

The dynamic colors of the Klamath River and what they tell us about the source and transport of sediments.

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PhD Student



Luke Zeitlin
Head of Software Engineering



Sara De Moitié
Founder and Chief Product Officer



Ivan Lalović
Founder and CEO



Omar Zurita
Founder and COO

Input Data

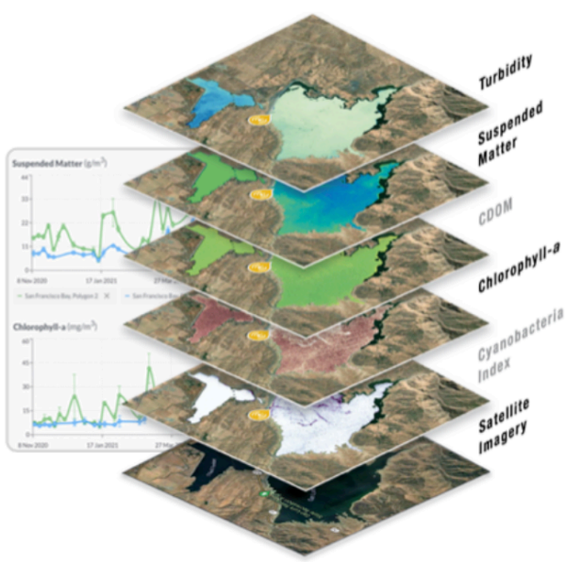
Satellite + Gybe Sensor
+ Weather Data



Comprehensive
Additional Data Sources

Water Data

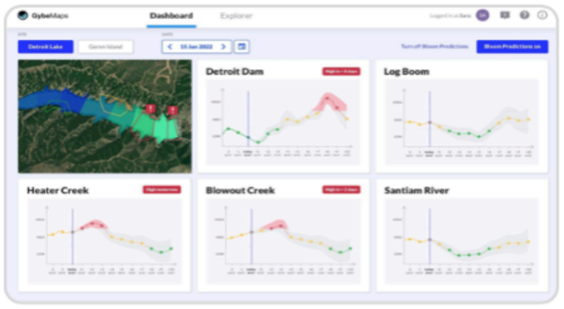
Time series + Data Maps
and derived information



Extendable
Enabling New
Parameters & Analytics

GybeMaps™ App

Decision making tools





Actionable
Prediction, Alerting,
and Collaboration Features

Papers: http://www.aquahue.net

Region:

Klamath River

Region and Dam Removal

Water Quality Monitoring

Problem:

Monitor source and transport of sediments, algae, and biogeochemical water constituents

Physics Tools:

Water Quality Spectroscopy (Measurements)

Gybe Spectrometer

Remote Sensing

Transport Models — Advection-Dispersion Equation (Models)

Ultimate Goal: Water ‘Weather’ Monitoring and Forecasts (Measurements + Models)

Real Time Picture of State of the River

Klamath River Dam Removal

EXPLANATION

- Dams to be removed
- Dams
- USGS Streamgages
- Study Reach

0 5 10 20 Miles

OREGON

CALIFORNIA

Upper Klamath Lake

LINK RIVER DIVERSION

KENO

JOHN C BOYLE

COPCO NO 2

COPCO NO 1

IRON GATE

Klamath River

Happy Camp

Yreka

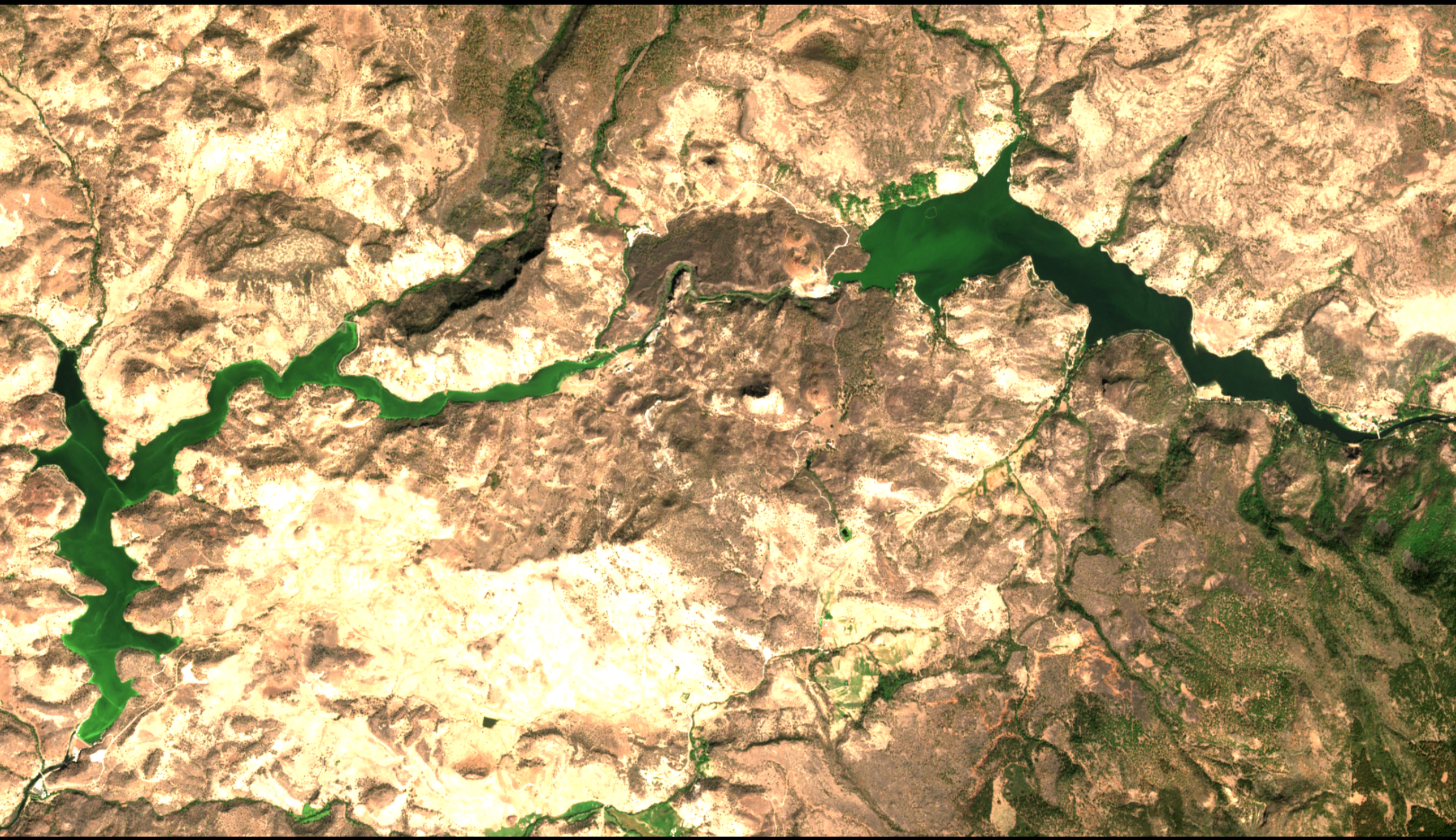
Klamath

Hoopa



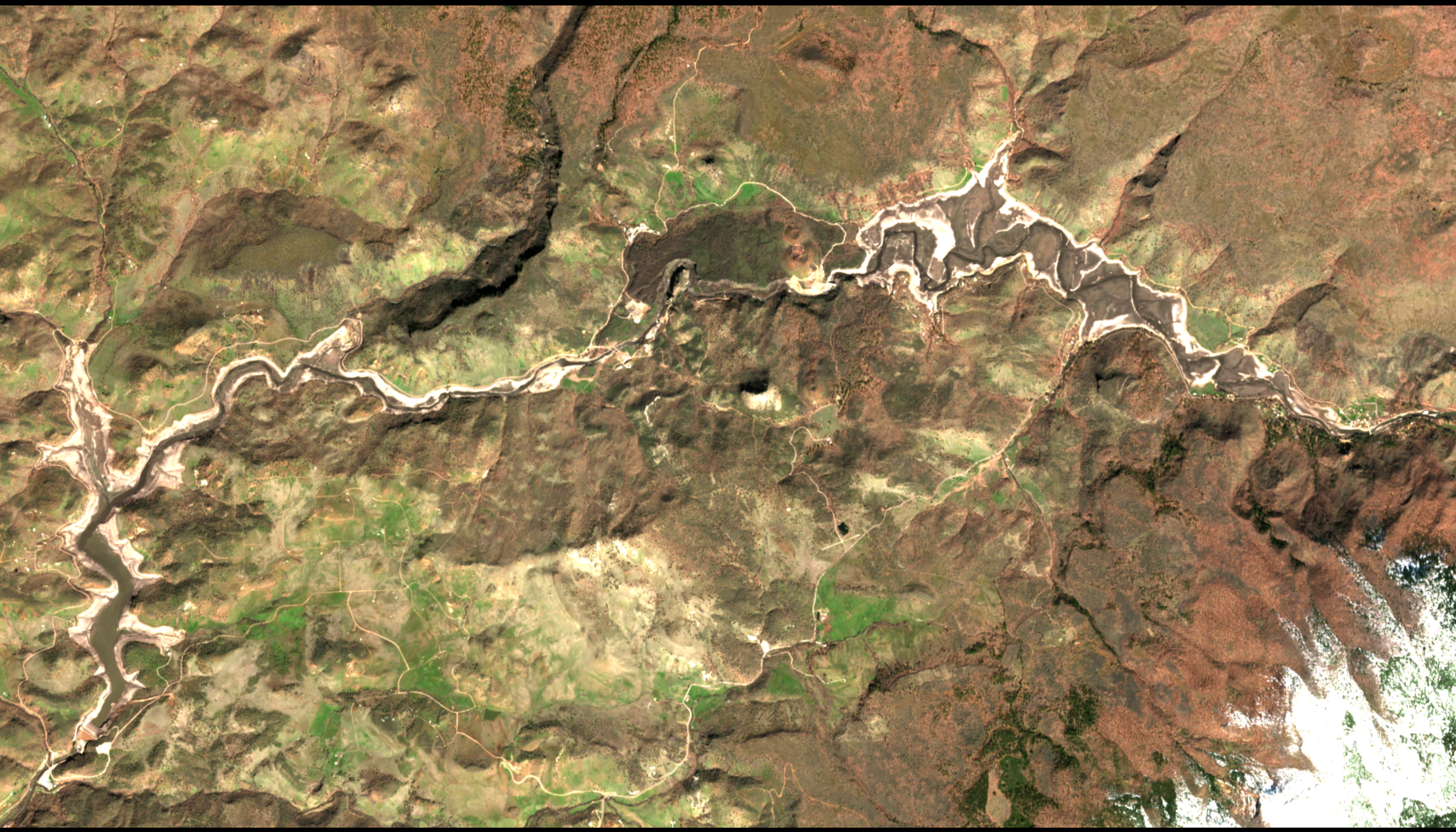
Airbus,USGS,NGA,NASA,CGIAR,NCEAS,NLS,OS,NMA,Geodatastyrelsen,GSA,GSI and the GIS User Community, Esri, HERE, Garmin, USGS, EPA, Esri, HERE, Garmin, USGS, EPA, NPS

Harmful Algal blooms formed 300 km upstream killed Salmon through out the whole river and this lead, eventually, to the removal of the dams past year.

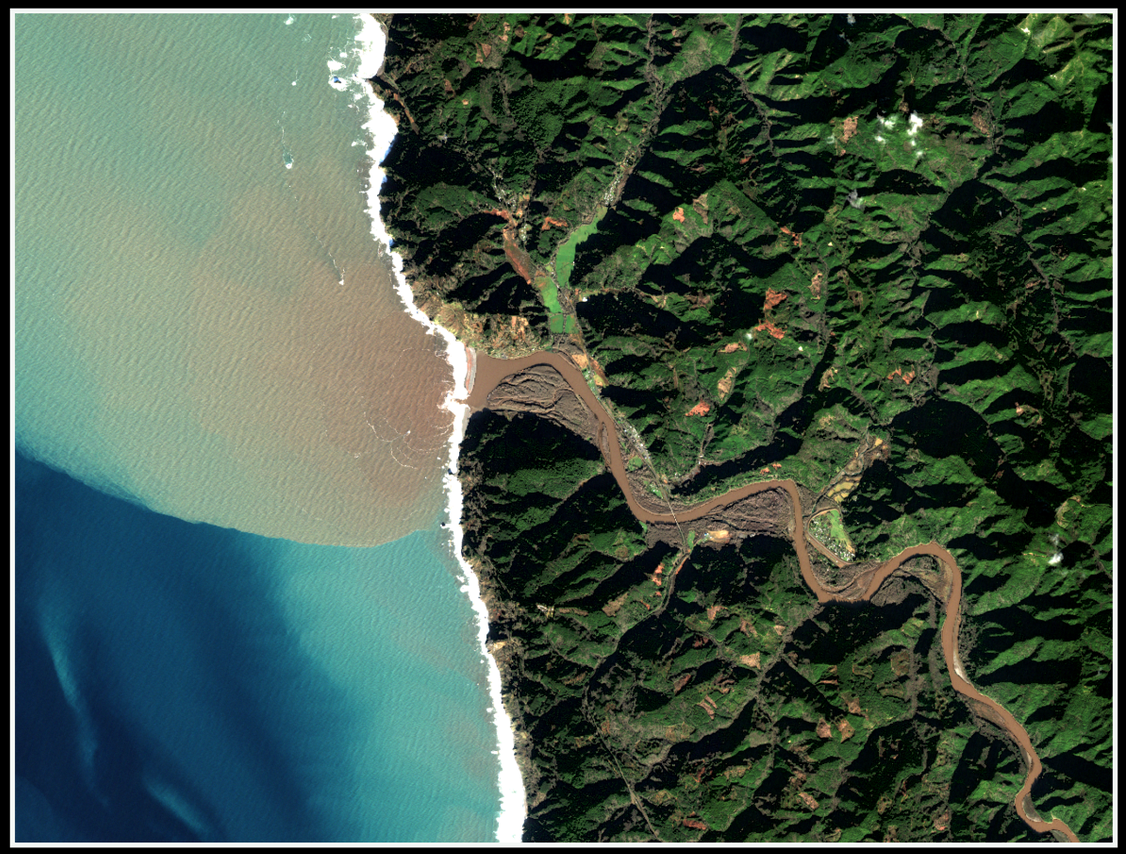


2023-09-19

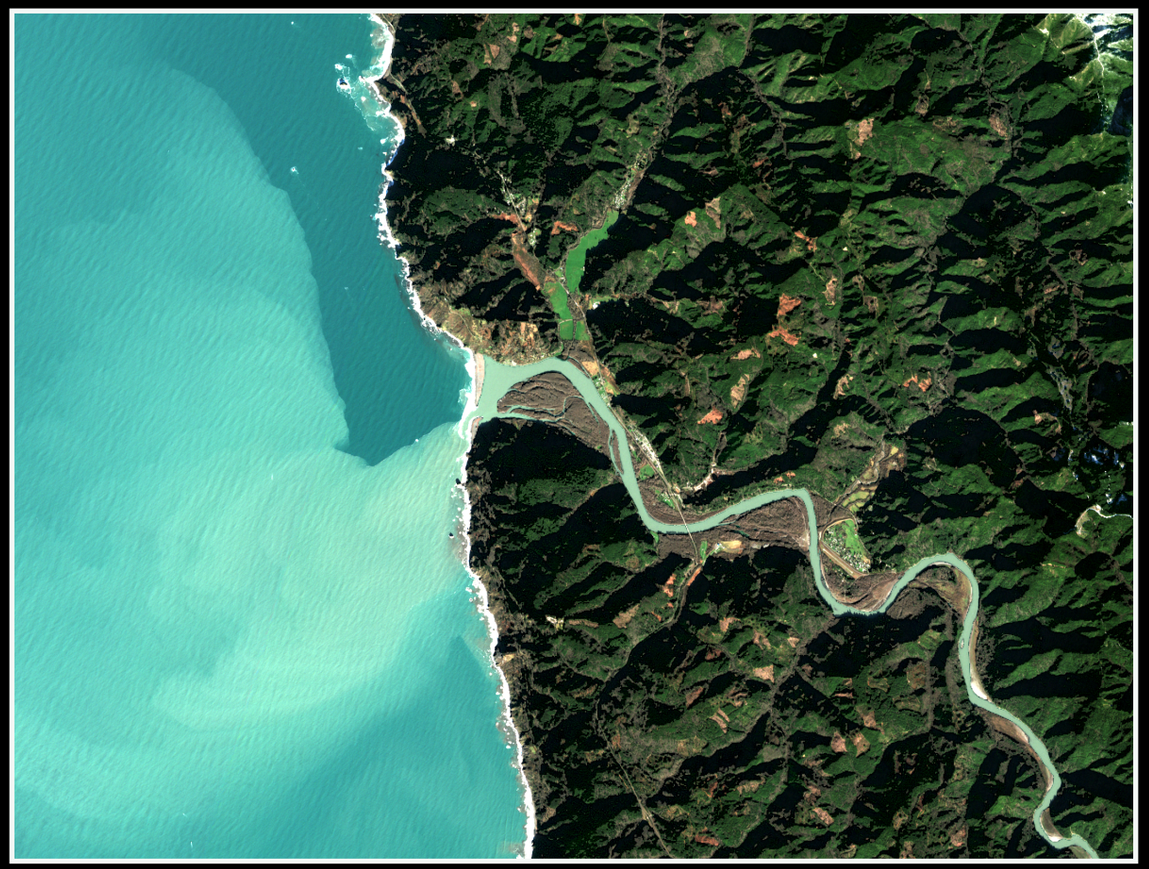
After dam removal



2024-03-17







Water Types at Turwar Gauge -- Klamath Estuary

Clear
2023-01-20



Green
2024-05-21



Brown
2022-12-11



Turquoise
2023-01-20



Olive
2024-03-07

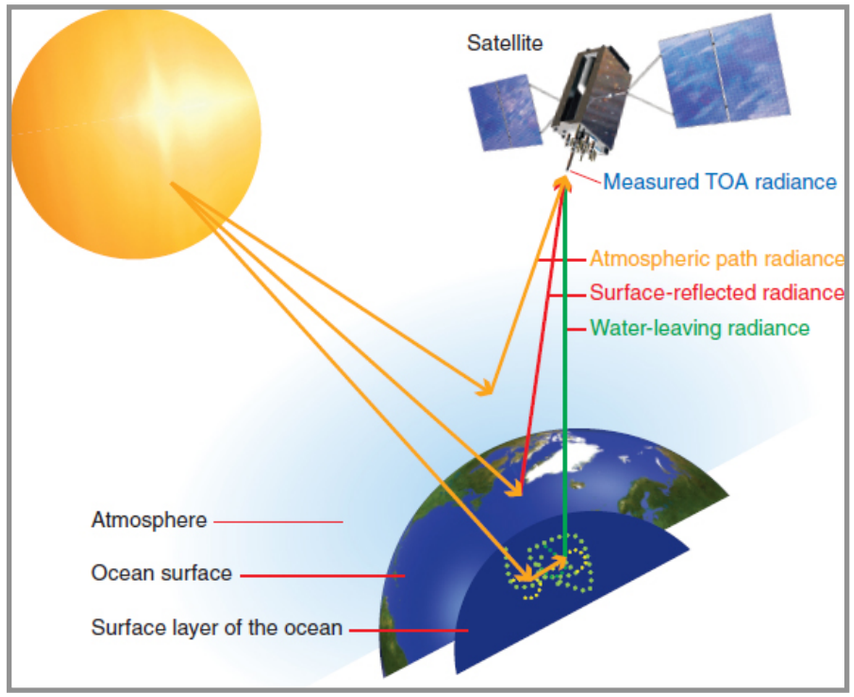


Red
2022-12-28



Data we use:

Satellite measured Top-of-Atmosphere (TOA) spectral radiometry (typically multi-spectral)



Gybe's coincident above water hyperspectral radiometry data connects *in situ* water properties to satellite observations



Lab analysis of water grabs



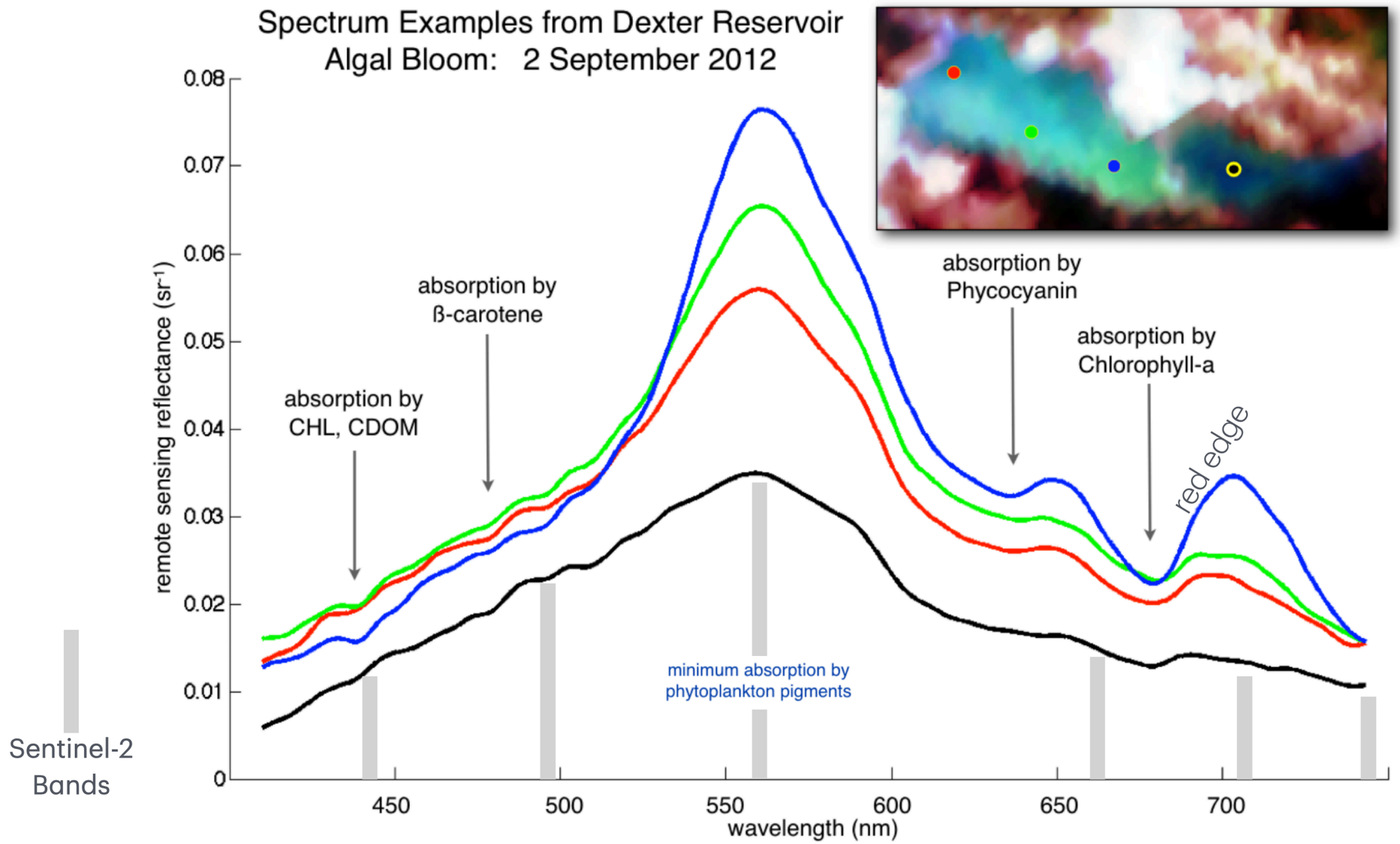
In situ measurements of in water biogeochemical properties



Estimating Target Products (eg. turbidity, chloropyyll concentrations) from IOP's or Remote Sensing Reflectence (Rrs)

The oceanographers' remote-sensing reflectance

$$R_{rs}\left(\theta_r, \phi_r\right) \equiv \frac{L_r\left(\theta_r, \phi_r\right)}{E_d} \quad \left(\mathrm{sr}^{-1}\right) \ ,$$



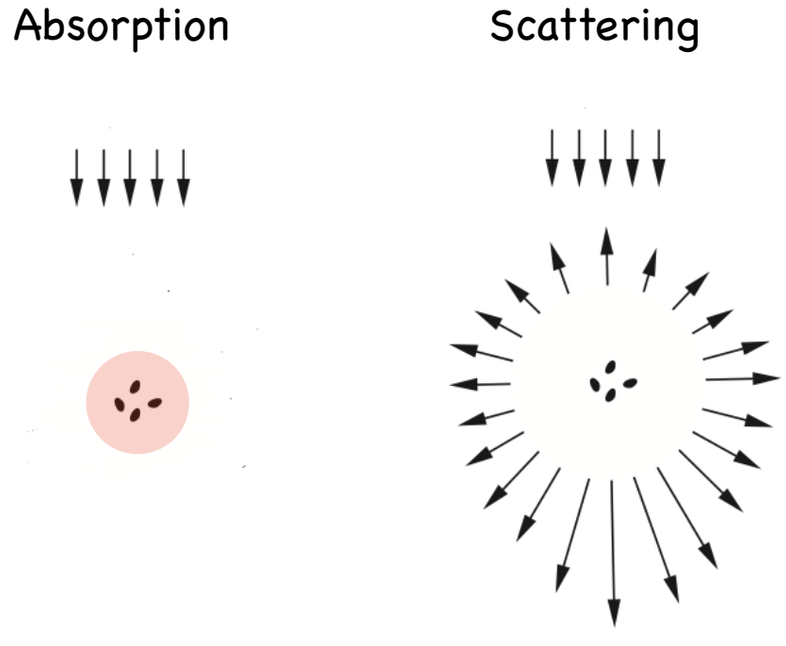
QAA: Quasi-Analytical Algorithm

First estimate:

Intrinsic **O**ptical **P**roperties (IOPs)

Absorption - $a(\lambda)$

Backscatter - $b_b(\lambda)$



Then use 'a,' 'b_b' as *state variables* to estimate products: Chl-a, sediments, ...

Why?

--- All optical properties determined by absorption and volume scattering function

--- Do not need detailed models of water constituents (type of pigments, or scattering particles) to estimate a, b_b

--- Physical insight, results can be checked along the way

--- Explicitly 'deconvolve' water absorption

--- Closer connection to lab assay

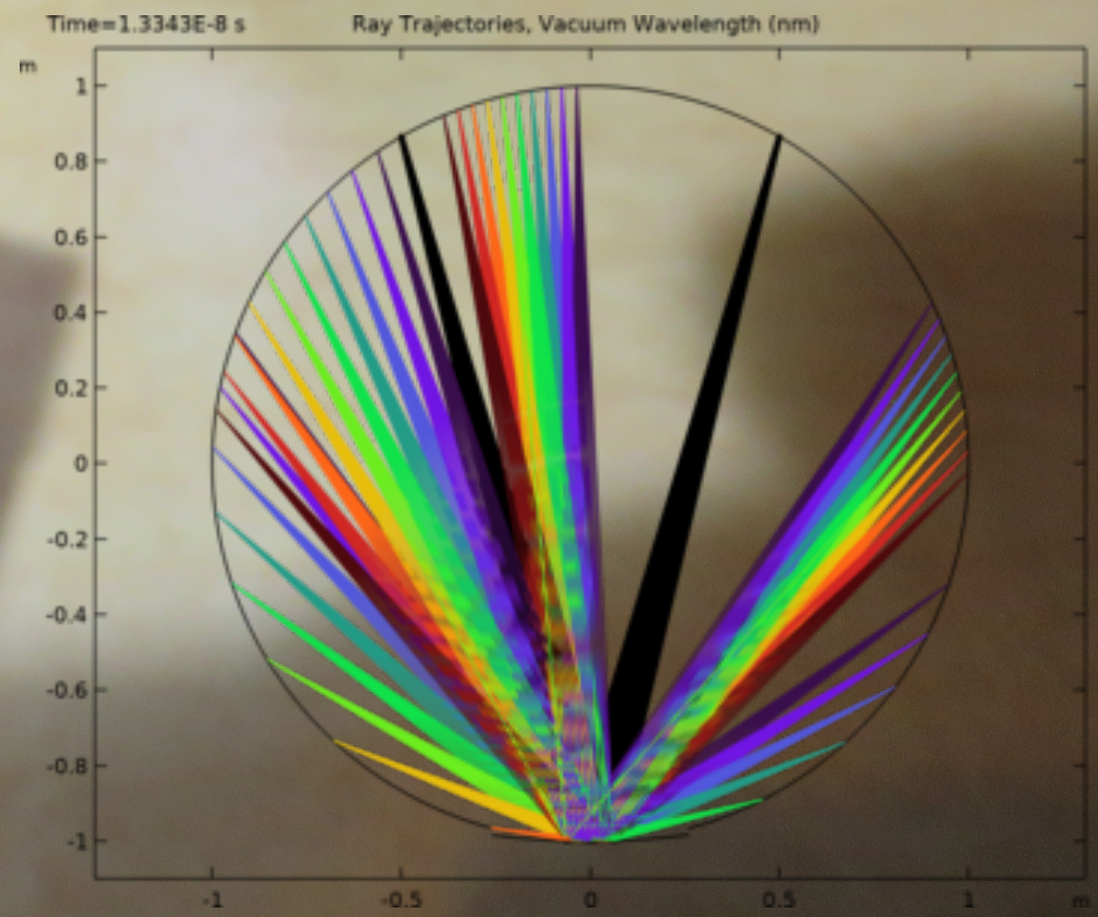
References

Lee, Z.; Carder, K.L.; Arnone, R.A. Deriving Inherent Optical Properties from Water Color: a Multiband Quasi-Analytical Algorithm for Optically Deep Waters. *Appl. Opt.* **2002**, *41*, 5755–5772.

Mishra, S.; Mishra, D.; Lee, Z. Bio-Optical Inversion in Highly Turbid and Cyanobacteria-Dominated Waters. *Geoscience and Remote Sensing, IEEE Transactions on* **2013**, pp. 1–14.

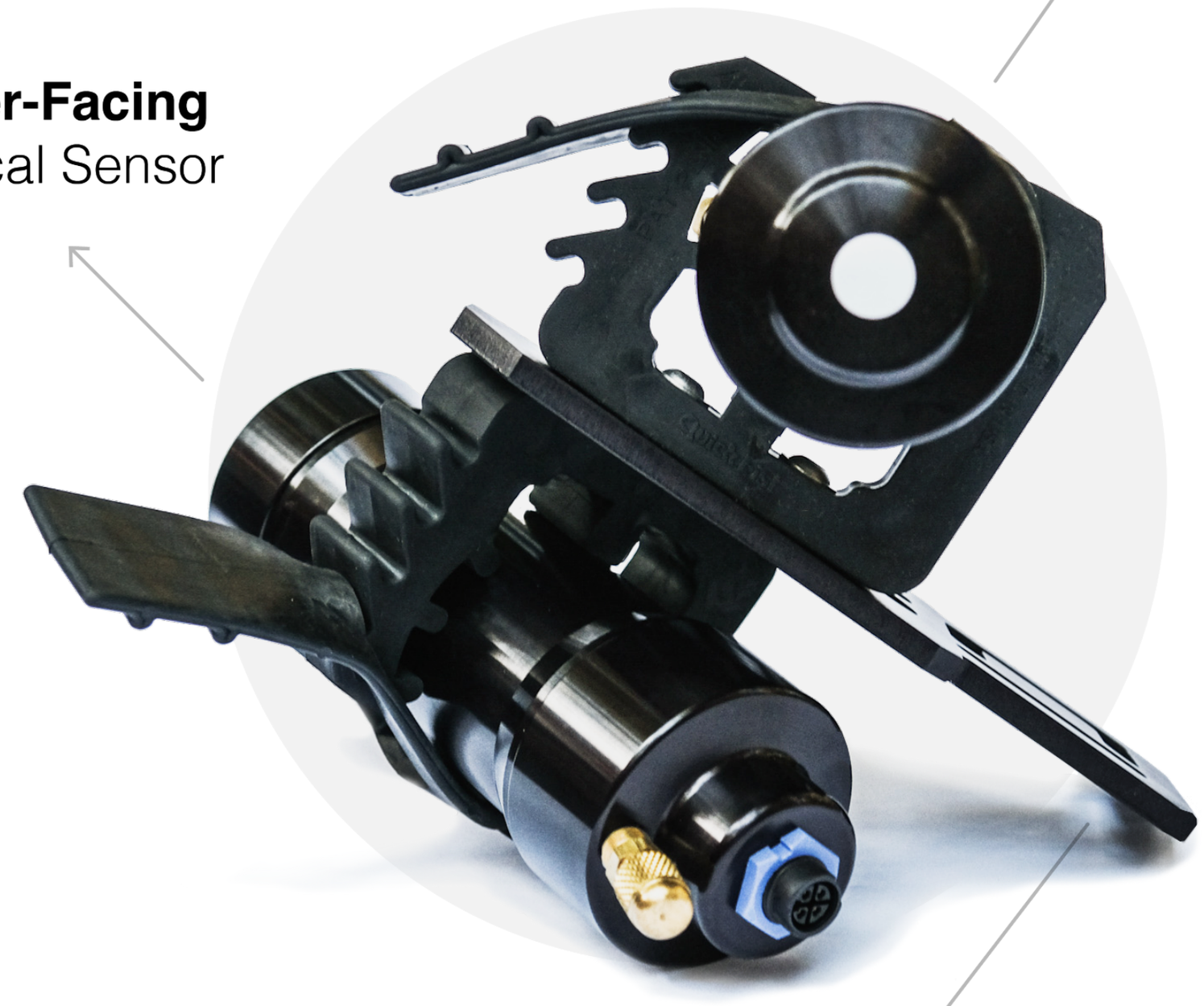
SYMBOLS AND ABBREVIATIONS

Symbol	Description	Unit
$a_p(\lambda)$	Absorption coefficient of particulate matter	m^{-1}
$a_d(\lambda)$	Absorption coefficient of detrital matter	m^{-1}
$a_{CDOM}(\lambda)$	Absorption coefficient of colored dissolved organic matter	m^{-1}
$a_{CDM}(\lambda)$	Absorption coefficient of CDOM and detritus	m^{-1}
$a_w(\lambda)$	Absorption coefficient of pure water	m^{-1}
$a_\phi(\lambda)$	Absorption coefficient of phytoplankton pigments	m^{-1}
$a_t(\lambda)$	Total absorption coefficients, $a_w(\lambda)+ a_\phi(\lambda)+ a_{CDM}(\lambda)$	m^{-1}
$a_{t\text{-}w}(\lambda)$	$a_t(\lambda) - a_w(\lambda)$	m^{-1}
$b_{bp}(\lambda)$	Backscattering coefficients of particulate matter	m^{-1}
$b_{bw}(\lambda)$	Backscattering coefficients of pure water	m^{-1}
$b_b(\lambda)$	Backscattering coefficients of the total, $b_{bw}(\lambda)+b_{bp}(\lambda)$	m^{-1}
η	Spectral power for backscattering coefficient	
$R_{rs}(\lambda)$	Above-surface remote sensing reflectance	sr^{-1}
$r_{rs}(\lambda)$	Subsurface remote sensing reflectance	sr^{-1}
S_{CDM}	Spectral slope of colored detrital matter absorption coefficient	nm^{-1}
TSS	Total suspended solids	$mg\ l^{-1}$
ISS	Inorganic suspended solids	$mg\ l^{-1}$
OSS	Organic suspended solids	$mg\ l^{-1}$
IOP	Inherent optical properties	
u	Ratio of backscattering coefficient to the sum of absorption and backscattering coefficient	


Time=1.3343E-8 s
Ray Trajectories, Vacuum Wavelength (nm)
m
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.5
0
0.5
1
m
650
600
550
500
450

Sky-Facing
Optical Sensor

Water-Facing
Optical Sensor



Sensor
Bracket

Requa - Klamath River Estuary












EAGLE
WATER QUALITY
YAMAHA
Raider



Detroit Lake, Oregon



Baton Rouge, Mississippi



Snake River, Idaho



Palisades Reservoir, Idaho



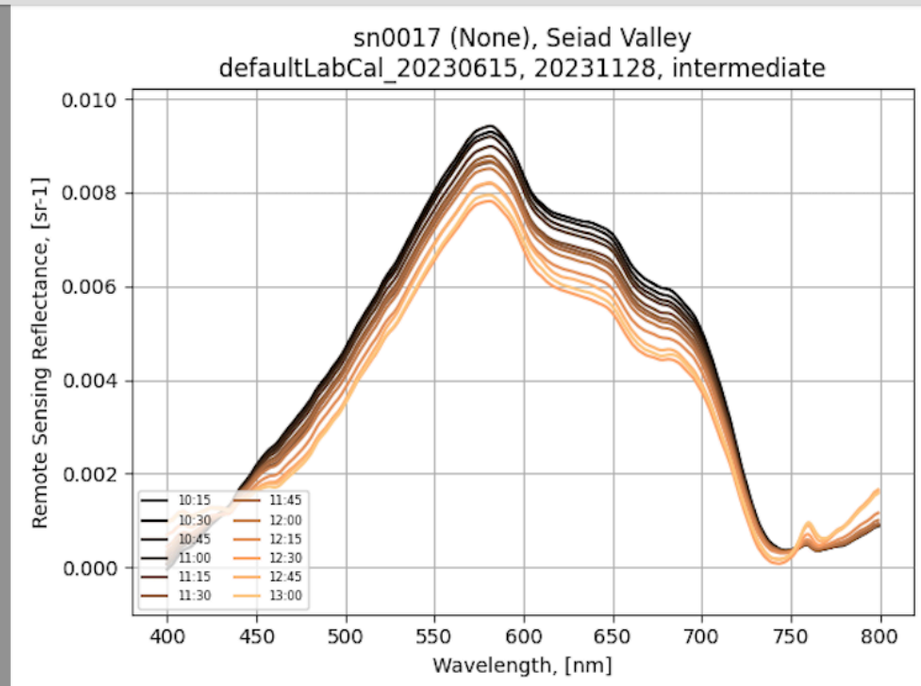
S2A/MSI 2023-11-28 19:12:49
ρ_s RGB



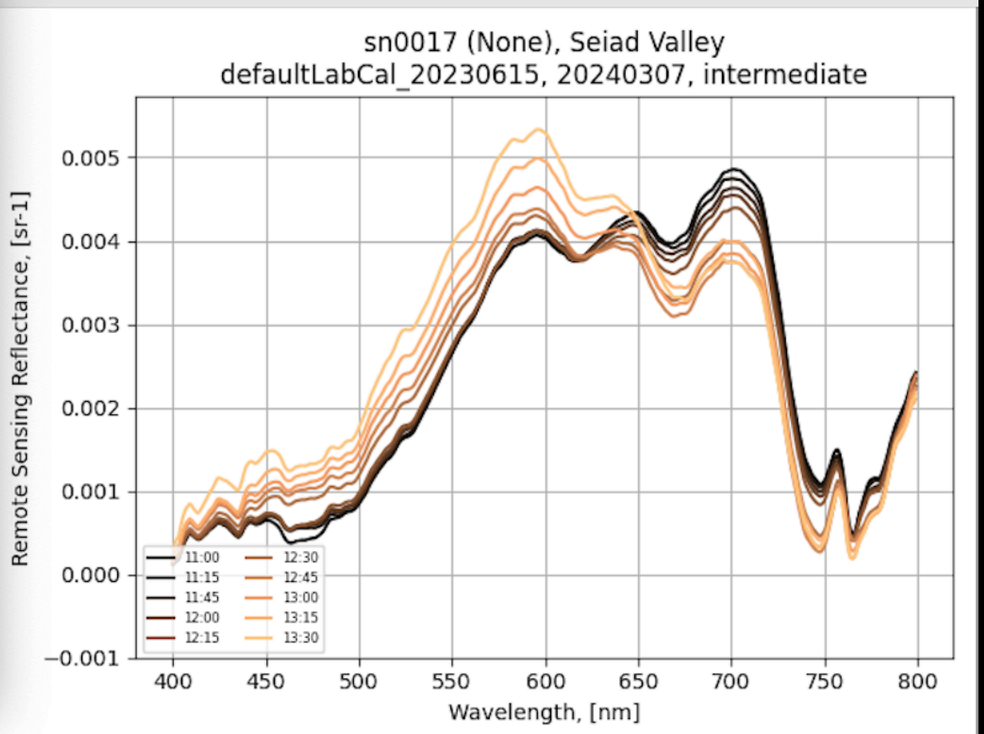
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ρ_s RGB



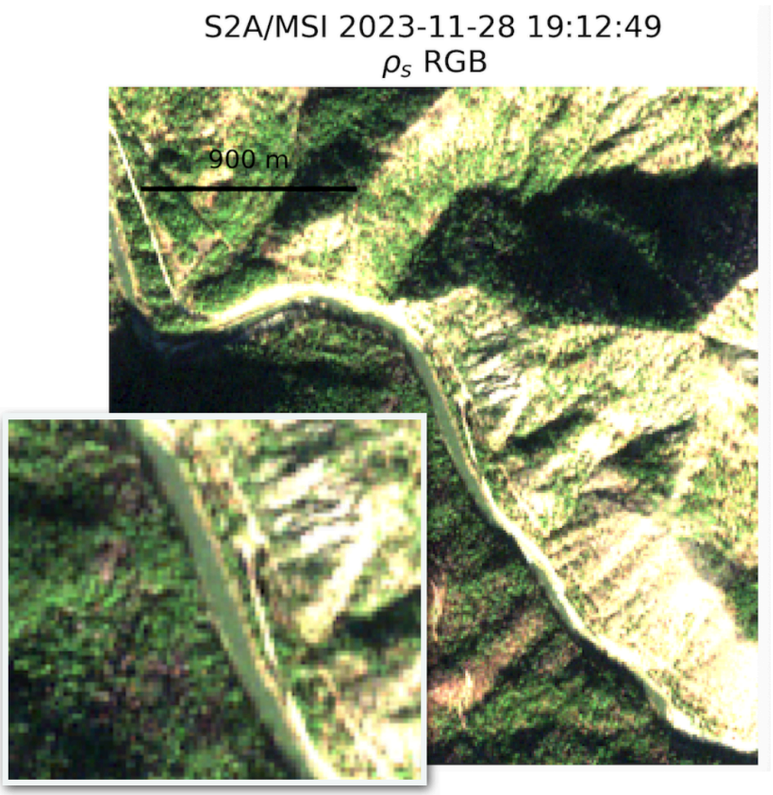
G2__Rrs_intermediate_202...



G2__Rrs_intermediate_20...

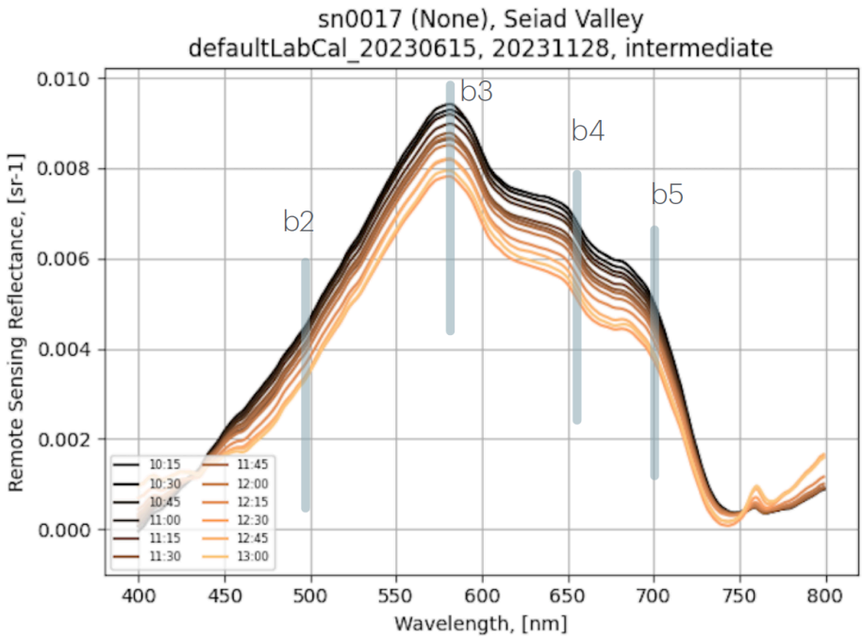


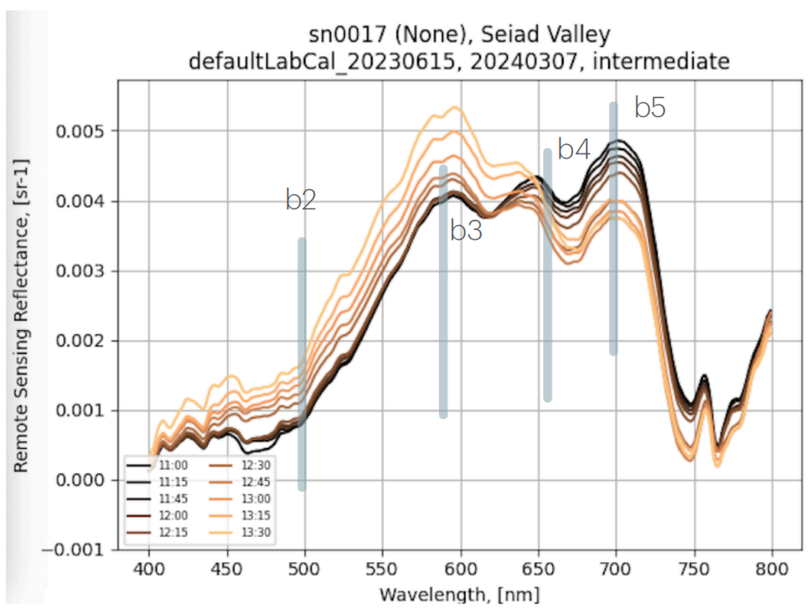
Examine Imagery





Use Gybe Sensor to identify water type and inform regression models

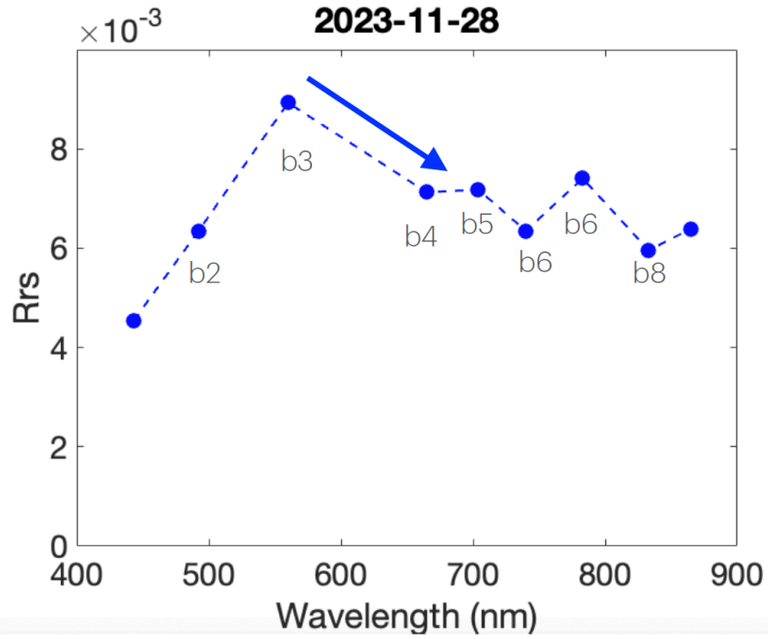




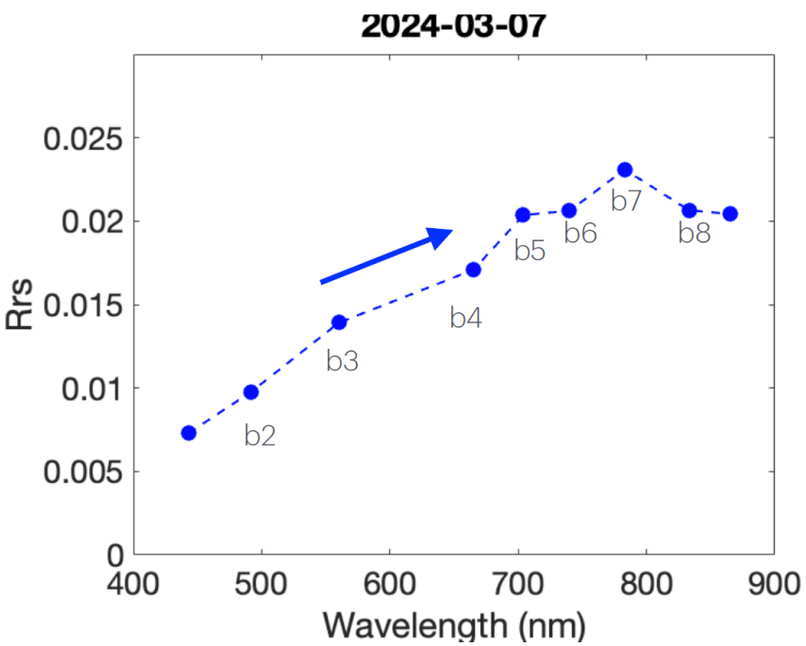
Build ID Rules:

Clearer water b4 < b3

Sentinel-2 Spectra



Turbid water b4 > b3



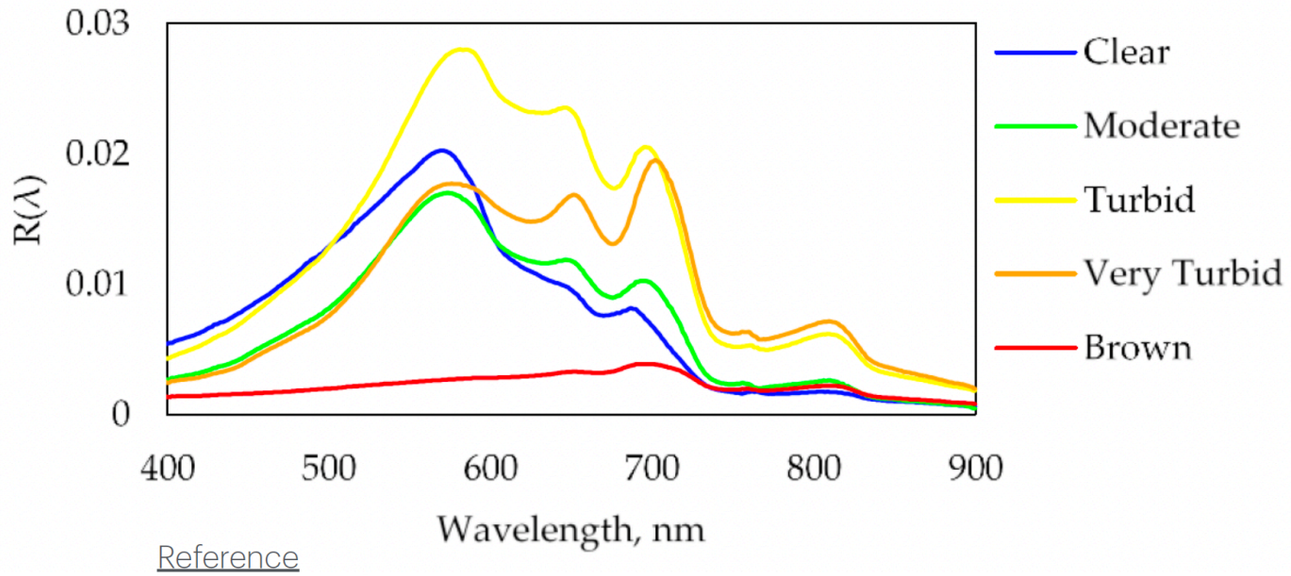
Gybe Improved Method for Water Quality Products

Method -- First Identify the 'water type'

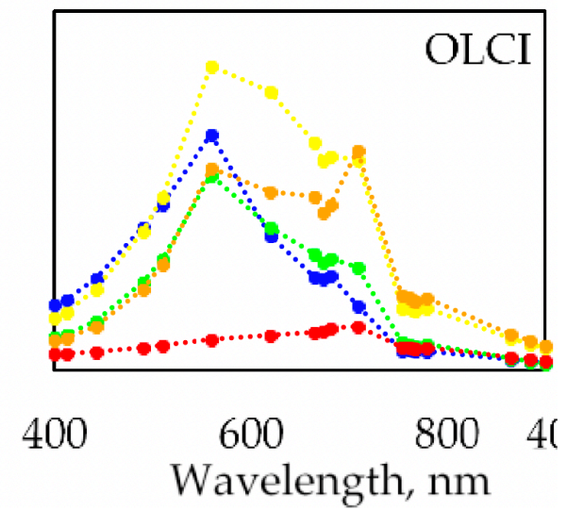
-- Develop turbidity model optimized for water type

-- Initial Example at Seiad Site

Spectral Shapes of Water Types



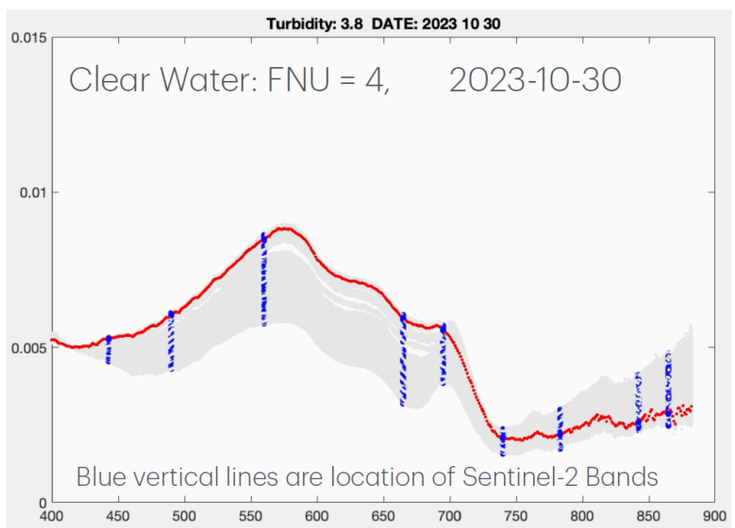
Sentinel-2 Spectra Signatures

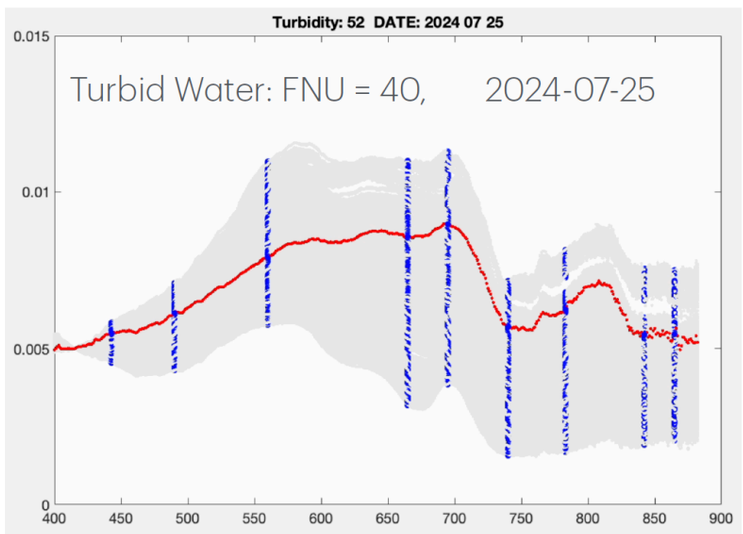


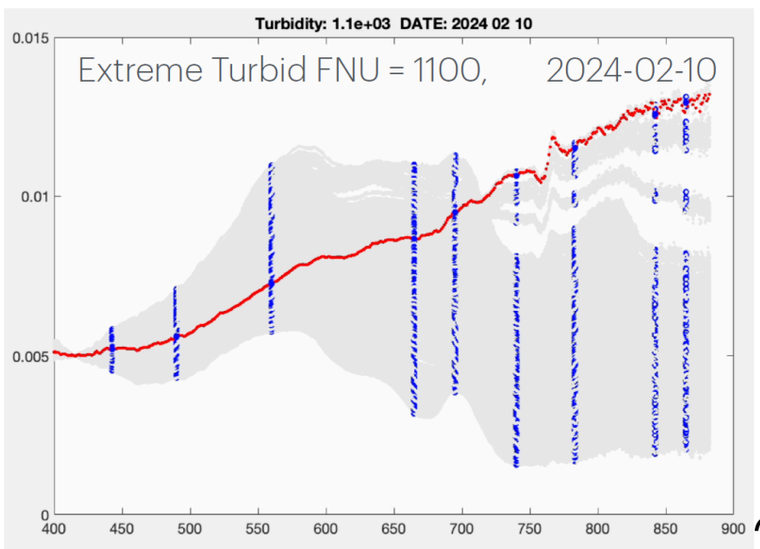
Reference

Uudeberg, K.; Ansko, I.; Põru, G.; Ansper, A.; Reinart, A. Using Optical Water Types to Monitor Changes in Optically Complex Inland and Coastal Waters. *Remote Sens.* **2019**, *11*, 2297. https://doi.org/10.3390/rs11192297

Example Spectra for Identifying Water Types from Gybe Sensor at Seiad Site







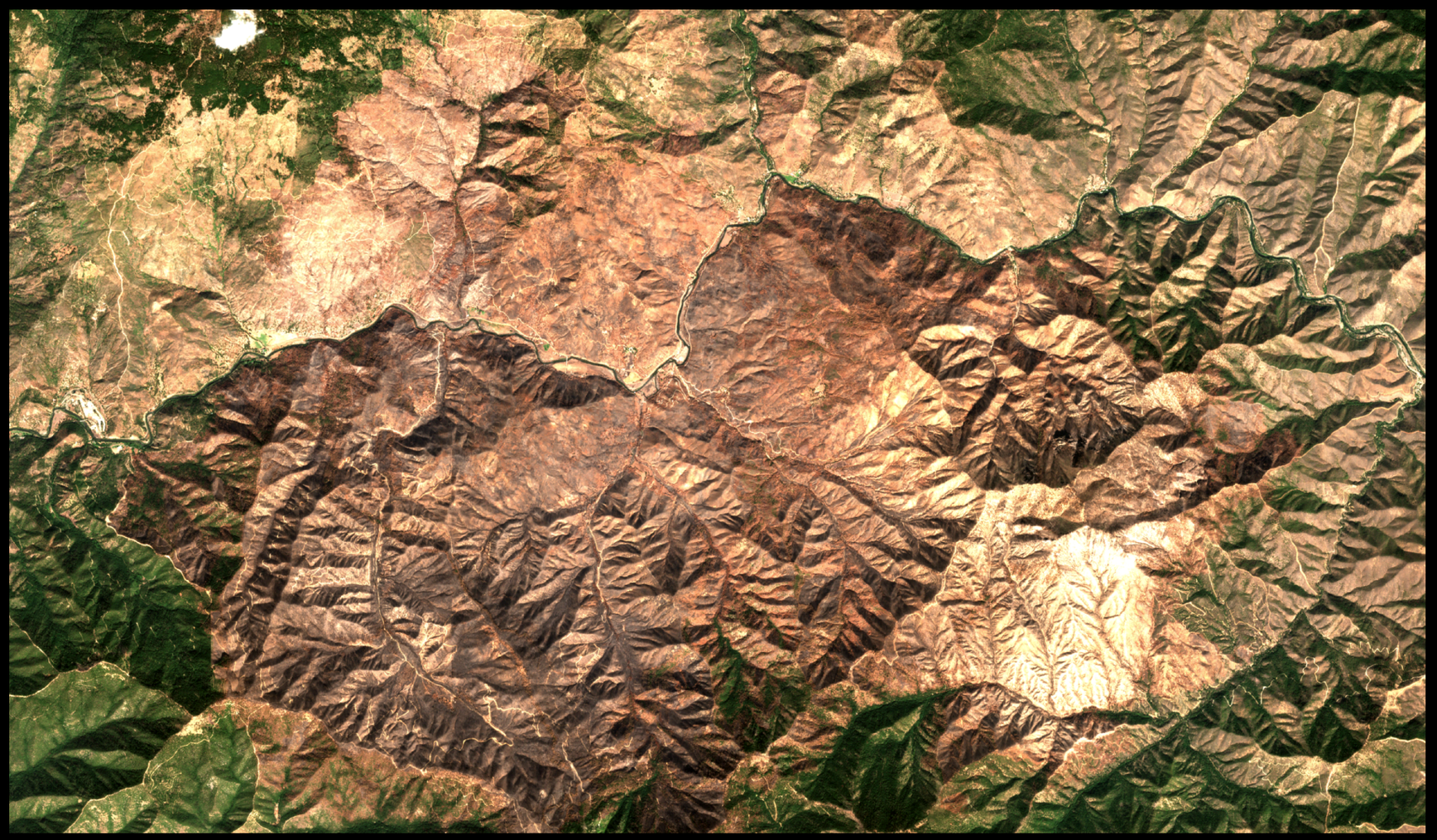
2022-12-28



2022-07-26



2022-09-29



McKinney Fire
29 July 2022
till
7 Sept 2022

2022-12-28 Walker Bridge

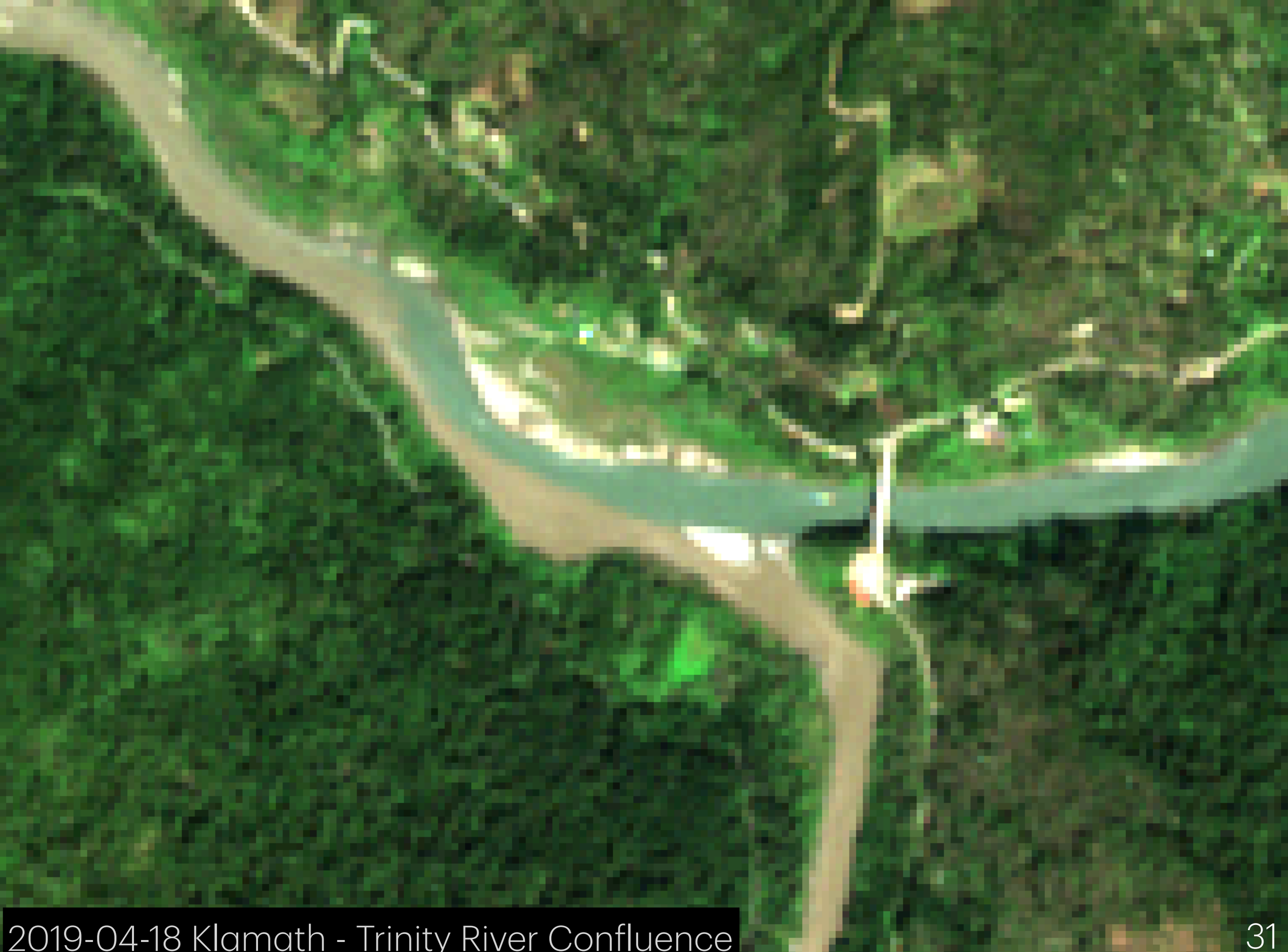
Gybe Walker Bridge Sensor



Walker Bridge Install



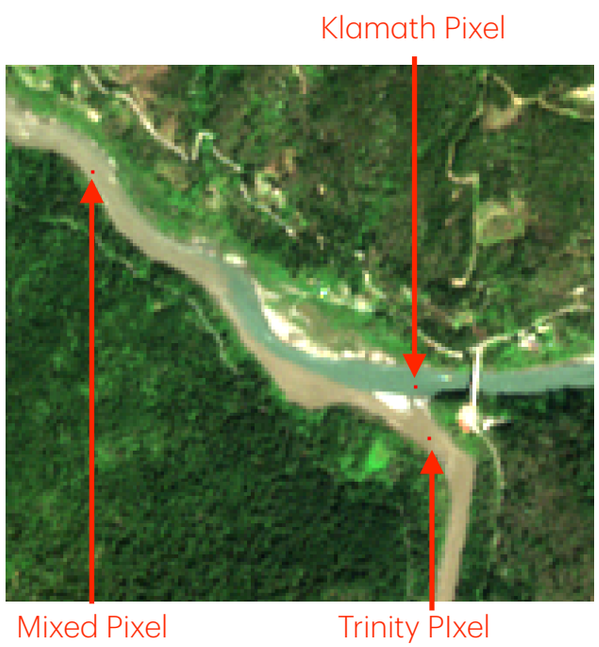
2019-04-18 Klamath to Trinity River Confluence

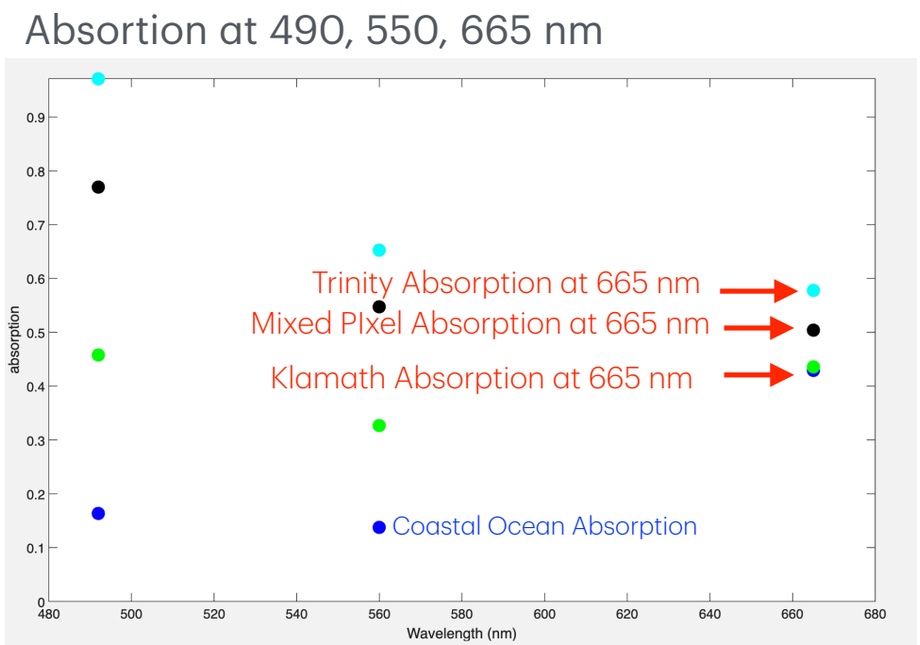


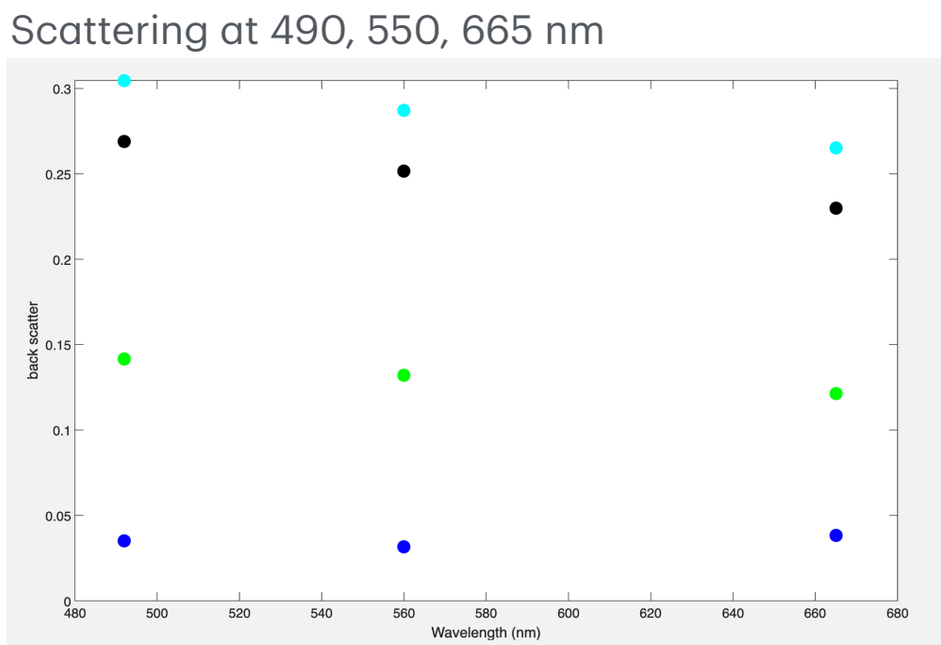
2019-04-18 Klamath - Trinity River Confluence

Can we use the color of the water before and after mixing at the confluence to gauge the (relative) discharge of the Klamath and Trinity Rivers?

Maybe …
We can estimate (spectral) absorption and scattering from Remote Sensing Reflectance as shown below. Assuming the two streams are ‘well mixed’ (good assumption), and the scattering can be neglected (usually not a good assumption), then the change of absorption should vary linearly with discharge. Back of the ‘envelope’ estimate for this scene is:

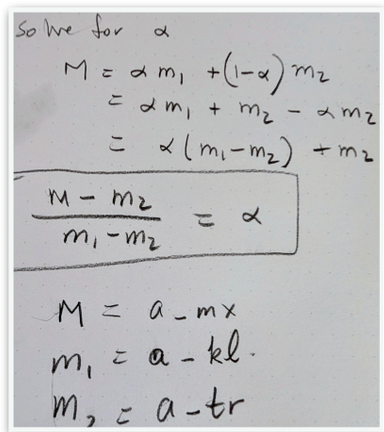


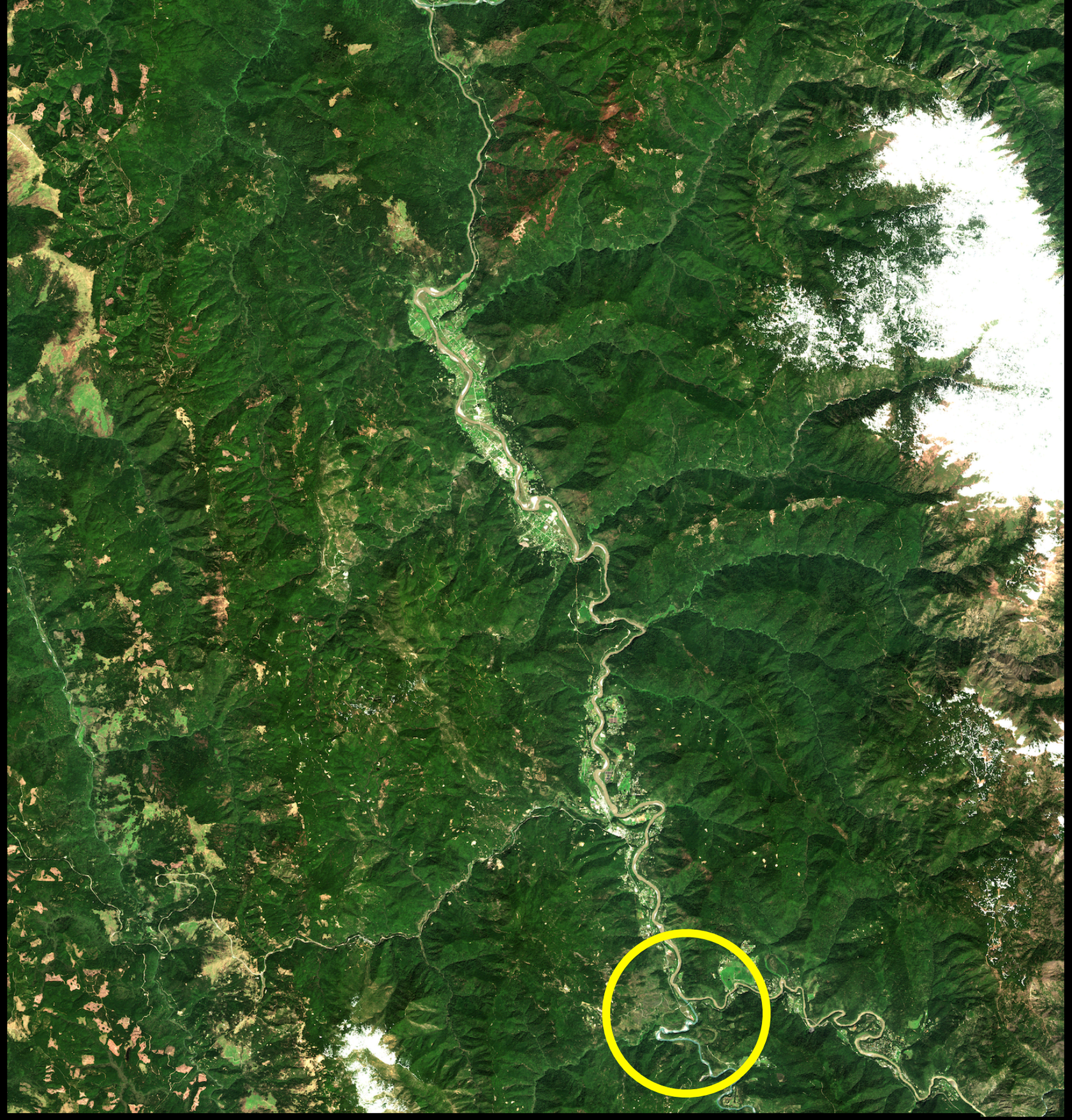




Reference for Algorithm: Pitarch, J., Vanhellemont, Q., 2021. The QAA-RGB,Remote Sensing of Environment 265, 112667.

Use 660 nm band (mass balance …):
52% of water is from Klamath and 48% from Trinity
From instream USGS Gauges:
Klamath Discharge at Orleans 20,000 ft^3/s
Trinity Discharge at Hoppa 16,500 ft^3/s
Discharge of Klamath relative to Trinity at Confluence 16,500/(16,500+20,000) = 0.55, or
55% of water is from Klamath and 45% from Trinity





2019-04-18 Trinity River - South Fork Confluence

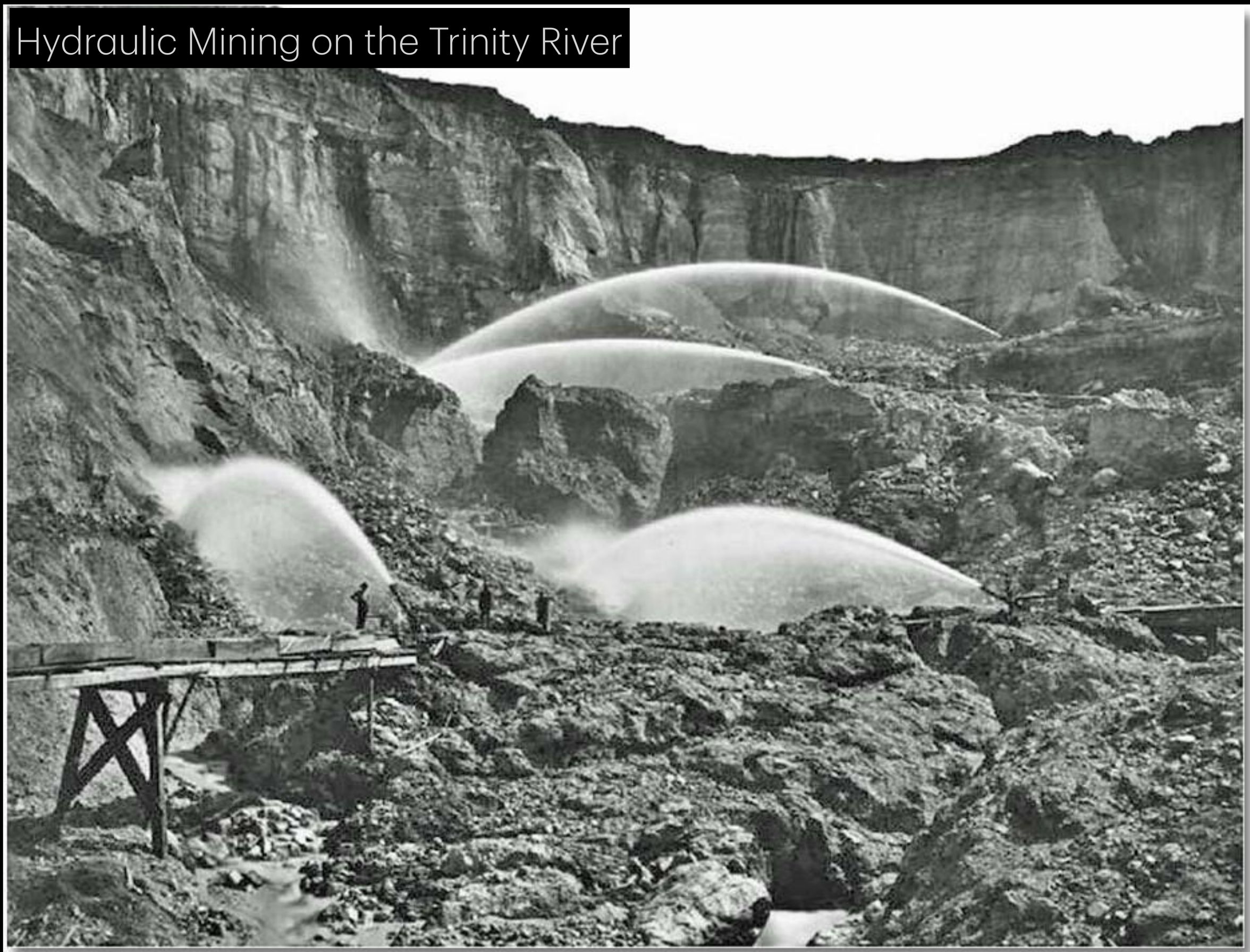
2019-04-18 Trinity River - South Fork Confluence

2019-04-18 Trinity River - North of Junction City, CA





Hydraulic Mining on the Trinity River





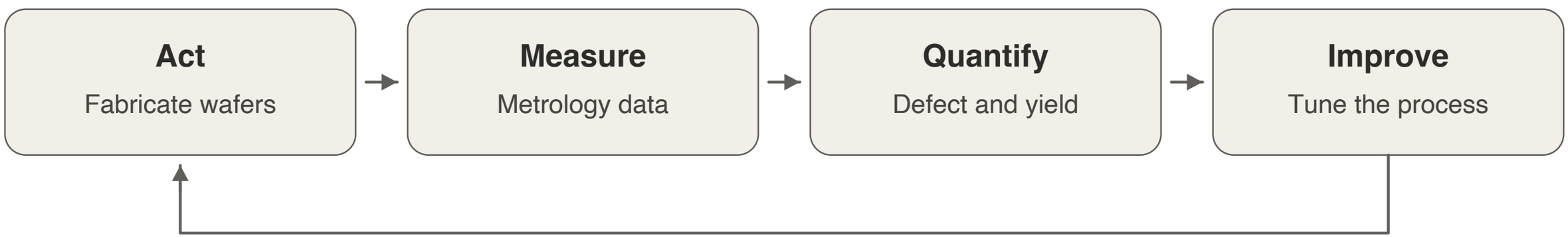
Prior to restoration, the Trinity River at Oregon Gulch ran in a straight line and mountains of mining tailings blockaded the bank. Photo: Aaron Martin, Yurok Tribal Fisheries Department

Trinity River Restoration began in 2022 at Oregon Gulch

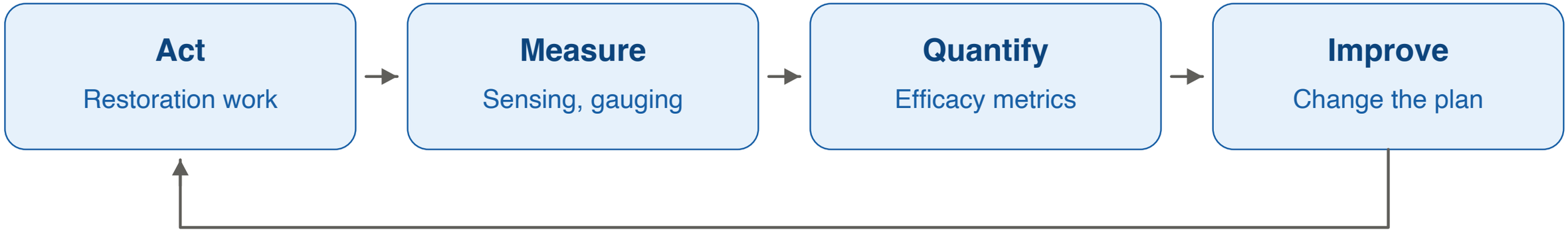


In Phase 1 of the Oregon Gulch project, thousands of cubic yards of legacy mining tailings were removed from the site. Photo: Aaron Martin, Yurok Tribal Fisheries Department

Semiconductor manufacturing



River restoration — Aqualytics



Transport of Sediments

A delta (function) in a river

Nicholas Tufillaro,* Philipp Grötsch, and Luke Zeitlin

Gybe, Corvallis, Oregon 97333 USA

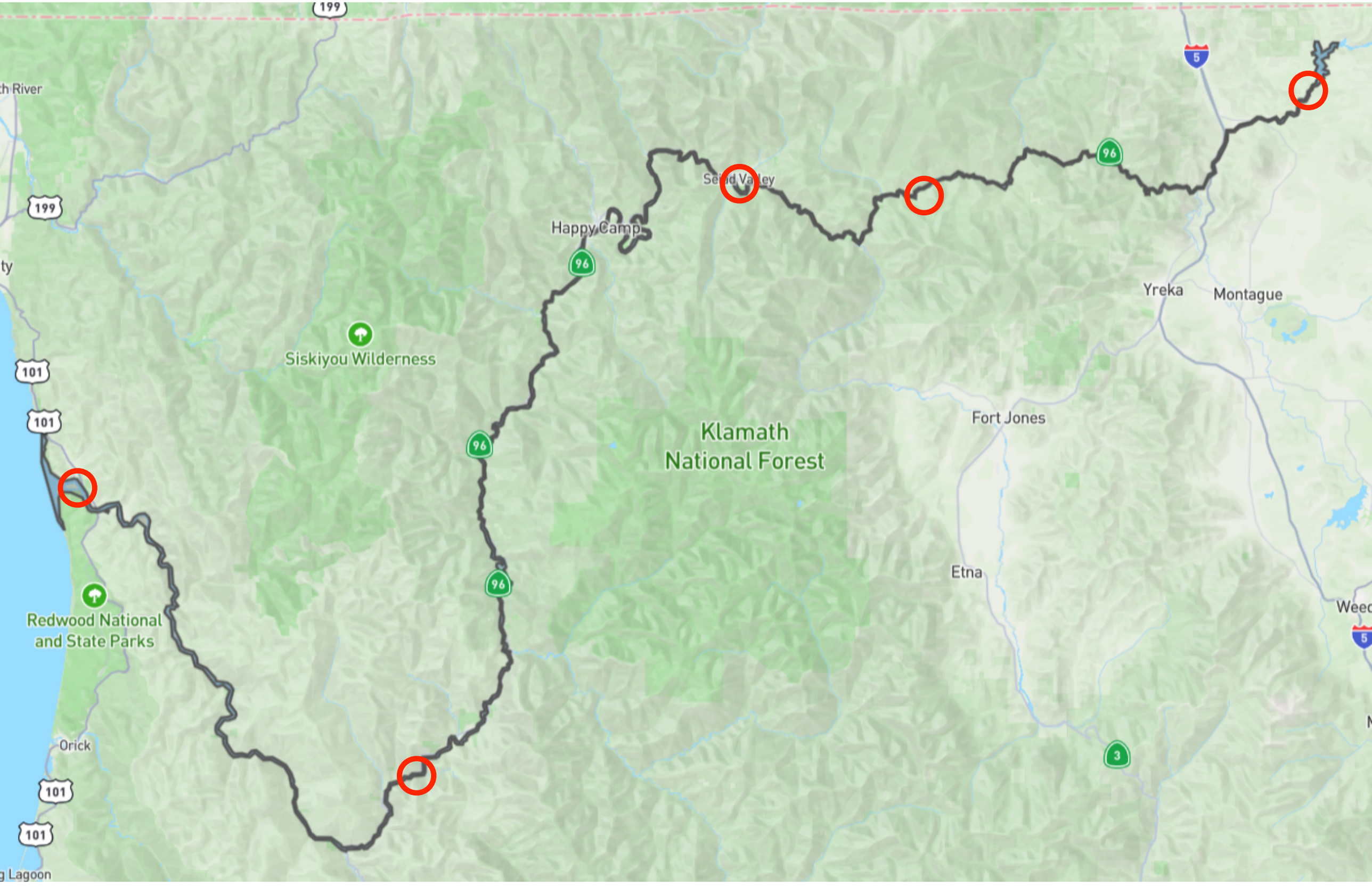
(Dated: February 24, 2026)

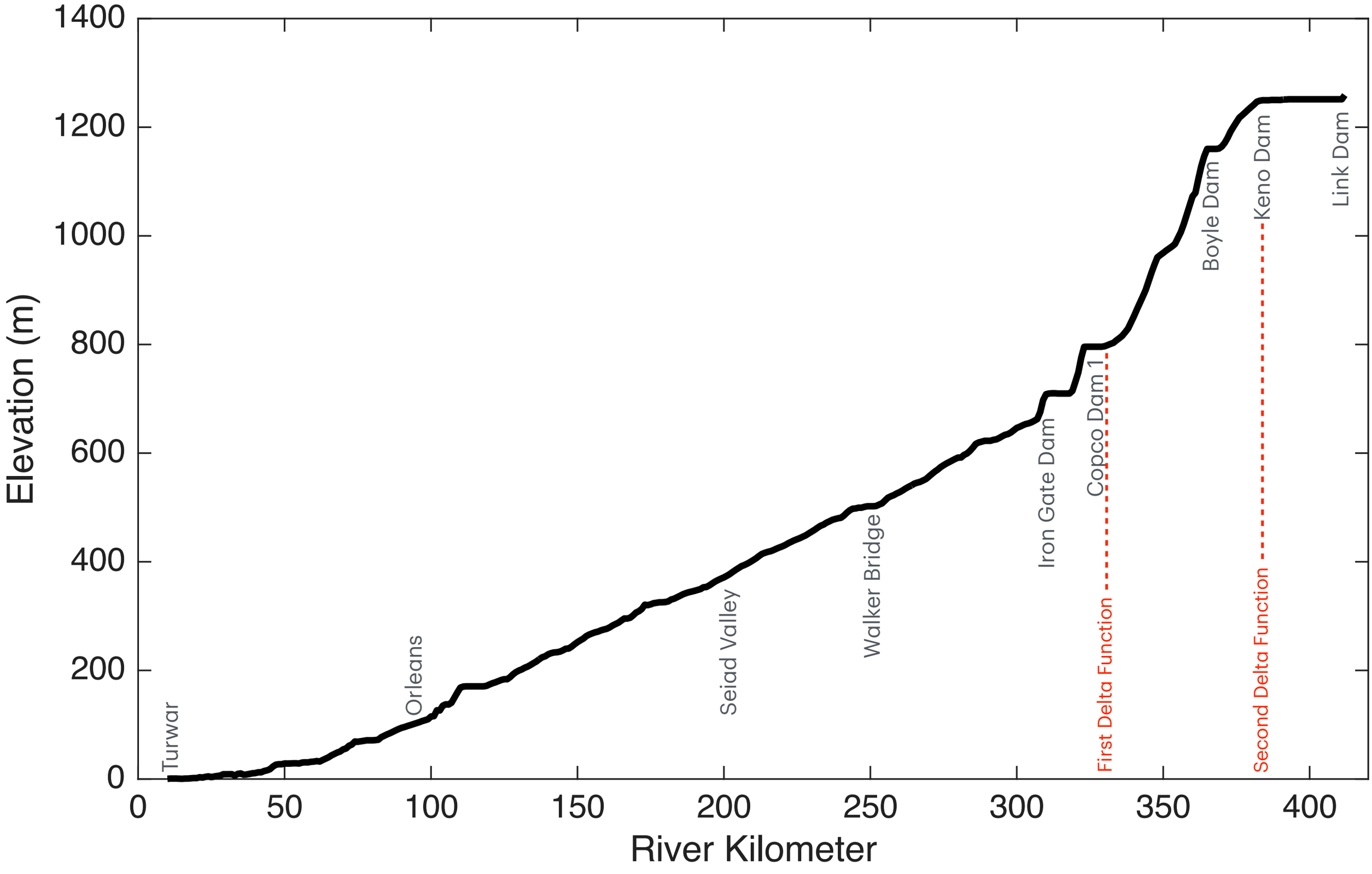
Abstract

We examine a data set that follows a pulse of turbidity down the Klamath River on 27 November 2025. The basic theory and data analysis provides an environmentally relevant application of the utility of linear wave theory and illustrates how high-frequency gauging can be used to mimic tracer experiments to arrive at estimates of basic flow parameters such as disperson. In addition to reseachers, this paper could also be of interest to teachers looking for examples of the application of applied mathematics to environmental monitoring.

https://aquahue.net/aquahue/papers/delta_tufillaro_2026_02_24.pdf

Monitoring Stations




1400
1200
1000
800
600
400
200
0
Elevation (m)
0
50
100
150
200
250
300
350
400
River Kilometer
Turwar
Orleans
Seiad Valley
Walker Bridge
Iron Gate Dam
Copco Dam 1
Boyle Dam
Keno Dam
Link Dam
First Delta Function
Second Delta Function

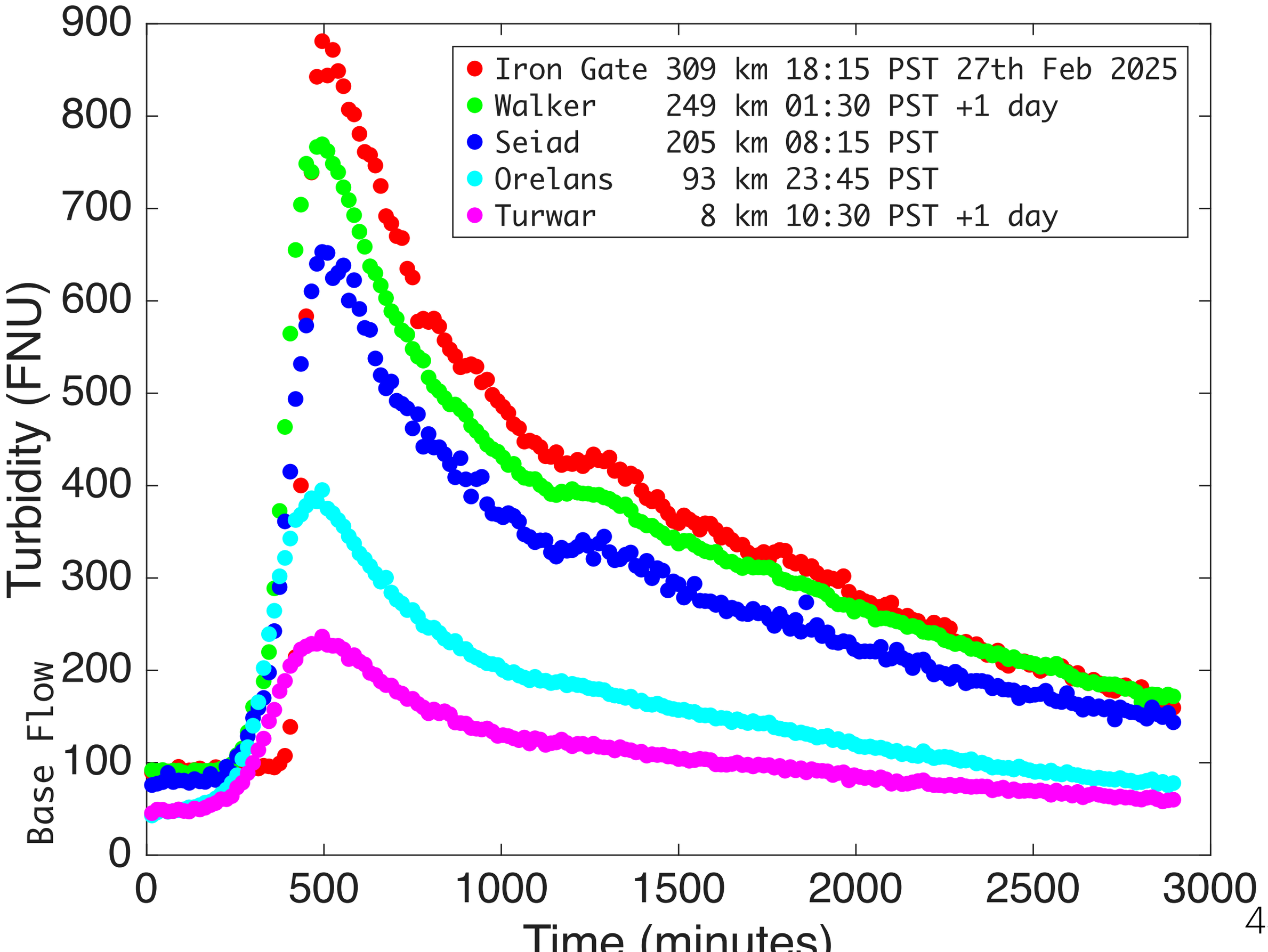

Iron Gate 309 km 18:15 PST 27th Feb 2025
Walker 249 km 01:30 PST +1 day
Seiad 205 km 08:15 PST
Orelans 93 km 23:45 PST
Turwar 8 km 10:30 PST +1 day
Turbidity (FNU)
Base Flow
900
800
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
Time (minutes)

TABLE I. Gauge Station River Parameters

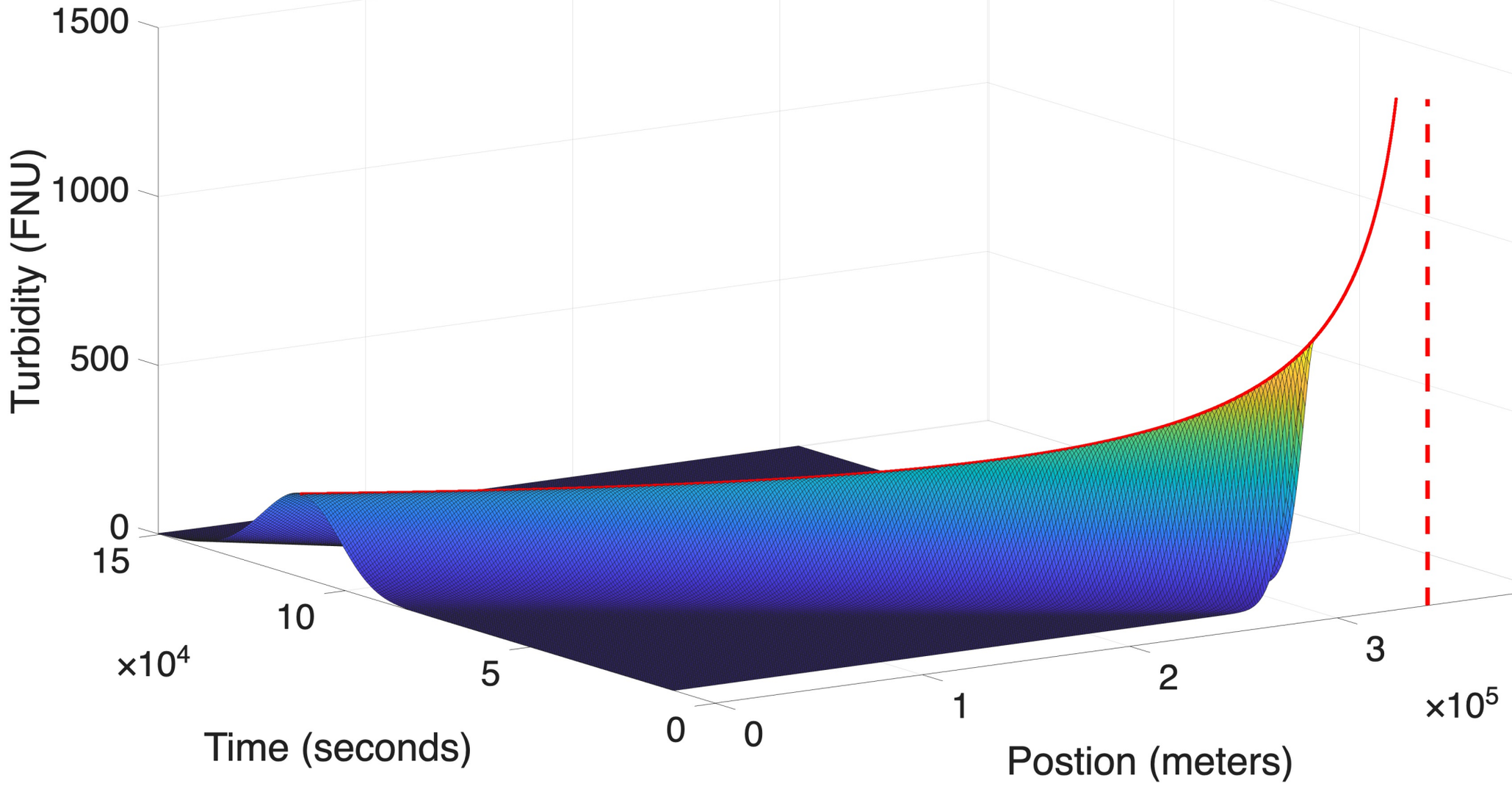
Station	River Km	Peak Arrival (PST)	Peak Turbitity (minus base)	Avg. Velocity (m/s)
Keno	385	2025-02-27 12:30	170	
Boyle	364	13:15	431	7.78
Iron Gate	309	18:15	881 (789)	3.06
Walker Bridge	249	2025-02-28 01:30	770 (672)	2.30
Seiad	205	08:15	653 (571)	1.81
Orleans	93	23:45	395 (352)	2.01
Turwar	8	2025-03-01 10:30	237 (196)	2.20

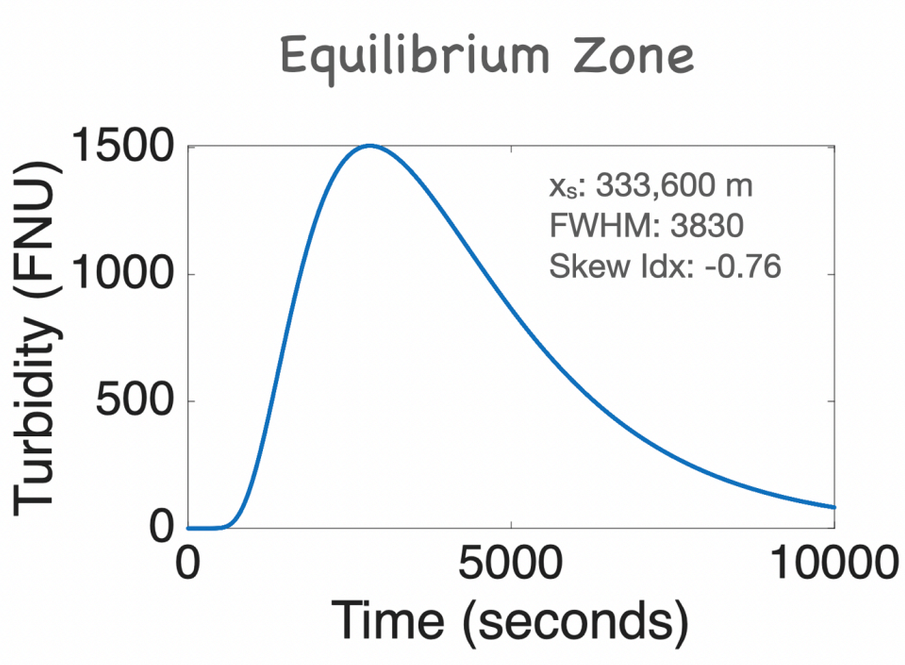
III. THE ADVECTION-DISPERSION EQUATION (ADE) AND ITS PRINCIPAL SOLUTION

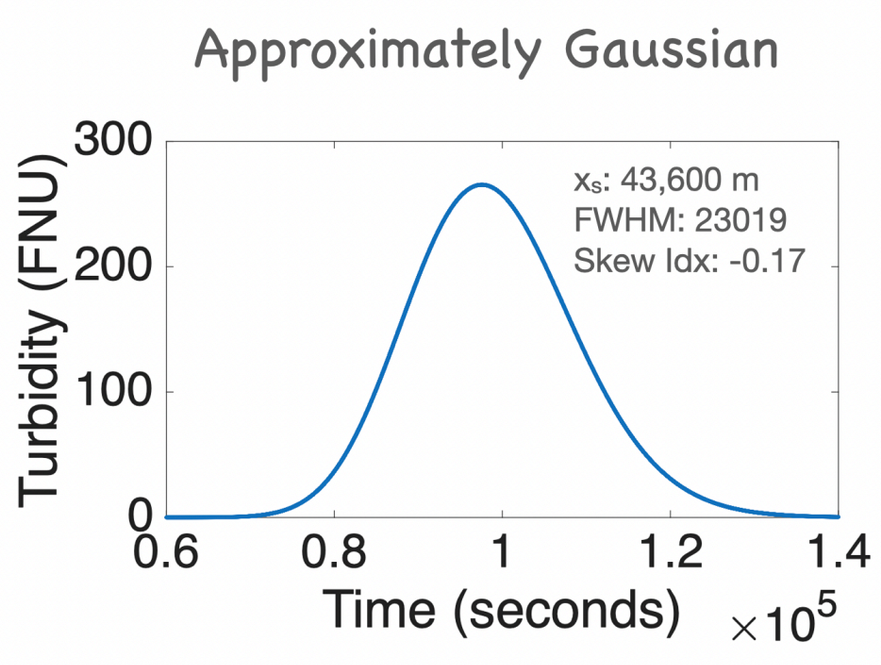
$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - u\frac{\partial C}{\partial x} \tag{1}$$

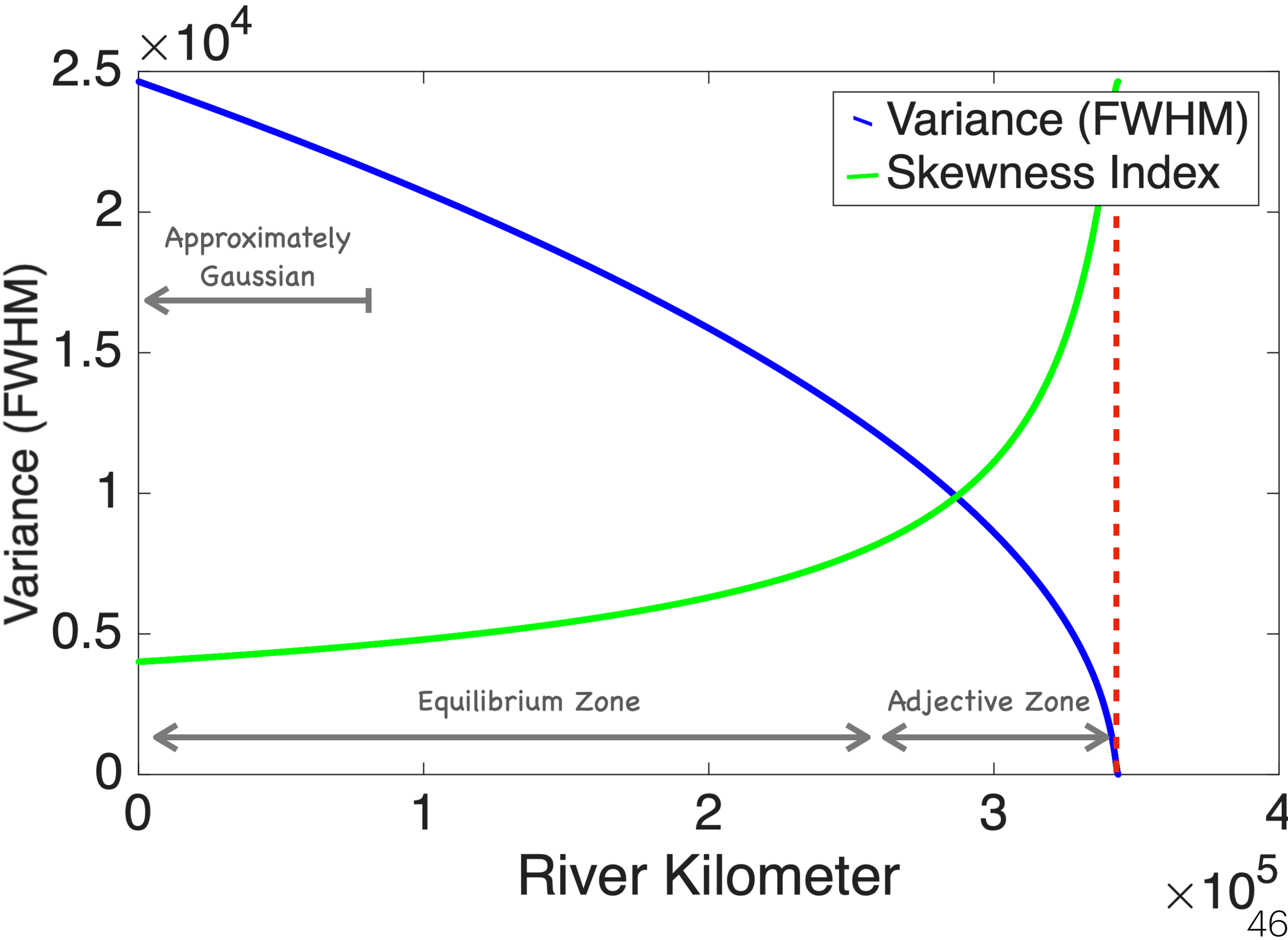
C (typically $[\mathrm{g/m^3}]$) is a cross-sectional average of the water constituent of interest (the tracer), u $[\mathrm{m/s}]$ is the cross-sectional average of the velocity, and D $[\mathrm{m^2/s}]$ is the longitudinal dispersion coefficient. The longitudinal direction variable is $x[\mathrm{m}]$, and $t[\mathrm{s}]$ is the time variable.

$$f(x,t) = \frac{M}{\sqrt{4\pi D}} t^{-\frac{1}{2}} \exp\left(\frac{-(x_d - x - ut)^2}{4Dt}\right)$$

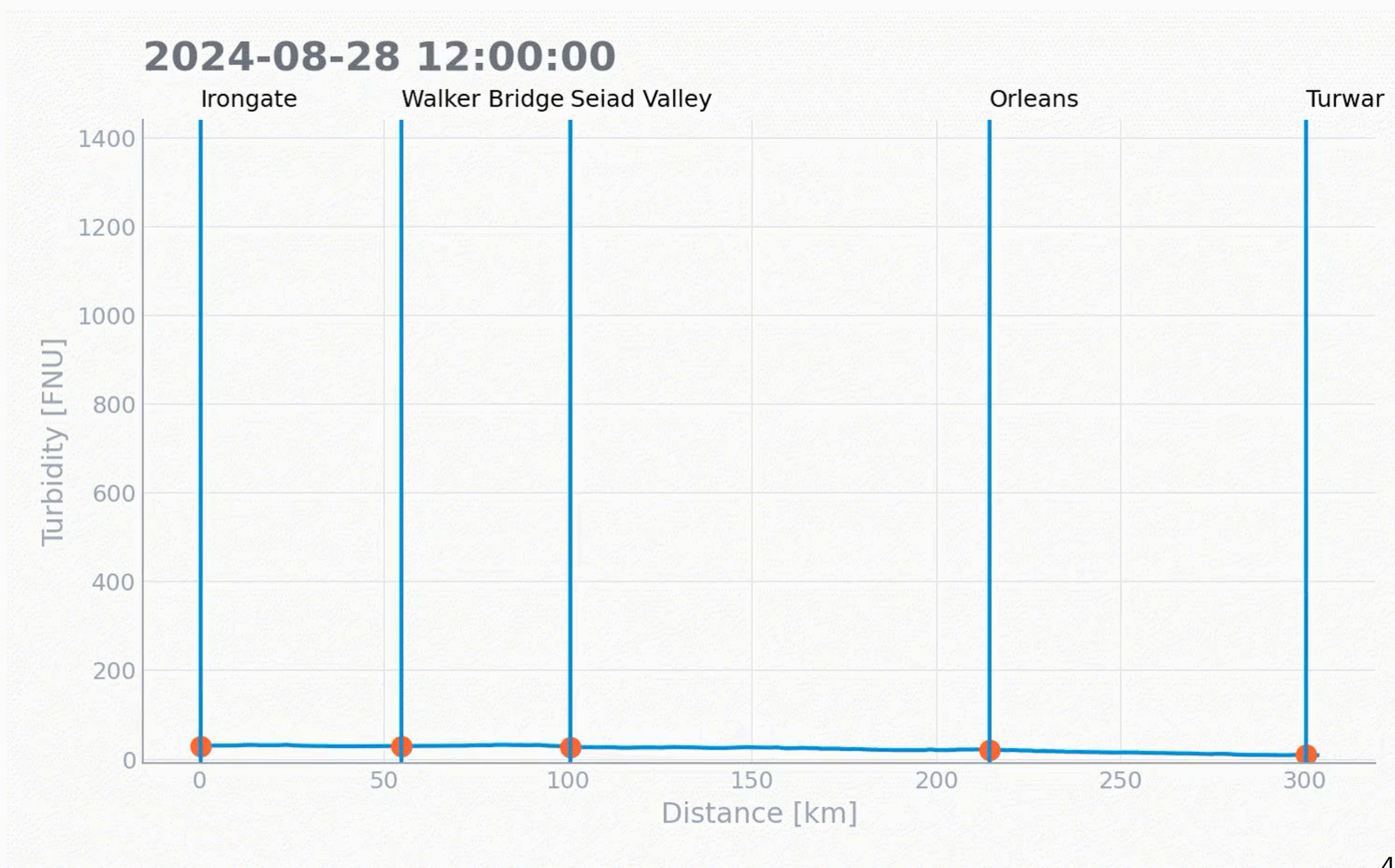

Turbidity (FNU)
1500
1000
500
0
15
10
×10^4
5
0
0
1
2
3
4
×10^5
Time (seconds)
Postion (meters)


Equilibrium Zone
Turbidity (FNU)
1500
1000
500
0
xs: 333,600 m
FWHM: 3830
Skew Idx: -0.76
0
5000
10000
Time (seconds)


Approximately Gaussian
Turbidity (FNU)
300
200
100
0
xs: 43,600 m
FWHM: 23019
Skew Idx: -0.17
0.6
0.8
1
1.2
1.4
Time (seconds)
×10^5


×10^4
2.5
2
1.5
1
0.5
0
Variance (FWHM)
Variance (FWHM)
Skewness Index
Approximately
Gaussian
Equilibrium Zone
Adjective Zone
0
1
2
3
4
River Kilometer
×10^5




2024-08-28 12:00:00
Irongate
Walker Bridge Seiad Valley
Orleans
Turwar
Turbidity [FNU]
1400
1200
1000
800
600
400
200
0
0
50
100
150
200
250
300
Distance [km]

Lots of fun physics problems!

Instrumentation:
Deep blue light sources and measurements of IOP's for pure water
Blue LED's and phosphorus

Automatic correction of impairments in low cost spectrometers
(dark current, order overlap ...)

Data Science:
Inferences in highly uncertain environmental conditions
Bayesian Inference

Manifold Learning Methods

Sparsity Methods for empirical correlations

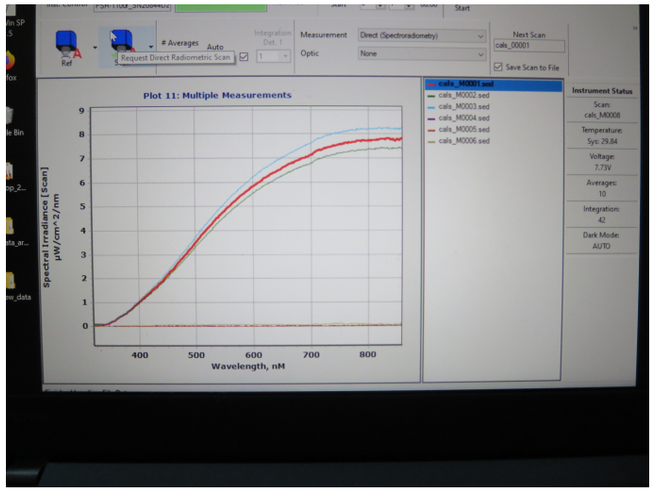
Ref: Sparsity based spectral super-resolution and applications to ocean water color, IGARSS 2014 Technical Abstract, 2014.

Modeling:
Physics based: Water 'weather forecasts'
Data assimilation
1,2,3 D flow models coupled biogeochemical optical models

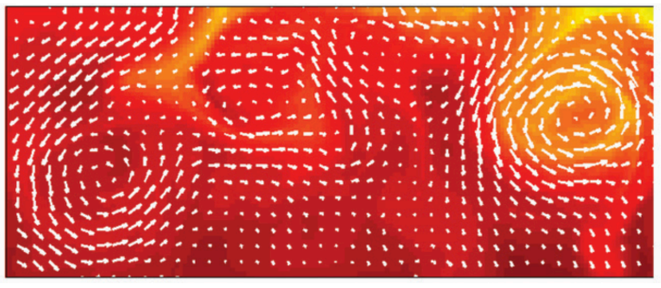
Ref: SFE-O: An optical model of the San Francisco Estuary, Proceedings of Ocean Optics XXII, 2016.

Data Drive Flow Modeling -- Optical Flows

Ref: A framework for estimating potential fluid flow from digital imagery, Chaos 23 (3), 033134, 2013.



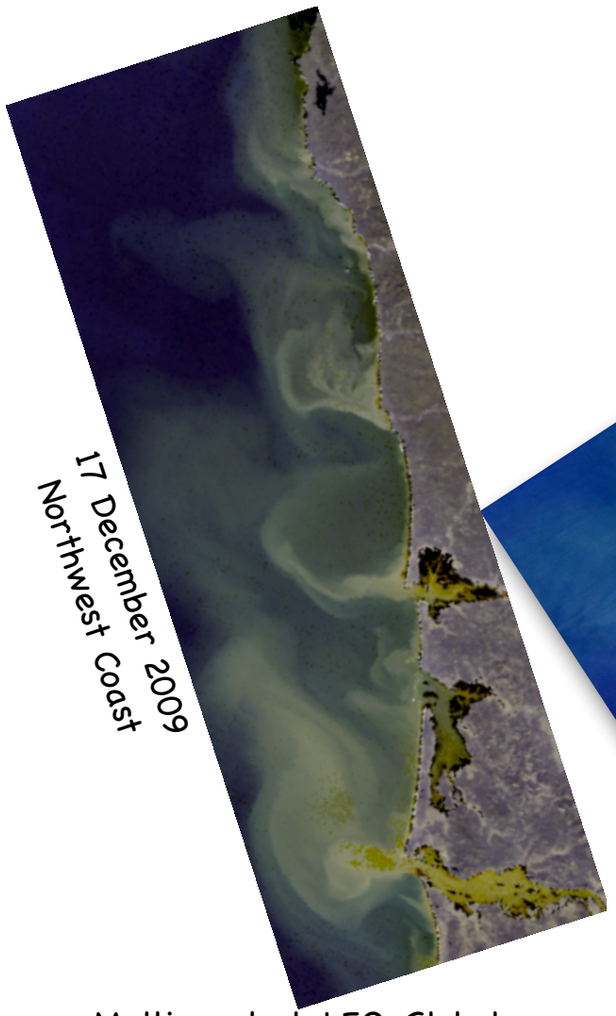




Papers at:
http://aquahue.net

Sensors

MERIS



Multispectral, LEO, Global

Agency	ESA
Launch	2003 - 2012
Spatial	300/1200 meters
Spectral	15 Bands
Temporal	~ 3 Days

LEO: Low Earth Orbit

HICO

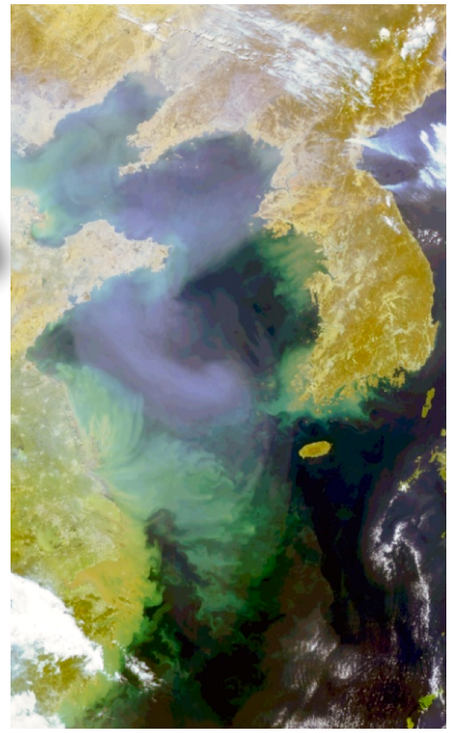


Hyperspectral, ISS, Targeted

Agency	NRL/NASA/OSU
Launch	2009
Spatial	92 meters
Spectral	88 Bands
Temporal	scheduled

ISS: International Space Station

GOCI



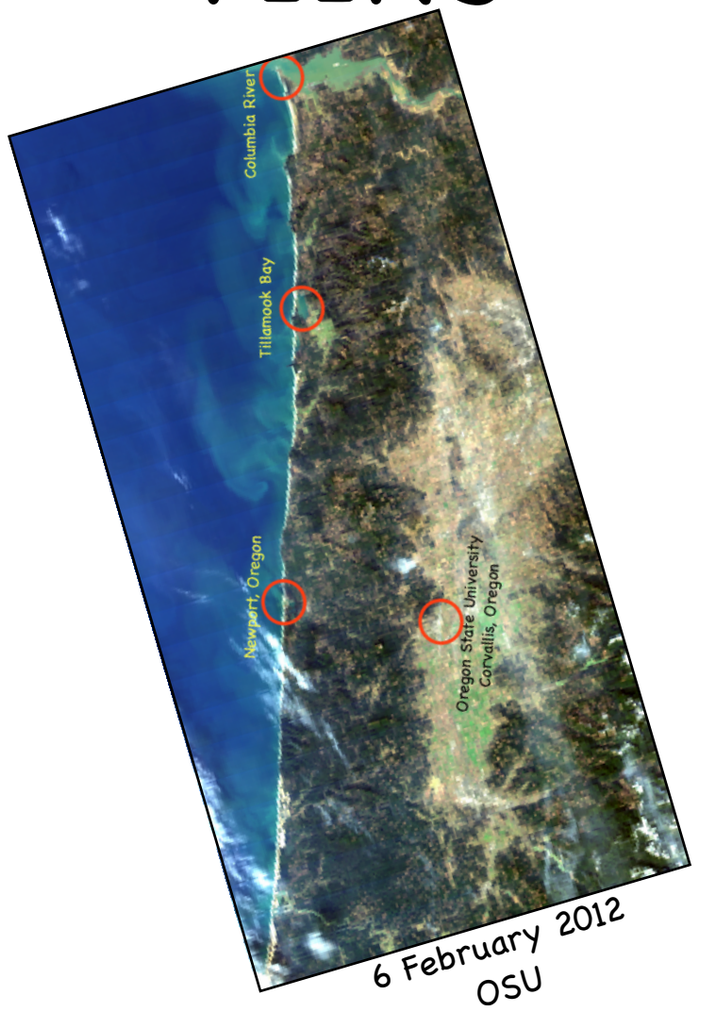
12 April 2011
Yellow & East China Sea

Multispectral, GEO, China Seas

Agency	KARI: South Korea
Launch	2010
Spatial	~500 meters
Spectral	8 Bands
Temporal	1 hour

GEO: Geosynchronous Orbit

VIIRS



Multispectral, LEO, Global

Agency	NOAA
Launch	2011
Spatial	750 meters
Spectral	9 bands
Temporal	1 Day

From data to information (since 2019)

Input Data

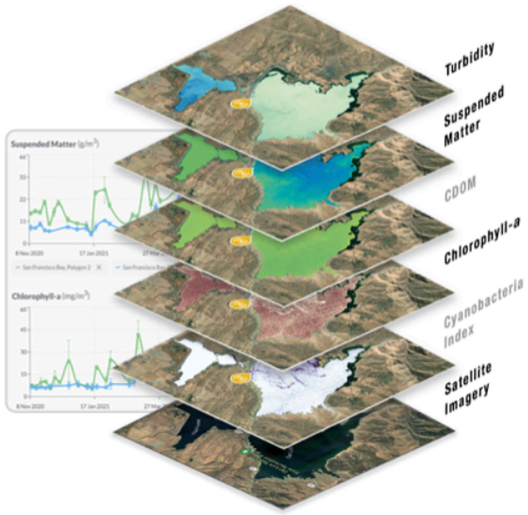
Satellite + Gybe Sensor
+ Weather Data



Comprehensive
Additional Data Sources

Water Data

Time series + Data Maps
and derived information



Extendable
Enabling New
Parameters & Analytics

GybeMaps™ App

Decision making tools



Actionable
Prediction, Alerting,
and Collaboration Features

Relevant Reference
Satellite Remote Sensing: A tool to Support Harmful Algal Bloom Monitoring and Recreational Heath Advisories in a California Reservoir,
Barreto, Hestir, Lee, and Beutel, GeoHealth 23 February 2024

Recent Gybe References: Available at http://www.aquahue.net

Monitoring water quality in the Lower Kansas River using remote sensing (preprint), River September 2024

Linking optical data and nitrates in the Lower Mississippi River to enable satellite-based monitoring of nutrient reduction goals, Ecohydrology January 2024

A manifold learning perspective on surrogate modeling of nitrates in the Kansas river, IWA Water Practice & Technology, 19 (7) April 2024

Decline in thermal habitat conditions for the endangered Delta Smelt as seen from Landsat Satellites (1985-2019) Journal Environmental Science & Technology, December 2021

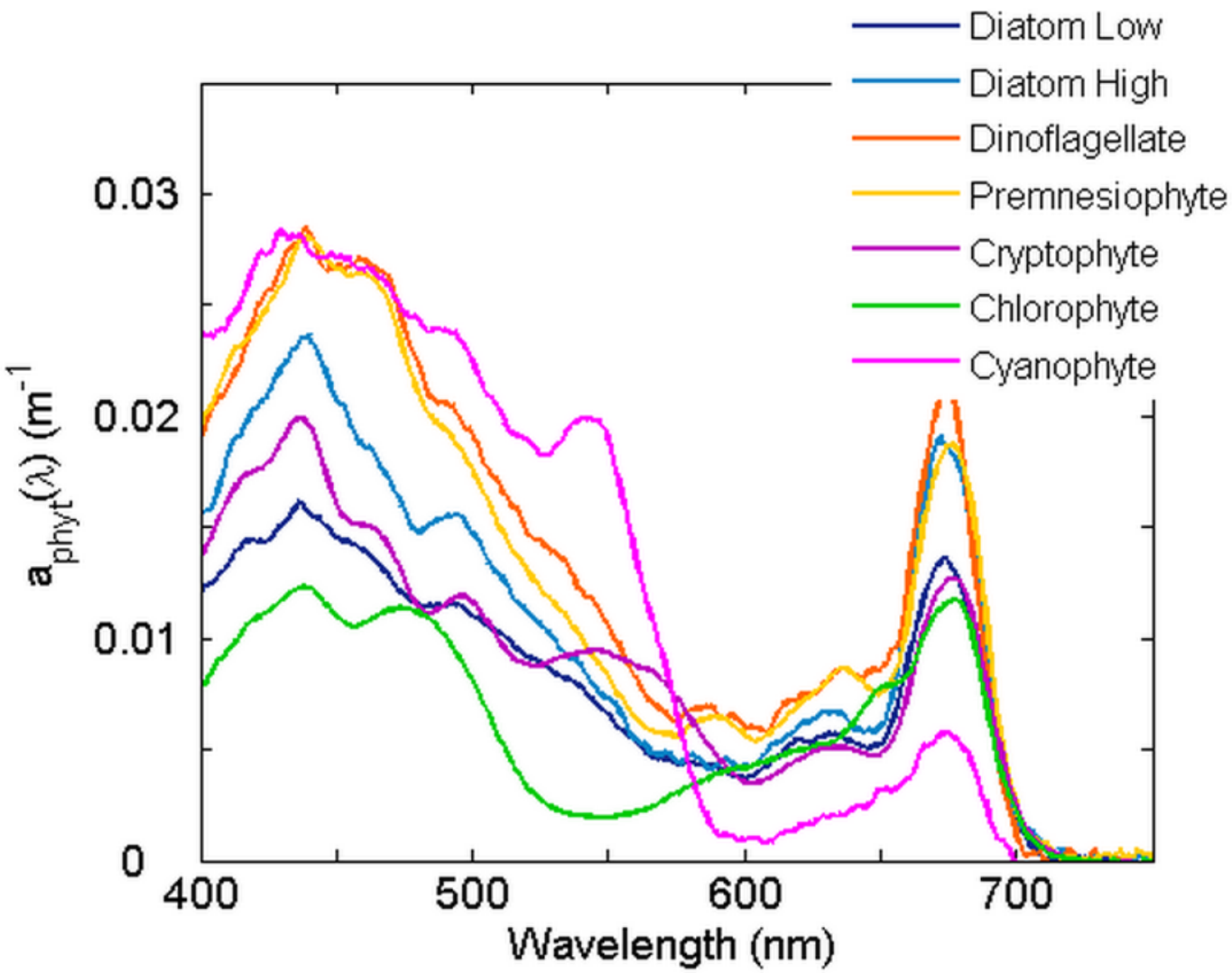
Monitoring turbidity in San Francisco Estuary and Sacramento-San Joaquin Delta using satellite remote sensing, Journal of the American Water Resources Association, 2021

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USGS (Brian Bergamaschi, PI, Sacramento Office)
NASA/JPL (Christine Lee, PI)
UC Merced (Erin Hester, PI)
DOE Grant DE-SC0020843

What color is the water?



Color variations for cultures of diatom, cryptophyte, chlorophyte, cyanophyte, and dinoflagellate.



Absorption spectra for a range of monospecific cultures.

Figures from Mobley, Ocean Optics Web Book

