Appendix 20. Laboratory Comparison between YSI EXO and YSI 6136 Turbidity Sensors using black clay at the Kansas Water Science Center Lab, Lawrence, Kansas

Comparison Description

Station name: Kansas Water Science Center laboratory, 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: Black clay and deionized water.

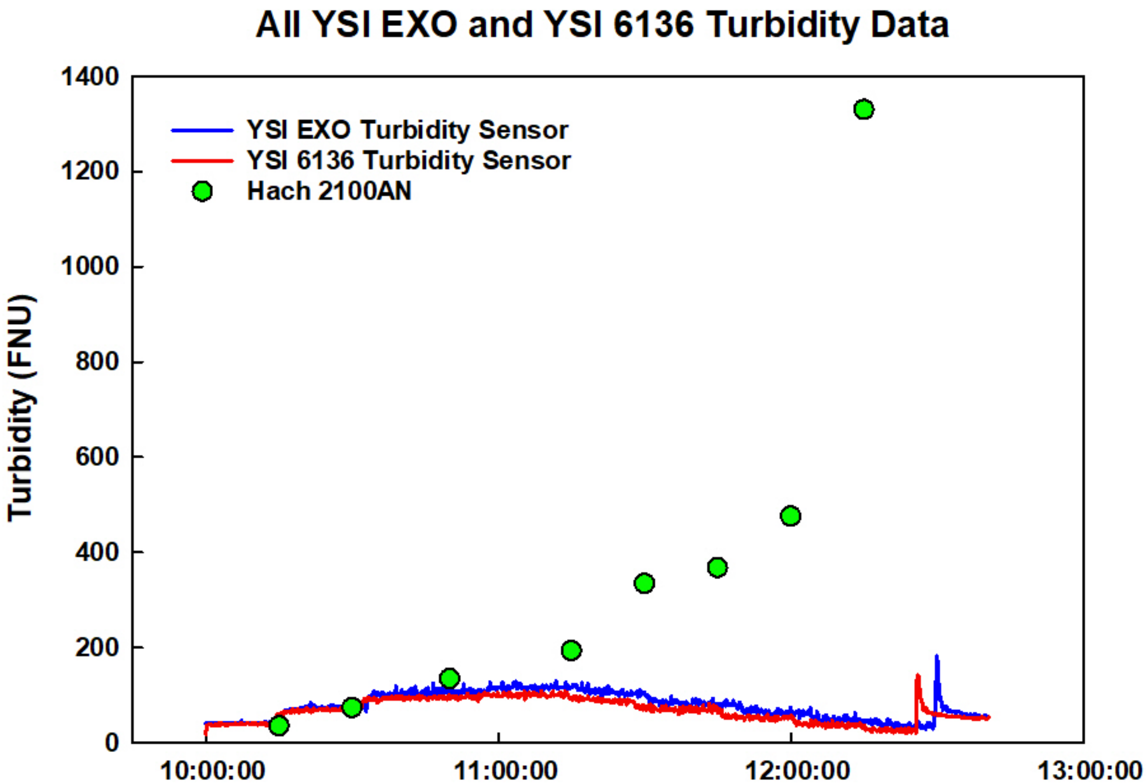
Calibration standard used: Hach StablCal standard.

Laboratory comparison date: March 1, 2017.

Datasets

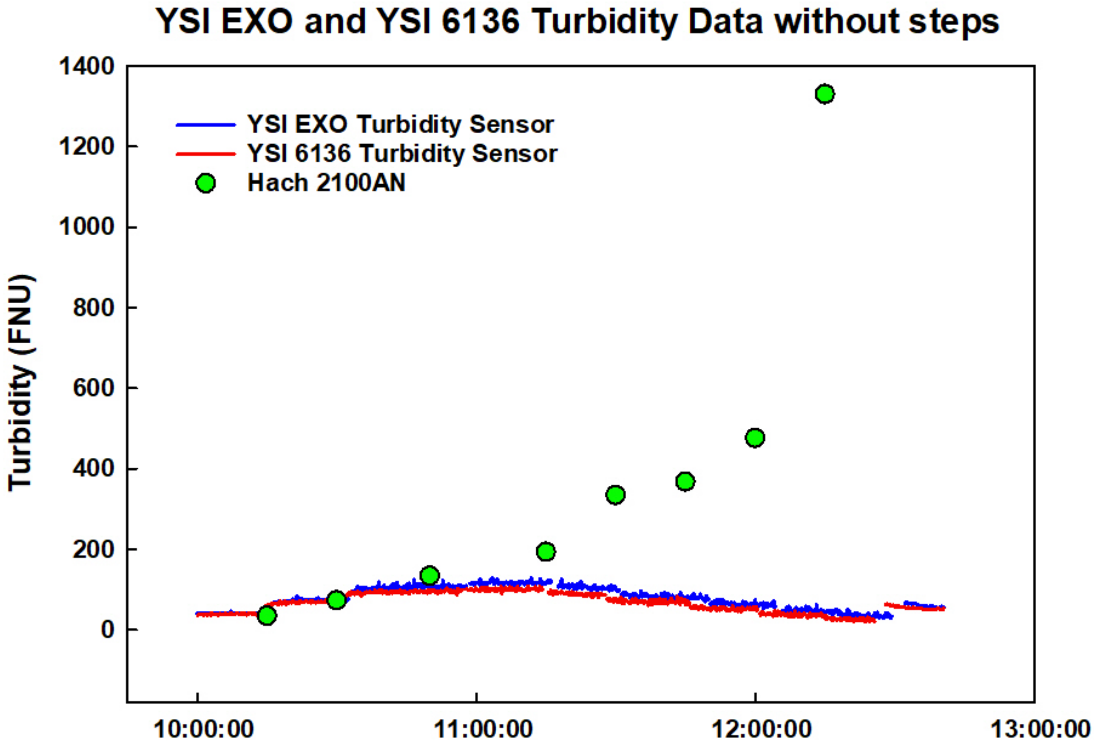
All data were collected using USGS protocols (U.S. Geological Survey, variously dated) and are published in King (2021). Data were edited to remove periods where material was added to the testing apparatus, leaving the steady-state data for analysis.

Time Series



All YSI EXO and YSI 6136 Turbidity Data
YSI EXO Turbidity Sensor
YSI 6136 Turbidity Sensor
Hach 2100AN
Turbidity (FNU)
1400
1200
1000
800
600
400
200
0
10:00:00
11:00:00
12:00:00
13:00:00

YSI EXO and YSI 6136 Turbidity Data without steps



Statistical Analyses - YSI EXO and YSI 6136 Data

Slope comparison

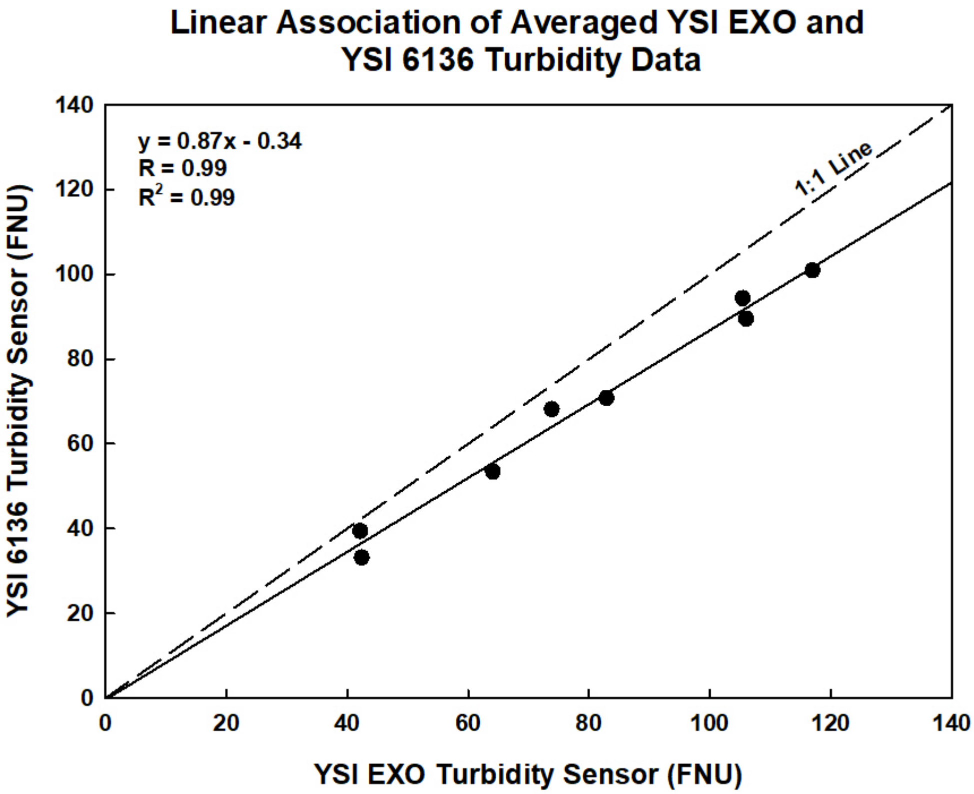
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI EXO turbidity sensor and a YSI 6136 turbidity sensor at the Kansas Water Science Center laboratory, Lawrence, Kansas, on February 8, 2017. The data used in the final regressions were averages for each step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

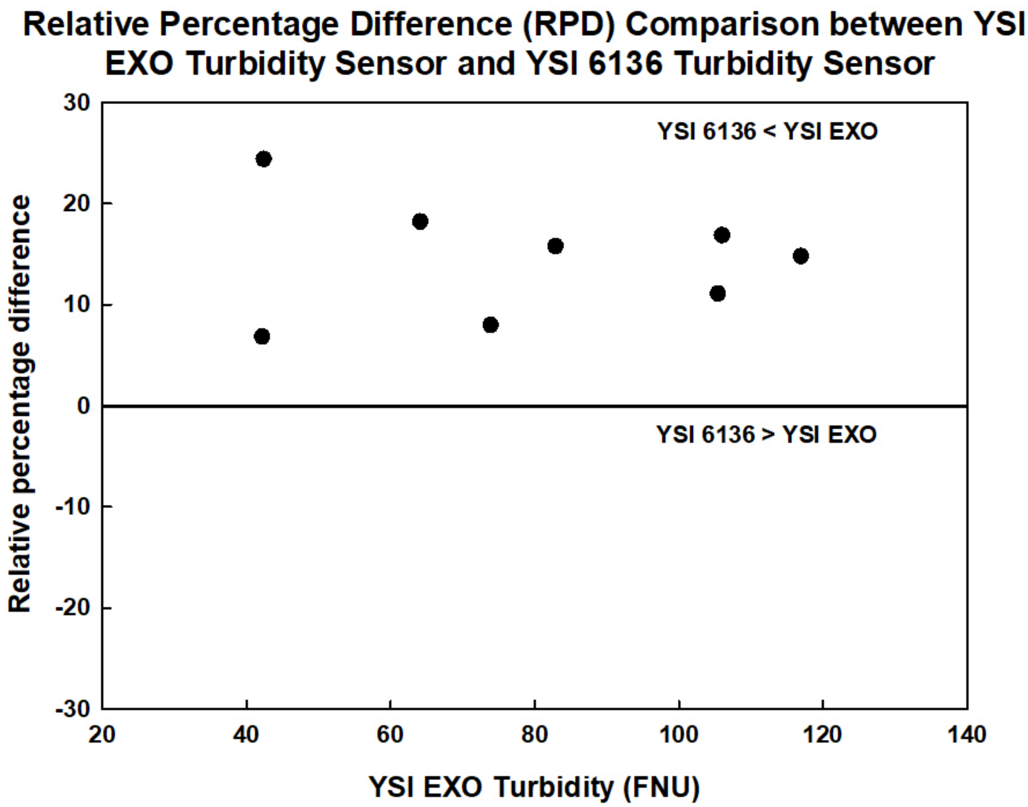
$$y = 0.87x - 0.34$$

where

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

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


Linear Association of Averaged YSI EXO and
YSI 6136 Turbidity Data
y = 0.87x - 0.34
R = 0.99
R2 = 0.99
1:1 Line
YSI 6136 Turbidity Sensor (FNU)
YSI EXO Turbidity Sensor (FNU)
0
20
40
60
80
100
120
140



Paired t-test for YSI EXO and YSI 6136 Data

SigmaPlot Statistical Output:

Normality Test (Shapiro-Wilk): Passed (P = 0.703)

Paired t-test:

Treatment Name	N	Missing	Mean	Std Dev	SEM
YSI EXO	8	0	79.219	28.857	10.203
YSI 6136	8	0	68.696	25.313	8.949
Difference	8	0	10.523	4.701	1.662

t = 6.331 with 7 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: 6.593 to 14.454

Two-tailed P-value = 0.000392

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

One-tailed P-value = 0.000196

The sample mean of treatment YSI EXO 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 YSI EXO. (P = <0.001)

Power of performed two-tailed test with alpha = 0.050: 1.000
Power of performed one-tailed test with alpha = 0.050: 1.000

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 0.99). Relative percentage difference ranged from 7 to 24 percent (median: 15 percent; mean: 14 percent). The data passed the Shapiro-Wilk test for normality (P=0.703); 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

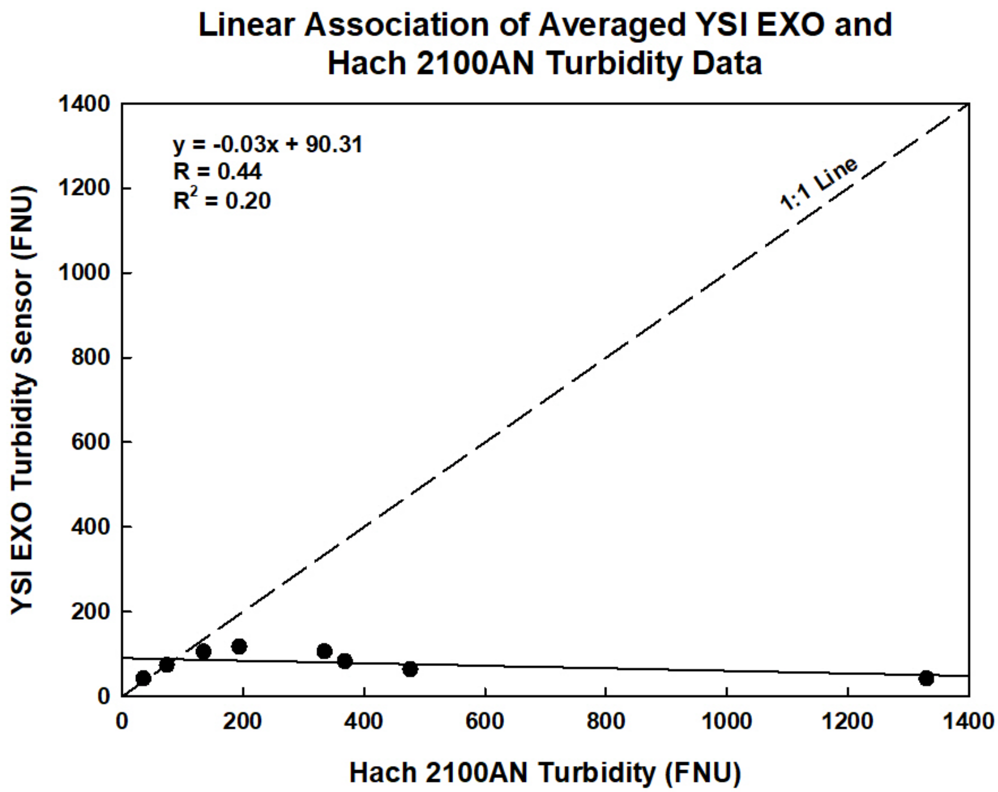
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI EXO turbidity sensor and a Hach 2100AN laboratory turbidimeter at the Kansas Water Science Center laboratory, Lawrence, Kansas, on February 8, 2017; the data used in the final regressions were averages of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

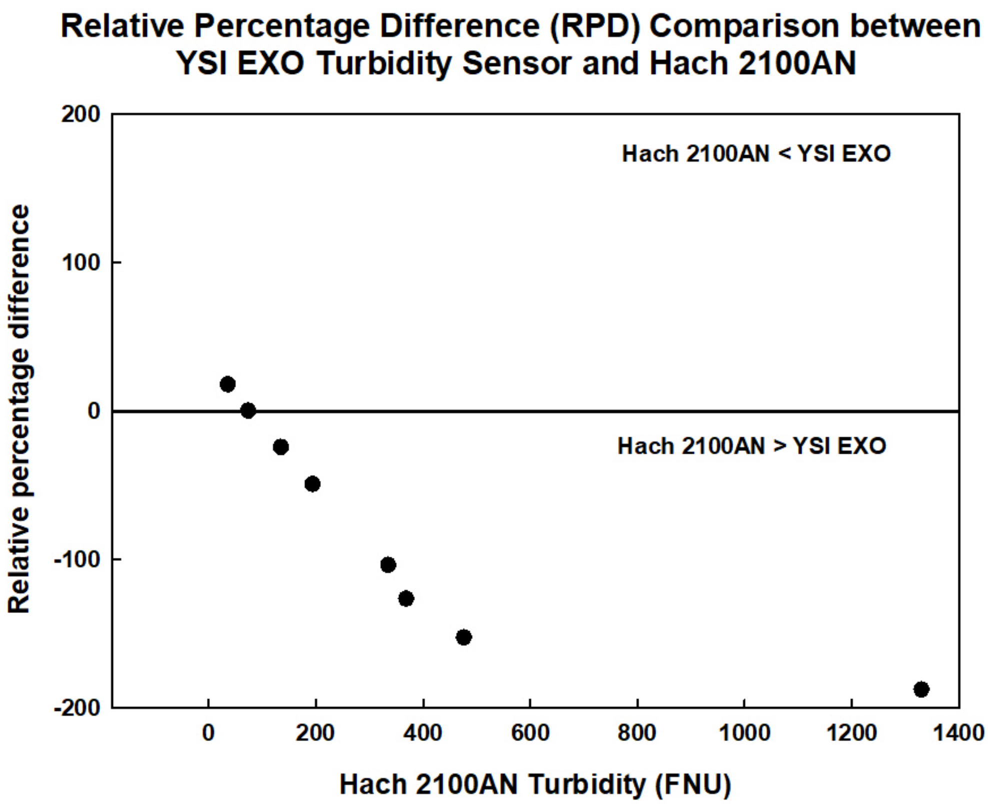
$$y = -0.03x + 90.31$$

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 = -0.03x + 90.31
R = 0.44
R² = 0.20
1:1 Line
YSI EXO Turbidity Sensor (FNU)
Hach 2100AN Turbidity (FNU)
0
200
400
600
800
1000
1200
1400



Wilcoxon Signed-Rank Test for YSI EXO and Hach 2100AN Data

SigmaPlot Statistical Output:

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

Group	N	Missing	Median	25%	75%
YSI EXO	8	0	78.374	47.813	105.845
Hach 2100AN	8	0	264.000	88.900	449.000

W= 30.000 T+ = 33.000 T-= -3.000

Z-Statistic (based on positive ranks) = 2.100
P(est.) = 0.042 P(exact)= 0.039

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant difference ($P = 0.039$).

R Statistical Output:

```
Wilcoxon Signed-Rank test with continuity correction

data:  Hach 2100AN and YSI EXO
V = 33, p-value = 0.03906
alternative hypothesis: true location shift is not equal to 0
95 percent confidence interval:
  11.08207 758.06557
sample estimates:
(pseudo)median
      191.6642
```

Summary of Results

There is a weak linear association between measurements made with the two sensors (R = 0.44). Relative percentage difference ranged from 0 to 188 percent (median: 77 percent; mean: 83 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 sensor and Hach 2100AN was statistically significant ($P<0.05$).

Statistical Analyses - YSI 6136 and Hach 2100AN Data

Slope comparison

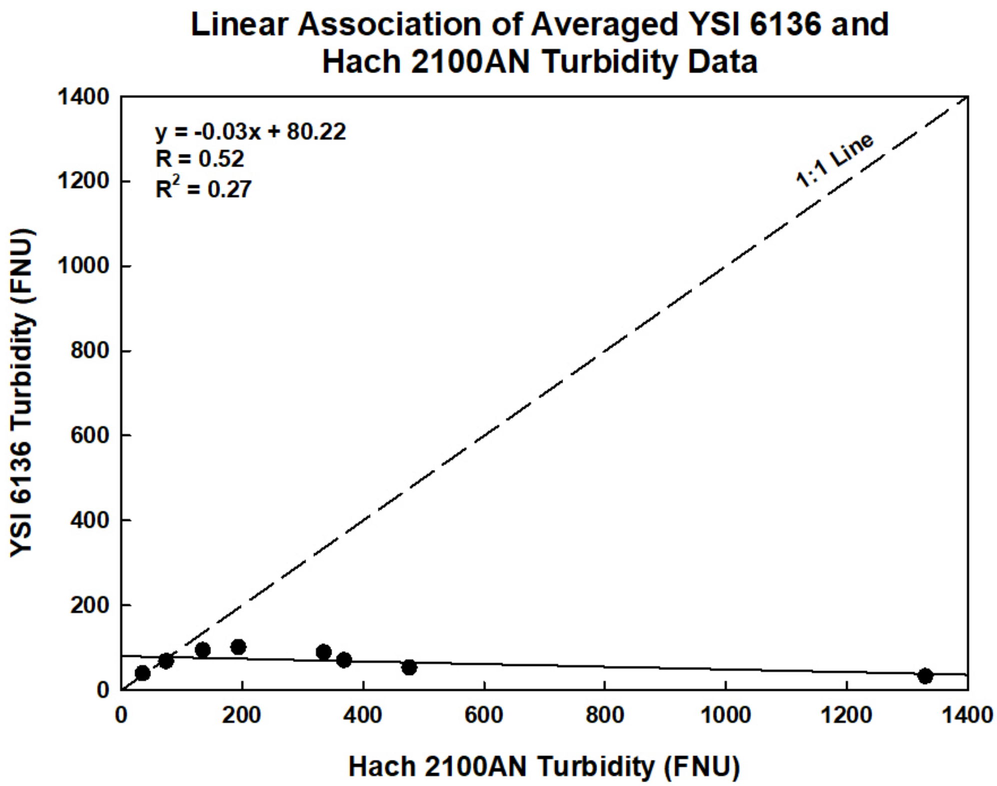
The following is a summary of final regression analysis for sensor-measured turbidity from a YSI 6136 turbidity sensor and a Hach 2100AN laboratory turbidimeter at the Kansas Water Science Center laboratory, Lawrence, Kansas, on February 8, 2017; the data used in the final regressions were averages of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

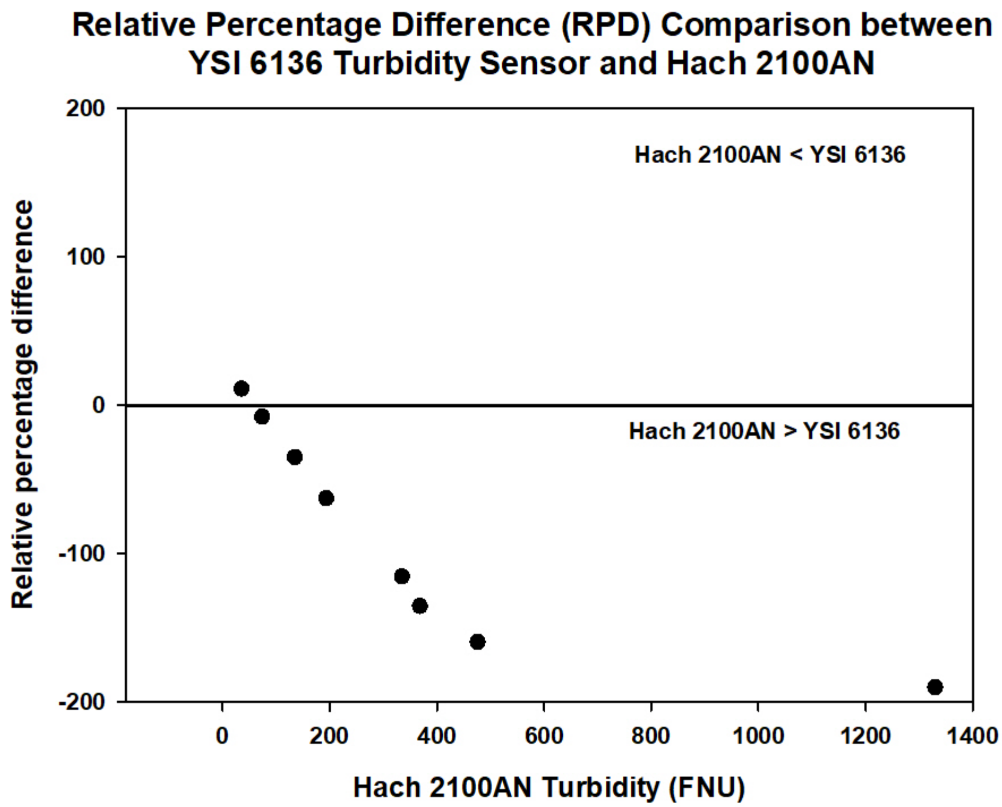
$$y = -0.03x + 80.22$$

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 = -0.03x + 80.22
R = 0.52
R2 = 0.27
1:1 Line
YSI 6136 Turbidity (FNU)
Hach 2100AN Turbidity (FNU)
0
200
400
600
800
1000
1200
1400



Wilcoxon Signed-Rank Test for YSI 6136 and Hach 2100AN Data

SigmaPlot Statistical Output:

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

Group	**N**	**Missing**	**Median**	**25%**	**75%**
YSI 6136	8	0	69.477	42.871	93.132
Hach 2100AN	8	0	264.000	88.900	449.000

W= 34.000 T+ = 35.000 T-= -1.000

Z-Statistic (based on positive ranks) = 2.380

P(est.) = 0.021 P(exact)= 0.016

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant difference (P = 0.016).

R Statistical Output:

```
Wilcoxon Signed-Rank test with continuity correction

data:  Hach 2100AN and YSI 6136
V = 35, p-value = 0.01563
alternative hypothesis: true location shift is not equal to 0
95 percent confidence interval:
  18.0216 770.9161
sample estimates:
(pseudo)median
      202.0947
```

Summary of Results

There is a weak linear association between measurements made with the two sensors (R = 0.52). Relative percentage difference ranged from 8 to 190 percent (median: 89 percent; mean: 80 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 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/.]