Appendix 17. Field Comparison between YSI EXO and YSI 6136 Turbidity Sensors at James River at Cartersville, Virginia (U.S. Geological Survey [USGS] Station Number 02035000), October 7, 2016 to July 10, 2017

Comparison Description

Station name: James River at Cartersville, Virginia (U.S. Geological Survey [USGS] station number 02035000).

Equipment: A Yellow Springs Instrument (YSI) EXO water-quality monitor equipped with a YSI EXO turbidity sensor and a YSI 6 series equipped with a YSI 6136 turbidity sensor were deployed at the site for comparison between the sensors. The monitors were set to log data every 15 minutes. The sensors were approximately one to two feet away from each other during deployment. Fouling and calibration corrections were applied when necessary. No datum corrections were applied to either dataset.

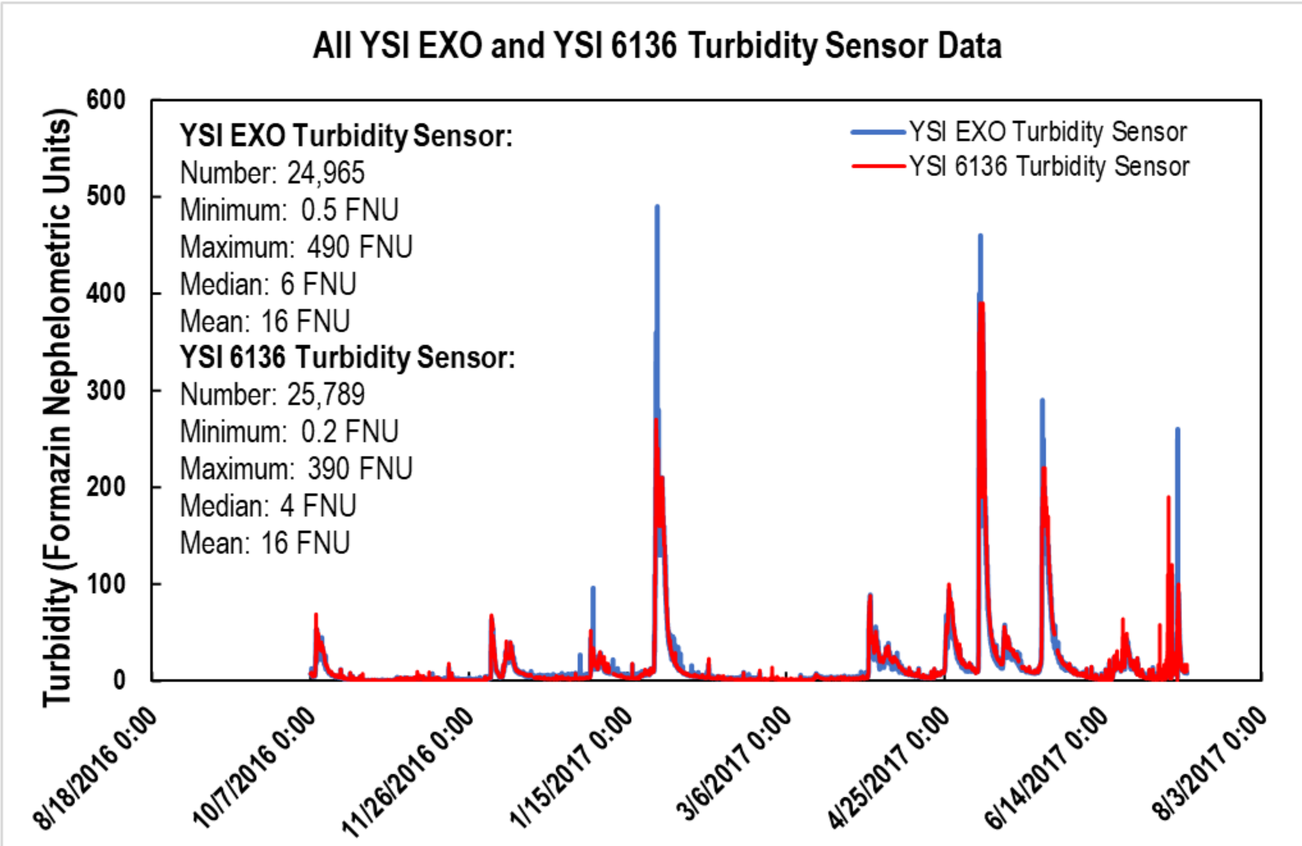
Calibration standard used: Hach StablCal standard.

Side-by-side comparison data period: October 7, 2016 to July 10, 2017.

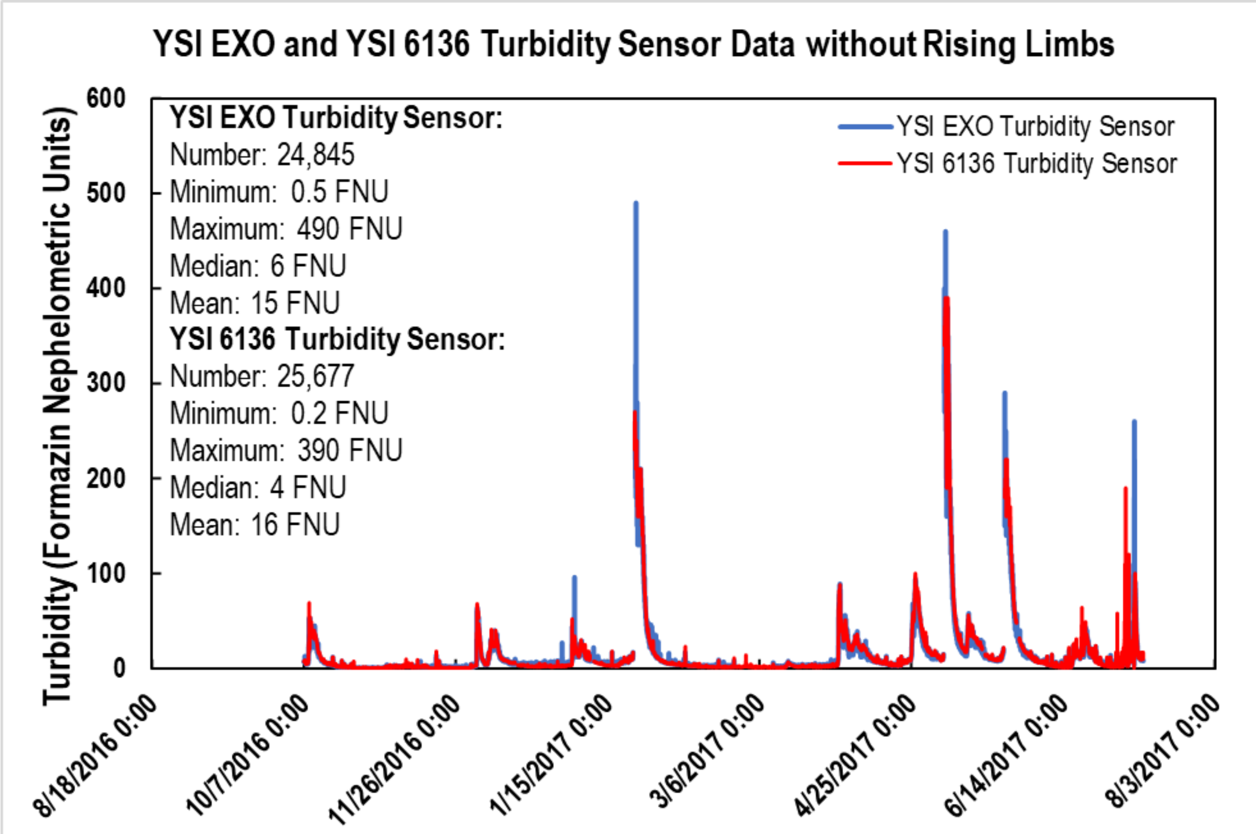
Datasets

All data were collected using USGS protocols (U.S. Geological Survey, variously dated) and are published in King (2021). Data were analyzed in three ways: (1) the entire dataset (0–1,000 formazin nephelometric units [FNU]) with only clearly erroneous data edited out, (2) 0–99 FNU with the rising limbs removed, and (3) 100–1,000 FNU with the rising limbs removed. Rising limbs were removed (on the basis of visual inspection, when the hydrograph became vertical to near vertical) to eliminate the effect of the highly variable turbidity readings commonly observed during this part of the hydrograph.

Time Series



All YSI EXO and YSI 6136 Turbidity Sensor Data
YSI EXO Turbidity Sensor:
Number: 24,965
Minimum: 0.5 FNU
Maximum: 490 FNU
Median: 6 FNU
Mean: 16 FNU
YSI 6136 Turbidity Sensor:
Number: 25,789
Minimum: 0.2 FNU
Maximum: 390 FNU
Median: 4 FNU
Mean: 16 FNU
YSI EXO Turbidity Sensor
YSI 6136 Turbidity Sensor
Turbidity (Formazin Nephelometric Units)
600
500
400
300
200
100
0
8/18/2016 0:00
10/7/2016 0:00
11/26/2016 0:00
1/15/2017 0:00
3/6/2017 0:00
4/25/2017 0:00
6/14/2017 0:00
8/3/2017 0:00



Statistical Analyses – All Data

Slope comparison

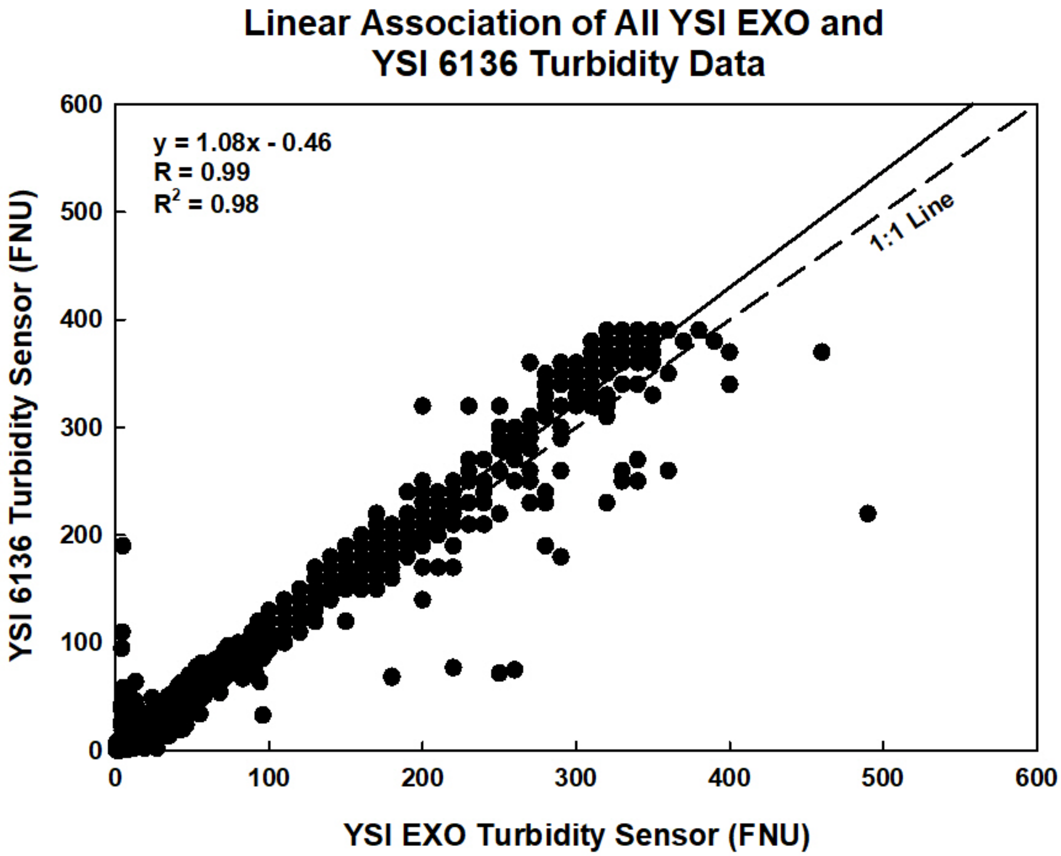
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI EXO turbidity sensor and a YSI 6136 turbidity sensor at James River at Cartersville, Virginia, October 7, 2016 to July 10, 2017.

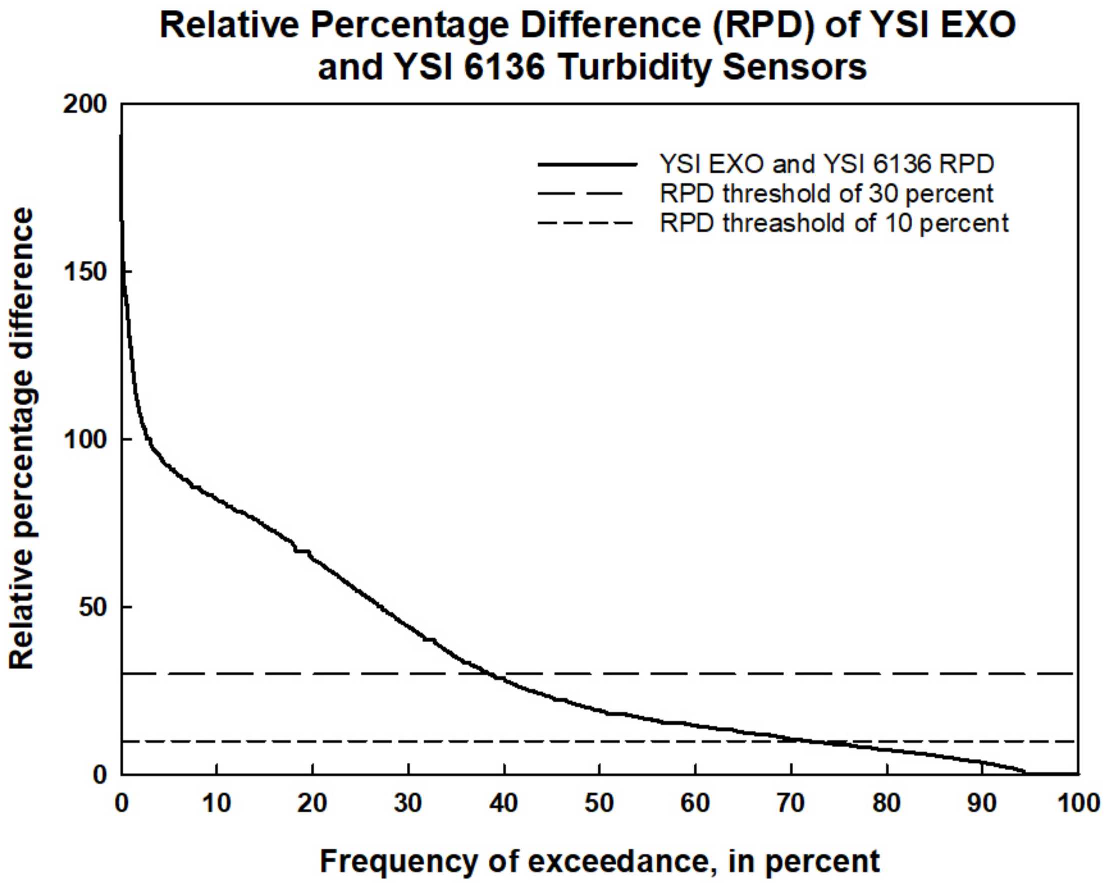
$$y = 1.08x - 0.46$$

where

y = turbidity measured with YSI 6136 turbidity sensor (FNU)

x = turbidity measured with YSI EXO turbidity sensor (FNU).


Linear Association of All YSI EXO and
YSI 6136 Turbidity Data
y = 1.08x - 0.46
R = 0.99
R2 = 0.98
1:1 Line
YSI 6136 Turbidity Sensor (FNU)
YSI EXO Turbidity Sensor (FNU)
0
100
200
300
400
500
600



Wilcoxon Signed-Rank Test for All Data

SigmaPlot Statistical Output:

Normality Test (Kolmogorov-Smirnov): Failed (P < 0.050)

Group	N	Missing	Median	25%	75%
YSI EXO	24280	0	5.800	3.000	13.000
YSI 6136	24280	0	4.600	1.900	15.000

W= -17536643.000 T+ = 122213981.000 T-= -139750624.000

Z-Statistic (based on positive ranks) = -8.772

(P = <0.001)

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

R Statistical Output:

```
Wilcoxon Signed-Rank test with continuity correction

data:  YSI 6136 and YSI EXO
V = 122213981, p-value < 2.2e-16
alternative hypothesis: true location shift is not equal to 0
95 percent confidence interval:
 -0.1999674 -0.1000465
sample estimates:
(pseudo)median
    -0.1500227
```

Summary of Results

There is a strong linear association between measurements made with the two sensors ($R = 0.99$). Thirty-eight percent of the time, the relative percentage difference in turbidity values measured with the two sensors was greater than 30 percent. The data did not pass the Kolmogorov-Smirnov test for normality ($P<0.05$); therefore, a Wilcoxon signed-rank test was performed. The difference between median values for the YSI EXO and YSI 6136 turbidity sensors was statistically significant ($P<0.05$).

Statistical Analyses - Low-Turbidity Conditions (0 to 99 FNU)

The data from the side-by-side comparison were separated into low- and high-turbidity conditions. These statistical analyses are for low-turbidity conditions between 0 and 99 FNU.

Slope comparison

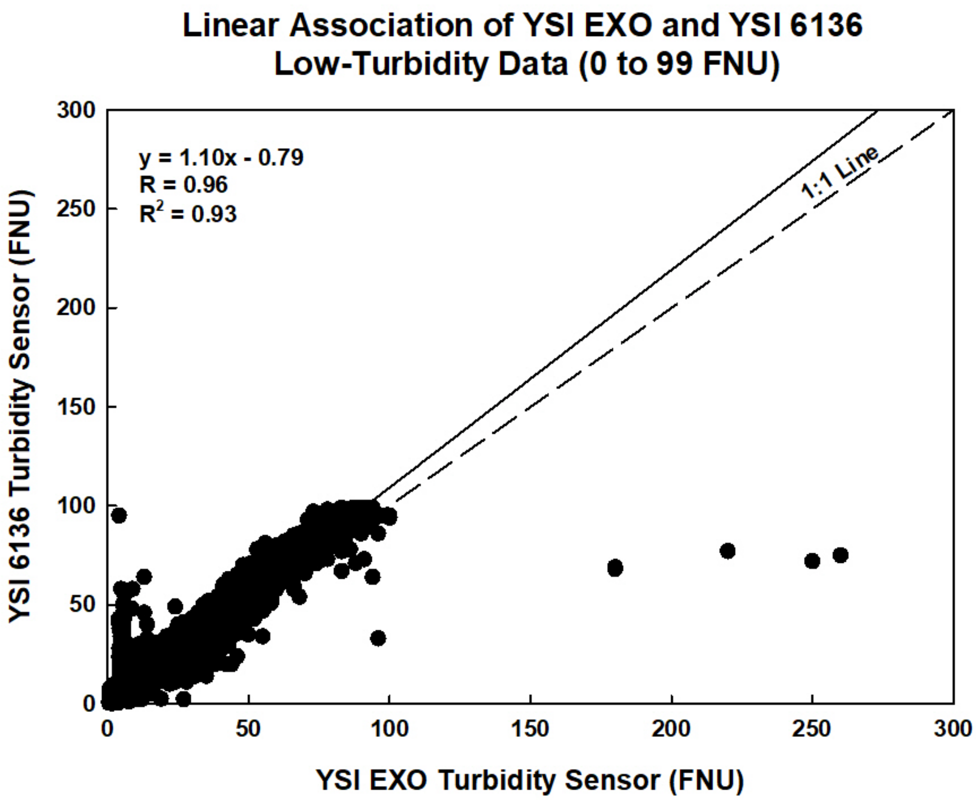
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI EXO turbidity sensor and a YSI 6136 turbidity sensor at low-turbidity conditions (0 to 99 FNU) at James River at Cartersville, Virginia, October 7, 2016 to July 10, 2017.

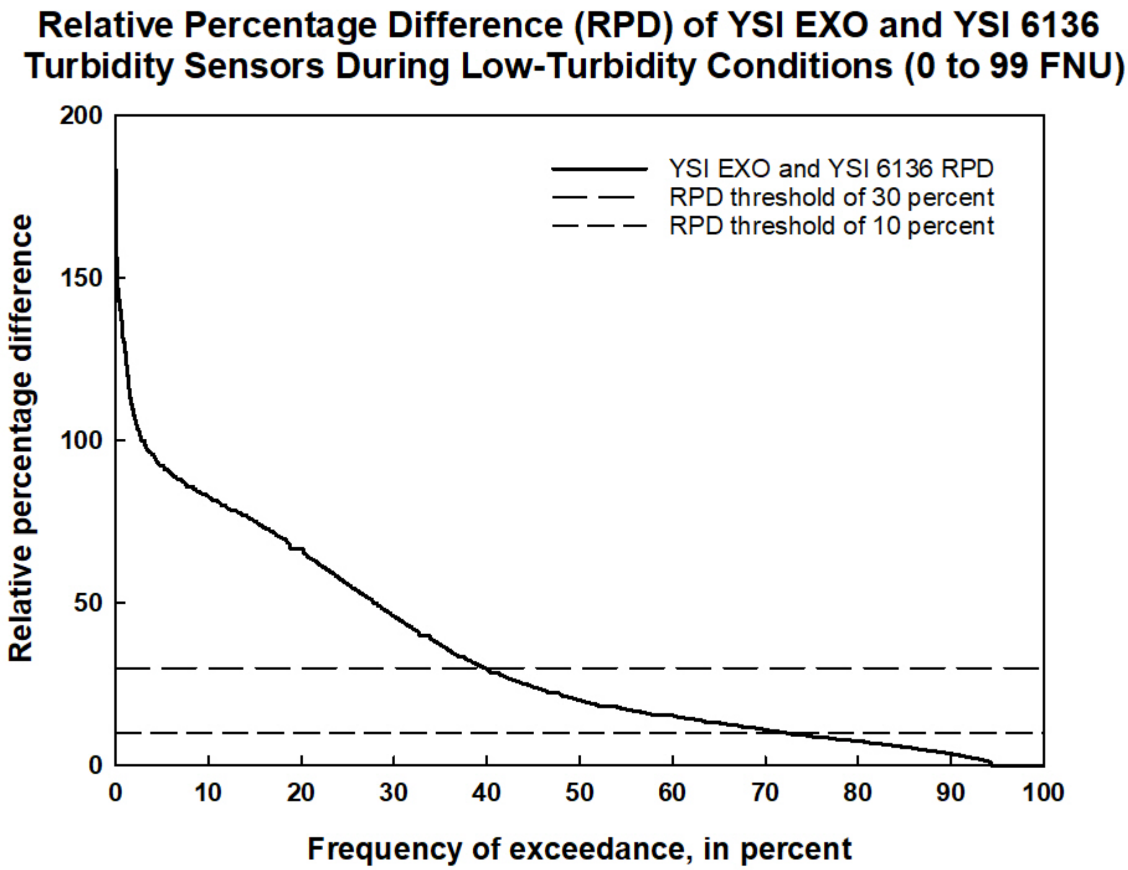
$$y = 1.10x - 0.79$$

where

y = Turbidity measured with YSI 6136 turbidity sensor (FNU)

x = Turbidity measured with YSI EXO turbidity sensor (FNU).


Linear Association of YSI EXO and YSI 6136
Low-Turbidity Data (0 to 99 FNU)
y = 1.10x - 0.79
R = 0.96
R² = 0.93
1:1 Line
YSI 6136 Turbidity Sensor (FNU)
YSI EXO Turbidity Sensor (FNU)
0
50
100
150
200
250
300



Wilcoxon Signed-Rank Test for Low-Turbidity Data

SigmaPlot Statistical Output:

Normality Test (Kolmogorov-Smirnov): Failed (P < 0.050)

Group	N	Missing	Median	25%	75%
YSI EXO	23496	0	5.600	3.000	12.000
YSI 6136	23496	0	4.200	1.900	13.000

W= -30666074.000 T+ = 107549730.500 T-= -138215804.500

Z-Statistic (based on positive ranks) = -16.093

(P = <0.001)

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

R Statistical Output:

```
Wilcoxon Signed-Rank test with continuity correction

data:  YSI 6136 and YSI EXO
V = 107549731, p-value < 2.2e-16
alternative hypothesis: true location shift is not equal to 0
95 percent confidence interval:
 -0.2999315 -0.2499708
sample estimates:
(pseudo)median
    -0.2500281
```

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 0.96). Forty percent of the time, the relative percentage difference in turbidity values measured with the two sensors was greater than 30 percent. The data did not pass the Kolmogorov-Smirnov test for normality ($P<0.05$); therefore, a Wilcoxon signed-rank test was performed. The difference between median values for the YSI EXO and YSI 6136 turbidity sensors was statistically significant ($P<0.05$).

Statistical Analyses - High-Turbidity Conditions (100 to 1,000 FNU)

The data from the side-by-side comparison were separated into low- and high-turbidity conditions. These statistical analyses are for high-turbidity conditions between 100 and 1,000 FNU.

Slope comparison

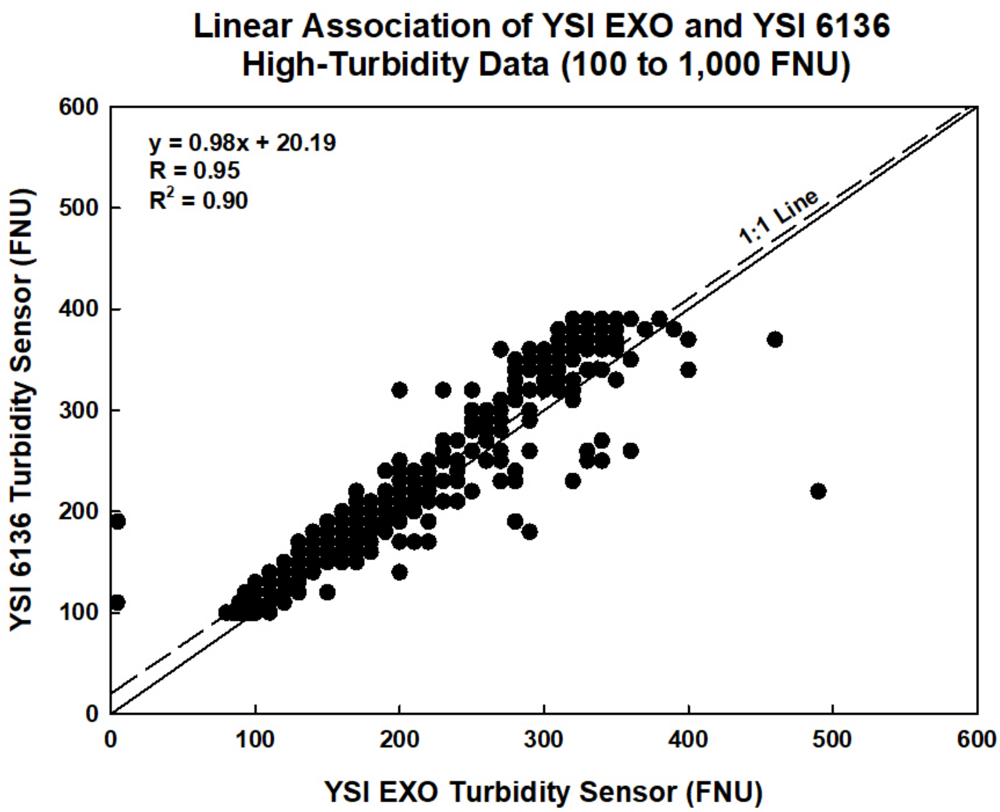
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI EXO turbidity sensor and a YSI 6136 turbidity sensor at high-turbidity conditions (100 to 1,000 FNU) at James River at Cartersville, Virginia, October 7, 2016 to July 10, 2017.

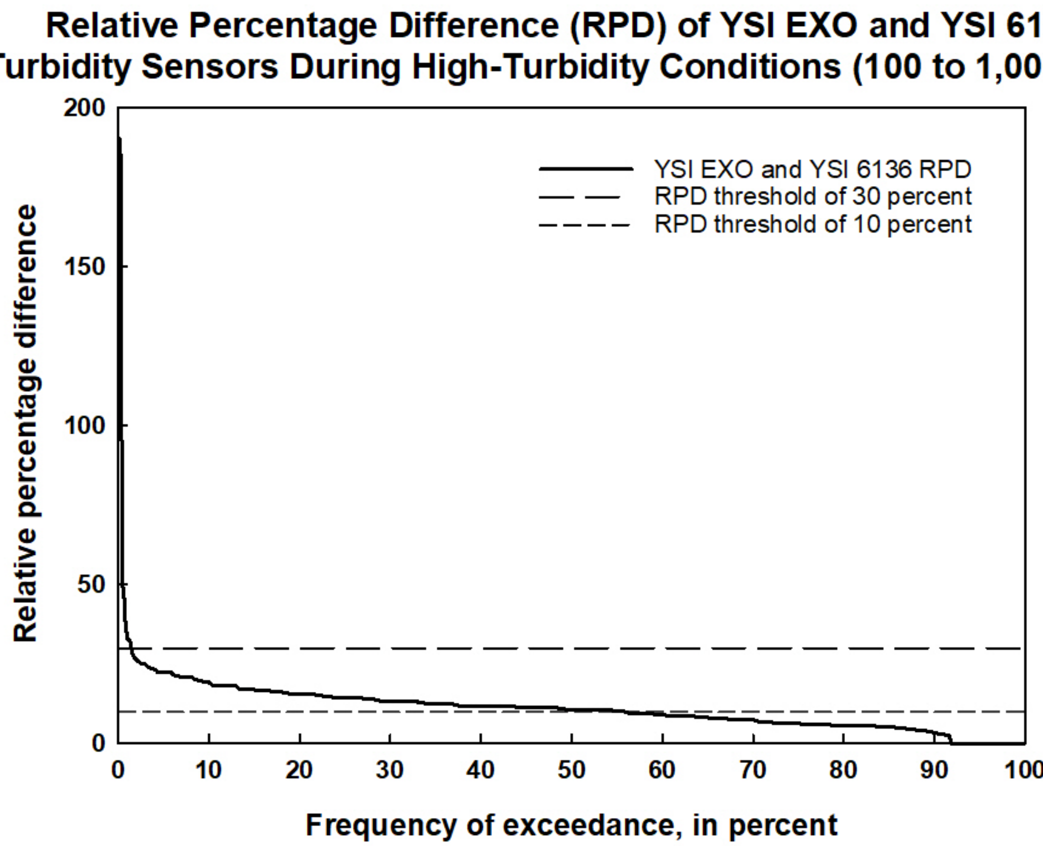
$$y = 0.98x + 20.19$$

where

y = turbidity measured with YSI 6136 turbidity sensor (FNU)

x = turbidity measured with YSI EXO turbidity sensor (FNU).


Linear Association of YSI EXO and YSI 6136
High-Turbidity Data (100 to 1,000 FNU)
y = 0.98x + 20.19
R = 0.95
R2 = 0.90
1:1 Line
YSI 6136 Turbidity Sensor (FNU)
YSI EXO Turbidity Sensor (FNU)
0
100
200
300
400
500
600



Wilcoxon Signed-Rank Test for High-Turbidity Data

SigmaPlot Statistical Output:

Normality Test (Shapiro-Wilk): Failed (P < 0.050)

Group	N	Missing	Median	25%	75%
YSI EXO	784	0	160.000	130.000	210.000
YSI 6136	784	0	180.000	150.000	230.000

W= 211058.000 T+ = 234949.000 T-= -23891.000

Z-Statistic (based on positive ranks) = 19.115

(P = <0.001)

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

R Statistical Output:

```
Wilcoxon Signed-Rank test with continuity correction

data:  YSI 6136 and YSI EXO
V = 234949, p-value < 2.2e-16
alternative hypothesis: true location shift is not equal to 0
95 percent confidence interval:
 16.49997 19.99996
sample estimates:
(pseudo)median
      19.99999
```

Summary of Results

There is a strong linear association between measurements made with the two sensors ($R = 0.95$). One percent of the time, the relative percentage difference in turbidity values measured with the two sensors was greater than 30 percent. The data did not pass the Shapiro-Wilk test for normality ($P<0.05$); therefore, a Wilcoxon signed-rank test was performed. The difference between median values for the YSI EXO and YSI 6136 turbidity sensors was statistically significant ($P<0.05$).

Selected References

Cleveland, W.S., 1979, Robust locally weighted regression and smoothing scatterplots: Journal of the American Statistical Association, v. 74, no. 368, p. 829–836.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources—Hydrologic analysis and interpretation: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 522 p. [Also available at https://doi.org/10.3133/twri04A3.]

King, L.R., 2021, Laboratory and field data for selected turbidity standard and sensor comparisons, October 2014 to September 2017: U.S. Geological Survey Data Release, https://doi.org/10.5066/P9EVSDHH.

U.S. Geological Survey, variously dated, The national field manual for the collection of water-quality data: U.S. Geological Survey Techniques and Methods, book 9, chaps A1–A10. [Also available at https://water.usgs.gov/owq/FieldManual/.]