Remote Sensing Software Tools to Assist USACE Water Quality Monitoring

Harmful Algal Bloom indicator estimation in small inland waterbodies: The ArcGIS Pro waterquality toolbox and HAB Explorer online web application

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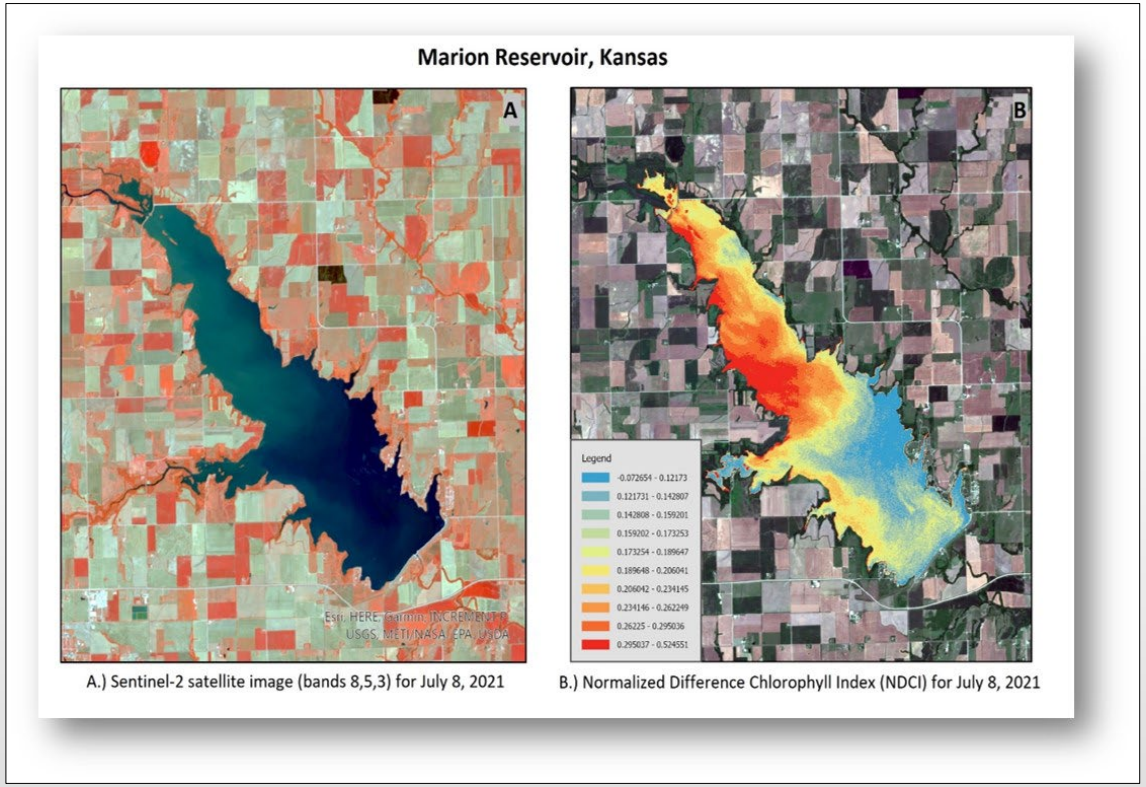
February 10, 2022

Outline

- Project Overview
- Sentinel Data Overview
- Toolbox Workflow
- Toolbox Requirements and Installation
- Exploring the Tools
- Harmful Algal Bloom (HAB) Explorer



A.) Sentinel-2 satellite image (bands 8,5,3) for July 8, 2021

B.) Normalized Difference Chlorophyll Index (NDCI) for July 8, 2021

Project Overview

- **Purpose:** 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

- **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

- **Approach:** 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

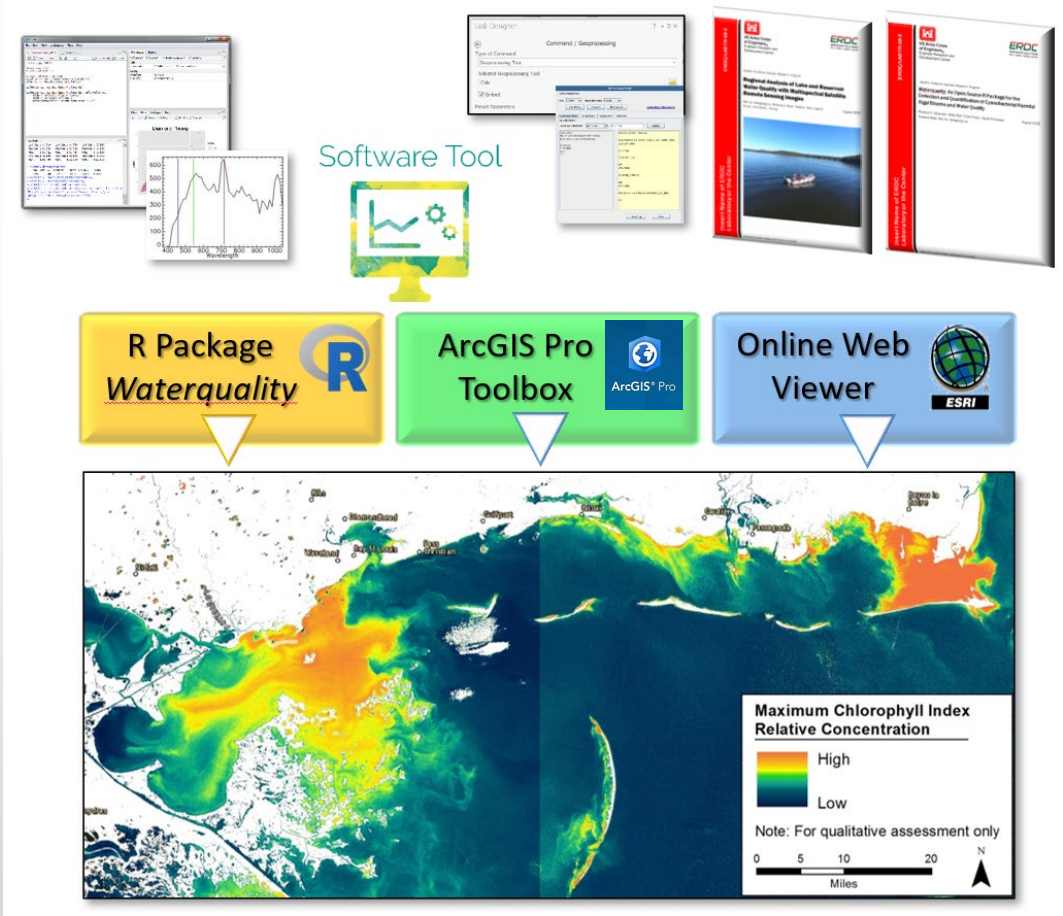
Project Overview

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

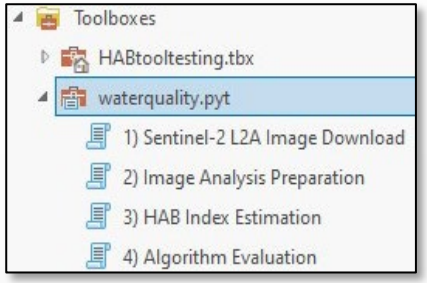
2. Python-based ArcGIS Pro toolbox with pre-set menus and limited options to streamline HAB indicator estimation

3. Online ESRI Web app for constrained options to rapidly screen for potential HAB conditions



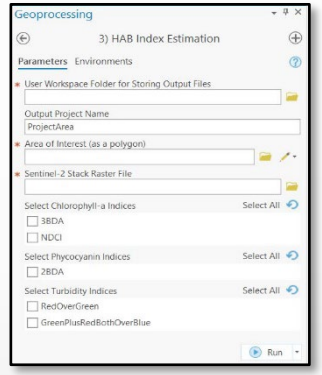
waterquality for ARCGIS Pro

- A python-based *waterquality* toolbox developed in ESRI ArcGIS Pro desktop software using Sentinel-2 satellite imagery with pre-set menus to produce abundance maps. Four tool components help to streamline analysis and product development. Beta-tested by USACE Districts and external collaborators at NOAA.



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 5 well-known indices
4. Converts estimated values using a regression model and in situ measurements

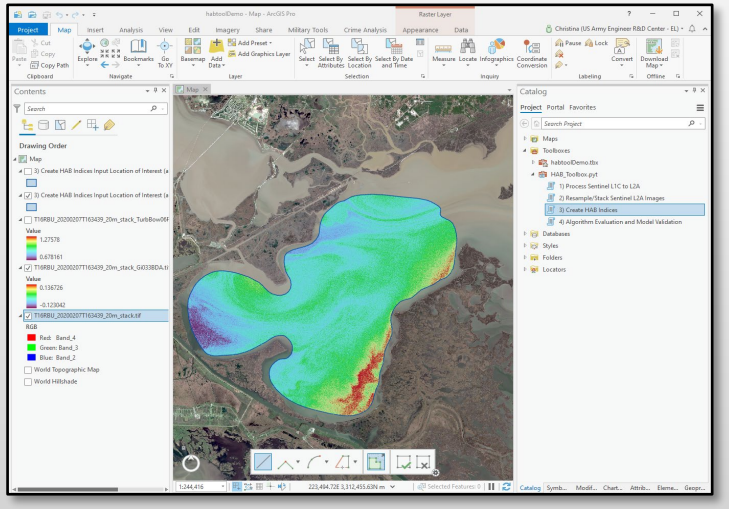


Tool Requirements:

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

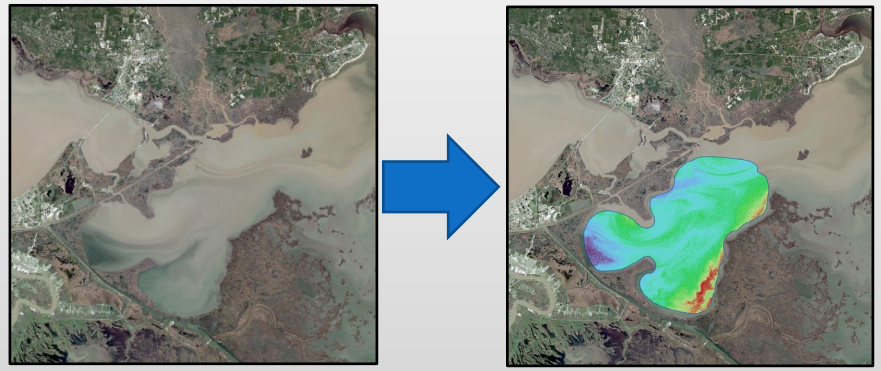
Data inputs:

- Sentinel-2 satellite imagery
- Area of interest polygon
- Choice of 5 water quality algorithms
- In situ data – csv format



Output:

- Water quality index raster
- PDF report and raster of estimated concentrations

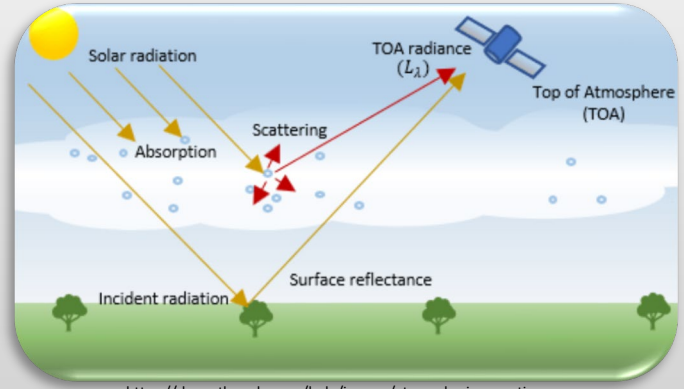


Sentinel-2
Lake Borgne, LA

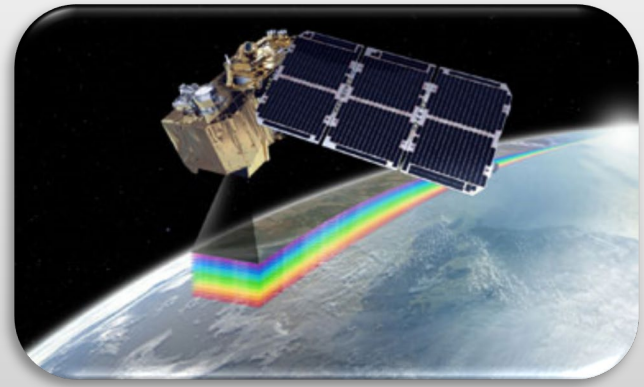
3BDA
Chlorophyll Index

Sentinel-2 Satellite Imagery

- Imager:
  - Constellation of two satellites (2A and 2B) Multispectral imager
  - European Space Agency (ESA)
  - Global coverage and freely available
  - 5-10 day revisit time
  - 10-20-60 meter spatial resolution
  - Level-2A is atmospherically corrected



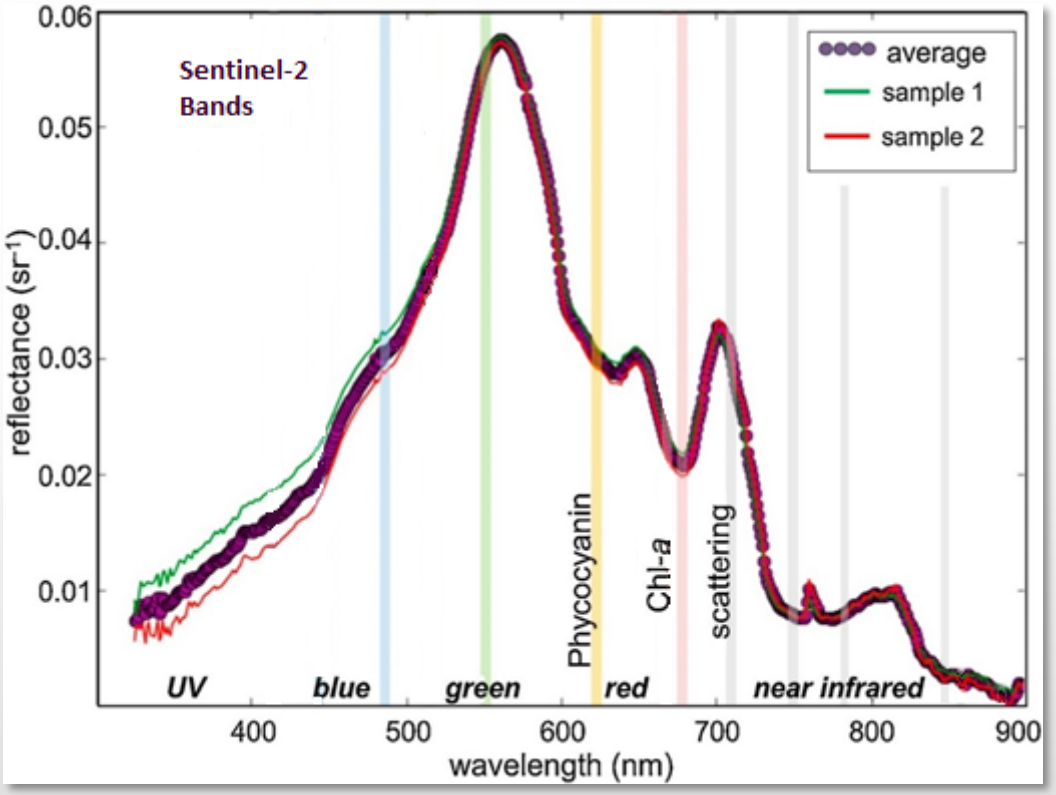
https://de.mathworks.com/help/images/atmosphericcorrection.png


https://www.ukspace.org/wp-content/uploads/2016/01/Sentinel-2-Airbus-DS.jpg

Spectral Band	Description	Center Wavelength (nm)	Initial Spatial Resolution (m)	Level-2A Available Product Spatial Resolution (m)
Band 1	Coastal Aerosol	443	60	60
Band 2	Blue	490	10	10; 20; 60
Band 3	Green	560	10	10; 20; 60
Band 4	Red	665	10	10; 20; 60
Band 5	Vegetation Red Edge	705	20	20; 60
Band 6	Vegetation Red Edge	740	20	20; 60
Band 7	Vegetation Red Edge	783	20	20; 60
Band 8	NIR	842	10	10
Band 8a	Narrow NIR	865	20	20; 60
Band 9	Water Vapor	940	60	60
Band 10	SWIR-Cirrus	1375	60	NA
Band 11	SWIR	1610	20	20; 60
Band 12	SWIR	2190	20	20; 60

Remote Sensing & Water Quality Proxies

- Remote sensing HABs is possible because the photo-reactive pigments produced by algae can be ‘sensed’ by satellite imagers
- **Chlorophyll(s) (Chl_a)**
  - Ubiquitous phytoplankton pigment with absorption features around 433 nm and 686 nm and reflectance peaks at 550 nm and 715 nm.
- **Phycocyanin**
  - Cyanobacteria specific pigment with major absorption feature at 620 nm.
- **Turbidity**
  - General measure of water clarity
  - Effect of backscattering caused by suspended material in the water column



Water Quality Indices

Water Quality Algorithm	Water Quality Parameter	Sentinel-2 Band Calculation wavelengths in nanometers (nm)	Reference
3BDA	Chlorophyll	(1/665 nm)/ (1/705 nm) * 740 nm	Gitelson et al 2003
NDCI	Chlorophyll	(705 nm - 665 nm)/ (705 nm + 665 nm)	Mishra and Mishra 2012
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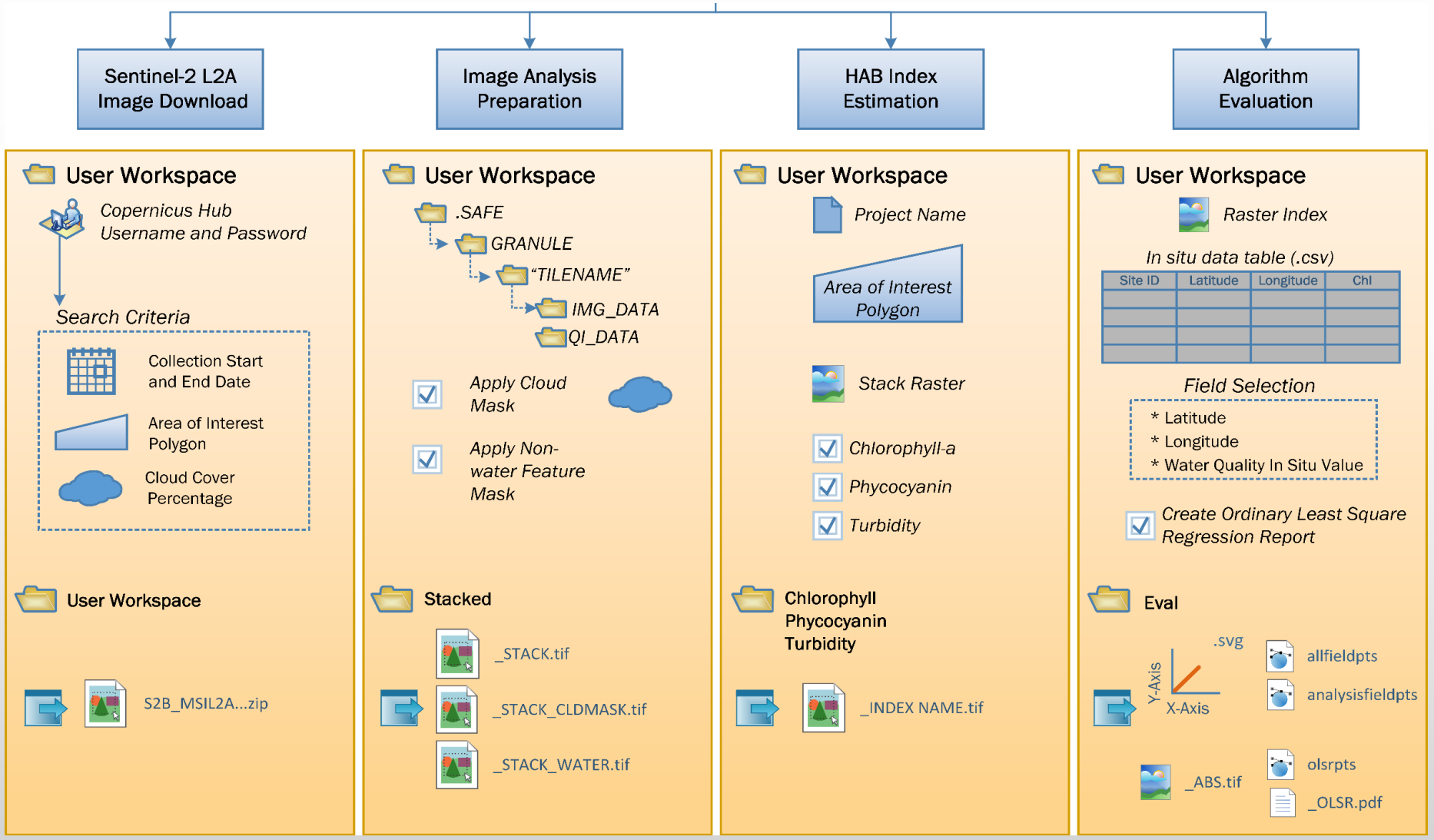
RedOverGreen	Turbidity	665 nm / 560 nm	Bowers and Binding 2006
GreenPlusRedBothOverBlue	Turbidity	(560 nm + 665 nm) / 490nm	Frohn and Autrey 2009

Toolbox Workflow

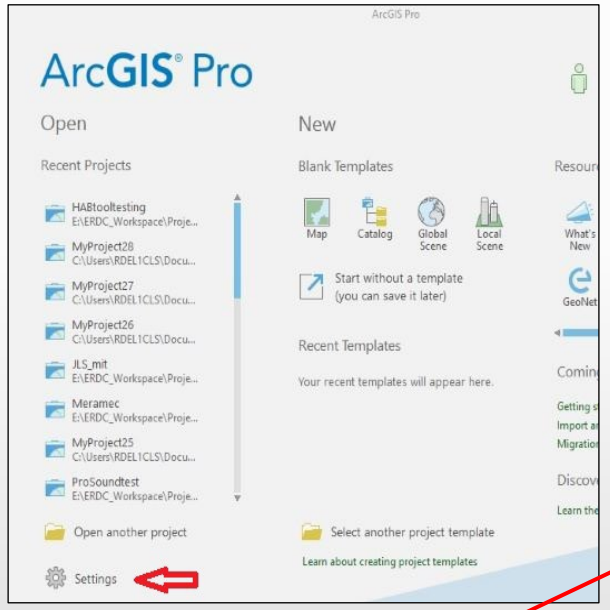


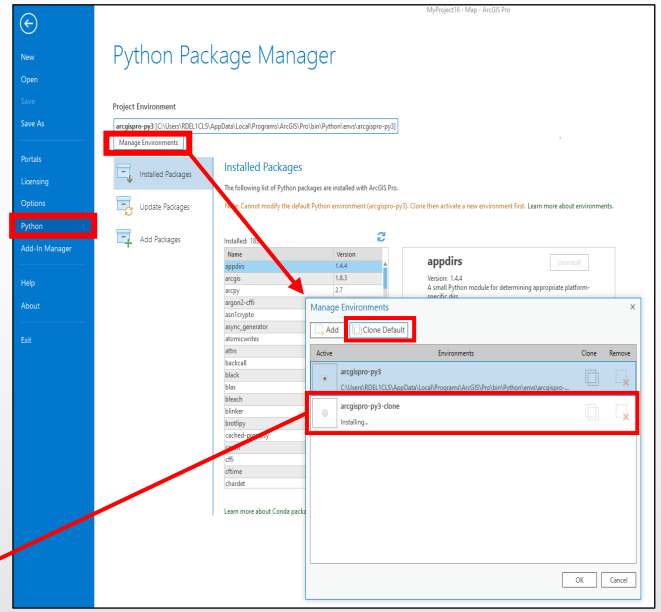
Toolbox Requirements

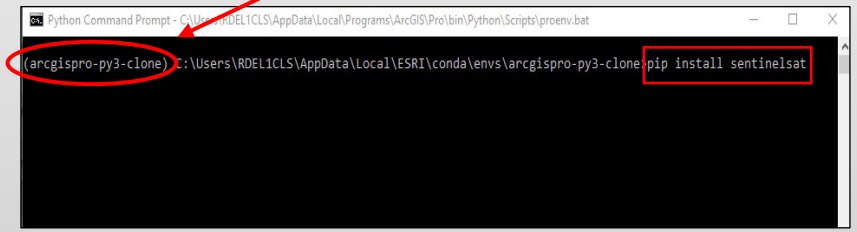
- ArcGIS Pro version 2.7 or greater
- Python version 3.7 or greater
- Advanced ArcGIS Pro and Spatial Analyst License
- Sentinelsat Python library

Toolbox Installation

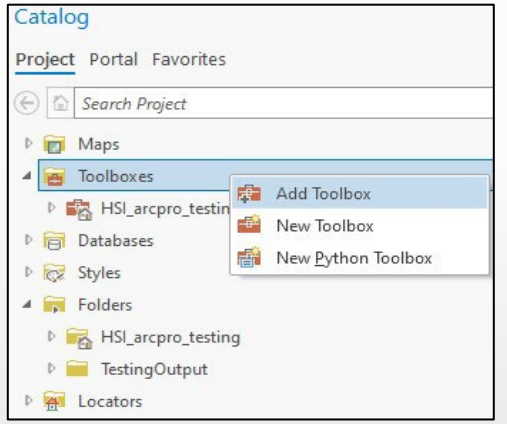
Sentinelsat Python Library Installation

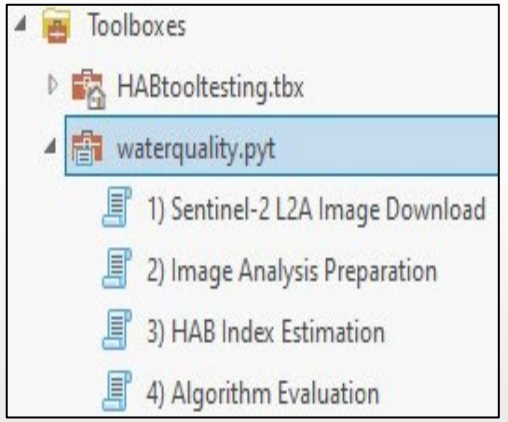




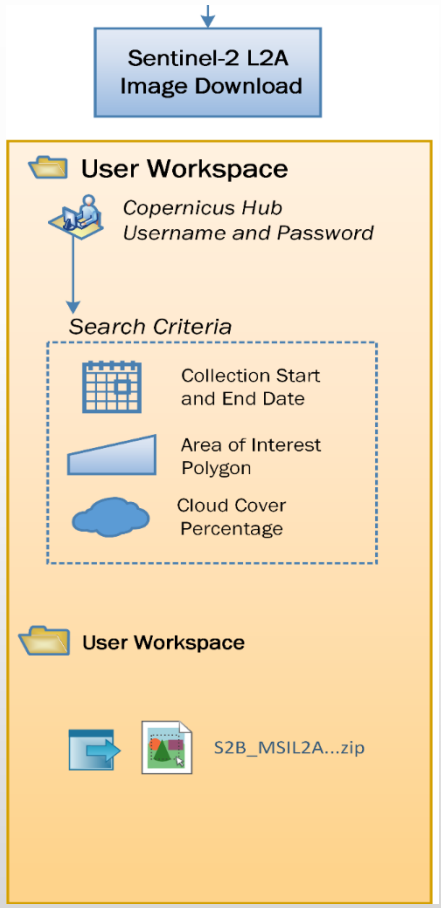


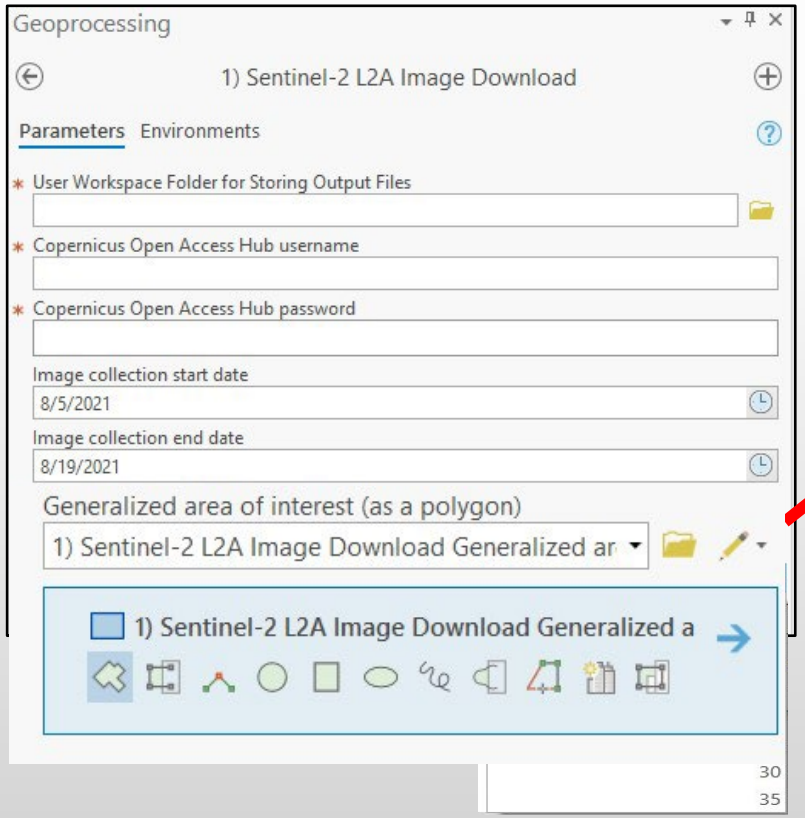
Waterquality Toolbox Installation

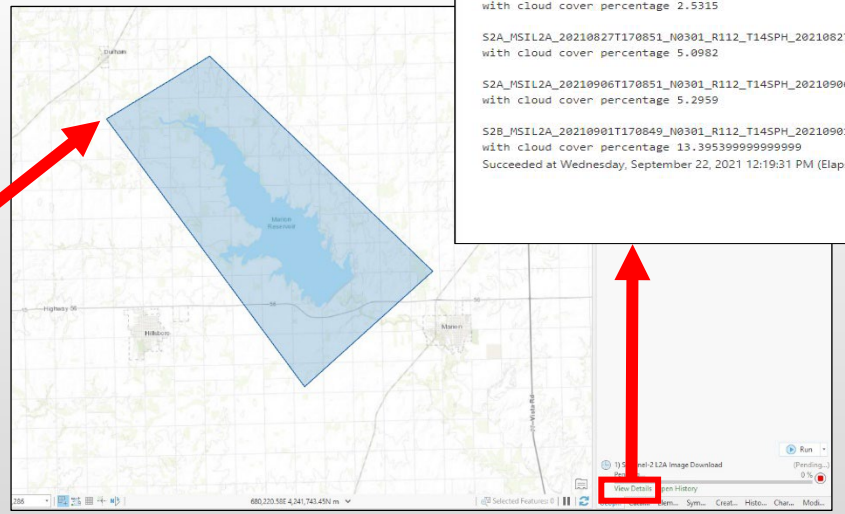


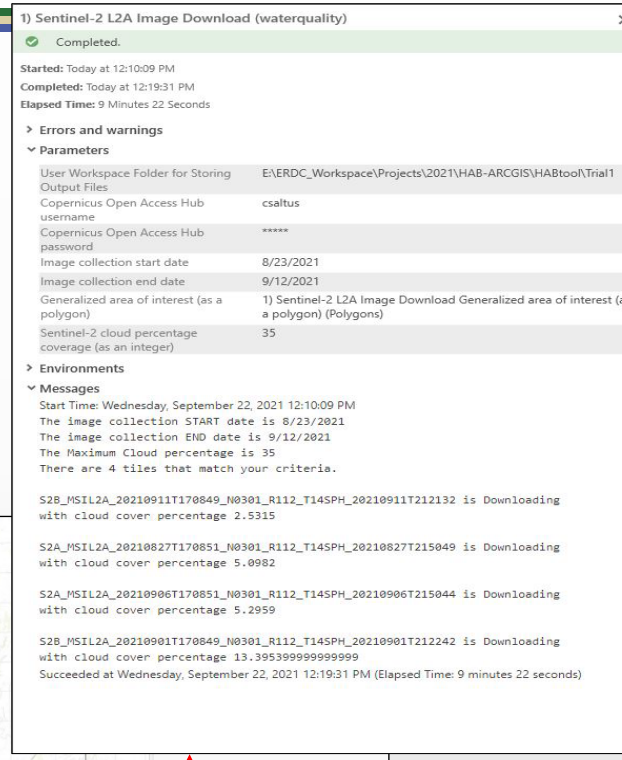


Sentinel-2 L2A Image Download Tool



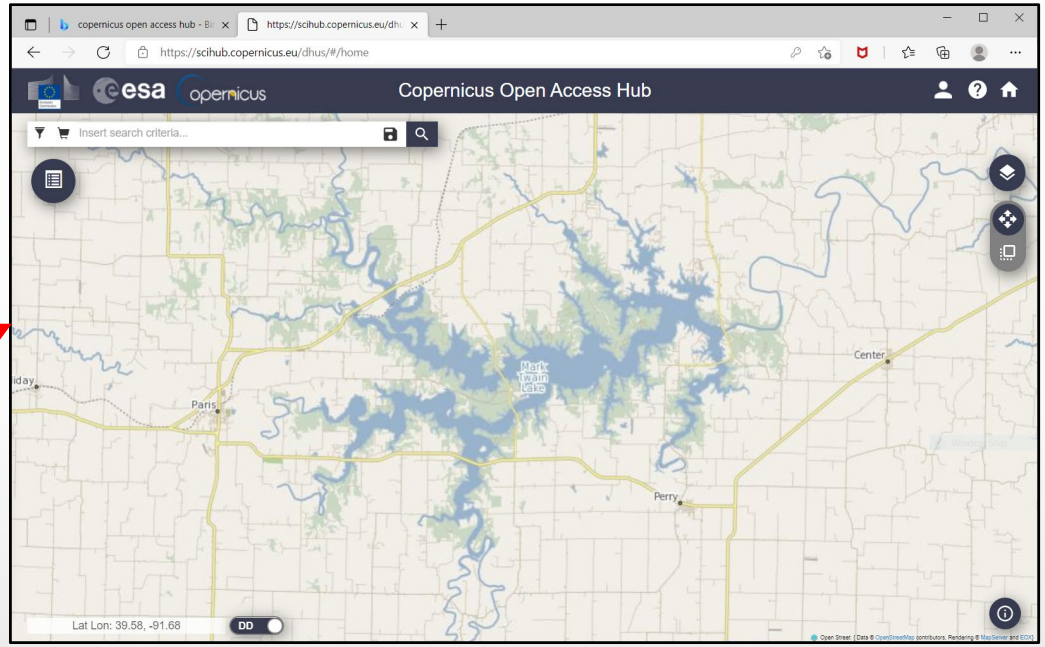


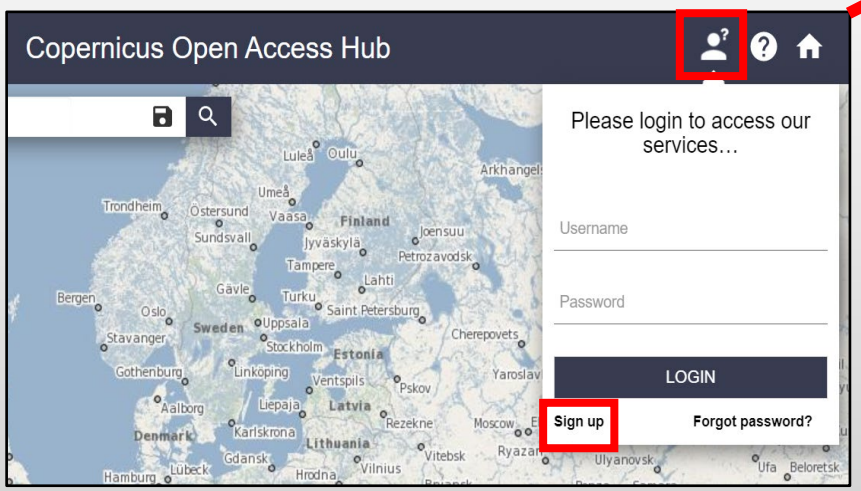




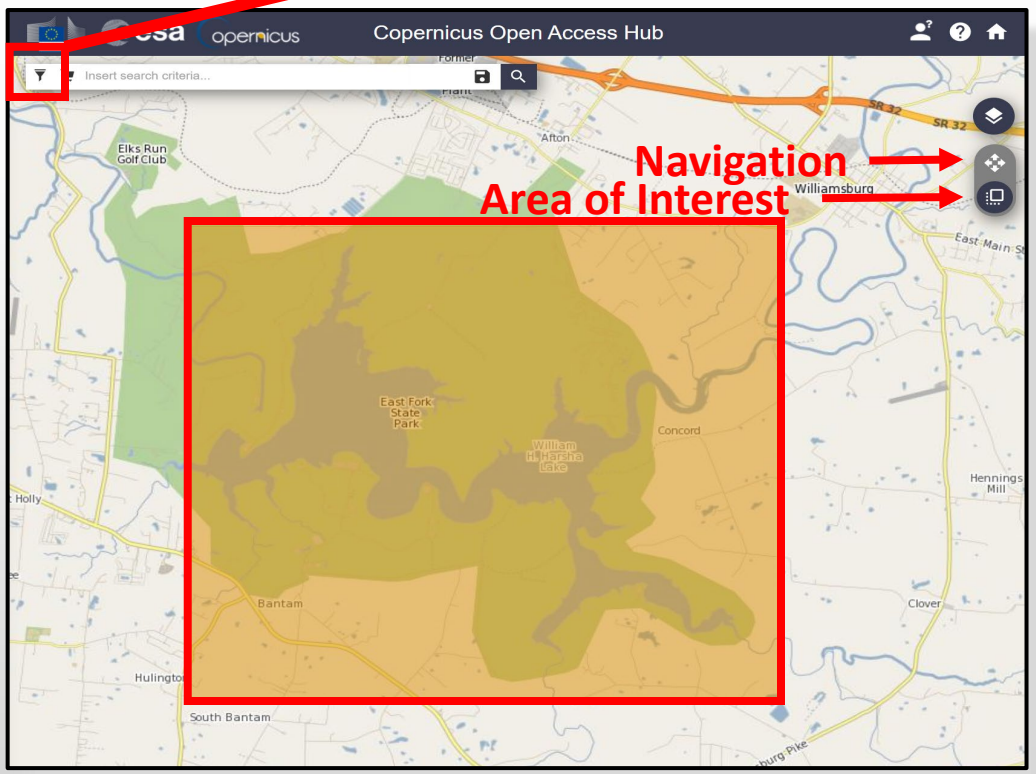
How to Setup an Account

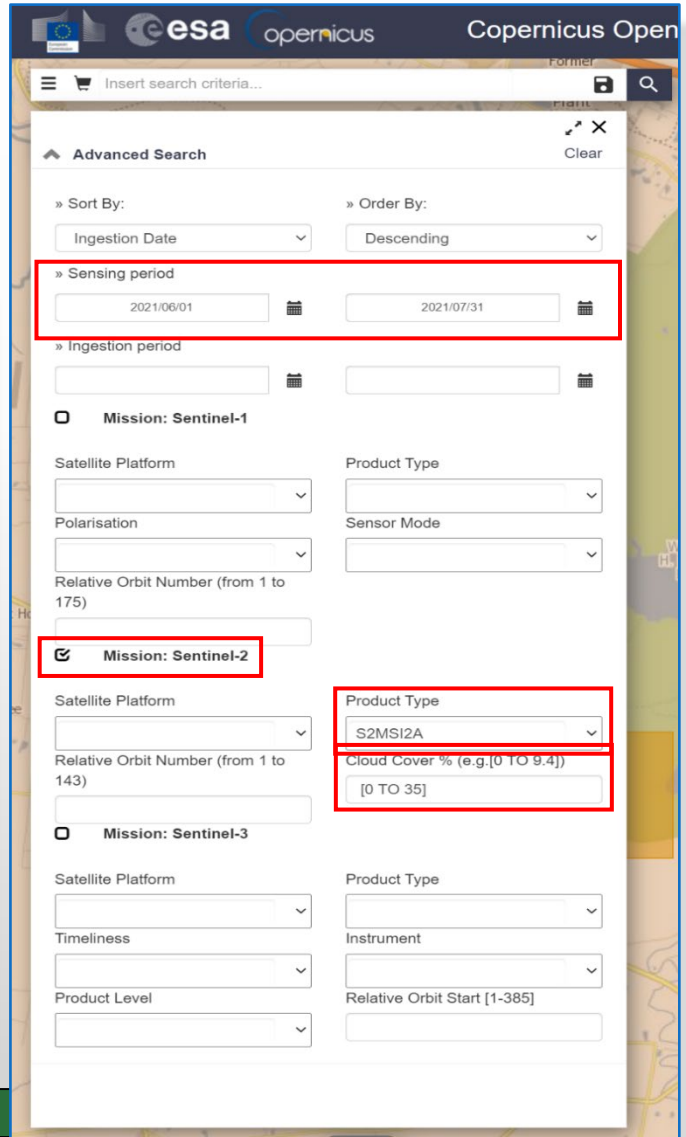
- Copernicus Open Access Hub website https://scihub.copernicus.eu/dhus/#/home
- Create an account https://scihub.copernicus.eu/userguide

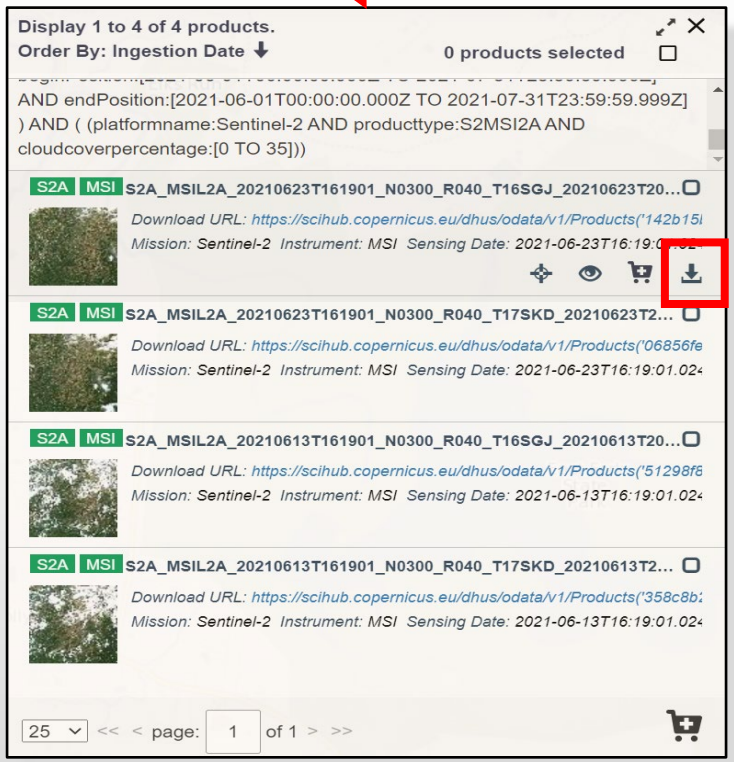




Sentinel-2 Image Download







SAFE File Naming Conventions and Directory Structure

MMM: Mission ID (S2A/S2B)

YYYYMMDDHHMMSS: the datatake sensing time.

ROOO: Relative Orbit number

Product Discriminator: Used to distinguish between different end user products from the same datatake.

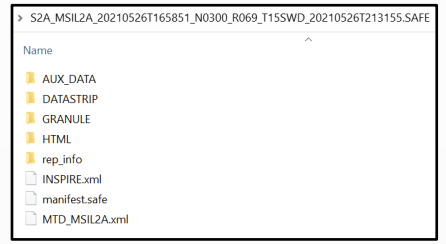
S2A_MSIL2A_20210526T165851_N0300_R069_T15SWD_20210526T213155.SAFE

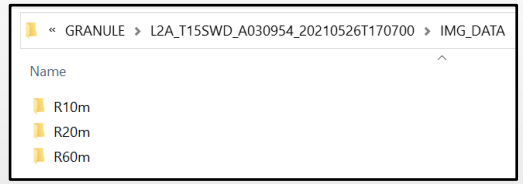
MSIXXX: Product Level MSIL1C (Level-1C) MSIL2A (Level-2A)

Nxxyy: PDGS Processing Baseline number

Txxxxx: Tile Number

SAFE: Product Format (Standard Archive Format for Europe)





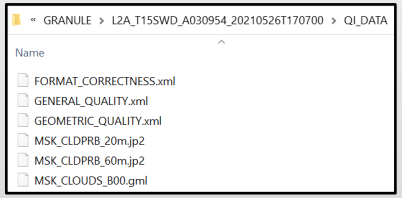
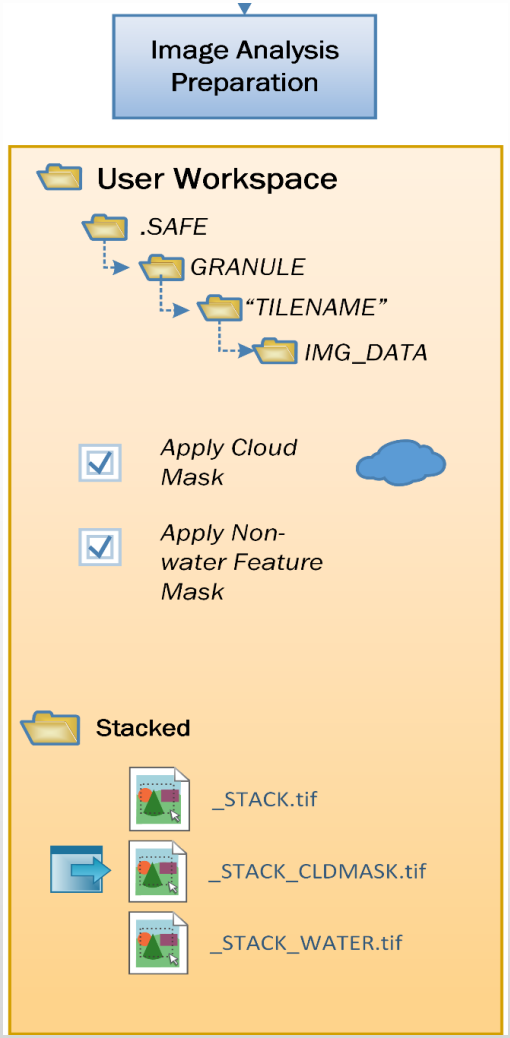
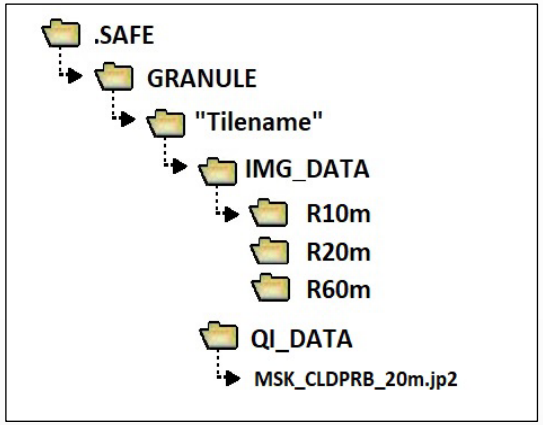
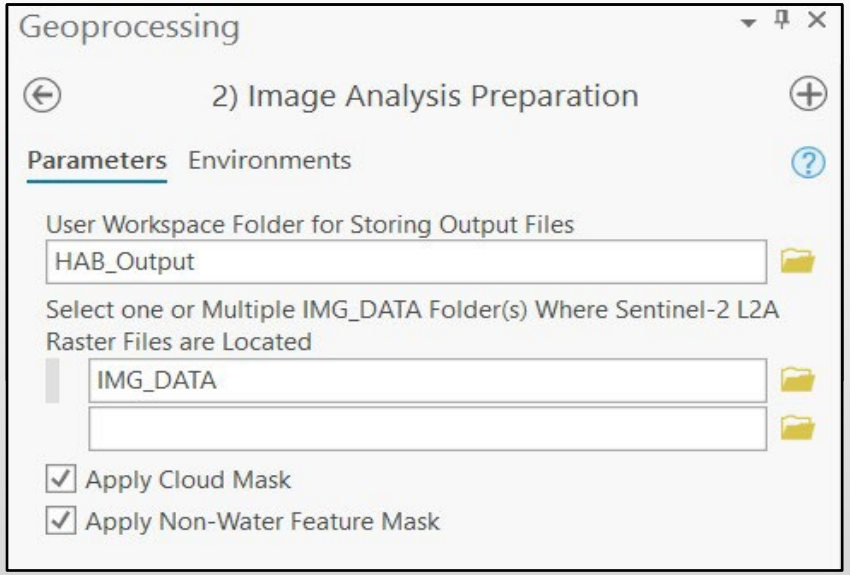


Image Analysis Preparation Tool







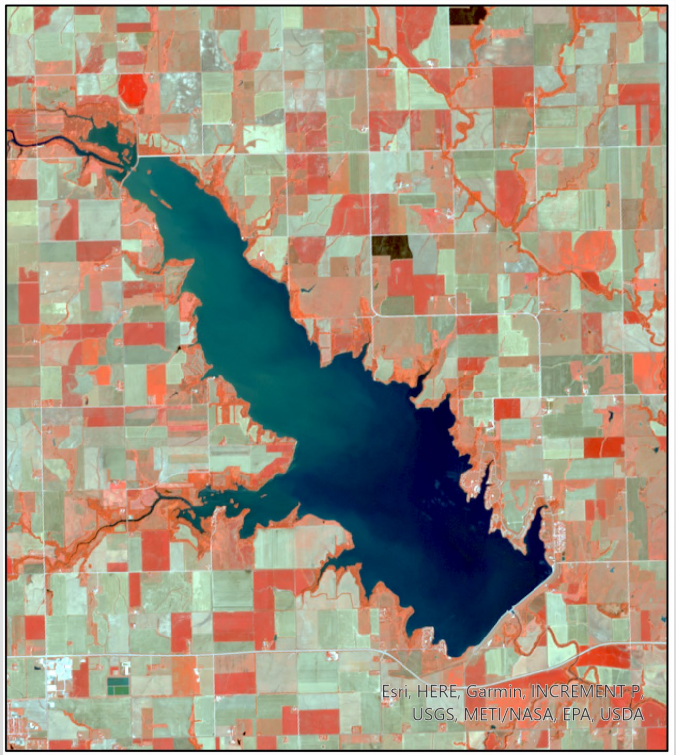
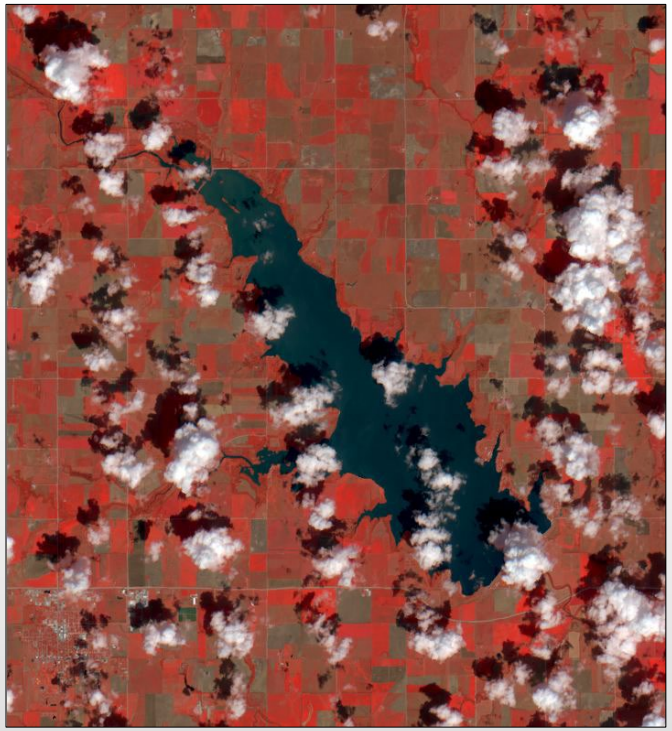


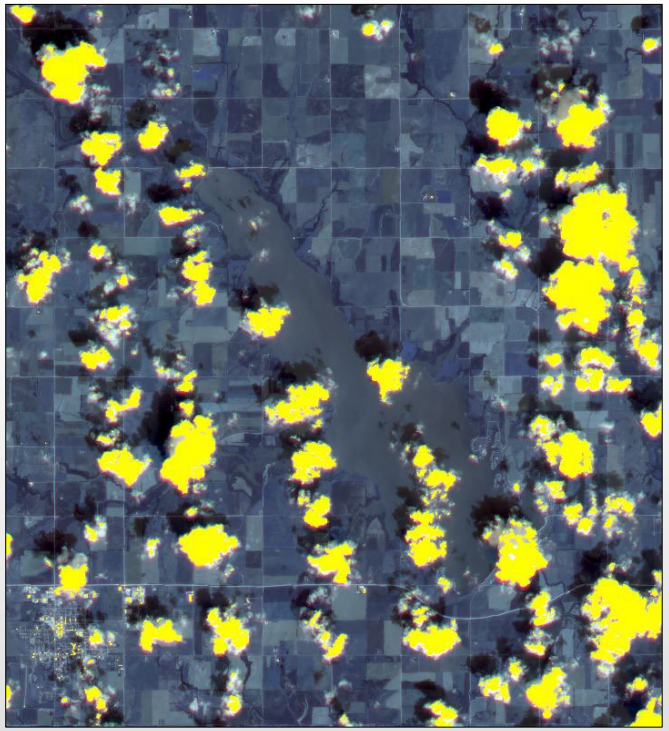
Image Analysis Preparation Tool Output

Marion Reservoir, KS
August 17, 2021



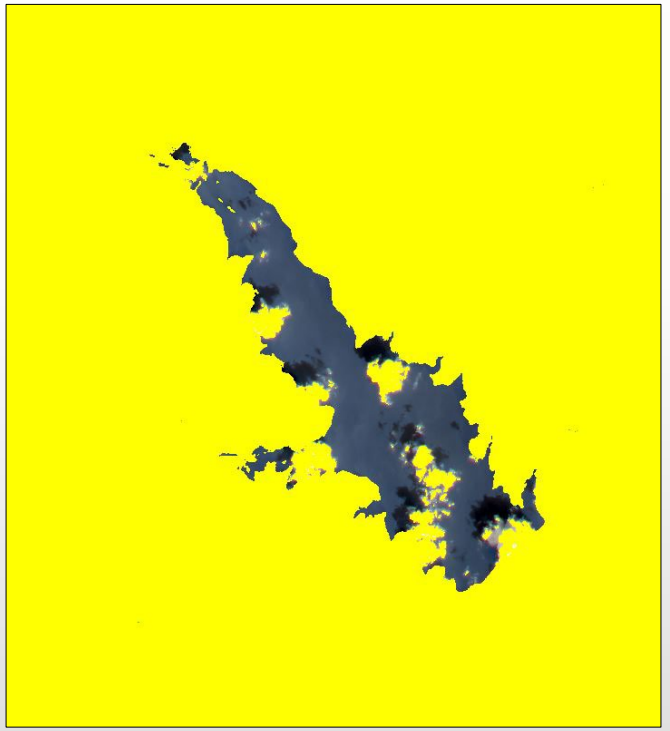
Stacked image

*_STACK.tif



Cloud Mask

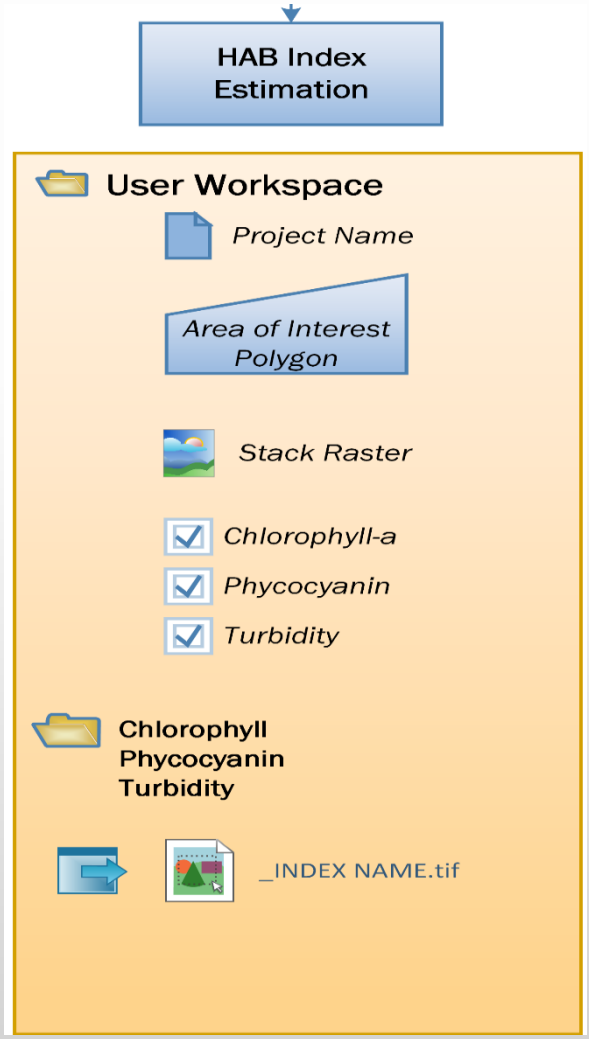
*_STACK_CLDMASK.tif

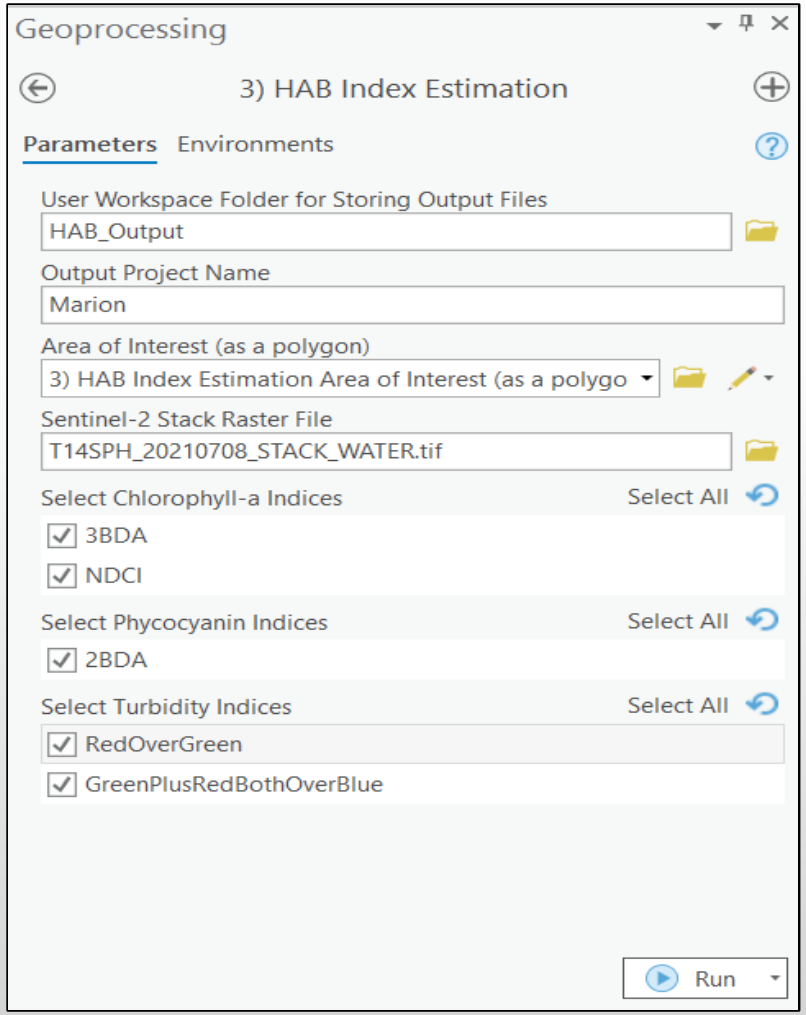


Only Water Features

*_STACK_WATER.tif

HAB Index Estimation Tool





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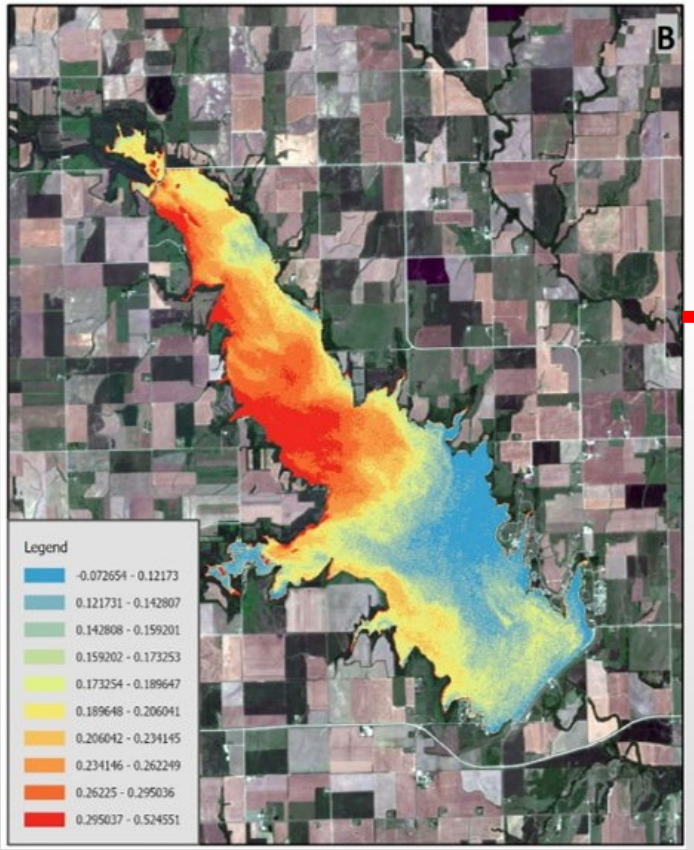
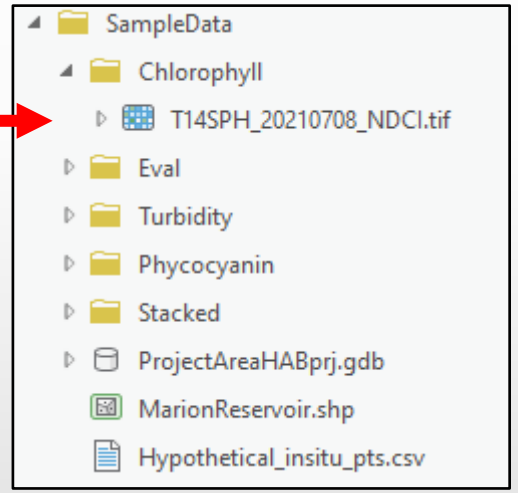
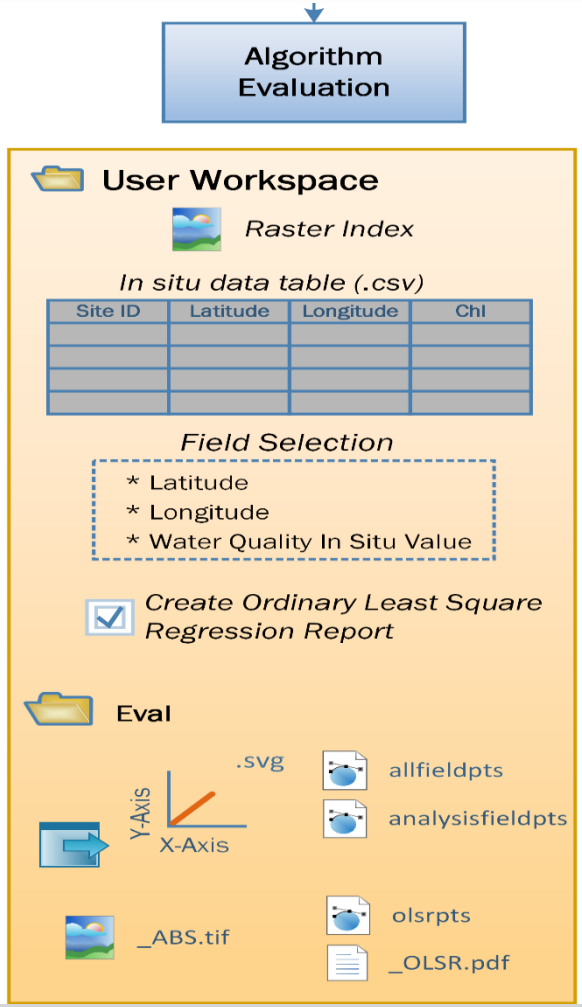
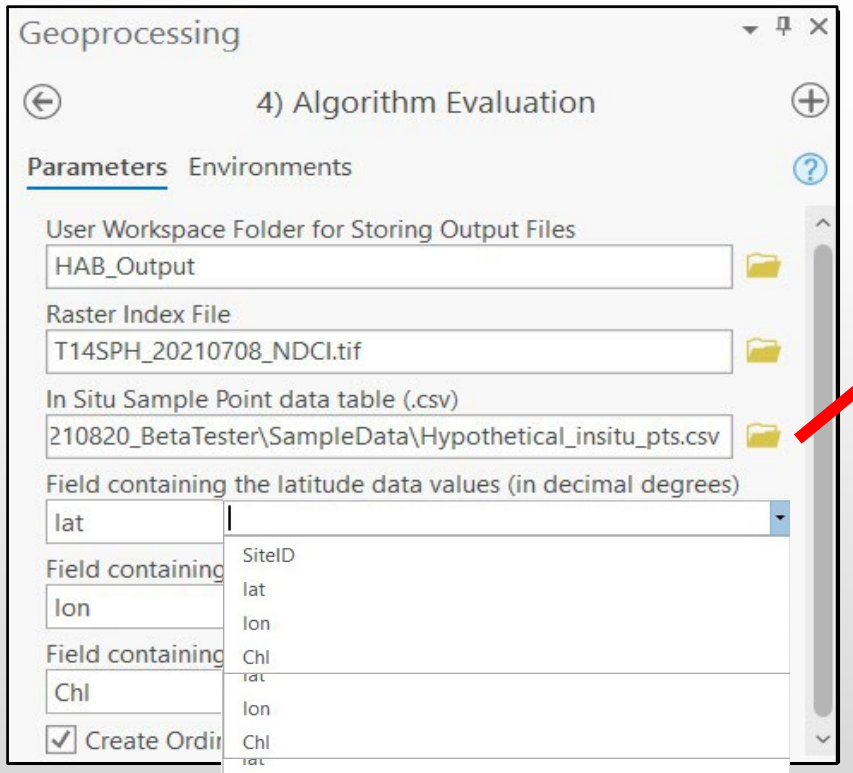




NDCI Marion Reservoir, KS July 8, 2021

Algorithm Evaluation Tool

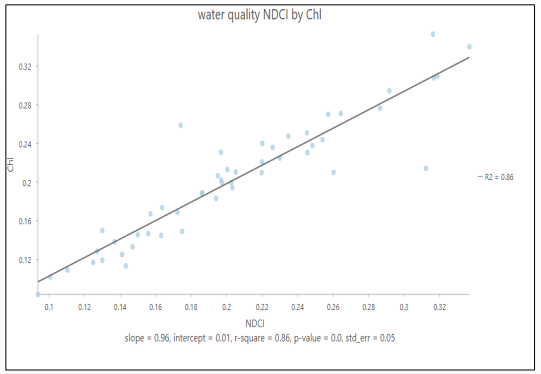




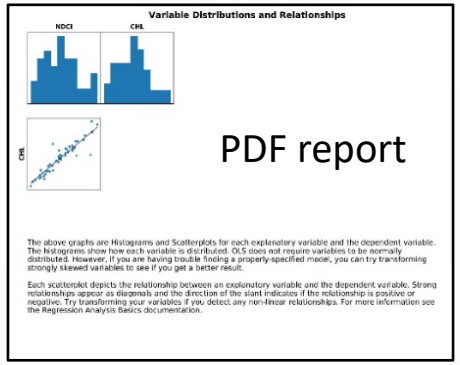
	A	B	C	D
1	SiteID	lat	lon	Chl
2	0	38.437	-97.158	0.244
3	1	38.447	-97.159	0.183
4	2	38.444	-97.154	0.231
5	3	38.442	-97.154	0.194
6	4	38.431	-97.146	0.225
7	5	38.429	-97.153	0.295
8	6	38.418	-97.146	0.271
9	7	38.419	-97.138	0.276
10	8	38.424	-97.137	0.238
11	9	38.425	-97.145	0.248
12	10	38.435	-97.150	
13	11	38.365		
	12			

Algorithm Evaluation Tool Output

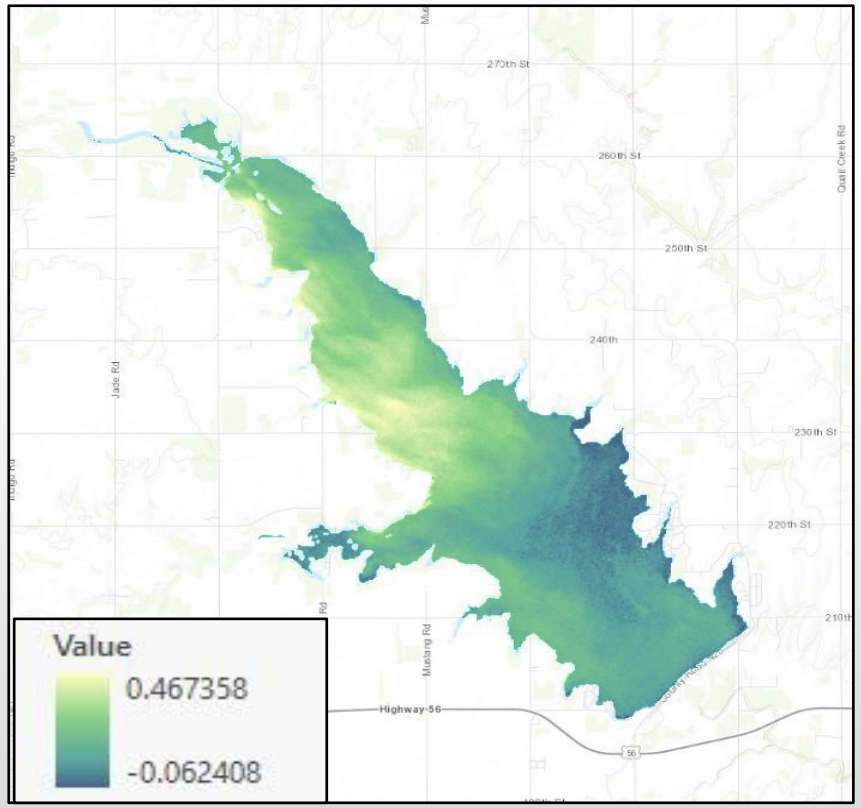
.svg file



OLRS Checkbox

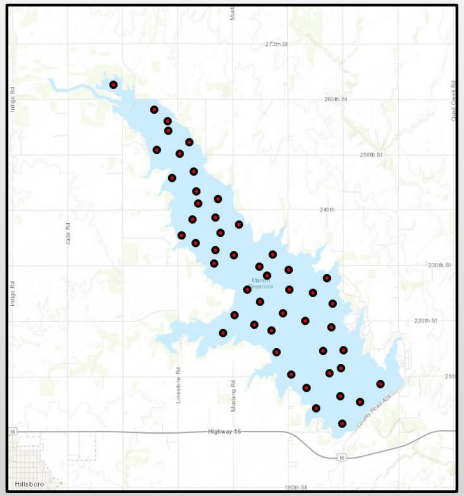


If r^2 >=.70

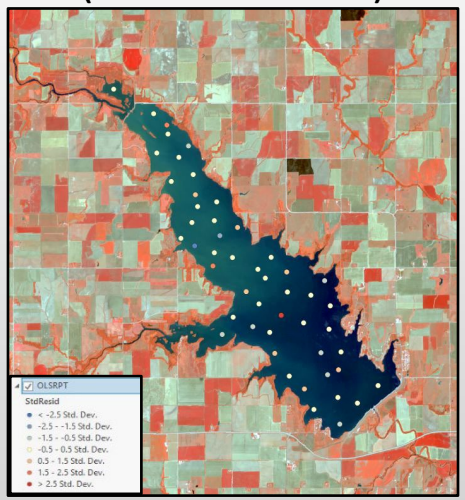


HAB concentrations (ABS)

Point Layers
(All Samples and Analysis)



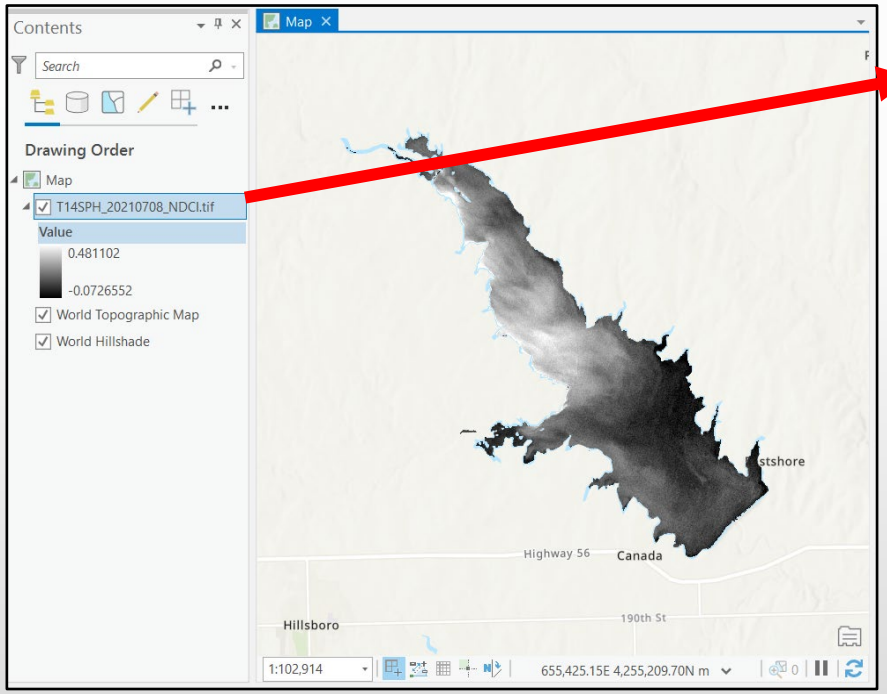
Point Layer
(OLSR statistics)



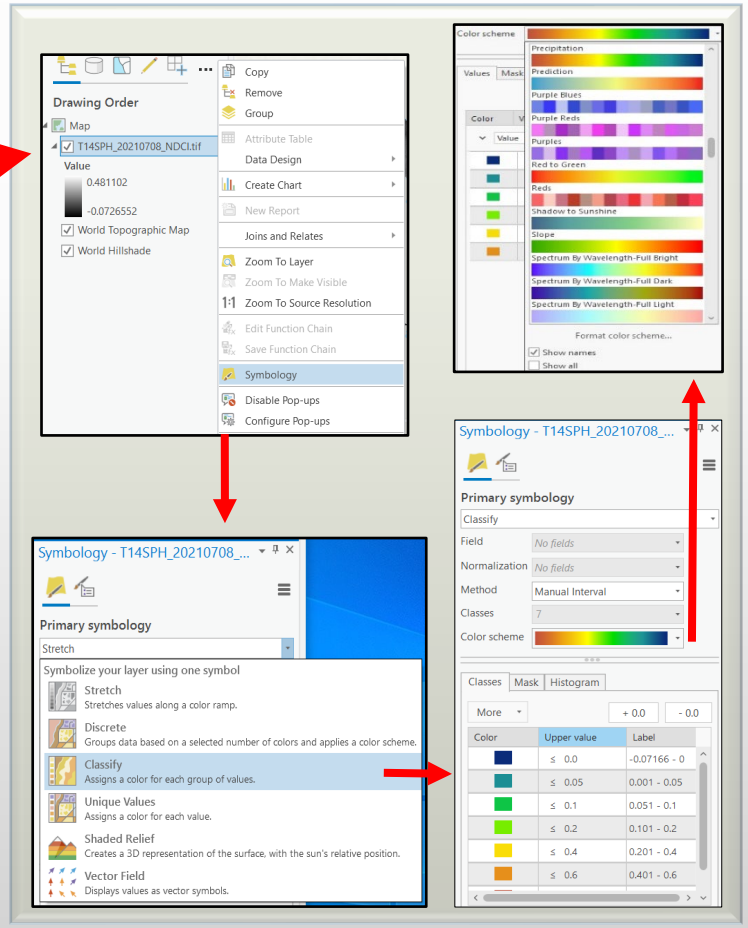
Explore the Data

Symbology

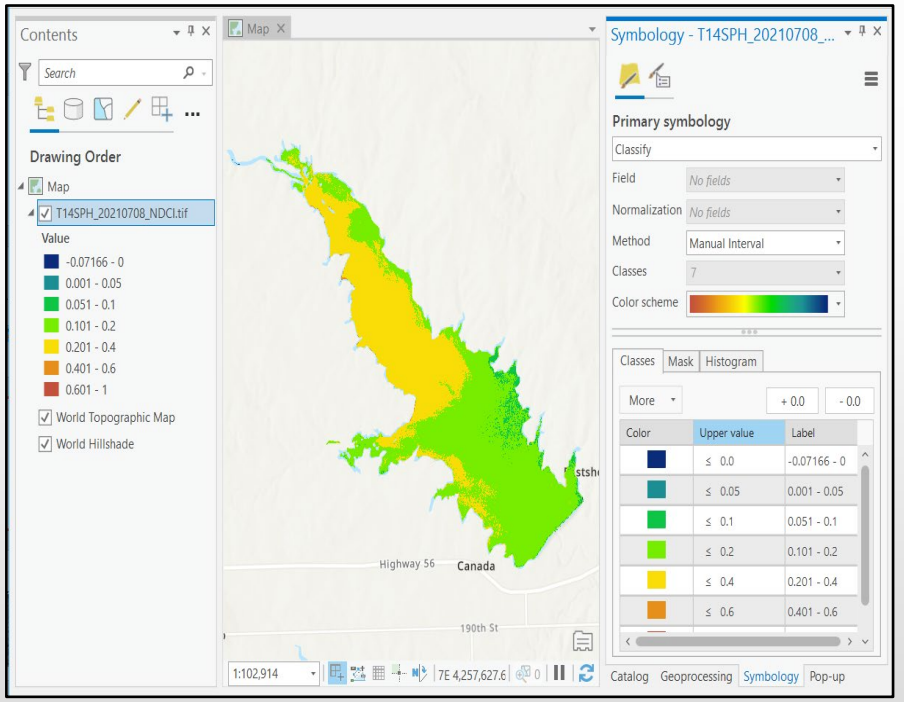
Default Tool Output



Select Symbology

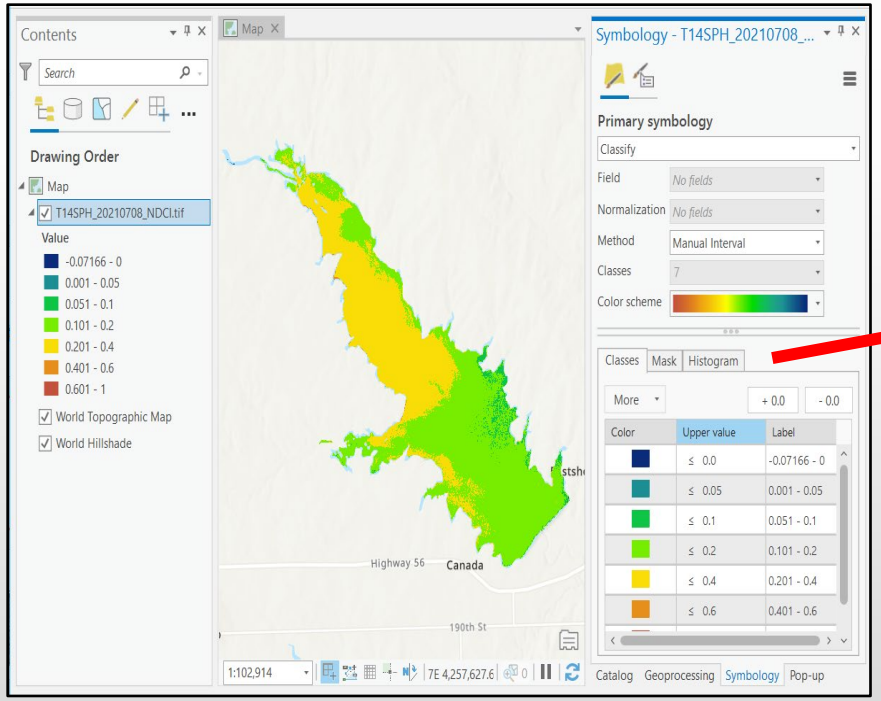


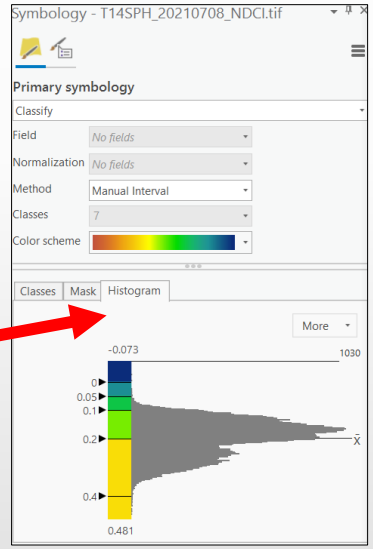
Output Symbology



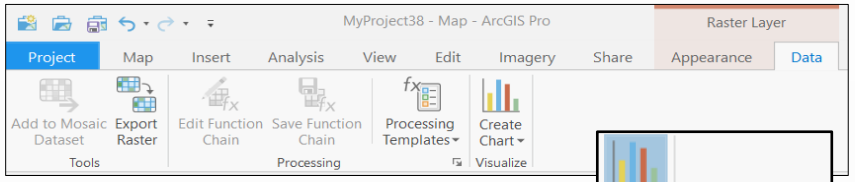
Explore the Data

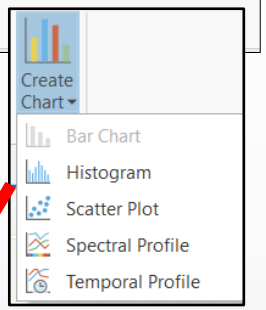
Histograms

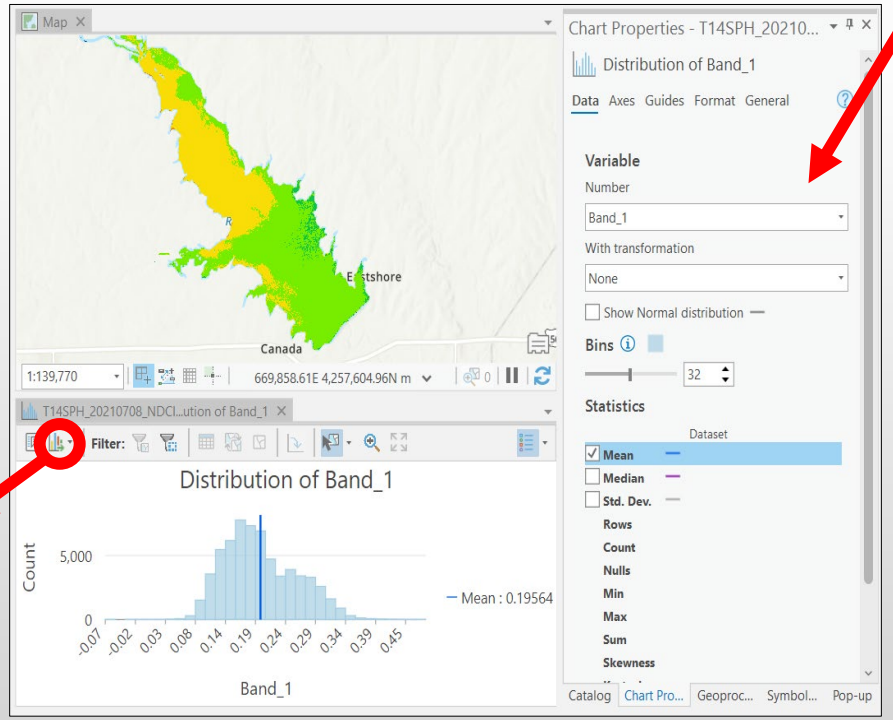




Export as
Table or Graphic

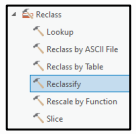




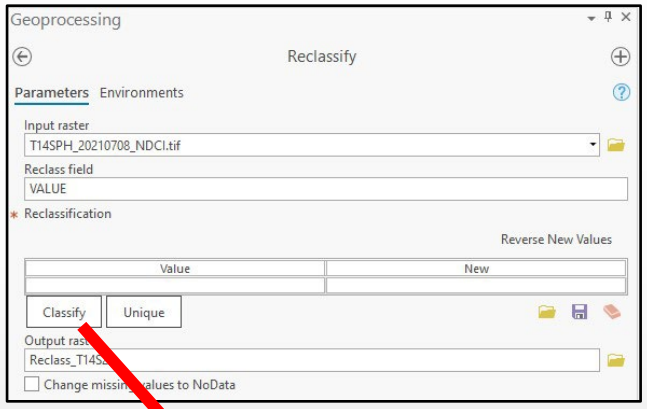


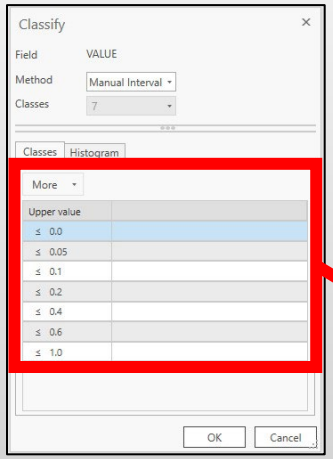
Explore the Data

Statistics

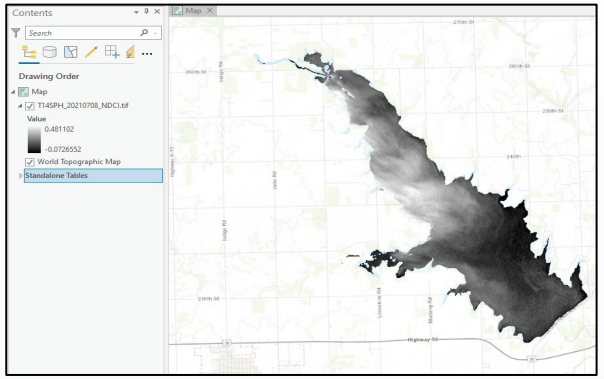


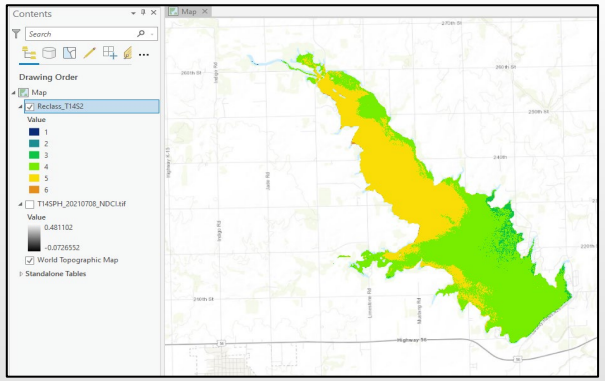
Spatial Analyst Tools>Reclass>
Reclassify

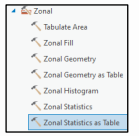




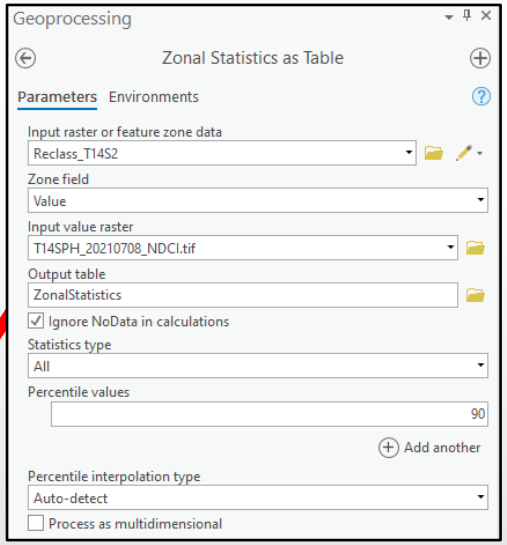
Start	End	New
-0.072655	0	1
0	0.05	2
0.05	0.1	3
0.1	0.2	4
0.2	0.4	5
0.4	0.6	6
0.6	1	7
NODATA	NODATA	NODATA







Spatial Analyst Tools>Zonal>
Zonal Statistics As Table



VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	MEDIAN	PCT90
0	1	400	-0.072655	-0.072655	0	-0.072655	0	-0.072655	-0.072655	-0.072655
1	7	2800	-0.057778	-0.006402	0.051376	-0.025259	0.014729	-0.17681	-0.020321	-0.013821
2	32	12800	0.007557	0.048159	0.040602	0.035099	0.01162	1.123174	0.037543	0.047589
3	1812	724800	0.050711	0.099893	0.049181	0.089489	0.009681	162.153743	0.092447	0.098782
4	35582	14232800	0.1	0.199731	0.099731	0.155891	0.026658	5546.901874	0.158392	0.191063
5	25958	10383200	0.2	0.399481	0.199481	0.257013	0.039701	6671.549666	0.253035	0.3116
6	89	35600	0.4	0.481102	0.081102	0.423887	0.019171	37.725969	0.420101	0.451294

Toolbox Updates Version 1.1

HAB Index Estimation Tool update:
Removal of the CI index from the Phycocyanin parameter and User's Guide Documentation

Anticipated Release Date:
March 2022

Request for feedback: Sentinel Hub connection issue (urllib3.py)

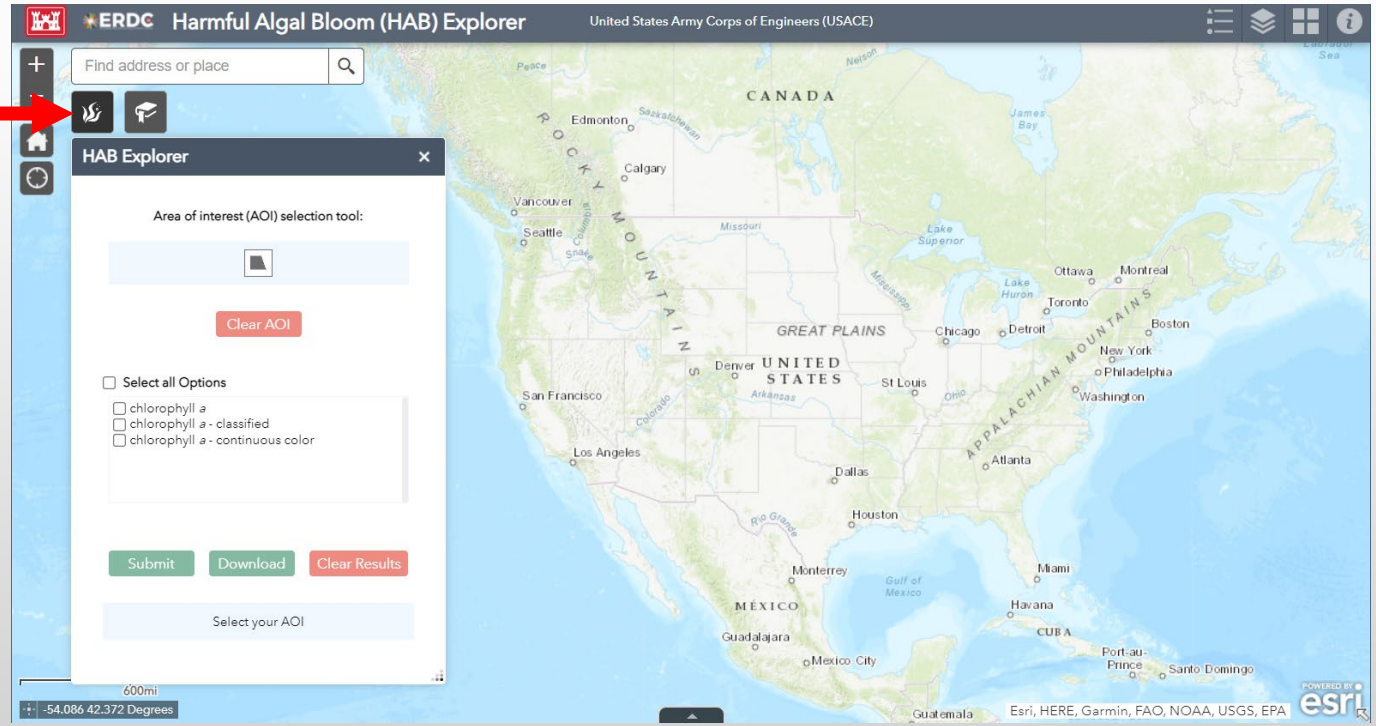
Christina Saltus:
Email: Christina.L.Saltus@erdc.dren.mil

HAB Explorer

- Prototype developed by ESRI with design/input/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*

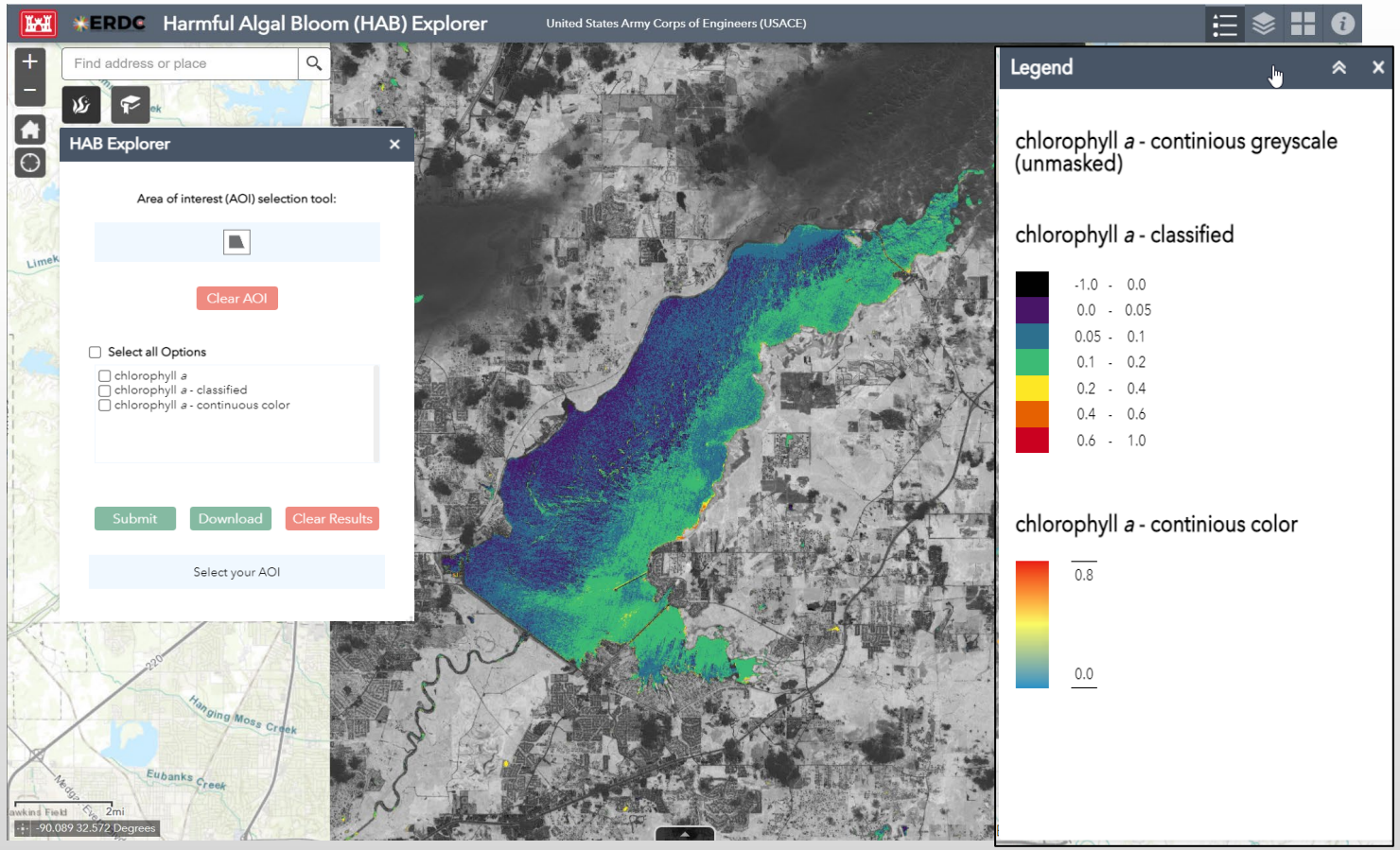
HAB Explorer available on the uCOP!
https://arcportal-ucop-corps.usace.army.mil/hab/



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 colored 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

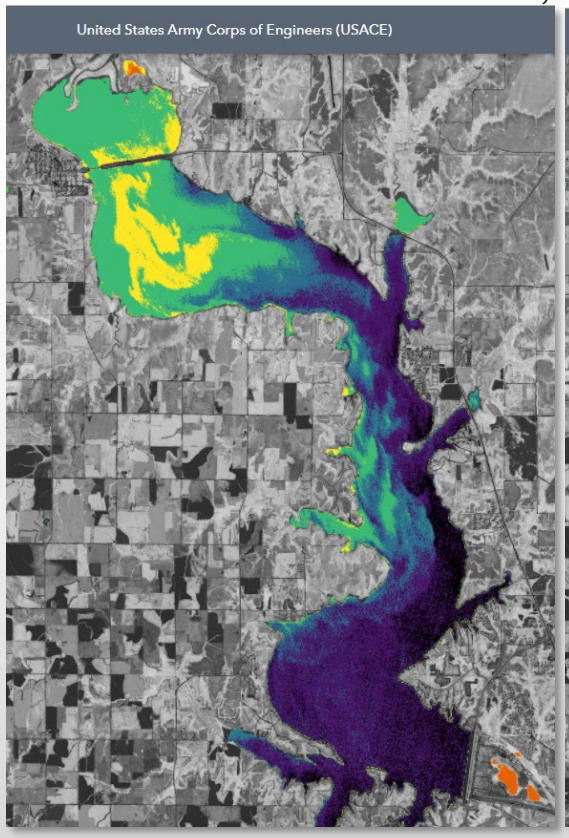


https://arcportal-ucop-corps.usace.army.mil/hab/

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 (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/

Use Considerations

1. **Area of interest** - size is limited to 750km² depending on the orientation of the area drawn; doesn't need to be detailed
2. **Clouds** - 35% threshold applied in the background, not adjustable; display in grey scale
3. **Symbology** - classified and continuous color options for water pixels only; 1 grey scale option for all pixels – all have same value ranges, -1 to 1
4. **Scene edges** - some lakes fall on scene boundaries; each scene is analyzed separately so scene edges may be apparent especially if they are from different dates
5. **Scene dates** - currently not listed in the web app
6. **Results** – dependent upon ESA scene classification (misclassifications of land/water/clouds may result in potential artifacts, such as land/clouds getting classified as water which may register as high in chl-a and/or water getting classified as clouds, which may result in omitted lake areas); artifacts tend to appear as "noise" or pixelated areas, which can occur near the shoreline, in dried up lakebeds, and/or near cloud edges
7. **Downloaded tiffs** - multiband images do not display in photo/paint or other graphics software; must be displayed in GIS software (change color stretch type to None to maintain color symbology)

Splash Screen

ERDC Harmful Algal Bloom (HAB) Explorer

United States Army Corps of Engineers (USACE)

Find address or place

Disclaimer

Welcome to the Harmful Algal Bloom (HAB) Explorer!

This application is meant to assist viewers with monitoring HABs in freshwater systems using readily available satellite imagery and was developed with support from the U.S. Army Corps of Engineers Aquatic Nuisance Species Research Program (ANSRP). The map products generated within the application show relative estimations of HAB water quality indicators and are intended as a cursory screening tool to quickly identify potential areas of concern that may require additional monitoring. The analytical methods used to generate the map products are based on current techniques available in the scientific literature and are subject to change as part of on-going research and development.

The user assumes and acknowledges the responsibility for determining accuracy, appropriateness for use, and acceptance of any data limitations.

I agree to the above terms and conditions

The recommended browser is Chrome.

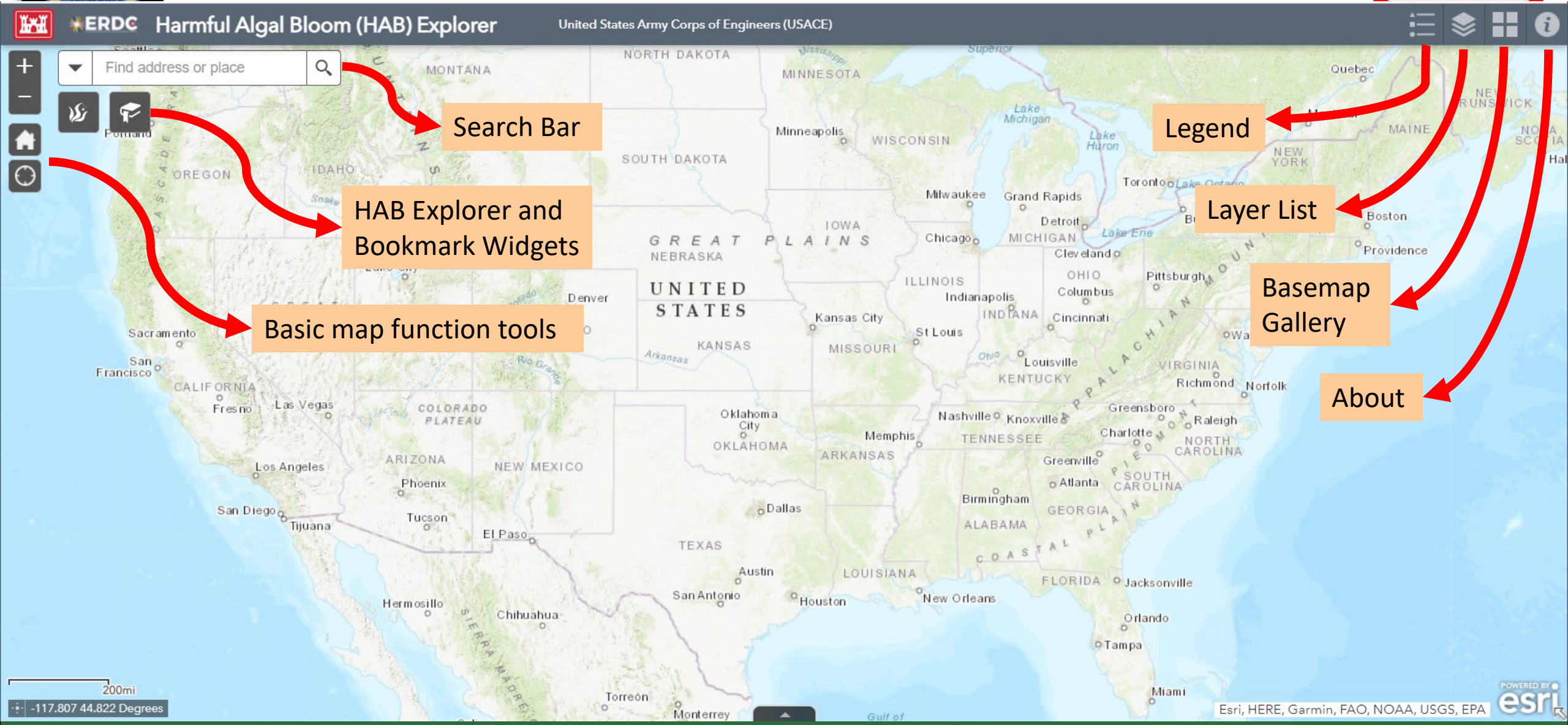
☐ Do not show this again

Ok

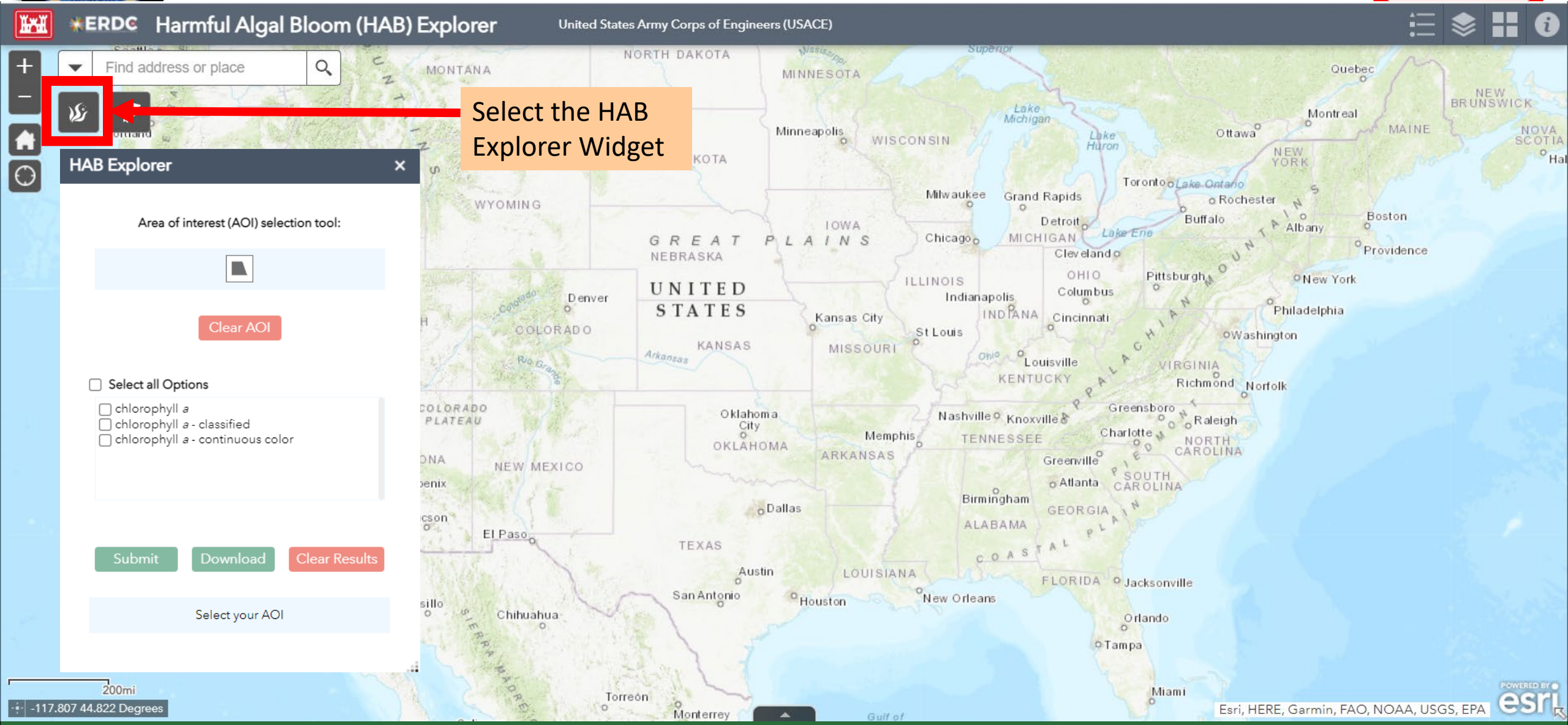
Move mouse to get coordinates

Esri, HERE, Garmin, FAO, NOAA, USGS, EPA

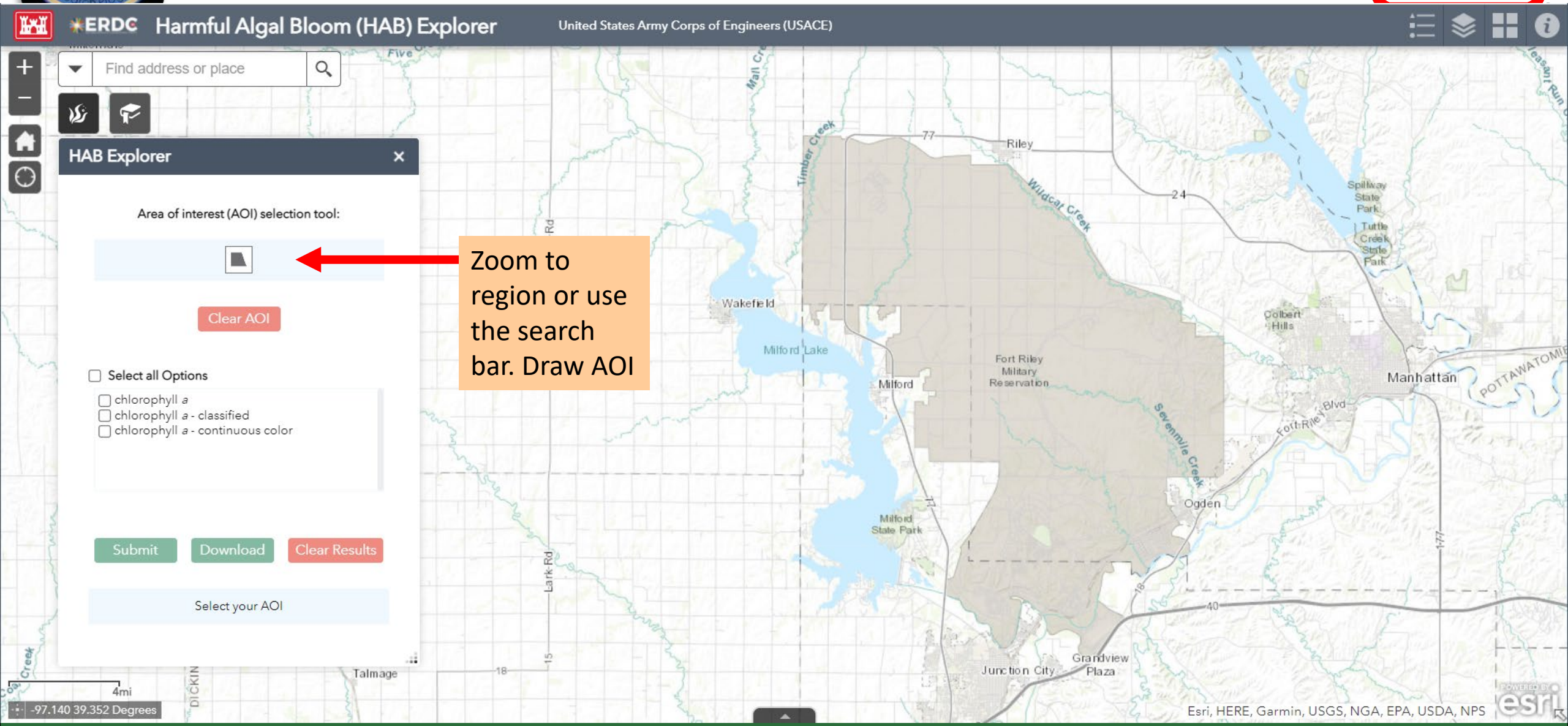
Widgets and Tools



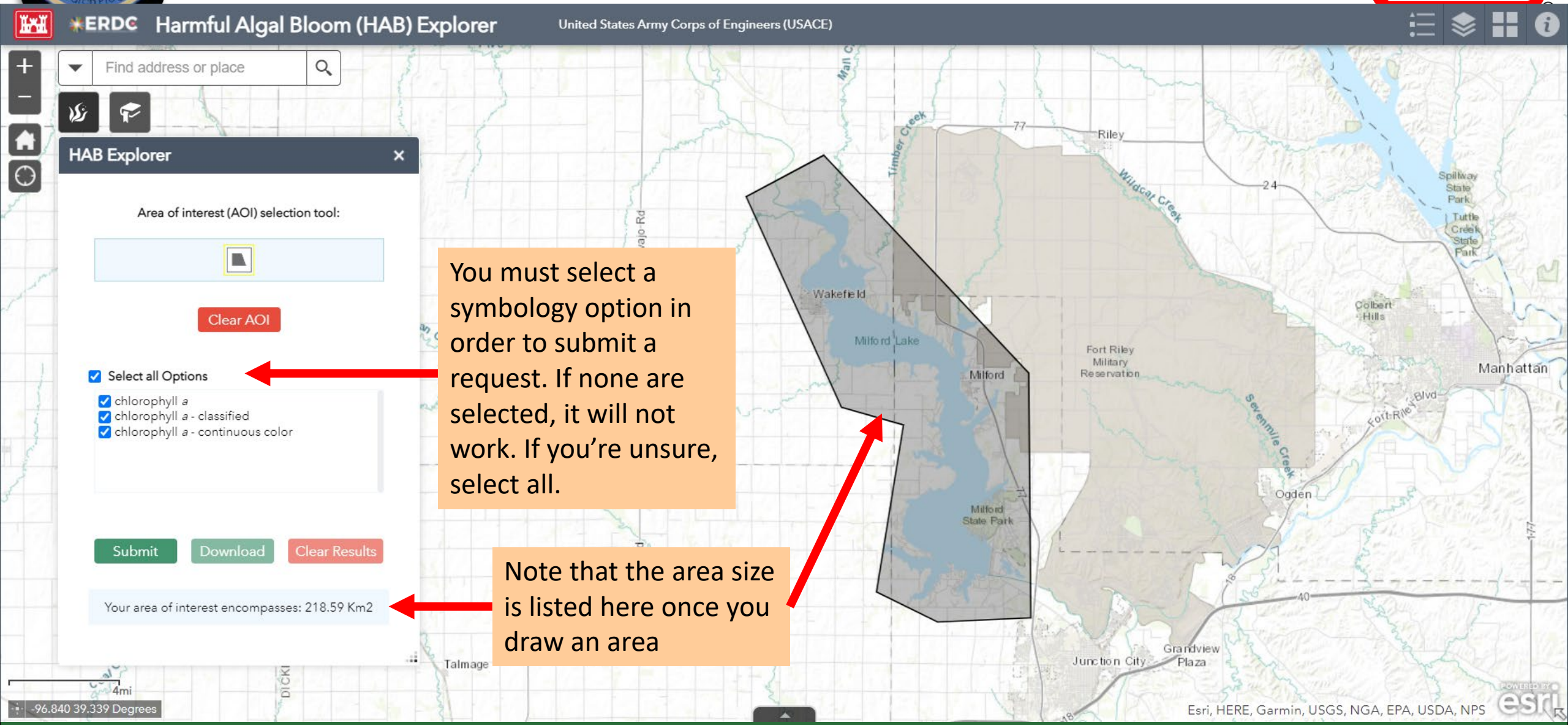
HAB Explorer Widget



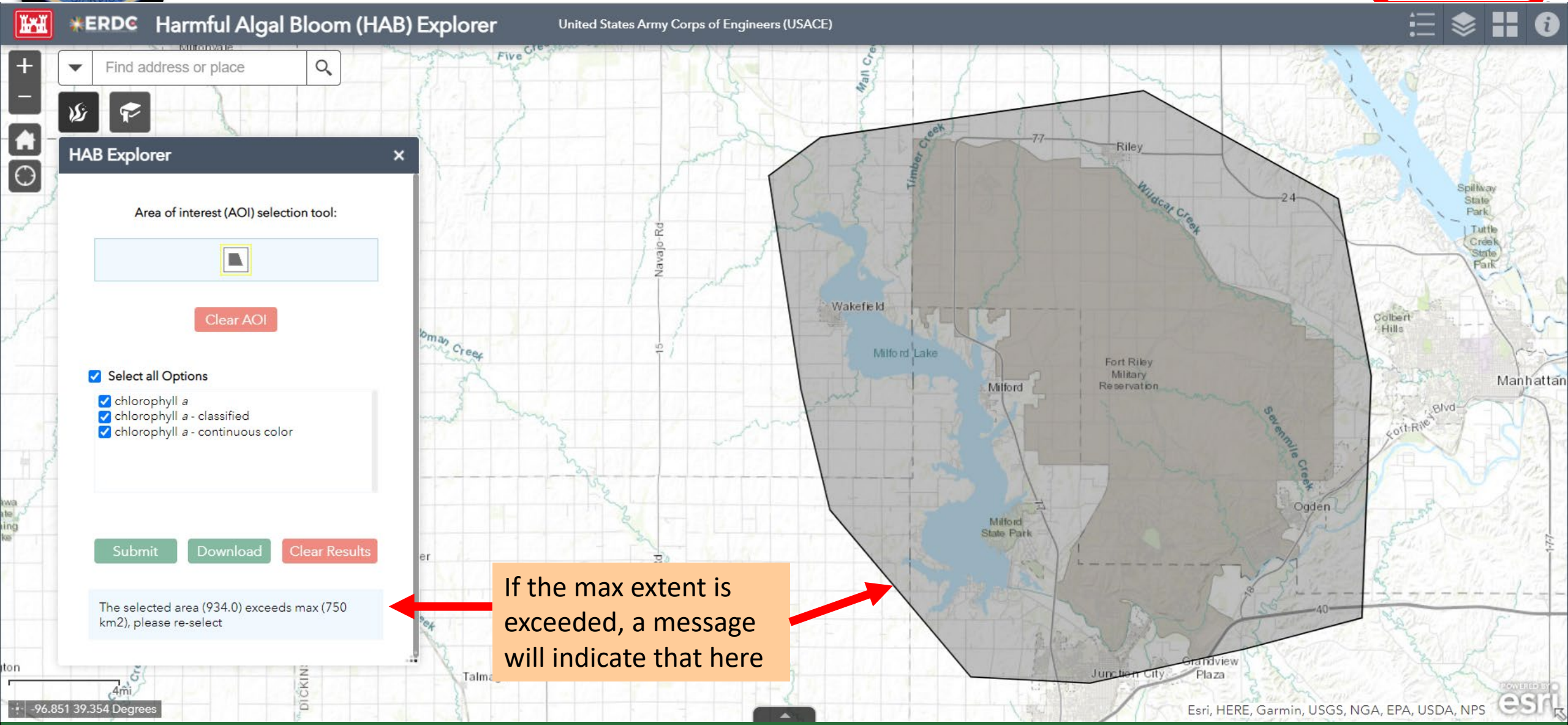
Area of Interest Selection



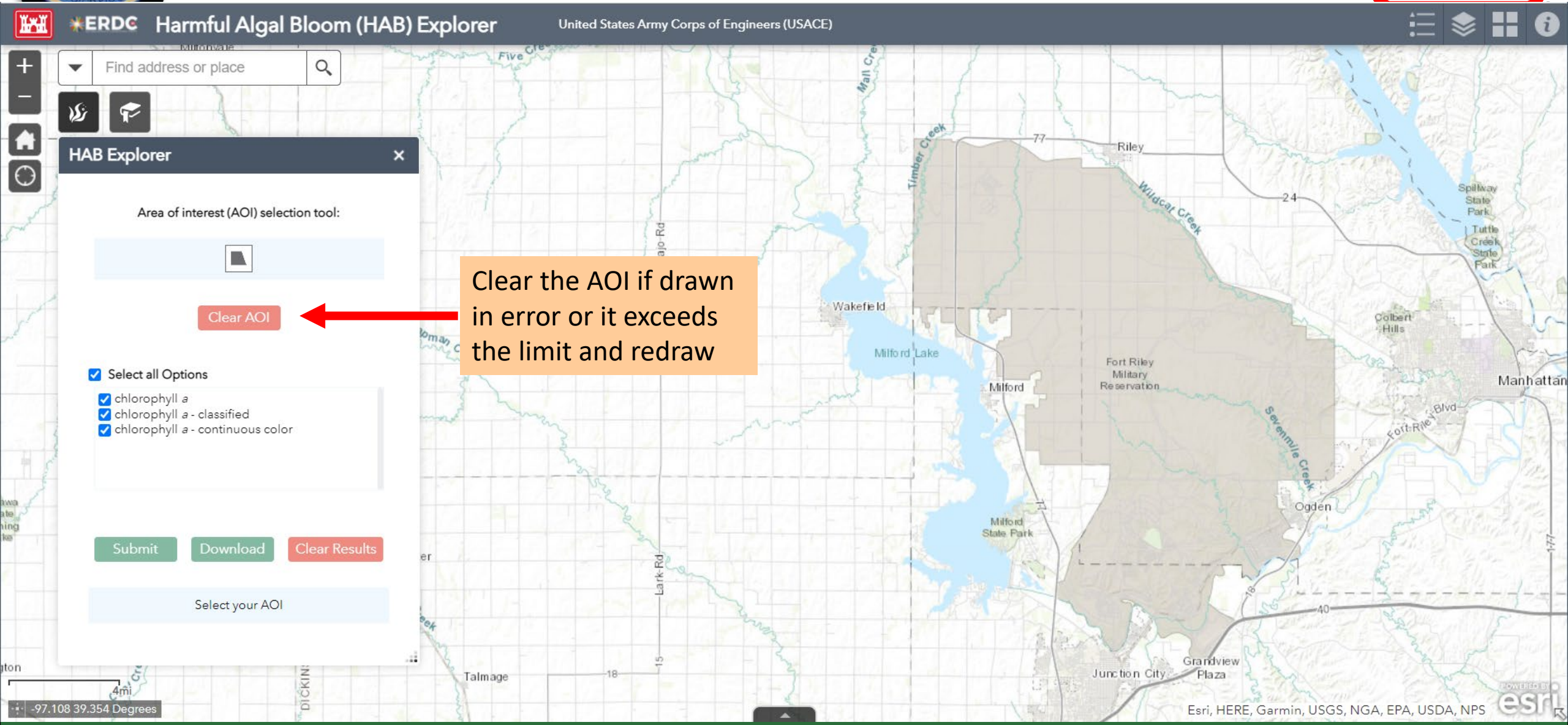
Area of Interest Selection



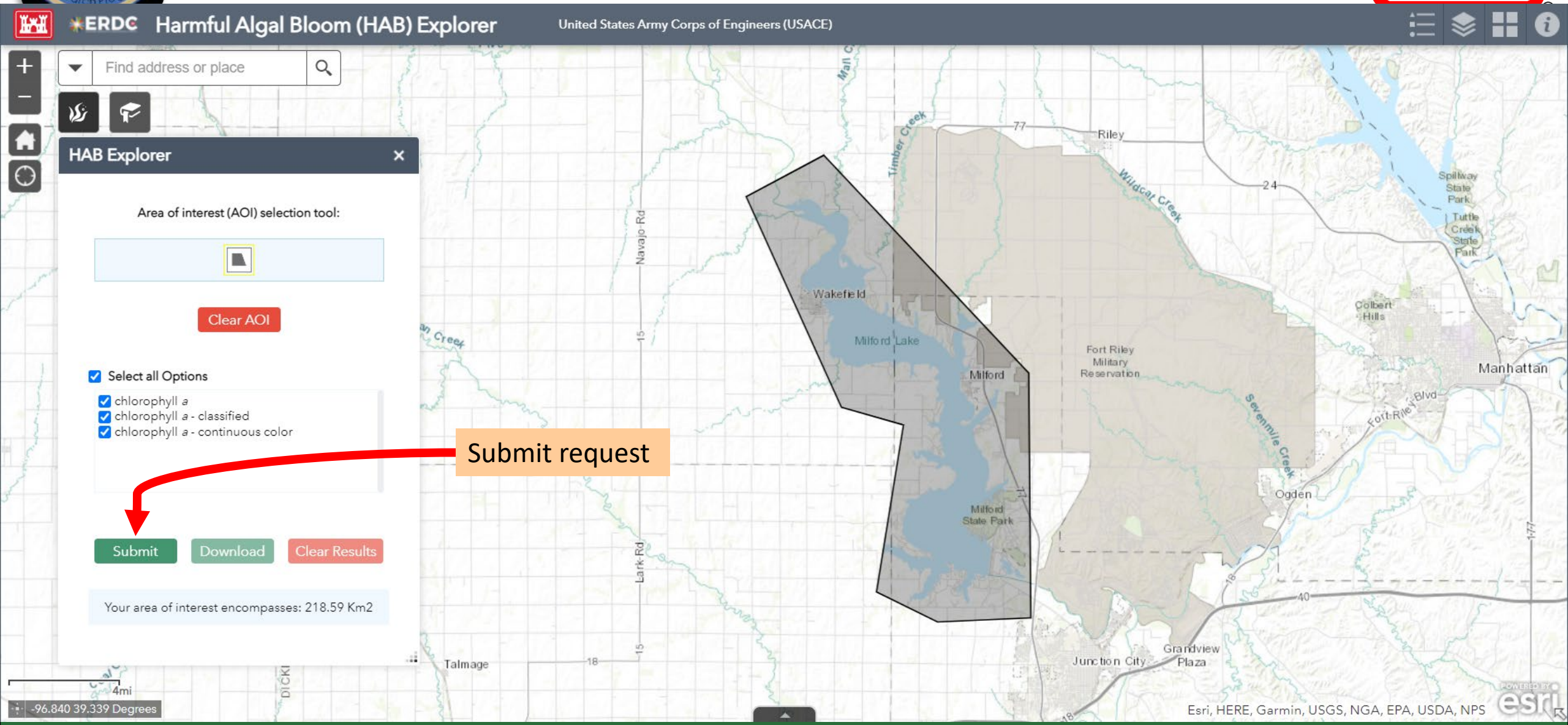
Area of Interest Selection



Area of Interest Selection



Submit Request



View Results

ERDC Harmful Algal Bloom (HAB) Explorer

United States Army Corps of Engineers (USACE)

Find address or place

HAB Explorer

Area of interest (AOI) selection tool:

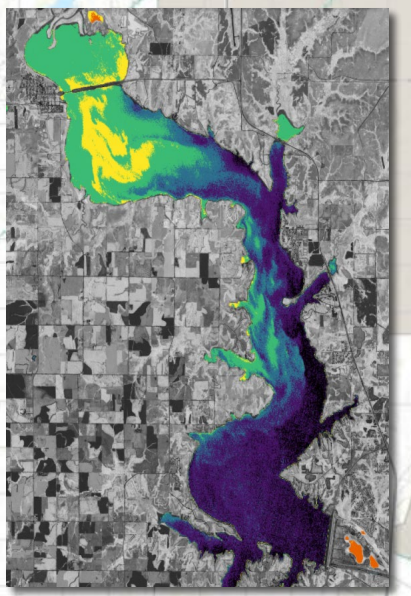
Clear AOI

Select all Options

- chlorophyll *a*
- chlorophyll *a* - classified
- chlorophyll *a* - continuous color

Submit | Download | Clear Results

Select your AOI



Layer List

Layers

- chlorophyll *a* - continuous color
- chlorophyll *a* - classi
- chlorophyll *a*

Zoom to

Transparency

Set visibility range

Move up

Move down

View in Attribute Table

Description

Navajo Rd

Lark Rd

Talmage

Junction City

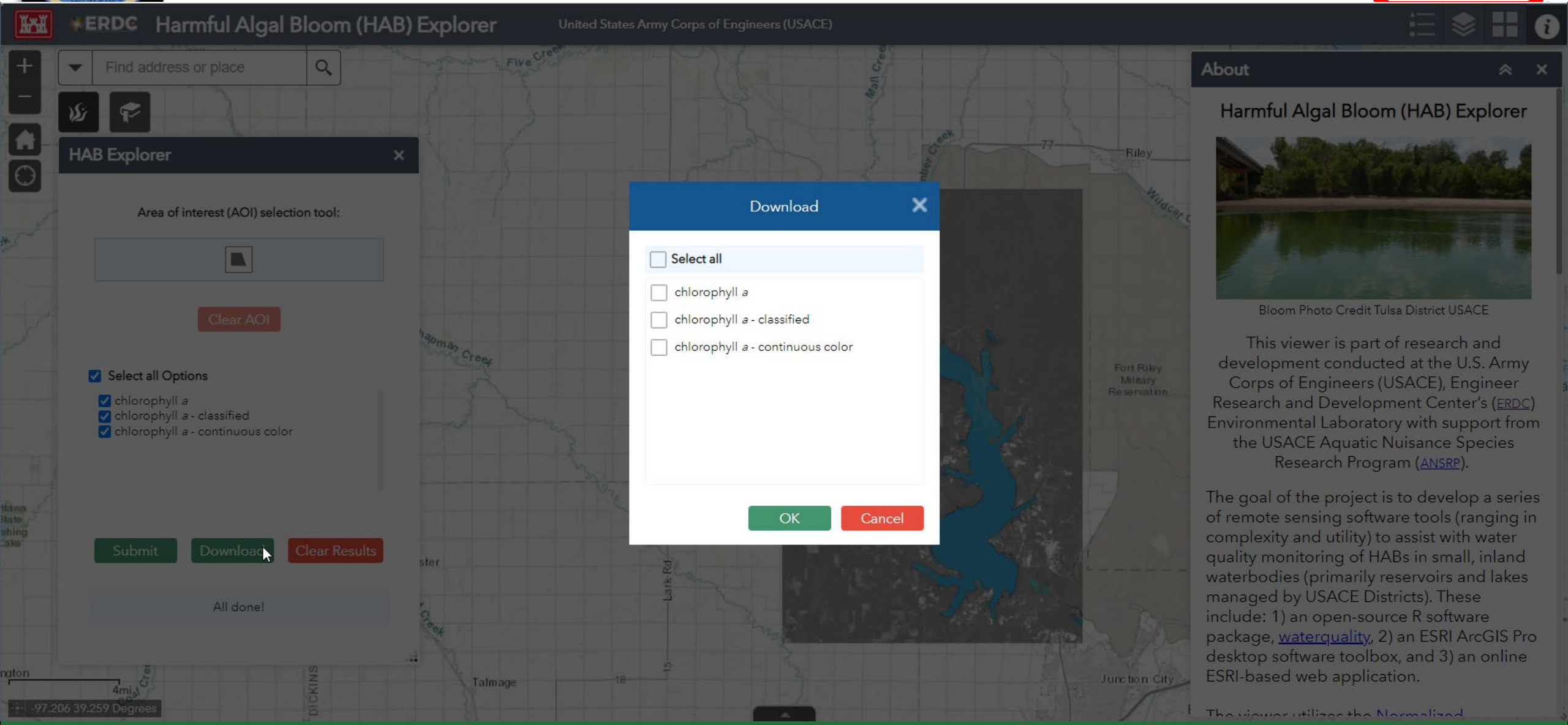
Fort Riley Military Reservation

Riley

4mi

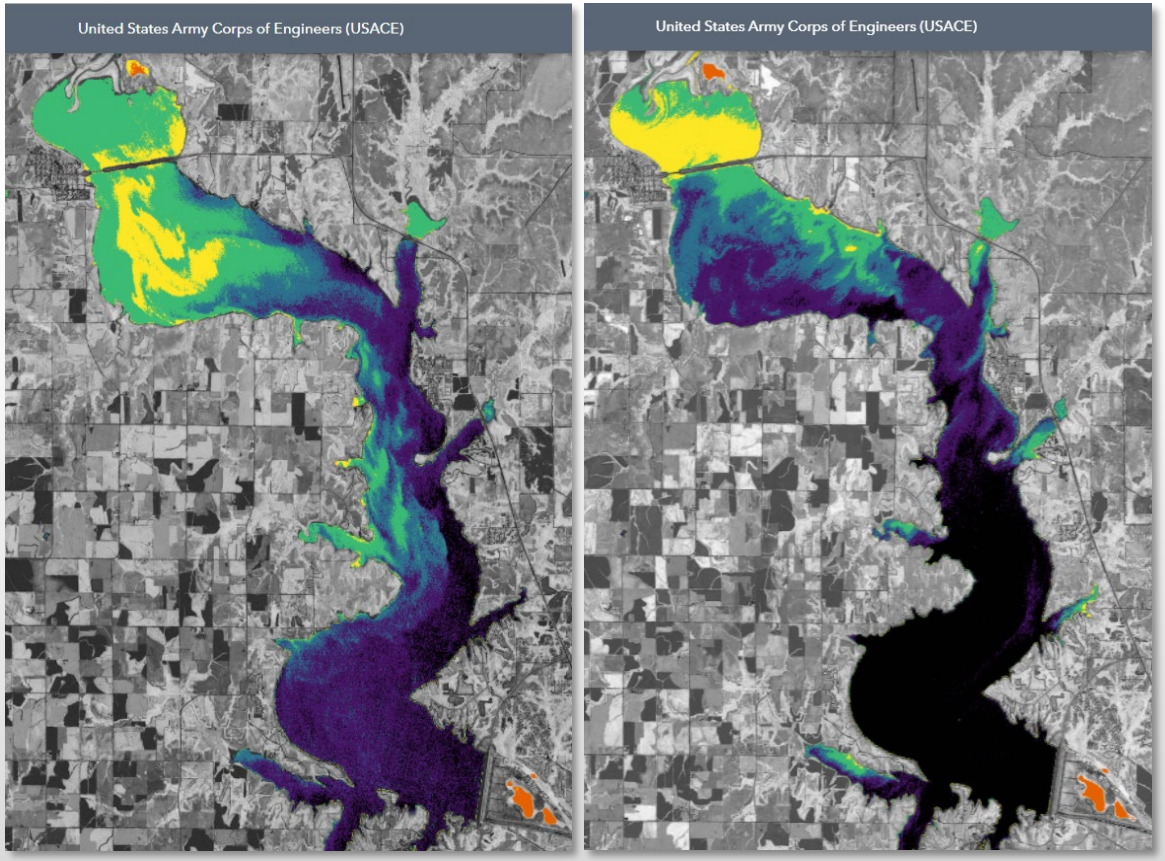
-97.108 39.354 Degrees

Download Results



HAB Explorer Benefits

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



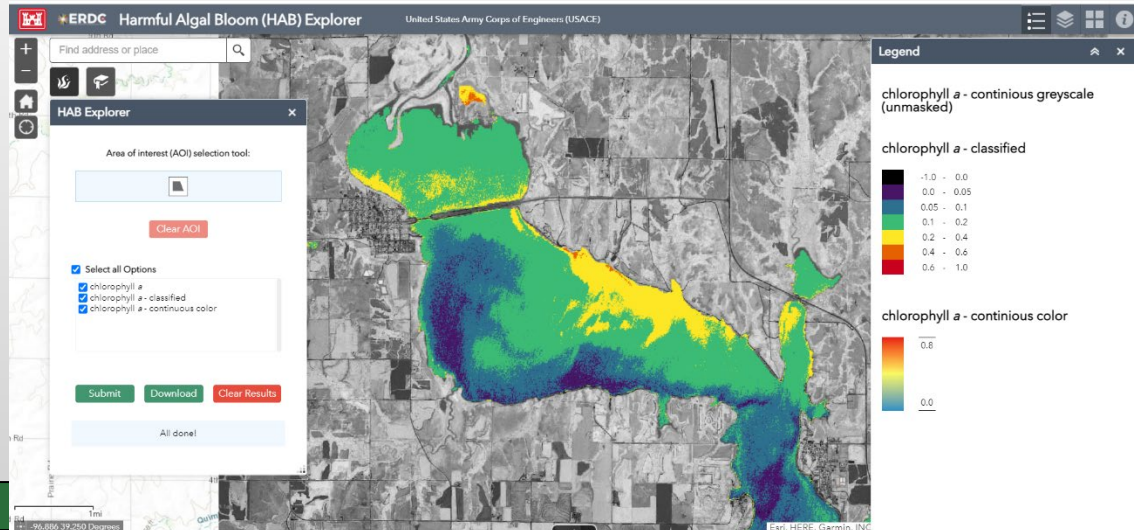
https://arcportal-ucop-corps.usace.army.mil/hab/

- Monitor whole-lake changes over time
- Visualize surface and near-surface phytoplankton biomass estimated through the NDCI
- Can help to initiate and prioritize location and timing of field-based sampling
- No GIS Desktop software required

Phase 2 Development?

1. Display date of source image
2. Display the source image (RGB version)
3. Clean up legend values, spelling, orientation (consistency)
4. Increase the AOI extent limit (can't exceed 1600km²)
5. Return pixel value of results when hovering (info button)?
6. Include more algorithms?
7. Generate results for past imagery?

Milford Lake; Photo Credit USACE Kansas City District



Interpreting Results…

1. Algorithm estimations are locally-dependent
   - Compare to in-situ data to better define what relative values mean in your area … no hard/fast rules to define values for all datasets in all areas
2. Algorithm accuracies are good, but every waterbody is unique
   - The tools help streamline the process to explore/understand potential bloom trends in your area
3. Start with NDCI if unsure or don't have in-situ data
   - It's normalized/consistent similar to NDVI
   - GENERAL guidance: <0 = minimal/no chl-a; 0 - 0.2 = low chl-a, and > 0.2/0.3 = higher chl-a with values approaching 1 to be the most consequential for HAB potential; anything more specific requires comparison to in-situ data
   - Watch values >0.2/0.3, pending movement/dynamics/persistence; could either be a HAB or be conducive for HAB development
4. Use the tools to target field-based resources in space/time to increase monitoring efficiency
   - The tools allow large area assessment in a matter of hours that would otherwise take days/weeks to sample
5. New R&D to build confidence and understanding of the algorithms
   - To help determine which ones work best in which waterbodies, environments, etc.

Follow-up & Contact List

These tools were specifically designed to assist the USACE monitoring of inland lakes and reservoirs to estimate water quality indicators of HABs. Your feedback is a critical component to the success and future development of these tools and ensuring that the capabilities and products generated are consistent with your priorities.

1. Need help? Please send us your in-situ measurements!
2. Provide feedback about the HAB Explorer!

- **Christina Saltus**:

Email: Christina.L.Saltus@erdc.dren.mil

- **Molly Reif**:

Email: Molly.K.Reif@usace.army.mil

- **Richard Johansen:**

Email: Richard.A.Johansen@usace.army.mil

- **Erich Emery**:

Email: Erich.B.Emery@usace.army.mil

Tool Links

- Open Source R Package: https://github.com/RAJohansen/waterquality
- ArcGIS Pro Toolbox: http://dx.doi.org/10.21079/11681/42240
- HAB Explorer Web App: https://arcportal-ucop-corps.usace.army.mil/hab/