Low-Cost Turbidity Sensors as a Method for Watershed Monitoring

Paul Baumgart, Andrew Schmitz, Dr. Kevin Fermanich, and Dr. Michael Zorn
University of Wisconsin-Green Bay
Environmental Science and Policy
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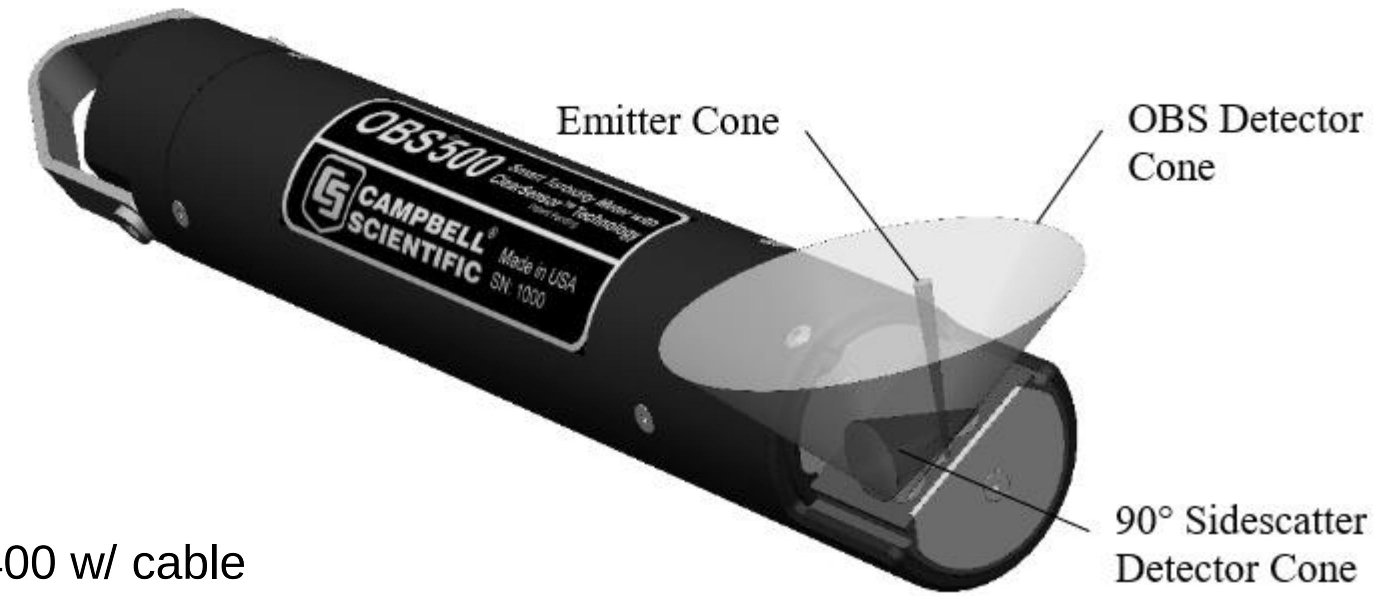
Problem Statement

- Turbidity sensors often used as surrogate for real-time continuous estimates for TSS, particulates, other
- Commercial sensors are costly for widespread deployments
  - ~ $1,500 to $3,400 for sensor alone;   Logger more $
- Are there viable alternatives?

Source: Amphenol



~ $3400 w/ cable

Source: Campbell Scientific OBS501 Operator's Manual

YSI 6136 Turbidity Sensor

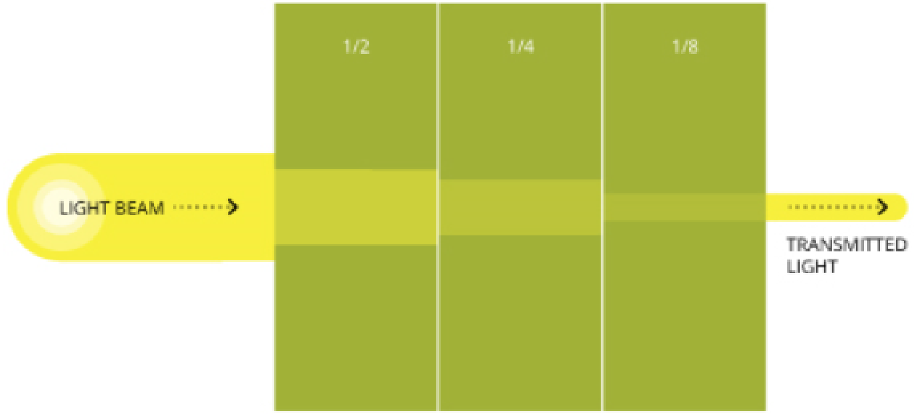
~ $1000+

Source: https://www.ysi.com/Accessory/id-6136/6136-Turbidity-Sensor

Transparency Tube

~ $80

Source: https://www.fondriest.com/water-transparency-turbidity-tubes.htm



As light passes through a sample, it will lose intensity due to scatter and absorption.

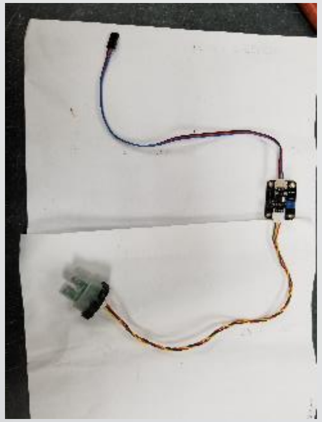
Source: https://www.fondriest.com/environmental-measurements/measurements/measuring-water-quality/turbidity-sensors-meters-and-methods/

Study Objectives

1. Evaluate low-cost turbidity sensors
2. Evaluate utility of low-cost sensor/logger system as a watershed monitoring network (~$150/unit)

- Bench Test low cost, appliance turbidity sensors in lab
- Develop initial calibration curves in lab
- Test accuracy of low-cost turbidity sensors in field conditions
  - Compare to commercial turbidity probes, such as the OBS 501
  - and to TSS or SSC
- Field test utility and reliability of low-cost monitoring stations (low-cost turbidity sensors and data loggers)

Source: Amphenol



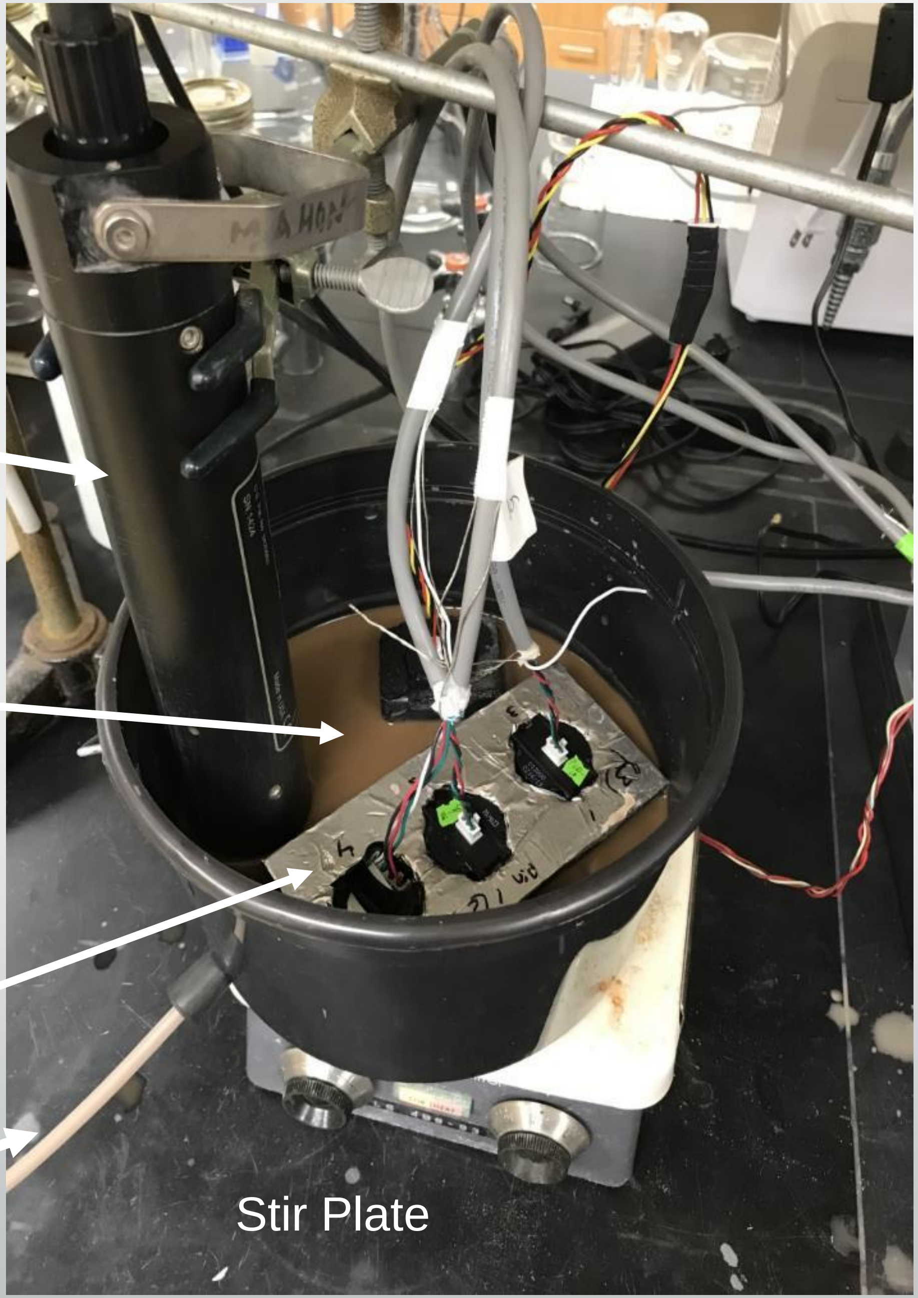
Campbell Scientific OBS 501

Composite suspended sediment field sample

Serial dilutions with 2 Liter fixed volume

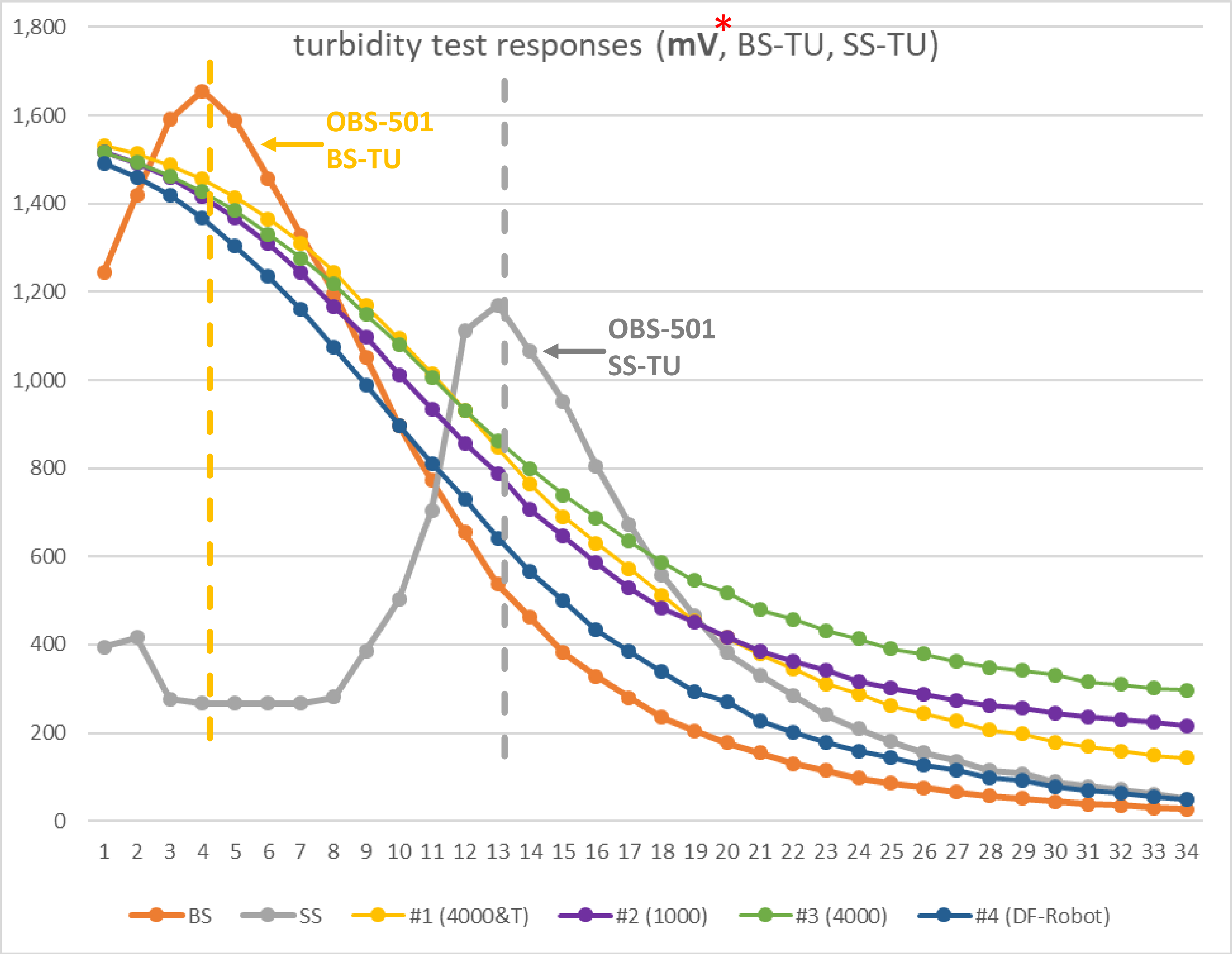
Low-cost sensors

Drain Tube with clamp



Bench Test Setup

4 Low-cost sensors and Campbell Scientific OBS-501 Turbidity Probe Connected to CS CR1000 logger via breadboard

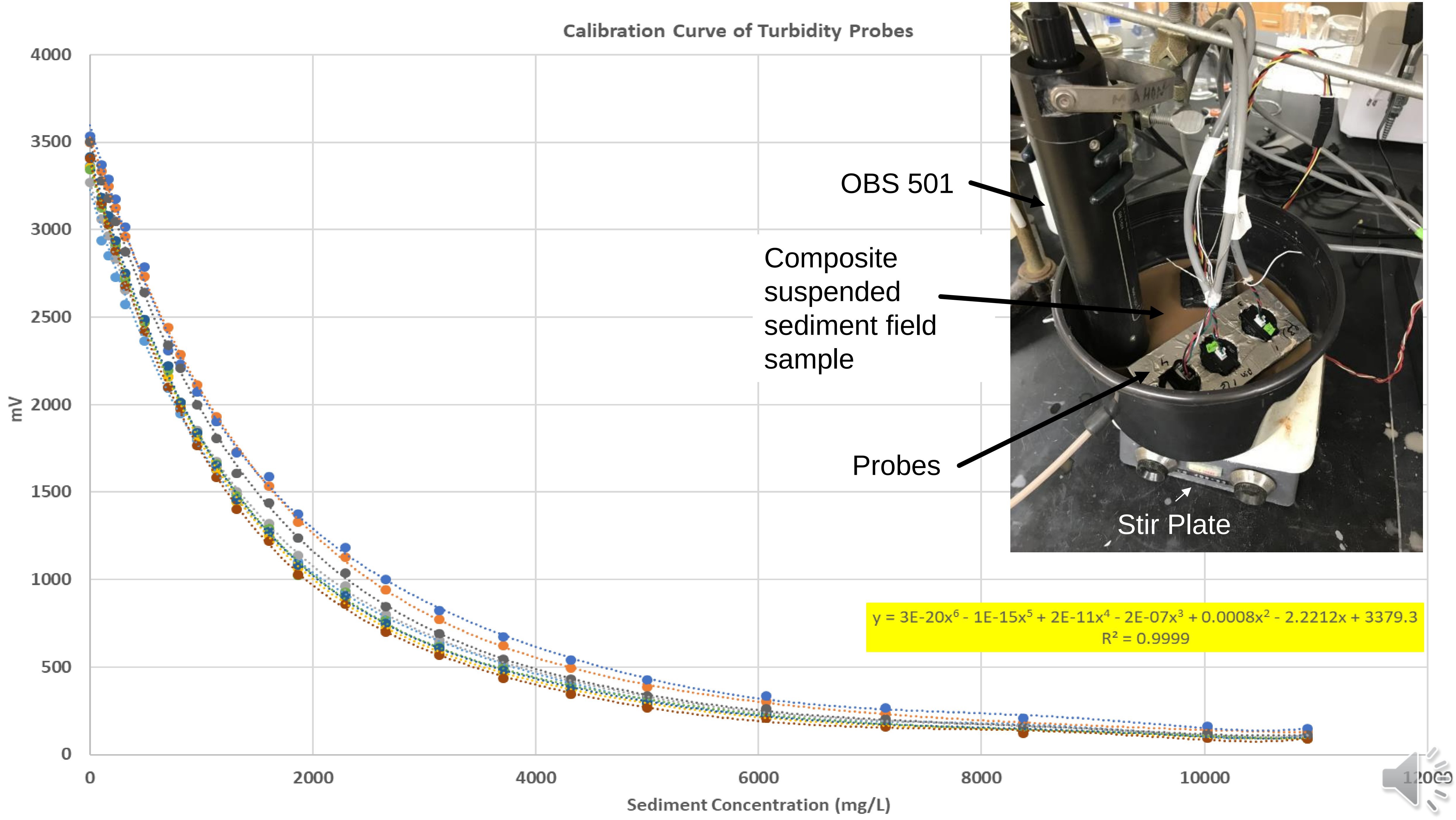


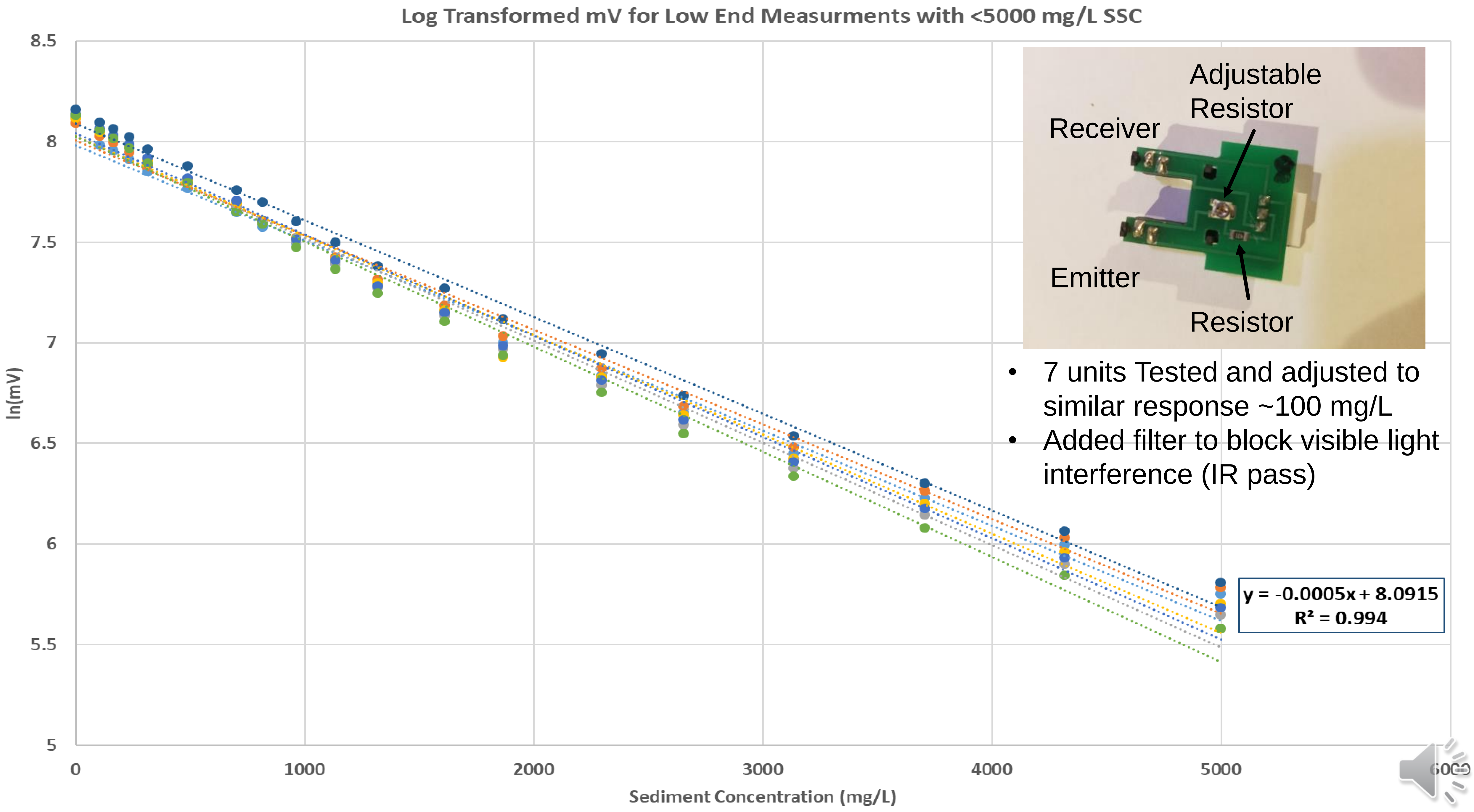
Bench Test Setup

4 Low-cost sensors (mV) and OBS-501 (TU)

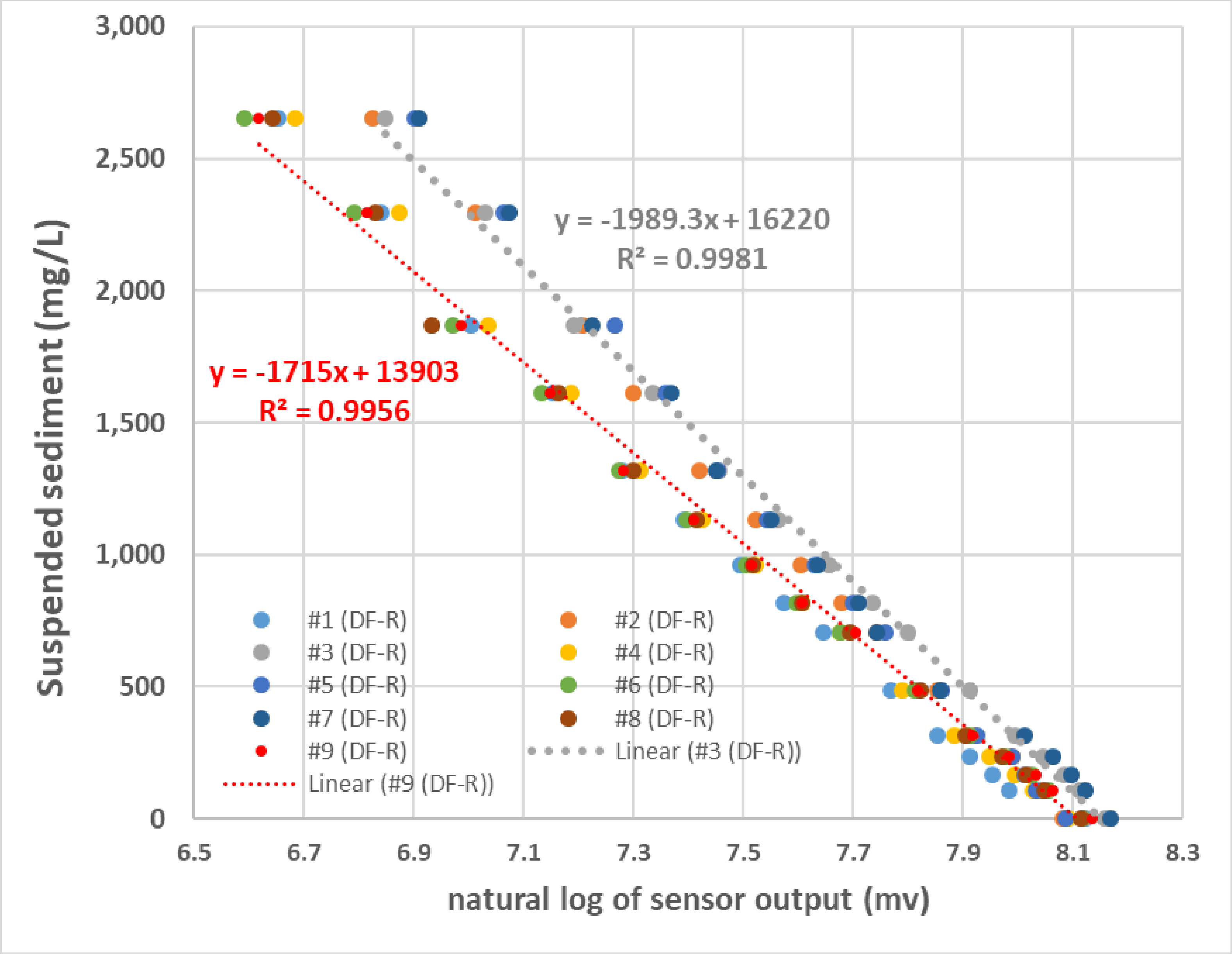
Primary Test #3 (34 samples from 44 to 5,730 mg/L)

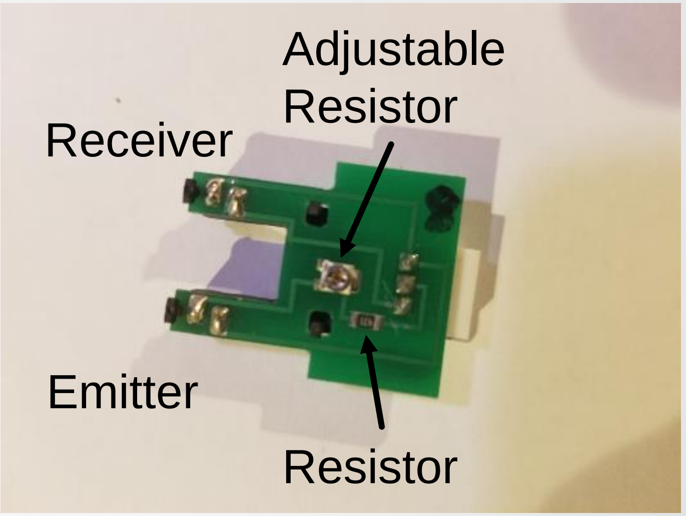
****** 1600 minus mV output from Sensor***


Calibration Curve of Turbidity Probes
mV
4000
3500
3000
2500
2000
1500
1000
500
0
0
2000
4000
6000
8000
10000
12000
Sediment Concentration (mg/L)
y = 3E-20x6 - 1E-15x5 + 2E-11x4 - 2E-07x3 + 0.0008x2 - 2.2212x + 3379.3
R² = 0.9999
OBS 501
Composite suspended sediment field sample
Probes
Stir Plate



- 7 units Tested and adjusted to similar response ~100 mg/L
- Added filter to block visible light interference (IR pass)

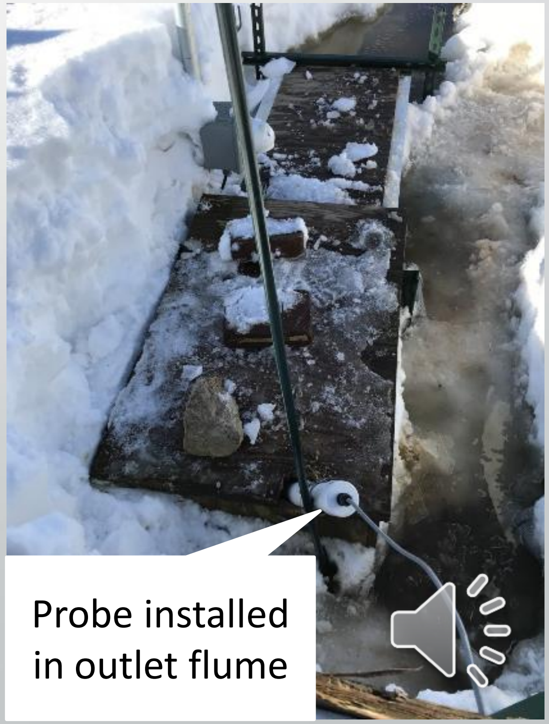


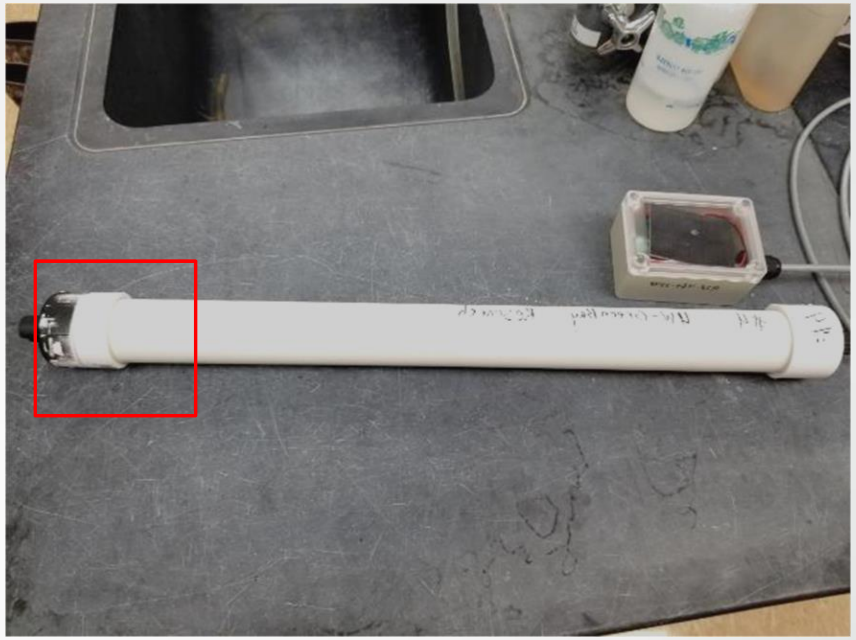


- Initial Calibration curves developed for field deployment
  - Curve Range to 2,650 mg/L SSC
- 9 units Tested and adjusted to similar response at ~100 mg/L
- Added filter to block visible light interference (IR pass)

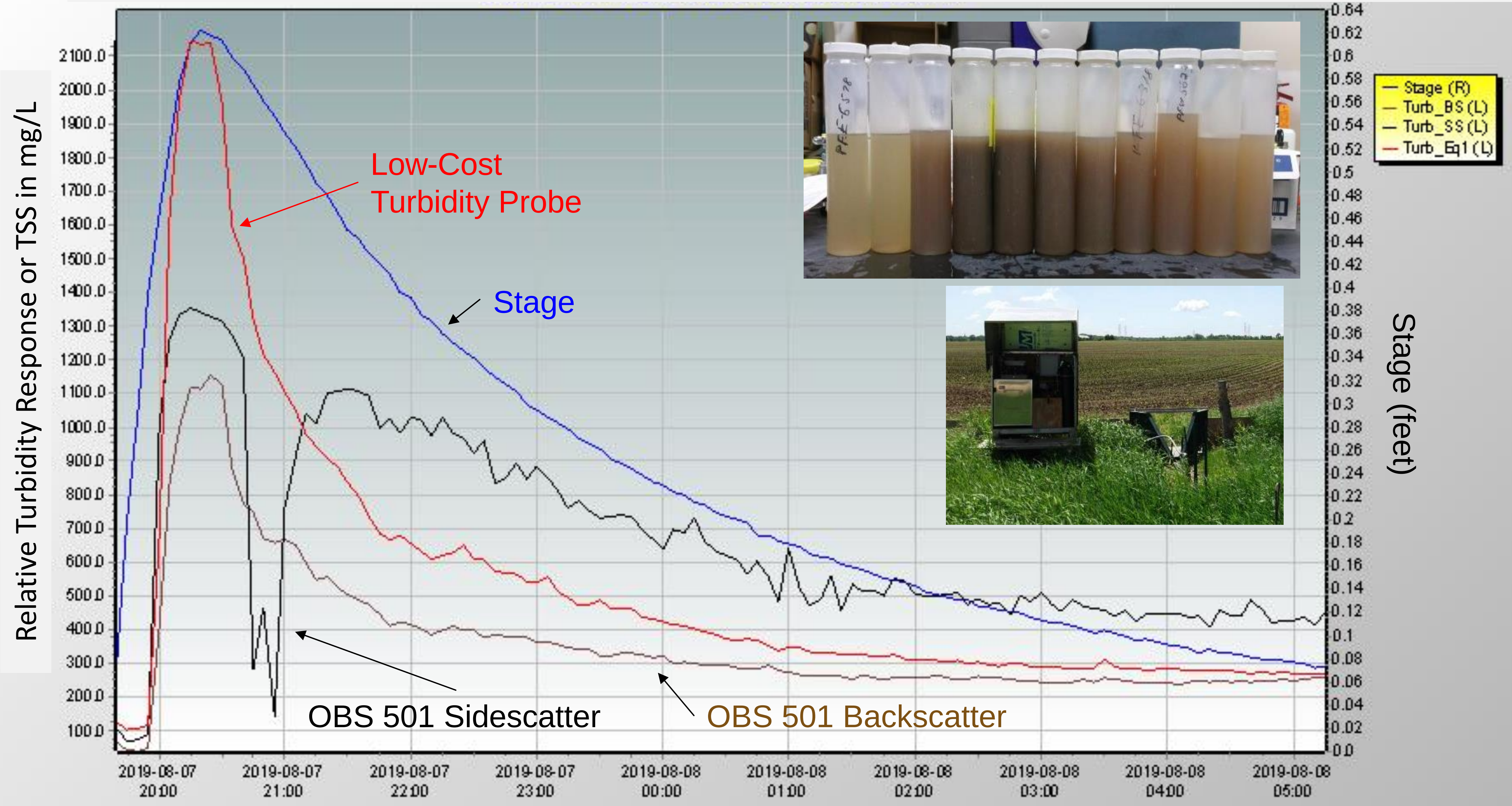
Low-cost Probe Field Deployments

- Five Low-cost sensors at intensive monitoring stations
  - Campbell OBS 501 Turbidity probe and Logger, ISCO autosampler
  - Plum Creek: Two Edge-of-Field, West Plum Creek, Wetland Outlet
  - Wequiock Creek
- Low-cost stations (next section)
  - DF Robot turbidity sensors and EnviroDIY Mayfly dataloggers
  - Programmed using Arduino IDE with 5 minute sample intervals
  - Three stations deployed on UW Green Bay campus
  - Three more stations deployed in Wequiock Creek watershed





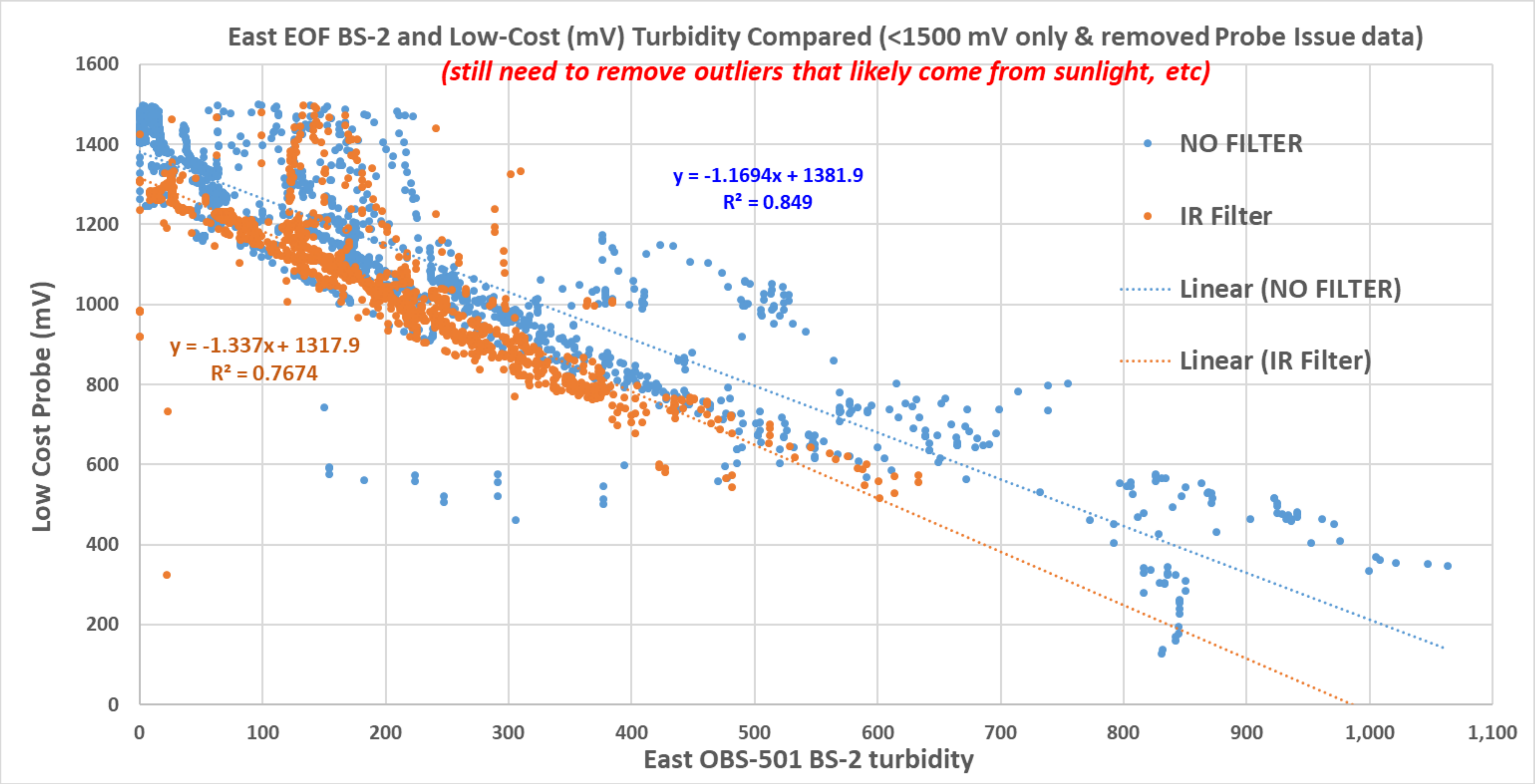
Low-cost Sensor output vs OBS 501 (back & side scatter) with Stage at **EAST** EoF site (8/7/19 event)



Edge-of-Field: EAST catchment

Commercial backscatter turbidity (FBU) vs Low-Cost Sensor (mV): n=4491

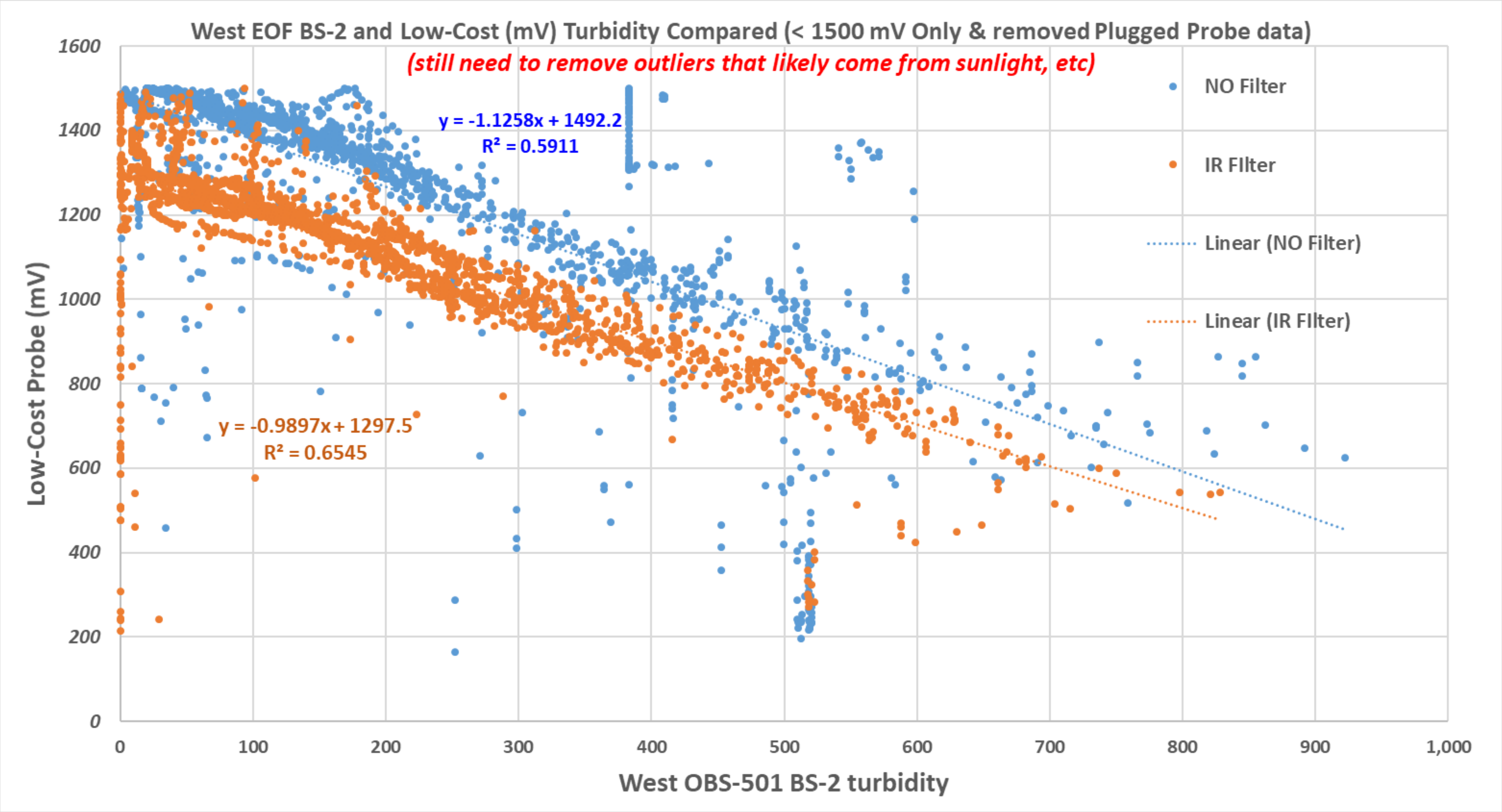
some noise in data not removed yet, but good correlation

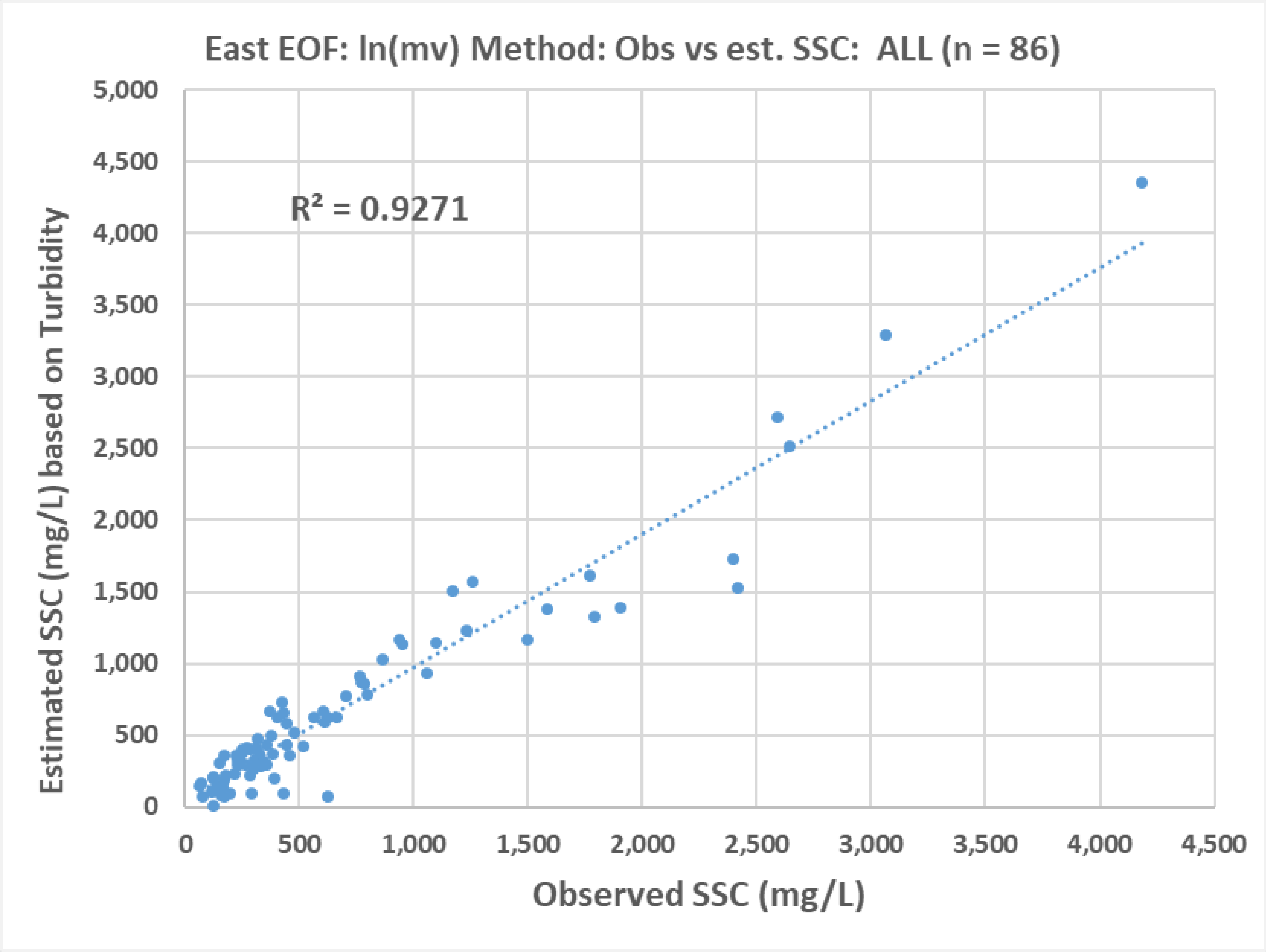


Edge-of-Field: <u>WEST catchment</u>

Commercial backscatter turbidity (FBU) vs Low-Cost Sensor (mV): n=6843

some noise in data not removed yet, but good correlation if outliers removed





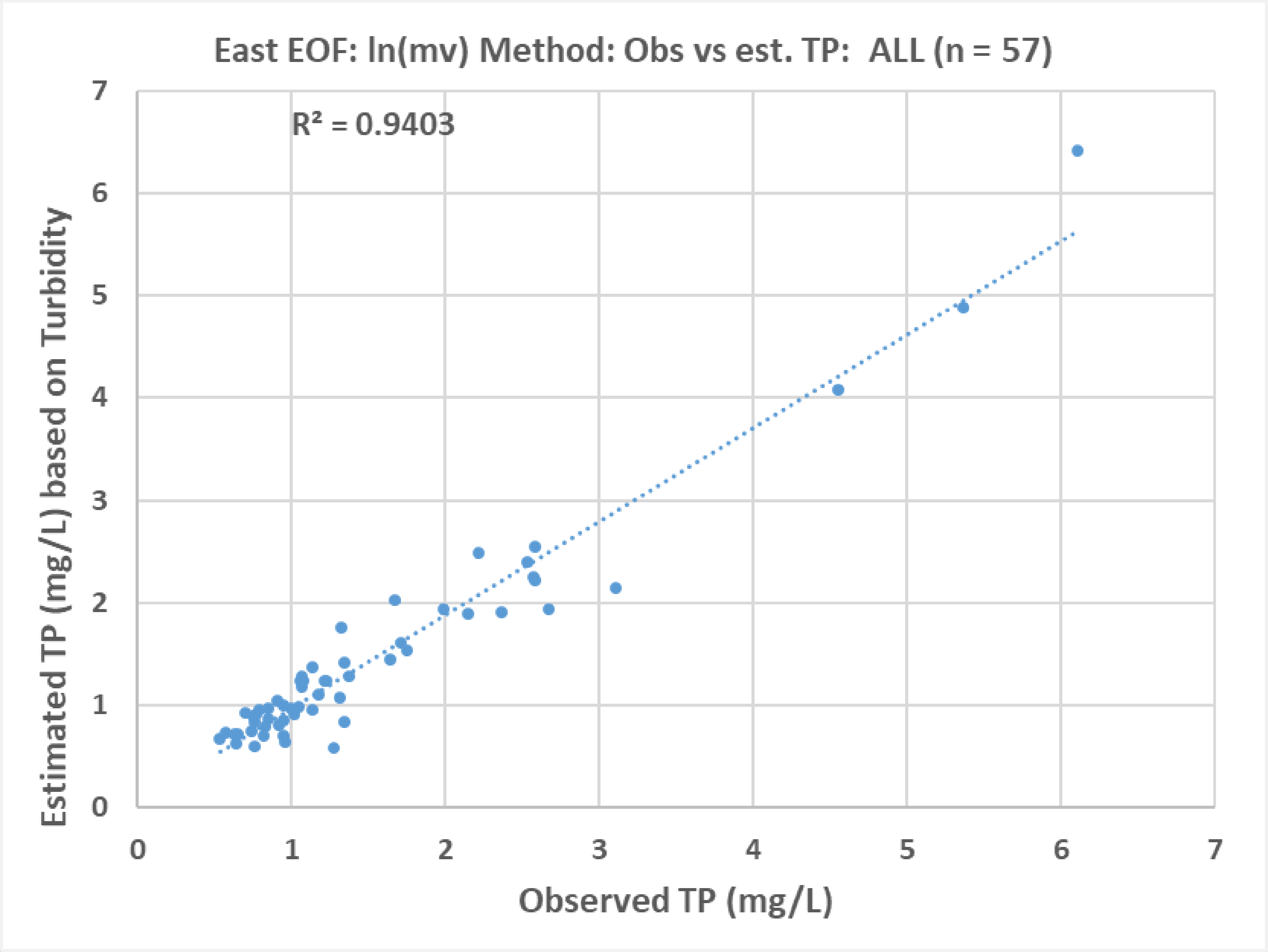
Edge-of-Field: EAST catchment

86 Discrete samples

Observed vs Low-Cost Sensor Estimated Suspended Sediment (mg/L)

sub-set of 2019 ISCO collected samples

EOF WEST site: relationship not as good, Turbidity vs Suspended sediment Rsq = 0.67 (113 samples); due to probe location in flume



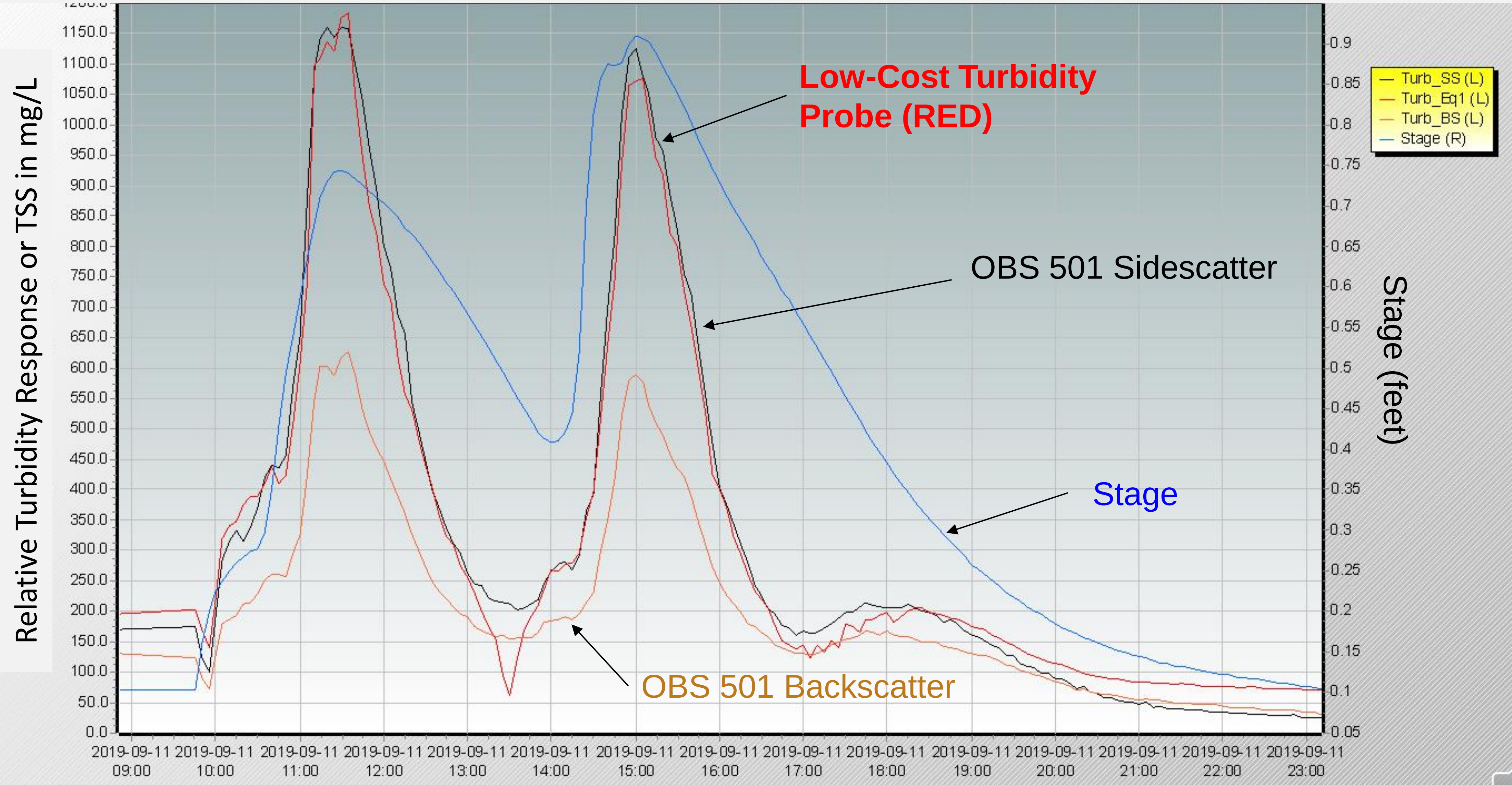
Edge-of-Field:
EAST catchment
57 discrete samples

Observed vs Low-Cost
Sensor Estimated
Total Phosphorus (mg/L)

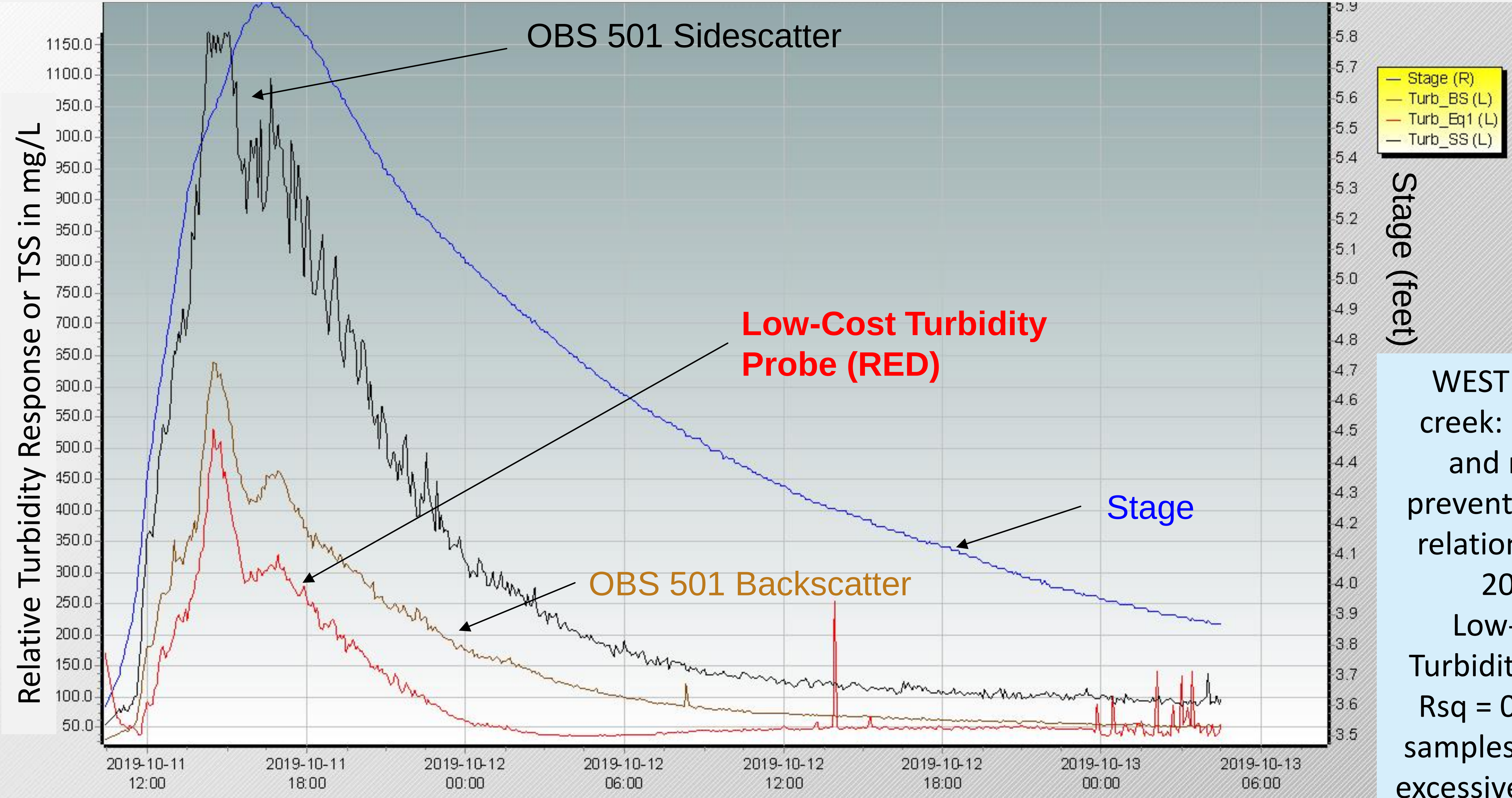
sub-set of 2019 ISCO collected samples

note: 2nd degree polynomial fit of natural log transformed sensor output voltage

Low-cost Sensor output vs OBS 501 (back & side scatter) with Stage at **WEST** EoF site (9/11/19 events)

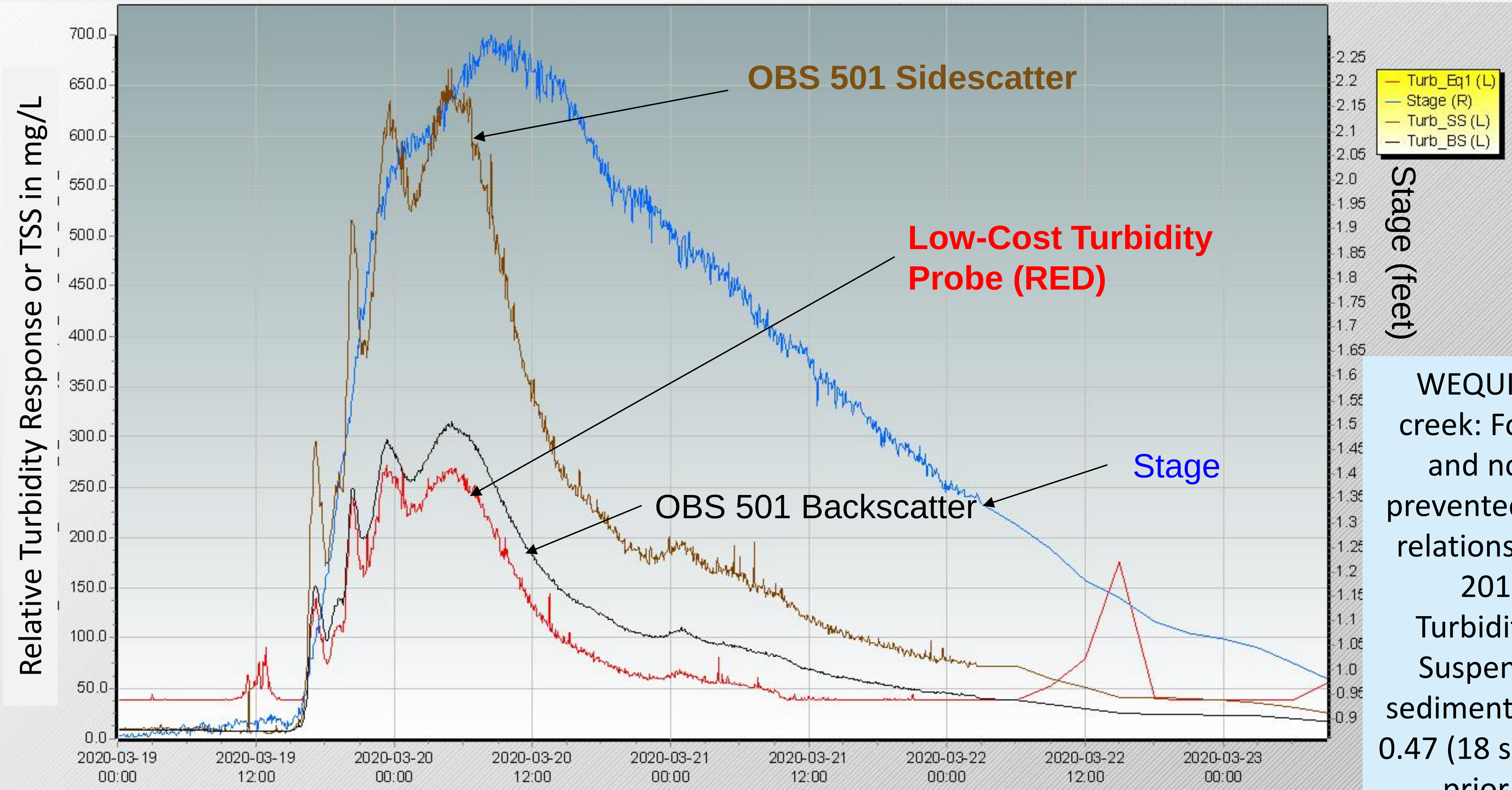


Low-cost Sensor output vs OBS 501 (back & side scatter) with Stage at **WEST PLUM creek** (10/11/19 event)



WEST PLUM creek: Fouling and noise prevented good relationship in 2019
Low-Cost Turbidity vs TSS R_{sq} = 0.46 (64 samples prior to excessive fouling)

Low-cost Sensor output vs OBS 501 (back & side scatter) with Stage at **WEQUIOCK creek** (3/20/19 event)

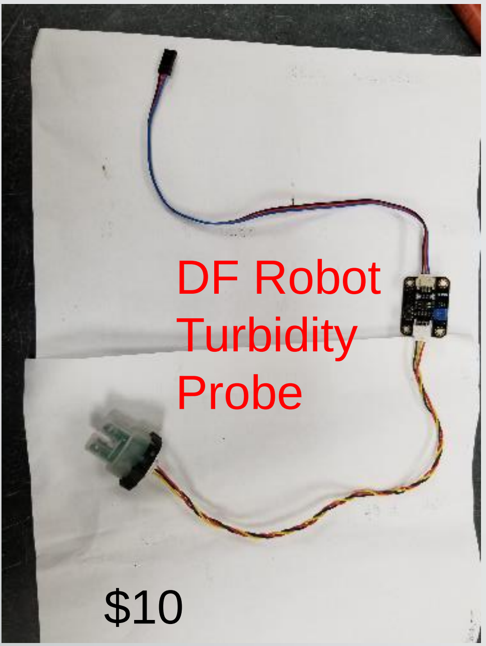


WEQUIOCK creek: Fouling and noise prevented good relationship in 2019

Turbidity vs Suspended sediment Rsq = 0.47 (18 samples prior to excessive fouling

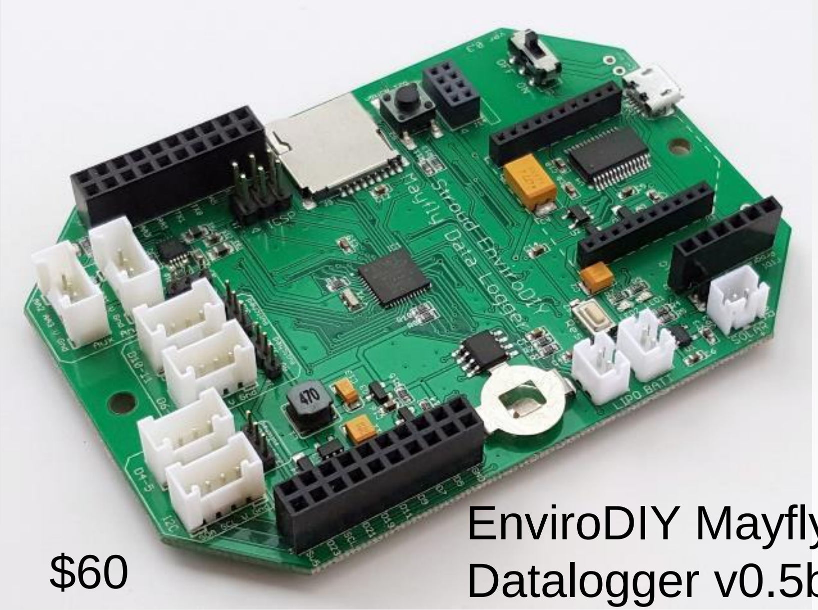
Low-cost Probe and Mayfly Logger Field Deployments

- Low-cost stations
  - DF Robot turbidity sensors and EnviroDIY Mayfly dataloggers
  - Programmed using Arduino IDE with 5 minute sample intervals
  - Three stations deployed on UW Green Bay campus
  - **Three more stations deployed in Wequiock Creek watershed**



DF Robot Turbidity Probe

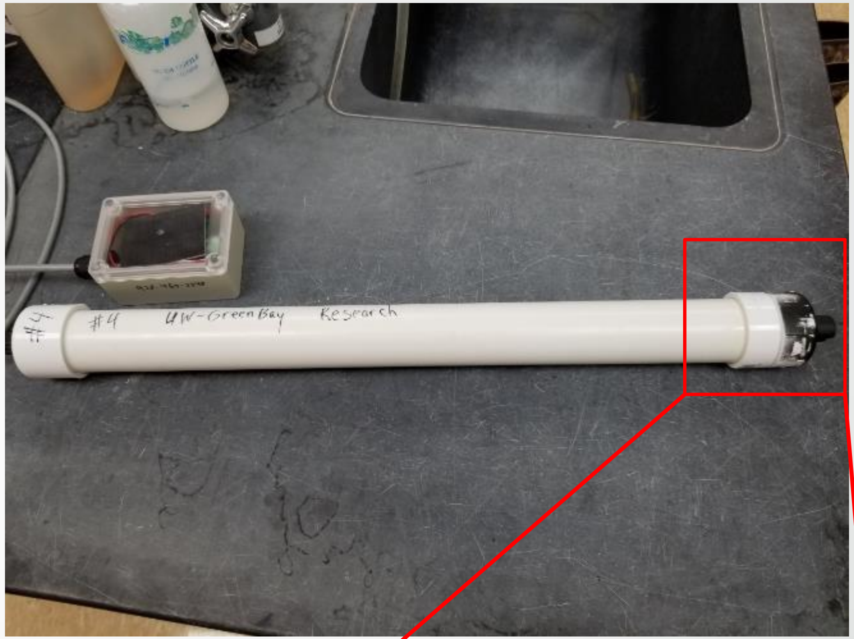
$10



$60

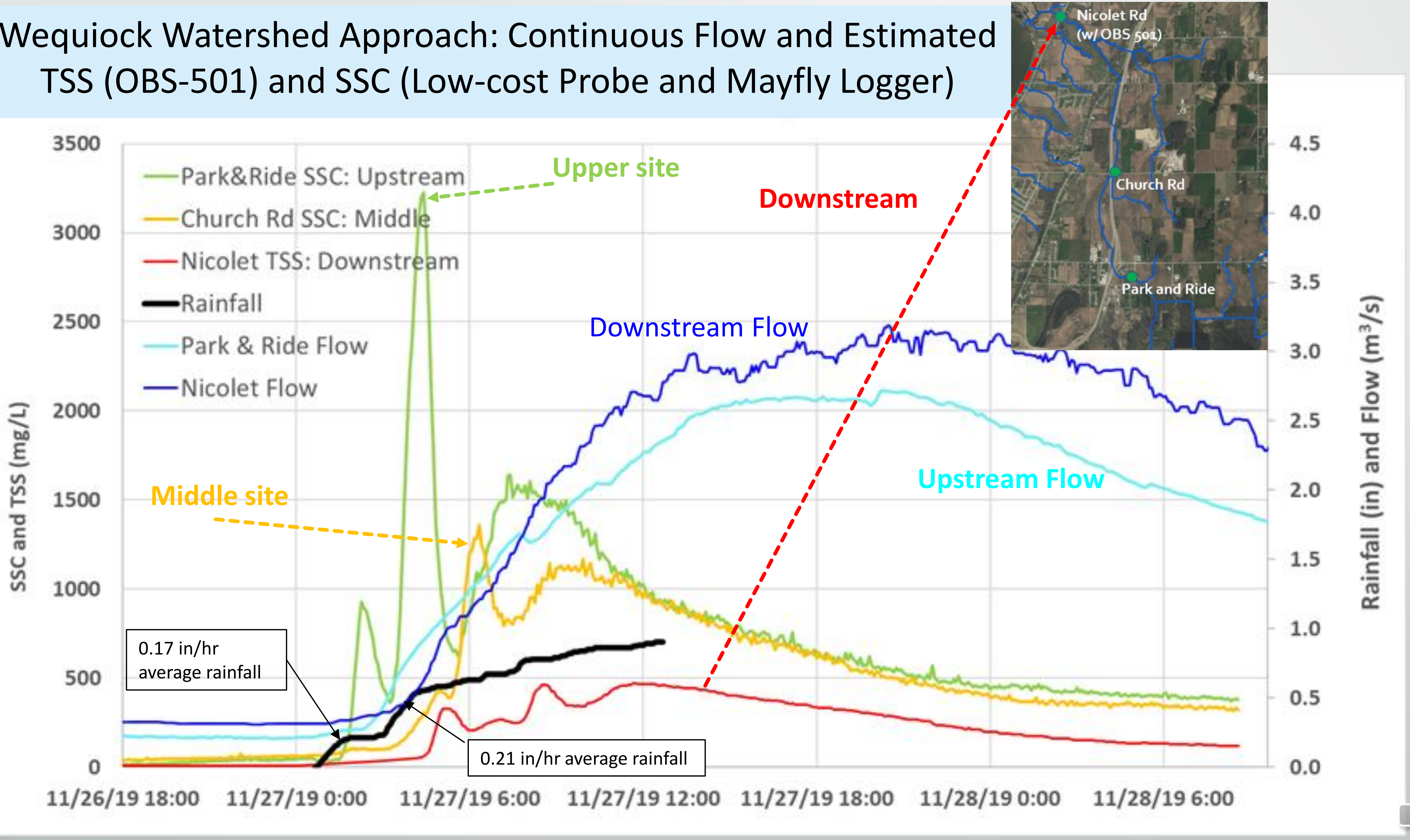
EnviroDIY Mayfly Datalogger v0.5b

Source: https://www.envirodiy.org/mayfly/

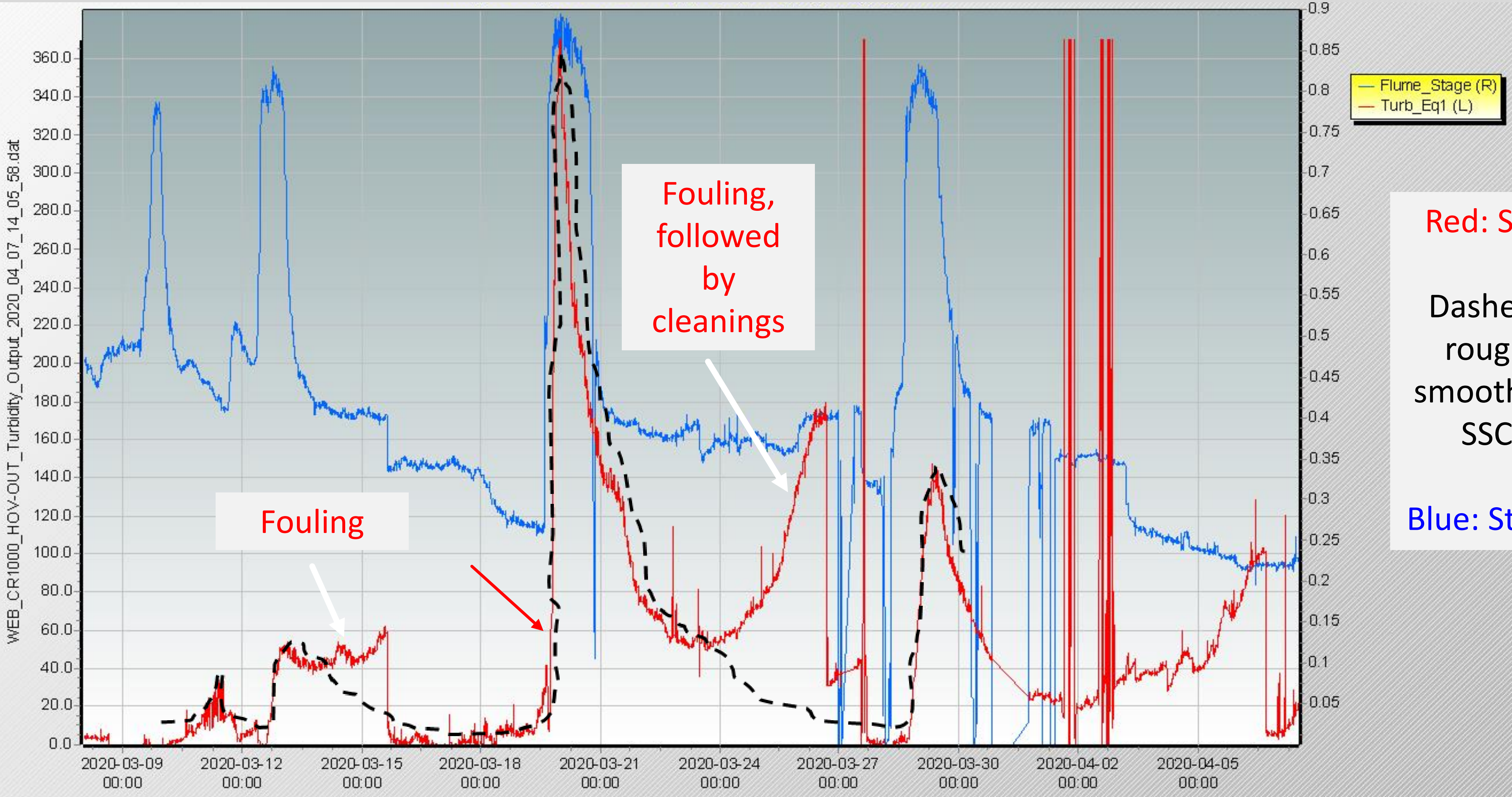


Low-Cost Monitoring Station Test
Watershed Deployment
Wequiock Creek
Nicolet Rd
(w/ OBS 501)
Van Lannen Rd
KWIGREEN111
Church Rd
Park and Ride
UW Green Bay
Brown County LIO, USDA FSA, DigitalGlobe, GeoEye, Earthstar Geographics

Wequiock Watershed Approach: Continuous Flow and Estimated TSS (OBS-501) and SSC (Low-cost Probe and Mayfly Logger)



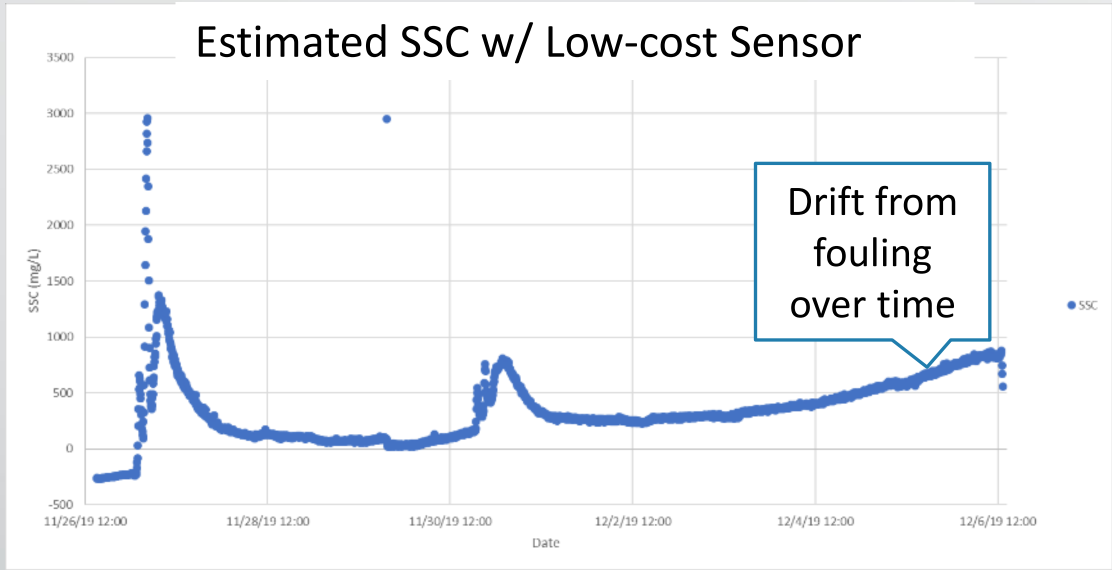
Treatment Pond Outlet: Estimated Suspended Sediment (mg/L) during March 2020



Red: SSC

Dashed: rough smoothed SSC

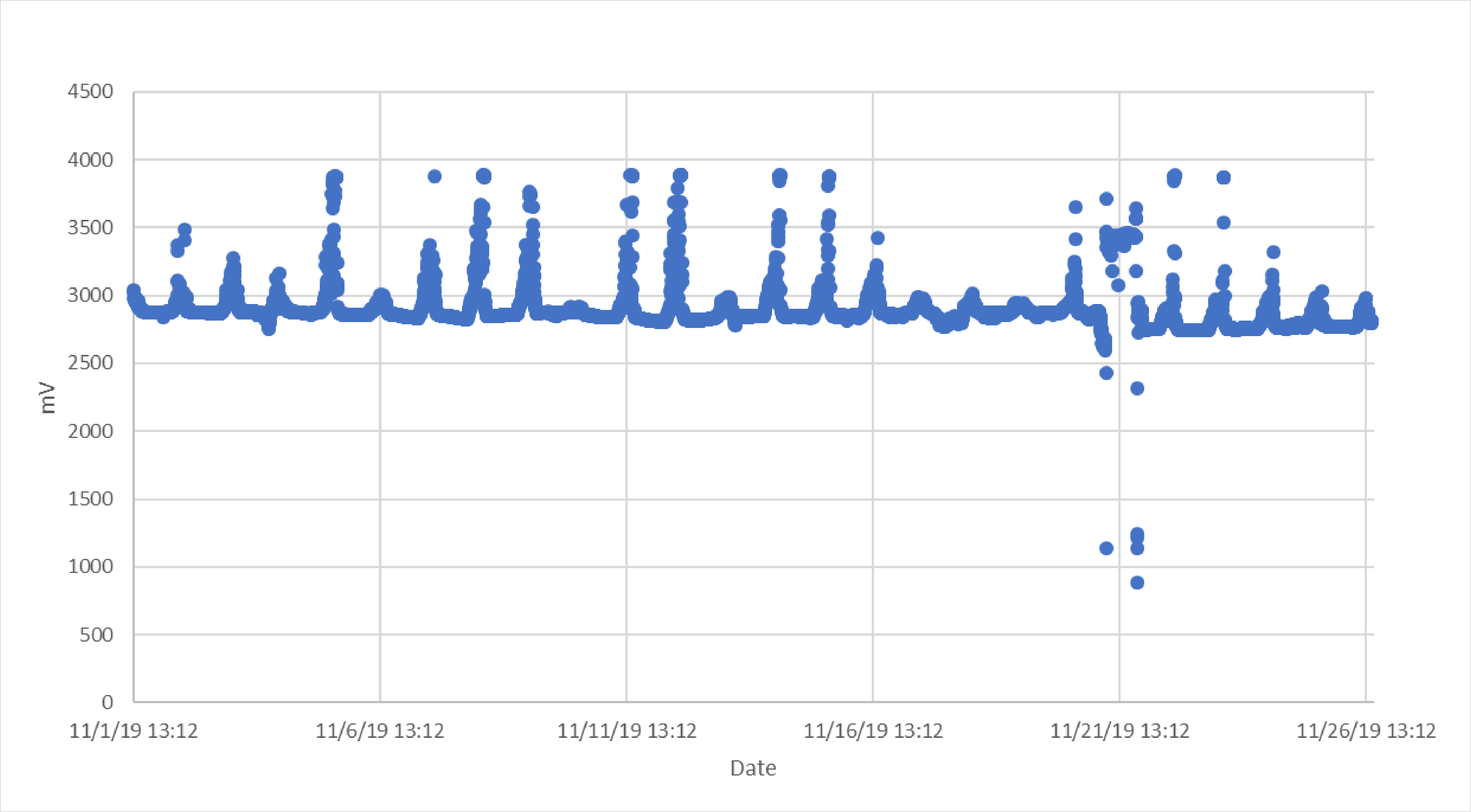
Blue: Stage



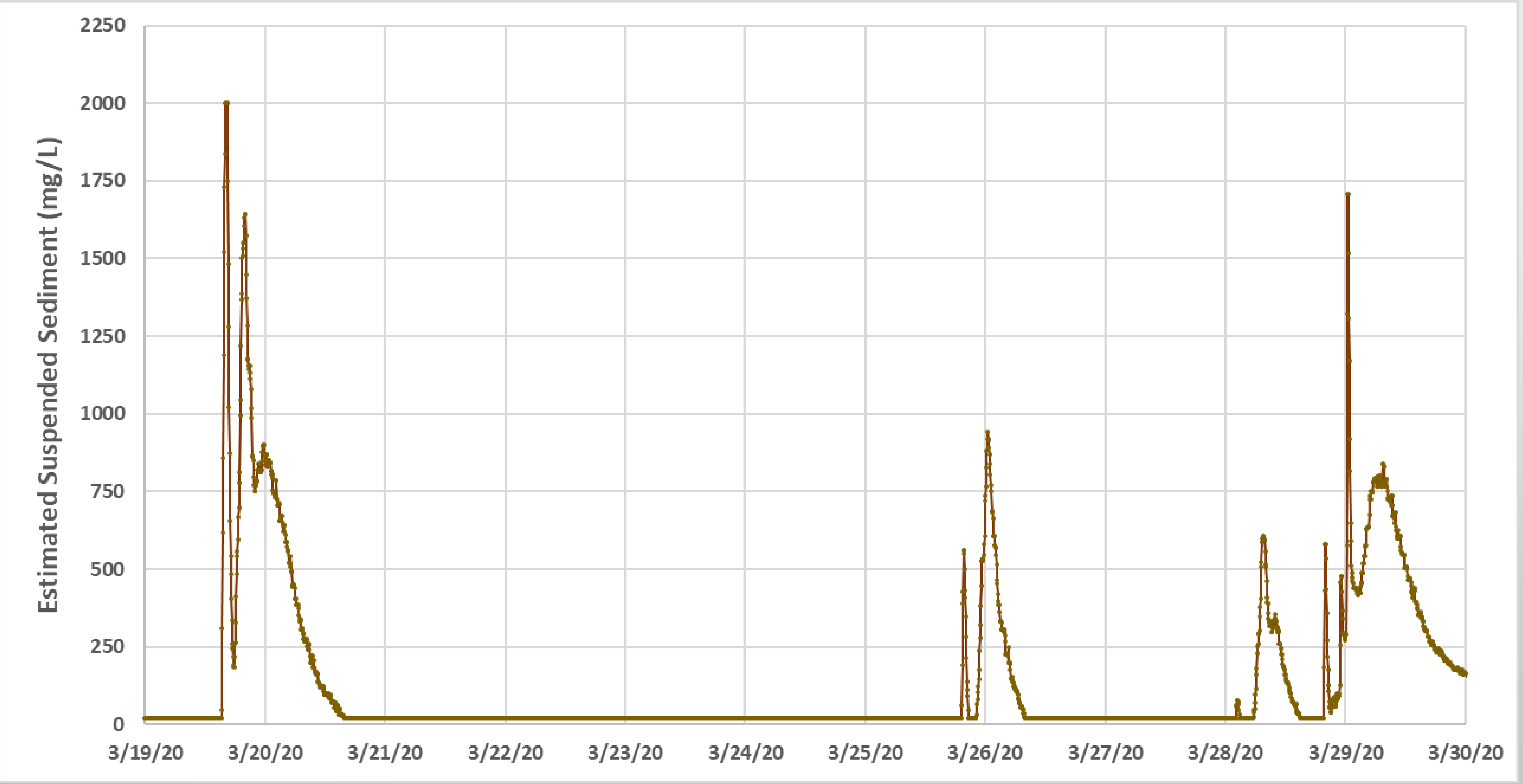
Fouling

- Sediment and/or biological buildup on the receiver and/or emitter
- Causes signal output to decrease over time, causing estimated SSC to go up
- Buildup can occur after storm events containing large amounts of sediment
- Biological buildup a problem late spring to late fall
- Possible Solutions: clean every week or two; keep sensor slightly above water level and adjust as needed (maybe add flag/switch for when water present)
- Few problems with edge-of-field, but major issue with streams, pond and tile outlets

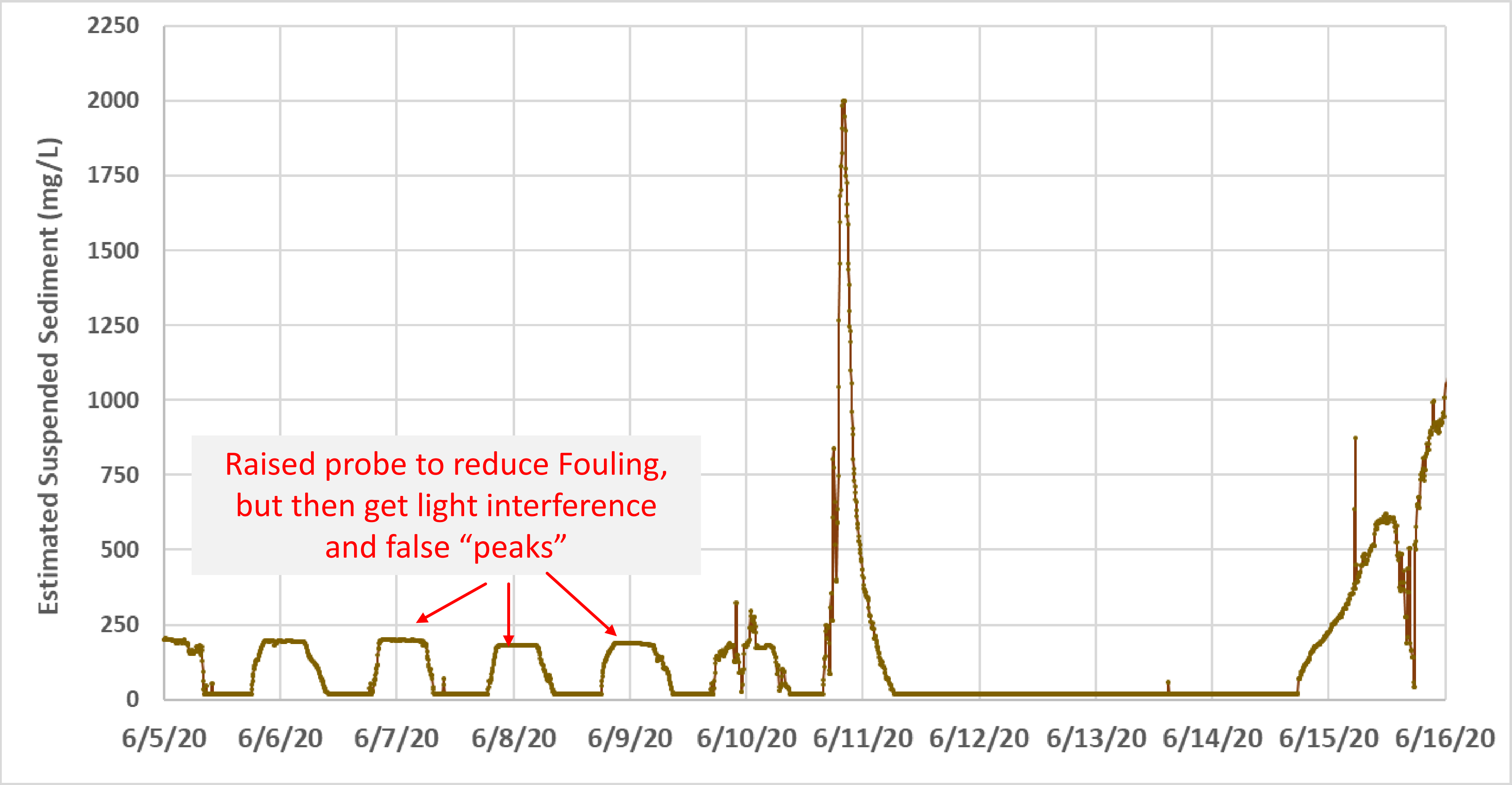
Light Interference from sunlight (especially when exposed to direct sunlight): note peaks every day



Wequiock Creek at Park & Ride (upstream site): March 2020 Low-cost Probe estimated Suspended Sediment (mg/L)



Wequiock Creek at Park & Ride (upstream site): June 2020
Low-cost Probe estimated Suspended Sediment (mg/L)



Intensive monitoring stations with existing loggers, automated samplers, and commercial turbidity probe for comparison: Conclusions

- Paired edge of field study: East and West catchments (7.5 and 10.8 acres)
  - Both worked very well, but some issues with West catchment placement of turbidity probes in flume so didn't correlate as well with ISCO drawn samples
- West Plum Creek: worked well, but fouling & sunlight issue at times
- Wequiock Creek: worked well at times, but fouling/sunlight an issue
- Resolve issues with fouling (clean 1x/week), raise probe above water

Low-cost System Conclusions & Future Work

- Successfully developed, tested, and deployed a monitoring system based on a low-cost appliance turbidity sensor
  - Sensitive over a wide range of SSC (~ 50 to 6,000 mg/L)
  - Mayfly logger and program/scripts worked well
- Deployed system was responsive to real world runoff suspended sediment dynamics and comparable to expensive, commercial sensor
- Also: Low-cost sensor combined with Onset 4-channel logger worked well

-------------------------------- next steps ---

- Deploy in a larger area, covering an entire watershed
- Resolve issues with fouling (clean 1x/week)
- Create a larger dataset of low-cost turbidity response vs grab samples (TSS and TP)
- Real-time connectivity

Acknowledgements

- UW Green Bay Heirloom Grant
- EnviroDIY/Stroud Water Research Center
- United States Geological Survey
- UW Extension
- Fox-Wolf Watershed Alliance
- Great Lakes Restoration Initiative
- Nature Conservancy

Thank you for listening.

Any questions?