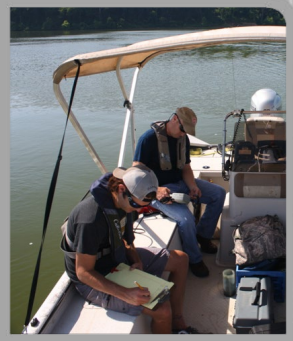
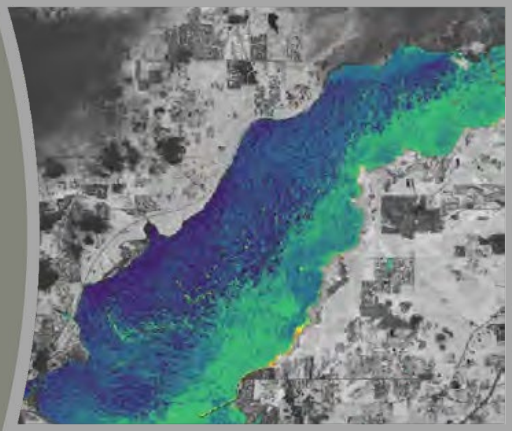
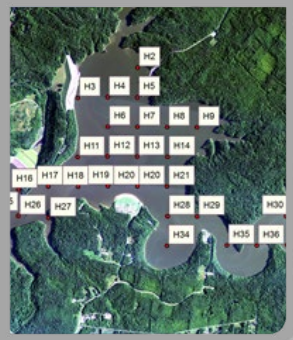
Remote Sensing Software Tools to Assist USACE Water Quality Monitoring







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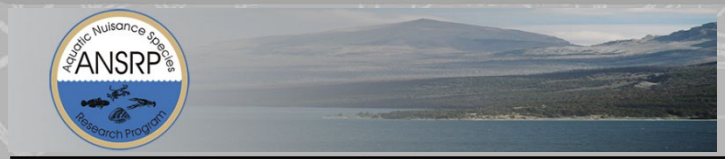
US Army Engineer Research and Development Center, Environmental Laboratory

[3]Water Quality Specialist, Great Lakes & Ohio River Division

26 January 2022



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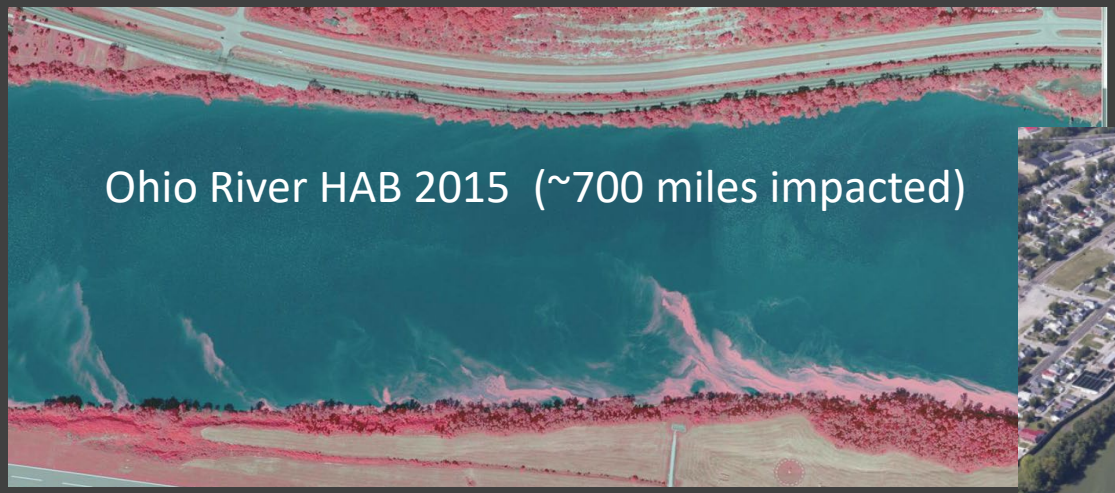
Presentation Outline

- **Harmful Algal Blooms (HABs)/USACE Water Quality Monitoring**
- **Project Goal**
- **Foundational Research**
- **Overall Approach to Tool Development**
- **Software Tool Highlights**
- **Benefits to USACE**
- **Future Work & Webinars**

Photo Credit: USACE Philadelphia District, 2019

HABs

- US has spent **>$1 billion** since 2010 to treat/prevent toxic algae outbreaks*
- Even higher price tag for economic losses due to HAB impacts to recreation, tourism, commercial fishing, and human/wildlife health
- Global decline in water quality with increasing HAB frequency, duration, and extent



Ohio River HAB 2015 (~700 miles impacted)

* Analysis conducted by the Environmental Working Group, 2020; The High Cost of Algae Blooms in U.S. Waters: More Than $1 Billion in 10 Years (ewg.org)

USACE Water Quality Monitoring

- USACE districts develop individual water quality programs/plans
- Traditional monitoring can be labor-intensive and limited to discrete data at a single point in space/time, making it difficult to characterize an entire waterbody

- **PROBLEM:** Diminishes the ability to proactively detect and manage HABs
- Failure to meet mission requirements could lead to limited project uses, aquatic life impairment, public complaints, increased risk to the public and possible legal actions against the USACE

Project Goal

- **GOAL:** Build on foundational research to develop remote sensing software tools to estimate water quality indicators of HABs, focusing on small, inland waterbodies in support of USACE water quality monitoring
- **WHY:** Software tools are needed to assist USACE with the challenge of monitoring hundreds of inland lakes and reservoirs that cover vast geographic areas, in which limited resources can lead to reactionary responses to HAB outbreaks

Foundational Research

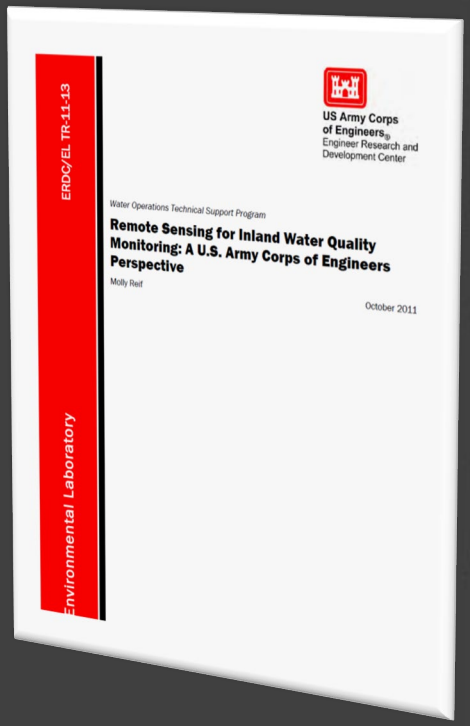
- ERDC Water Operations Technical Support (WOTS) request (2010)

  Remote Sensing for Inland Water Quality Monitoring: A U.S. Army Corps of Engineers Perspective

- Statement of Need (SoN) submitted by LRD to Civil Works R&D (2012)

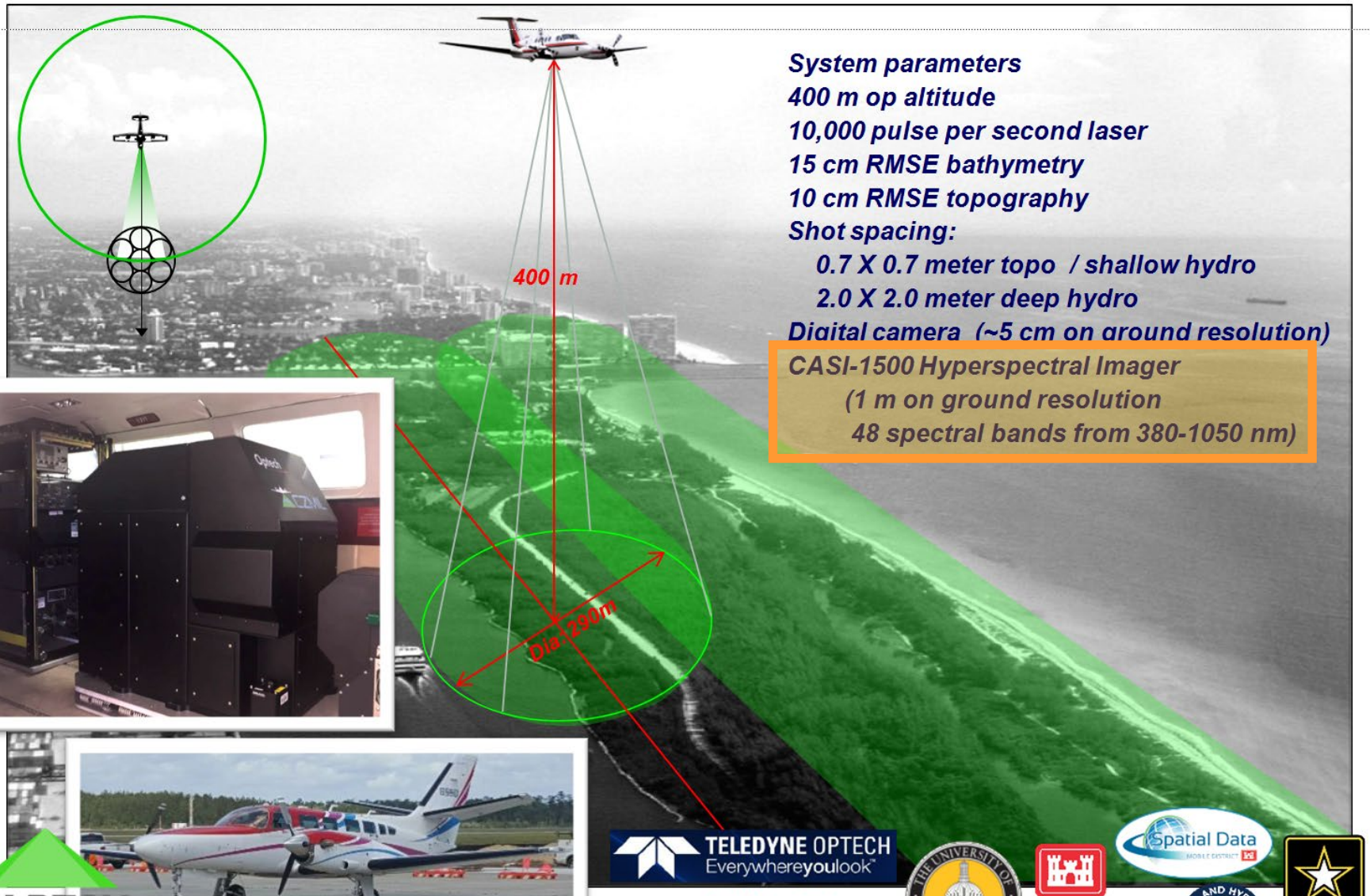
- **Support LRD's water quality monitoring program**
  - Assess airborne hyperspectral and synthetic satellite imagery to identify water quality indicators of HABs
  - Evaluate remote sensing to help prioritize field-based monitoring and provide early warning system

- **Pilot Demonstration:**
  - Coordinate airborne image surveys and field sampling:
    - Taylorsville Lake, KY: June 18 2014
    - Harsha (East Fork) Lake, OH: June 27 2014
  - Develop and refine algorithms to estimate HAB indicators: chlorophyll-a (chl-a), phycocyanin (a proxy for cyanobacterial or blue-green algal biomass), and turbidity



Reif, M. 2011. Remote Sensing for Inland Water Quality Monitoring: A U.S. Army Corps of Engineers Perspective. ERDC/EL TR-11-13. *WOTS Technical Report Collection*. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

CZMIL Coastal Zone Mapping and Imaging Lidar



System parameters
400 m op altitude
10,000 pulse per second laser
15 cm RMSE bathymetry
10 cm RMSE topography
Shot spacing:
0.7 X 0.7 meter topo / shallow hydro
2.0 X 2.0 meter deep hydro
Digital camera (~5 cm on ground resolution)
CASI-1500 Hyperspectral Imager
(1 m on ground resolution
48 spectral bands from 380-1050 nm)

JALBTCX

TELEDYNE OPTECH Everywhereyoulook

Spatial Data

US Army Corps of Engineers

U.S.ARMY

WMR 532

Jennifer.M.Wozencraft@usace.army.mil 228-806-6044

Pilot Demonstration Project

- **Many partners for coordinated airborne and field surveys:**
  - LRD, LRL, LRH, Univ. of Cincinnati, US EPA, Kentucky Div. of Water, ERDC, and JALBTCX

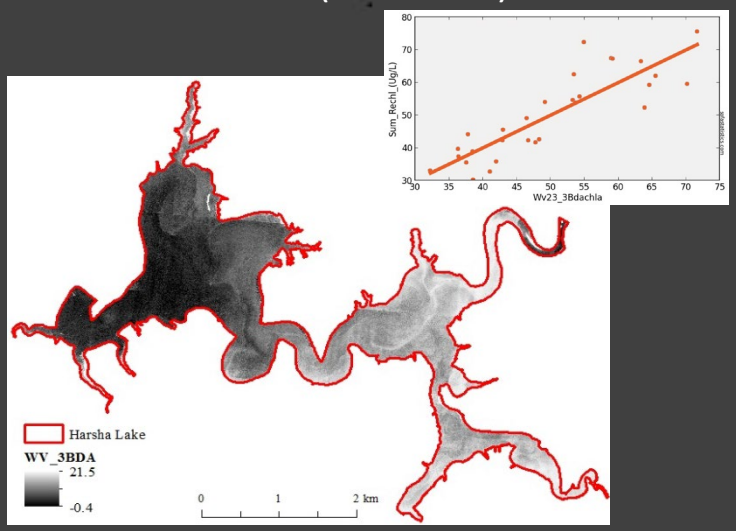
- **Field Samples:**
  1. Water samples for lab analysis by US EPA
  2. In situ sensor measurements of Chl-a, Phycocyanin, Turbidity, Specific Conductance, pH, water temperature, dissolved oxygen, and Secchi Depth

- **Analysis Approach:**
  - Airborne imagery used to create synthetic satellite imagery
  - Algorithms used to estimate HAB indicators
  - Regression tests compared water measurements (observed) with image-estimations (predicted)

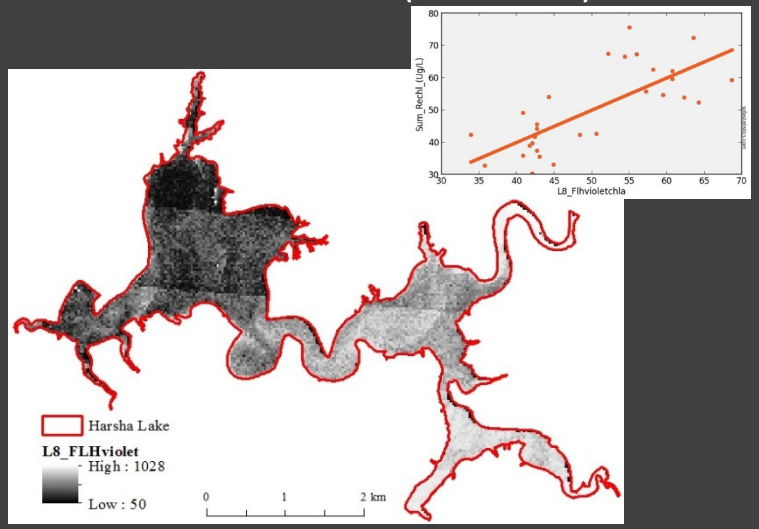
Pilot Demonstration Project: Chl-a

- Apply many existing and new algorithms to test efficacy for estimating chl-a

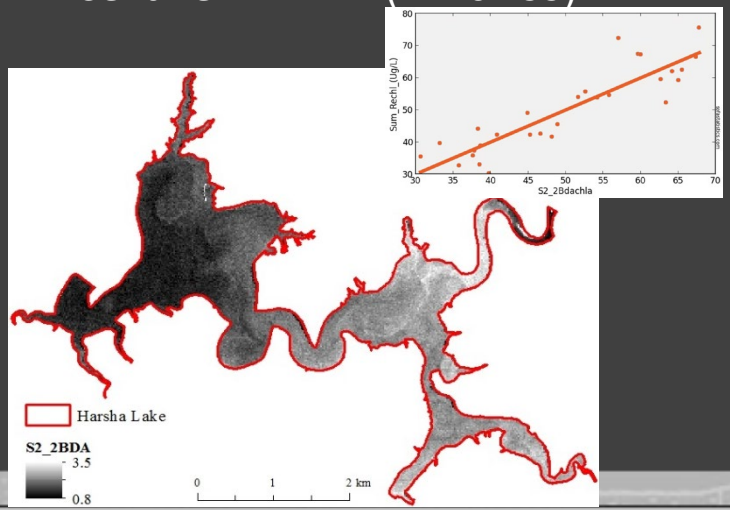
WV-2: 3BDA (r^2 = 0.741)



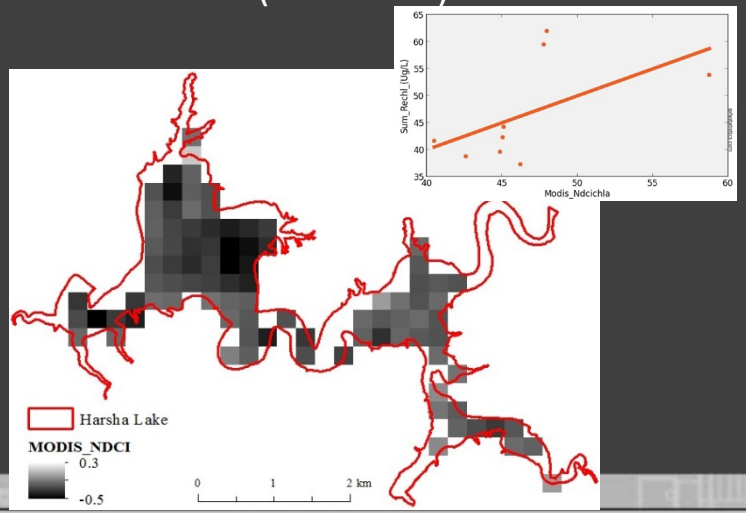
Landsat-8: FLH Violet (r^2 = 0.548)



Sentinel-2: 2BDA (r^2 = 0.799)



MODIS: NDCI (r^2 = 0.301)



10 papers from foundational research!

Beck et al., 2016. Comparison of satellite reflectance algorithms for estimating chlorophyll-a in a temperate reservoir using coincident hyperspectral aircraft imagery and dense coincident surface observations, Remote Sensing of Environment, vol. 178, 01 June 2016, pages 15-30.

Beck et al., 2017. Comparison of satellite reflectance algorithms for estimating phycocyanin in a temperate reservoir using coincident hyperspectral aircraft imagery and dense coincident surface observations, Remote Sensing, vol. 9, pages 1-30.

Johansen et al., 2018. Evaluating the portability of satellite derived chlorophyll-a algorithms for temperate inland lakes using airborne hyperspectral imagery and dense surface observations, Harmful Algae, vol. 76, 35-46.

Beck et al., 2018. Adapting Low-Cost Drone Technology to CubeSats for Environmental Monitoring and Management: Harmful Algal Bloom Satellite-1 (HABsat-1), Proceedings of the 32nd, Annual AIAA/USU Conference on Small Satellites ("SmallSat") 2018, 12 pages.

Xu et al., 2018. A spectral space partition guided ensemble method for retrieving chlorophyll-a concentration in inland waters from Sentinel 2A satellite imagery. Journal of Great Lakes Research, 45, 454-465.

Johansen et al., 2019. HABSat-1: Assessing the feasibility of using CubeSats for the detection of cyanobacterial harmful algal blooms in inland lakes and reservoirs. Lake and Reservoir Management, pp.1-15.

Xu et al., 2019. Regionally and locally adaptive models for retrieving chlorophyll-a concentration in inland waters from remotely sensed multispectral and hyperspectral imagery. IEEE Transactions on Geoscience and Remote Sensing, 57(7), pp. 4758-4774.

Beck et al., 2019. Comparison of satellite reflectance algorithms for estimating turbidity and cyanobacterial concentrations in productive freshwaters using hyperspectral aircraft imagery and dense coincident surface observations. Journal of Great Lakes Research, 45, 413-433.

Wang, et al. 2020. Mapping Freshwater Chlorophyll-a Concentration at a large regional scale by integrating multi-sensor satellite observations with Google Earth Engine. Remote Sensing, 12(20): 3278.

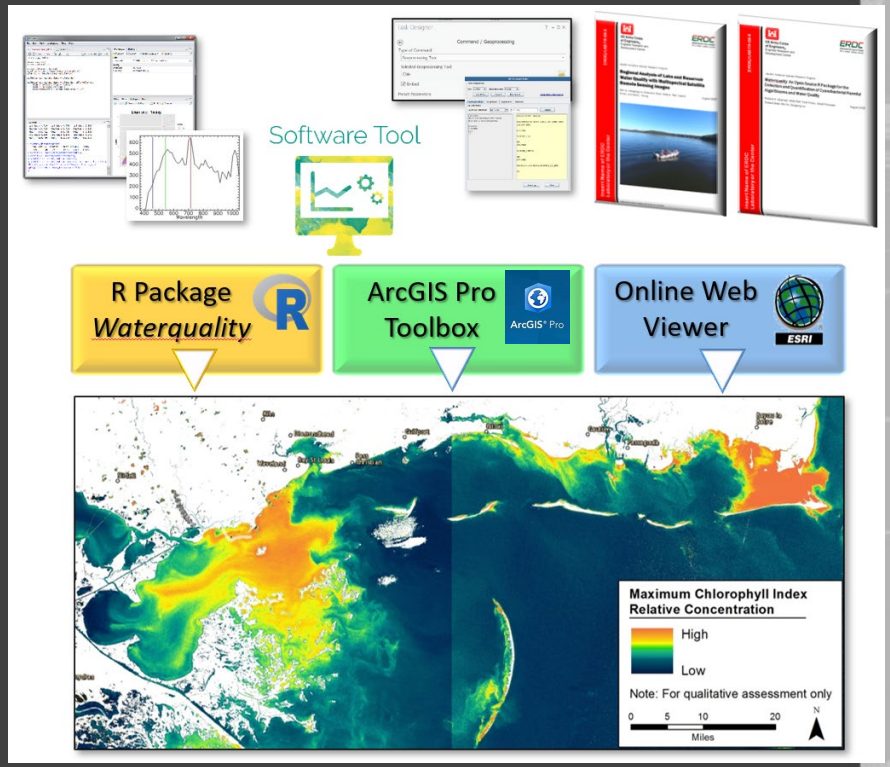
Xu et al., 2022. "Implementation Strategy and Spatiotemporal Extensibility of Multipredictor Ensemble Model for Water Quality Parameter Retrieval With Multispectral Remote Sensing Data," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 60, pp. 1-16.

Overall Approach to Tool Development

Develop satellite image-based tools to estimate potential HAB indicators: 1) chlorophyll-a, 2) phycocyanin, a proxy for cyanobacterial or blue-green algal biomass, and 3) turbidity

Array of software options to accommodate broad user base and skills:

1. Open-source **R software package**, a U. of Cincinnati collaboration and most extensive option for developing image-based abundance maps of HAB indicators
2. Python-based **ArcGIS Pro toolbox** with pre-set menus and limited options to streamline HAB indicator estimation
3. Online ESRI **Web app** for constrained options to rapidly screen for potential HAB conditions



R-Package, *waterquality*

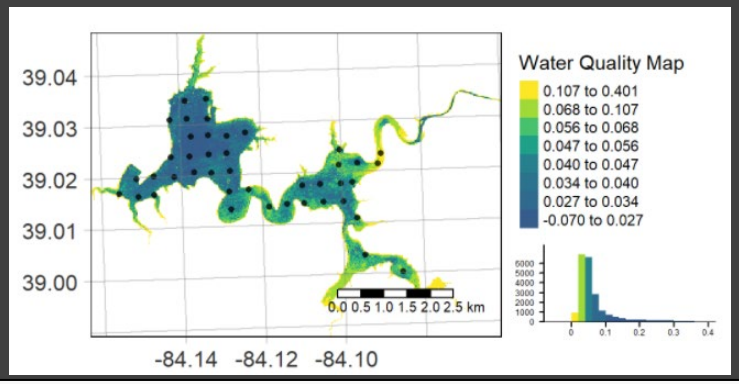
CRAN 0.2.6 | build error | codecov 17% | downloads 14K

- Open-source tool to aggregate a near-comprehensive list of water quality algorithms for comparison across multiple satellite imagers
- Computationally intense: 45 algorithms, 6 sensors, 3 water quality parameters
- New map functions to produce abundance maps, graphs, and statistical outputs

R-package, waterquality: https://github.com/RAJohansen/waterquality

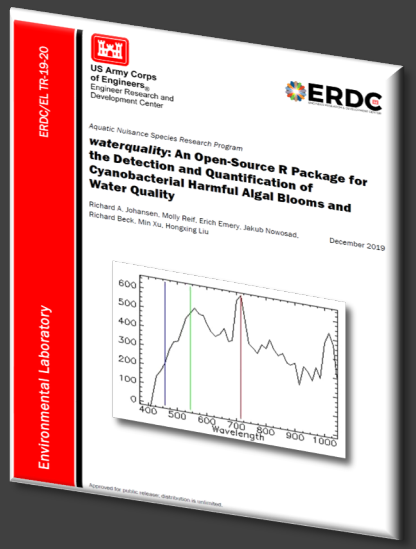
Report and User-guide: http://dx.doi.org/10.21079/11681/35053

Recorded webinar materials available on the WQ sharepoint site and GitHub



R_Squared	Slope	Intercept	P_Value	CV_R_Squared	RMSE	MAE
<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
0.162	26.2	4.69	0.153	0.514	1.87	1.41

Map, graph and statistical output from the R package, waterquality, illustrating conditions at Harsha (East Fork) Lake, OH



ArcGIS Pro *waterquality* Toolbox

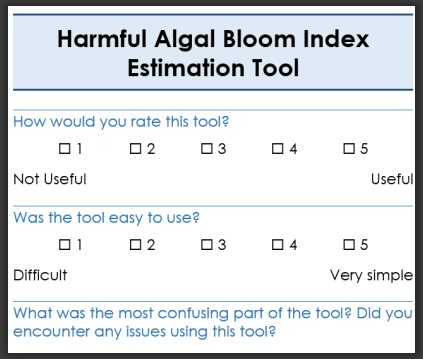
- Python-based toolbox for use in ESRI ArcGIS Pro desktop 2.7 and greater
- Uses Sentinel-2 satellite imagery with pre-set menus and constrained options to produce image-based abundance maps
- Toolbox includes 4 components to streamline analysis and product development
- Beta-tested by users from USACE Districts and external collaborators at NOAA

ArcGIS Pro toolbox, draft User-Guide, and sample data available on the ERDC Knowledge Core!

http://dx.doi.org/10.21079/11681/42240

Tool Requirements:

- ArcGIS Pro 2.7
- Advanced License
- Spatial Analyst Extension
- Python 3.7
- Sentinelsat Python Library



Harmful Algal Bloom Index Estimation Tool

How would you rate this tool?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

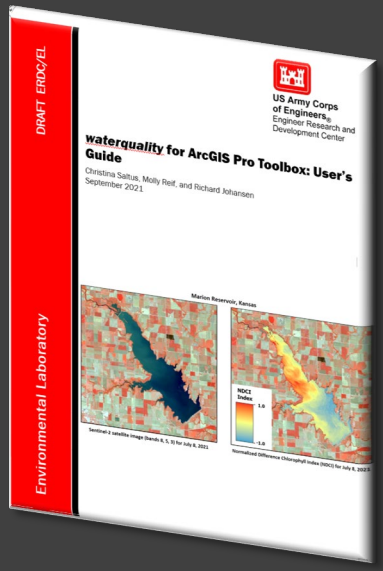
Not Useful — Useful

Was the tool easy to use?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Difficult — Very simple

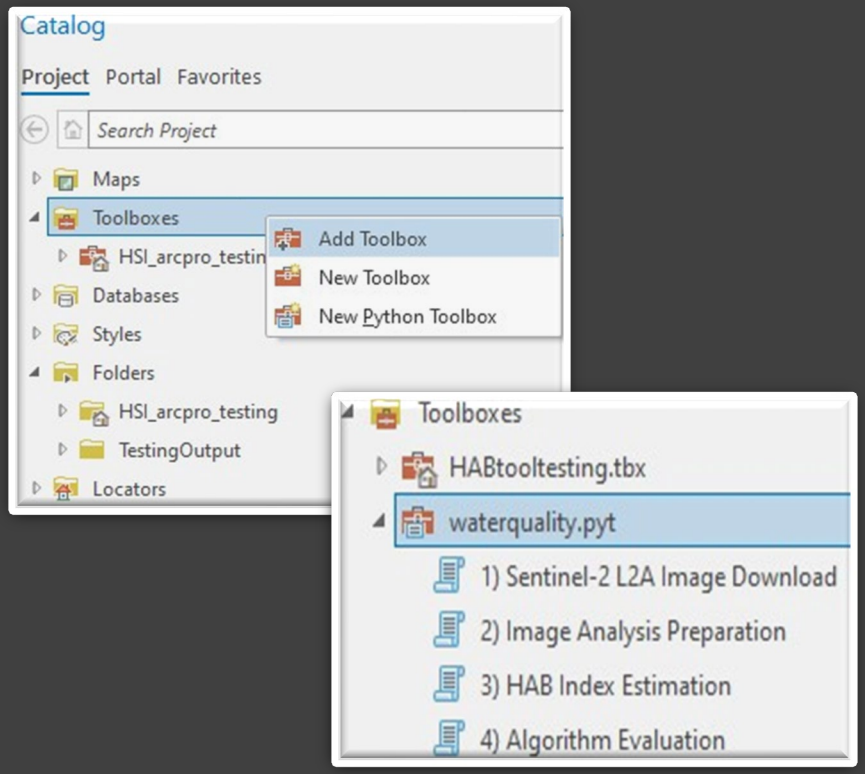
What was the most confusing part of the tool? Did you encounter any issues using this tool?



ArcGIS Pro *waterquality* Toolbox

Data inputs:

- Sentinel-2 satellite imagery
- Area of interest polygon
- In situ data – csv format

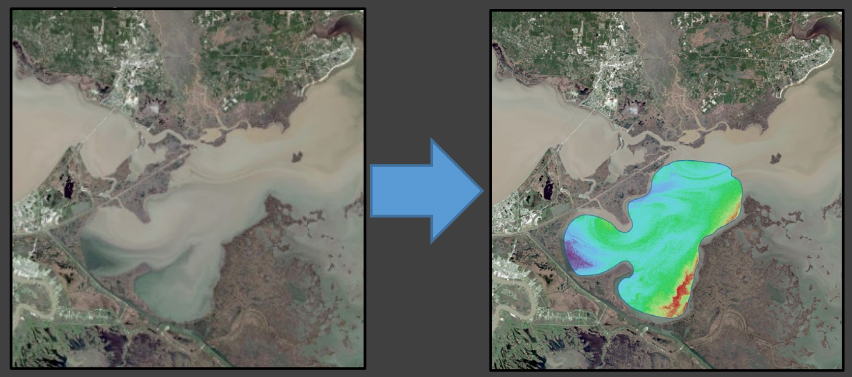


Available Tools:

1. Sentinel-2 L2A image download
2. Automates creation of composite Sentinel-2 L2A image (cloud and land masks)
3. Estimates HAB water quality indicator using 6 well-known indices
4. Converts estimated values using a regression model and in situ measurements

Output:

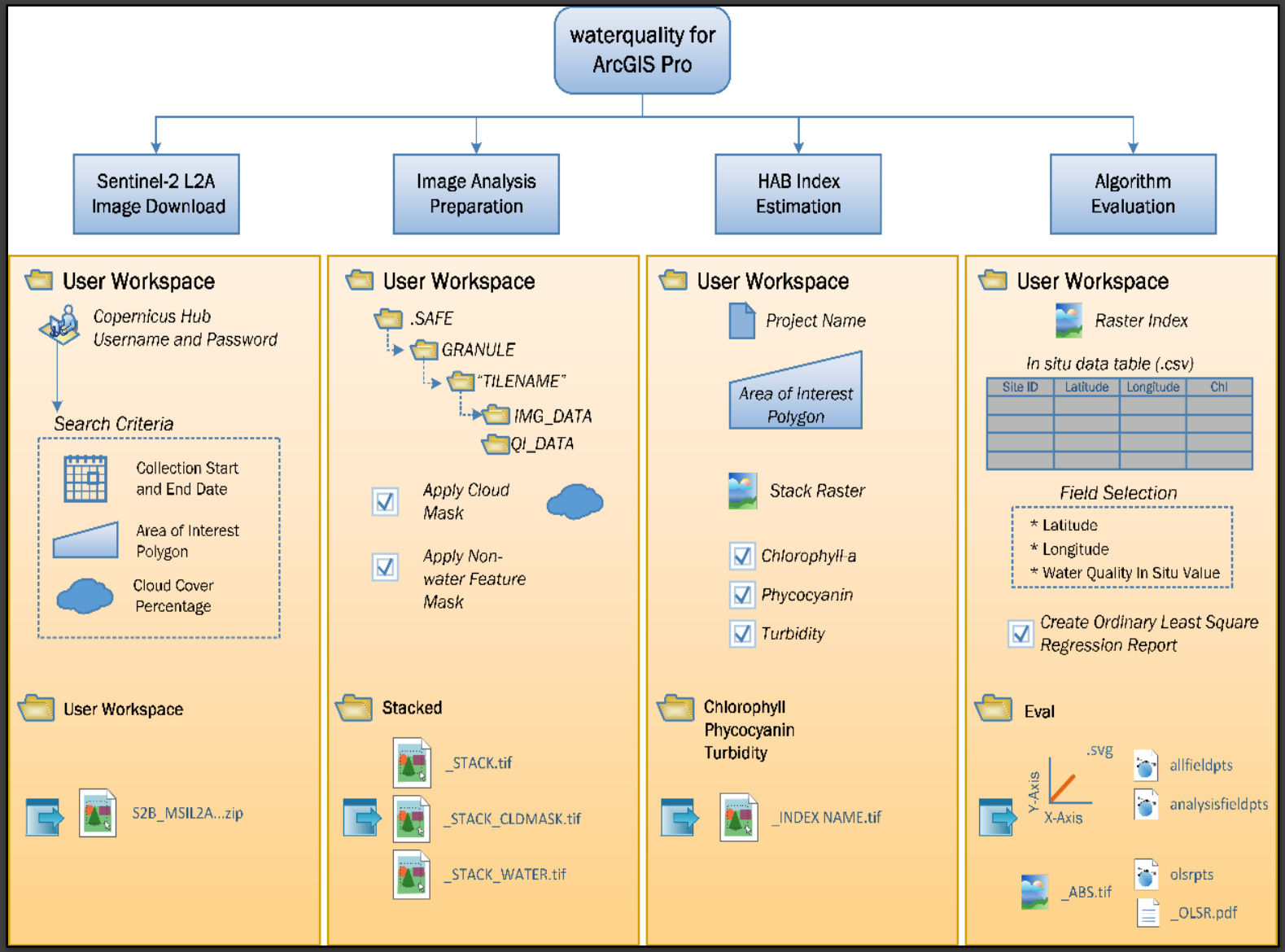
- Water quality index raster
- CSV file of estimated concentration



Sentinel-2
Lake Borgne, LA

Gi033BDA
Chlorophyll Index

waterquality for ArcGIS Pro toolbox: 4 tools in one!



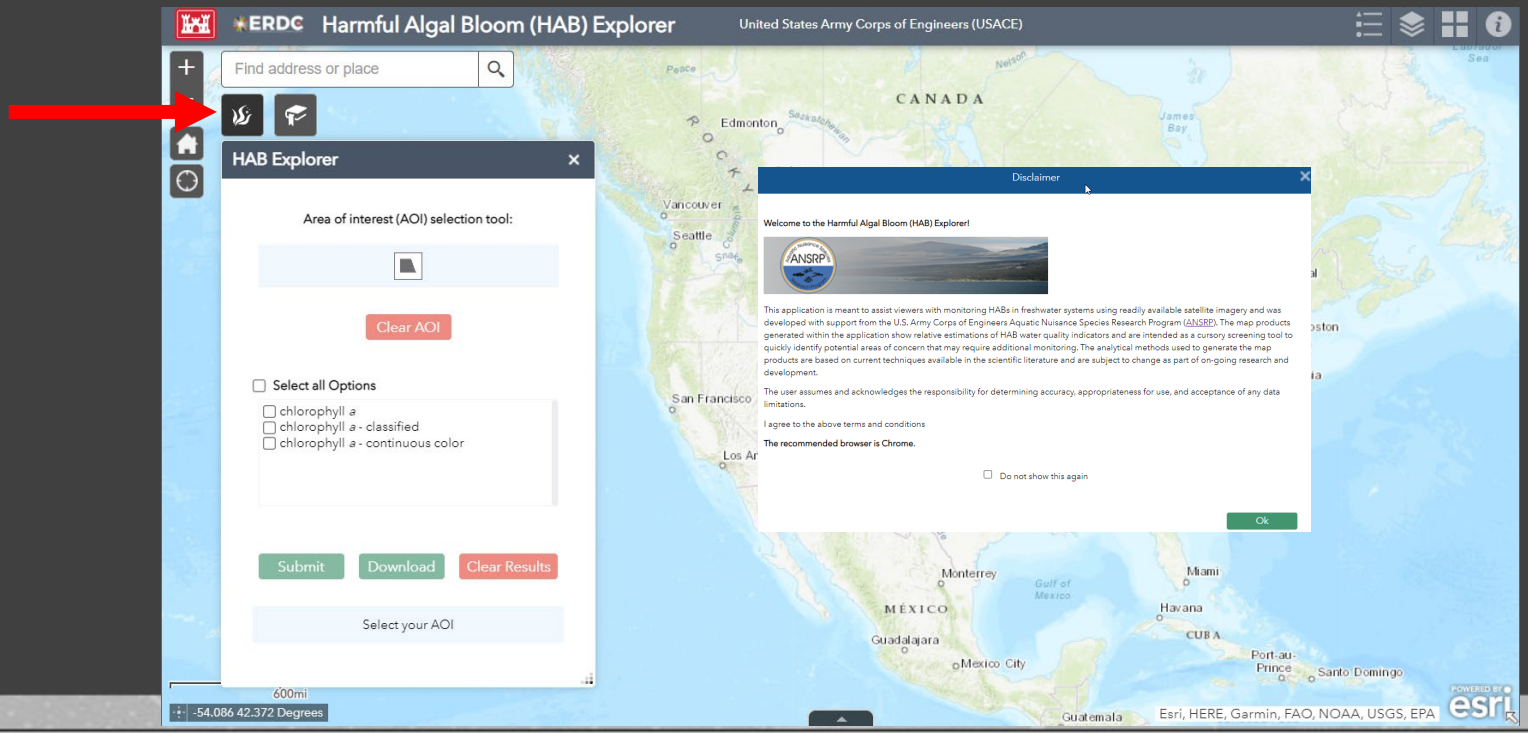
http://dx.doi.org/10.21079/11681/42240

ESRI online web app, *HAB Explorer*

- Prototype developed by ESRI with design/input and testing from ERDC (Phase 1)
- Fast, simple way to assess inland lakes and reservoirs, in which constrained algorithm and visualization options allow for rapid screening of potential HAB conditions
- Hosted on the uCOP Production Portal (Corpsnet*); Best viewed in Google Chrome

  **Requires VPN or USACE network access (to pull CAC credentials); RDE users via CANPC*

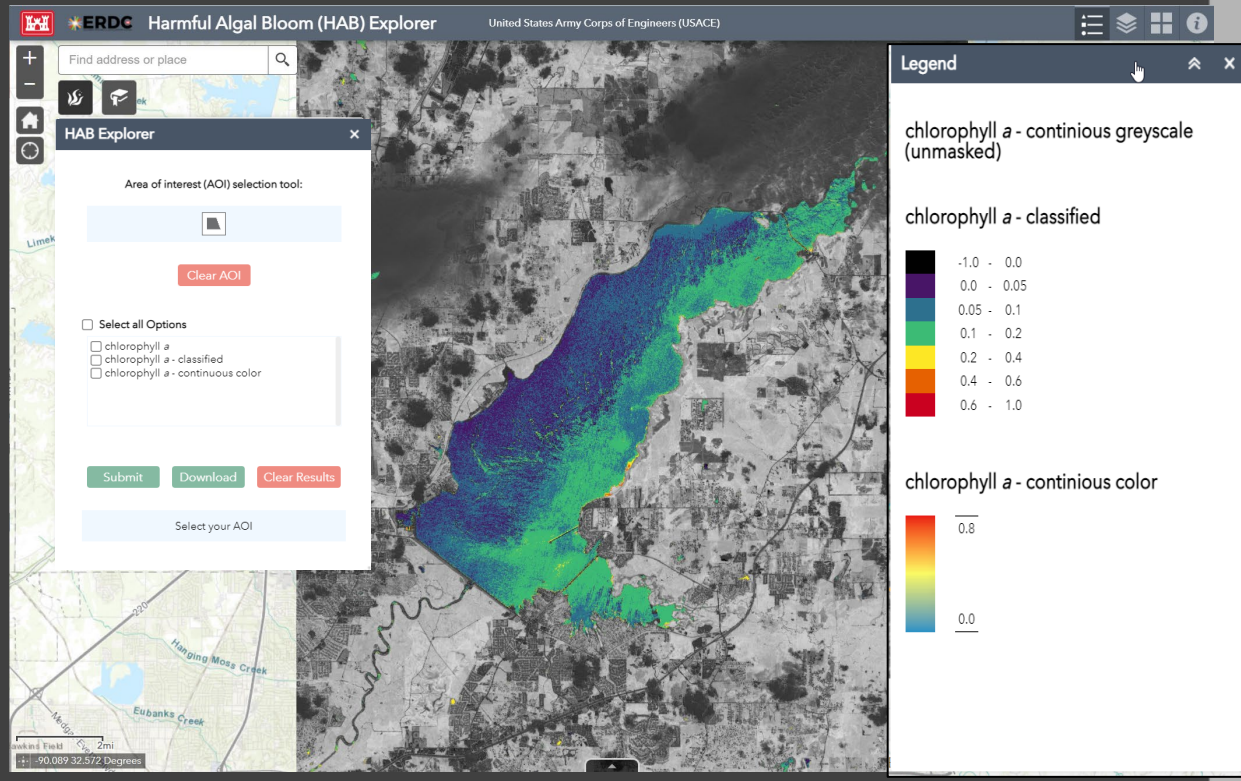
HAB Explorer available on the uCOP!
https://arcportal-ucop-corps.usace.army.mil/hab/



ESRI online web app, *HAB Explorer*

- Accesses ESA's Sentinel-2 L2A imagery via a cloud-based image service (most recent image meeting cloud threshold available)
- On-the-fly application of the Normalized Difference Chlorophyll Index (NDCI)
  (B5-B4) / (B5+B4)
- Two map products to help visualize the relative estimation of chl-a, HAB indicator
- Makes use of ESA scene classification to remove non-water pixels (i.e., land and clouds)

Ross Barnett Reservoir, MS Aug 2021

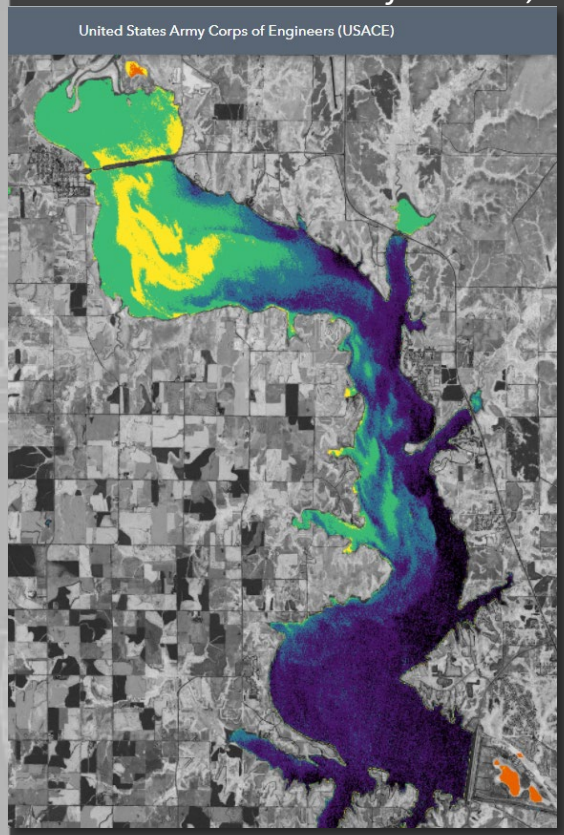


https://arcportal-ucop-corps.usace.army.mil/hab/

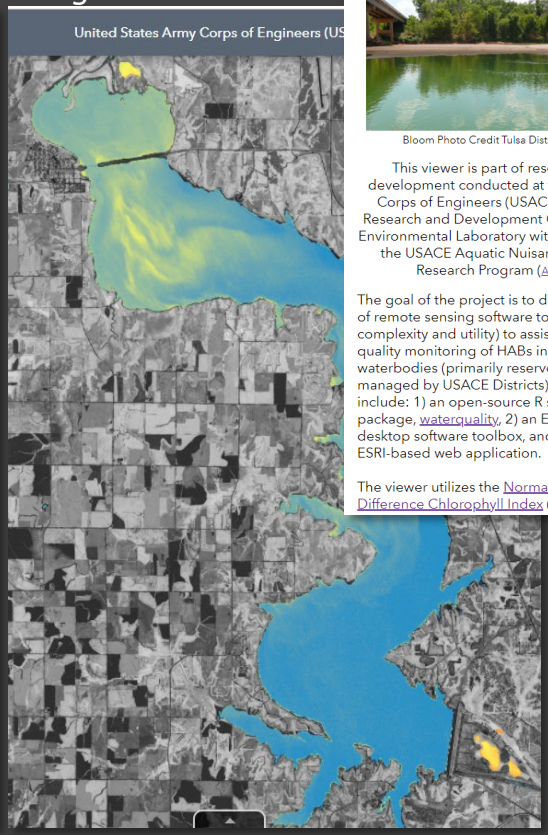
ESRI online web app, *HAB Explorer*

Five steps to produce & download a map illustrating relative estimation of chl-a

Milford Lake, KS Aug 2021



Classified



Continuous

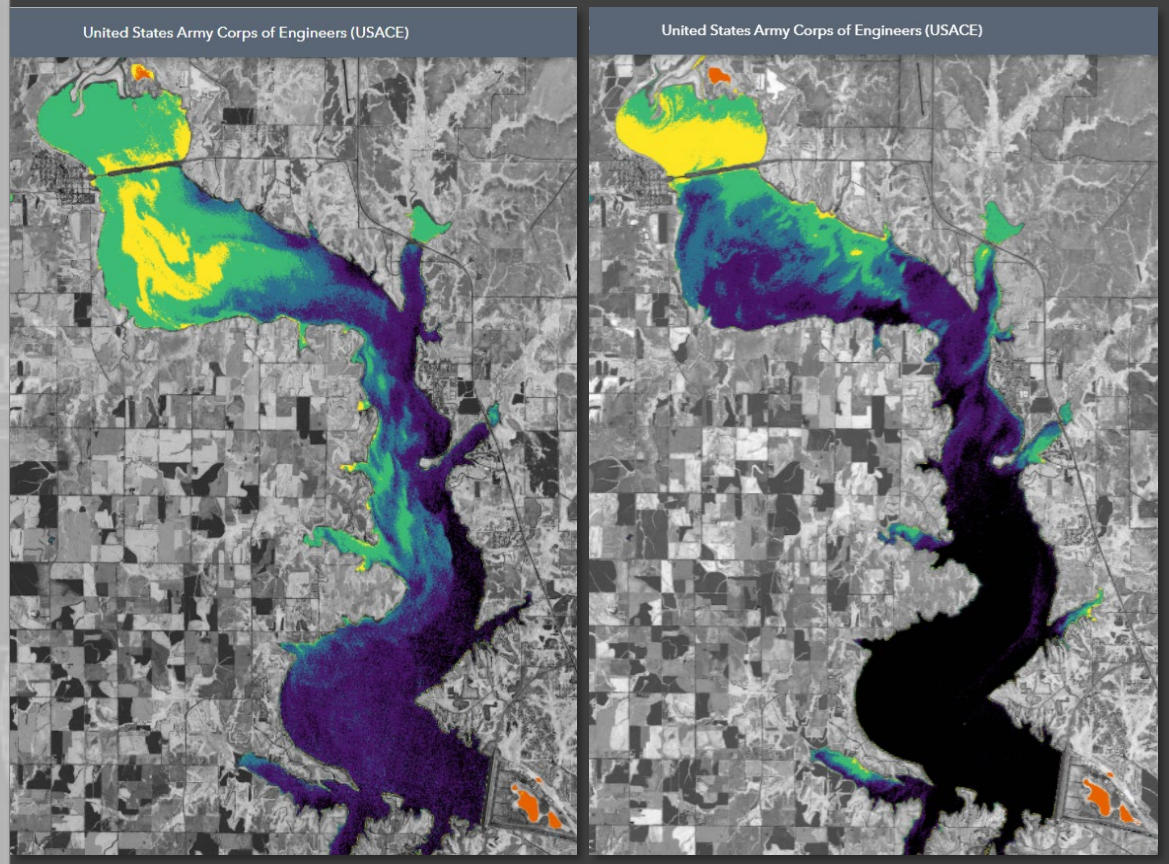
1. Select AOI (max extent is limited)
2. Check box for desired symbology option (all, continuous, or classified)
3. Submit options/AOI (wait ~30 – 45 seconds for algorithm processing)
4. View layer results – toggle on/off
5. Download geotagged tiffs and view in GIS desktop software with other spatial data*

*change color stretch type to None

https://arcportal-ucop-corps.usace.army.mil/hab/

ESRI online web app, *HAB Explorer*

Aug, 2021 *Milford Lake, KS* *Sept, 2021*



https://arcportal-ucop-corps.usace.army.mil/hab/

- Monitor whole-lake changes over time
- Visualize surface and near-surface phytoplankton biomass estimated through the NDCI
- Assess the amount of lake surface exceeding critical thresholds in chl-a to initiate and prioritize field-based sampling
- No GIS Desktop software required
- *We even used this to plan another project's field campaign!*

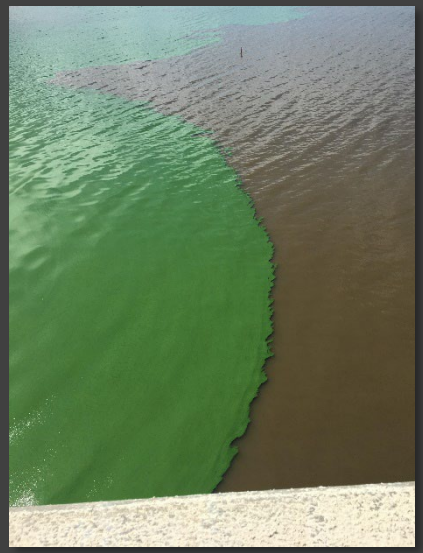
HAB Tools Quick Guide Matrix

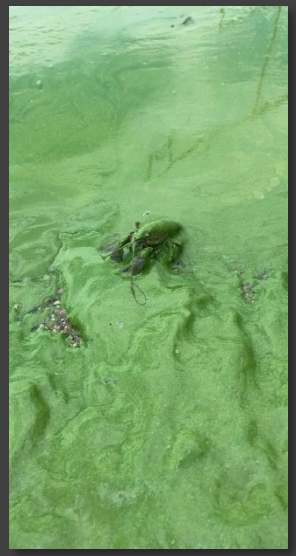
Tool (hyperlinked) Skill/Requirement	wateraquality for R Advanced (Coding)	wateraquality for Pro Intermediate (GIS)	HAB Explorer Basic (Google Chrome)
Type	Open-Source R Program	ESRI ArcGIS Pro Toolbox (v. 2.7+)	ESRI Online Web Application
Location	GitHub	ERDC Knowledge Core	uCOP Corpsnet (CAC required)
Price	Free	Free (ArcGIS Pro Advanced license required)	Free
Sensors			
WorldView-2 (<3 meters)	No cost to DoD (licensed)	NO	NO
Sentinel-2 (10-20 meters)	Free	Free	Free
Landsat-8 (30 meters)	Free	NO	NO
MODIS/MERIS/OLCI (>200 meters)	Free	NO	NO
Parameters			
Chlorophyll-a	YES	YES	YES
Phycocyanin	YES	YES	NO
Turbidity	YES	YES	NO
Total Algorithms	45	6	1
Features			
Customizable	YES	NO	NO
Image pre-processing (radiometric correction)	YES	NO	NO
Batch processing	YES	Limited	NO
Statistical evaluation	Multiple	One	NO

Access/Capability

- Maximum
- Limited/Conditional
- Minimum/None

Benefits to USACE



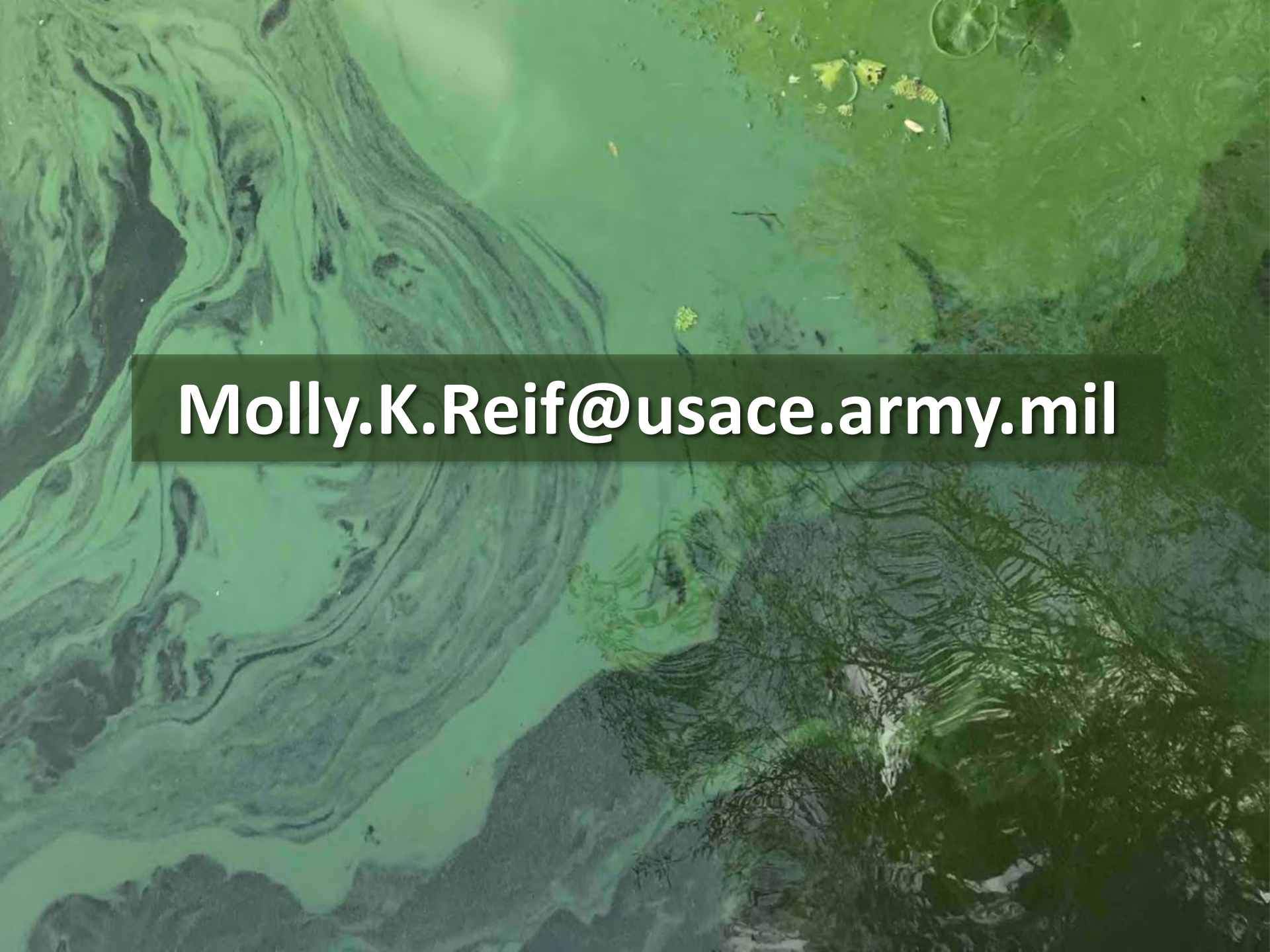


Milford Lake; Photo Credit USACE Kansas City District

- Tools provide a range of options to assist with HAB monitoring and management
- Communication of HAB potential to managers, leadership, partners, and the public
- While the tools can't assess toxicity directly, they can help reduce costs through targeting field sampling efforts
- Widespread applicability to USACE projects
- Transforms and leverages years of USACE-funded remote sensing investigative analyses into tools
- Remote options especially beneficial with pandemic-related travel restrictions

Future Work & Webinars

- New tools require updated technical skills, time to learn, and overcoming hesitancy to rely on satellite-based approaches
- FY22 work to help with Technical Transfer (LRD support)
  - Links to tools from USACE websites
  - Phase 2 of the HAB Explorer
  - Executive summary and quick guide matrix
  - Videos
- **UPCOMING VIRTUAL TRAINING WEBINAR!**
  - ArcGIS Pro Toolbox and HAB Explorer, February 10


Molly.K.Reif@usace.army.mil