Appendix 21. Laboratory Comparison between YSI EXO and YSI 6136 Turbidity Sensors using pink clay at the Kansas Water Science Center Laboratory, Lawrence, Kansas

Comparison Description

Station name: Kansas Water Science Center Lab, Lawrence, Kansas.

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 in a laboratory turbidity testing apparatus for comparison between the two sensors.(See "Performance Evaluation Tests," "Laboratory Tests," p. 7 of main report, for a full description of laboratory methods.) The Hach model 2100AN laboratory turbidimeter with a flow-through cell was used as a reference to measure the turbidity in the apparatus bucket every 15 minutes before adding more sediment. No datum corrections were applied to either dataset.

Testing material and water: Pink clay and deionized water.

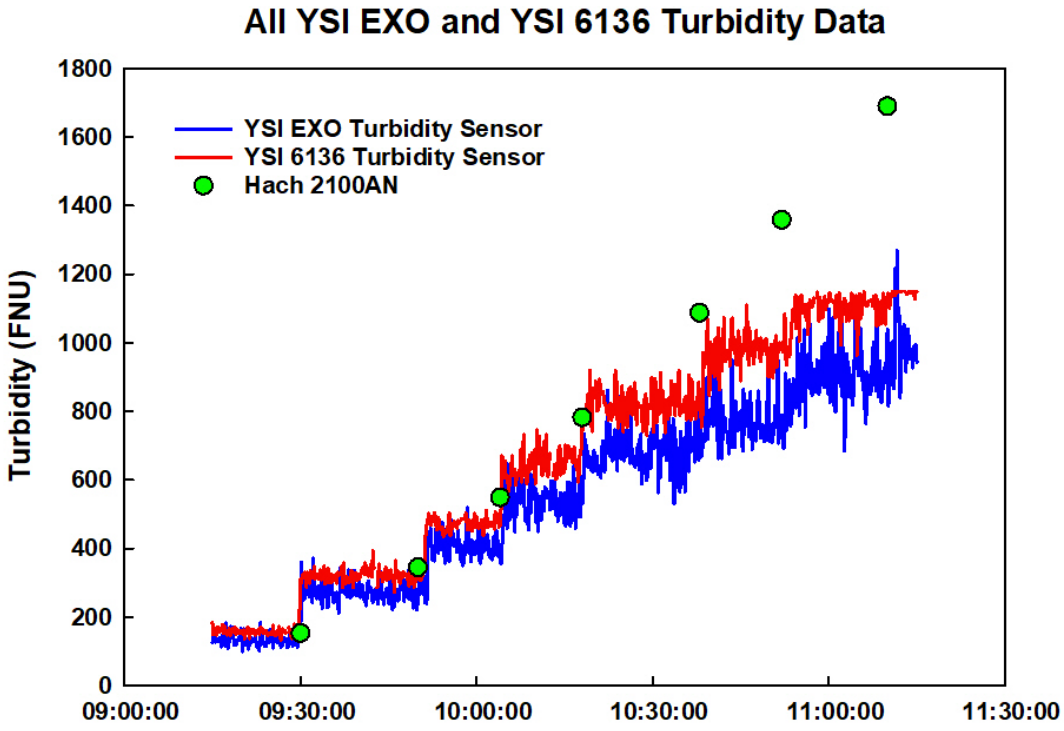
Calibration standard used: Hach StablCal standards.

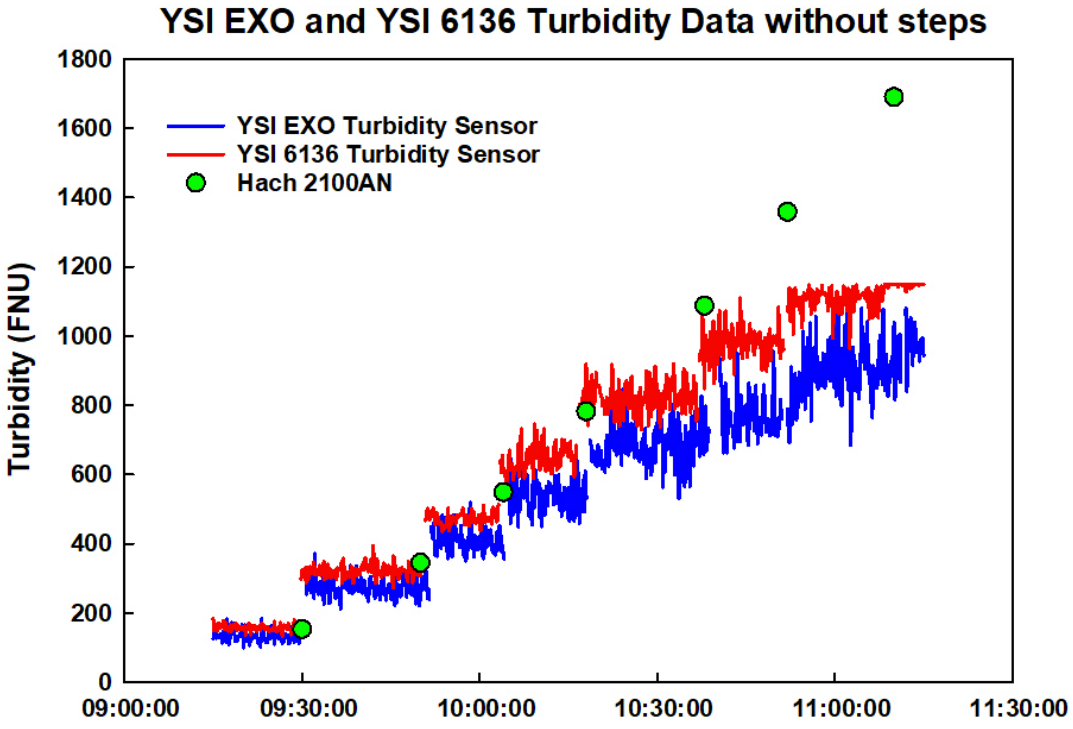
Laboratory comparison date: February 15, 2017.

Datasets

All data were collected using USGS protocols (U.S. Geological Survey, variously dated) and are published in King (2021). Data were edited to remove periods where material was added to the testing apparatus, leaving the steady-state data for analysis.

Time Series


All YSI EXO and YSI 6136 Turbidity Data
YSI EXO Turbidity Sensor
YSI 6136 Turbidity Sensor
Hach 2100AN
Turbidity (FNU)
0
200
400
600
800
1000
1200
1400
1600
1800
09:00:00
09:30:00
10:00:00
10:30:00
11:00:00
11:30:00


YSI EXO and YSI 6136 Turbidity Data without steps
YSI EXO Turbidity Sensor
YSI 6136 Turbidity Sensor
Hach 2100AN
Turbidity (FNU)
0
200
400
600
800
1000
1200
1400
1600
1800
09:00:00
09:30:00
10:00:00
10:30:00
11:00:00
11:30:00

Statistical Analyses - YSI EXO and YSI 6136 Data

Slope comparison

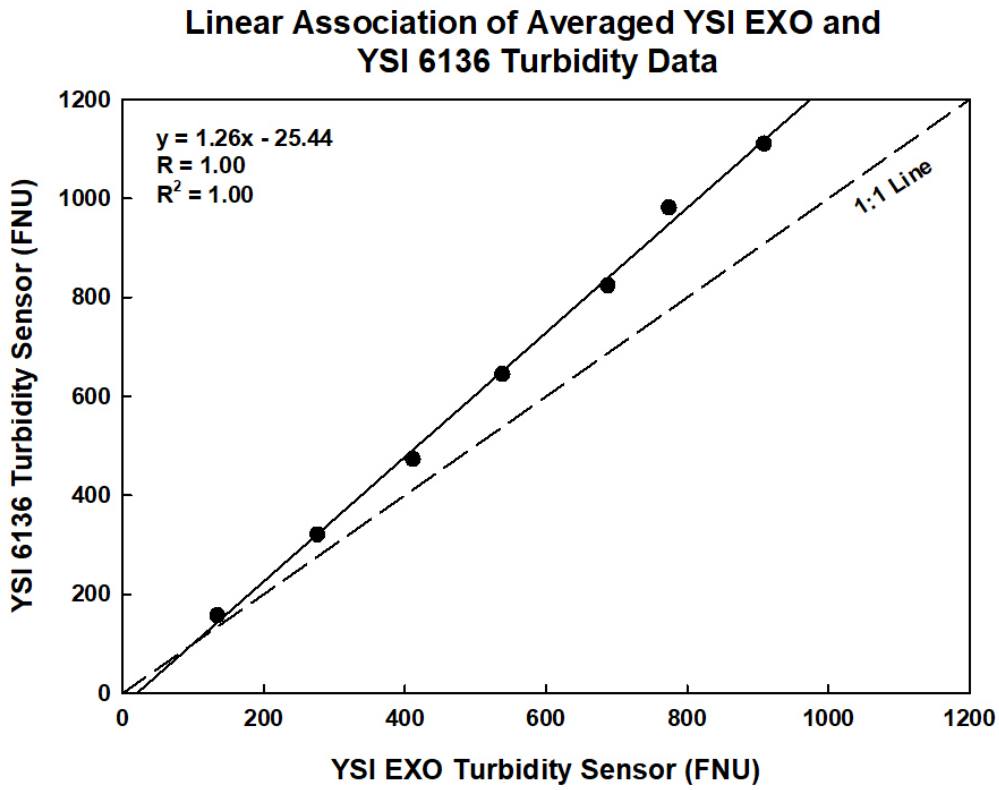
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI EXO turbidity sensor and a YSI 6136 turbidity sensor at the Kansas Water Science Center laboratory, Lawrence, Kansas, on February 8, 2017; the data used in the final regressions were averages of turbidity for each step, each of which had a duration of approximately 15 minutes once the sensor had stabilized:

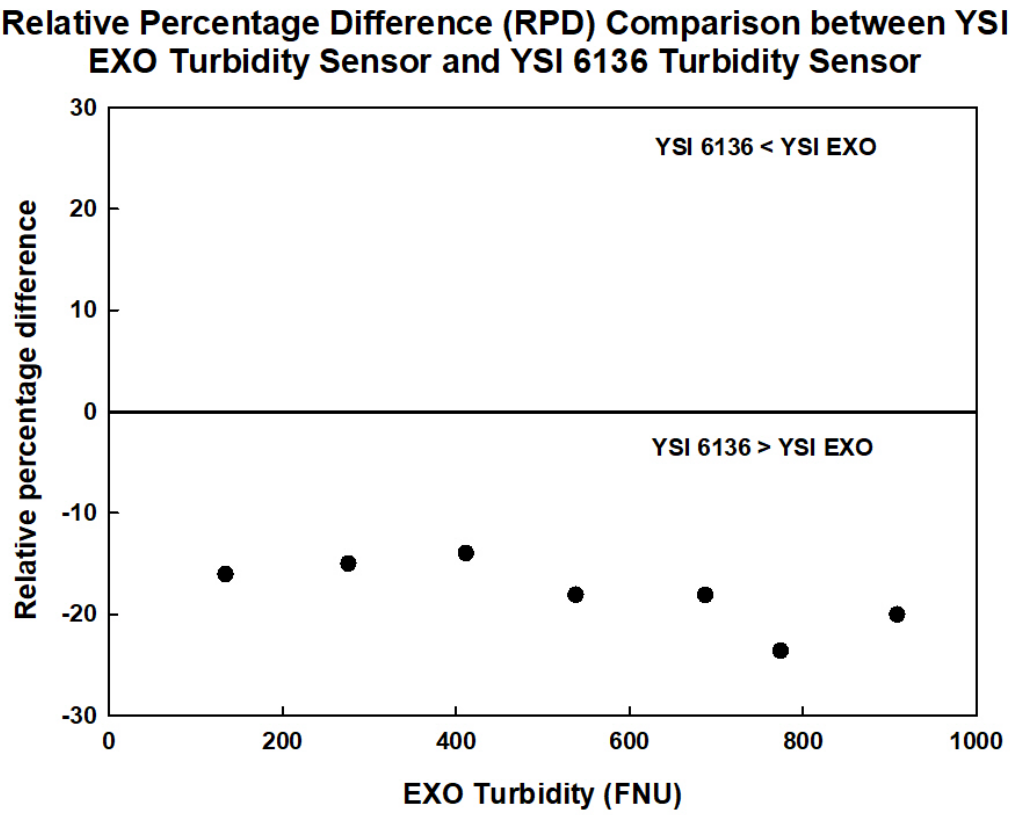
$$y = 1.26x - 25.44$$

where

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

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





Paired t-test for YSI EXO and YSI 6136 Data

SigmaPlot Statistical Output:

Normality Test (Shapiro-Wilk): Passed (P = 0.412)

Paired t-test:

Treatment Name	N	Missing	Mean	Std Dev	SEM
YSI EXO	7	0	532.811	277.873	105.026
YSI 6136	7	0	644.616	349.914	132.255
Difference	7	0	-111.804	73.817	27.900

t = -4.007 with 6 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: -180.073 to -43.535

Two-tailed P-value = 0.00706

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = 0.007)

One-tailed P-value = 0.00353

The sample mean of treatment YSI 6136 exceeds the sample mean of treatment YSI EXO by an amount that is greater than would be expected by chance, rejecting the hypothesis that the population mean of treatment YSI EXO is greater than or equal to the population mean of treatment YSI 6136. (P = 0.007)

Power of performed two-tailed test with alpha = 0.050: 0.913
Power of performed one-tailed test with alpha = 0.050: 0.969

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 1.00). Relative percentage difference ranged from 14 to 24 percent (median: 18 percent; mean: 18 percent). The data passed the Shapiro-Wilk test for normality (P=0.412); therefore, a paired t-test was performed. The difference between mean values for the YSI EXO and YSI 6136 turbidity sensors was statistically significant (P<0.05).

Statistical Analyses - YSI EXO and Hach 2100AN Data

Slope comparison

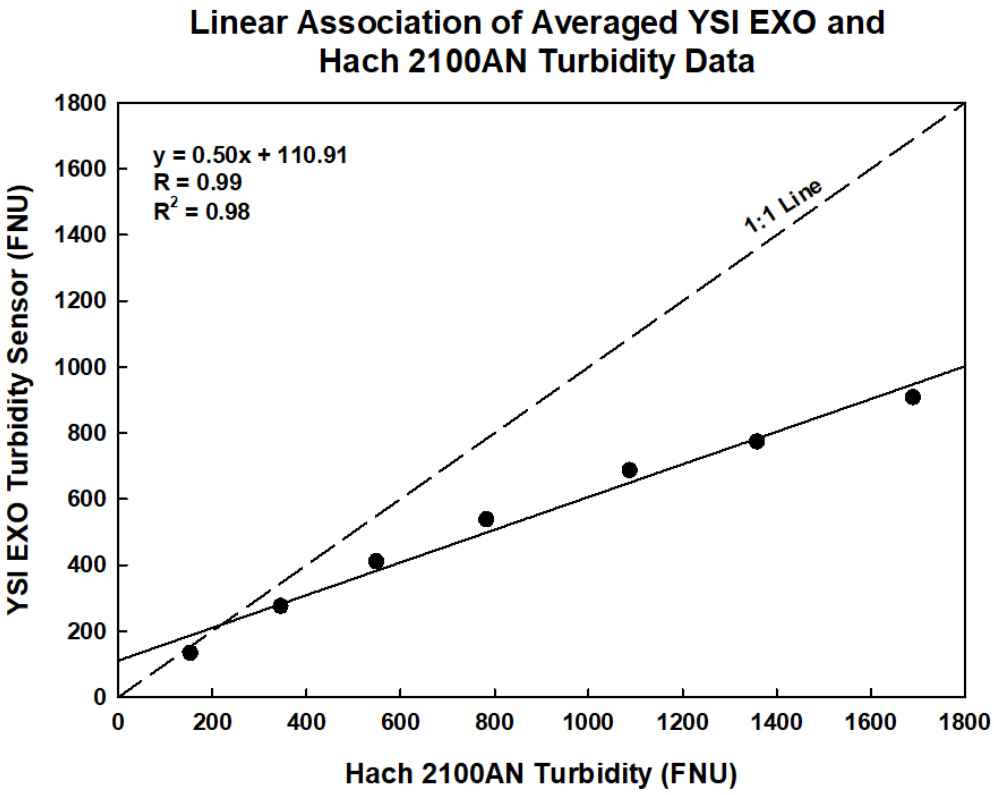
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI EXO turbidity sensor and a Hach 2100AN laboratory turbidimeter at the Kansas Water Science Center laboratory, Lawrence, Kansas, on February 8, 2017; the data used in the final regressions were averages of turbidity for each step, each of which had a duration of approximately 15 minutes once the sensor had stabilized:

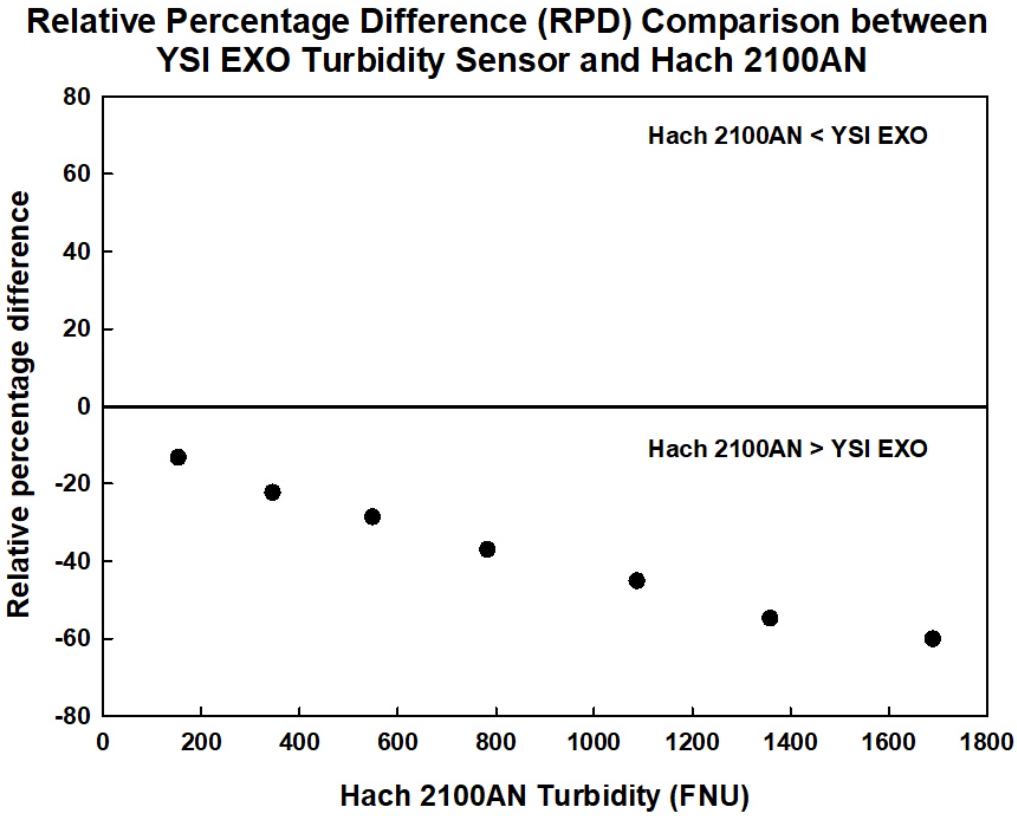
$$y = 0.50x + 110.91$$

where

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

x = turbidity measured with Hach 2100AN turbidimeter (FNU).


Linear Association of Averaged YSI EXO and Hach 2100AN Turbidity Data
y = 0.50x + 110.91
R = 0.99
R2 = 0.98
1:1 Line
YSI EXO Turbidity Sensor (FNU)
Hach 2100AN Turbidity (FNU)
0
200
400
600
800
1000
1200
1400
1600
1800


Relative Percentage Difference (RPD) Comparison between YSI EXO Turbidity Sensor and Hach 2100AN
Hach 2100AN < YSI EXO
Hach 2100AN > YSI EXO
Relative percentage difference
Hach 2100AN Turbidity (FNU)
80
60
40
20
0
-20
-40
-60
-80
0
200
400
600
800
1000
1200
1400
1600
1800

Paired t-test for YSI EXO and Hach 2100AN Data

SigmaPlot Statistical Output:

Normality Test (Shapiro-Wilk): Passed (P = 0.525)

Paired t-test:

Treatment Name	N	Missing	Mean	Std Dev	SEM
YSI EXO	7	0	532.811	277.873	105.026
Hach 2100AN	7	0	852.071	556.178	210.215
Difference	7	0	-319.260	283.224	107.049

t = -2.982 with 6 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: -581.198 to -57.322

Two-tailed P-value = 0.0246

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = 0.025)

One-tailed P-value = 0.0123

The sample mean of treatment Hach 2100AN exceeds the sample mean of treatment YSI EXO by an amount that is greater than would be expected by chance, rejecting the hypothesis that the population mean of treatment YSI EXO is greater than or equal to the population mean of treatment Hach 2100AN. (P = 0.025)

Power of performed two-tailed test with alpha = 0.050: 0.70

Power of performed one-tailed test with alpha = 0.050: 0.837

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 0.99). Relative percentage difference ranged from 13 to 60 percent (median: 37 percent; mean: 37 percent). The data passed the Shapiro-Wilk test for normality (P=0.525); therefore, a paired t-test was performed. The difference between mean values for the YSI EXO sensor and Hach 2100AN was statistically significant (P<0.05).

Statistical Analyses - YSI 6136 and Hach 2100AN Data

Slope comparison

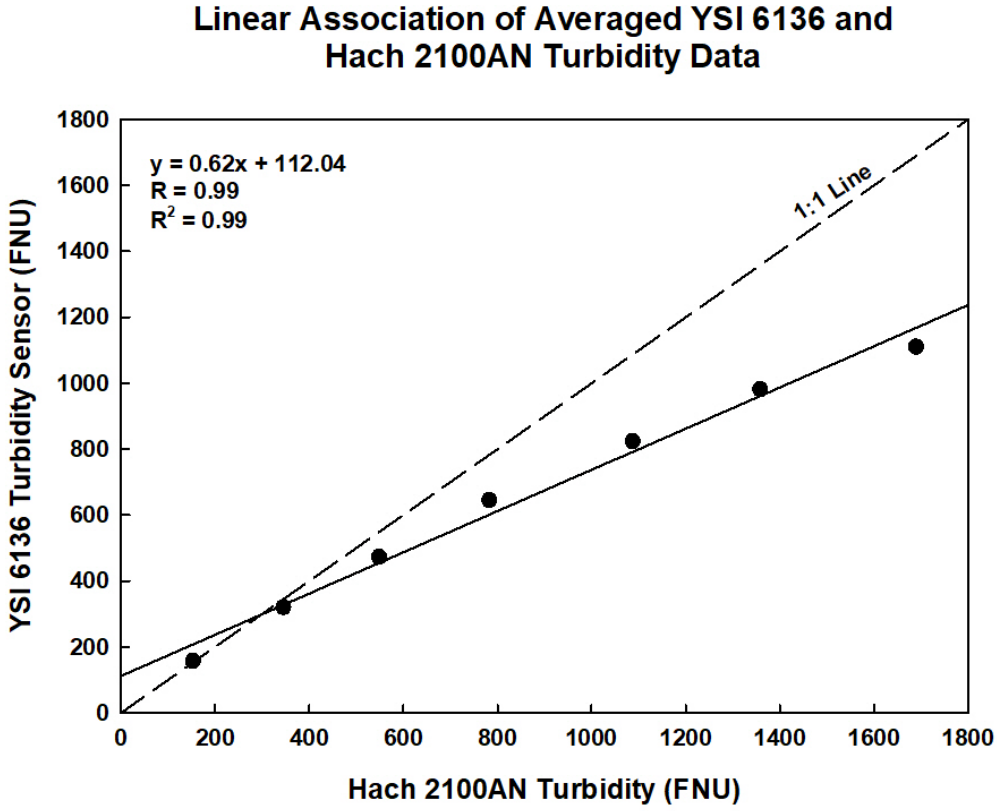
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI 6136 turbidity sensor and a Hach 2100AN laboratory turbidimeter at the Kansas Water Science Center laboratory, Lawrence, Kansas, on February 8, 2017; the data used in the final regressions were averages of turbidity for each step, each of which had a duration of approximately 15 minutes once the sensor had stabilized:

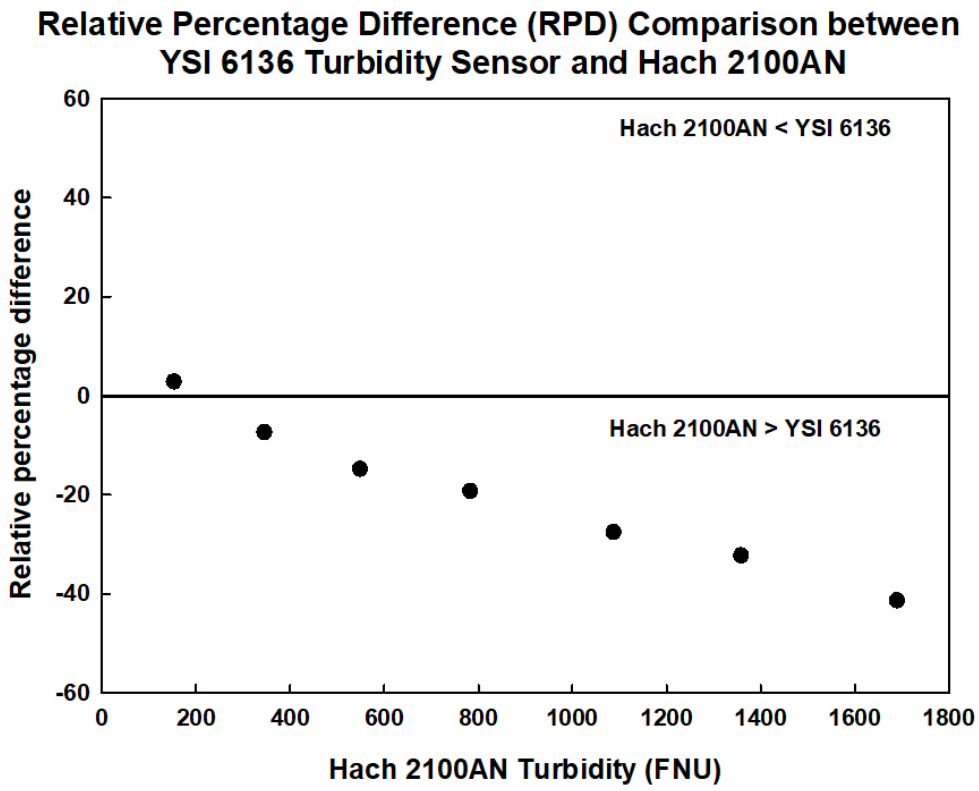
$$y = 0.62x + 112.04$$

where

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

x = turbidity measured with Hach 2100AN turbidimeter (FNU).





Paired t-test for YSI 6136 and Hach 2100AN Data

SigmaPlot Statistical Output:

Normality Test (Shapiro-Wilk): Passed (P = 0.413)

Paired t-test:

Treatment Name	N	Missing	Mean	Std Dev	SEM
YSI 6136	7	0	644.616	349.914	132.255
Hach 2100AN	7	0	852.071	556.178	210.215
Difference	7	0	-207.456	212.331	80.254

t = -2.585 with 6 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: -403.829 to -11.082

Two-tailed P-value = 0.0415

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = 0.041)

One-tailed P-value = 0.0207

The sample mean of treatment Hach 2100AN exceeds the sample mean of treatment YSI 6136 by an amount that is greater than would be expected by chance, rejecting the hypothesis that the population mean of treatment YSI 6136 is greater than or equal to the population mean of treatment Hach 2100AN. (P = 0.041)

Power of performed two-tailed test with alpha = 0.050: 0.581

Power of performed one-tailed test with alpha = 0.050: 0.737

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 0.99). Relative percentage difference ranged from 3 to 41 percent (median: 19 percent; mean: 21 percent). The data passed the Shapiro-Wilk test for normality (P=0.413); therefore, a paired t-test was performed. The difference between mean values for the YSI 6136 sensor and Hach 2100AN 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/.]