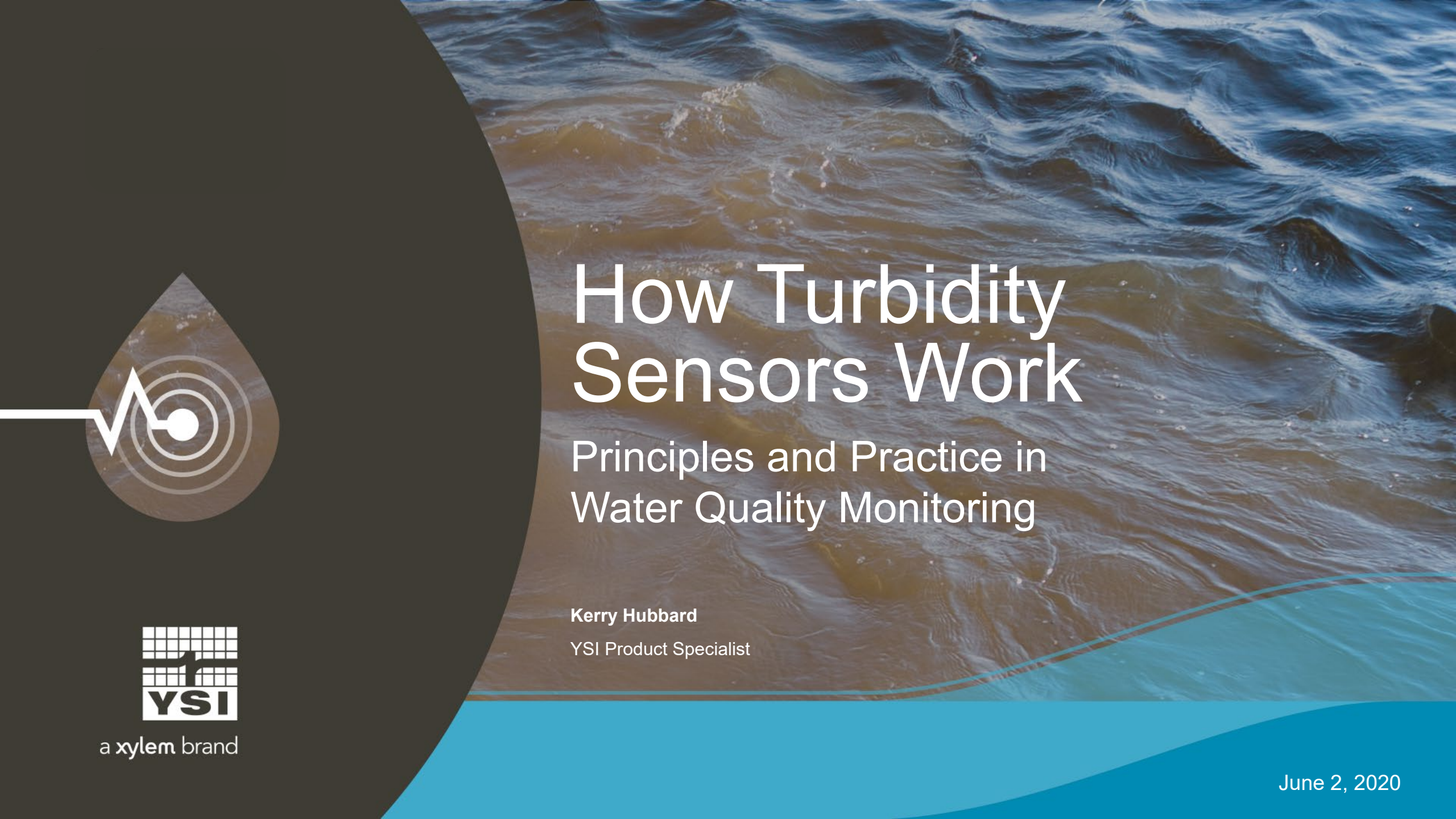

How Turbidity Sensors Work

Principles and Practice in Water Quality Monitoring

Kerry Hubbard

YSI Product Specialist

YSI

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June 2, 2020

How Sensors Work:
6-Part Series on Water Quality Monitoring

Once a week, we will discuss why it is important to monitor critical water quality parameters.

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recorded

recorded

June 2nd

June 9th

June 16th

June 23rd

Kerry Hubbard

BACKGROUND

BS in Earth and Atmospheric Studies
Georgia Institute of Technology

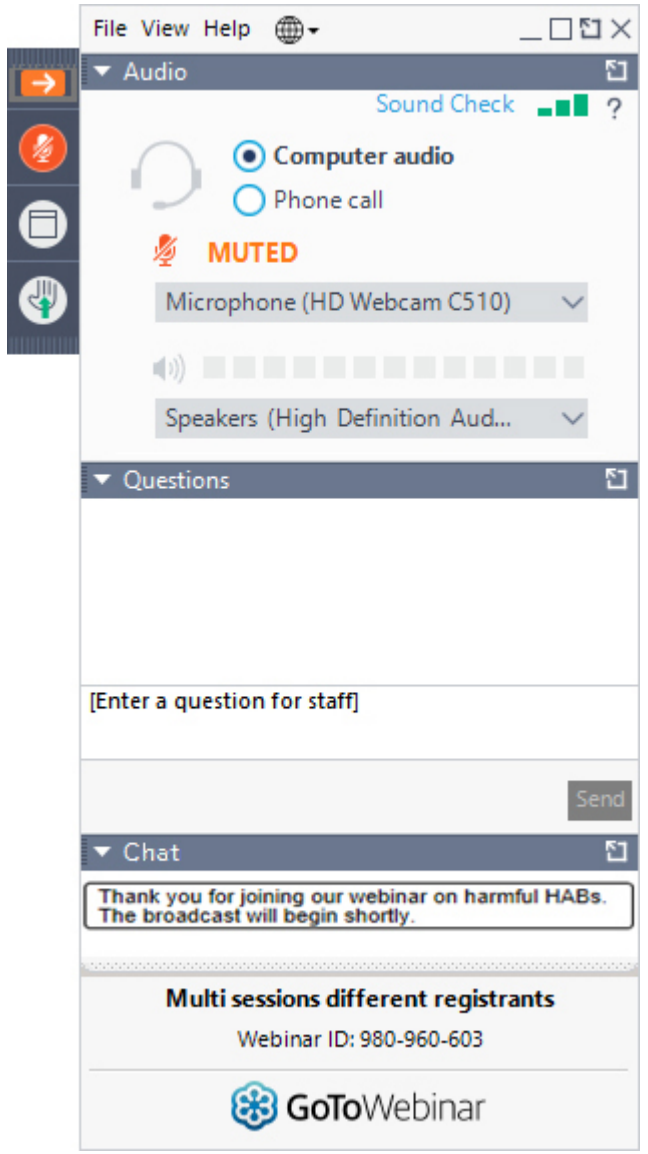
- Product Specialist,
  Outdoor Water Quality
- 10 years working in the field assisting with water quantity and quality projects

GoTo Webinar

Audio Settings
Make sure you can hear us loud and clear

Ask Questions
We'll try to answer as many as we can during the presentation

Chat
You can also use the Chat panel to ask questions or contact us if you're having technical difficulties



Modify Audio Settings

Please Ask Questions!

Overview

I. Why Monitor for Turbidity?
II. Evolution of Turbidity Monitoring
III. Principles: How Turbidity Sensors Work
IV. Practice: Real-World Monitoring

Why Monitor for Turbidity?

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Why do you monitor for turbidity?

What is Turbidity?

- Optical characteristic of water
- A Simple Definition: The clarity of water
- More Complete Definition: The cloudiness, opacity, or thickness of water due to suspended matter
- Suspended matter can include sand, silt, clay, algae, plankton, sewage, and more.

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What is Turbidity?

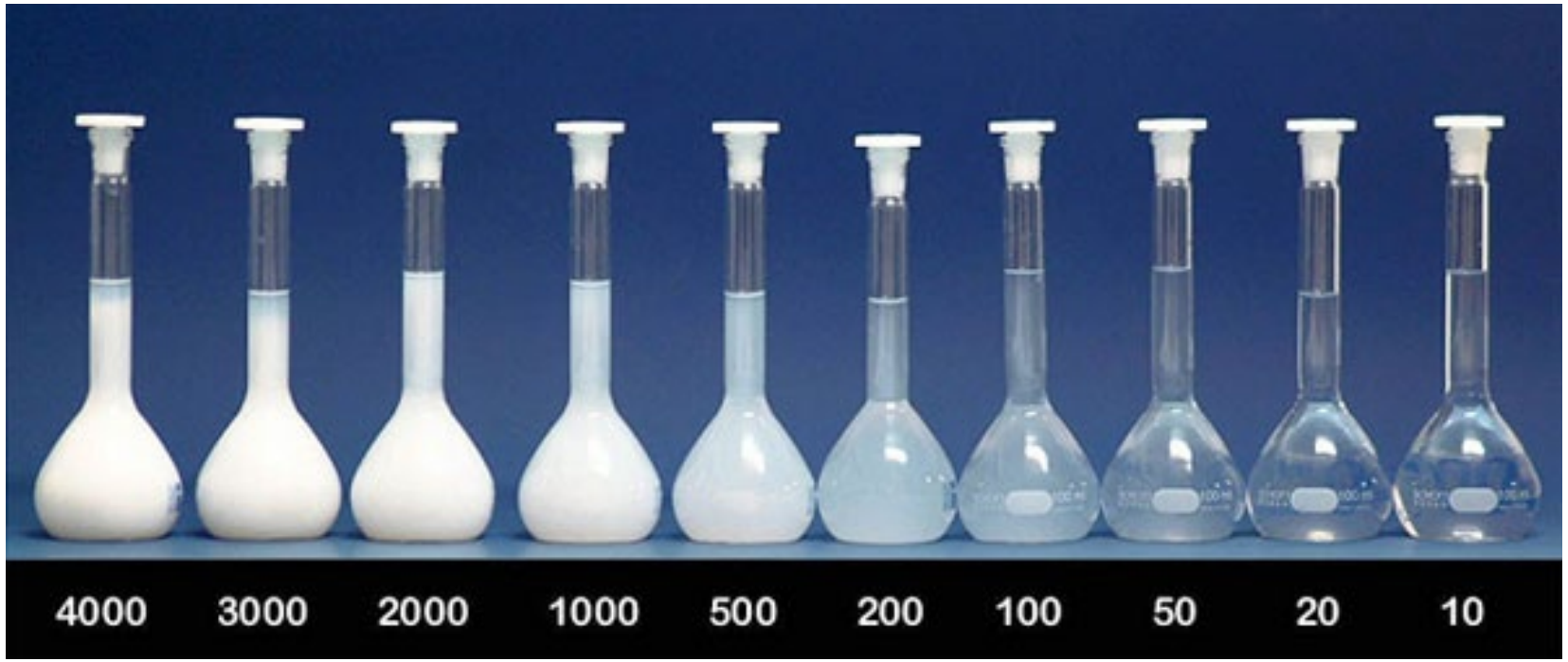

Image Credit: Coastal Wiki

Units of Measurement

- **NTU: Nephelometric Turbidity Units**
- **FNU: Formazin Nephelometric Units**
- NTRU: Nephelometric Turbidity Ratio Units
- FNRU: Formazin Nephelometric Ratio Units
- BU: Backscatter Units
- FBU: Formazin Backscatter Units
- BRU: Backscatter Ratio Units
- FBRU: Formazin Backscatter Ratio Units
- AU: Attenuation Units
- FAU: Formazin Attenuation Units
- NTMU: Nephelometric Turbidity Multibeam Units
- FNMU: Formazin Nephelometric Multibeam Units
- JTU: Jackson Turbidity Units

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What Turbidity is NOT

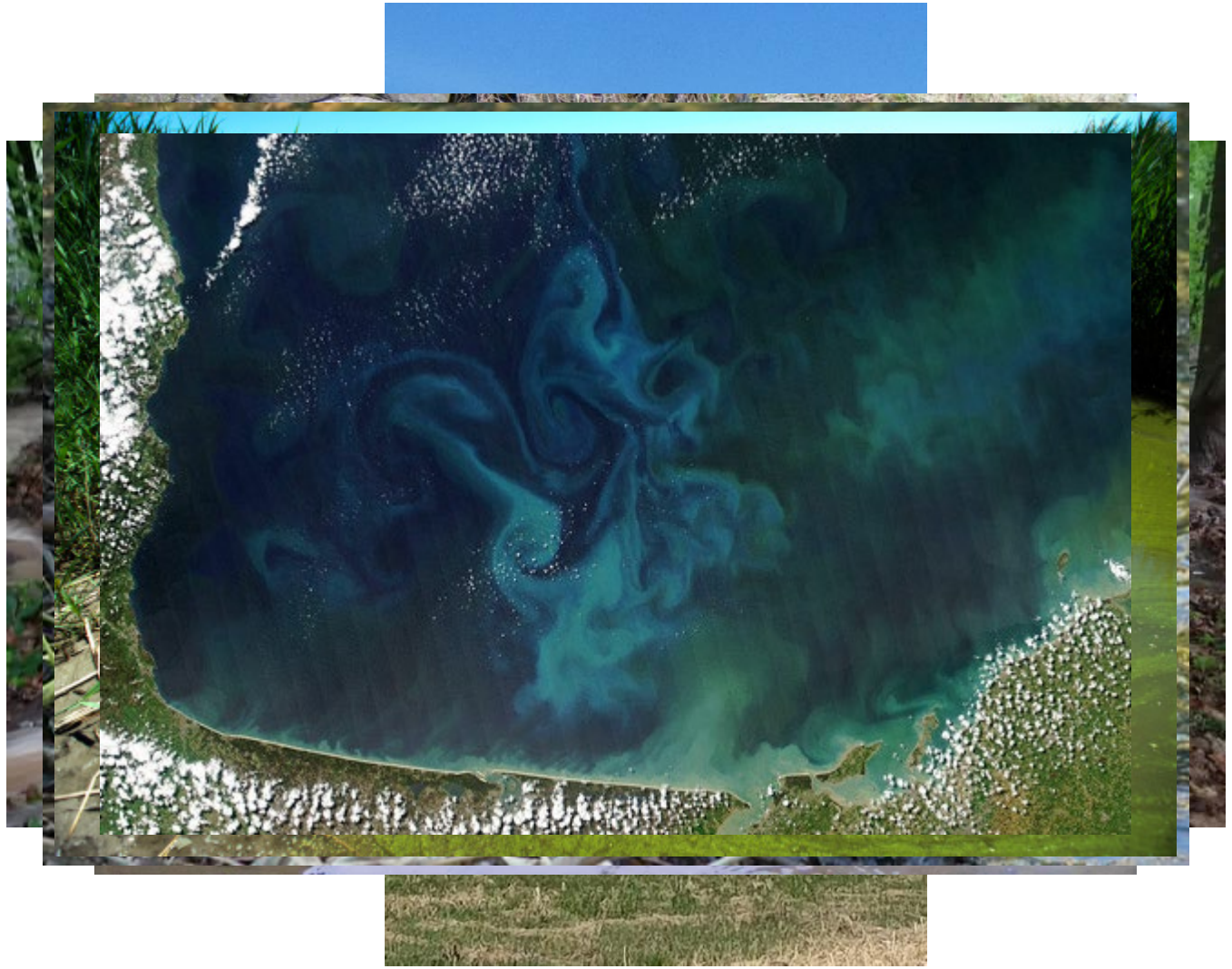
- Turbidity is not a measure of color
  - Dyes
  - Tannins

- Blackwater looks dark, but can have low turbidity!
  - 2.8 FNU at time of image
  - Very little particulate matter

Image Credit: Ben Thepaut, USGS. Gage station 02110550: Waccamaw River above Conway, SC

Causes of Increased Turbidity

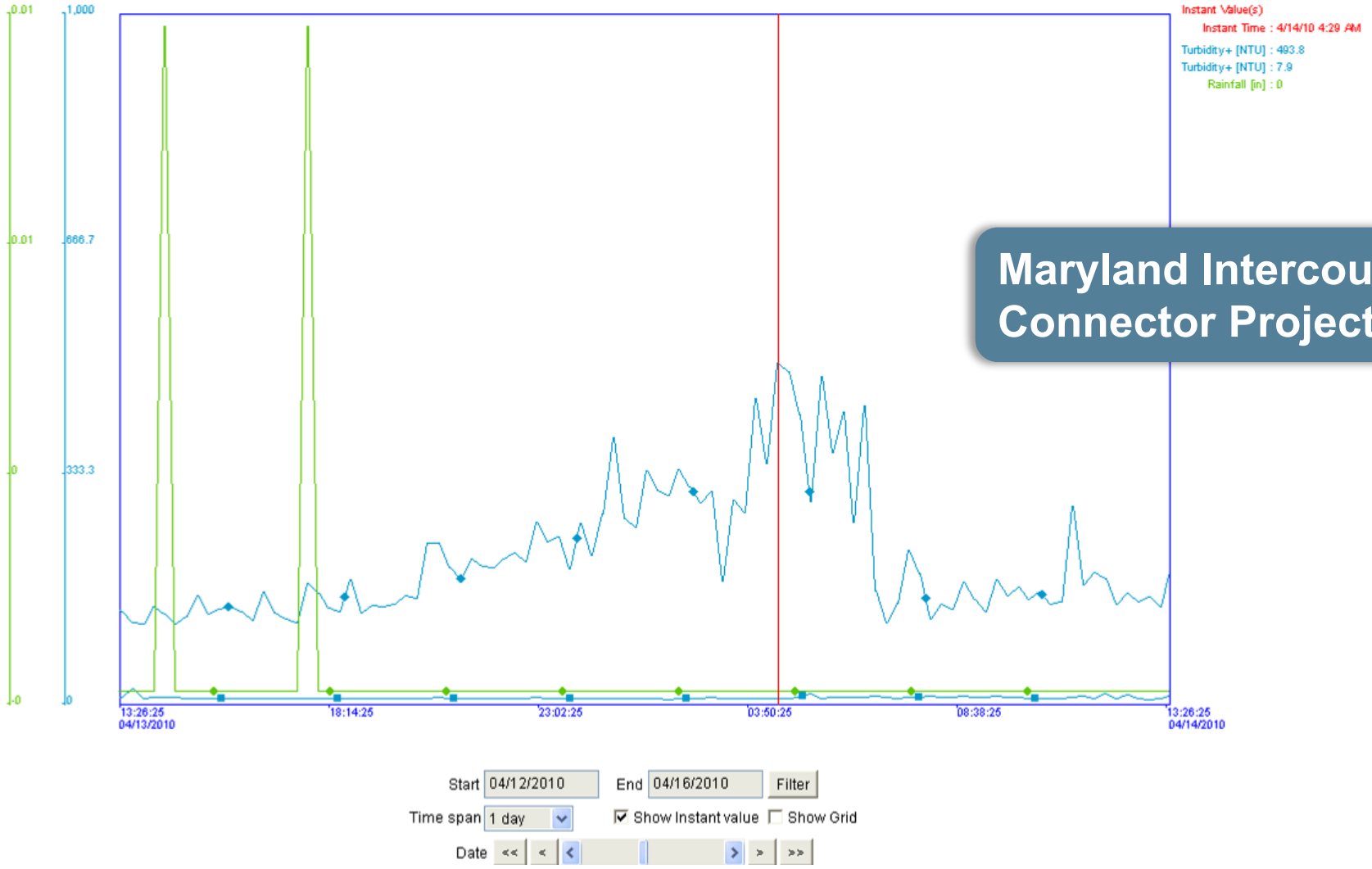
- Storm Runoff
- Wind Erosion
- Coastal Erosion
- Construction
- Dredging
- Sewer Discharge
- Animal Activity
- Algae Growth
- Phytoplankton



Why Monitor for Turbidity?

- Overall indicator of ecosystem health
  - Aquatic animal habitat
    - Respiration
    - Reproduction
  - Dredging and construction impacts
- Pollutant indicator
  - Bacteria
  - Metals
  - Sediment
- BMP Effectiveness
- Recreational Activity
- Drinking water compliance

Why Monitor for Turbidity?



Maryland Intercounty Connector Project

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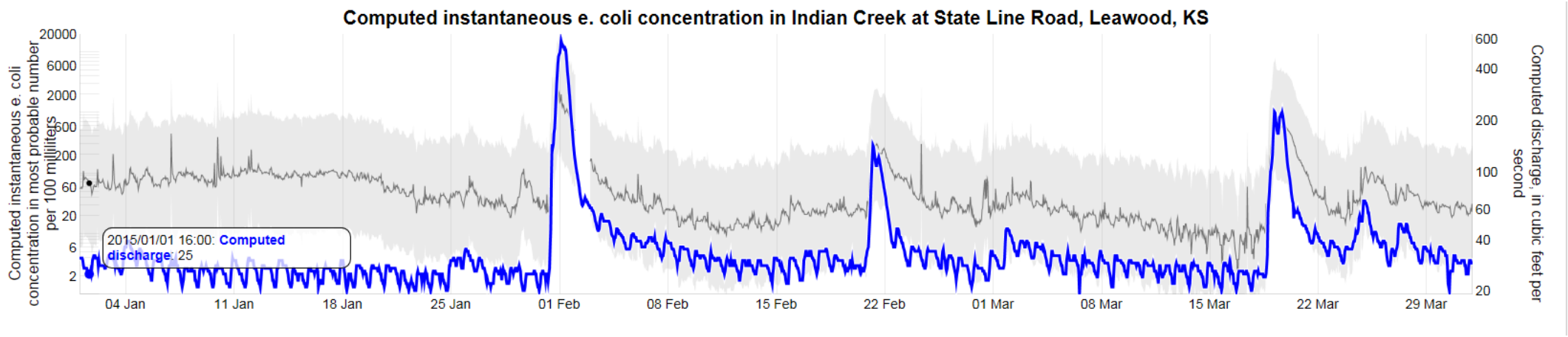
Why Monitor for Turbidity?

- Surrogates for Additional Parameters
  - Bacteria (fecal coliform, E. coli, etc.)
  - Phosphorus
  - Organic Carbon
  - Mercury
  - Metals (Pb, Zn, Cu, etc.)
  - Nitrogen
  - **Total Suspended Solids (TSS)**
  - Suspended Sediment Concentration (SSC)



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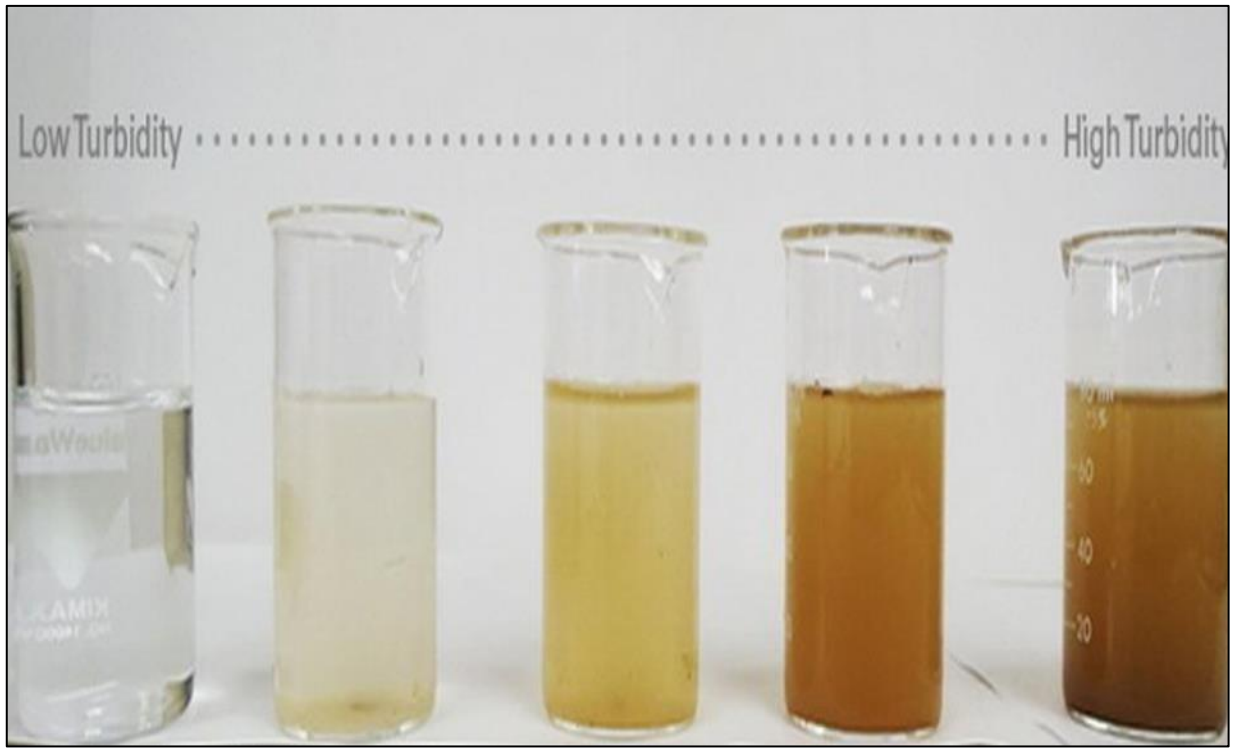
What is TSS?

Total **S**uspended **S**olids

- Dry weight of suspended particles that can be trapped by a filter
- Things like:
  - Sediment: Silt, Sand, Clay
  - Plankton
  - Algae
  - Plant and Animal Decay
- Sources:
  - Industrial discharge
  - Sewage
  - Fertilizer
  - Soil Erosion



Why Measure TSS?

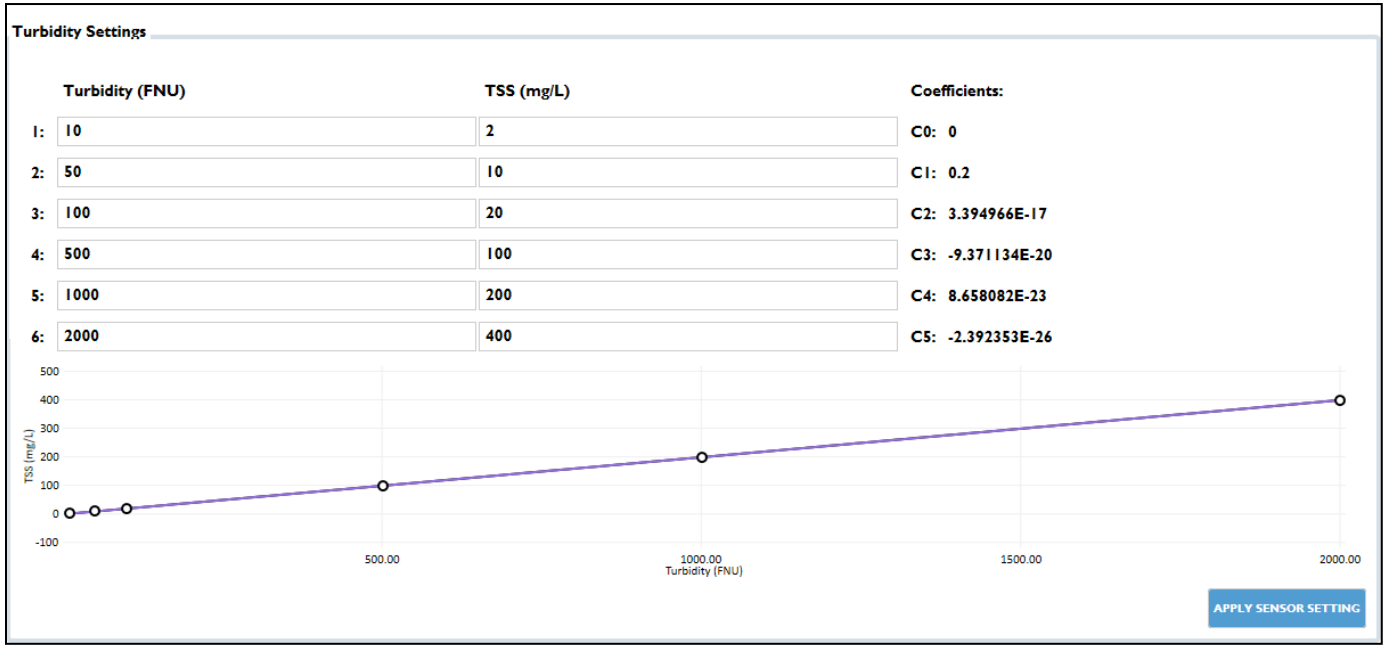
Just a few reasons:

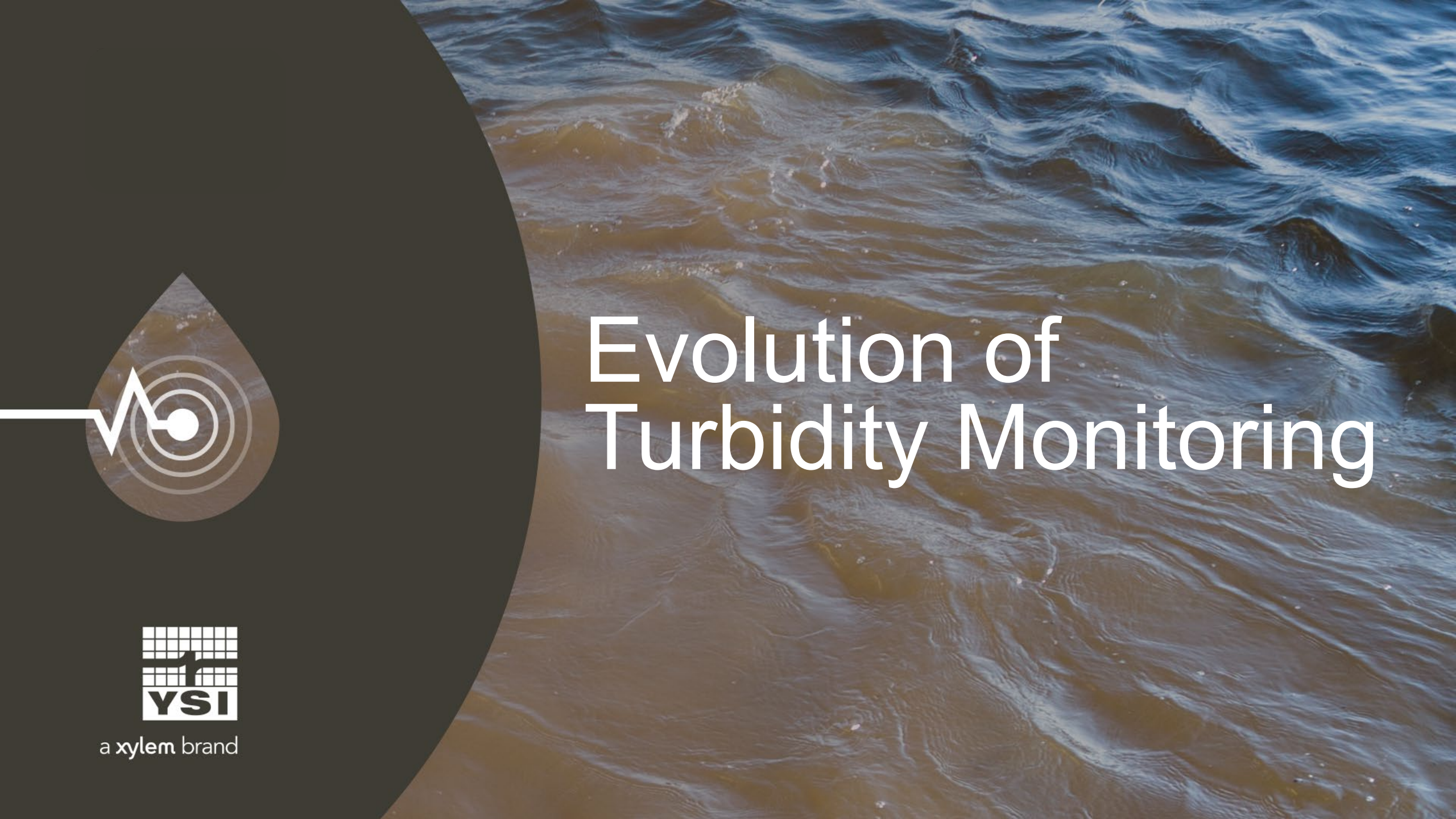
- Can signify toxins
- Signals changing environment
- Animal reproduction
- Plant photosynthesis
- Unpalatable drinking water
- Reduce efficiency of drinking water plants

How Can I Measure TSS?

- Discrete: Filtration Method
- Continuous: Regression Analysis
  - ***Regression needs to be periodically verified with additional samples

$$\frac{Weight_{final}(g) - Weight_{initial}(g) \times 1{,}000{,}000}{Sample\ Volume\ (mL)} = mgTSS/L$$





Evolution of Turbidity Monitoring

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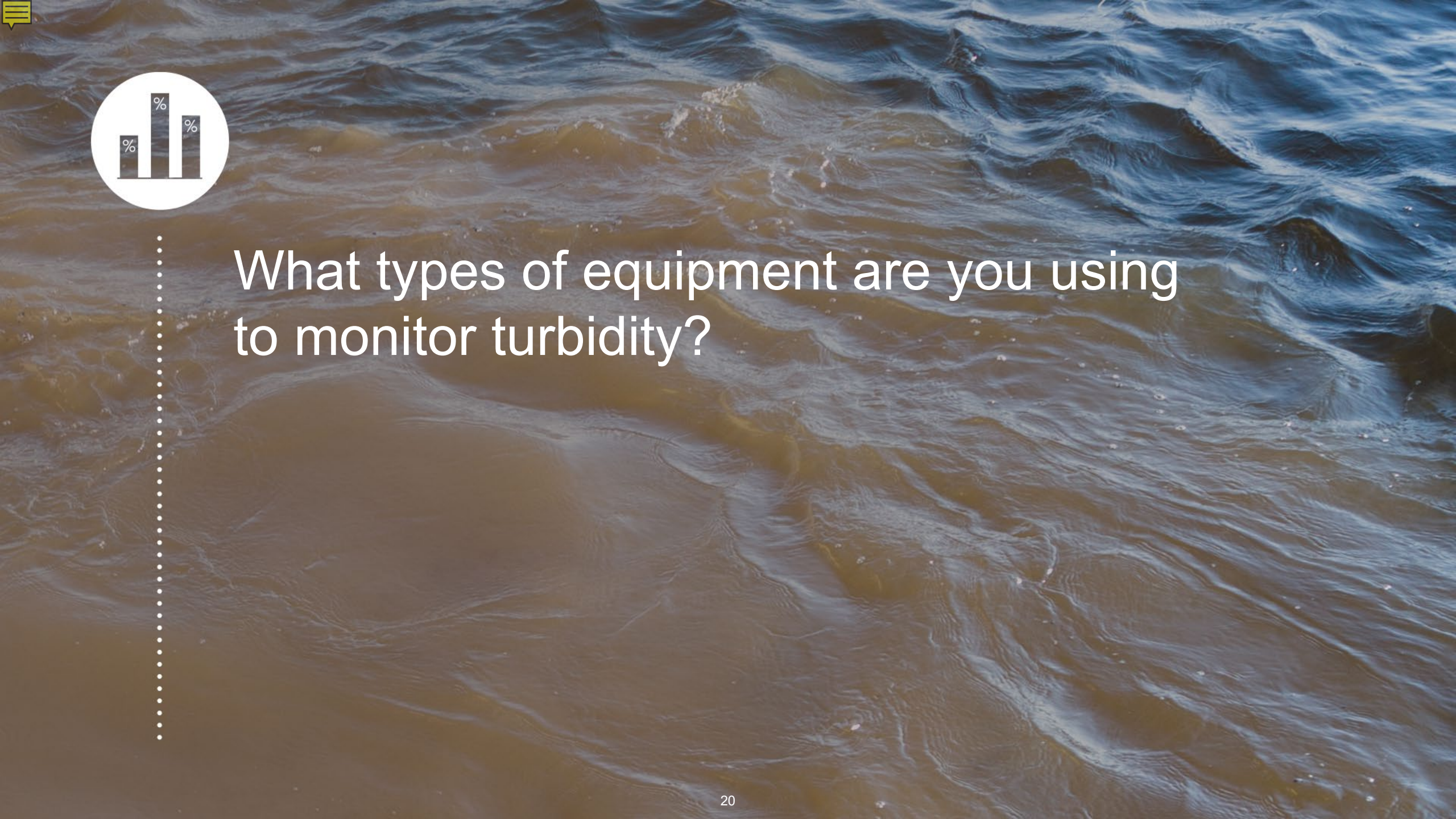


What types of equipment are you using to monitor turbidity?

Turbidity Monitoring Tools

Spot Sampling

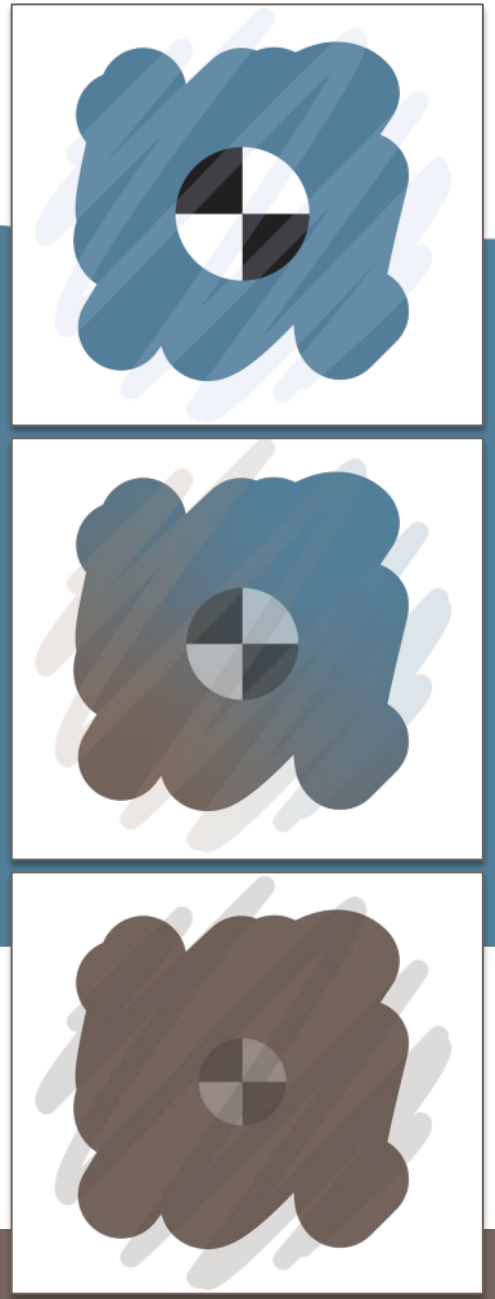
Laboratory Analysis

Continuous Profiling

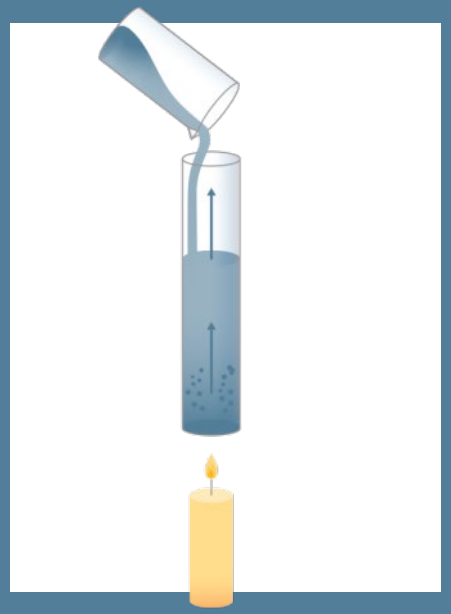
Spot Sampling – Secchi Disk

Credit: University of Washington

- Units of distance
- 8-inch diameter disk
- Alternating black and white quadrants
- Created in 1865 by Angelo Secchi
- Modified in 1899 by George Whipple
- Advantages: Low cost, easy to learn, easy to use

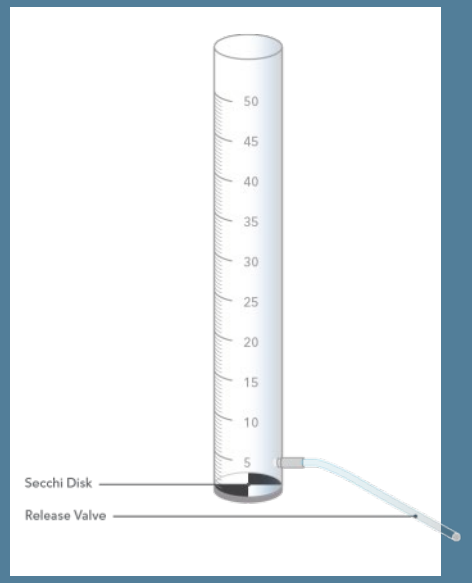


Spot Sampling – Jackson Candle Turbidimeter

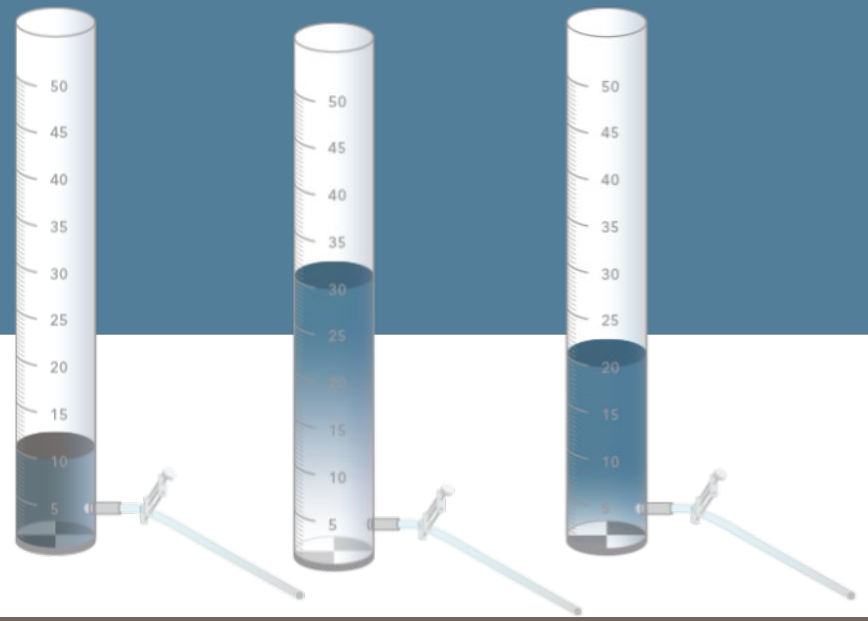


- Circa 1900
- Units are JTU
- Not good for measuring low turbidity levels due to the color of the candle
- Advantages: Low cost, easy to learn

Spot Sampling – Transparency Tube



- Units of distance
- Tables available to convert distance to NTU
- Approximately 120cm tall
- 4.5cm secchi disk at bottom
- Advantages: Low cost, portable, easy to use, easy to learn



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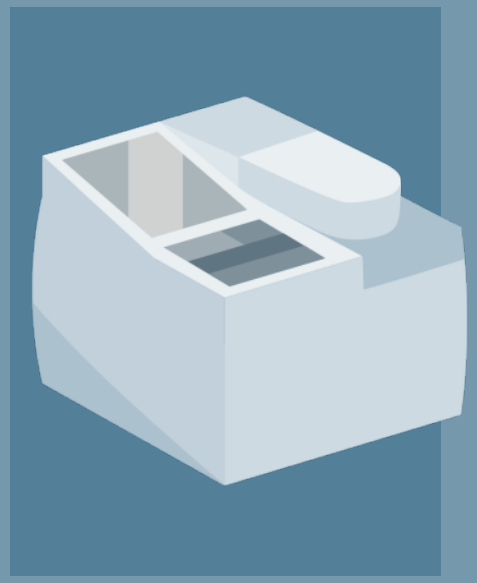
Laboratory Analysis – Benchtop Meter

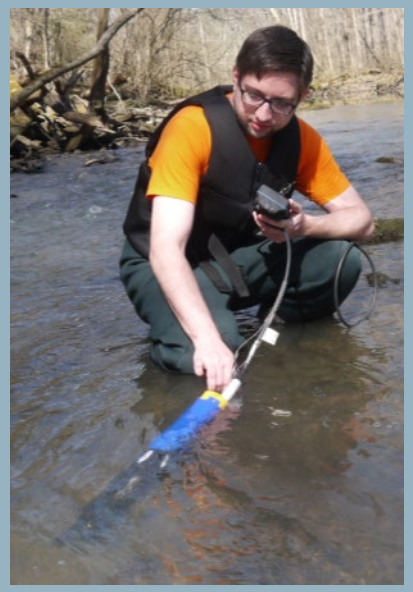
- Typically units are NTU
- High turbidity samples need to be diluted
- Light passes through cuvette of sample water
- Scatter method of measurement
- Advantages: Extremely accurate, some are portable, can measure low values
- EPA 180.1

Laboratory Analysis – Spectrophotometer

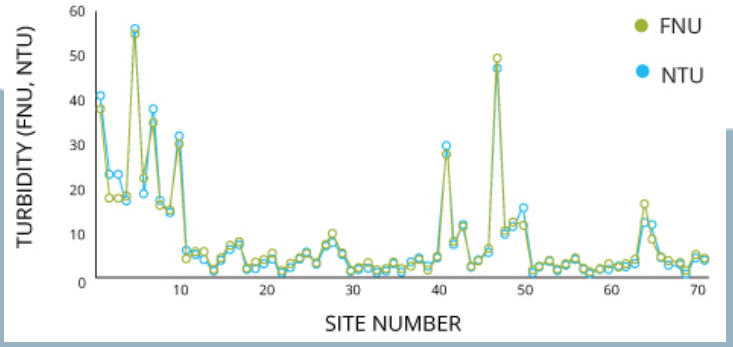


- Units are absorbance percentage
- Absorbance method of measurement
- Correlate this data to turbidity level
- Specific wavelength needs to be selected

Continuous and Profiling – Optical Sensor



- Units of FNU and NTU
  - Typically FNU
- Samples do not need to be diluted
- Sensor submerged directly in water or larger sample aliquot
- Advantages: Extremely accurate, portable, measure high values without dilution
- ISO 7027



How Turbidity Sensors Work: Principles

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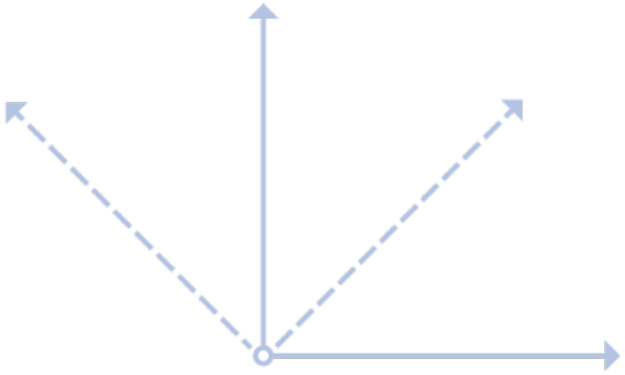
What range of turbidity values do you measure?

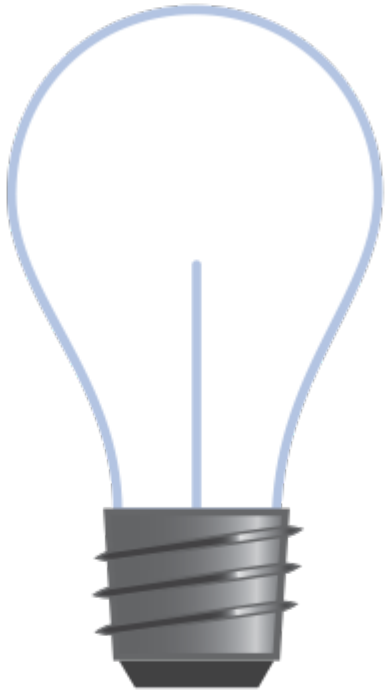
Sensor Principles

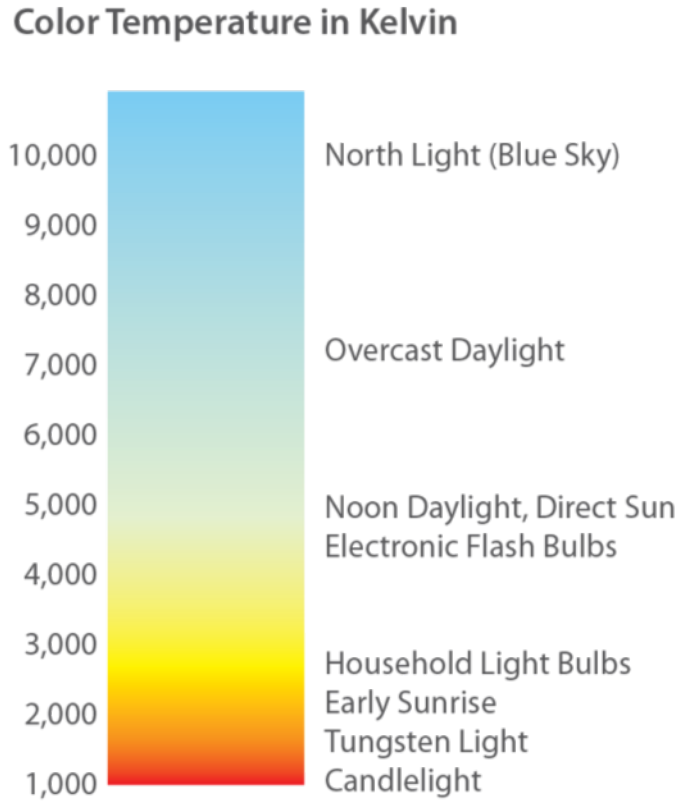
I. Light Angles and Sources
II. Temperature Compensation
III. How YSI Turbidity Sensors Work



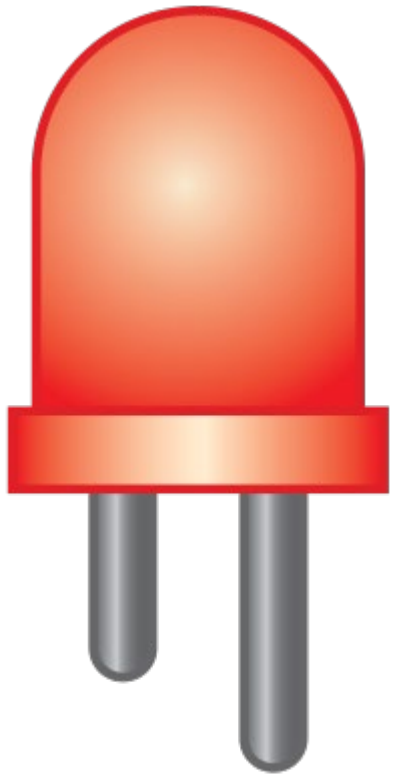
Light Sources

EPA 180.1: White Light: 400-680nm

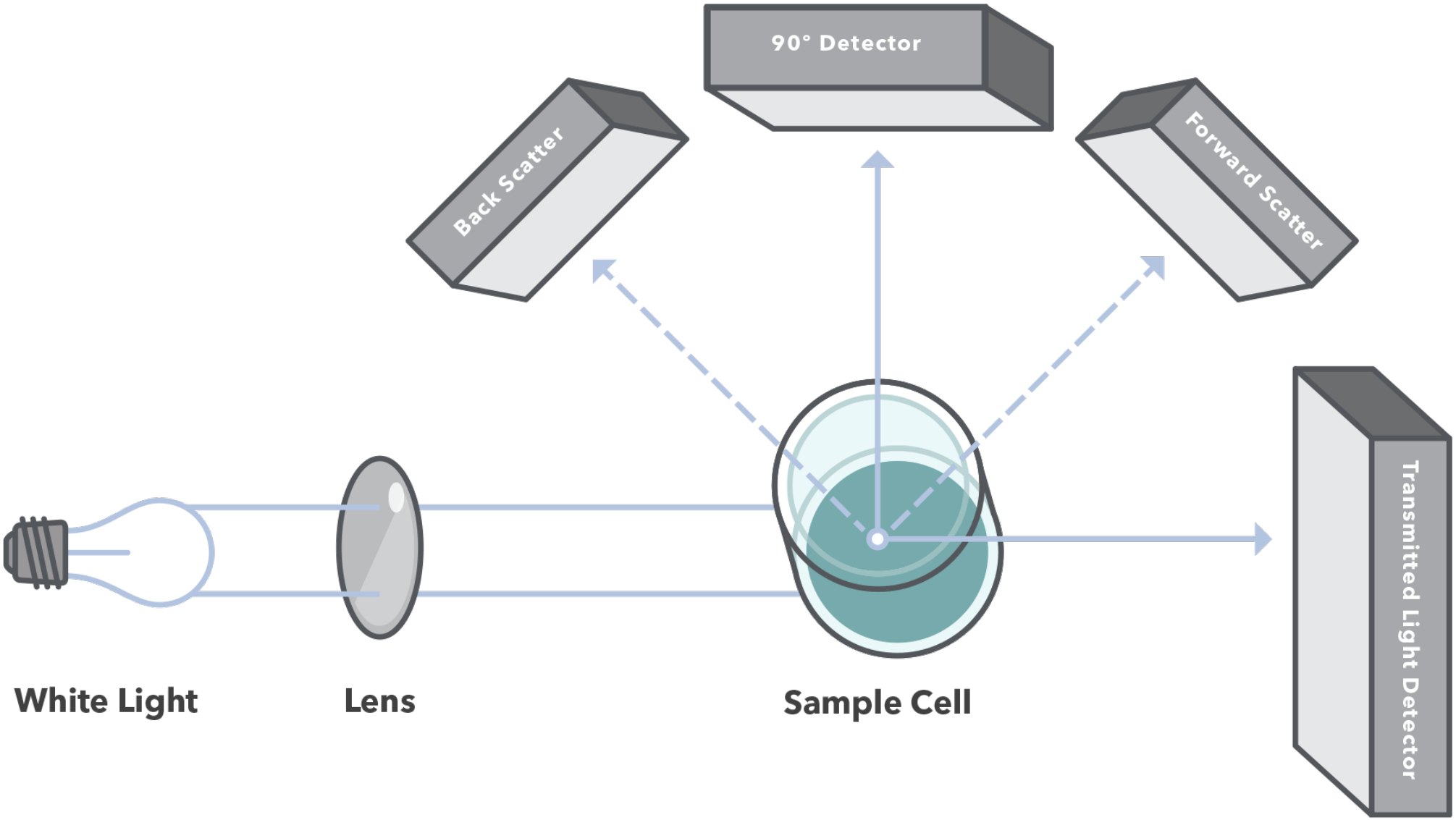




ISO 7027: Infrared: 860nm

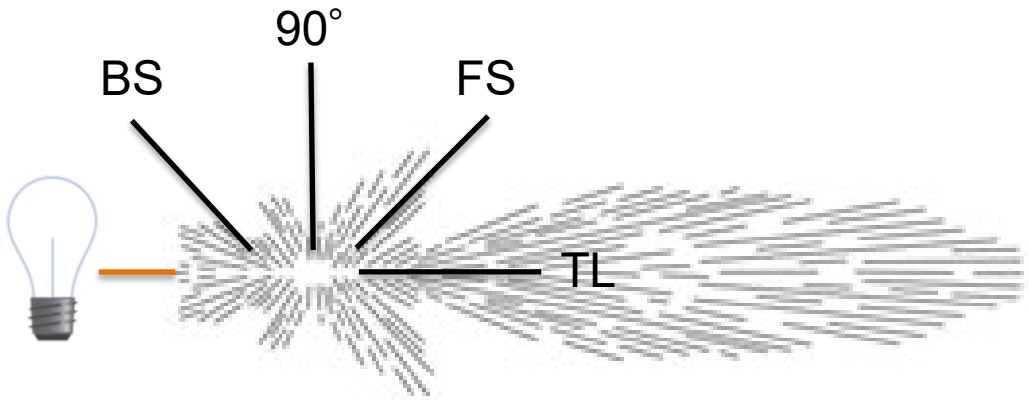


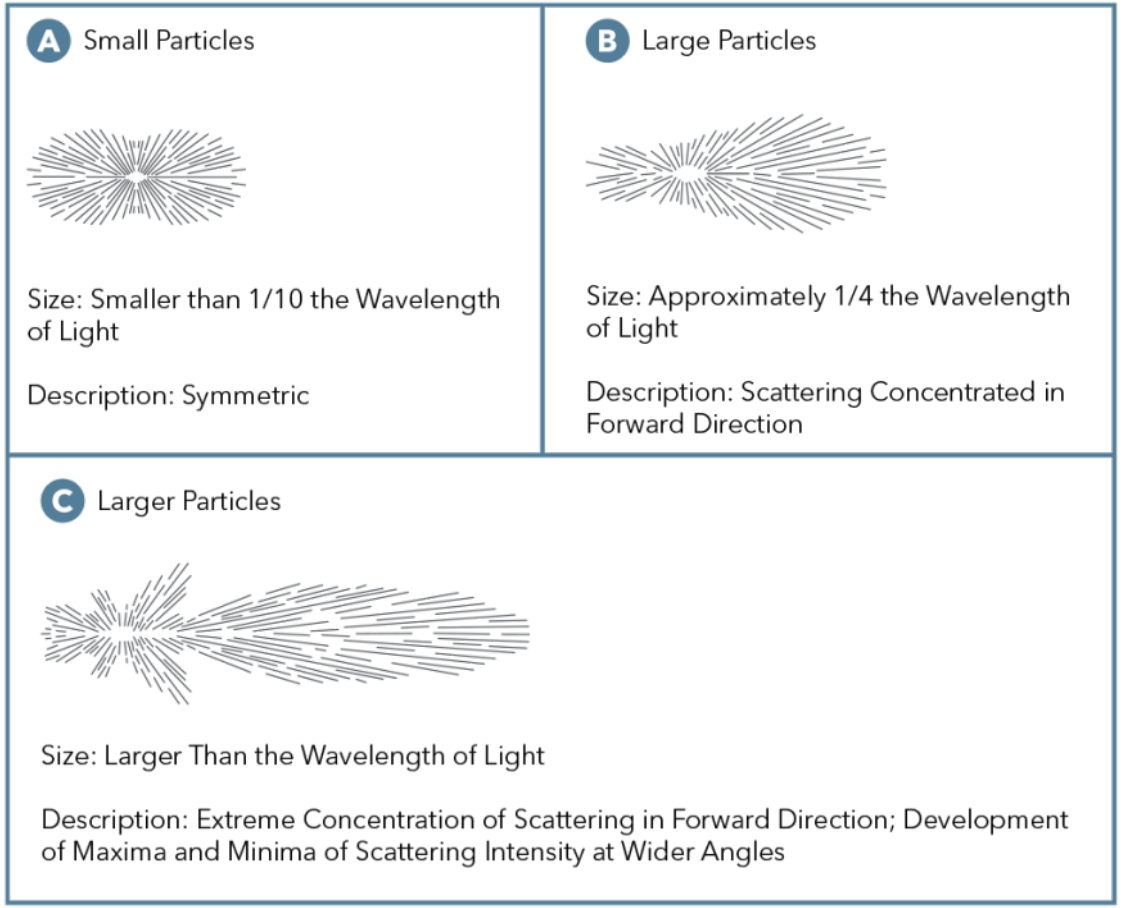
Light Angles



Why 90° ?

- Minimize error due to differences in particle size
- Simple optical system to develop
- Low stray light

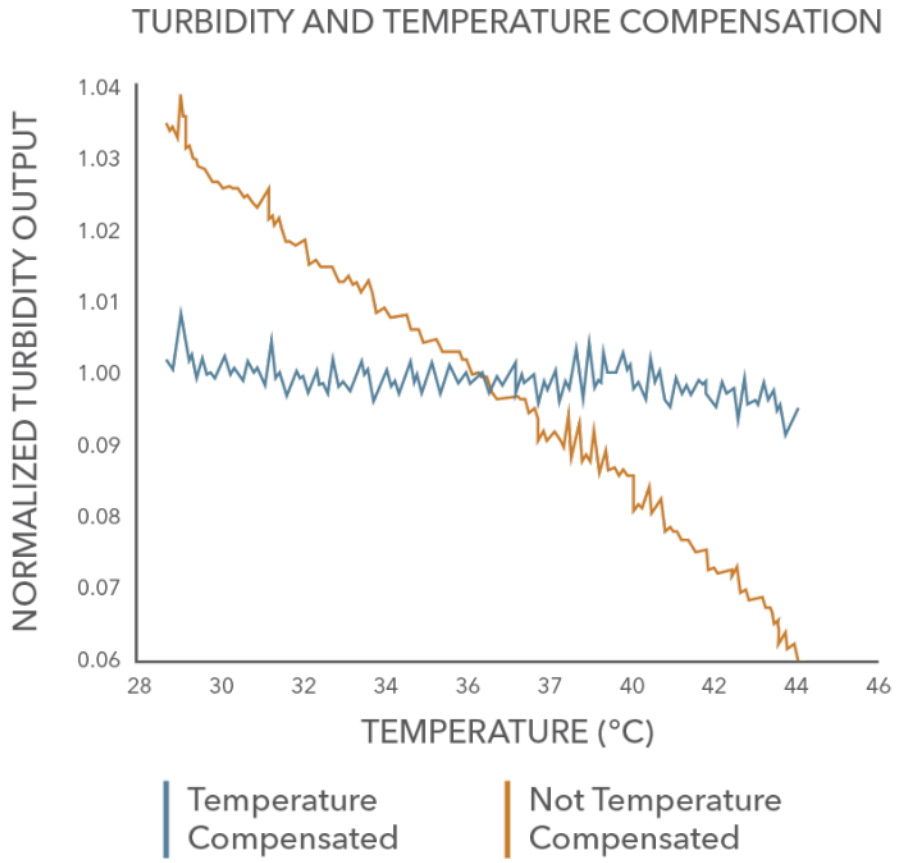




Angular patterns of scattered intensity from particles of three sizes. A Small Particles, B Large Particles, C Larger Particles. From Brumberger, et al, "Light Scattering," *Science and Technology*, November, 1968, page 38.

Temperature Compensation

- Turbidity is not affected by temperature changes
- Electronics are affected by temperature
  - LED output dependent on temperature
- Internal compensation by sensor



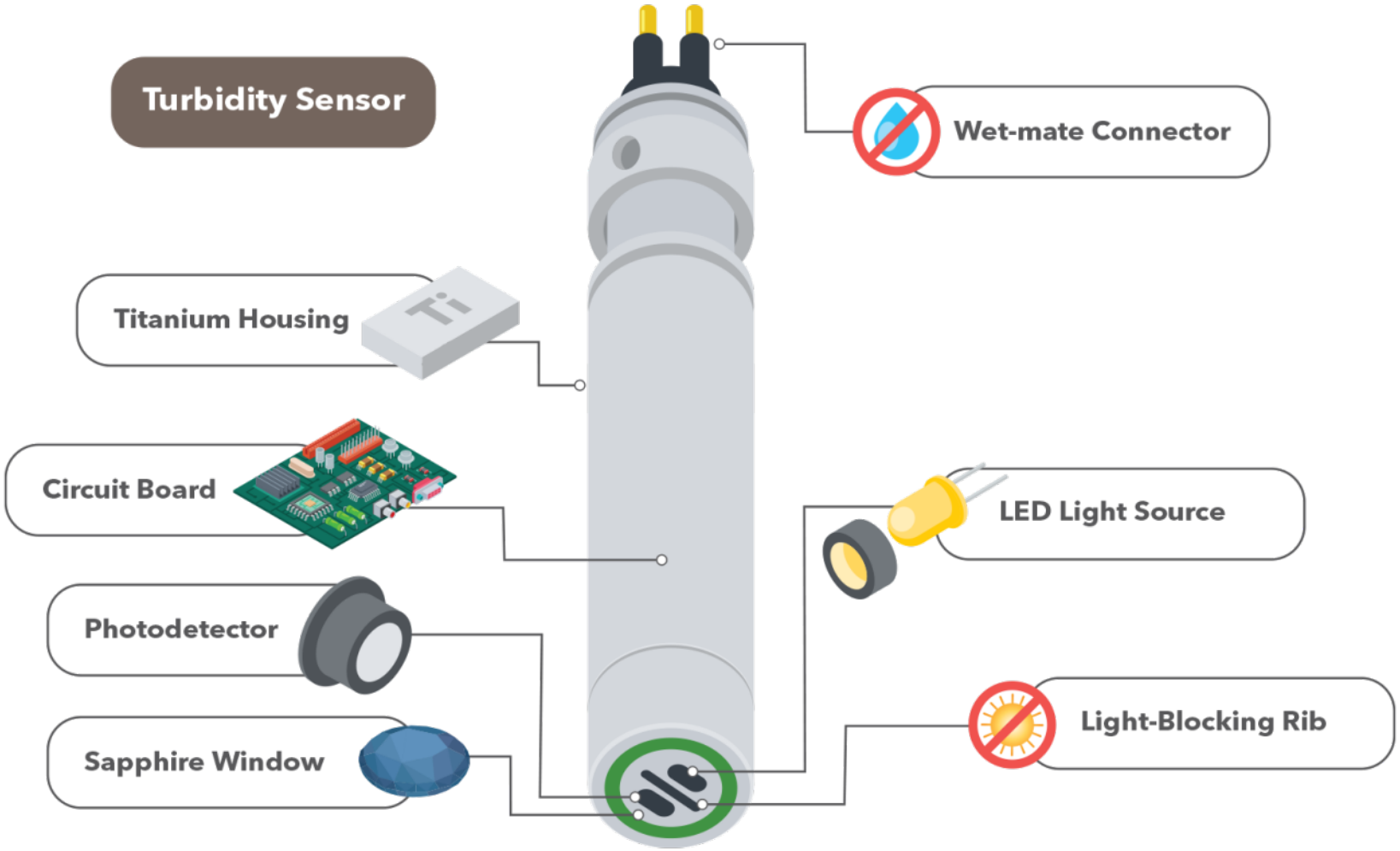
How Turbidity Sensors Work

EXO™ Continuous Monitoring

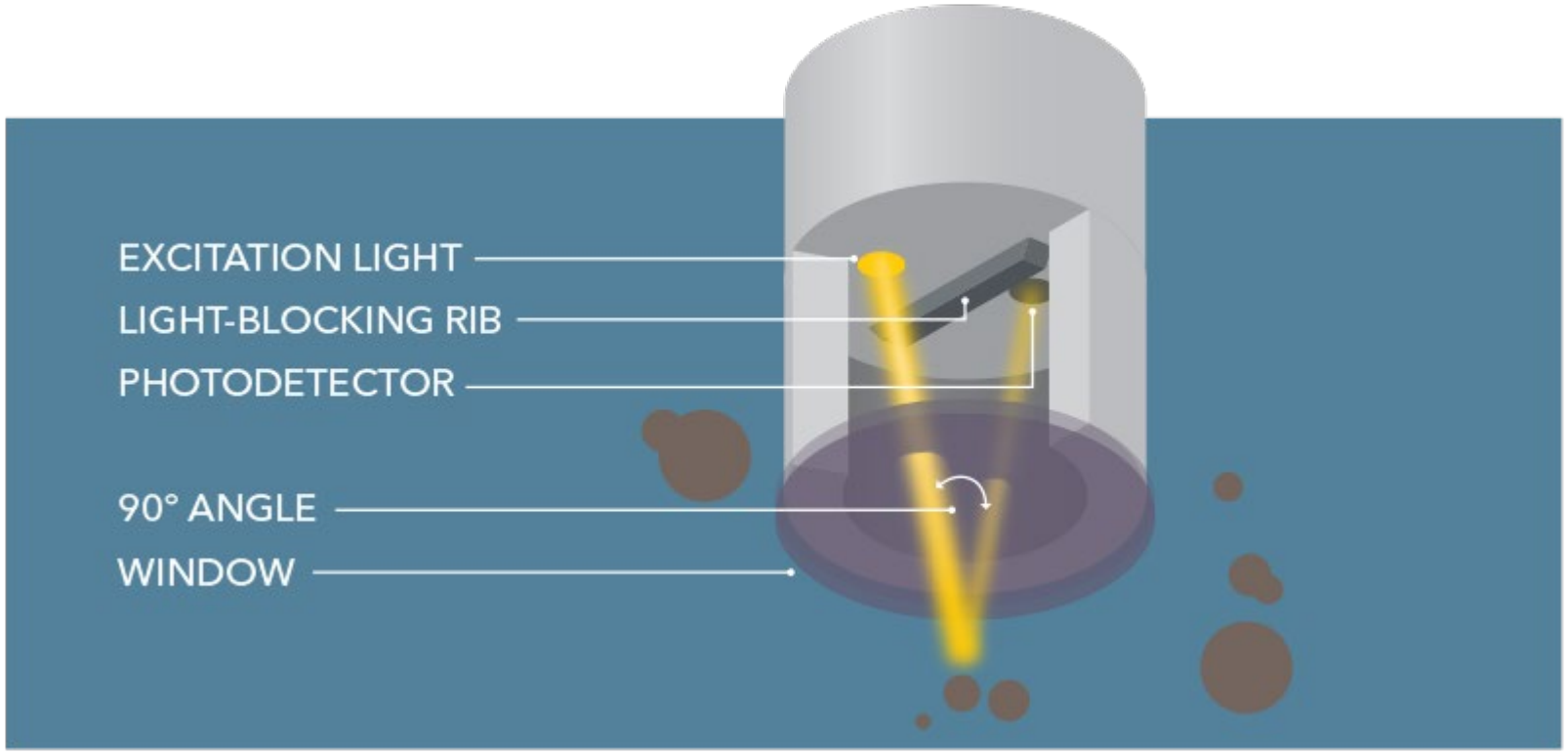
ProDSS Spot Sampling

YSI a xylem brand

Anatomy of YSI's Turbidity Sensor



Anatomy of YSI's Turbidity Sensor



How Turbidity Sensors Work: Best Practices

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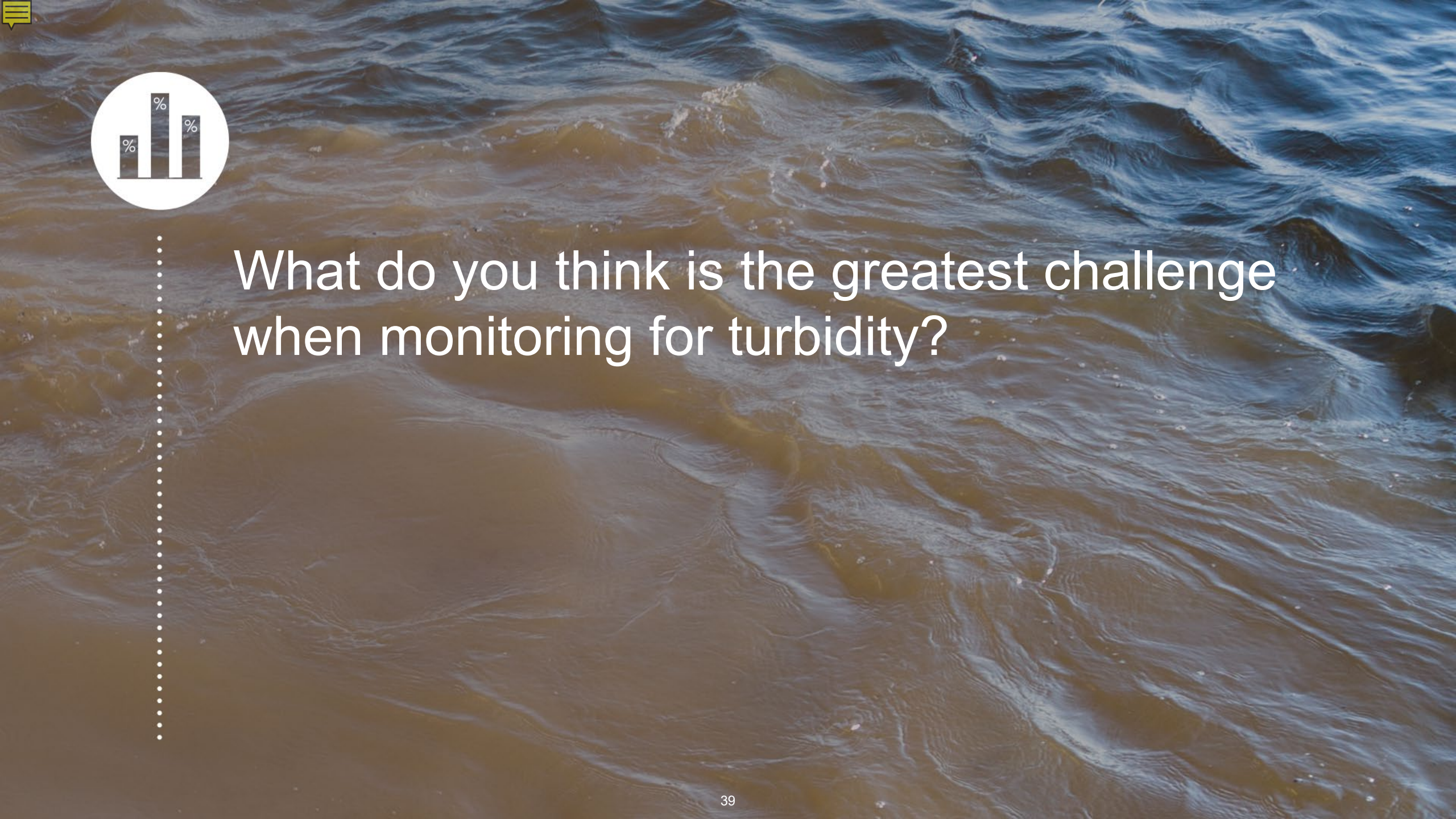


What do you think is the greatest challenge when monitoring for turbidity?

Best Practice

I. Sensor Calibration

II. Prevent Biofouling

Calibration Record:

Sensor Type: Turbidity
Last Calibration Time: <Unknown>
Calibration Start Time: 6/23/2019 7:56:47 PM
Calibration End Time: 6/23/2019 8:03:20 PM

General

Parameter	Turbidity (FNU)
Instrument Serial Number	18H109272
Instrument Firmware Version	1.0.73
Instrument Type	EXO2
Instrument Name	Sonde 18H109272
Sensor Serial Number	19A102334
Sensor Firmware Version	3.0.0
Calibrated By	khubbard
Calibration Status	Completed
QC Score	Good

Calibration Point #1

Pre Calibration Value	0.18 FNU
Post Calibration Value	0.00 FNU
Temperature	22.097 °C
Standard Value	0.00 FNU
Type	0FNU
Manufacturer	YSI
Lot Number	
Is Stable	True

Calibration Point #2

Pre Calibration Value	124.52 FNU
Post Calibration Value	124.00 FNU
Temperature	22.025 °C
Standard Value	124.00 FNU
Type	Polymer
Manufacturer	YSI
Lot Number	18H18303752
Is Stable	True

Calibration Point #3

Pre Calibration Value	960.63 FNU
Post Calibration Value	1010.00 FNU
Temperature	22.027 °C
Standard Value	1010.00 FNU
Type	Polymer
Manufacturer	YSI
Lot Number	18H18303926
Is Stable	True

Notes

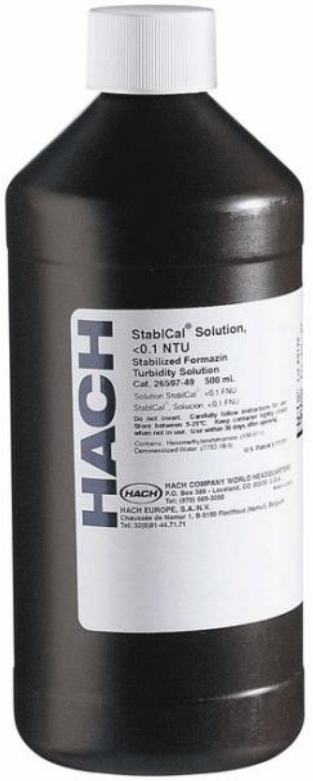
ADD NOTE

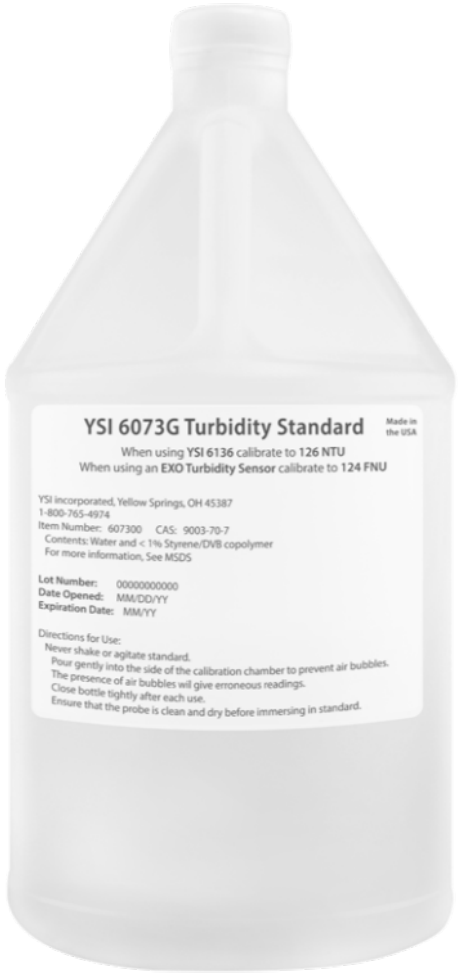
Calibration Standards

Three types:

1. Formazin
2. StableCal
3. Polymer Beads

- Values for EXO/DSS Calibration
  - 0-1 FNU/NTU
  - 5-199 FNU/NTU
  - 400-4000 FNU/NTU





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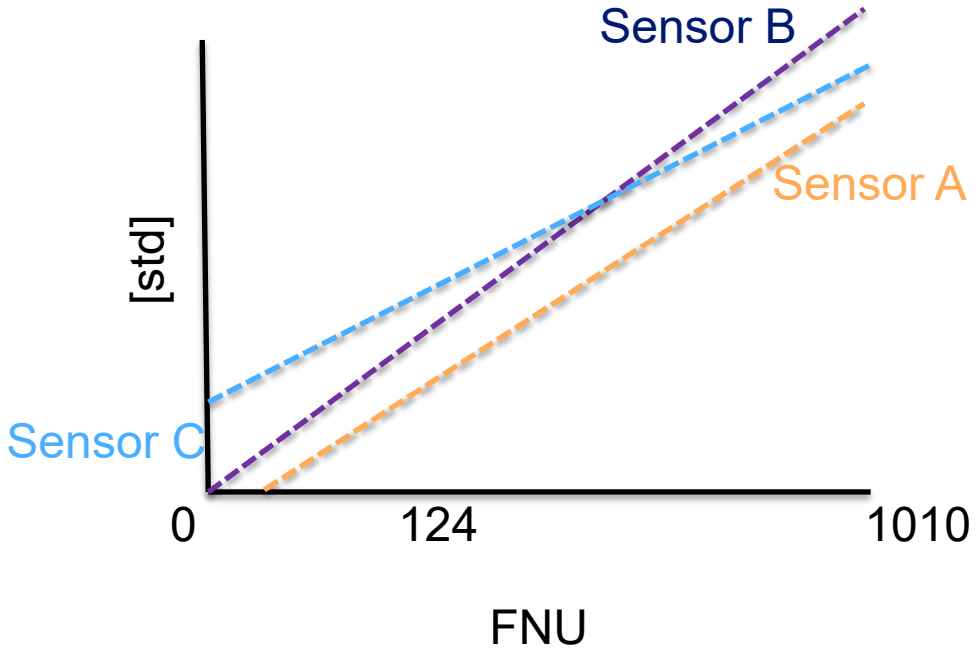
Calibration Standards - Tips

- Avoid extreme temps
- Keep bottles closed
- Don’t cause excess bubbles
  - No excessive shaking
  - No rough pouring

Sensor Calibration: Why

Individual sensors are *not* identical

- Raw output differs from sensor to sensor
- Each sensor is adjusted so that its turbidity reading is 0-4000 FNU
  - Coefficients in the polynomial will vary
- Calibration of turbidity against standards allows the sensor outputs to be compared

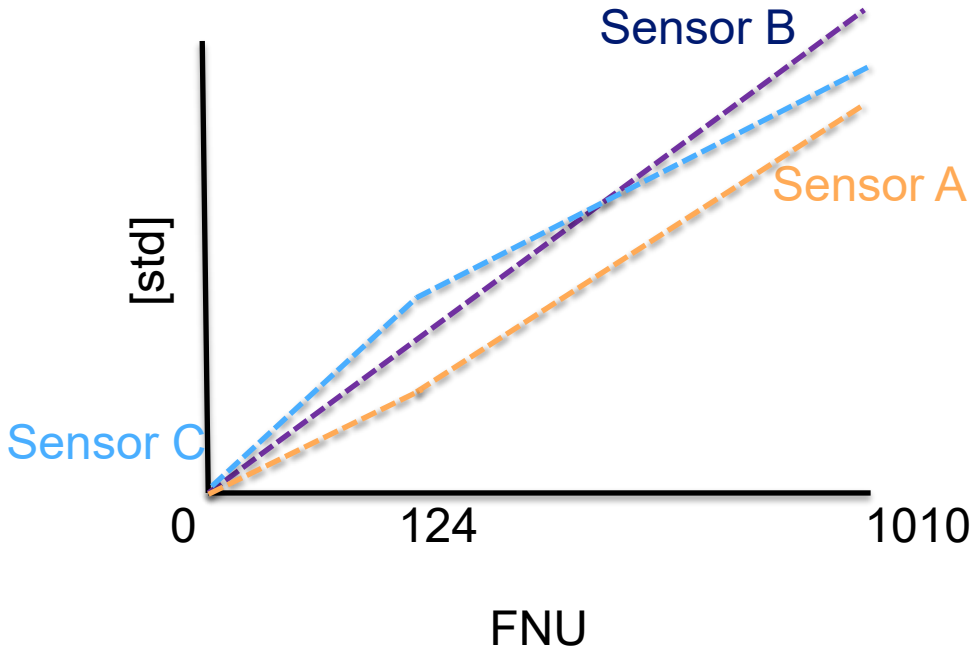


Sensor Calibration: Why

"One-point" Calibration

- Low end calibration
  - Zero FNU standard
  - Filtered DI water
  - Inorganic blank water
- Resets the zero value only
- Still significant differences between sensors as turbidity range increases

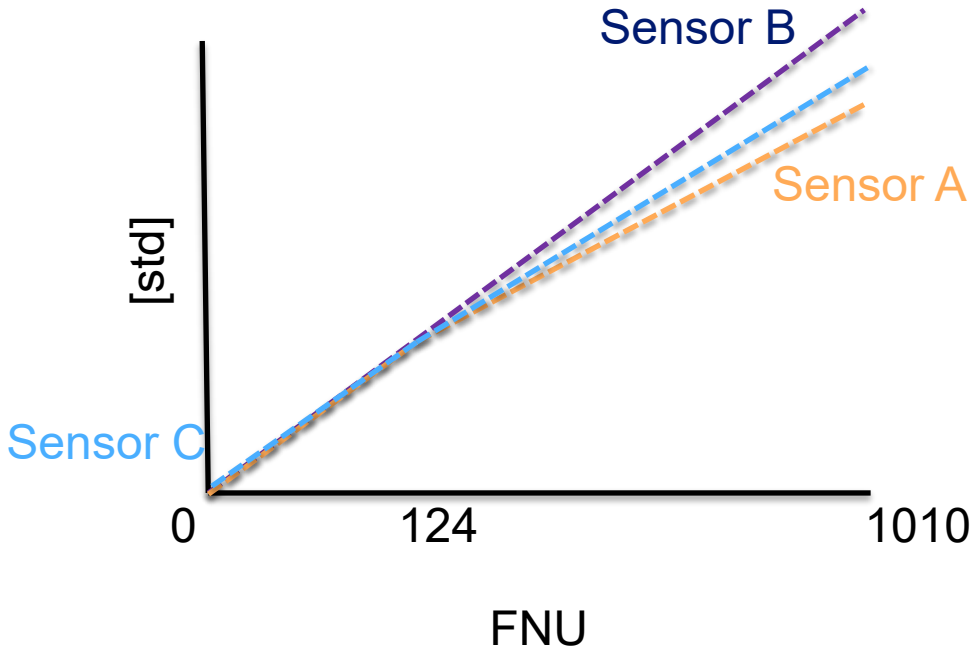
- One-point calibration is not good enough!!



Sensor Calibration: Why

"Two-point" Calibration

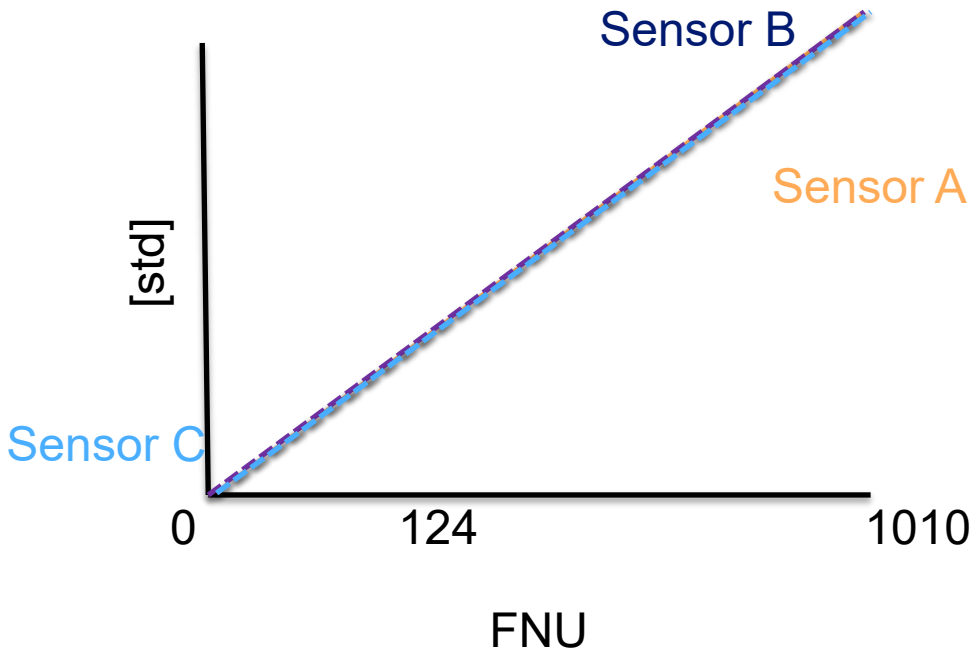
- Next standard must be between 5-199 FNU
  - Common standards used are 12.4, 124
- Sensors are now reading together between 0-124 FNU
- Still differences between 124-1000 FNU

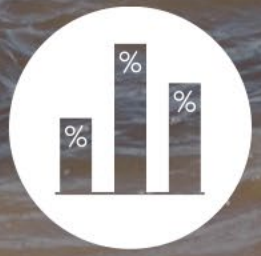


Sensor Calibration: Why

"Three-point" Calibration

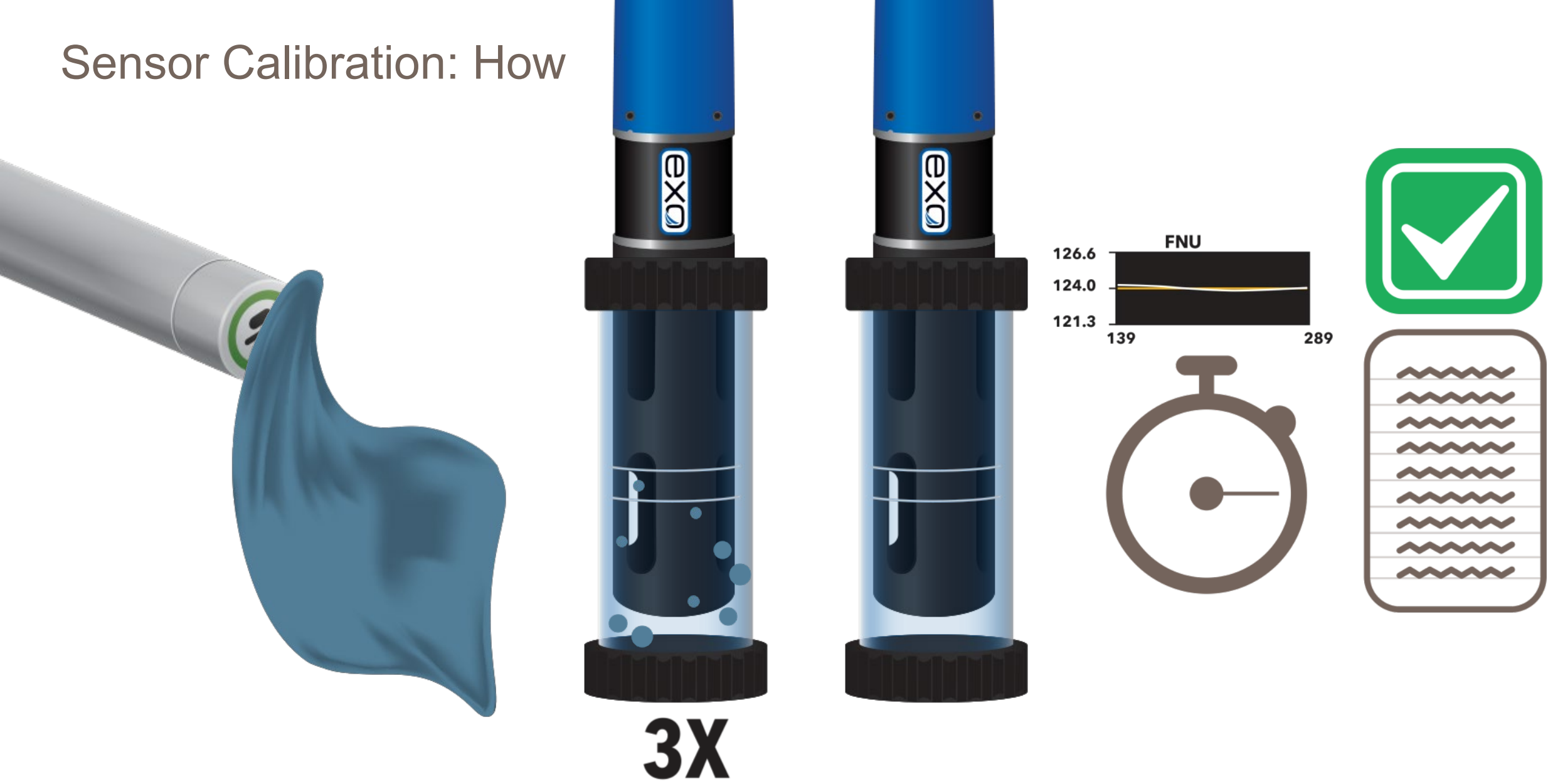
- Standard must be between 400-4200 FNU
- 1010 FNU YSI EXO Polymer Beads
- 1000 FNU StableCal
- 4000 FNU Formazin
- Sensors now compare across the range of expected measurements





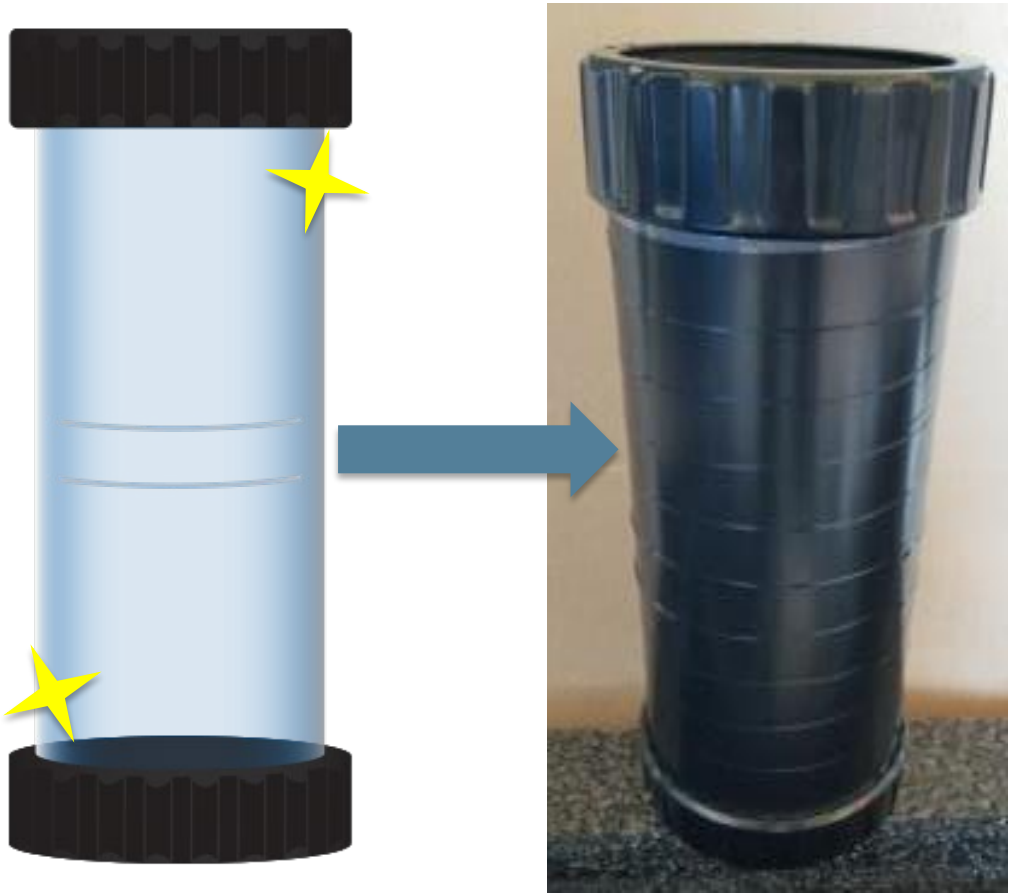
How many calibration points do you typically use?

Sensor Calibration: How



Calibration Tips

- Ensure calibration cups are CLEAN
  - Use separate cal cups for turbidity
- Remove wiper brush
- Turbidity should never be negative
  - Most likely a bad calibration
  - Perform factory restore and recalibrate
  - Check source of 0 FNU standard for contamination
- Do not calibrate in direct sunlight
  - Wrap cal cup in towel, electrical tape, place in PVC, etc.



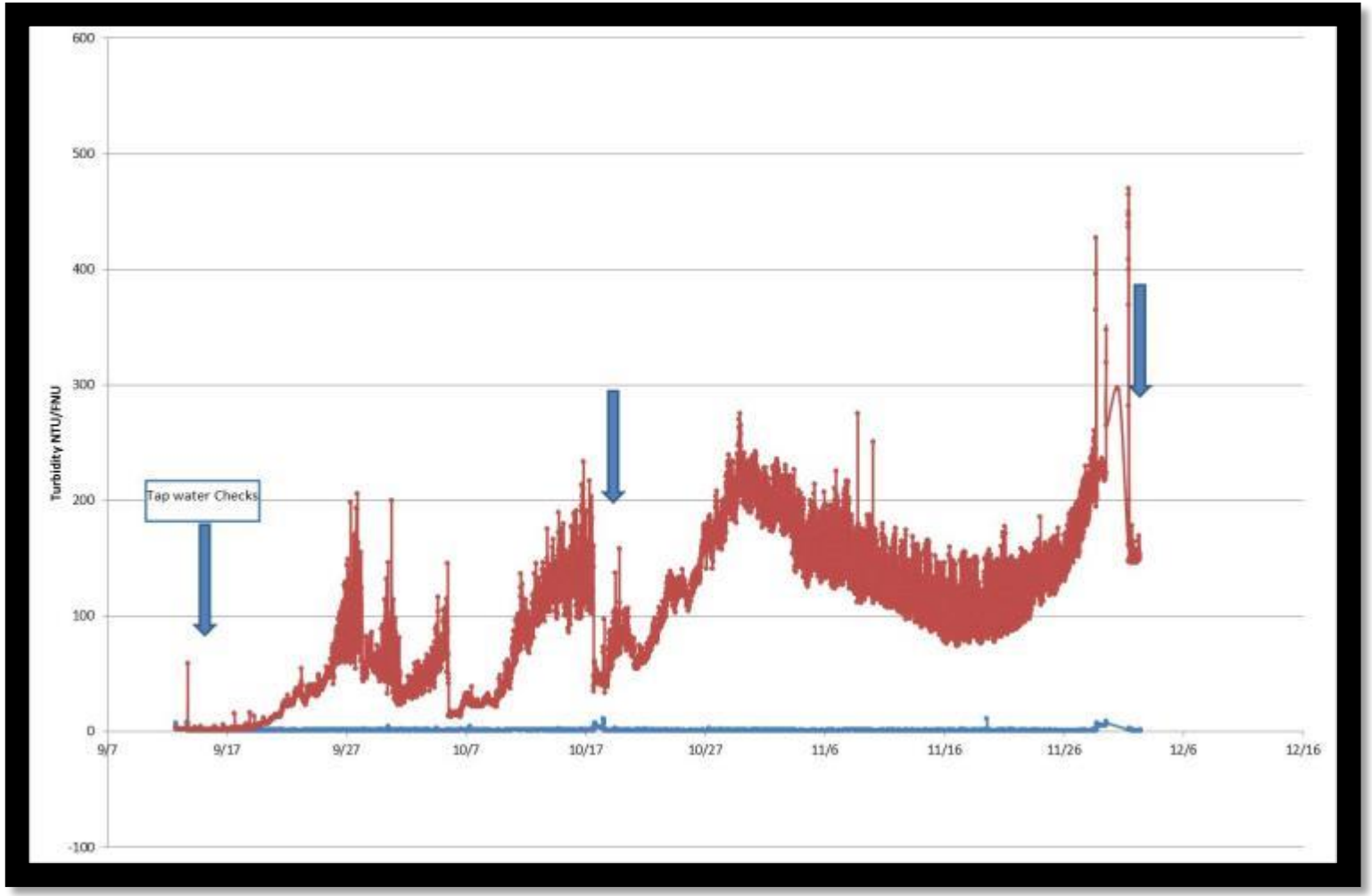
Prevent Fouling

Prevent Fouling

Optical sensors are susceptible to effects of fouling

Fouling can be from

- Sediment
- Algal growth
- Macroinvertebrates
- Trash
- Debris
- …



Prevent Fouling

Prevent Fouling - Sonde

- Copper components
  - Copper tape
  - Copper sonde guard
- C-Spray
- Sonde and sensor heat-shrink sleeves
- Duct tape
- Central Wiper

Prevent Fouling

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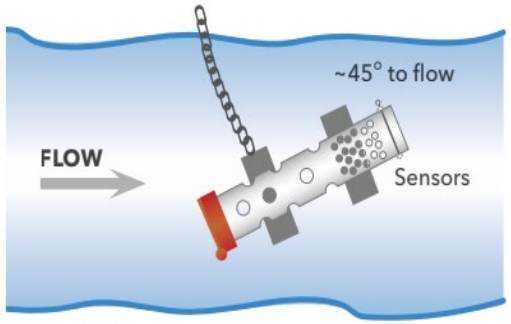
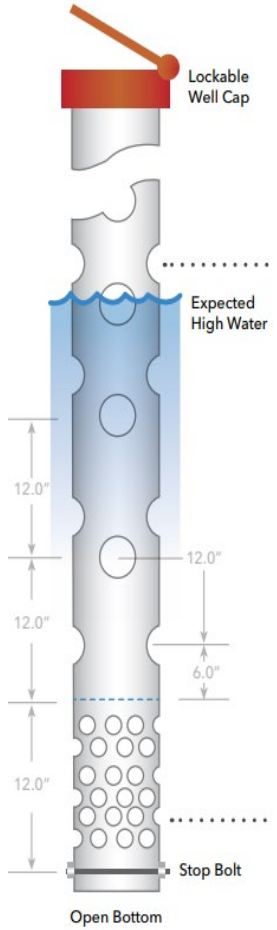
Prevent Fouling – Deployment Location

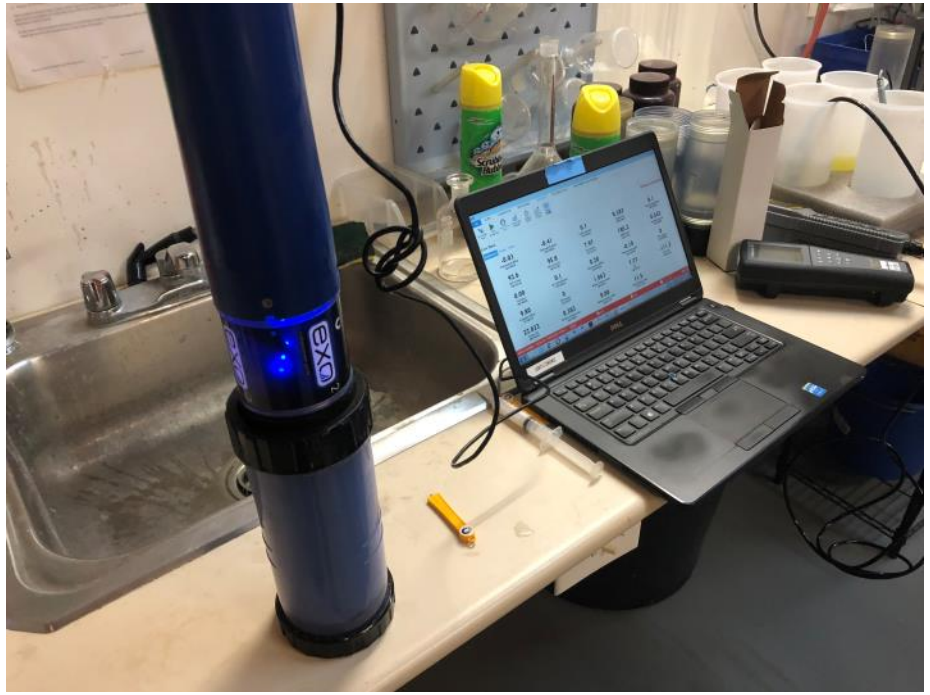
- Vertical is ideal
- Ensure enough holes for adequate flow
  - Spaced further apart at top of pipe
  - More at bottom where sonde is
  - Leave bottom open
- Deploy in location with good flow
  - Avoid eddies
- Can apply anti-fouling to pipe

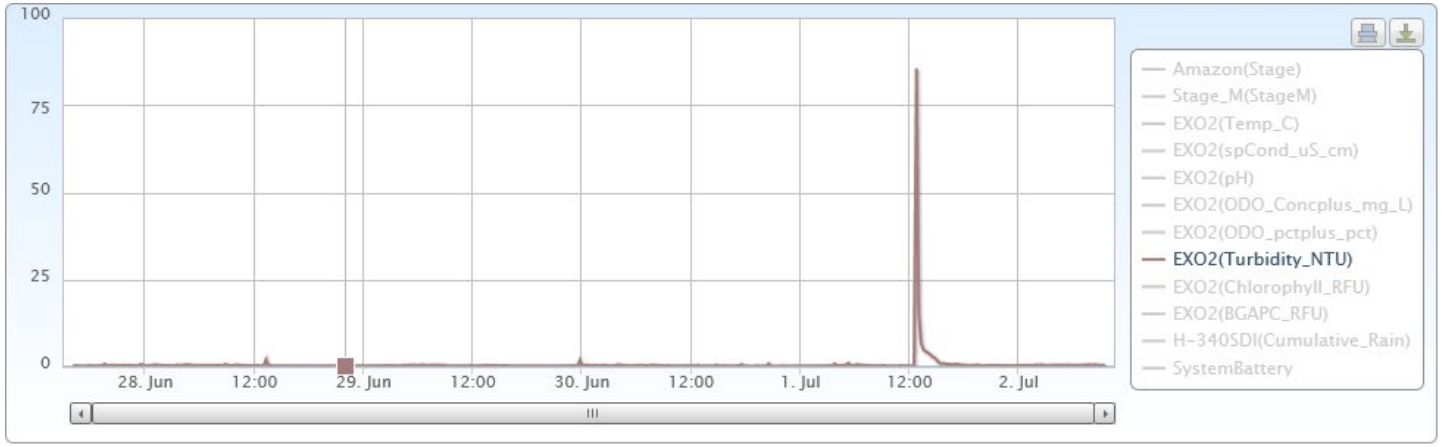


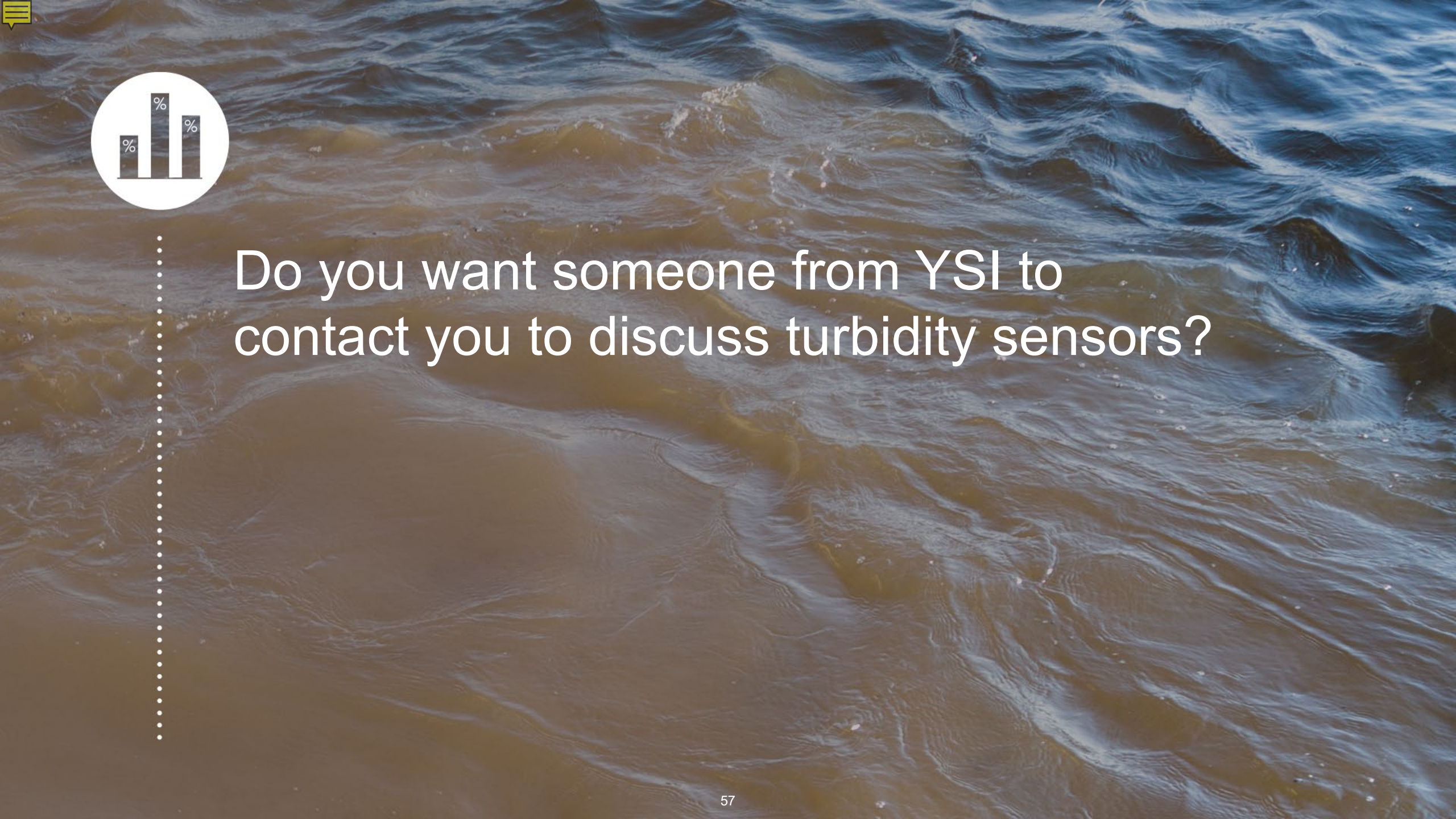


Best Practice - Summary

- Check calibration
- Whenever possible, do a two- or three-point calibration
- Prevent fouling







Do you want someone from YSI to contact you to discuss turbidity sensors?

Questions?

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