Appendix 22. Laboratory Comparison between YSI EXO and YSI 6136 Turbidity Sensors using natural sediment and water (from Mill Creek at Johnson Drive, Shawnee, Kansas, U.S. Geological Survey [USGS] station number 06892513) at the Kansas Water Science Center Lab, 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: Water and sediment from Mill Creek at Johnson Drive, Shawnee, Kansas (U.S. Geological Survey [USGS] station number 06892513).

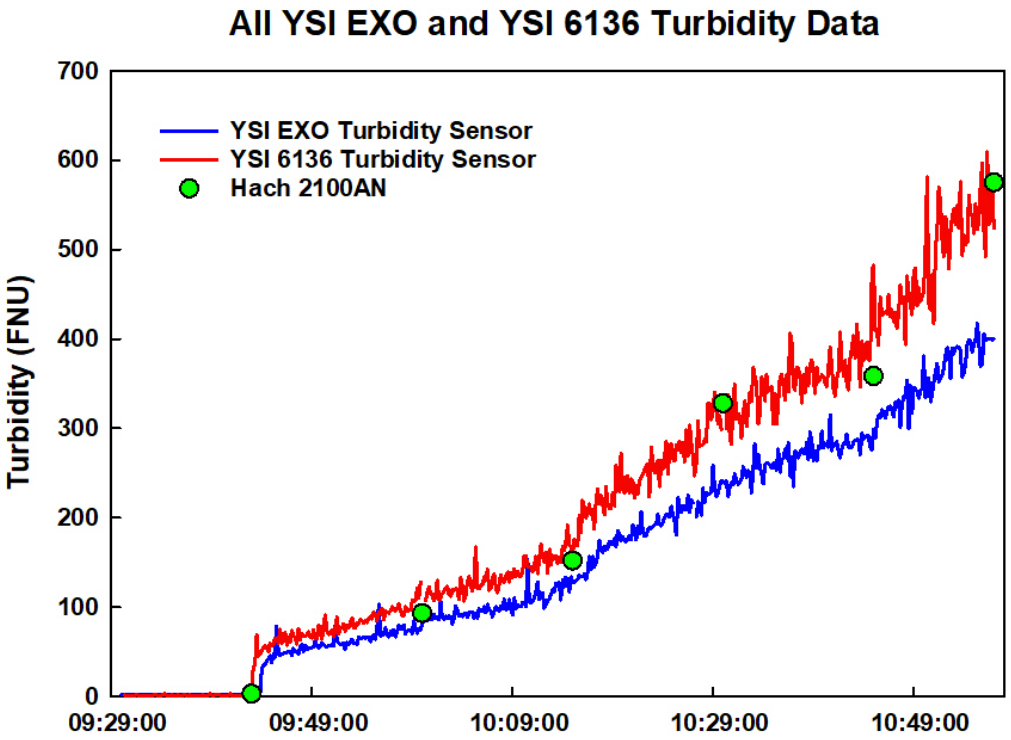
Calibration standard used: Hach StablCal standard.

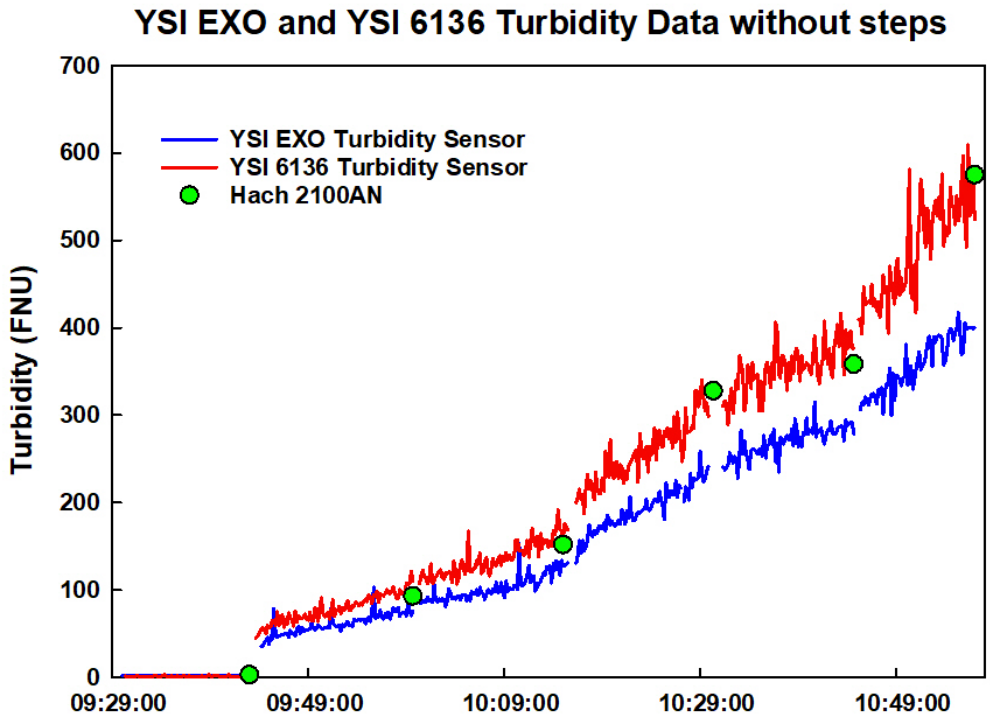
Laboratory comparison date: February 7, 2017.

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
100
200
300
400
500
600
700
09:29:00
09:49:00
10:09:00
10:29:00
10:49:00


YSI EXO and YSI 6136 Turbidity Data without steps
YSI EXO Turbidity Sensor
YSI 6136 Turbidity Sensor
Hach 2100AN
Turbidity (FNU)
0
100
200
300
400
500
600
700
09:29:00
09:49:00
10:09:00
10:29:00
10:49:00

Statistical Analyses - YSI EXO and YSI 6136 Data

Slope comparison

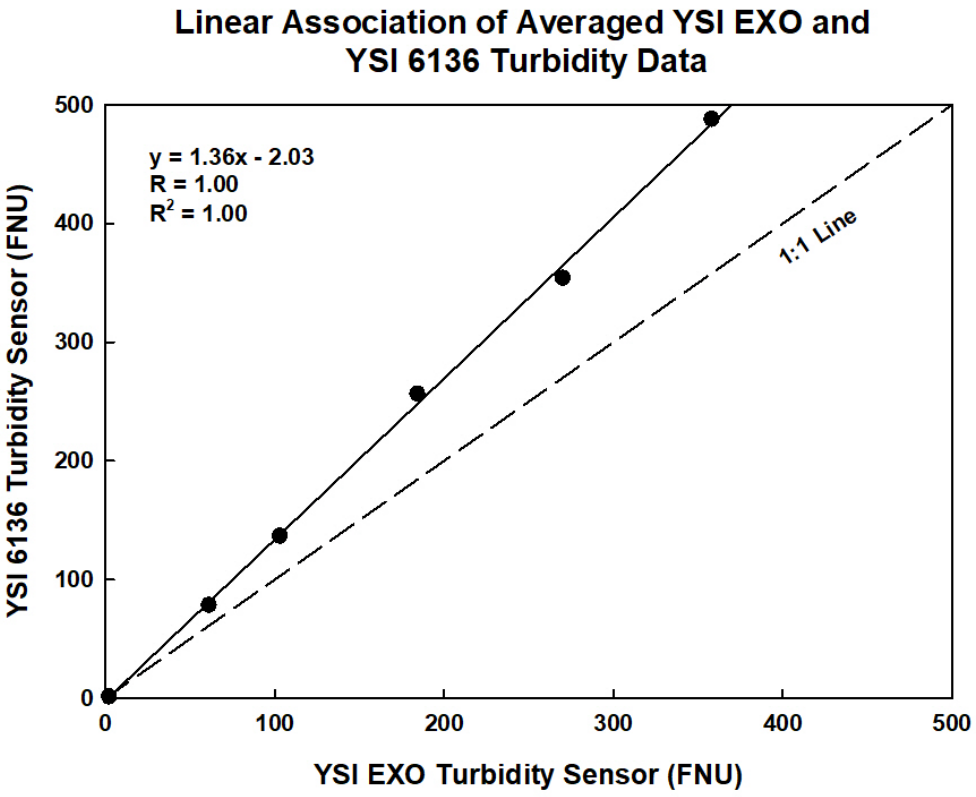
The following is a summary of final regression analysis for sensor-measured turbidity from an YSI EXO turbidity sensor and a YSI 6136 turbidity sensor at the Kansas Water Science Center laboratory, Lawrence, Kansas, on February 8, 2017; the data used in the final regressions were averages of turbidity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

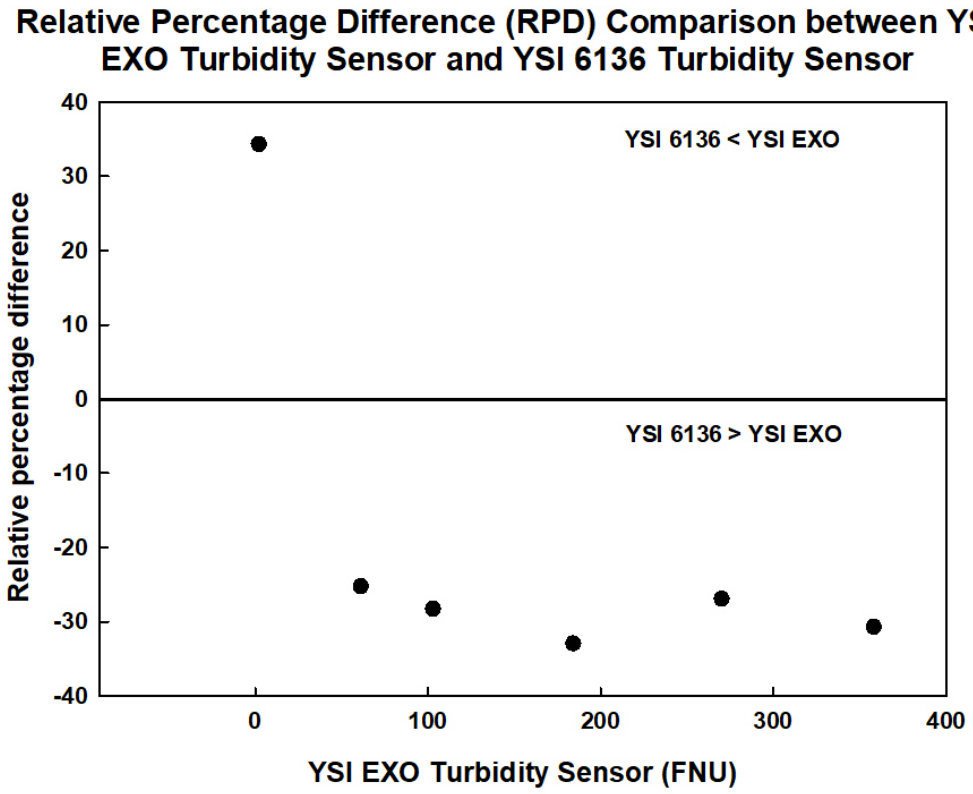
$$y = 1.36x - 2.03$$

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 = 0.826)

Paired t-test:

Treatment Name	N	Missing	Mean	Std Dev	SEM
YSI EXO	6	0	163.076	134.077	54.737
YSI 6136	6	0	219.312	182.093	74.339
Difference	6	0	-56.236	48.333	19.732

t = -2.850 with 5 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: -106.958 to -5.513

Two-tailed P-value = 0.0358

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = 0.036)

One-tailed P-value = 0.0179

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 = 0.036)

Power of performed two-tailed test with alpha = 0.050: 0.629
Power of performed one-tailed test with alpha = 0.050: 0.787

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 1.00). Relative percentage difference ranged from 25 to 34 percent (median: 29 percent; mean: 30 percent). The data passed the Shapiro-Wilk test for normality (P=0.826); 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

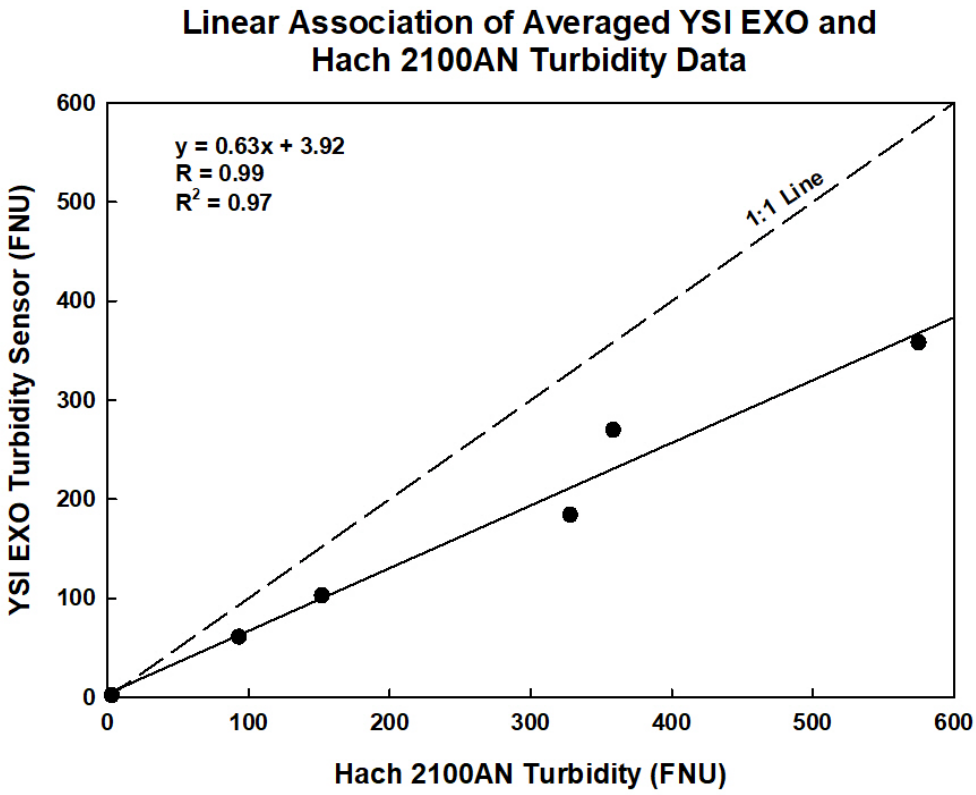
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI EXO turbidity sensor and a Hach 2100AN laboratory turbidimeter at the Kansas Water Science Center laboratory, Lawrence, Kansas, on February 8, 2017; the data used in the final regressions were averages of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

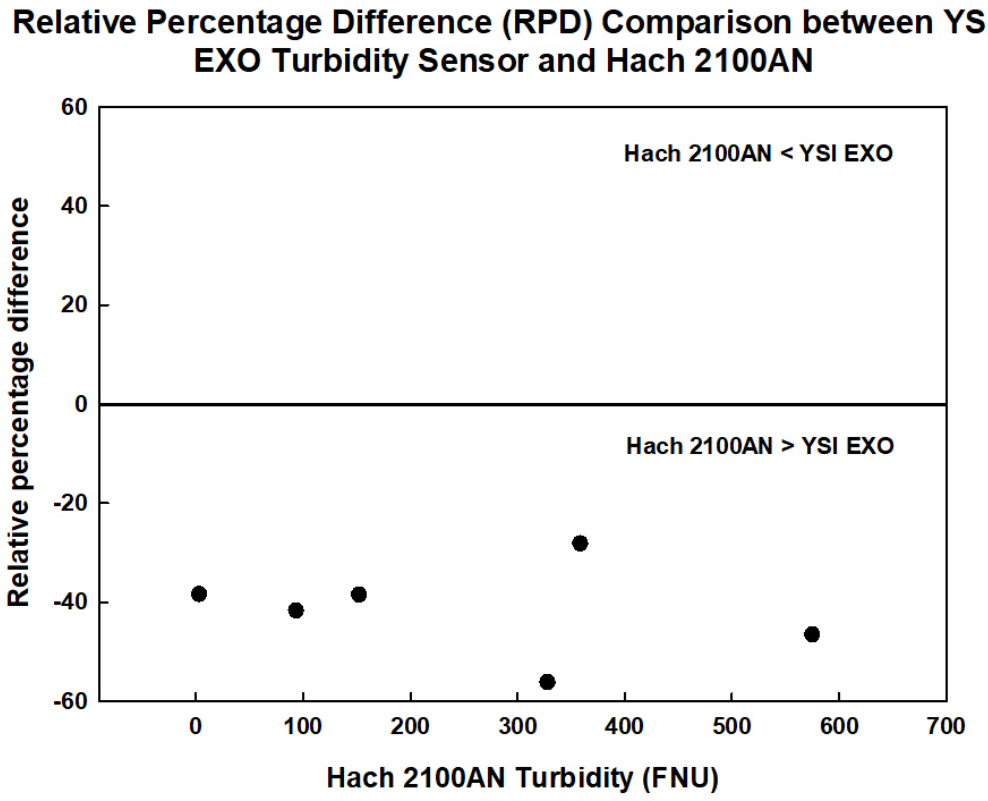
$$y = 0.63x + 3.92$$

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 = 0.63x + 3.92
R = 0.99
R2 = 0.97
1:1 Line
YSI EXO Turbidity Sensor (FNU)
Hach 2100AN Turbidity (FNU)
0
100
200
300
400
500
600



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

SigmaPlot Statistical Output:

Normality Test (Shapiro-Wilk): Passed (P = 0.693)

Paired t-test:

Data source: Data 3 in Mill Creek Results.JNB

Treatment Name	N	Missing	Mean	Std Dev	SEM
YSI EXO	6	0	163.076	134.077	54.737
Hach 2100AN	6	0	251.626	209.111	85.369
Difference	6	0	-88.550	79.923	32.628

t = -2.714 with 5 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: -172.424 to -4.676

Two-tailed P-value = 0.0421

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P = 0.042)

One-tailed P-value = 0.0210

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 = 0.042)

Power of performed two-tailed test with alpha = 0.050: 0.589

Power of performed one-tailed test with alpha = 0.050: 0.752

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 0.99). Relative percentage difference ranged from 28 to 56 percent (median: 40 percent; mean: 42 percent). The data passed the Shapiro-Wilk test for normality (P=0.693); 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

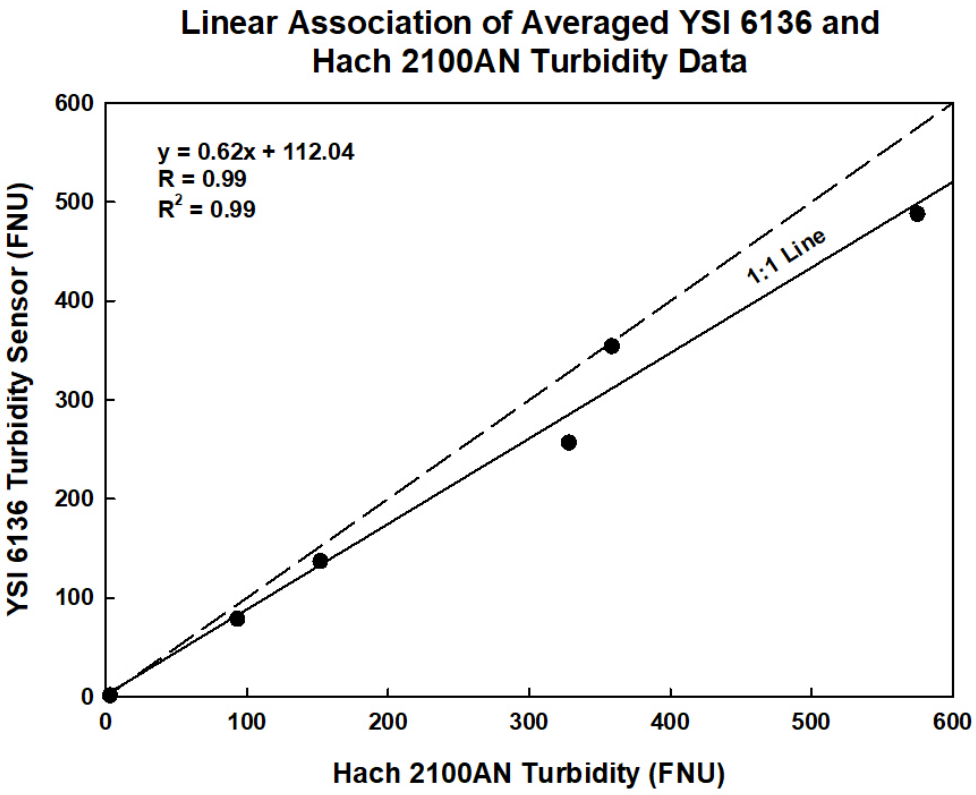
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI 6136 turbidity sensor and a Hach 2100AN laboratory turbidimeter at the Kansas Water Science Center laboratory, Lawrence, Kansas, on February 8, 2017; the data used in the final regressions were averages of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

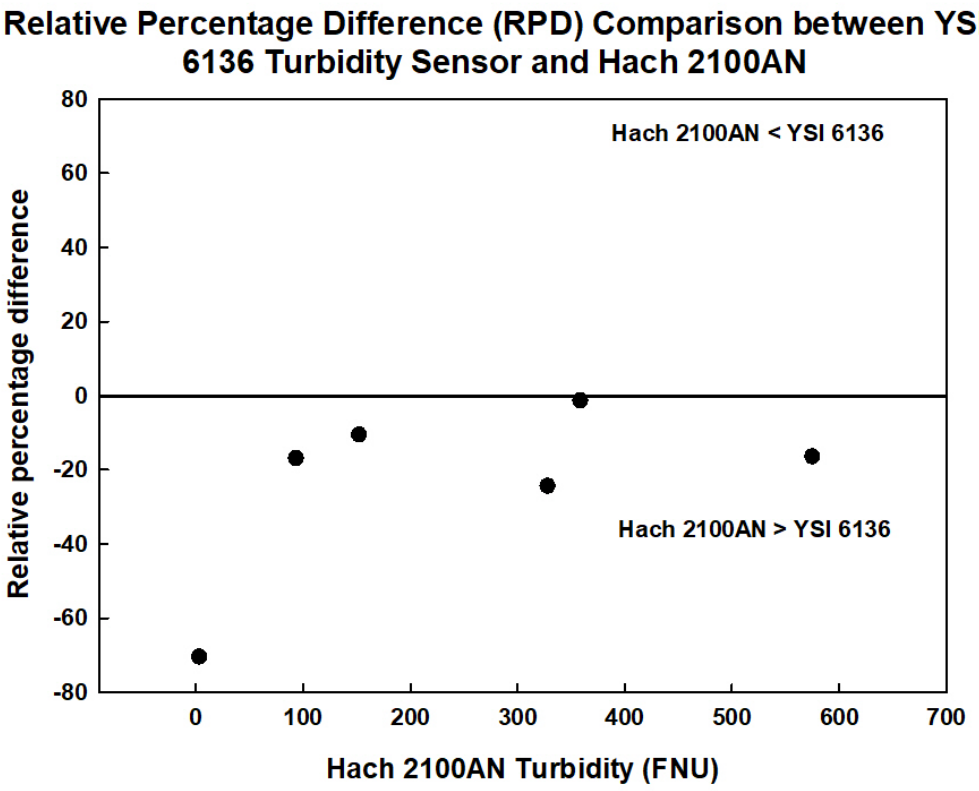
$$y = 0.62x + 112.04$$

where

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

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


Linear Association of Averaged YSI 6136 and Hach 2100AN Turbidity Data
y = 0.62x + 112.04
R = 0.99
R2 = 0.99
1:1 Line
YSI 6136 Turbidity Sensor (FNU)
Hach 2100AN Turbidity (FNU)
0
100
200
300
400
500
600



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

SigmaPlot Statistical Output:

Normality Test (Shapiro-Wilk): Passed (P = 0.053)

Paired t-test:

Treatment Name	N	Missing	Mean	Std Dev	SEM
YSI 6136	6	0	219.312	182.093	74.339
Hach 2100AN	6	0	251.626	209.111	85.369
Difference	6	0	-32.314	37.015	15.111

t = -2.138 with 5 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: -71.159 to 6.531

Two-tailed P-value = 0.0855

The change that occurred with the treatment is not great enough to exclude the possibility that the difference is due to chance (P = 0.085)

One-tailed P-value = 0.0427

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 = 0.085)

Power of performed two-tailed test with alpha = 0.050: 0.410

Power of performed one-tailed test with alpha = 0.050: 0.578

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 0.99). Relative percentage difference ranged from 1 to 70 percent (median: 17 percent; mean: 23 percent). The data passed the Shapiro-Wilk test for normality (P=0.053); therefore, a paired t-test was performed. The difference between mean values for the YSI 6136 sensor and Hach 2100AN was not 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/.]