Appendix 6. Laboratory Comparison between StablCal and multiple lots of Polymer Turbidity Standard at the Kansas Water Science Center Laboratory, Lawrence, Kansas

Comparison Description

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

Equipment: Two Yellow Spring Instrument (YSI) EXO water-quality monitors, one equipped with two YSI EXO turbidity sensors calibrated in polymer standard and one equipped with one YSI EXO turbidity sensor calibrated in StablCal turbidity standard were deployed in a laboratory turbidity testing apparatus for comparison between the standards. (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: White clay and deionized water

Calibration standard used: One sensor was calibrated with Hach StablCal turbidity standard and two sensors calibrated with YSI polymer standard.

Laboratory comparison date: September 7, 2017.

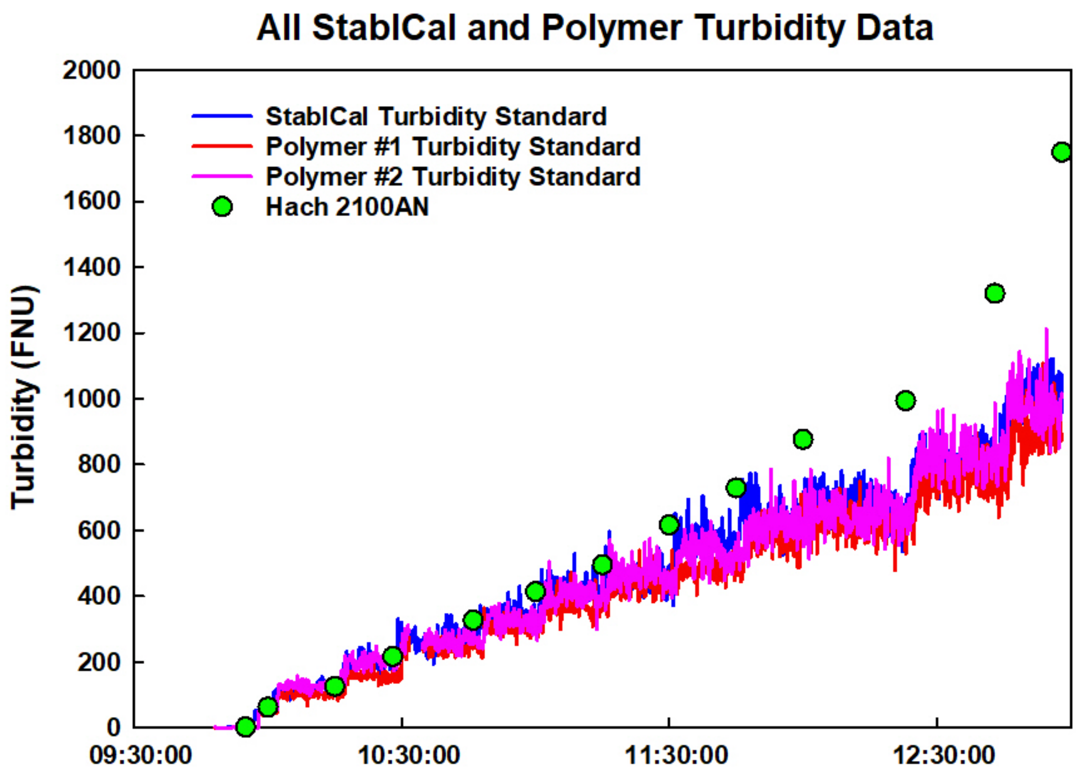
Datasets

All data were collected using U.S. Geological Survey [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.

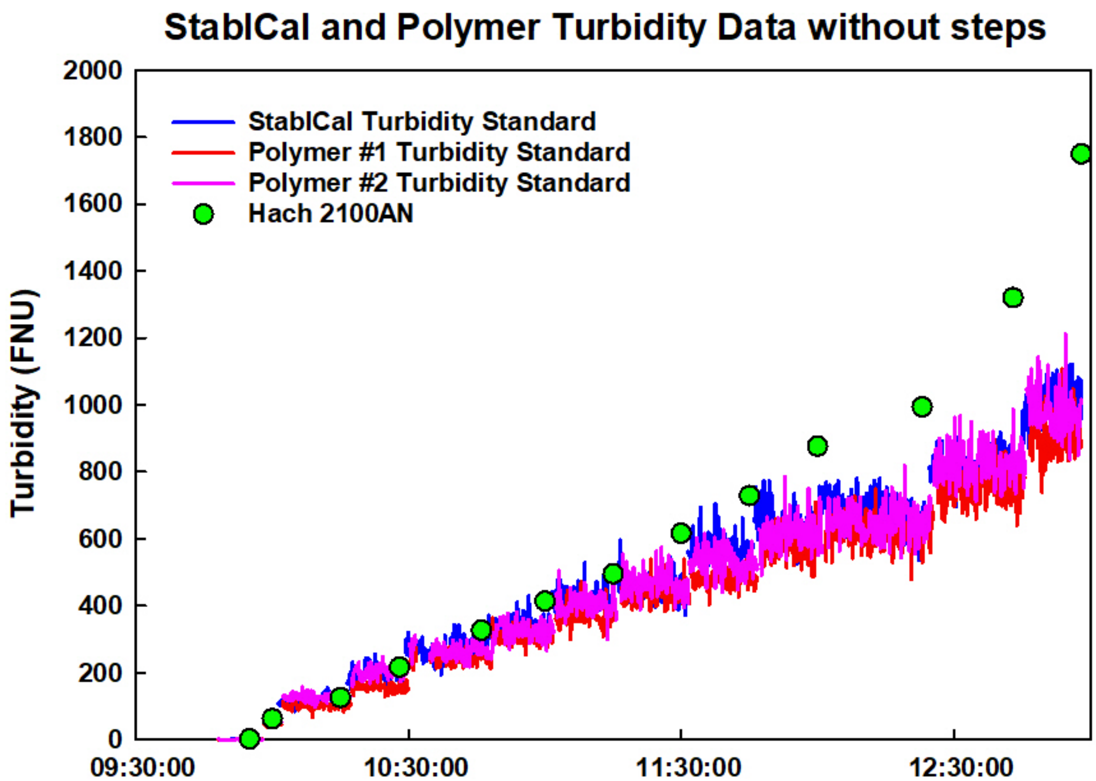
Polymer Standard Identification

	124 FNU Lot Number	1,010 FNU Lot Number
Polymer #1	17H798860	17H797418
Polymer #2	17E796816	17E794976

Time Series



All StablCal and Polymer Turbidity Data
StablCal Turbidity Standard
Polymer #1 Turbidity Standard
Polymer #2 Turbidity Standard
Hach 2100AN
Turbidity (FNU)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
09:30:00
10:30:00
11:30:00
12:30:00



Statistical Analyses - StablCal and Polymer #1 Data

Slope comparison

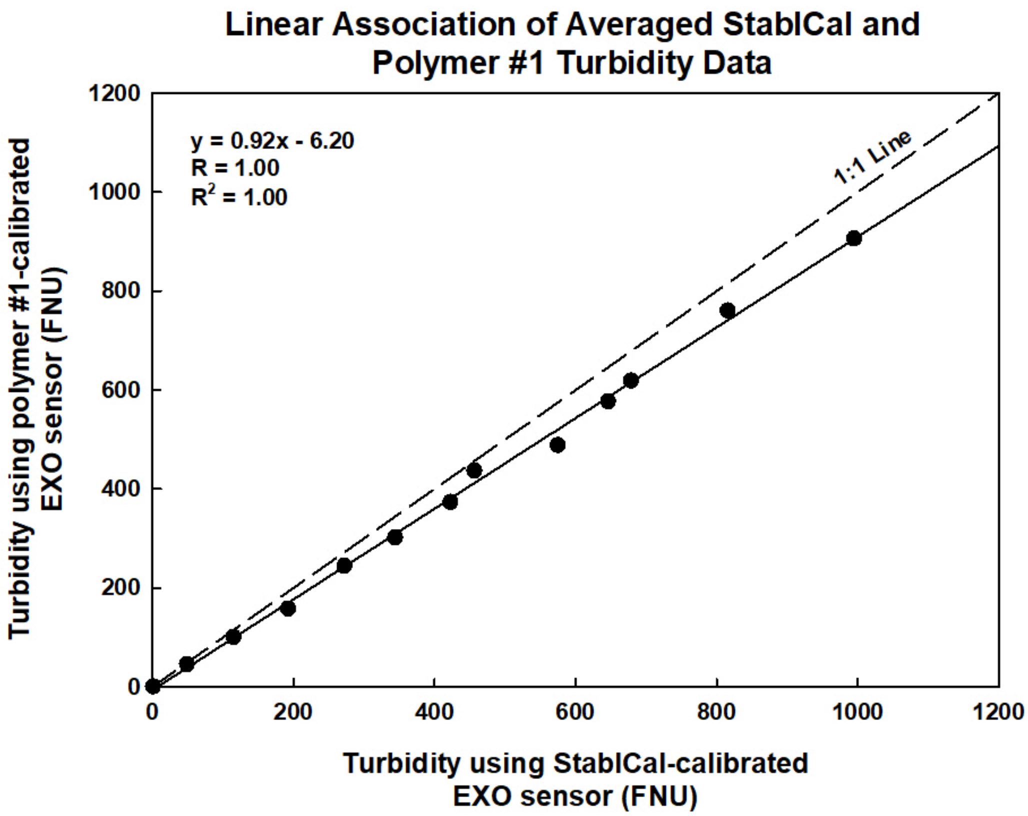
The following is a summary of final regression analysis for sensor-measured turbidity from one YSI EXO turbidity sensor calibrated by using StablCal turbidity standard and one YSI EXO turbidity sensor calibrated by using polymer #1 turbidity standard at the Kansas Water Science Center laboratory, Lawrence, Kansas, on September 7, 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:

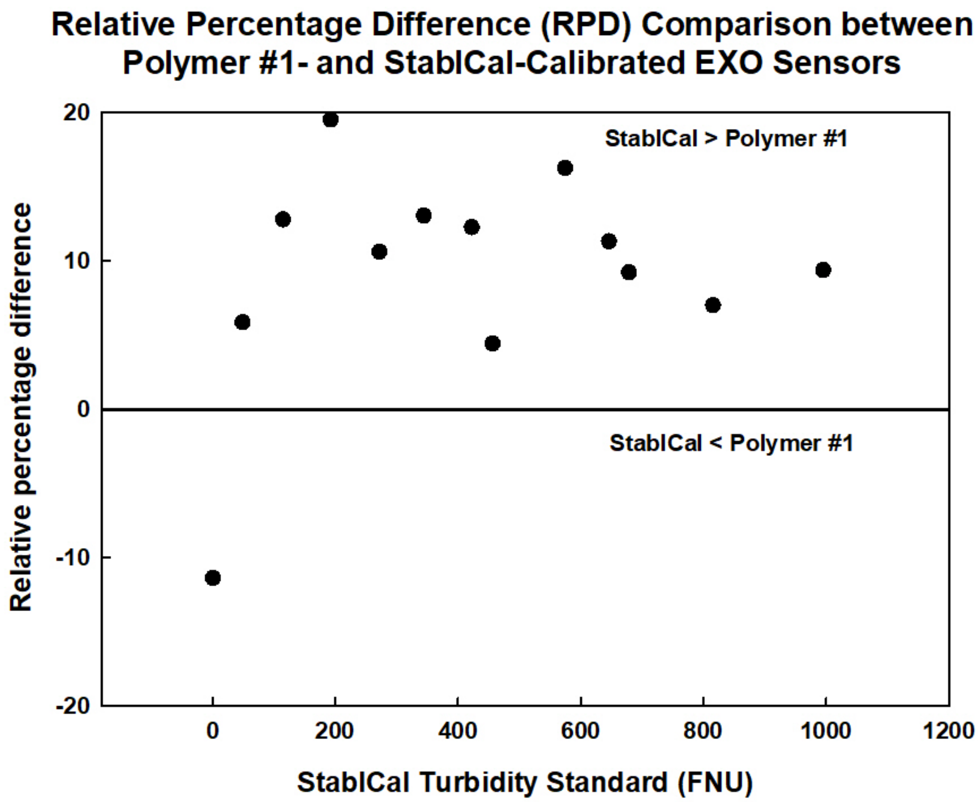
$$y = 0.92x - 6.20$$

where

y = turbidity measured with polymer #1-calibrated EXO sensor (FNU)

x = turbidity measured with StablCal-calibrated EXO sensor (FNU).


Linear Association of Averaged StablCal and
Polymer #1 Turbidity Data
y = 0.92x - 6.20
R = 1.00
R2 = 1.00
1:1 Line
Turbidity using polymer #1-calibrated EXO sensor (FNU)
Turbidity using StablCal-calibrated EXO sensor (FNU)
0
200
400
600
800
1000
1200



Paired t-test for StablCal and Polymer #1 Data

SigmaPlot Statistical Output:

Normality Test (Shapiro-Wilk): Passed (P = 0.757)

Paired t-test:

Treatment Name	N	Missing	Mean	Std Dev	SEM
StablCal	13	0	427.873	304.935	84.574
Polymer #1	13	0	385.723	279.678	77.569
Difference	13	0	42.150	29.328	8.134

t = 5.182 with 12 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: 24.427 to 59.873

Two-tailed P-value = 0.000229

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 = 0.000114

The sample mean of treatment StablCal exceeds the sample mean of treatment polymer #1 by an amount that is greater than would be expected by chance, rejecting the hypothesis that the population mean of treatment Polymer #1 is greater than or equal to the population mean of treatment StablCal (P = <0.001).

Power of performed two-tailed test with alpha = 0.050: 0.997

Power of performed one-tailed test with alpha = 0.050: 0.999

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 1.00). Relative percentage difference ranged from 4 to 19 percent (median: 11 percent; mean: 11 percent). The data passed the Shapiro-Wilk test for normality (P=0.757); therefore, a paired t-test was performed. The difference between mean values for the StablCal- and polymer #1-calibrated EXO sensor was statistically significant (P<0.05).

Statistical Analyses - StablCal and Polymer #2 Data

Slope comparison

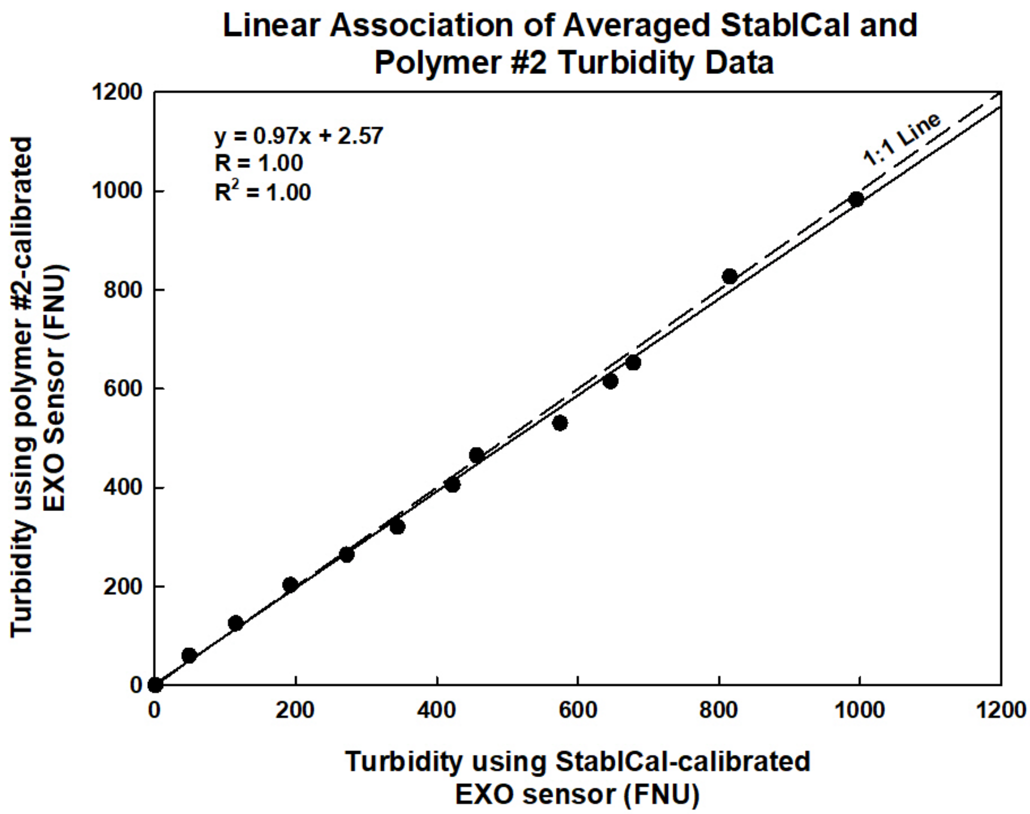
The following is a summary of final regression analysis for sensor-measured turbidity from one YSI EXO turbidity sensor calibrated by using StablCal turbidity standard and one YSI EXO turbidity sensor calibrated by using polymer #2 turbidity standard at the Kansas Water Science Center laboratory, Lawrence, Kansas, on September 7, 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:

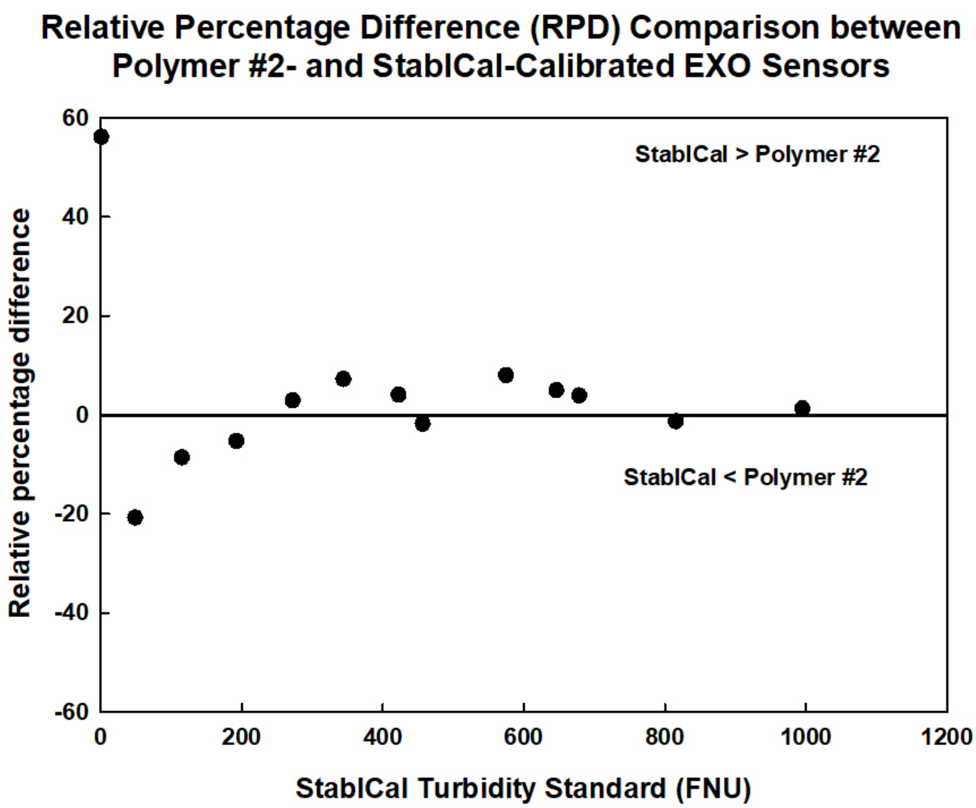
$$y = 0.97x + 2.57$$

where

y = turbidity measured with polymer #2-calibrated EXO sensor (FNU)

x = turbidity measured with StablCal-calibrated EXO sensor (FNU).


Linear Association of Averaged StablCal and
Polymer #2 Turbidity Data
y = 0.97x + 2.57
R = 1.00
R2 = 1.00
1:1 Line
Turbidity using polymer #2-calibrated
EXO Sensor (FNU)
Turbidity using StablCal-calibrated
EXO sensor (FNU)
0
200
400
600
800
1000
1200



Paired t-test for StablCal and Polymer #2 Data

SigmaPlot Statistical Output:

Normality Test (Shapiro-Wilk): Passed (P = 0.128)

Paired t-test:

Treatment Name	N	Missing	Mean	Std Dev	SEM
StablCal	13	0	427.873	304.935	84.574
Polymer #22	13	0	419.213	297.421	82.490
Difference	13	0	8.660	18.836	5.224

t = 1.658 with 12 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: -2.722 to 20.043

Two-tailed P-value = 0.123

The change that occurred with the treatment is not great enough to exclude the possibility that the difference is due to chance (P = 0.123)

One-tailed P-value = 0.0616

The sample mean of treatment StablCal does not exceed the sample mean of the treatment Polymer 2 by an amount great enough to exclude the possibility that the difference is due to random sampling variability. The hypothesis that the population mean of treatment Polymer 2 is greater than or equal to the population mean of treatment StablCal cannot be rejected. (P = 0.123)

Power of performed two-tailed test with alpha = 0.050: 0.332

The power of the performed test (0.332) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.

Power of performed one-tailed test with alpha = 0.050: 0.468

The power of the performed test (0.468) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 1.00). Relative percentage difference ranged from 1 to 56 percent (median: 5 percent; mean: 10 percent). The data passed the Shapiro-Wilk test for normality (P=0.128); therefore, a paired t-test was performed. The difference between mean values for the StablCal- and polymer #2-calibrated EXO sensors was not statistically significant (P>0.05).

Statistical Analyses - Polymer #1 and Polymer #2 Data

Slope comparison

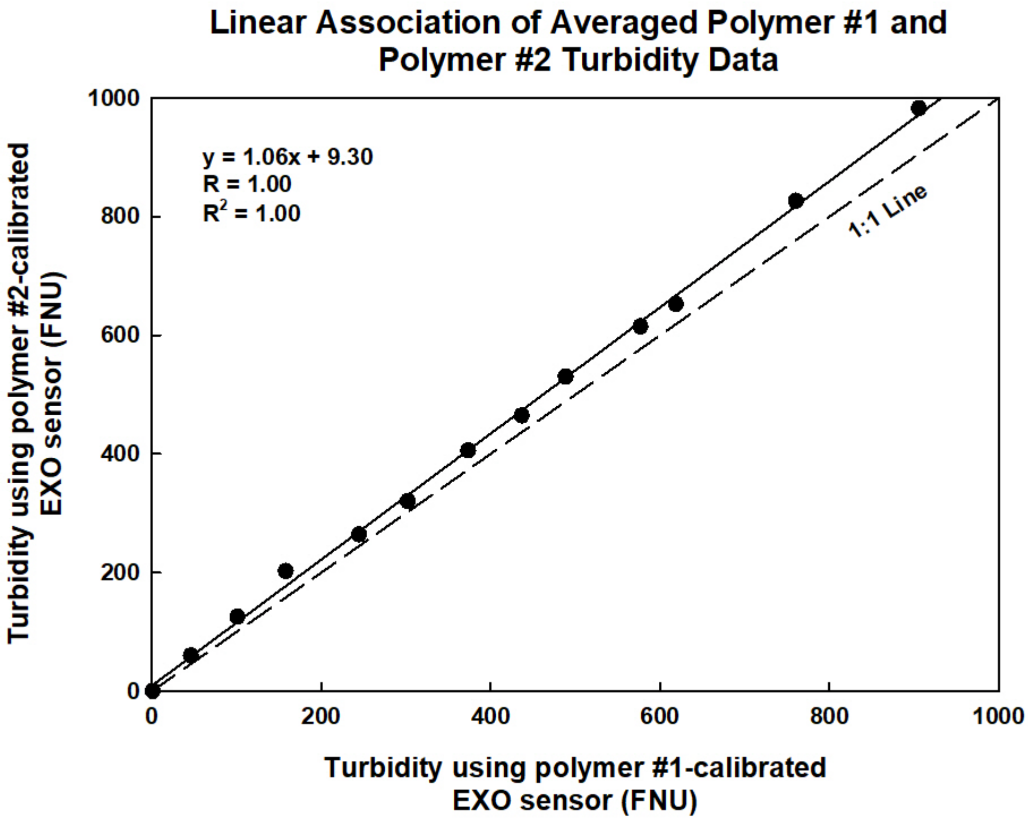
The following is a summary of final regression analysis for sensor-measured turbidity from one YSI EXO turbidity sensor calibrated in polymer #1 turbidity standard and one YSI EXO turbidity sensor calibrated in polymer #2 turbidity standard at the Kansas Water Science Center laboratory, Lawrence, Kansas, on September 7, 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:

$$y = 1.06x + 9.30$$

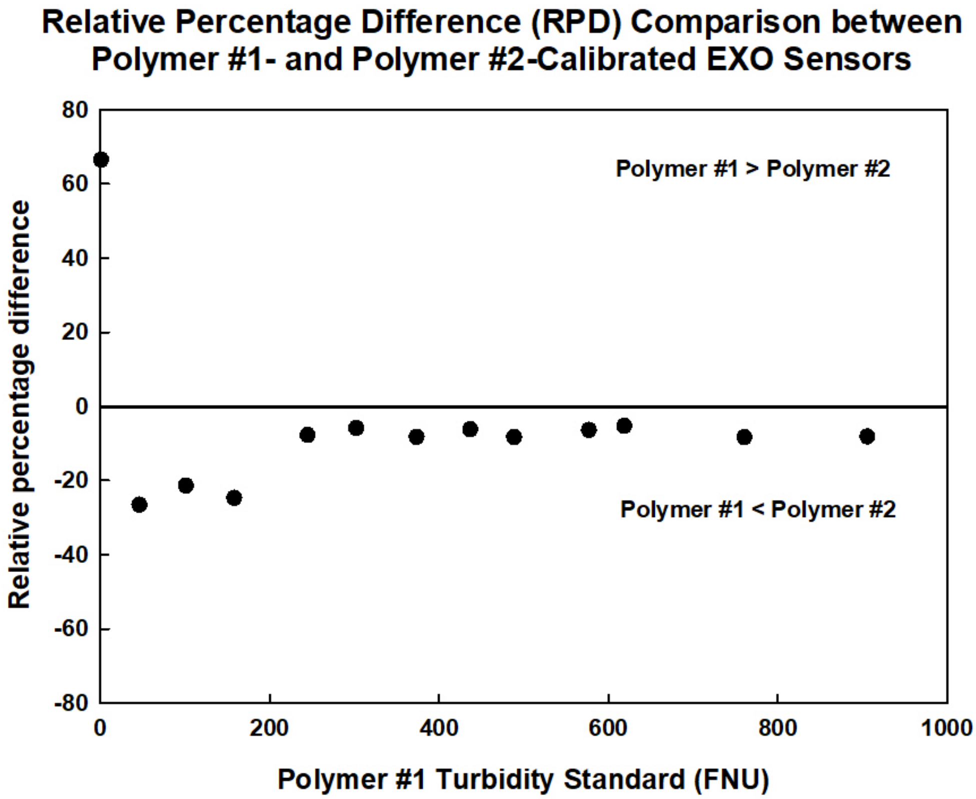
where

y = turbidity measured with polymer #2-calibrated EXO sensor (FNU)

x = turbidity measured with polymer #1-calibrated EXO sensor (FNU).



Linear Association of Averaged Polymer #1 and Polymer #2 Turbidity Data
y = 1.06x + 9.30
R = 1.00
R^2 = 1.00
1:1 Line
Turbidity using polymer #2-calibrated EXO sensor (FNU)
Turbidity using polymer #1-calibrated EXO sensor (FNU)
0
200
400
600
800
1000



Paired t-test for Polymer #1 and Polymer #2 Data

SigmaPlot Statistical Output:

Normality Test (Shapiro-Wilk): Passed (P = 0.707)

Paired t-test:

Treatment Name	**N**	**Missing**	**Mean**	**Std Dev**	**SEM**
Polymer #1	13	0	385.723	279.678	77.569
Polymer #2	13	0	419.213	297.421	82.490
Difference	13	0	-33.490	20.757	5.757

t = -5.817 with 12 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: -46.033 to -20.946

Two-tailed P-value = 0.0000825

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 = 0.0000412

The sample mean of treatment Polymer 2 exceeds the sample mean of treatment Polymer 1 by an amount that is greater than would be expected by chance, rejecting the hypothesis that the population mean of treatment Polymer 1 is greater than or equal to the population mean of treatment Polymer 2. (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 ($R = 1.00$). Relative percentage difference ranged from 5 to 66 percent (median: 8 percent; mean: 16 percent). The data passed the Shapiro-Wilk test for normality ($P=0.707$); therefore, a paired t-test was performed. The difference between mean values for the polymer #1- and polymer #2-calibrated EXO sensors was statistically significant ($P<0.05$).

Statistical Analyses - StablCal and Hach 2100AN Data

Slope comparison

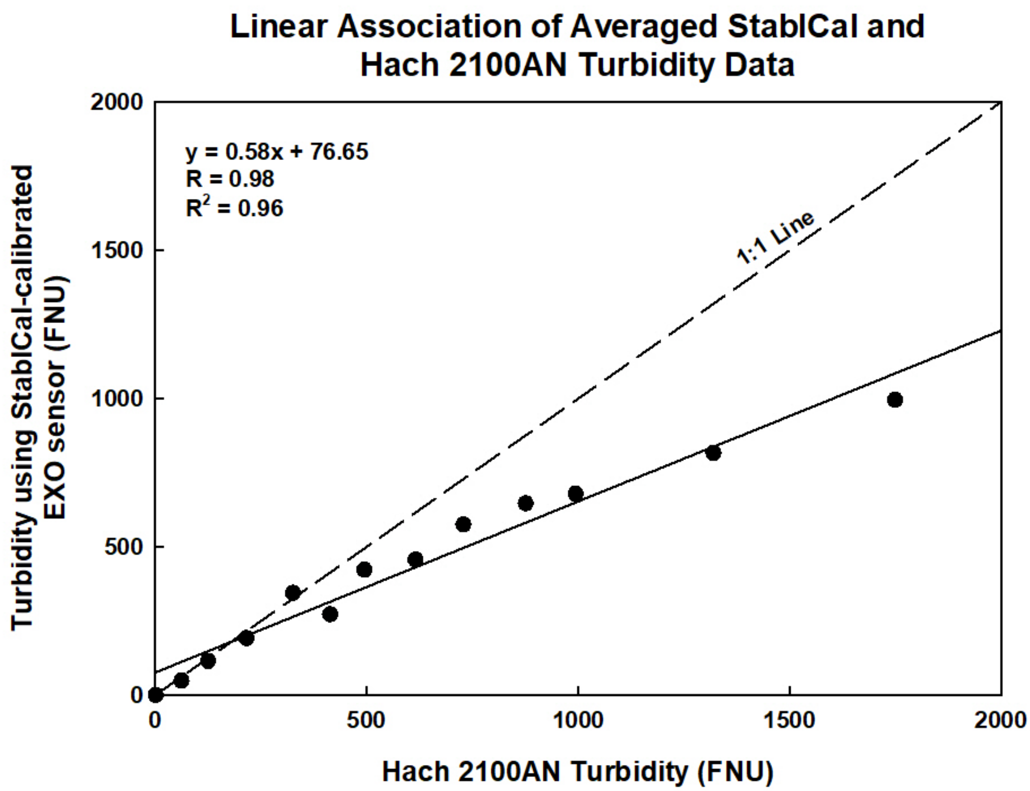
The following is a summary of final regression analysis for sensor-measured turbidity from one YSI EXO turbidity sensor calibrated by using StablCal turbidity standard and the Hach 2100AN laboratory turbidimeter at Kansas Water Science Center laboratory, Lawrence, Kansas, on September 7, 2017; the data 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:

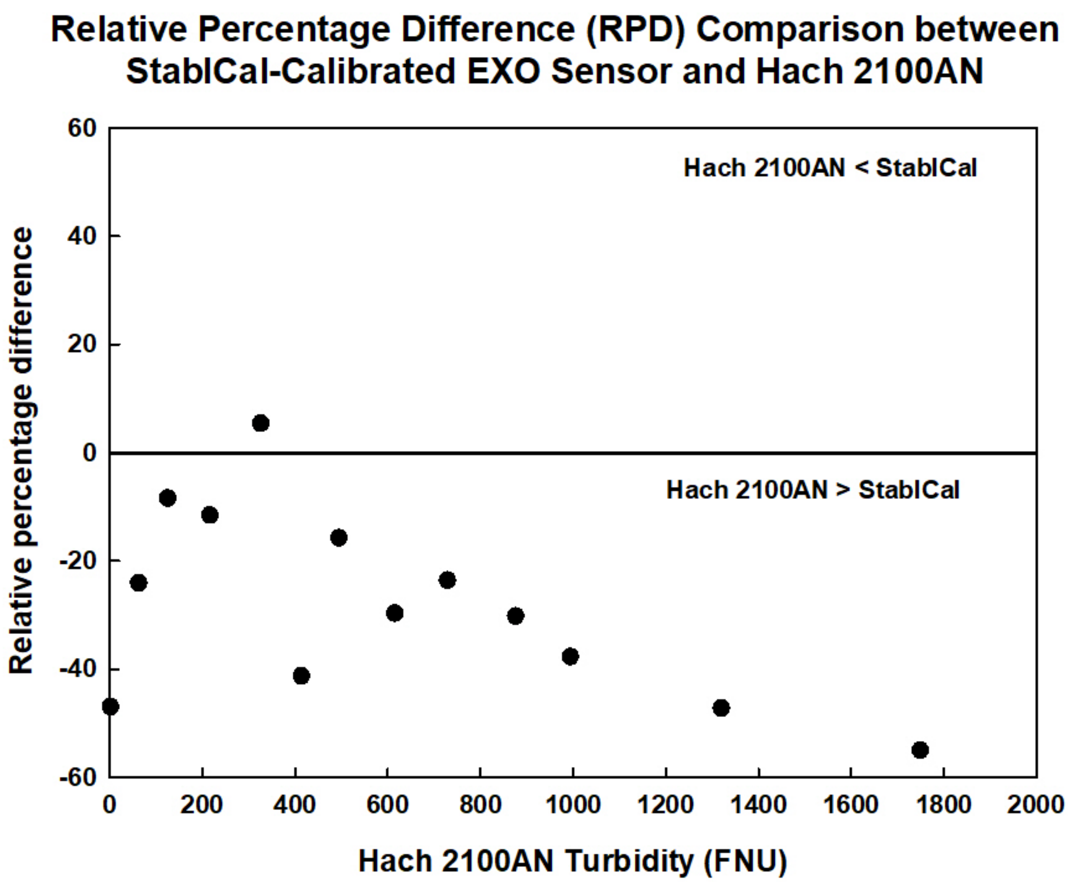
$$y = 0.58x + 76.65$$

where

y = turbidity measured with StablCal-calibrated EXO sensor (FNU)

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


Linear Association of Averaged StablCal and
Hach 2100AN Turbidity Data
y = 0.58x + 76.65
R = 0.98
R2 = 0.96
1:1 Line
Turbidity using StablCal-calibrated
EXO sensor (FNU)
Hach 2100AN Turbidity (FNU)
0
500
1000
1500
2000



Wilcoxon Signed-Rank Test for StablCal and Hach 2100AN Data

SigmaPlot Statistical Output:

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

Group	N	Missing	Median	25%	75%
Hach 2100AN	13	0	494.500	170.500	935.000
StablCal	13	0	422.343	153.652	662.453

W= -83.000 T+ = 4.000 T-= -87.000

Z-Statistic (based on positive ranks) = -2.900

P(est.) = 0.004 P(exact)= 0.002

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant difference ($P = 0.002$).

R Statistical Output:

```
Wilcoxon Signed-Rank test with continuity correction

data:  Hach 2100AN and StablCal
V = 87, p-value = 0.001709
alternative hypothesis: true location shift is not equal to 0
95 percent confidence interval:
  41.3620 329.2395
sample estimates:
(pseudo)median
       148.086
```

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 0.98). Relative percentage difference ranged from 5 to 55 percent (median: 30 percent; mean: 29 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 StablCal-calibrated EXO sensor and Hach 2100AN was statistically significant ($p<0.05$).

Statistical Analyses - Polymer #1 and Hach 2100AN data

Slope comparison

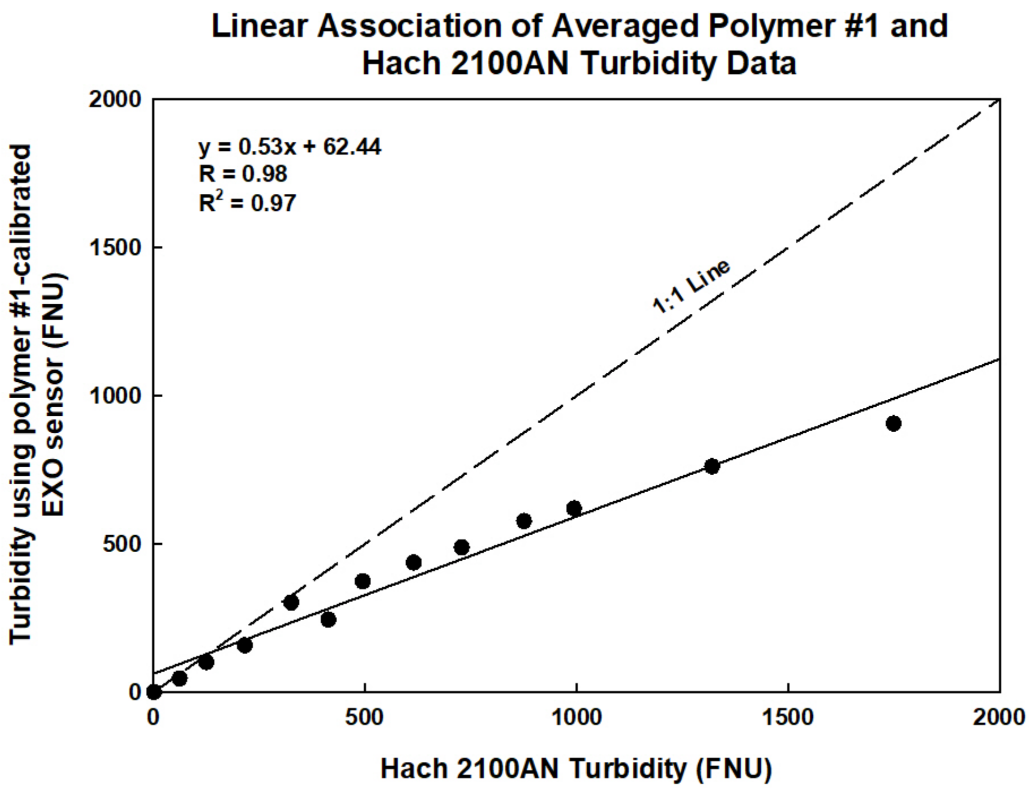
The following is a summary of final regression analysis for sensor-measured turbidity from one YSI EXO turbidity sensor calibrated by using polymer #1 turbidity standard and the Hach 2100AN laboratory turbidimeter at the Kansas Water Science Center laboratory, Lawrence, Kansas, on September 7, 2017; 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:

$$y = 0.53x + 62.44$$

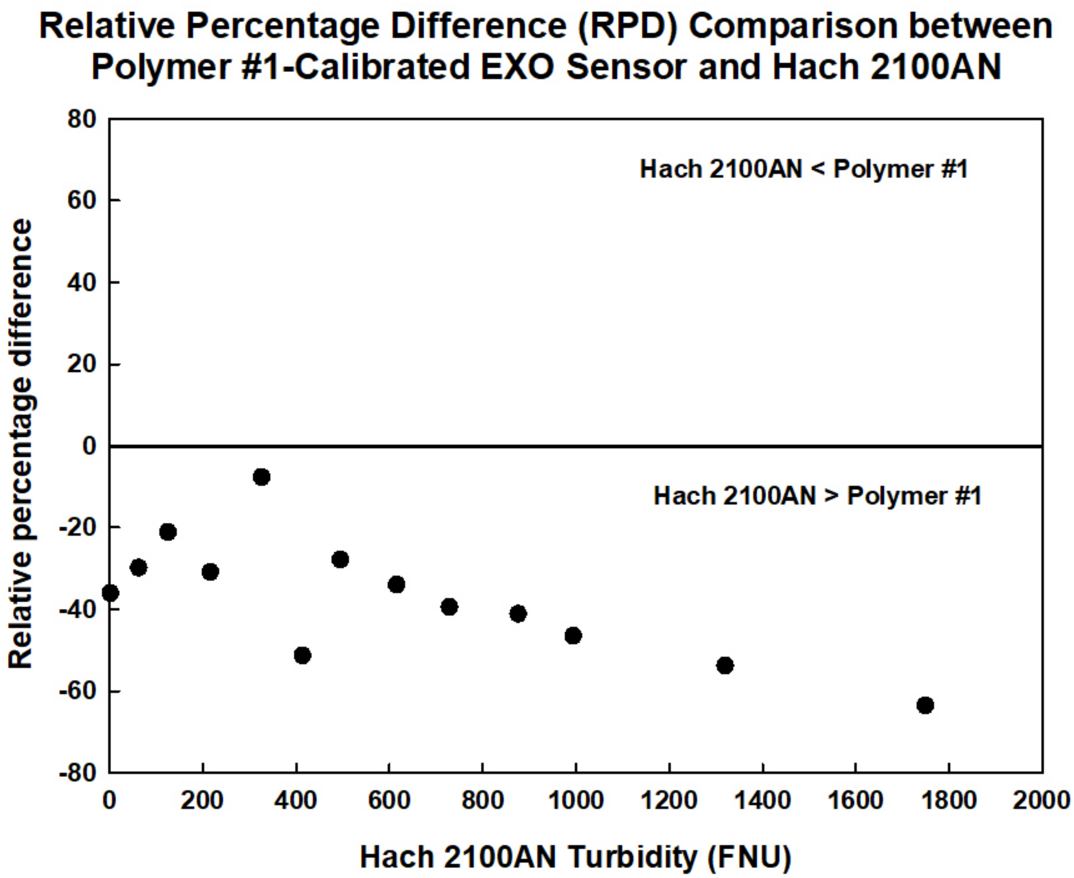
where

y = turbidity measured with polymer #1-calibrated EXO sensor (FNU)

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



Linear Association of Averaged Polymer #1 and
Hach 2100AN Turbidity Data
y = 0.53x + 62.44
R = 0.98
R2 = 0.97
1:1 Line
Turbidity using polymer #1-calibrated
EXO sensor (FNU)
0
500
1000
1500
2000
0
500
1000
1500
2000
Hach 2100AN Turbidity (FNU)



Wilcoxon Signed-Rank Test for Polymer #1 and Hach 2100AN Data

SigmaPlot Statistical Output:

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

Group	N	Missing	Median	25%	75%
Hach 2100AN	13	0	494.500	170.500	935.000
Polymer #1	13	0	373.589	129.662	598.007

W= -91.000 T+ = 0.000 T-= -91.000

Z-Statistic (based on positive ranks) = -3.180

P(est.) = 0.002 P(exact)= <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:  Hach and Polymer #1
V = 91, p-value = 0.0002441
alternative hypothesis: true location shift is not equal to 0
95 percent confidence interval:
  72.39077 375.07734
sample estimates:
(pseudo)median
      178.7571
```

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 0.98). Relative percentage difference ranged from 8 to 64 percent (median: 36 percent; mean: 37 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 polymer #1-calibrated EXO sensor and Hach 2100AN was statistically significant ($P<0.05$).

Statistical Analyses - Polymer #2 and Hach 2100AN Data

Slope comparison

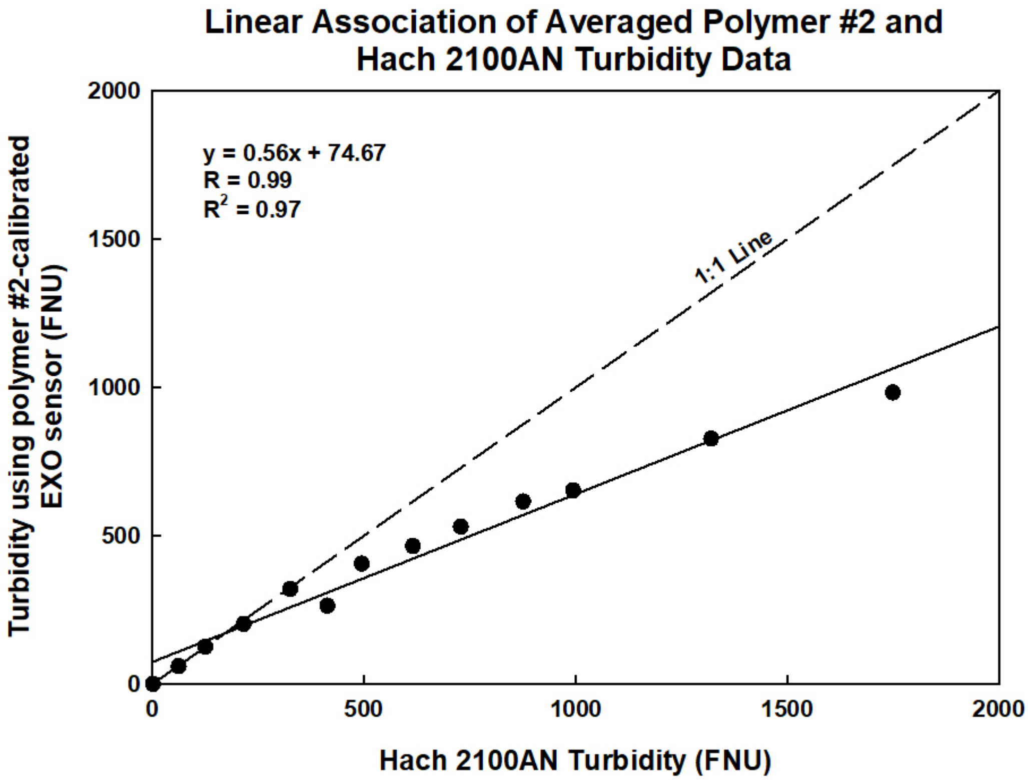
The following is a summary of final regression analysis for sensor-measured turbidity from one YSI EXO turbidity sensor calibrated by using polymer #2 turbidity standard and the Hach 2100AN laboratory turbidimeter at Kansas Water Science Center laboratory, Lawrence, Kansas, on September 7, 2017; the 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:

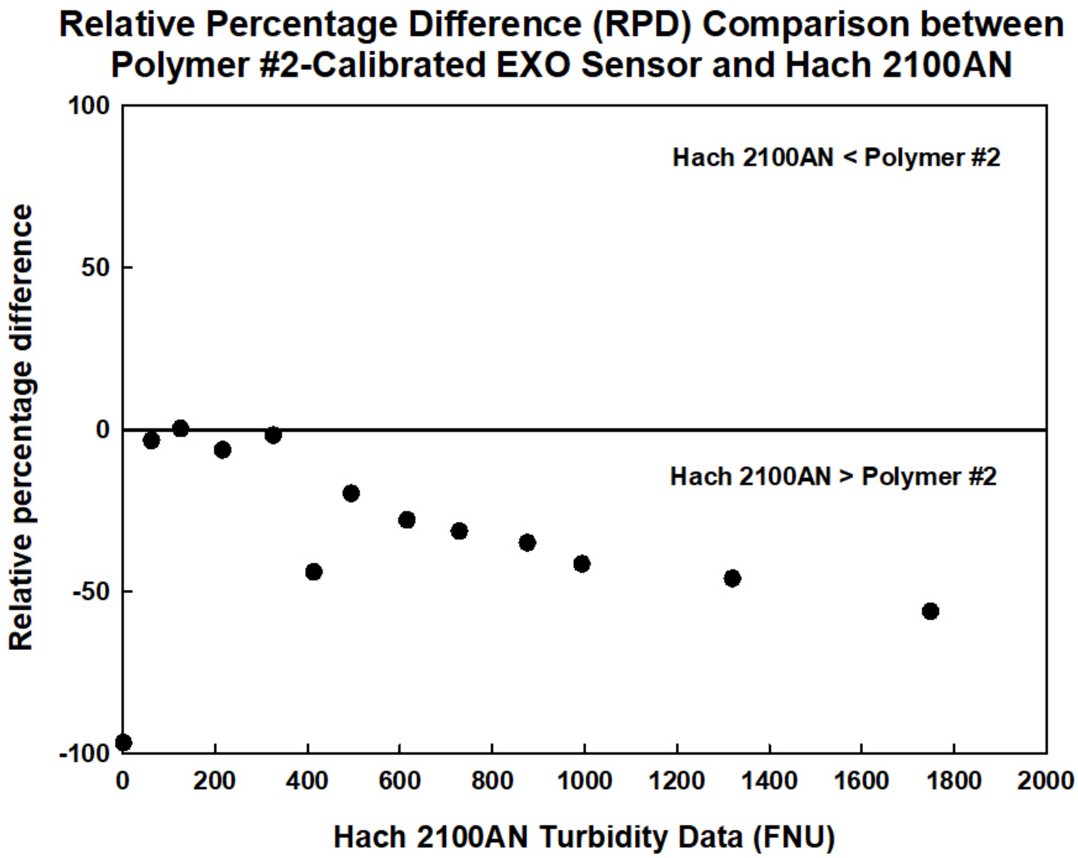
$$y = 0.56x + 74.67$$

where

y = turbidity measured with polymer #2-calibrated EXO sensor (FNU)

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


Linear Association of Averaged Polymer #2 and
Hach 2100AN Turbidity Data
y = 0.56x + 74.67
R = 0.99
R2 = 0.97
1:1 Line
Turbidity using polymer #2-calibrated
EXO sensor (FNU)
Hach 2100AN Turbidity (FNU)
0
500
1000
1500
2000



Wilcoxon Signed-Rank Test for Polymer #2 and Hach 2100AN Data

SigmaPlot Statistical Output:

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

Group	**N**	**Missing**	**Median**	**25%**	**75%**
Hach 2100AN	13	0	494.500	170.500	935.000
Polymer #2	13	0	405.529	164.047	633.662

W= -89.000 T+ = 1.000 T-= -90.000

Z-Statistic (based on positive ranks) = -3.110

P(est.) = 0.002 P(exact)= <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:  Hach 2100AN and Polymer
V = 90, p-value = 0.0004883
alternative hypothesis: true location shift is not equal to 0
95 percent confidence interval:
  45.64418 341.56130
sample estimates:
(pseudo)median
         150.6
```

Summary of Results

There is a strong linear association between measurements made with the two sensors (R = 0.99). Relative percentage difference ranged from 0 to 97 percent (median: 31 percent; mean: 32 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 polymer #2-calibrated EXO 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/.]