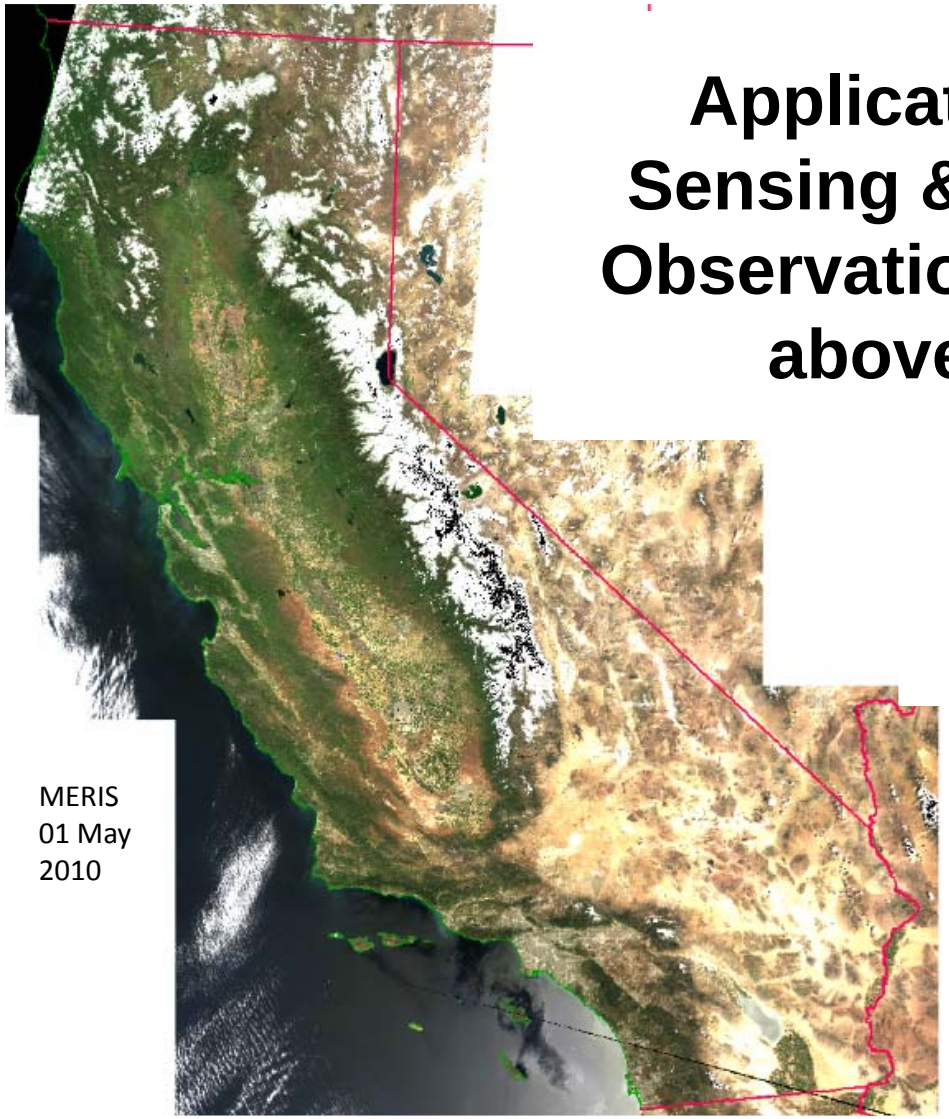
For assistance in accessing this document please send an email to EPACyanoHABs@epa.gov



MERIS
01 May
2010

Applications of Remote Sensing & Satellite Data: Observations from 800 km above California

Rick Stumpf
NOAA
Randy Turner
SFEI

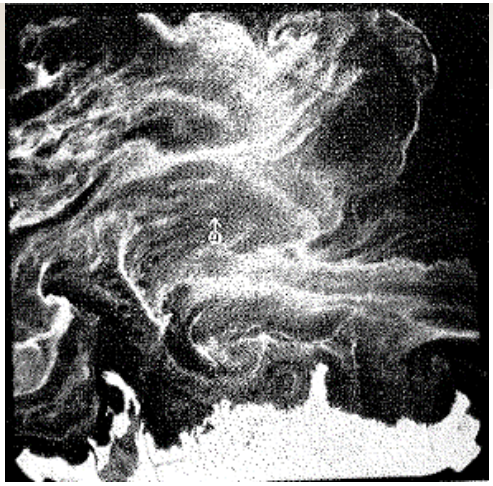
First Remote sensing of an algal bloom, 1974

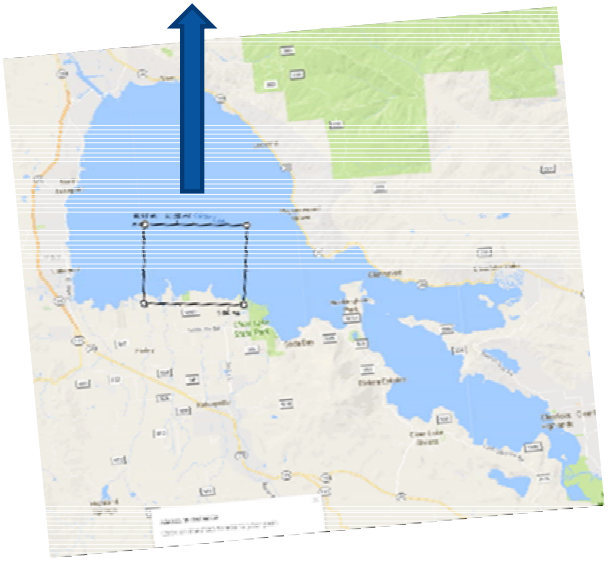
letters to nature

Nature **250**, 213 - 214 (19 July 1974); doi:10.1038/250213a0

Remote sensing and lake eutrophication

ROBERT C. WRIGLEY* & ALEXANDER J. HORNE†





An infrared photograph of part of Clear Lake, California (Fig. 1) shows beautiful, complex patterns of blue-green algal blooms which were not observed by conventional limnological techniques. Repeated observations of patterns such as these can be used to chart the surface movement of these buoyant algae and can also be used to help control algal scums in eutrophic lakes.

Where Are We With Satellite

- We are concentrating on cyanos for this project
- Cyano blooms are observable.
- Cyano blooms are distinguishable from other blooms depending on the sensor
  - Some uncertainties on distinction between cyanos and non-cyanos
  - We are examining strategies to reduce these.
- All sensors can find scum
- Most sensors have limitations
  - Resolution trade-offs: spatial, spectral, temporal
- Experimental systems and field radiometers allow for evaluation of future high resolution strategies (not going to discuss that today).

Satellite Comparison for cyano applications

Satellite	Spatial	Temporal	Key Spectral
MERIS 2002-12 OLCI Sentinel-3a 2016-	300 m *OK*	2 day *good*	10 (5 on red edge) *good*
MODIS high res Terra 1999; Aqua 2002	250/500 m *OK*	1-2 day *good*	4 (1 red, 1 NIR) *marginal*
MODIS low res	1 km *poor*	1-2 day *good*	7-8 (2 in red edge) *OK*
Landsat	30 m *good*	8 or 16 day *poor*	4 (1 red, 1 NIR) *marginal*
Sentinel-2 (2015)	20 m *good*	10 day (5 day with 2nd satellite in 2017) *Potential with 2*	5 (1 red; 2 NIR, 1 in red edge) *potential*

Clouds take out 1/2 to 2/3 of imagery

Some sunglint is not a problem for our algorithms

Minimum resolution, 3 pixels across (2 mixed land/water)

MERIS (Medium Resolution Imaging Spectrometer)
OLCI (Ocean Land Colour Instrument)

MERIS on Envisat-1 Launched April 2002; Ceased operations April 2012.

- Spectral Resolution = 13 visible bands
- Spatial Resolution = 300 meters
- Temporal Resolution = 3-4 scenes a week.
- Cost = Free

OLCI launched on Sentinel-3a February 2016.

- Same basic configuration as MERIS

OLCI data

Feb 28, 2017 Central California

OLCI (MERIS replacement)

Ocean Land Colour Instrument on Sentinel-3

Sentinel-3a launched February 2016.

Data after Oct 20 available

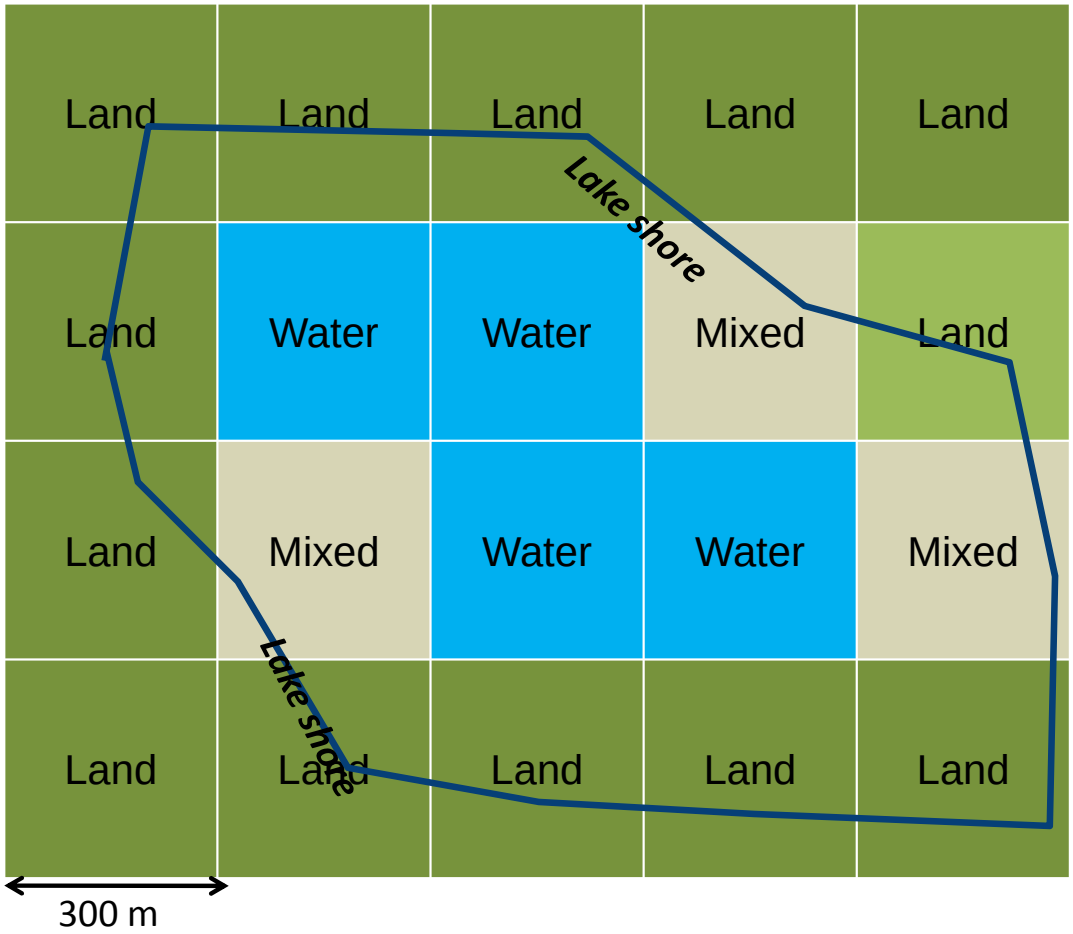
Summer data pending.

1270 km swath 300-m data will be routine

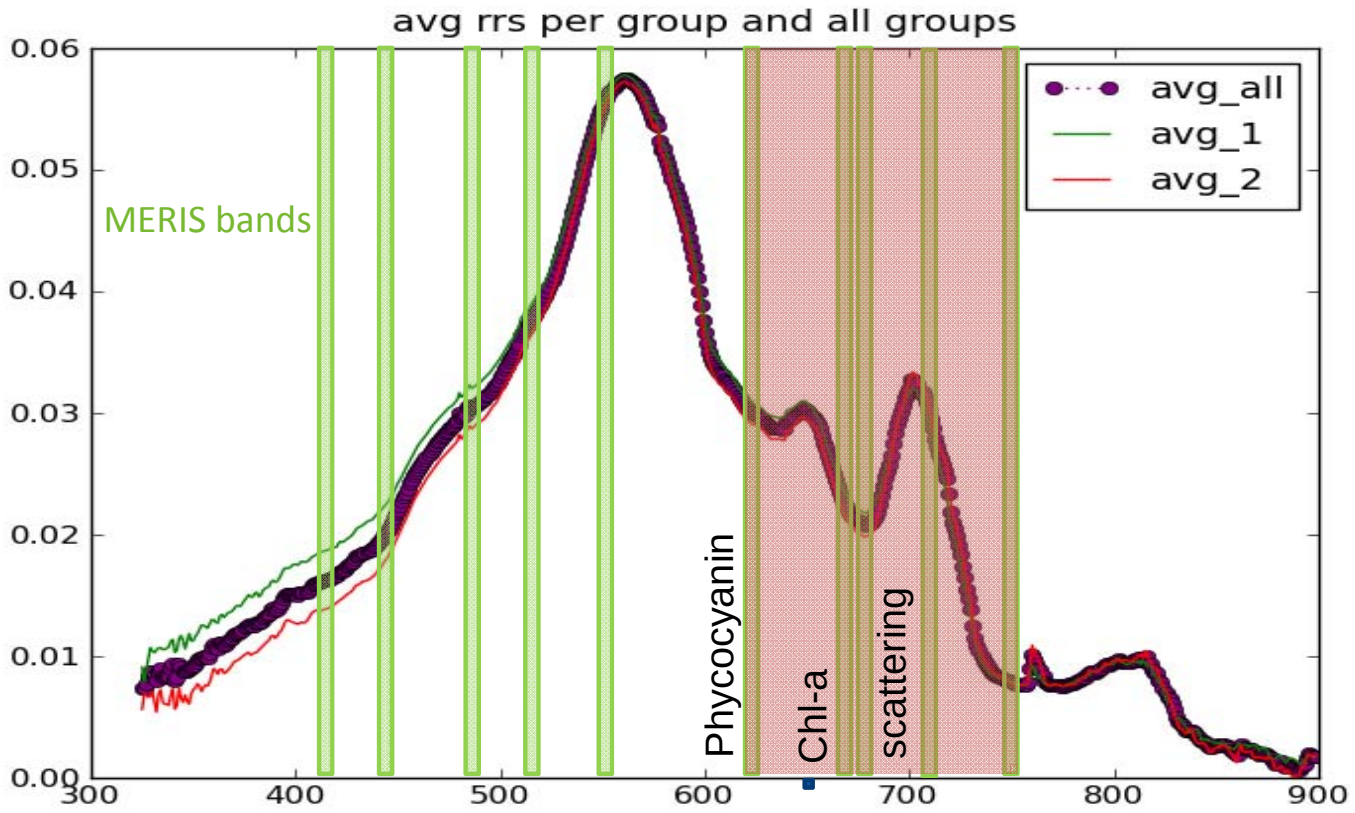
Sentinel 3b launch planned within the year

Satellite Spatial Resolution, limits on detection

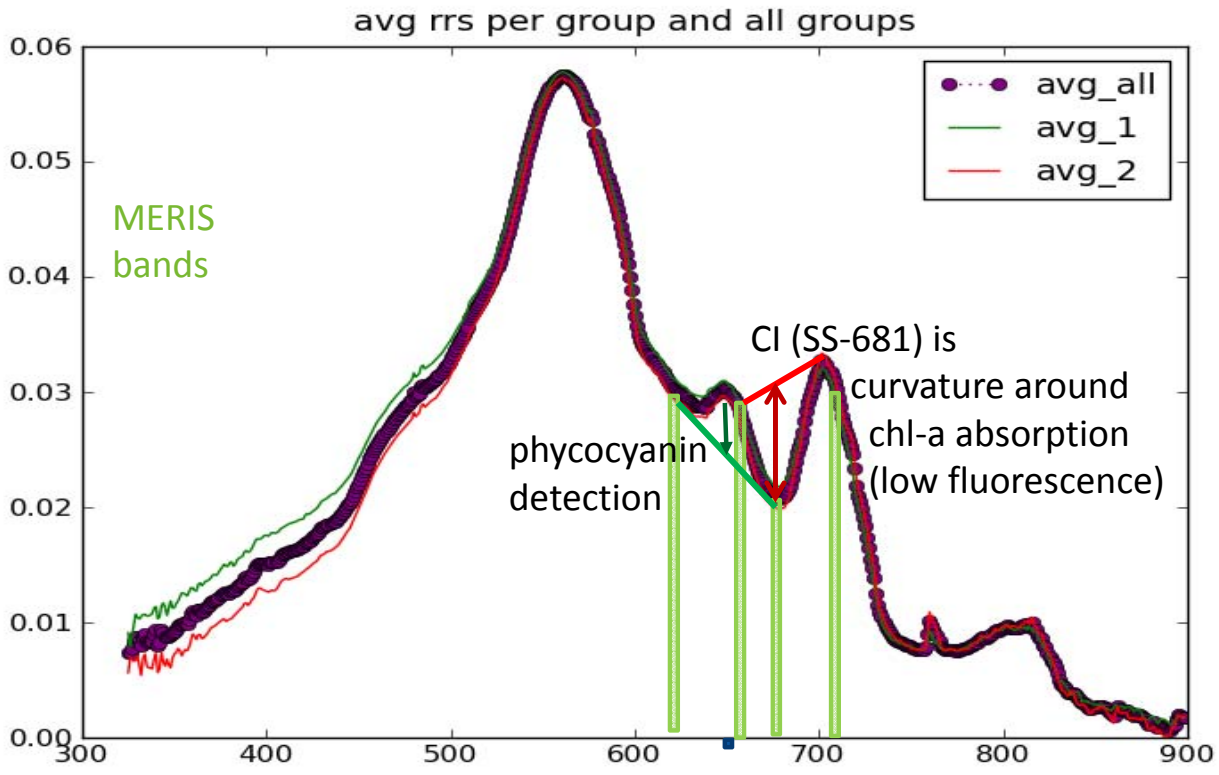
3 Pixels minimum width



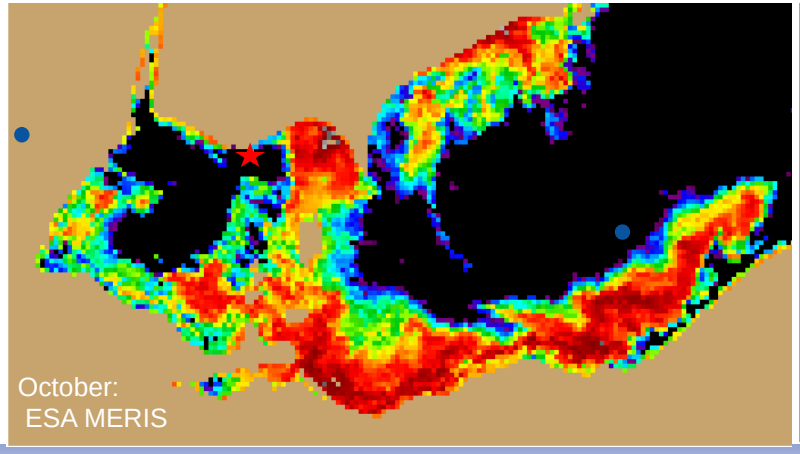
Intense blooms in water, red/NIR bands provide discrimination

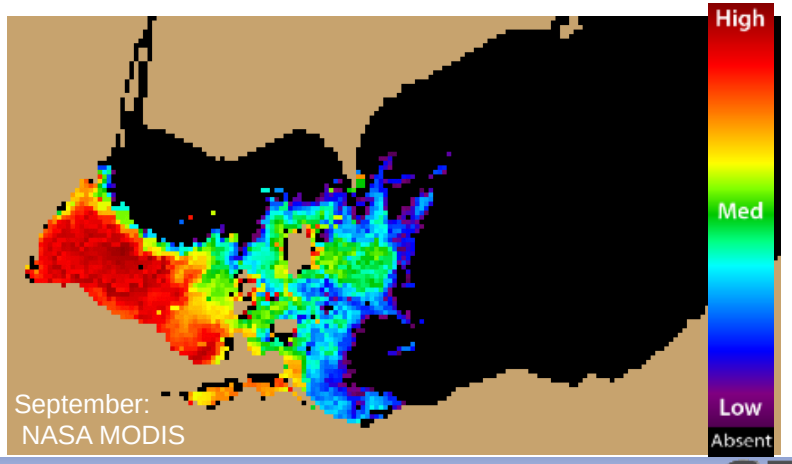


CI/SS681, Cyanos have weak chlorophyll fluorescence and presence of phycocyanin



"CI" algorithm detects and quantifies blooms

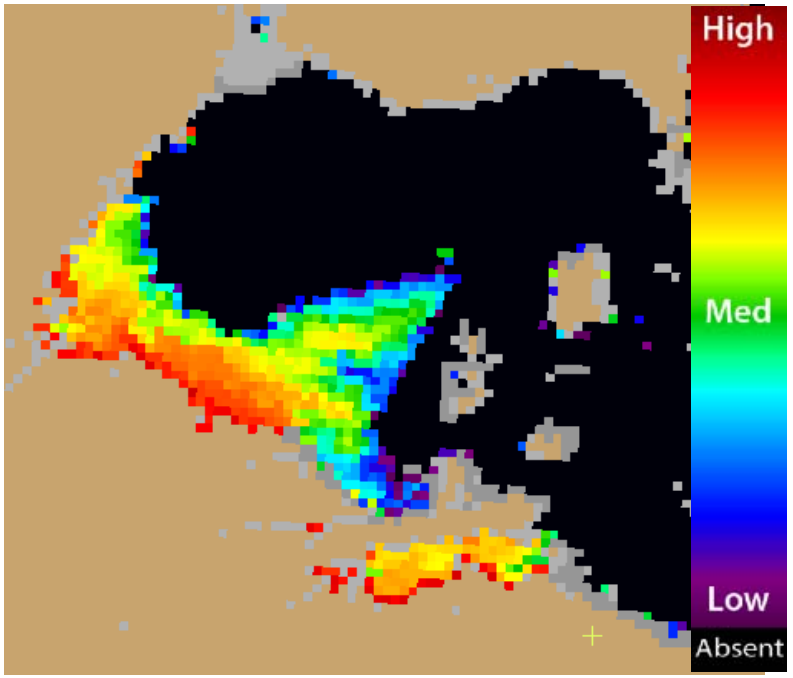




Even when the bloom is not obvious.

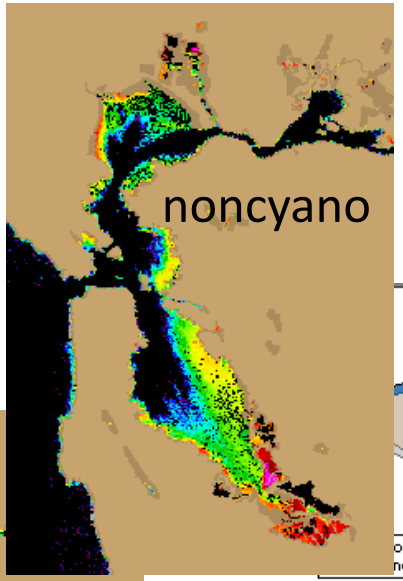
Enhanced true color, Aug 16, 2014

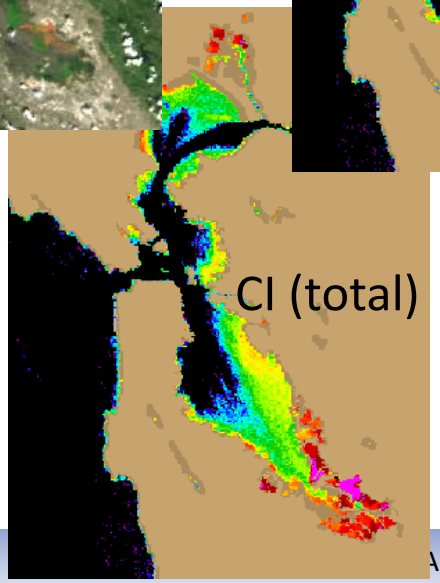
Cyano index



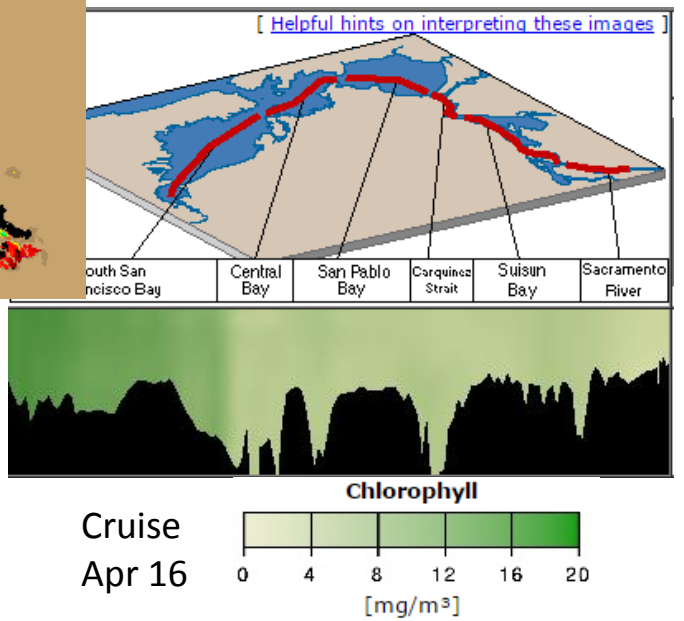
MODIS Cyano Index (CI)

Example of non-cyano

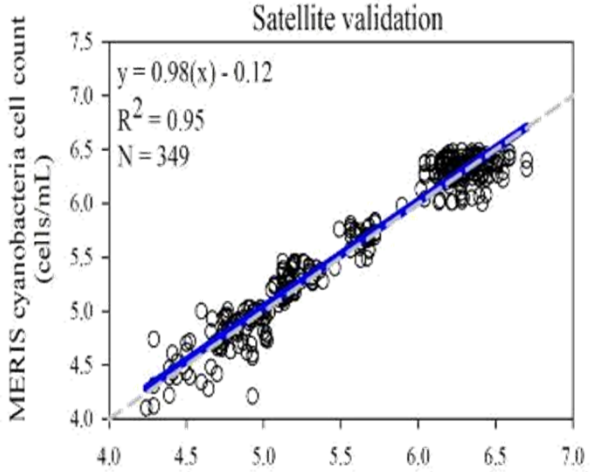


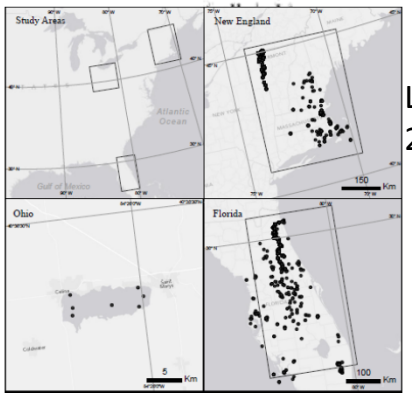


2009Apr14 image showing “noncyano” spring bloom in south SF Bay.

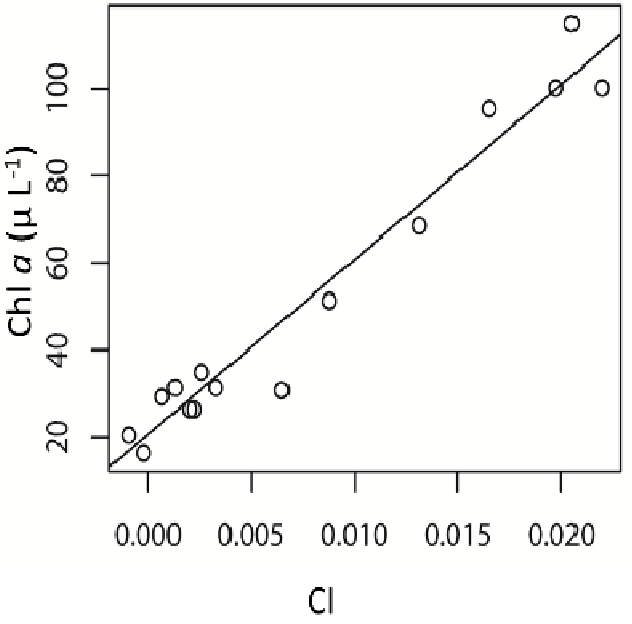


Example quantification for CI, Lake Erie transferred to many other lakes





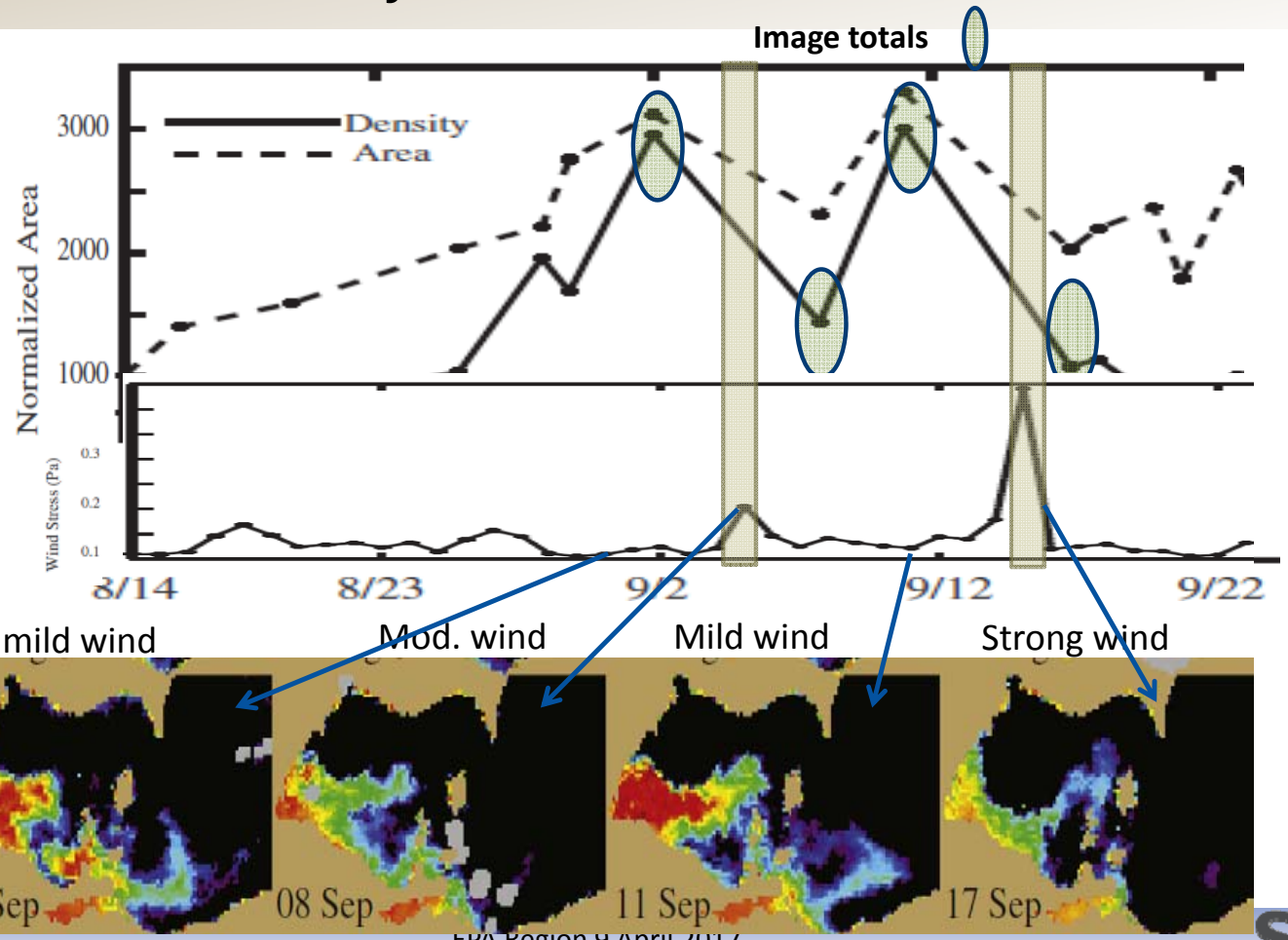
Lunetta et al., 2014



Relationship to chl-a
Tomlinson et al., 2016

Satellite sees either surface scum or surface concentration. Winds ilute" blooms. We use 10-day maximum to correct for clouds and wind.

Figure from Wynne et al., 2013)



Considerations

CyAN project will address algorithm improvements.

Refinement of algorithms to address identified errors ("non-water", halobacteria)

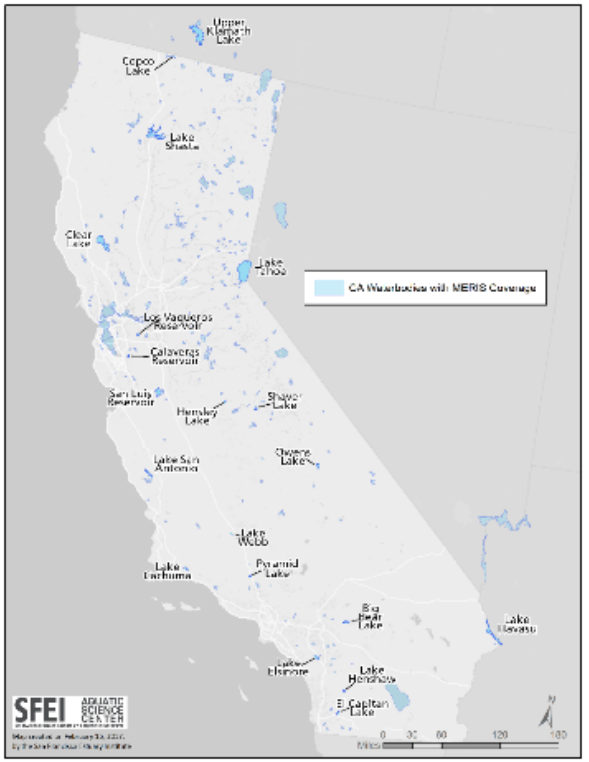
OLCI data processing will shift to CyAN system for long-term

CA Surface Water Ambient Monitoring Program (SWAMP) ontracted with SFEI

Develop infrastructure to process satellite imagery

Analyze data for 255 water bodies (20 in detail)

- Historic Data
  - MERIS data from ENVIS satellite (2002-2012)
- New Data
  - OLCI data from Sentinel-3a satellite (Oct 2016)

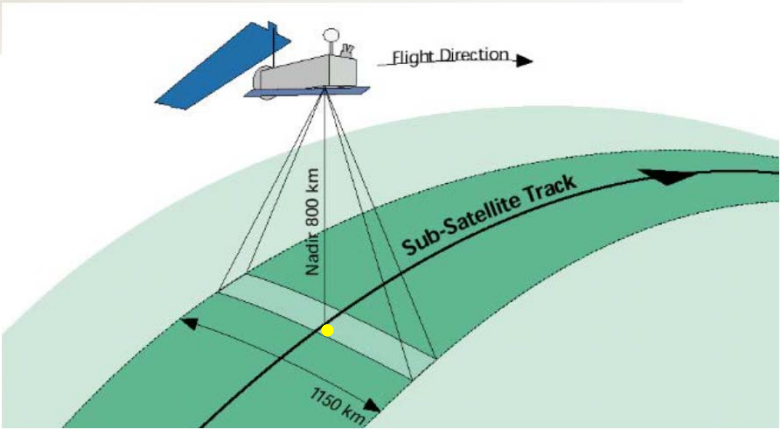


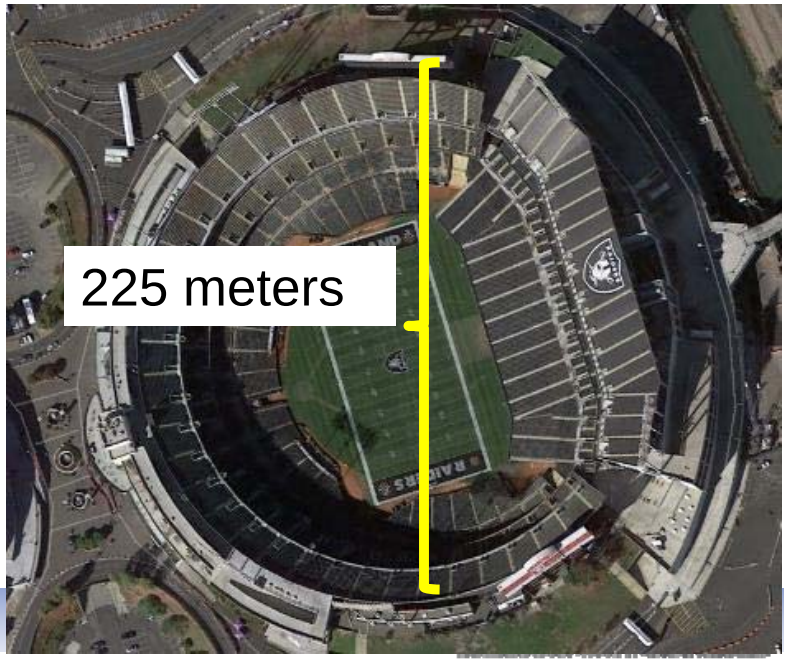
CA Surface Water Ambient Monitoring Program (SWAMP) ontracted with SFEI

- Reporting
  - MERIS
    - Write Status and Trends report
  - MERIS and OLCI
    - Create web portal to view imagery and related data
  - OLCI
    - Inform water body managers when blooms occur
    - Issue regular bulletins and newsletters

Pixels

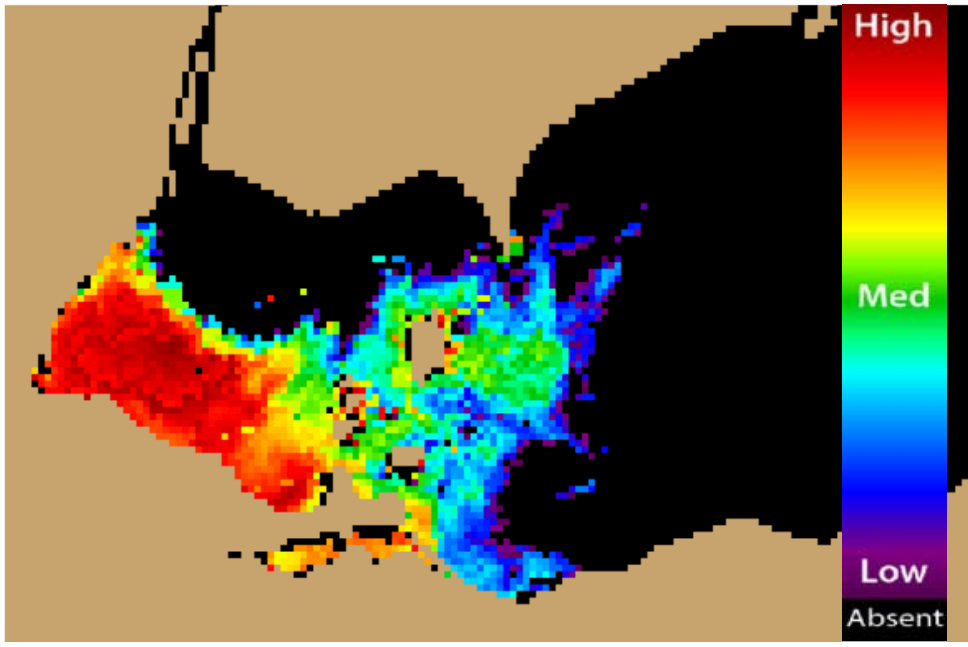
- Pixel size is 300m x 300m
- Pixel location always the same
- Each pixel assigned a value based on concentration





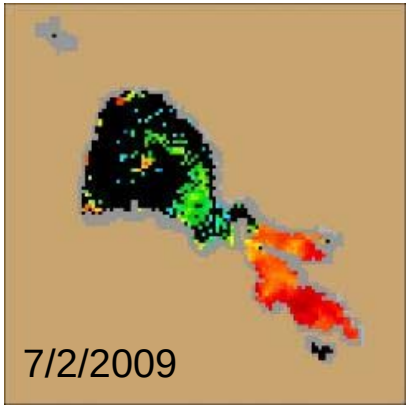
Satellite Basics

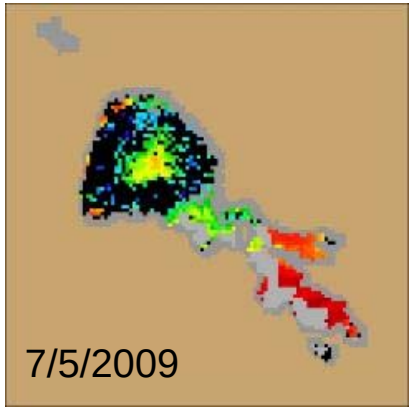
- Estimate pixel concentrations separately for:
  - Total algal biomass
    - **Cyanobacteria**
    - Non-cyanobacteria
- Doesn't measure toxins
- Generate composite images
  - 10 day running max composites
    - Detailed analysis
  - Monthly max composites
    - Statewide summary

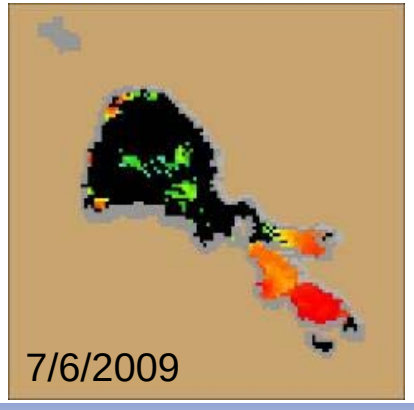


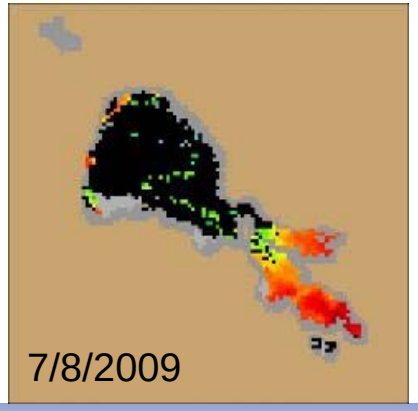
Create Composite Images

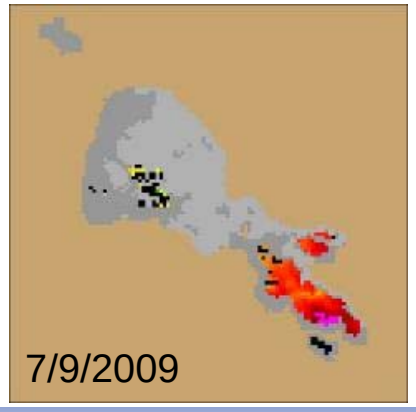
- Review all scenes for 10 day period
- For each pixel location, determine maximum value
- Generate running 10 day max composites

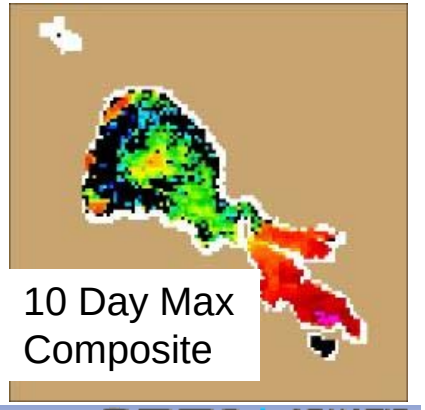






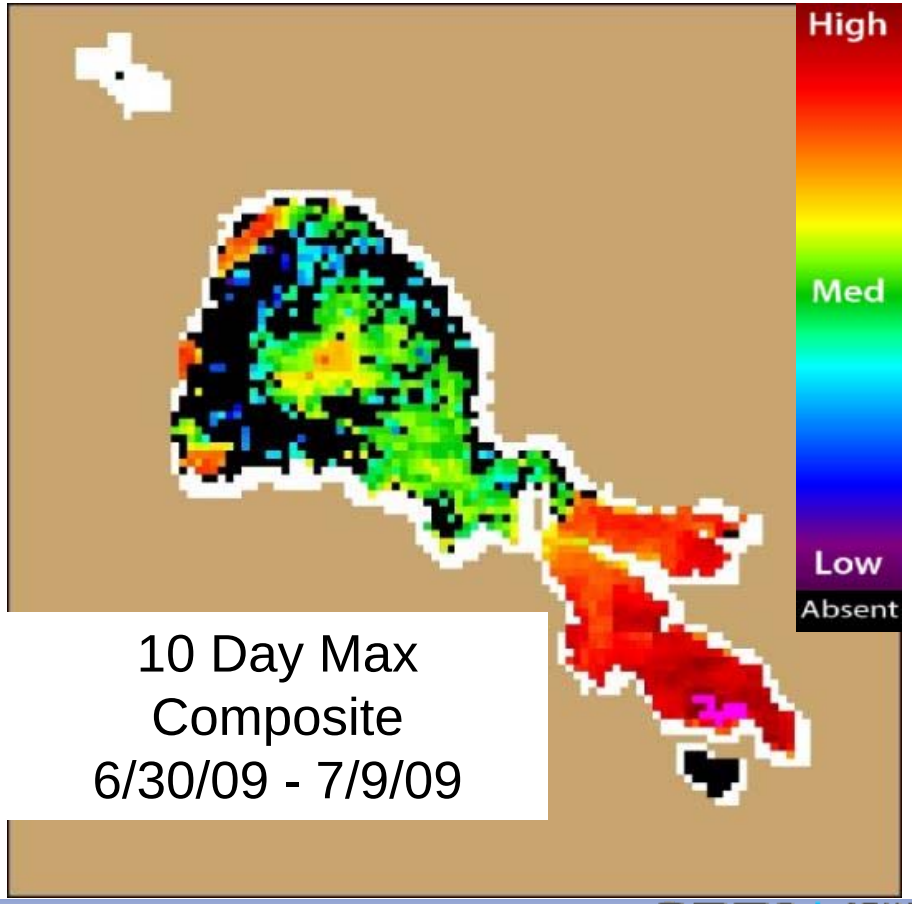






Generate Statistics

- Valid composites need >17 pixels
  - NOAA recommended
- Estimate concentration in:
  - Cyanobacterial Index (CI)
  - Chlorophyll-a (ug/L)
  - ***Microcystis sp.* equivalents (cells/mL)**
- From each composite, generate **water body-wide estimates** for:
  - Mean
  - Median
  - **90th percentile of max**

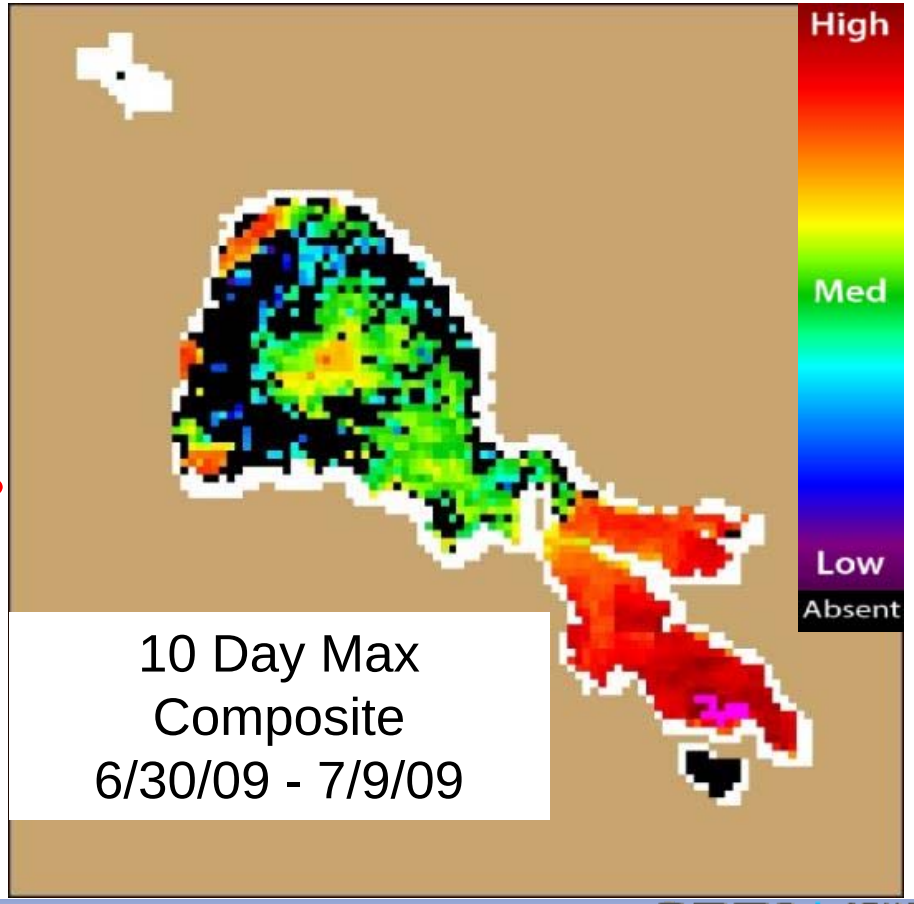


10 Day Max Composite
6/30/09 - 7/9/09

Generate Statistics

			Cyano Mean >17	Cyano Median >17	Cyano 90th % >17
start_date	end_date	Pixels	MC (cells/mL)	MC (cells/mL)	MC (cells/mL)
6/22/2009	7/1/2009	1757	109,648	131,826	1,995,262
6/23/2009	7/2/2009	1779	123,027	154,882	1,949,845
6/24/2009	7/3/2009	1739	109,648	134,896	1,949,845
6/25/2009	7/4/2009	1739	109,648	134,896	1,949,845
6/26/2009	7/5/2009	1721	134,896	181,970	1,778,279
6/27/2009	7/6/2009	1709	125,893	186,209	1,548,817
6/28/2009	7/7/2009	1709	125,893	186,209	1,548,817
6/29/2009	7/8/2009	1733	134,896	194,984	1,584,893
6/30/2009	7/9/2009	1721	**125,893**	**186,209**	**1,621,810**

- Mean and median may underestimate public health risk
- 90th percentile value shows area of higher public health risk
  - Similar to event response grab samples



10 Day Max Composite
6/30/09 - 7/9/09

Trigger Levels and Satellite Thresholds

			Cyano Mean >17	Cyano Median >17	Cyano 90th % >17
start_date	end_date	Pixels	MC (cells/mL)	MC (cells/mL)	MC (cells/mL)
6/22/2009	7/1/2009	1757	109,648	131,826	1,995,262
6/23/2009	7/2/2009	1779	123,027	154,882	1,949,845
6/24/2009	7/3/2009	1739	109,648	134,896	1,949,845
6/25/2009	7/4/2009	1739	109,648	134,896	1,949,845
6/26/2009	7/5/2009	1721	134,896	181,970	1,778,279
6/27/2009	7/6/2009	1709	125,893	186,209	1,548,817
6/28/2009	7/7/2009	1709	125,893	186,209	1,548,817
6/29/2009	7/8/2009	1733	134,896	194,984	1,584,893
6/30/2009	7/9/2009	1721	**125,893**	**186,209**	**1,621,810**

	Action Trigger	Warning TIER 1	Danger TIER 2
Primary Thresholds [a]			
Total Microcystins [b]	**0.8** µg/L	**6** µg/L	**20** µg/L
Anatoxin-a	**Detection** [c]	**20** µg/L	**90** µg/L
Cylindrospermopsin	**1** µg/L	**4** µg/L	**12** µg/L
Secondary Thresholds			
Cell Density (*Toxin producing cells*)	**4,000** cells/mL	--	--
Site Specific Indicators of Cyanobacteria	Blooms, scums, mats	--	--

Satellite detection range

- *Microcystis sp.* equivalents
- 10,000 – 3,100,000 cells/mL

Level	Value (cells/mL)
CA Action Trigger	4,000
Satellite 'background' level	~10,000

Trigger Levels and Satellite Thresholds

			Cyano Mean >17	Cyano Median >17	Cyano 90th % >17
start_date	end_date	Pixels	MC (cells/mL)	MC (cells/mL)	MC (cells/mL)
6/22/2009	7/1/2009	1757	109,648	131,826	1,995,262
6/23/2009	7/2/2009	1779	123,027	154,882	1,949,845
6/24/2009	7/3/2009	1739	109,648	134,896	1,949,845
6/25/2009	7/4/2009	1739	109,648	134,896	1,949,845
6/26/2009	7/5/2009	1721	134,896	181,970	1,778,279
6/27/2009	7/6/2009	1709	125,893	186,209	1,548,817
6/28/2009	7/7/2009	1709	125,893	186,209	1,548,817
6/29/2009	7/8/2009	1733	134,896	194,984	1,584,893
6/30/2009	7/9/2009	1721	**125,893**	**186,209**	**1,621,810**

	Action Trigger	Warning TIER 1	Danger TIER 2
Primary Thresholds [a]			
Total Microcystins [b]	**0.8** µg/L	**6** µg/L	**20** µg/L
Anatoxin-a	**Detection** [c]	**20** µg/L	**90** µg/L
Cylindrospermopsin	**1** µg/L	**4** µg/L	**12** µg/L
Secondary Thresholds			
Cell Density (*Toxin producing cells*)	**4,000** cells/mL	--	--
Site Specific Indicators of Cyanobacteria	Blooms, scums, mats	--	--

Satellite detection range

- *Microcystis sp.* equivalents
- 10,000 – 3,100,000 cells/mL
- Values have +- 15% uncertainty

Level	Value (cells/mL)
CA Action Trigger	4,000
Satellite 'background' level	~10,000
Low Risk (WHO)	<20,000
Moderate Risk (WHO)	20,000-100,000
High Risk (WHO)	>100,000
Very High Risk (Proposed)	>1,000,000

Trigger Levels and Satellite Thresholds

			Cyano Mean >17	Cyano Median >17	Cyano 90th % >17
start_date	end_date	Pixels	MC (cells/mL)	MC (cells/mL)	MC (cells/mL)
6/22/2009	7/1/2009	1757	109,648	131,826	1,995,262
6/23/2009	7/2/2009	1779	123,027	154,882	1,949,845
6/24/2009	7/3/2009	1739	109,648	134,896	1,949,845
6/25/2009	7/4/2009	1739	109,648	134,896	1,949,845
6/26/2009	7/5/2009	1721	134,896	181,970	1,778,279
6/27/2009	7/6/2009	1709	125,893	186,209	1,548,817
6/28/2009	7/7/2009	1709	125,893	186,209	1,548,817
6/29/2009	7/8/2009	1733	134,896	194,984	1,584,893
6/30/2009	7/9/2009	1721	**125,893**	**186,209**	**1,621,810**

	Action Trigger	Warning TIER 1	Danger TIER 2
Primary Thresholds [a]			
Total Microcystins [b]	**0.8** µg/L	**6** µg/L	**20** µg/L
Anatoxin-a	**Detection** [c]	**20** µg/L	**90** µg/L
Cylindrospermopsin	**1** µg/L	**4** µg/L	**12** µg/L
Secondary Thresholds			
Cell Density (*Toxin producing cells*)	**4,000** cells/mL	--	--
Site Specific Indicators of Cyanobacteria	Blooms, scums, mats	--	--

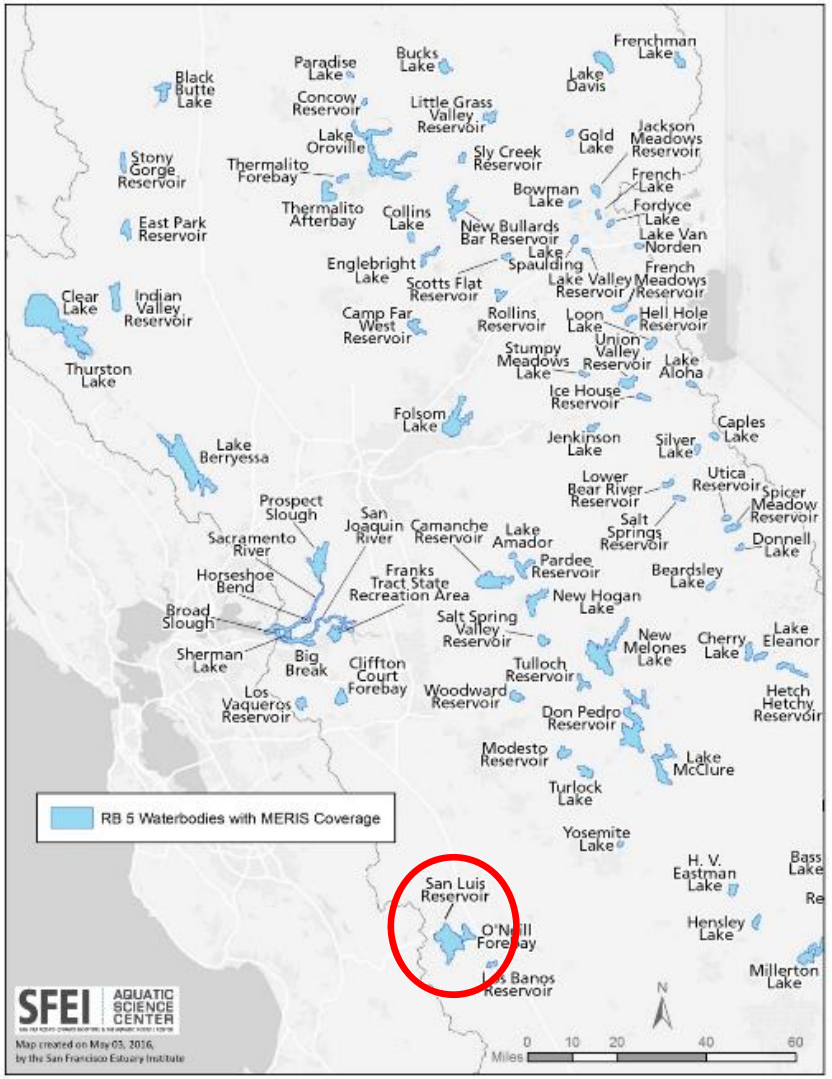
Understand exceedance of 'thresholds'

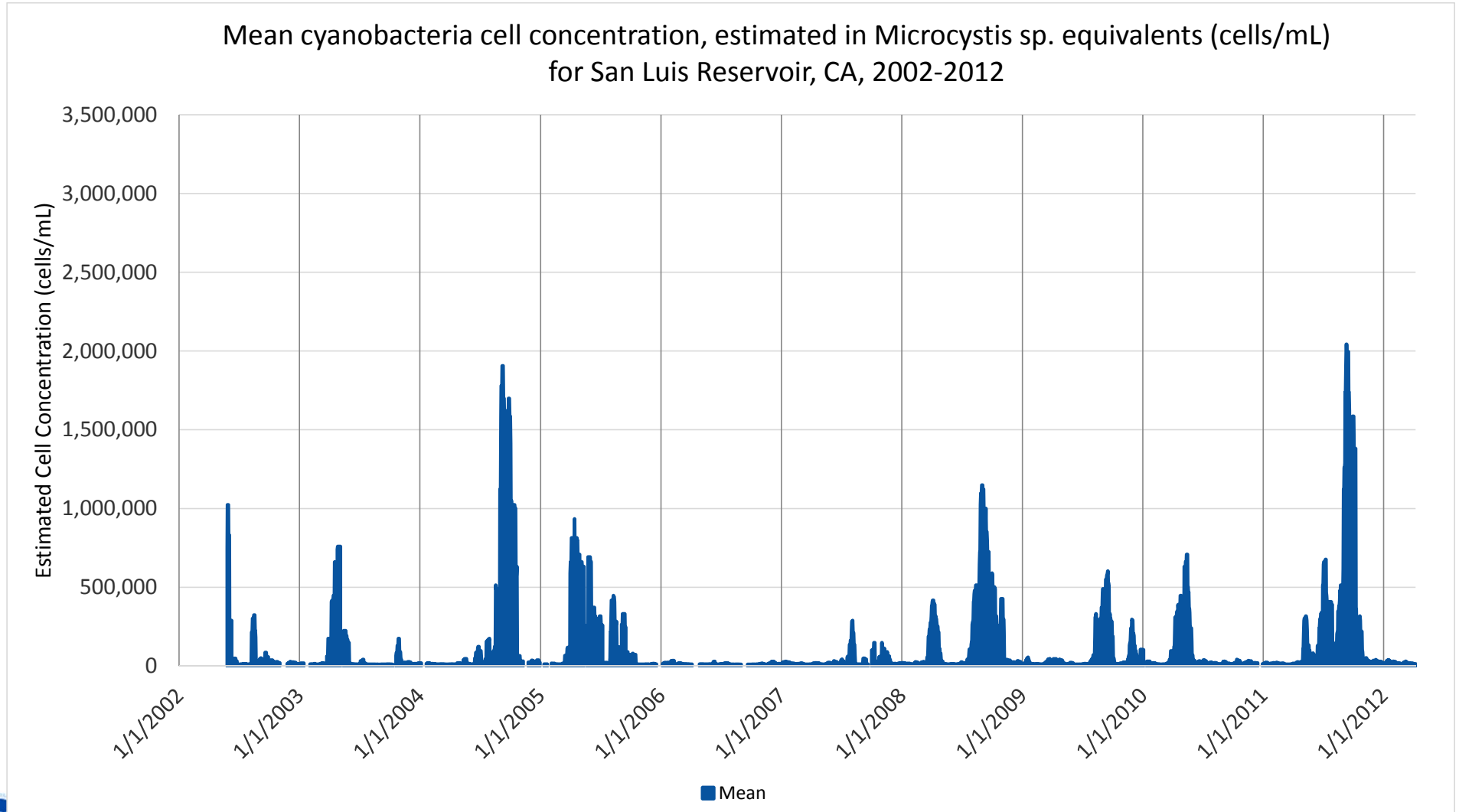
- How often?
- How long?
- How many waterbodies?

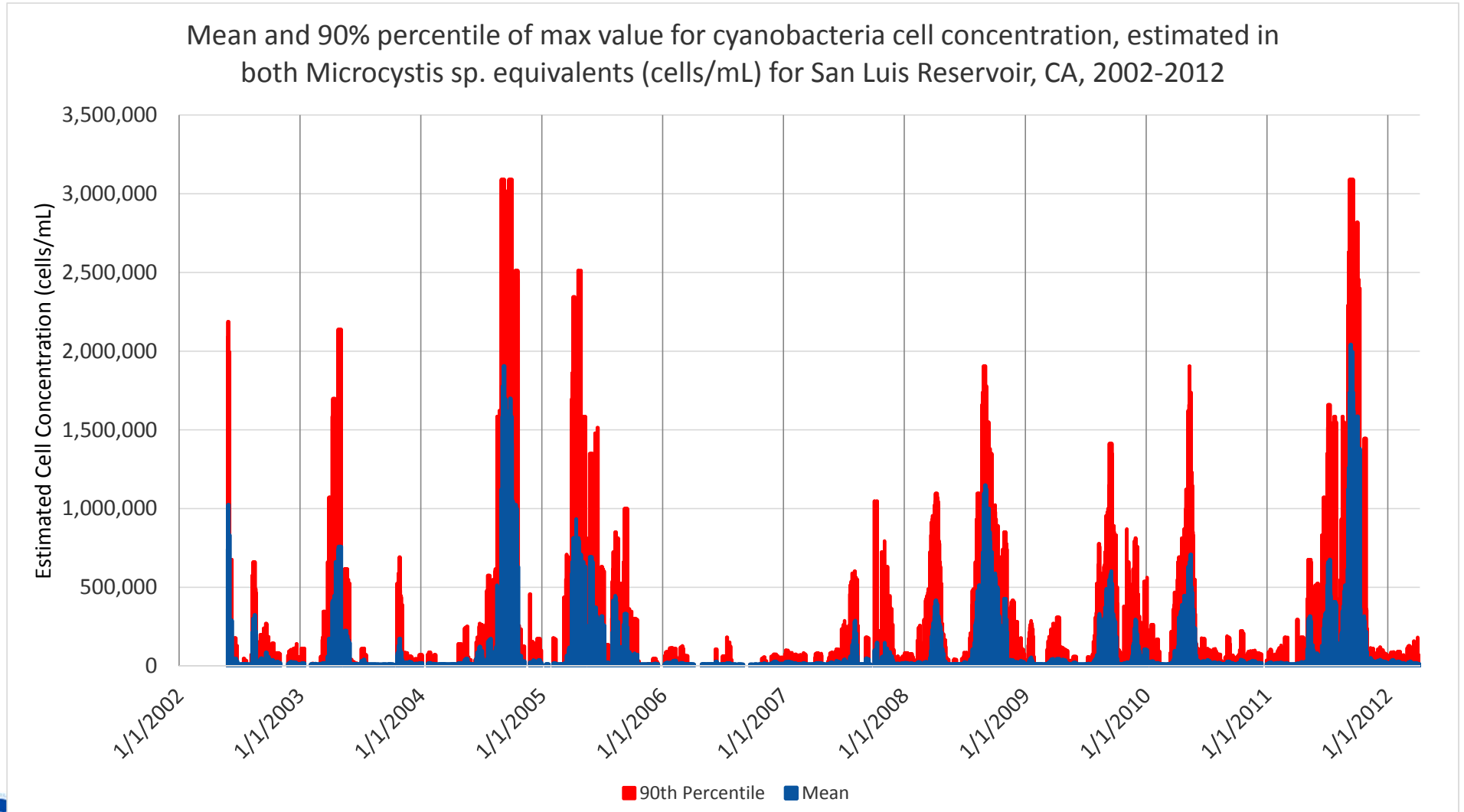
Level	Value (cells/mL)
Low Risk	**10,000- 20,000**
Moderate Risk	**20,000-100,000**
High Risk	**100,000-1,000,000**
Very High Risk	**>1,000,000**

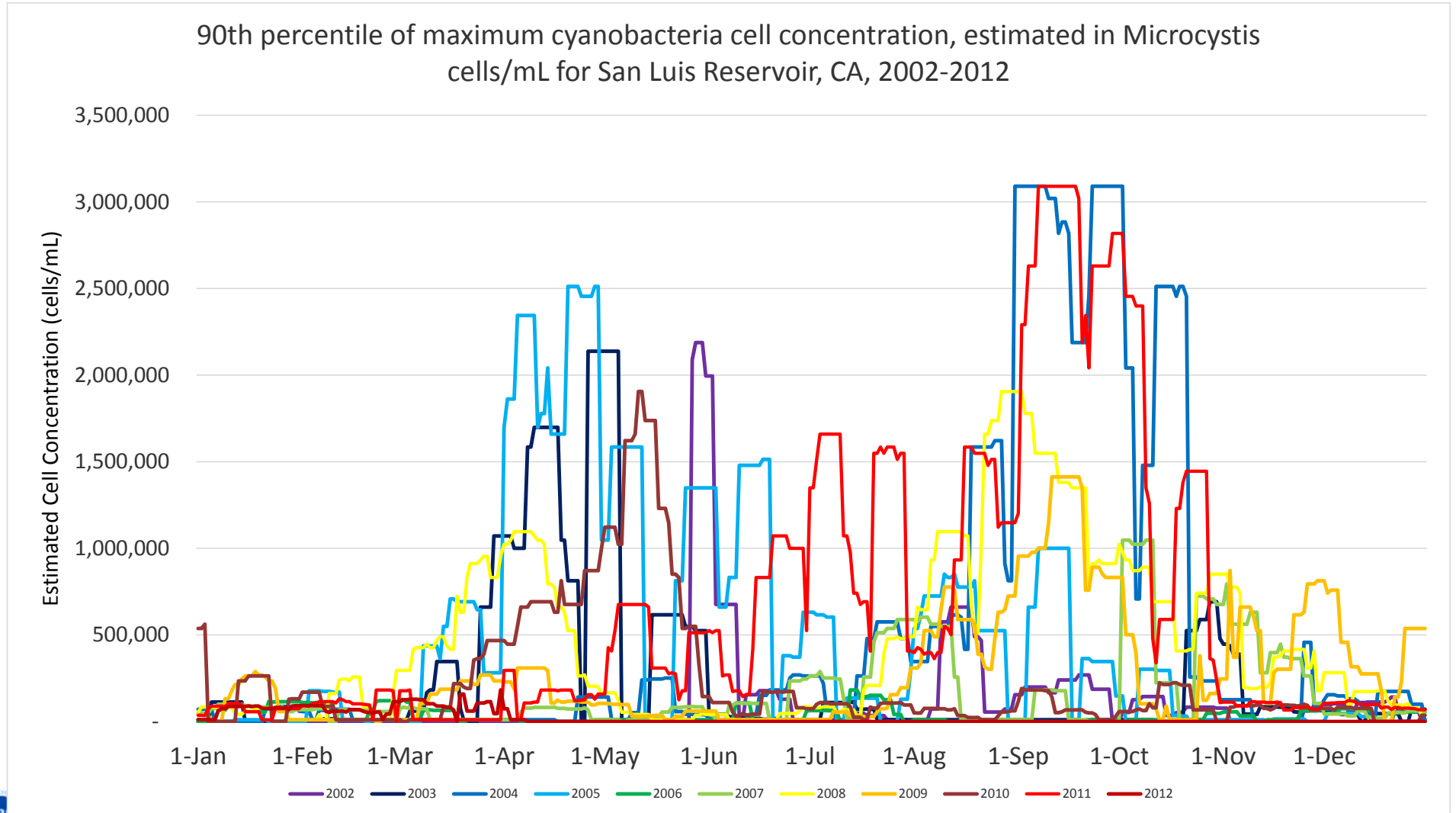
Historic satellite data for San Luis Reservoir

All data is preliminary
Please do not cite

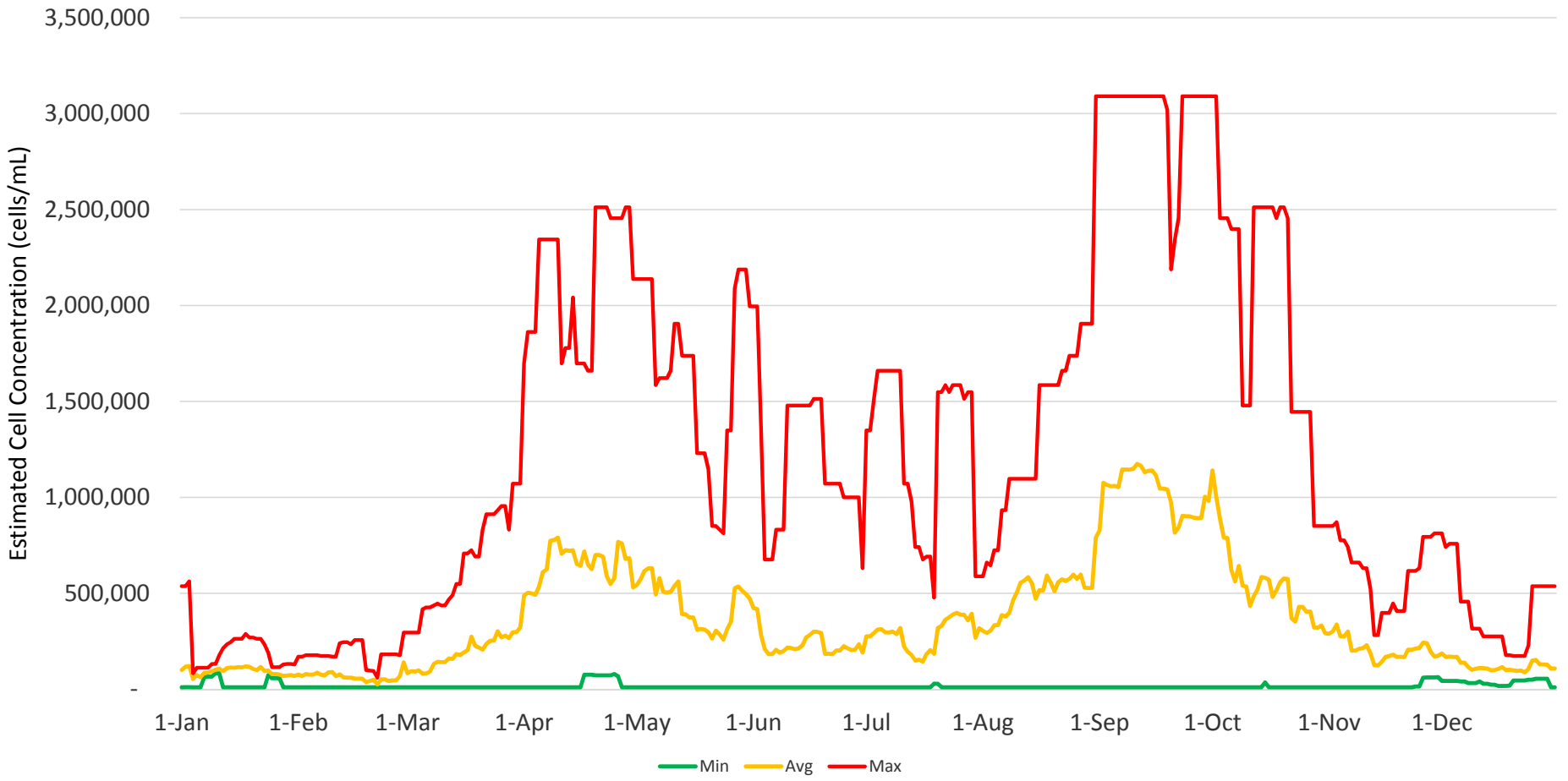






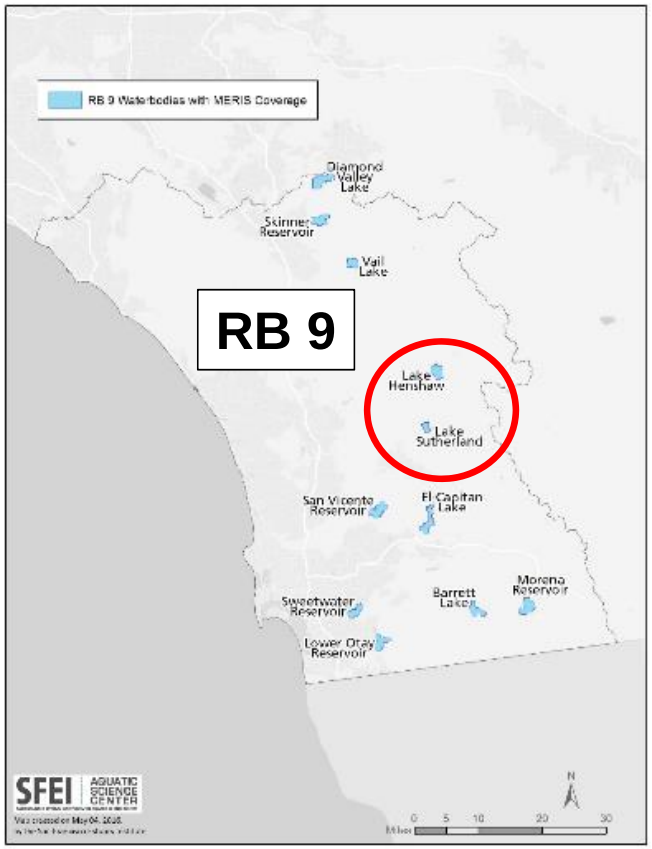


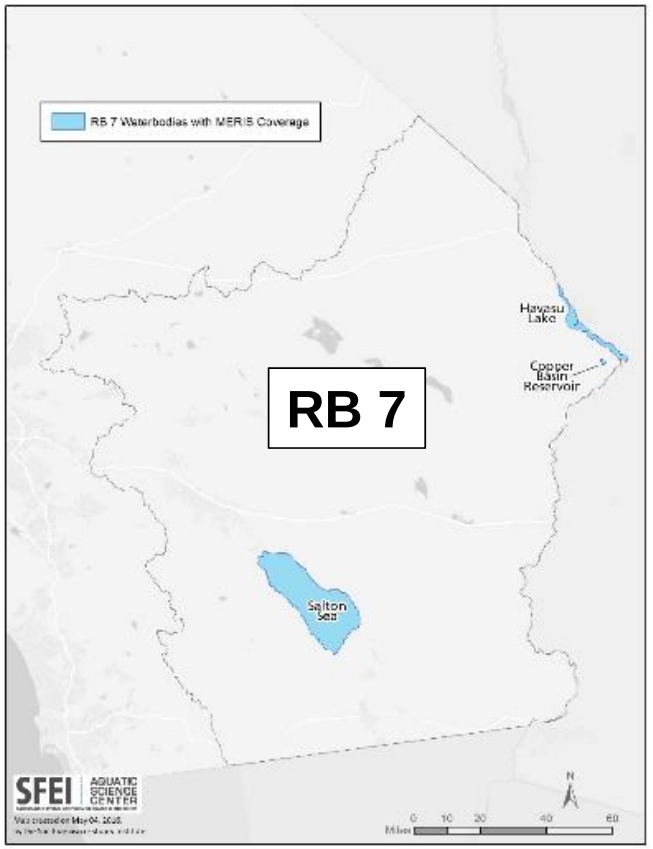
Daily minimum, average, and maximum of 90th percentile of maximum cell concentration, estimated in Microcystis cells/mL for San Luis Reservoir, CA, 2002-2012

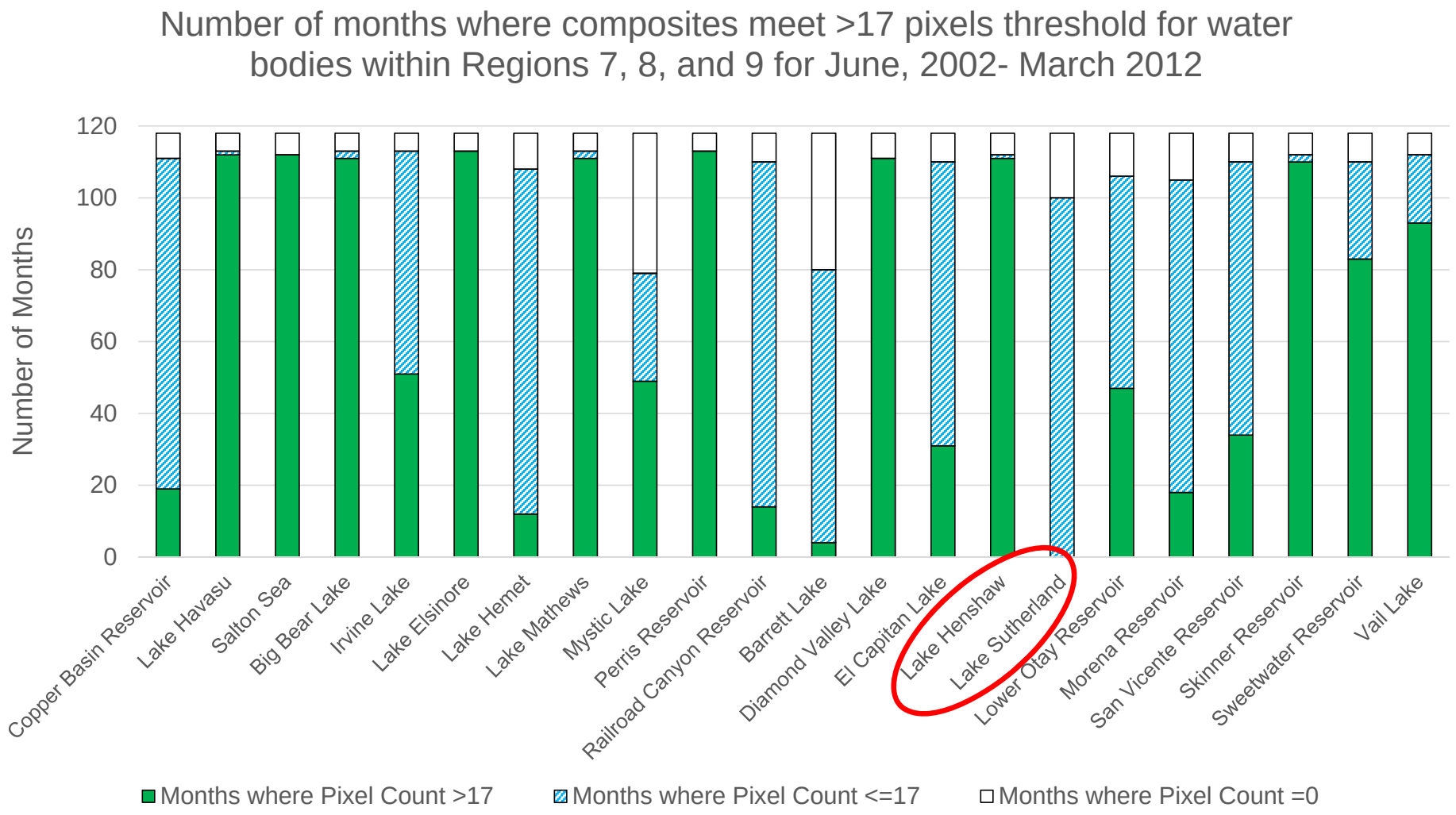


Region 7,8, and 9 Summary

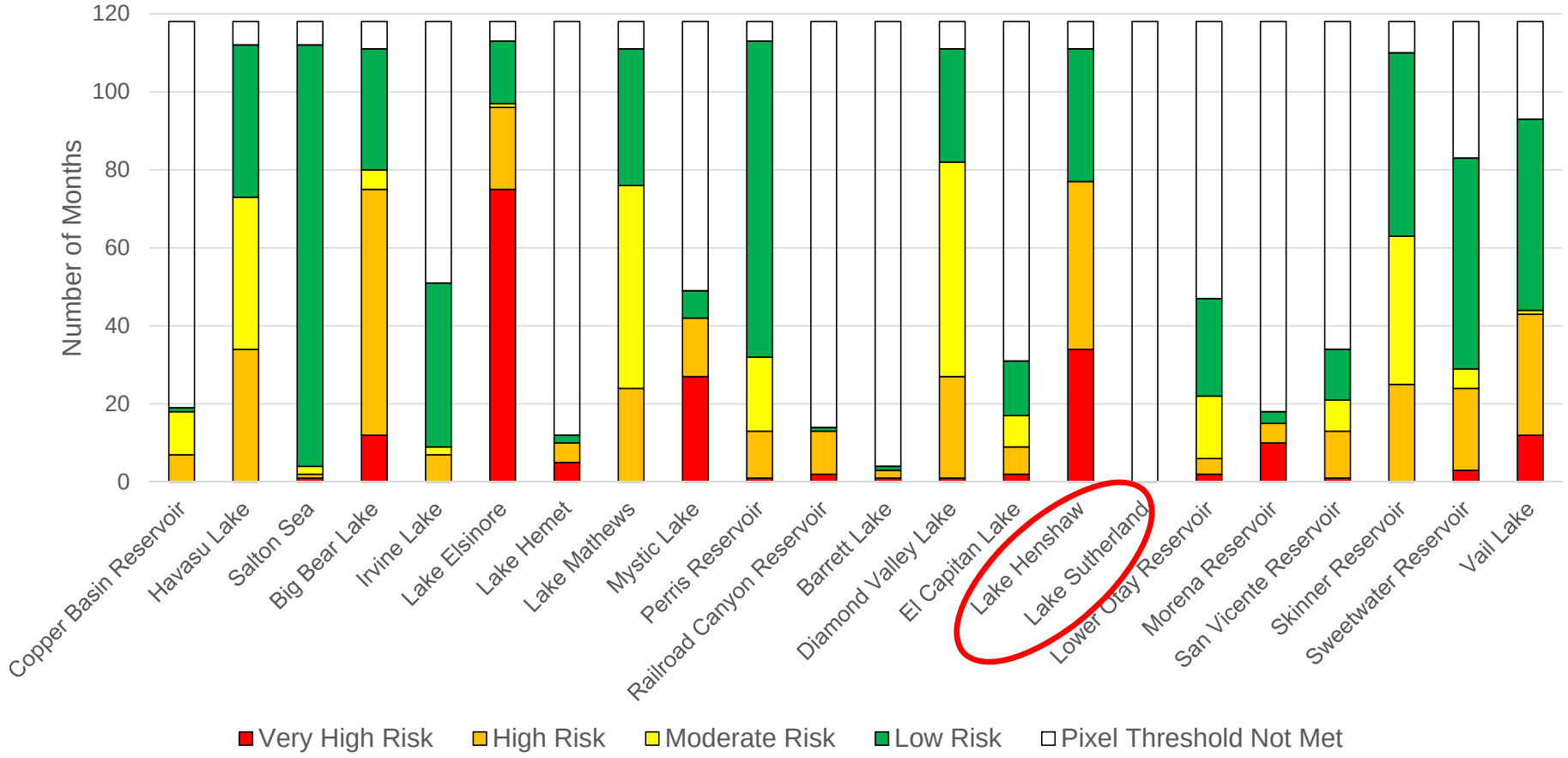
onthly composites (not 10 day)



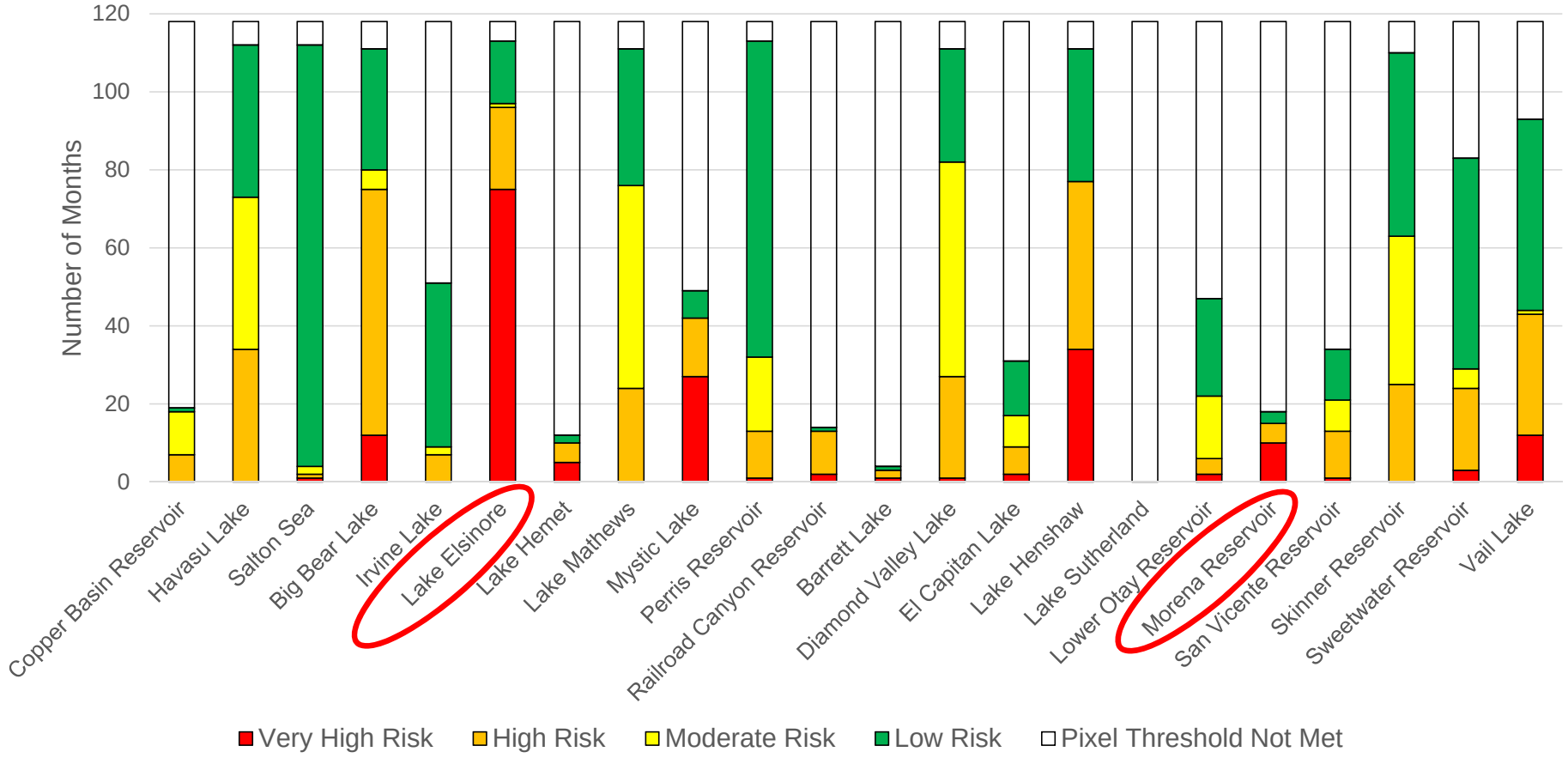




Number of months where 90th percentile 90th percentile values exceed Moderate, High, or Very High Risk thresholds for water bodies within Regions 7, 8, and 9 for June, 2002- March 2012

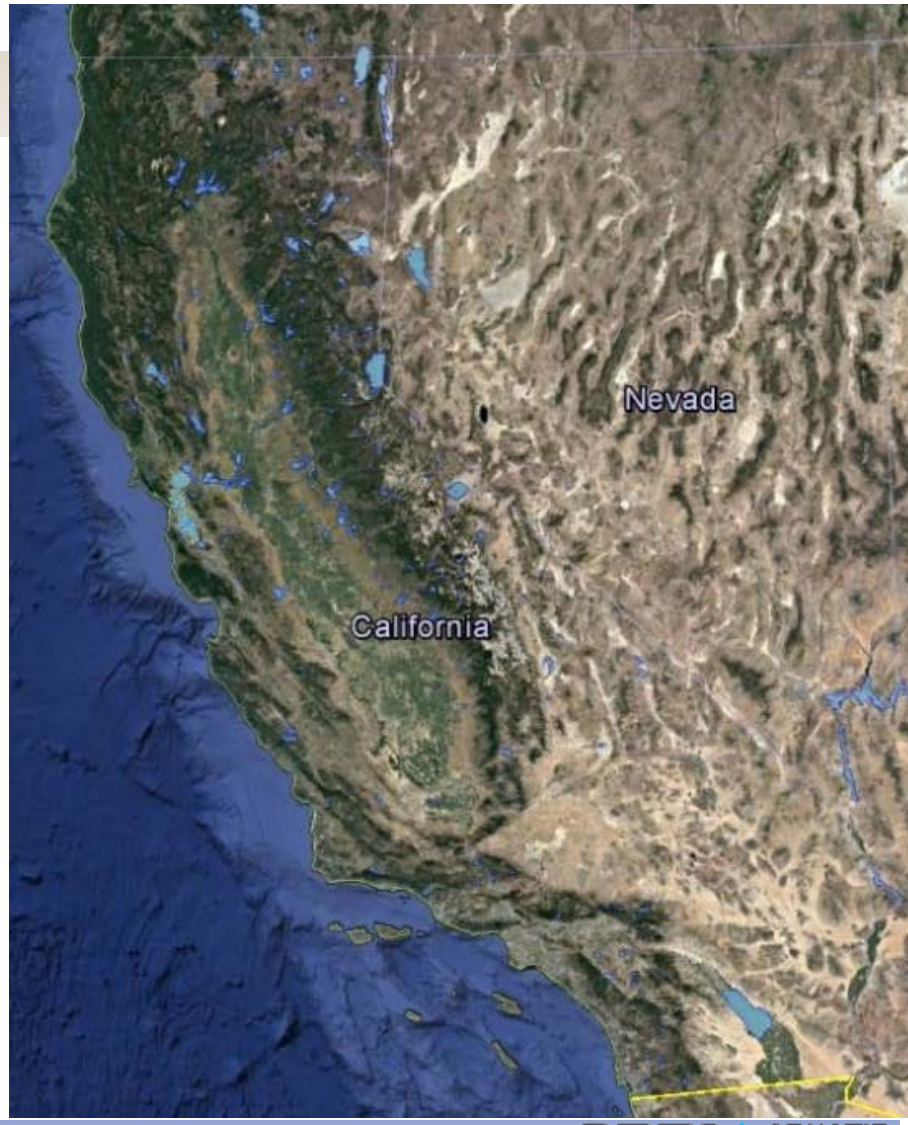


Number of months where 90th percentile 90th percentile values exceed Moderate, High, or Very High Risk thresholds for water bodies within Regions 7, 8, and 9 for June, 2002- March 2012

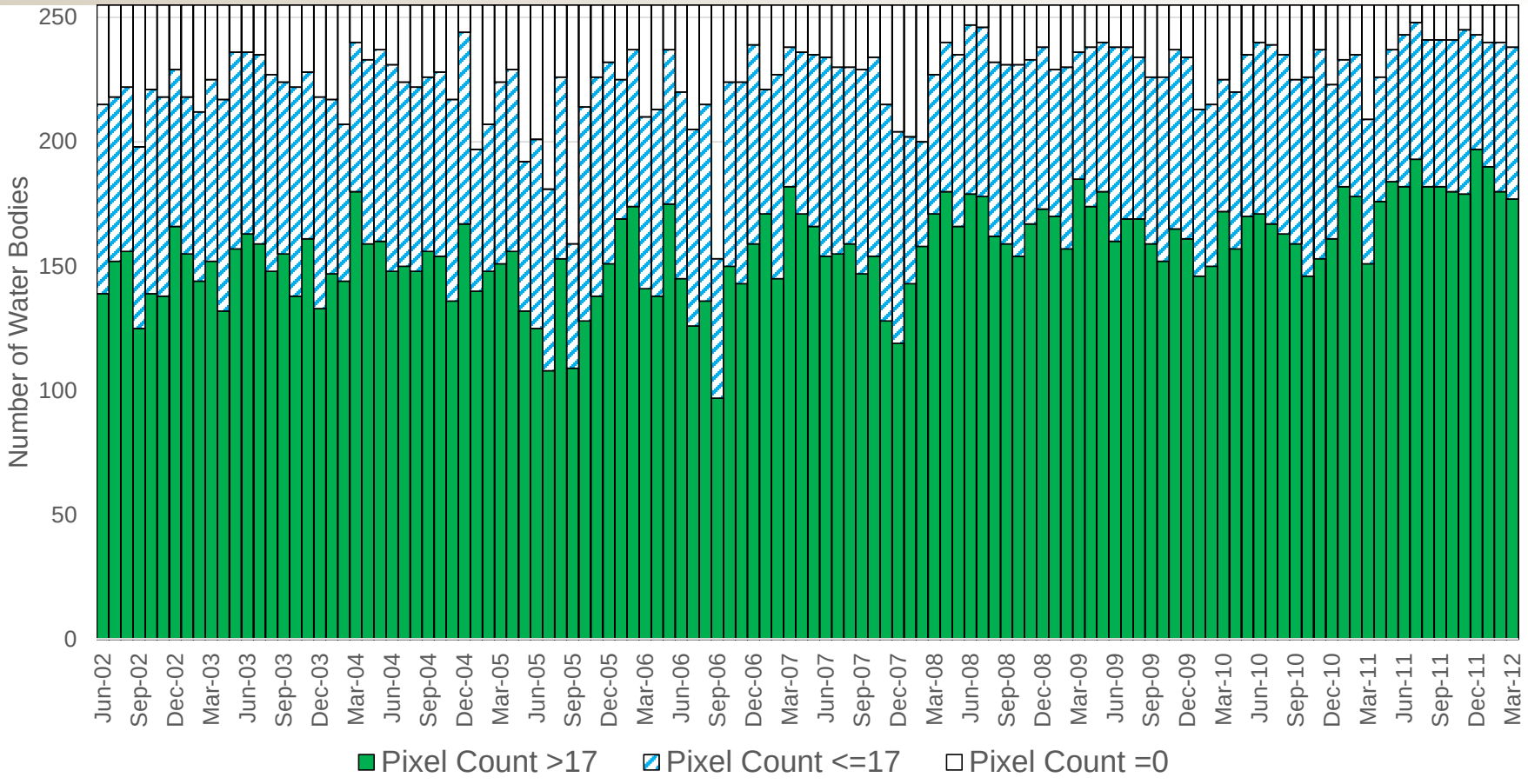


Statewide Summary

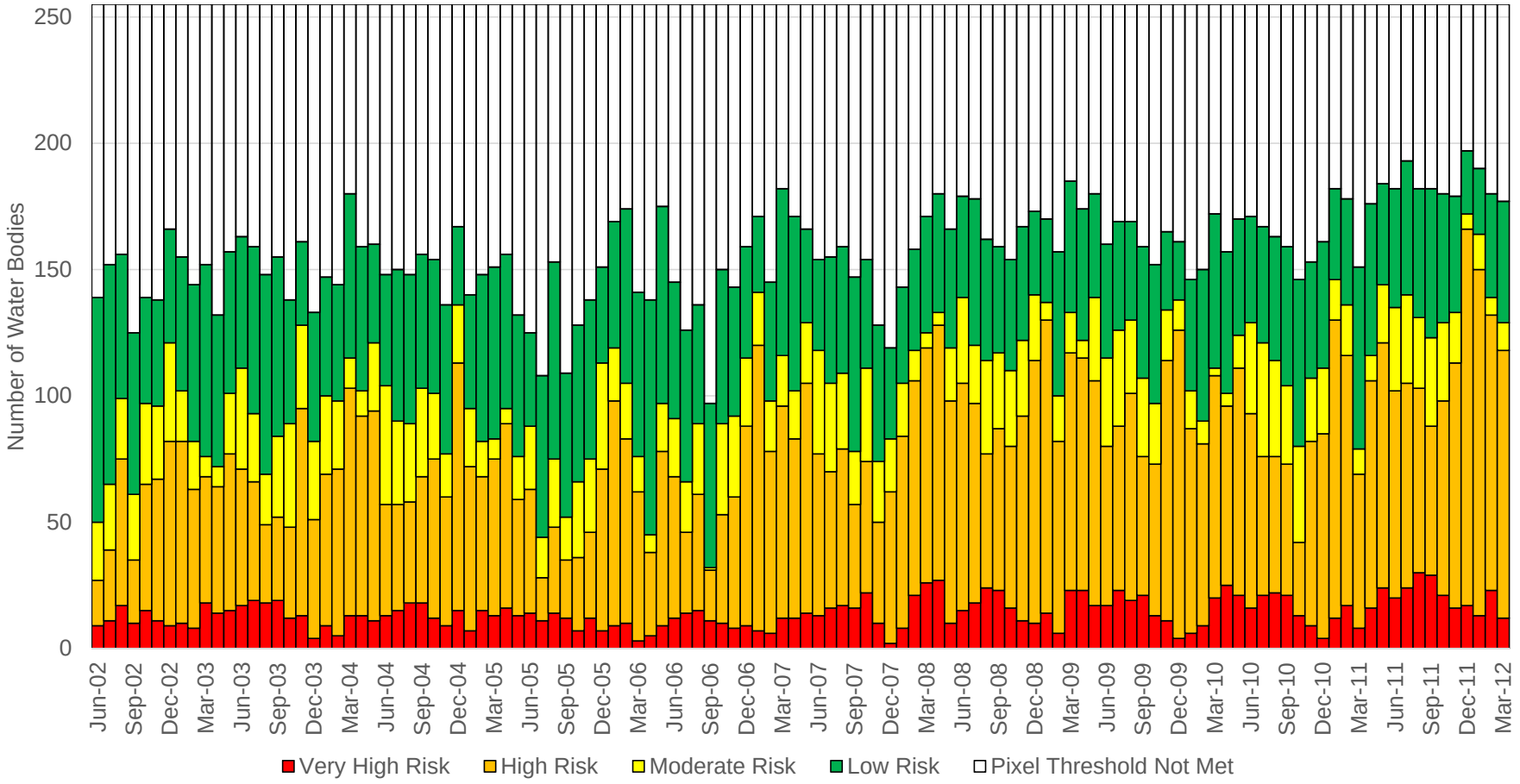
- 255 water bodies
- Monthly composites



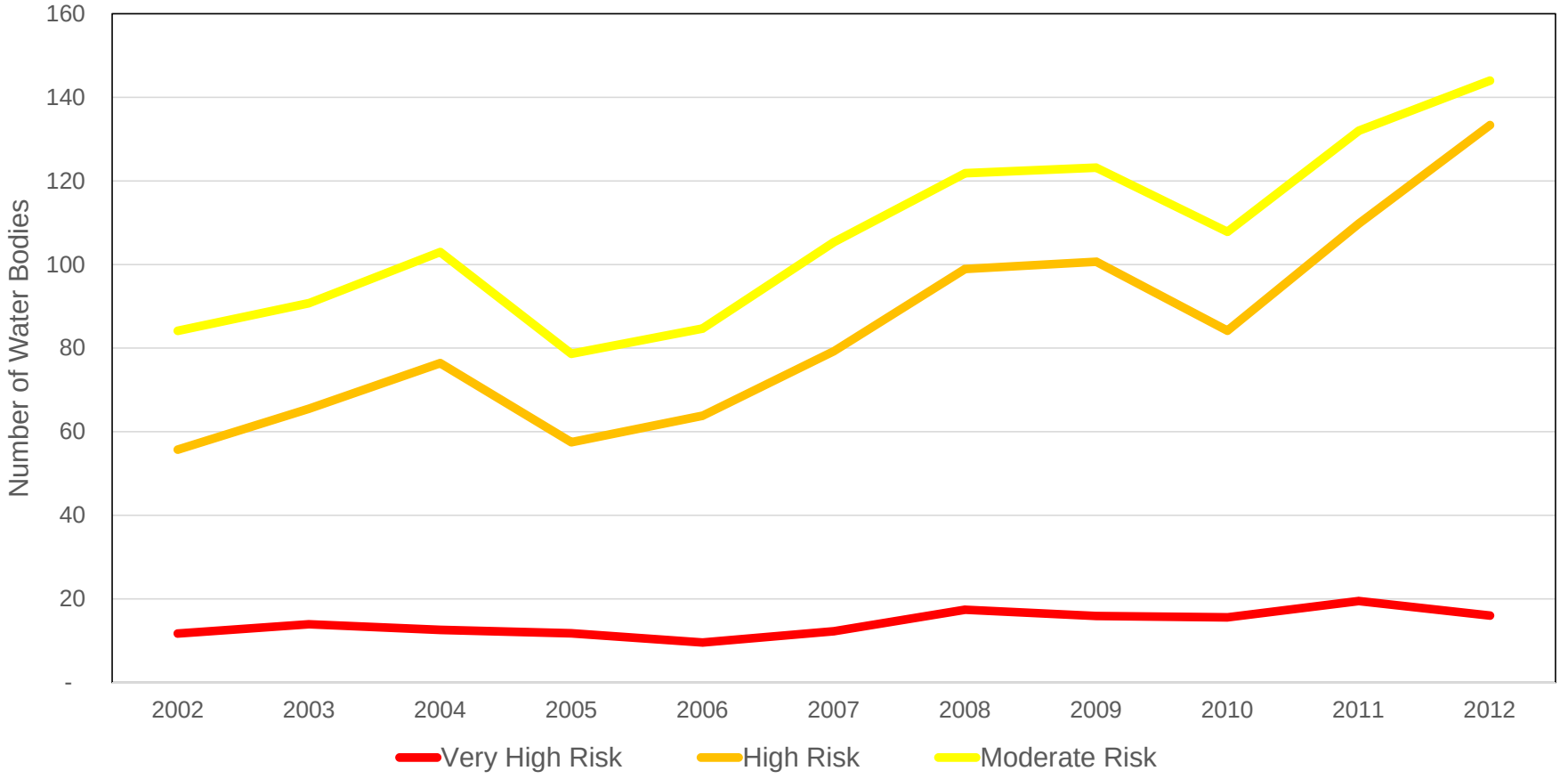
Monthly number of 255 water bodies where pixel counts are >17; <=17; or 0, from June 2002 to March 2012



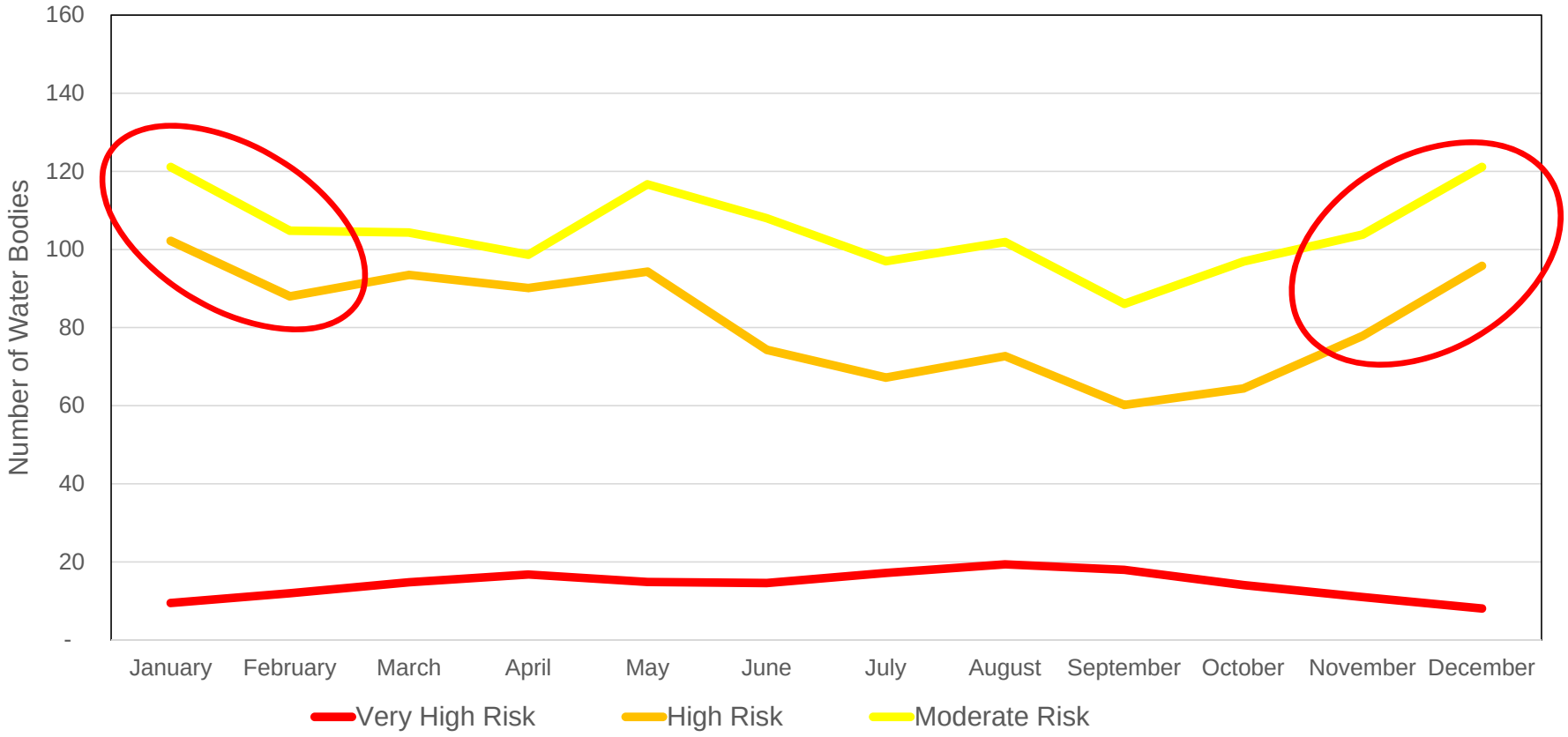
Number of water bodies where 90th percentile values within monthly composites xceed Moderate, High, or Very High Risk thresholds for June 2002 to March 2012



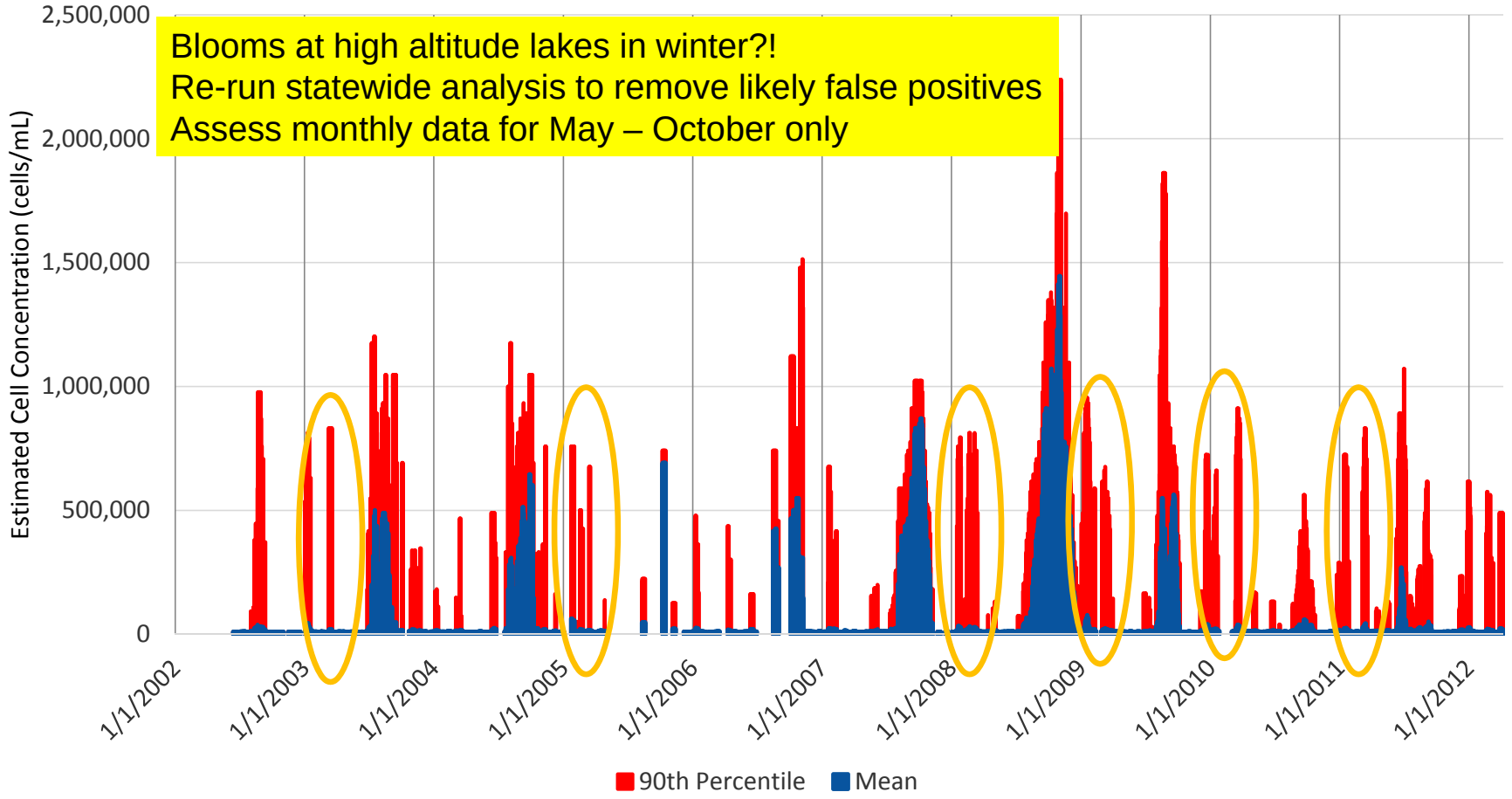
Annual average number of water bodies where 90th percentile concentration estimates within monthly composites exceed Moderate, High, or Very High thresholds for June, 2002- March 2012



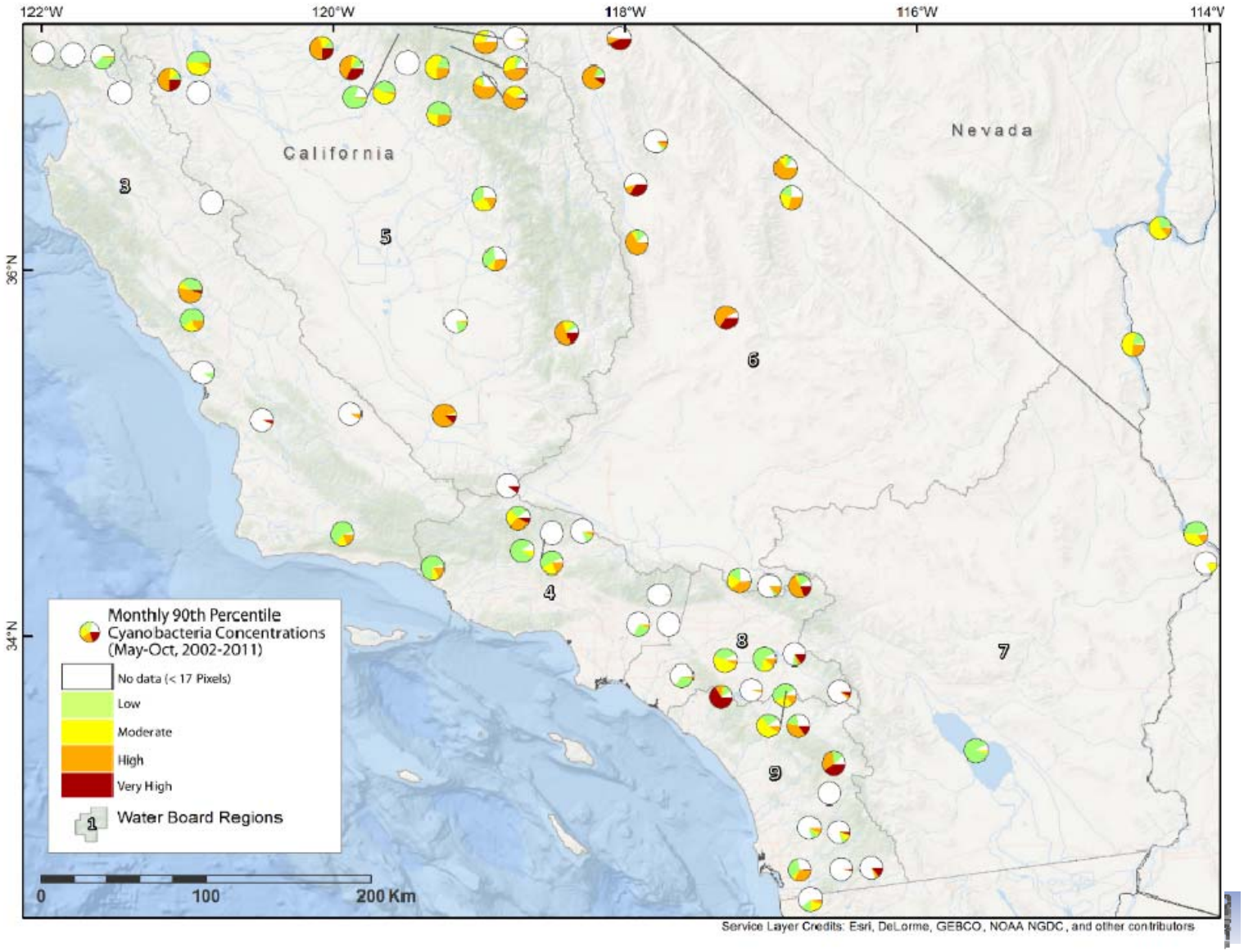
Monthly average number of water bodies where 90th percentile concentration estimates within monthly composites exceed Moderate, High, or Very High Risk thresholds, for June, 2002- March 2012



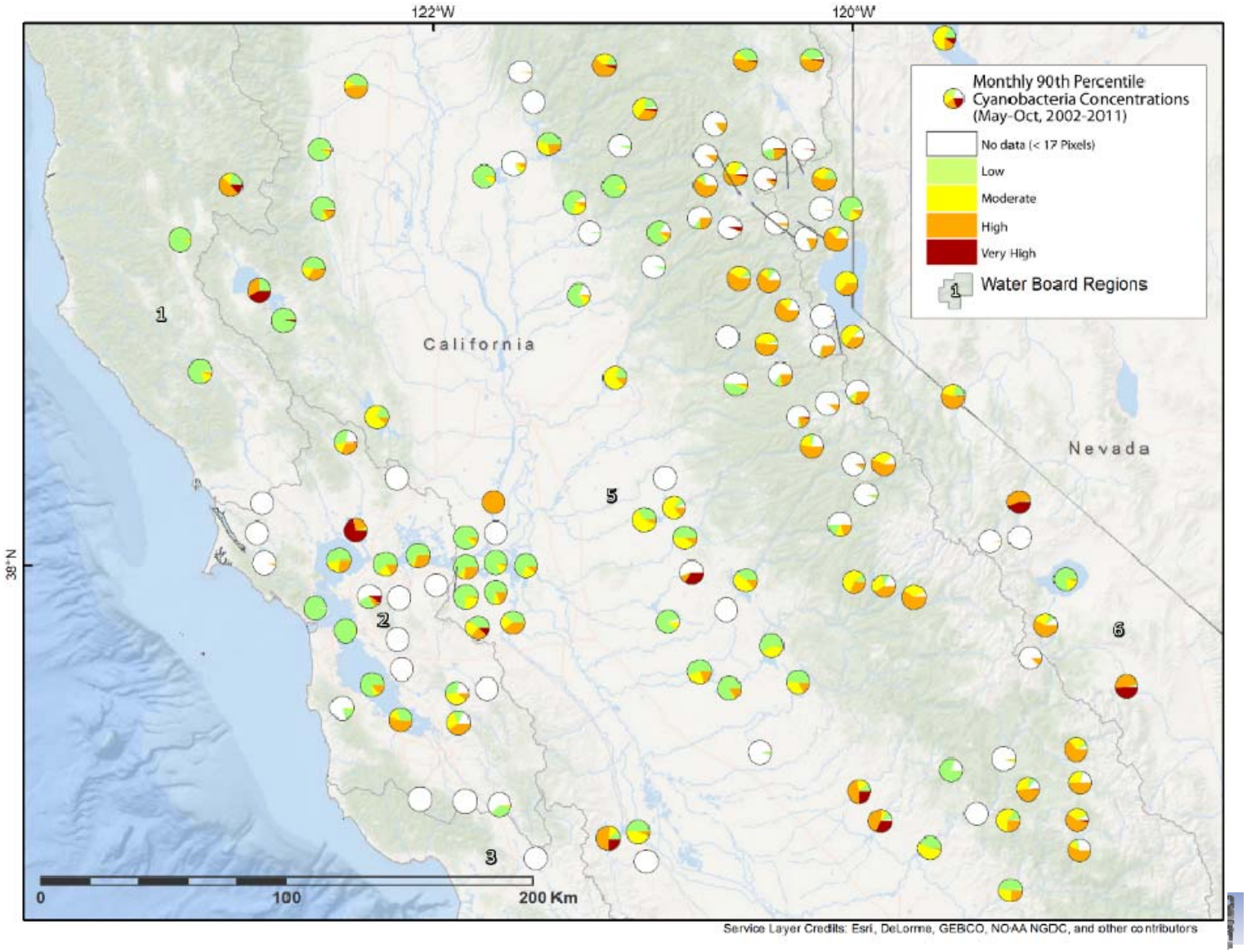
Mean and 90% percentile of max value for cyanobacteria cell concentration, estimated in Microcystis sp. equivalents (cells/mL) for Big Bear Lake, CA, 2002-2012



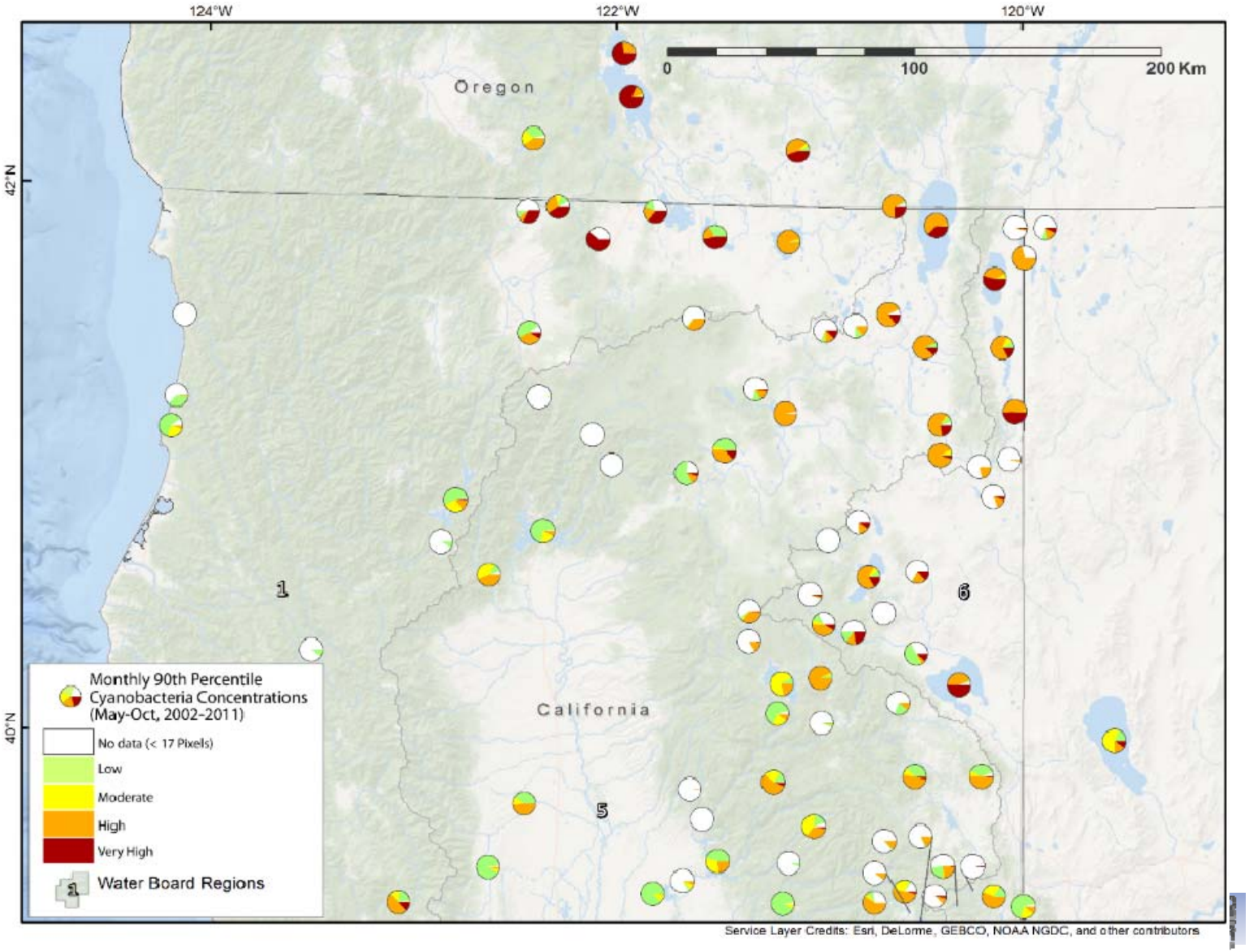
Monthly Exceedances (May - Oct) Southern California



Monthly Exceedances (May - Oct) Central California

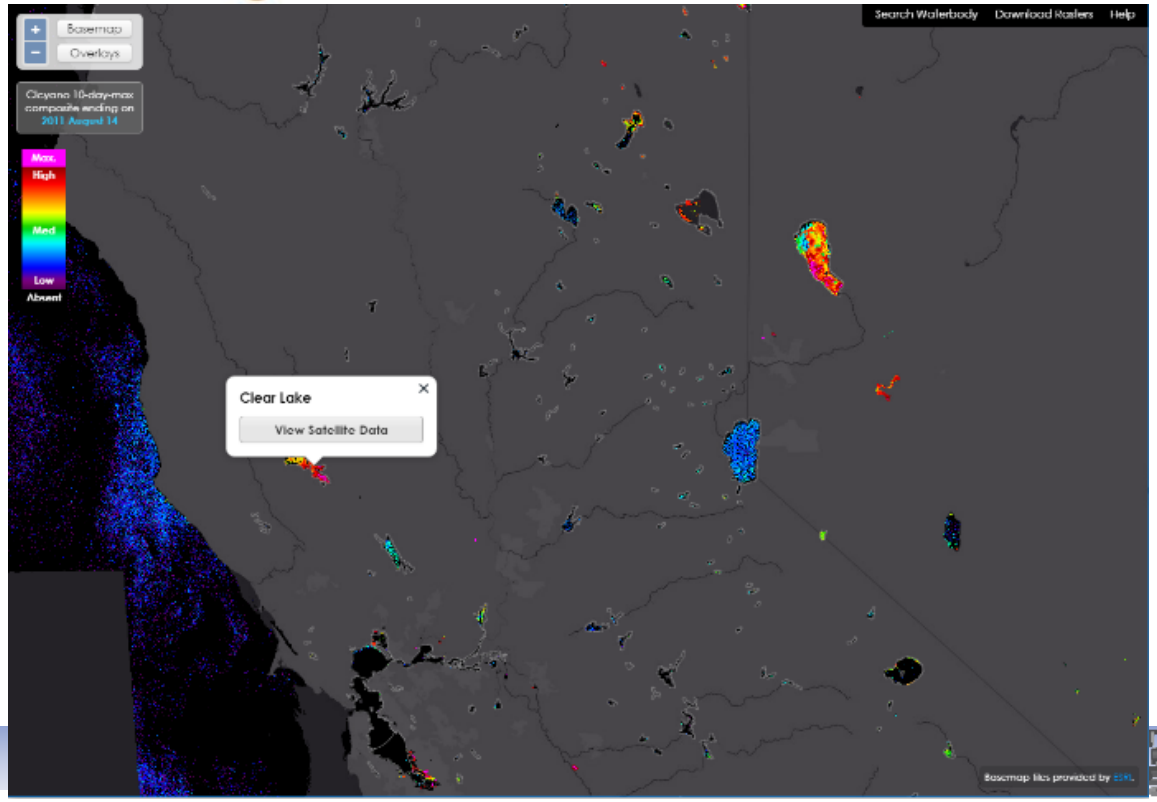


Monthly Exceedances (May - Oct) Northern California



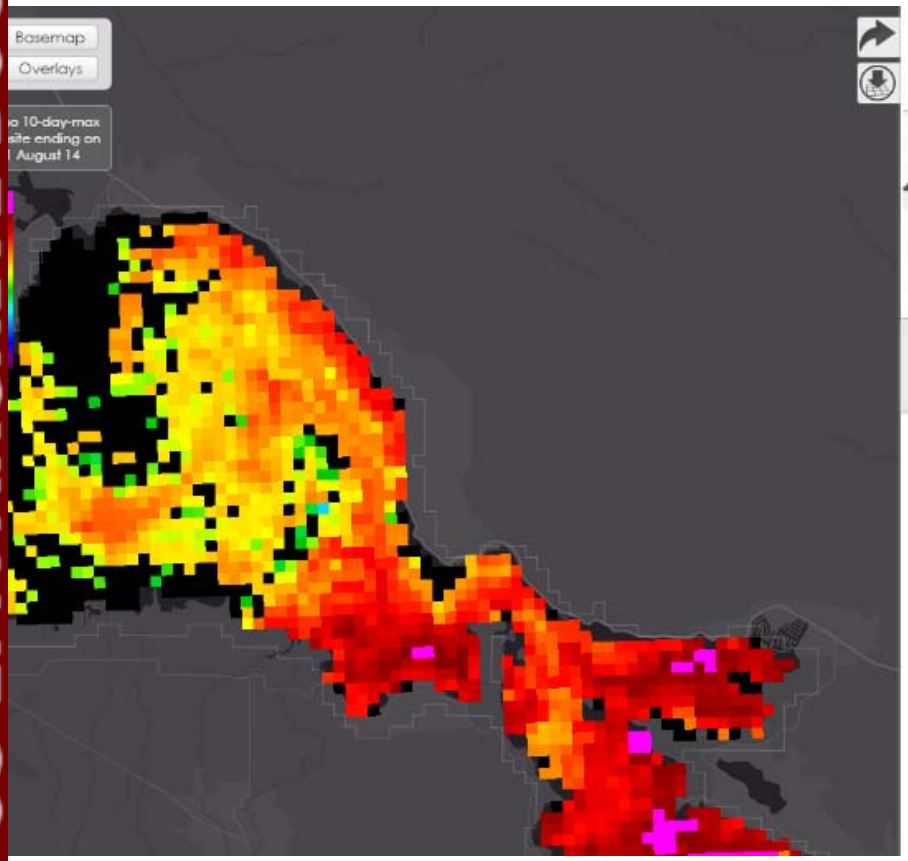
What do satellite images tell us about harmful algal blooms?

DRAFT CyanoHAB Satellite Imagery Analysis Tool



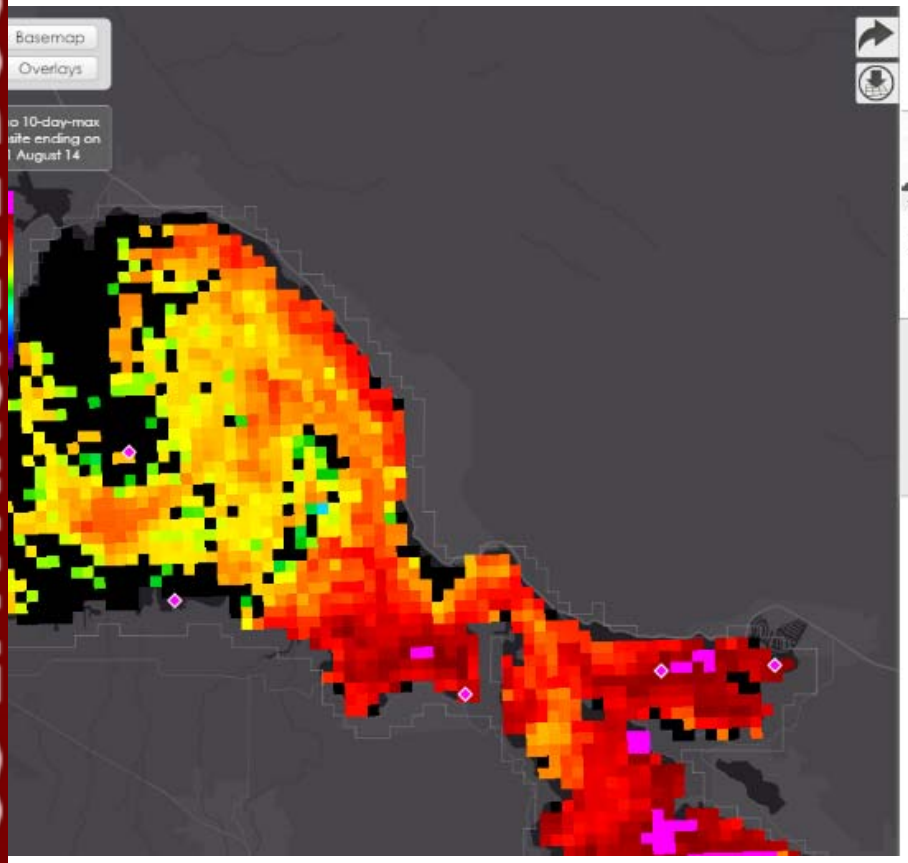
CyanoHAB Satellite Imagery Analysis Tool

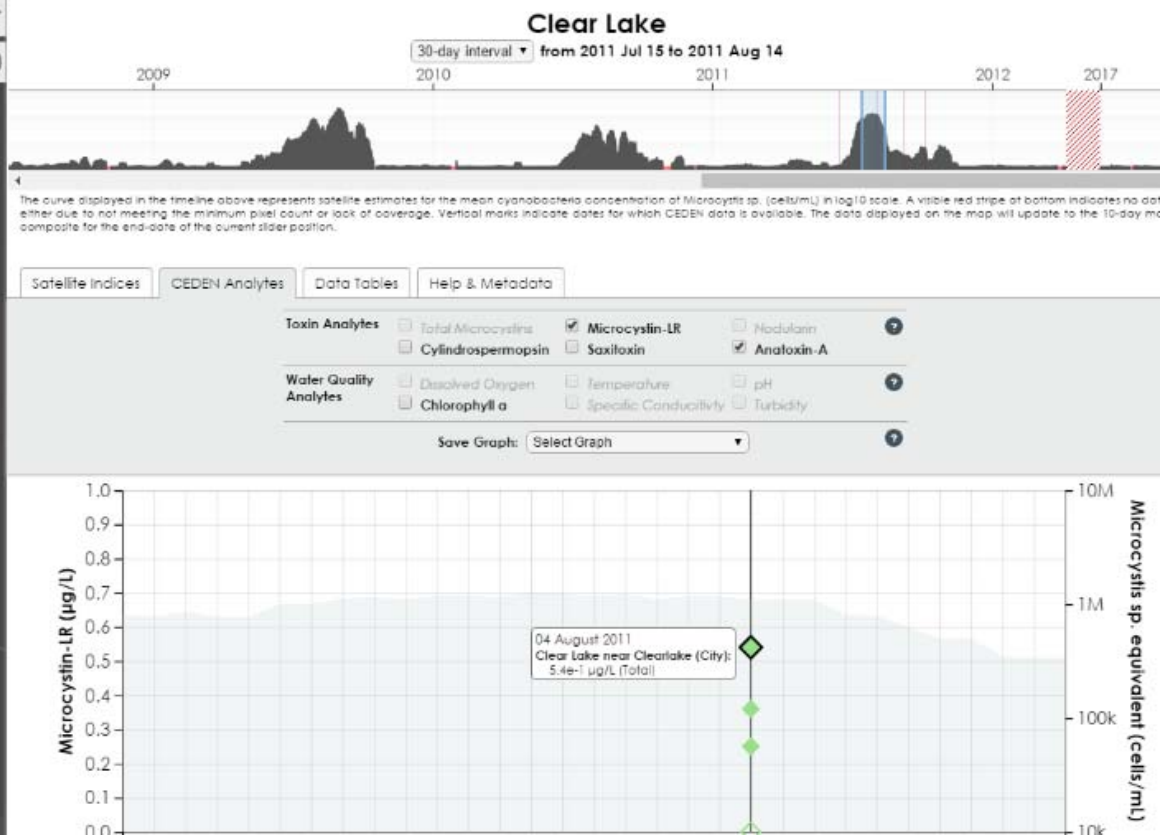
- Display spatial and time series data



CyanoHAB Satellite Imagery Analysis Tool

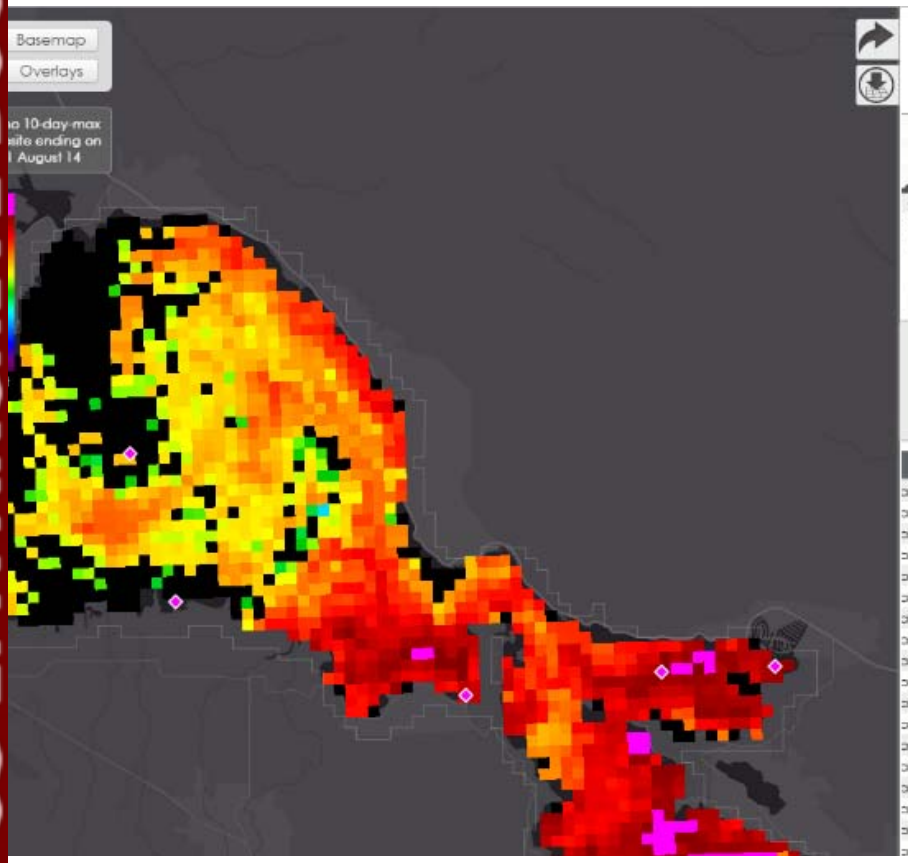
- Compare satellite data to WQ data in CEDEN

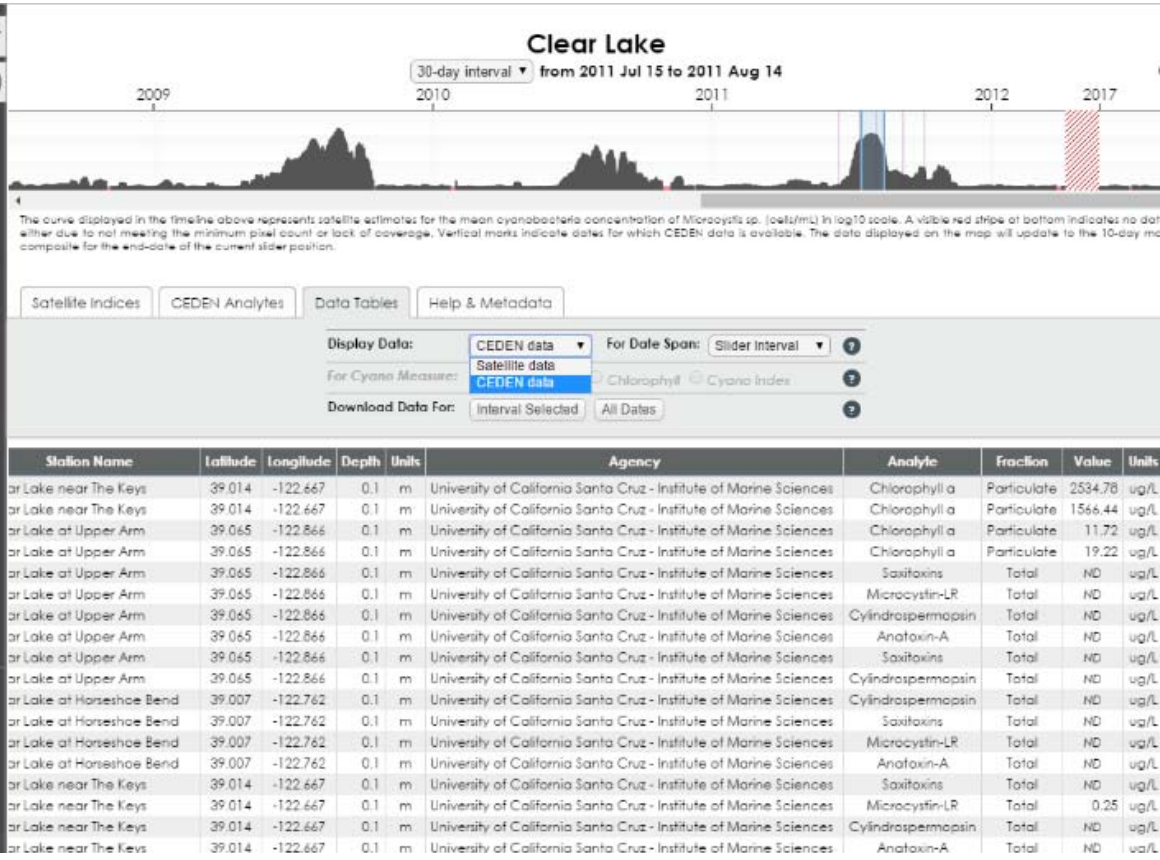




CyanoHAB Satellite Imagery Analysis Tool

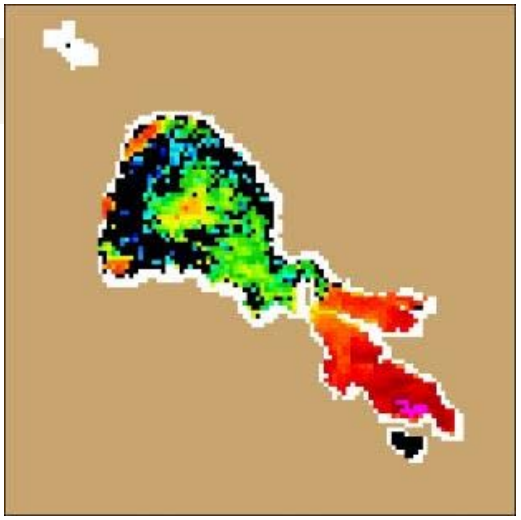
- Download satellite or CEDEN data





Station Name	Latitude	Longitude	Depth	Units	Agency	Analyte	Fraction	Value	Units
ar Lake near The Keys	39.014	-122.667	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Chlorophyll a	Particulate	2534.78	ug/L
ar Lake near The Keys	39.014	-122.667	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Chlorophyll a	Particulate	1566.44	ug/L
ar Lake at Upper Arm	39.065	-122.866	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Chlorophyll a	Particulate	11.72	ug/L
ar Lake at Upper Arm	39.065	-122.866	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Chlorophyll a	Particulate	19.22	ug/L
ar Lake at Upper Arm	39.065	-122.866	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Saxitoxins	Total	ND	ug/L
ar Lake at Upper Arm	39.065	-122.866	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Microcystin-LR	Total	ND	ug/L
ar Lake at Upper Arm	39.065	-122.866	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Cylindrospermopsin	Total	ND	ug/L
ar Lake at Upper Arm	39.065	-122.866	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Anatoxin-A	Total	ND	ug/L
ar Lake at Upper Arm	39.065	-122.866	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Saxitoxins	Total	ND	ug/L
ar Lake at Upper Arm	39.065	-122.866	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Cylindrospermopsin	Total	ND	ug/L
ar Lake at Horseshoe Bend	39.007	-122.762	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Cylindrospermopsin	Total	ND	ug/L
ar Lake at Horseshoe Bend	39.007	-122.762	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Saxitoxins	Total	ND	ug/L
ar Lake at Horseshoe Bend	39.007	-122.762	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Microcystin-LR	Total	ND	ug/L
ar Lake at Horseshoe Bend	39.007	-122.762	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Anatoxin-A	Total	ND	ug/L
ar Lake near The Keys	39.014	-122.667	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Saxitoxins	Total	ND	ug/L
ar Lake near The Keys	39.014	-122.667	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Microcystin-LR	Total	0.25	ug/L
ar Lake near The Keys	39.014	-122.667	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Cylindrospermopsin	Total	ND	ug/L
ar Lake near The Keys	39.014	-122.667	0.1	m	University of California Santa Cruz - Institute of Marine Sciences	Anatoxin-A	Total	ND	ug/L

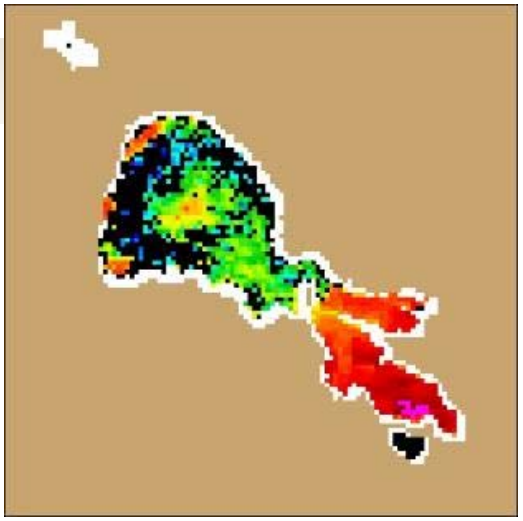
Satellites- What They Can't Do



Cyanobacteria blooms can be detected but…

- Clouds and glint block images
- Estimates all cyanobacteria (not just toxin producers)
- Doesn't measure toxin levels
- No direct comparisons to HAB thresholds
- Values are estimates (NOAA recommends +-15% uncertainty)
- Less confidence with data for lowest concentration
- False positives can occur
- Limited to large lakes (currently)

Satellites- What They Can Do

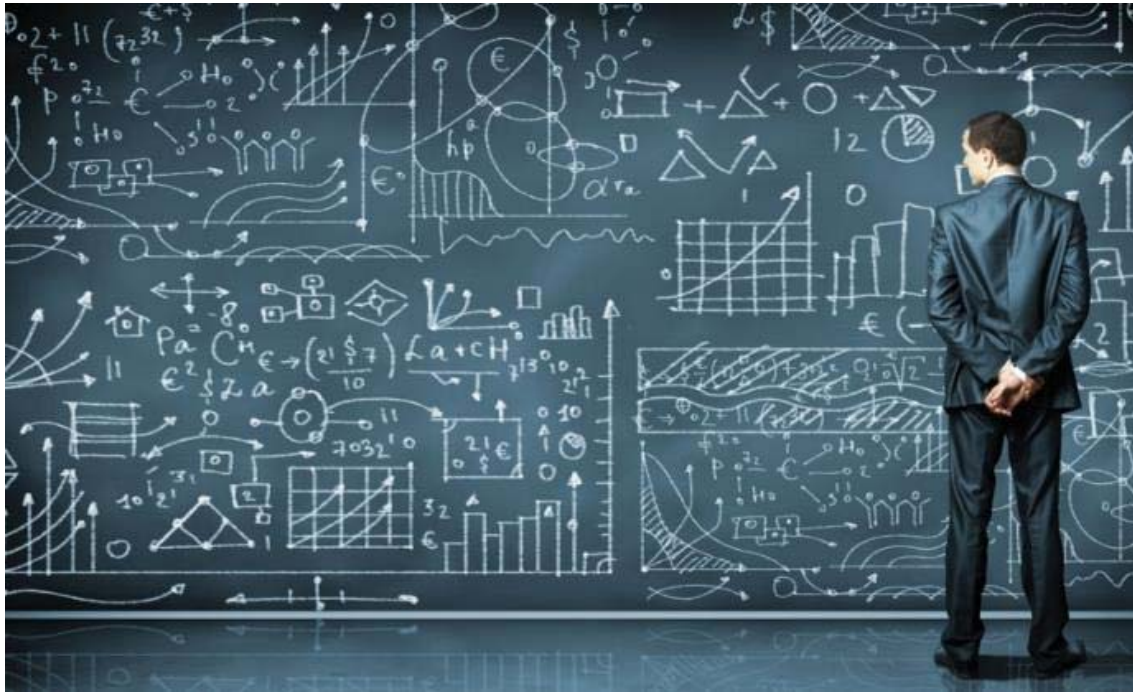


- Cyanobacteria blooms can be detected and…
  - Provide understanding of bloom conditions from 2002-2012
    - Identify trends and severity of blooms
  - Data can help understand bloom drivers, management
  - Screening tool- Monitor ~150 waterbodies in CA at once
  - Inform public about changing bloom status and location
  - Communicate data to help guide event response monitoring by:
    - Water body managers
    - County public health officials
    - Others involved in management or response

SWAMP needs YOUR contact information!

Further Research Needed

- Continue testing satellite data for interference:
  - Snow/ice?
  - Alkali lakes?
  - Halobacteria? (Owens Lake)
  - Clear water? (Lake Tahoe)
- Satellite raster data is available through SFEI. Compare against:
  - Water quality/cyanoHAB data
  - Weather
  - Inflow/lake levels
  - Geology
  - 303 (d) listings
  - Etc.



Questions?

Rick Stumpf
NOAA
richard.stumpf@noaa.gov

Randy Turner
San Francisco Estuary Institute
randyt@sfei.org
707-499-5521