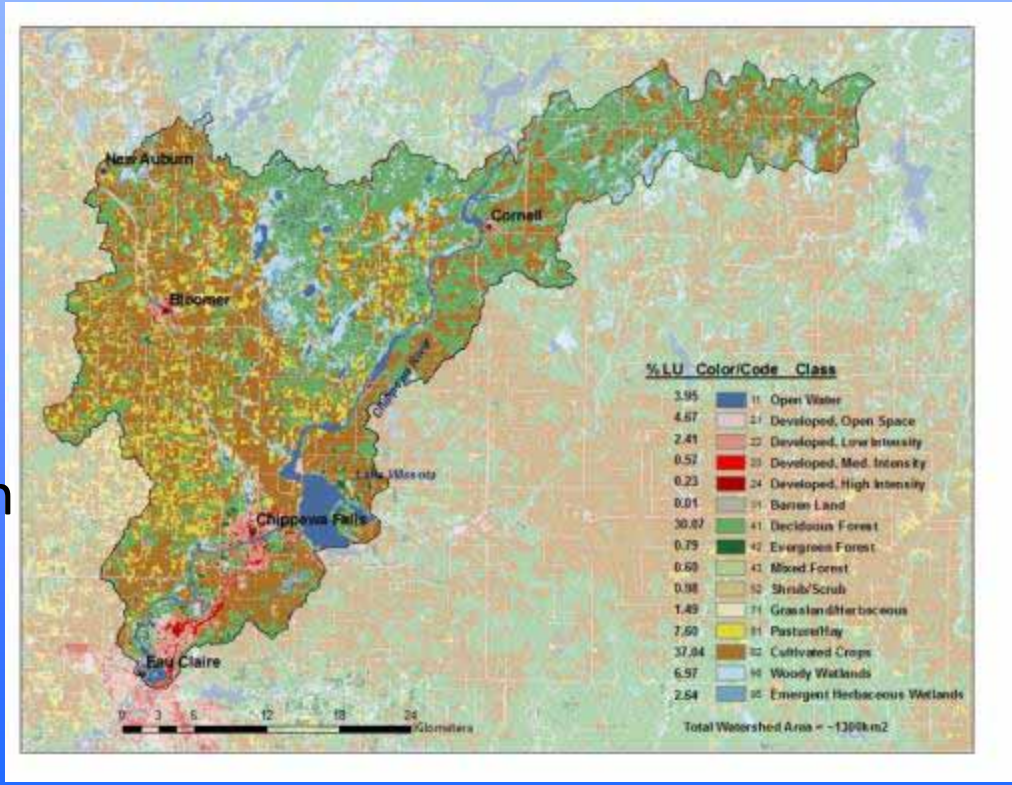
23 Lakes with 24 Years of Data



Positive Trends in water clarity over the 30 year record (0.7-1.5cm/yr), independent of lake type.

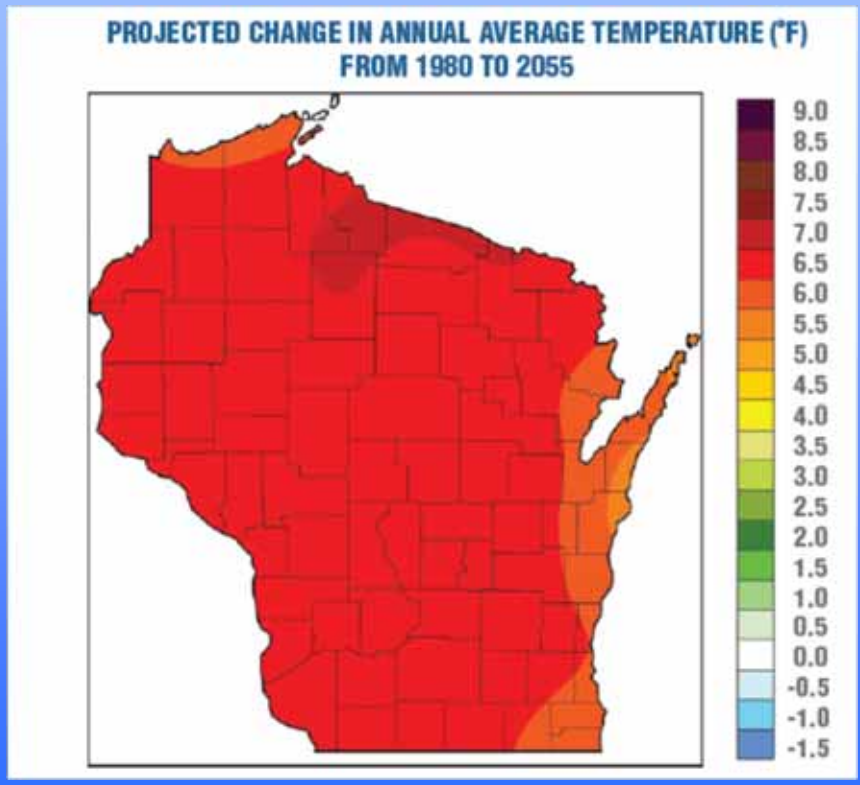
Landscape and Climate Impacts on Lakes

- Many in-lake and landscape conditions affect lake water quality.
  - Land Use Land Cover (LULC)
  - Size of watershed
  - Lake landscape position
  - Lake morphometry



Landscape and Climate Impacts on Lakes

- Climate change will also have an effect.
  - Increased temp, especially in N. WI
  - Increased frequency of high intensity storm events, but no increase in ave. annual precip.



Wisconsin's Changing Climate: Impacts and Adaptation. 2011. Nelson Institute for Environmental Studies, University of Wisconsin-Madison, and the Wisconsin Department of Natural Resources, Madison, Wisconsin.

New Collaboration with UW-Madison

- PhD project in Landscape Ecology Lab, Dr. Monica Turner, Zoology Dept, UW-Madison.
- Thesis (working) title: *Using Satellite Remote Sensing to Develop Predictive Models of Lake Water Clarity: Investigating Driver Interactions and Impacts of Climate Change*

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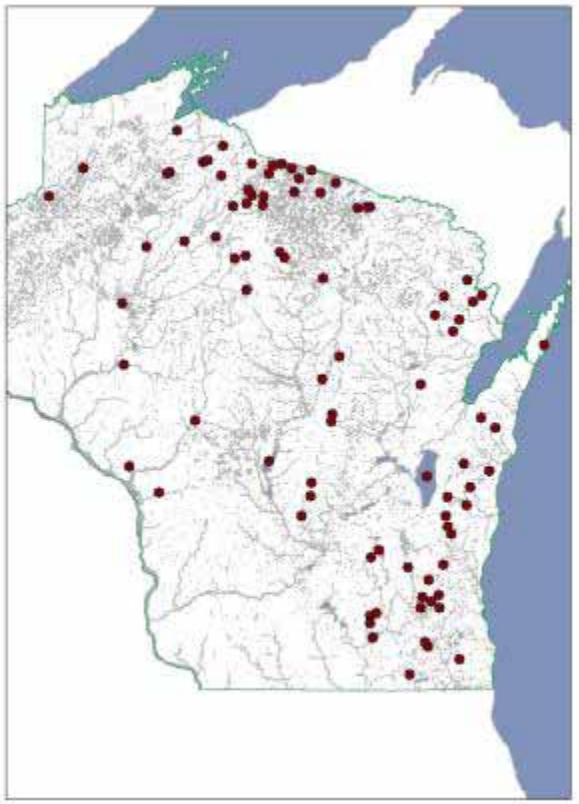
New Collaboration with UW-Madison: Goals

- Explore and understand entire 30 year database of satellite clarity estimates
- Investigate trends, landscape influences, and ultimately climate drivers that may impact lake clarity in WI in the future.
- Year 1 of Project
  - Exploratory data phase of satellite estimates
  - Subset of 90 lakes (data from1999-2010)

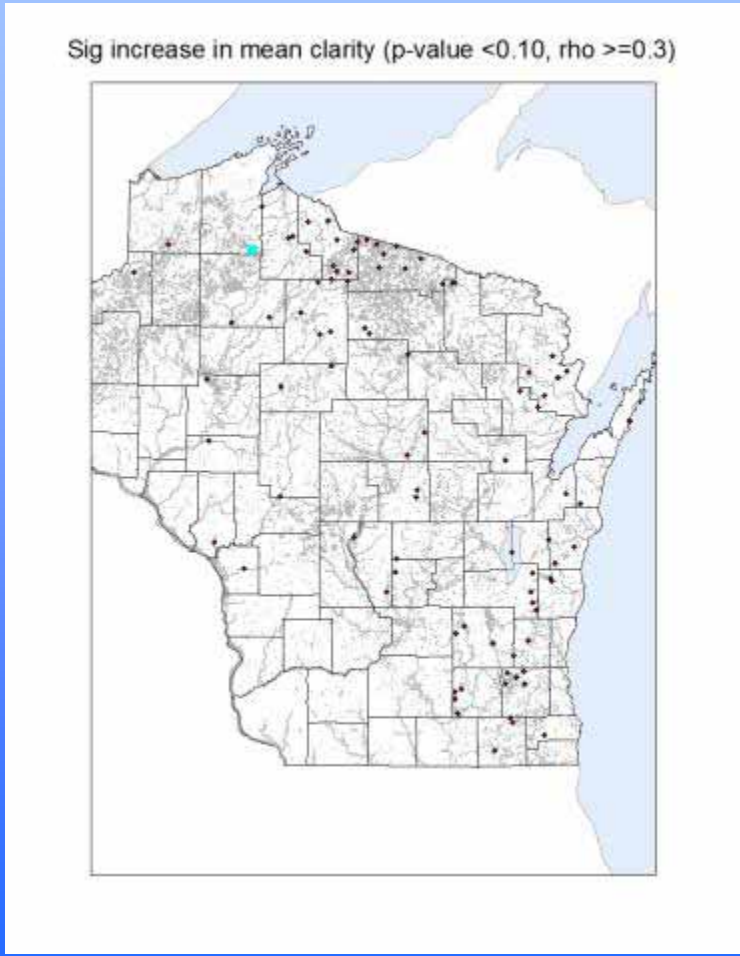
New Collaboration with UW-Madison: Analysis

- Analysis:
  - 90 lakes, >6 yrs of data
  - Clarity trends and interannual variability of individual lakes
  - Categorized by lake type, depth class, and lake size



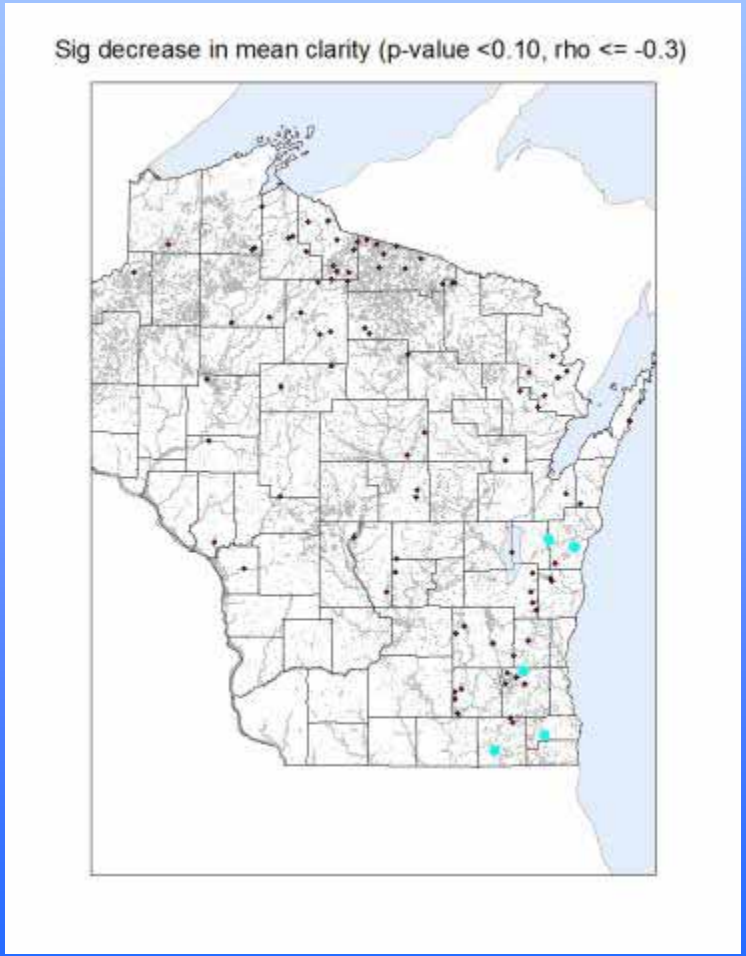
New Collaboration with UW-Madison: Init. Results

- Preliminary results:
  - Most lakes showed no significant change in clarity (99-10)
  - 1 lake showed increase in clarity
    - N. WI headwater lake
    - Ghost Lake, Bayfield Co.
    - Size: 136 acres
    - Max depth: 27 ft.



New Collaboration with UW-Madison: Init. Results

- Preliminary results:
  - 5 lakes showed decrease in clarity
    - SE WI lakes; Drainage, Seepage, Impoundment
    - English Lake(Manitowoc Co.)
    - Bullhead Lake(Manitowoc Co.)
    - Eagle Lake(Racine Co.)
    - Delavan Lake(Walworth Co.)
    - Lake Keesus(Waukesha Co.)



New Collaboration with UW-Madison: Init. Results

- Preliminary results:
  - Clarity differed by lake type
    - Seepage > Drainage or Impoundments
    - Seepage and Headwater > Drainage lakes
  - Clarity and variability differed by depth
    - Deepest lakes were most clear and least variable
  - No differences by size class

New Collaboration with UW-Madison: Init. Results

- Preliminary analysis (landscape vars):
  - Correlations between secchi depth and LULC, topography, soils, elevation
- Sig. Correlations:
- LULC (watershed)
  - % Forest (pos)
  - % Grassland (neg)
- Topo/Geographic
  - Relative Elev. (neg)
  - Soil erodability (neg)
  - Catchment Area:Lake Area (neg)
  - Max depth (pos)

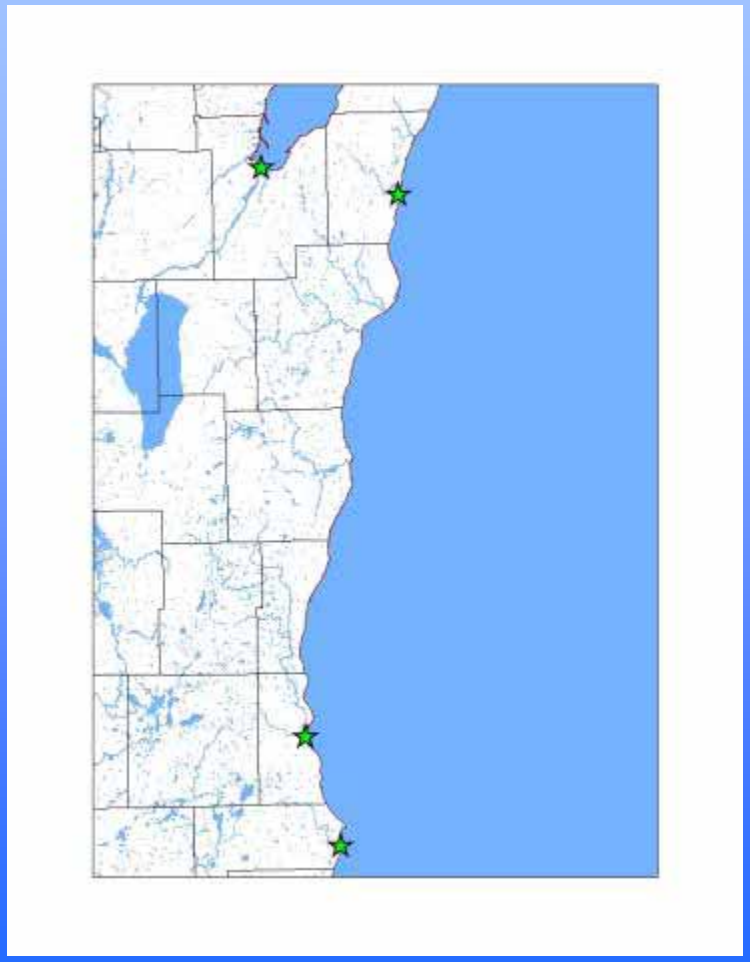
Other Remote Sensing Projects

- Evaluation of Areas of Concern (AOC) Water Quality using Satellite Remote Sensing: A Pilot Study
  - Goal: Evaluate feasibility of satellite remote sensing for the evaluation of water quality in WI AOC harbors.
  - 2 satellite sensors evaluated: Landsat and Worldview-2

AOC Water Quality

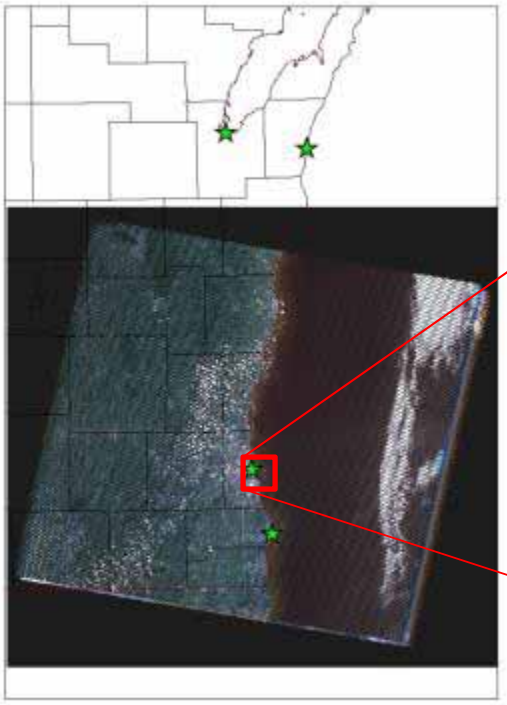
- While substantial amount of water quality data exist for AOCs, comprehensive data sets often not available.
- Satellite RS can provide spatial data on WQ concentrations across large scales.
  - Potential for using this data to gather info on sediment loads and fluxes, sedimentation rates and productivity.

AOC Water Quality



AOC Water Quality

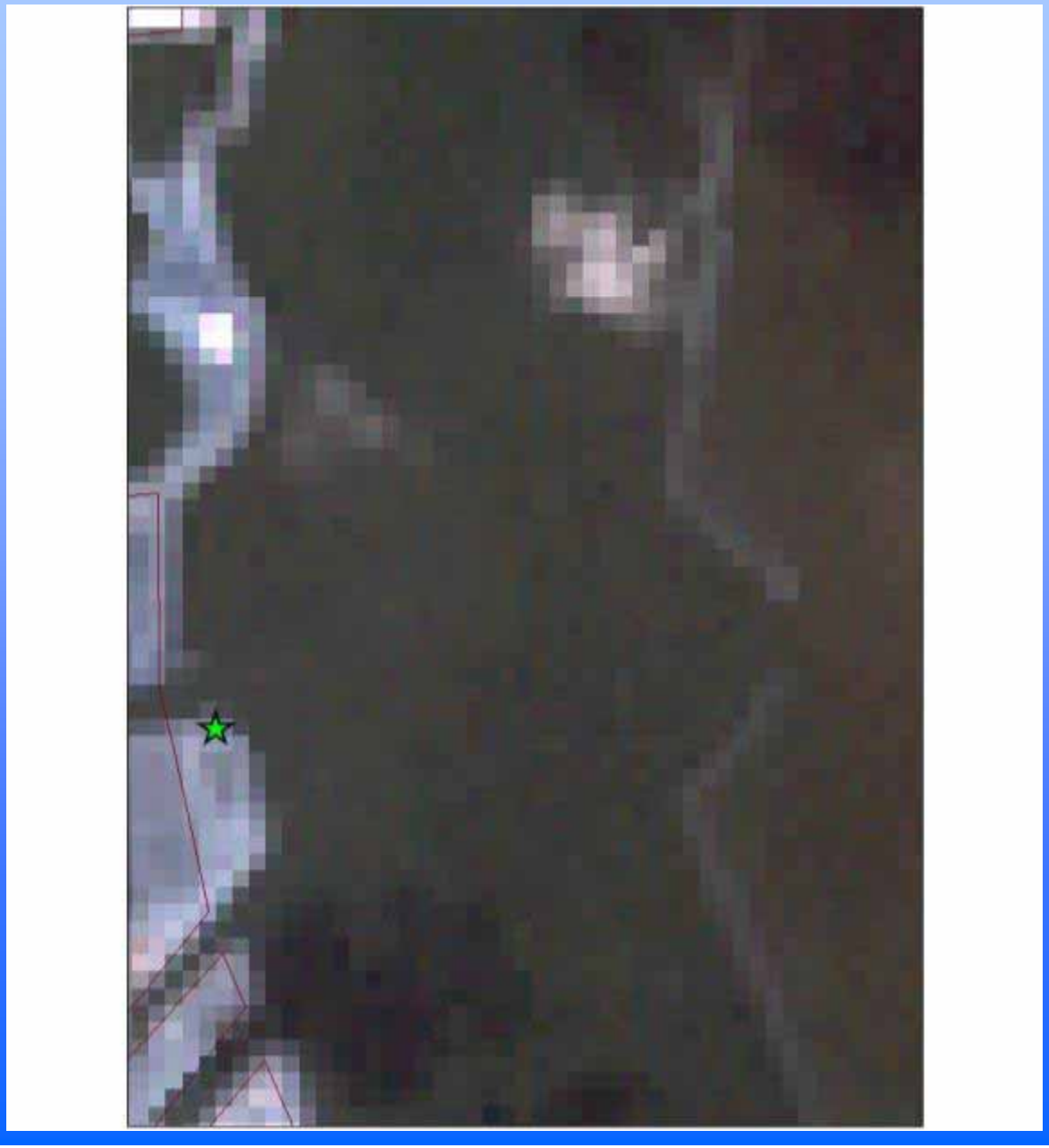
Landsat 7



Worldview-2

Worldview-2

Landsat 7



AOC Water Quality

Landsat 7

- 30m resolution
- Overpass every 16 days
- Free imagery-USGS
- Water quality products:
  - Water clarity

Worldview-2

- ~2m resolution
- Overpass ever 1.1 days
- Expensive imagery >>$1000
- Water quality products (expected):
  - Chl *a*
  - CDOM
  - Suspended solids

AOC Water Quality

Landsat 7 imagery task

- Using existing water clarity relationships developed for inland lakes to estimate clarity values for pixels within and near study sites.
- Collect field secchi disk measurements near overpass dates to test estimates.

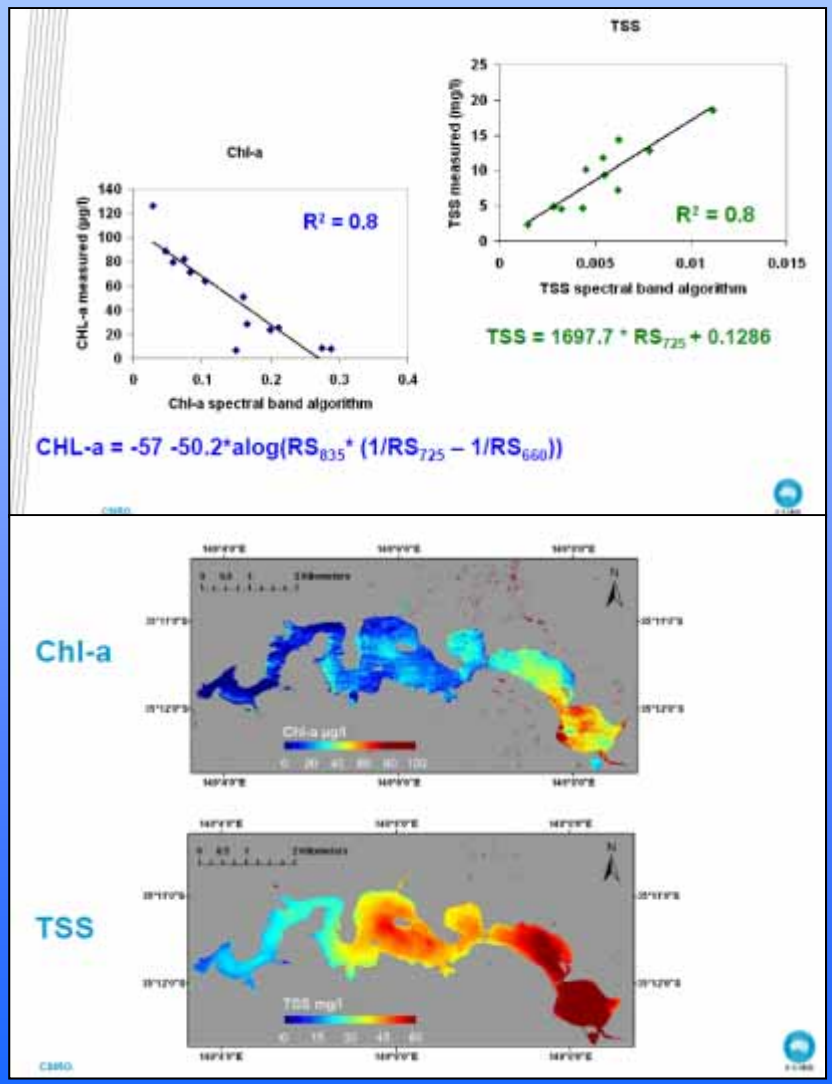
Worldview-2 imagery task

- Request window of collection dates from commercial provider
- Within 48 hours of notification of imagery acquisition, visit AOC and reference sites by boat to collect water samples, physical parameters, and light conditions.

AOC Water Quality

Worldview-2 imagery task

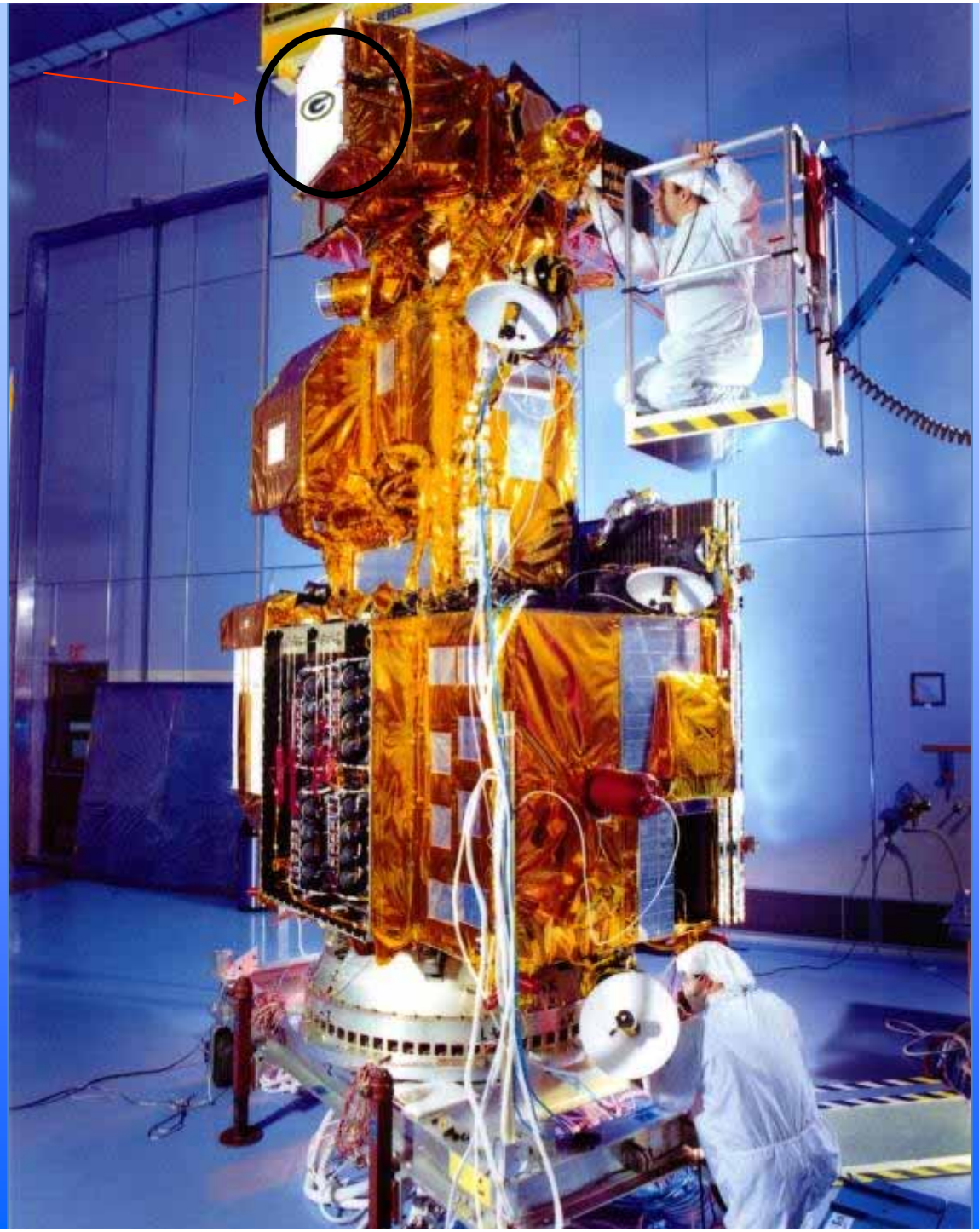
- Submit samples to State Lab of Hygiene (SLOH) for chemical analysis.
- Develop algorithms for Worldview-2 images
- Colleagues in AU have shown good success developing algorithms and concentration maps for chl *a* and TSS

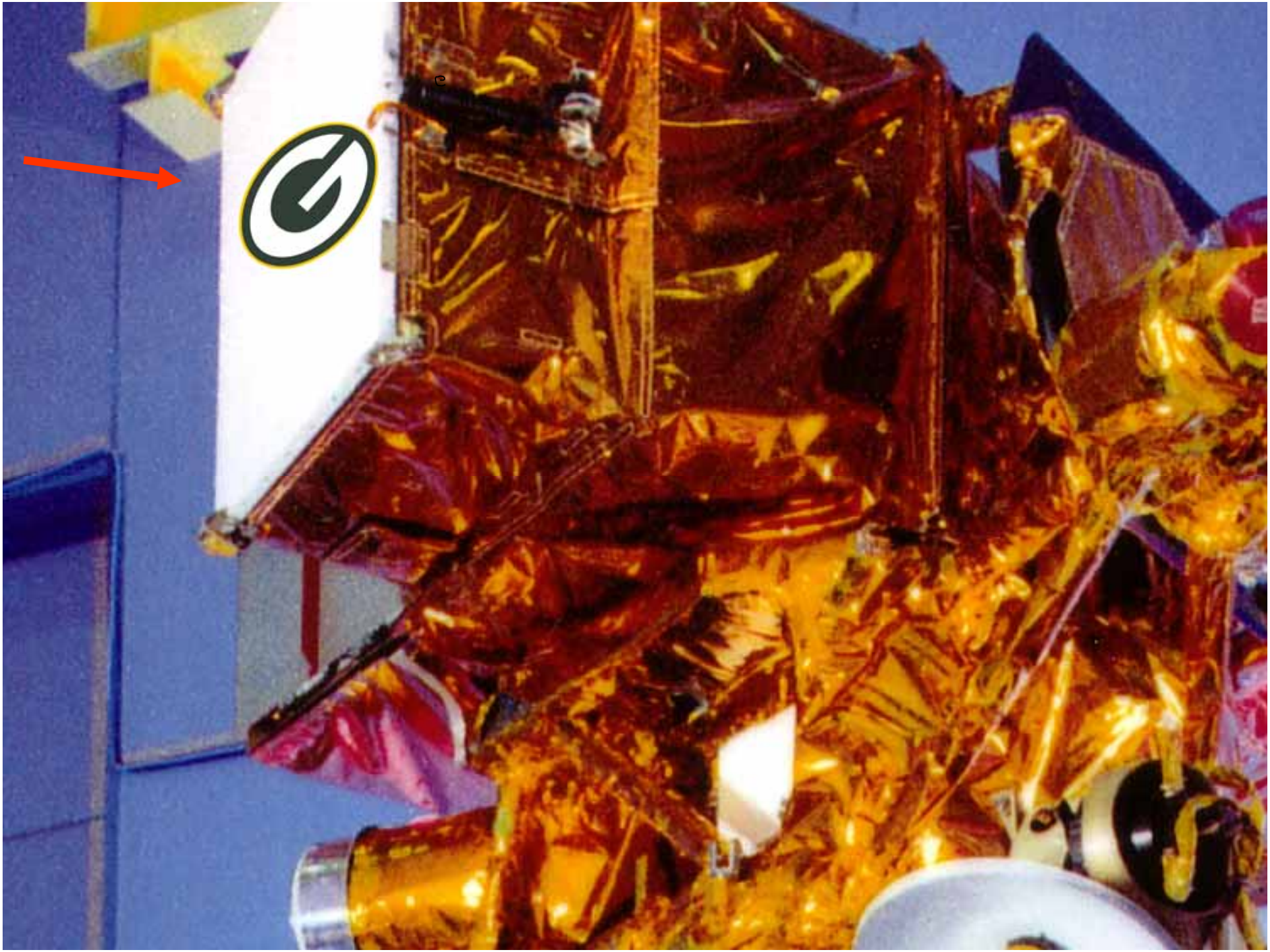


Dr. Tim Malthus, Environmental Earth Observation Group, CSIRO Land and Water; http://www.csiro.au/org/CLW.html

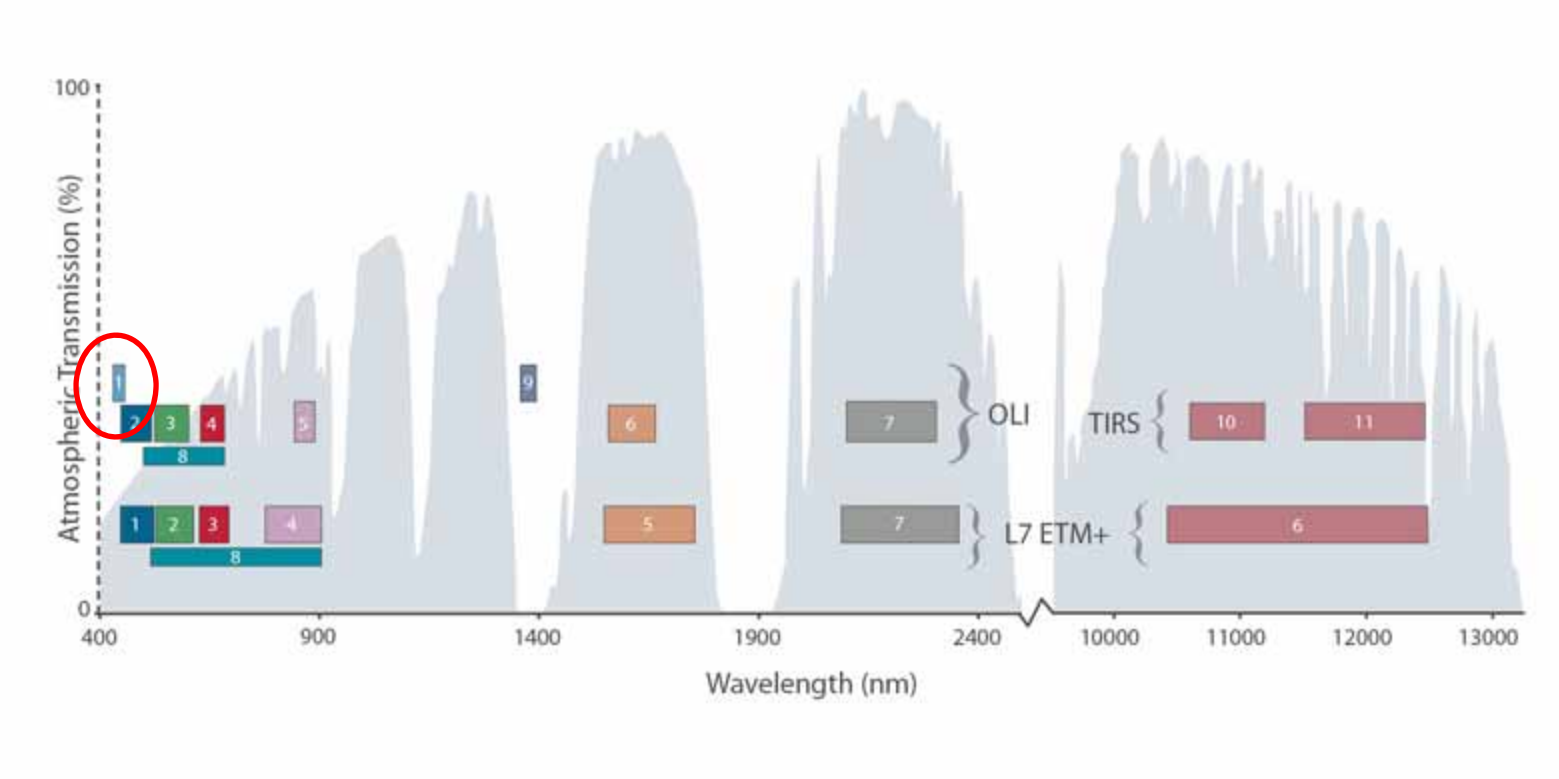
Other Remote Sensing Projects

- Landsat 8 launch (*v2*)
- Successful launch Feb 11, 2013
- New life for aging program/new sensor technologies
- Extends the life of 40 year program monitoring
- Imagery start to become available for download end of May 2013, 24hrs after acquisition.





Landsat 8 Improvements



- New sensor technologies and improvements
- Inclusion of new “deep blue” band in the visible portion of the spectrum specifically designed for monitoring of inland waters and coastal resources.

Landsat 8 Improvements

- Previous simulation experiments found reasonably high success in quantifying constituent concentrations.

	CHL(μg/L)		SM(mg/L)		CDOM(1/m)	
AVIRIS	.5		.1		.1	
ETM+	.5		.6		.2	
LDCM	.5		.5		.1	
ETM+ Quantized	5.7	8.4%	2.8	11.7%	1.7	12.1%
LDCM Quantized	1.2	1.8%	.6	2.5%	.2	1.4%
ETM+ Noise & Quantized	7.4	10.9%	4.8	20.0%	3.2	22.9%
LDCM Noise & Quantized	3.7	5.4%	1.2	5.0%	.9	6.4%

Gerace, A., and J. Schott. 2008. An Increased Potential for the Landsat Data Continuity Mission to Contribute to Water Quality Studies for Inland, Case 2 Waters, p. IV - 379-IV - 382. Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. IEEE International.

Evaluating Landsat 8 for Water Quality Monitoring

- Starting summer 2013, work with CBMs to collect more water samples from inland lakes throughout the state.
- Collaboration with RTI researchers to develop algorithms to estimate Chl *a*, TSS, and CDOM from Landsat 8 imagery.

Summary

- Success of satellite remote sensing of lake water clarity
- Statewide 30 year trends
- New collaboration with UW-Madison-PhD work
- New technologies/remote sensing of water quality research