Comparison of Testing the Waters array to YSI Professional Pro

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Overview

The goal of this project was to compare reading from industry standard multiparameter instrument (YSI Professional Plus) with the Current Data prototype used in Testing the Waters project. Comparisons were made for both static and moving readings and the results analyzed and documented.

Equipment

Details on each of the devices tested in this comparison:

Standard multiparameter instrument – YSI

YSI Professional Plus

- 3.4 firmware
- Quatro field cable
- 1001 pH sensor
- 2003 Polarographic dissolved oxygen sensor
- 5560 Conductivity/temperature sensor

New membrane and electrolytic solution placed on DO sensor per instructions. Note that version 4.0 firmware is available, but since this isn't my unit, didn't feel comfortable upgrading.

Prototype multiparameter instrument – Current Data (labeled RRC #1 in graphs)

Custom array built by Eric Compas using off-the-shelf components and connected to an Arduino open hardware microcontroller. List of components and vendor:

- pH Kit (glass bulb type), Atlas Scientific
- Dissolved oxygen kit (galvanic membrane), Atlas Scientific
- Conductivity kit K 0.1 (most sensitive, meant for fresh water), Atlas Scientific
- Whitebox Labs Tentacle Shield (to electronically isolate each probe from one another), Atlas Scientific
- Maxim DS18B20 Temperature probe, SparkFun
- Arduino Uno, SparkFun
- Other components: Bluetooth chip, battery pack, water resistance case, mounting hardware

The array communicates to a cell phone where GPS coordinates are added (accuracy varies between 3 and 10 meters) and sent to a server at UWW.

Testing procedure

The testing procedure consisted of calibrating the two units, recording pre-sample calibration values, field sampling along a stretch of the Bark and Rock Rivers, and post-sampling calibration values.

Calibration

All units were first calibrated twice[1] in the same calibration solutions and rinse water that was stored in same room for at least 5 hours before procedure began (to equalize temperatures). When both units were calibrated to the same standard, the exact same solution was used. Calibration procedures specified by the vendors was used except for a modified dissolved oxygen process for the Current Data array (using an aerated solution as per USGS Field Manual, Rounds et al. 2013).

Overview of calibration procedures and number of calibration points for each parameter:

DO:
- YSI: 1 point, calibrated at 100% saturation in humid storage chamber
- Current: 1 point, calibrated in 100% saturation bubble bath (USGS methodology)

pH:
- YSI: 3 point, stayed in calibration for at least 1 minute for 7.01, 4, and 10.01 pH
- Current: 3 point, stayed in calibration solution for at least 1 minute for same

EC:
- YSI: 1 point, stayed in calibration solution for at least 1 minute at 1,413 uS/cm
- Current: 3 point, dry and at 1 minute in 84 and then 1,413 uS/cm

Temperature cannot be calibrated in either unit. Barometric pressure was set to the calibration site (my house) which is at the same altitude as the sample location. Note that the calibration procedures for each device are similar except for dissolve oxygen.

After calibration, measurement of calibration solution for each probe was taken and recorded.

Field method

The field sampling included paddling approximately ½ mile of the lower Bark River into the Rock River to the take out at the Fort Atkinson Water Utility (Figure 1). This section was chosen since there is typically a significant difference in the temperature, dissolved oxygen, and conductivity values between the two water bodies and therefore would better highlight differences between each unit and how they respond to this gradient.

[1] Both units had been in storage for more than a month, and I find in general the units perform better the more they're used. Plus, the repeated calibration reduced the change of operator error in the process.

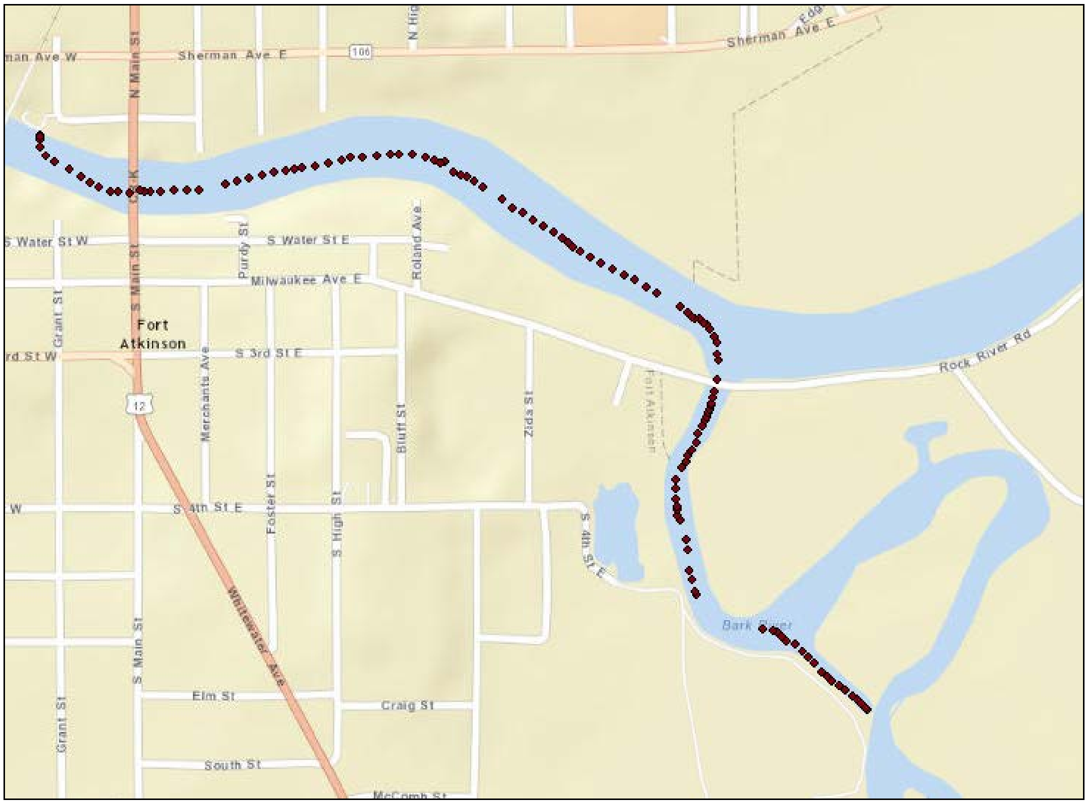


Figure 1. Sampled stream section showing Current array sample points.

The Current unit was mounted on kayak as in the Testing the Water event and set to a depth of 15cm (higher blue tape marking). Similar tape added to YSI at approximately the same height (top of the quatro cable housing), and when taking measurements was set at this height.

At the beginning of the sample stretch, both units were placed in the water and turned on for five minutes (to equilibrate) before any measurements were taken. Both were set to take samples every 10 seconds and the author paddled at Testing the Waters speed for approximately 100 yards, then drifted for a minute, and then repeated the 100-yard paddle until the take out was reached. At the end of the paddle, a photo was taken of the YSI screen to allow a later calculation of the time offset between the Current and YSI units.

After field sampling, the units were then again placed in new calibration standards for each parameter to measure sensor drift across the afternoon (approximately 5 hours).

In order to “line up” Current and YSI samples, an algorithm was written which accounted for the time difference between the two units (47 seconds) and matched samples that were within 10 seconds of one another.

Results

The pre- and post-sampling measurement of calibration standards is shown in Table 1.

Table 1. Pre- and post-sampling measurement of calibration standards for each unit.

Unit	Parameter	Calibration target value	Pre-sample measure	Pre-sample deviation	Pre-sample % change	Post-sample measure	Post-sample deviation	Post-sample % change	Pre- to Post-deviation
RRC #1	DO% bubbler	100	101.2	1.2	1.2%	102.3	2.3	2.3%	1.1
RRC #2	pH	7.01	7.0	-0.039	-0.6%	7.2	0.193	2.7%	0.232
RRC #3	EC	1,413	1,414.0	1.0	0.1%	1,441.0	28.0	2.0%	27.0
YSI	DO% tube	100	99.8	-0.2	-0.2%	98.6	-1.4	-1.4%	-1.2
YSI	DO% bubbler	100	92.1	-7.9	-7.9%	93.3	-6.7	-6.7%	1.2
YSI	pH	7.01	7.0	0.005	0.1%	7.0	0.010	0.1%	0.005
YSI	EC	1,413	1,420.5	7.5	0.5%	1,427.5	14.5	1.0%	7.0

The pre- and post-sampling measurements of calibration standards reveals several differences between the units. The pre-sample percent deviations for both units are similar and are all within 1% except for each in the dissolved oxygen bubbler solution (note that the YSI wasn't calibrated in this solution, so the larger deviation is expected). Post-sampling changes, however, were greater for the Current/RRC unit at around 2% drift as compared to around 1% drift for the YSI. Given the total sampling period was fairly short, around 4-5 hours between pre- and post-measurements, it would be expected that higher drift value would be expected on Testing the Waters sampling days.

The field sampling yielded 152 paired sample points were time stamps were within 10 seconds of one another. Table 2 shows the mean values and standard deviations for these samples and the mean difference between paired samples.

Table 2. Means, mean differences, and standard deviations for both unit during field sampling (*n* = 152).

	RRC #1		YSI		
	Mean	**SD**	**Mean**	**SD**	**Mean difference**
Temp C	16.49	0.061	16.57	0.145	-0.0737
pH	7.81	0.114	7.74	0.098	-0.0739
DO mg/L	6.53	1.311	6.08	1.255	-0.4035
DO %	66.81	13.438	61.97	12.939	-4.3974
Cond uS/cm	565.67	62.111	705.17	70.024	143.2243

The differences in means show relatively small differences except for conductivity values.

Plots of paired samples along the sampled river section (Figure 2) better reveal the differences and consistencies between the two units.

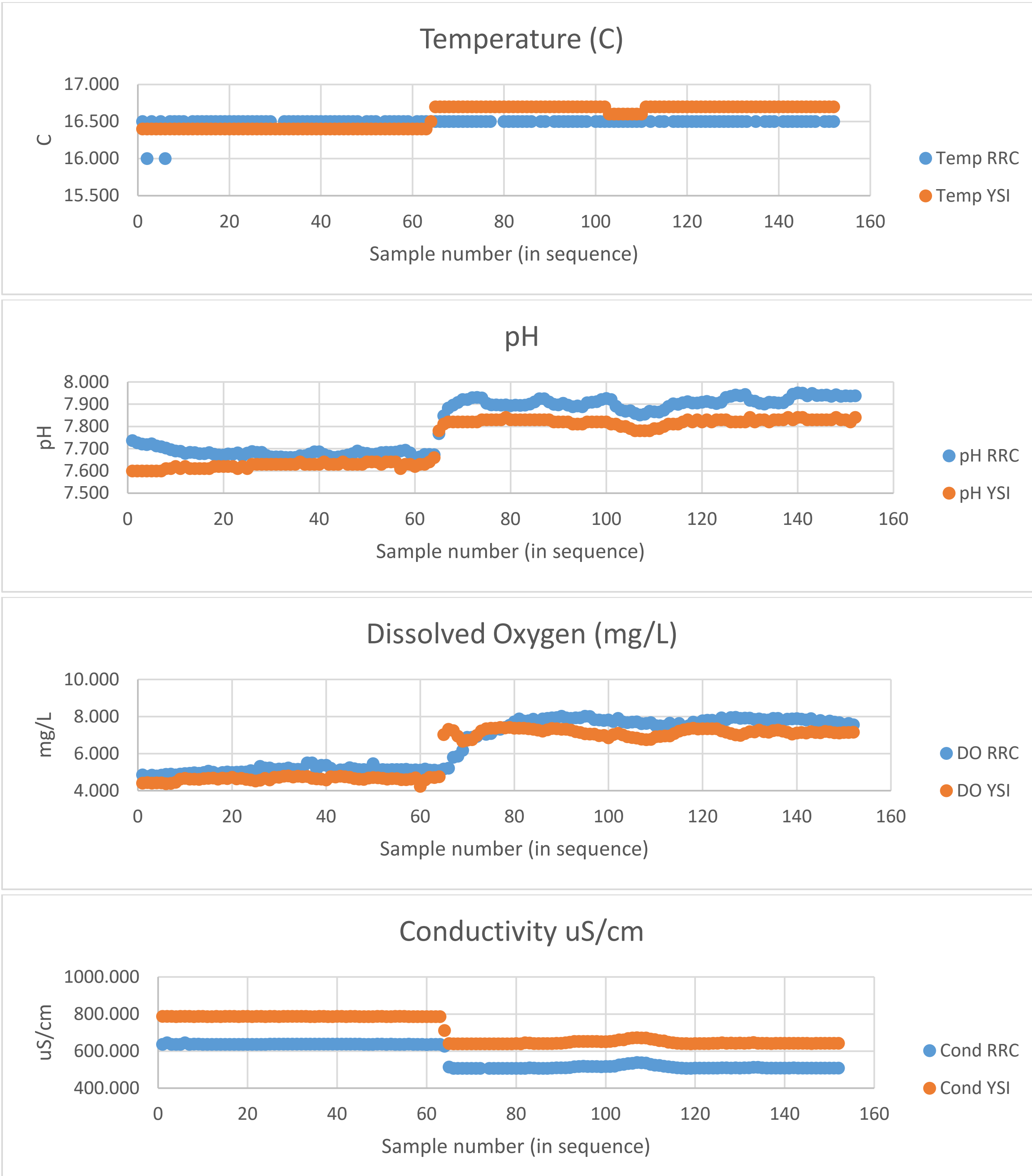
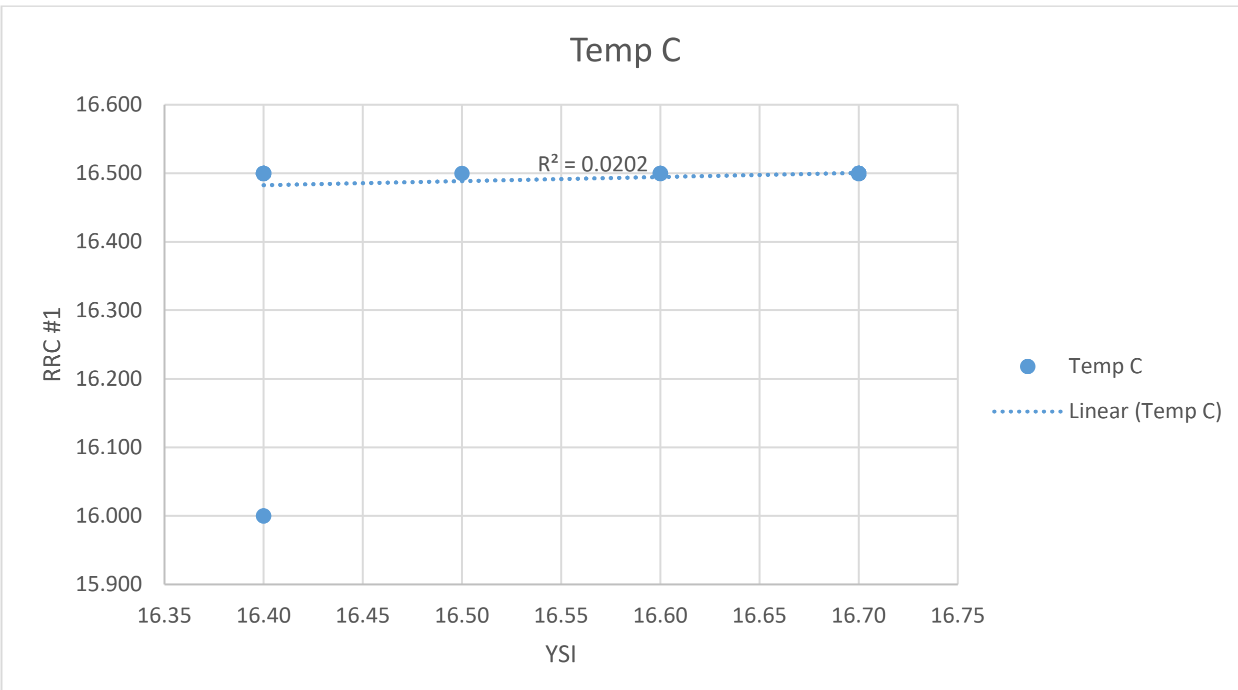
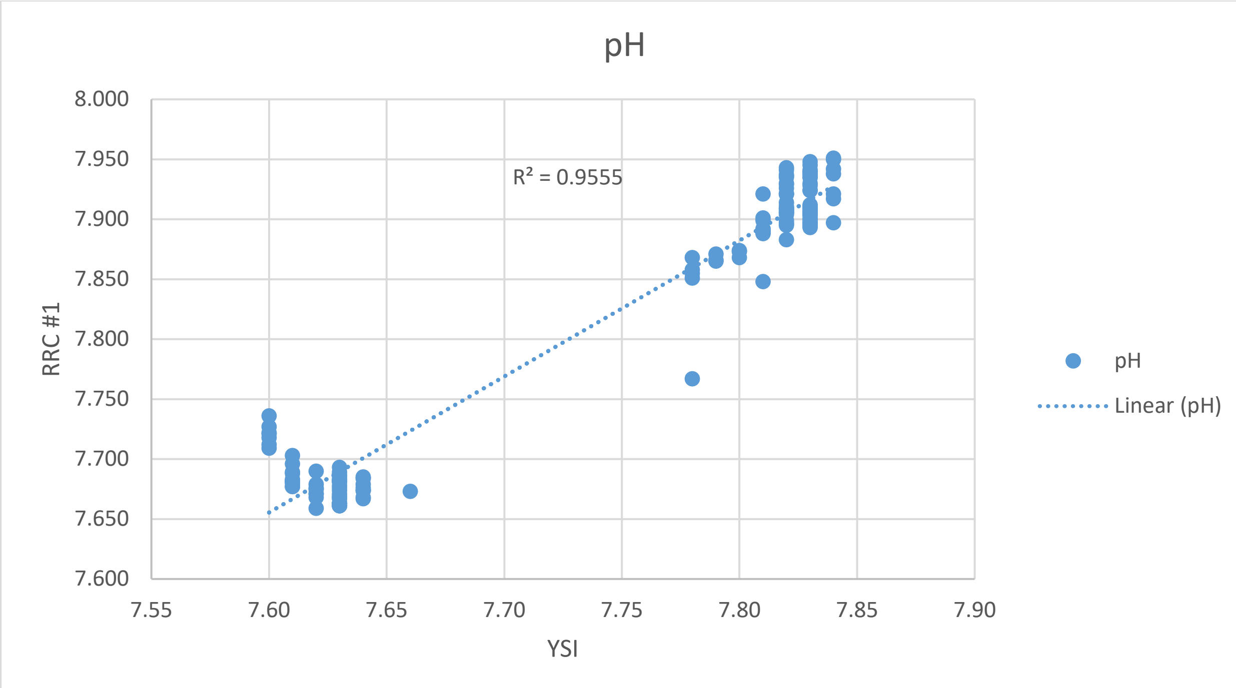


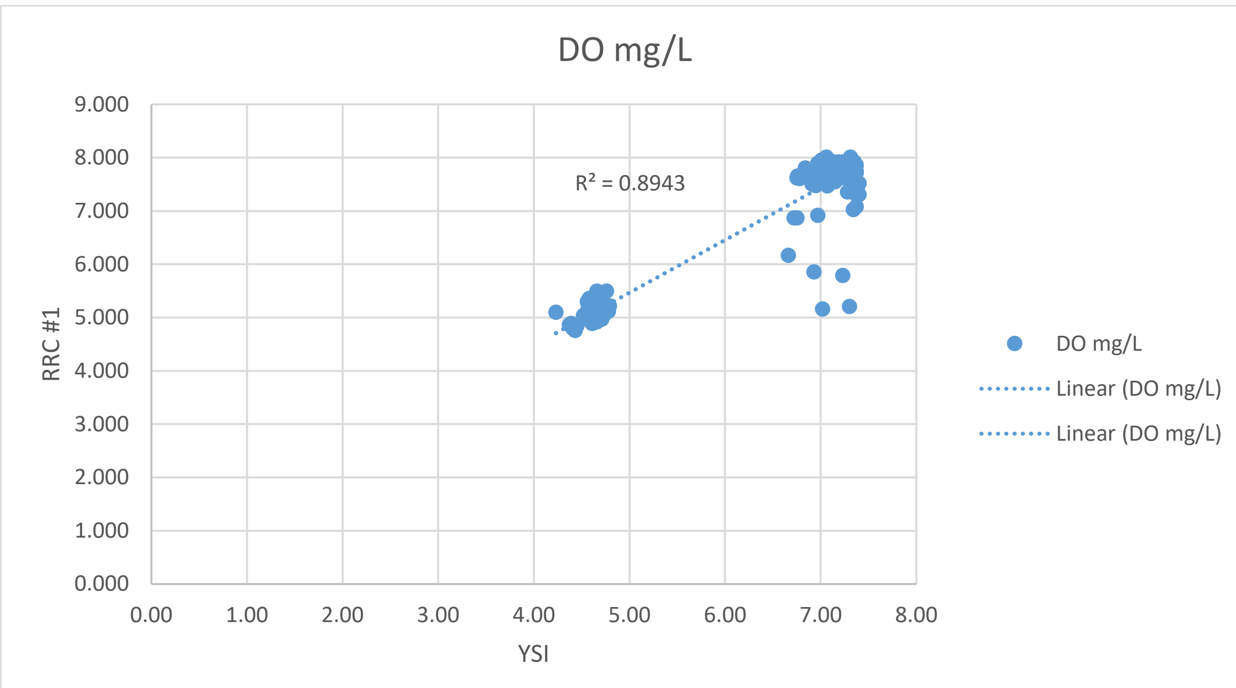
Figure 2. Plots of paired sample values from Bark River into Rock River to Fort Atkinson municipal take out.

The graphs of pair samples show general agree between the units in relative change in water parameters and highlight differences in initial calibration. In general, the YSI exhibits a “smoother” data series (which may be due to internal sampling and smoothing algorithms). Conductivity values mirror each other very closely. Temperate value, while close, highlight the limits of the Current array which measures only to the nearest 0.5°C while the YSI measures to the nearest 0.1°C. The pH values show some disagreement at the beginning of the sample – the Current pH probe may take longer to settle on an accurate reading – and shows greater variability during the sample. Interestingly, the difference between pH values is higher in the Rock River than the differences in the Bark River samples. Additionally, the pH values do show a change when drifting, and show up as small peaks in the pH values in the graph. For the Current unit pH values are more in agreement with the YSI *while moving* than when standing still. For dissolved oxygen, there is clearly a lag in the readings from the Current/RRC unit. As the kayak entered the Rock River and DO values increased, the YSI responded more quickly to the change. The Current/RRC unit took about a minute longer to reach the same higher values. Here, the YSI appears to be responding to the boat's velocity with the DO values dropping slightly when the boat is drifting (the peaks in the Current/RRC unit match the valleys in the YSI DO readings)

Finally, Figure 3 shows scatterplots of paired values with linear trend lines and R^2 values.




pH
8.000
7.950
7.900
7.850
7.800
7.750
7.700
7.650
7.600
RRC #1
R^2 = 0.9555
7.55
7.60
7.65
7.70
7.75
7.80
7.85
7.90
YSI
pH
Linear (pH)


DO mg/L
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
RRC #1
R^2 = 0.8943
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
YSI
DO mg/L
Linear (DO mg/L)
Linear (DO mg/L)

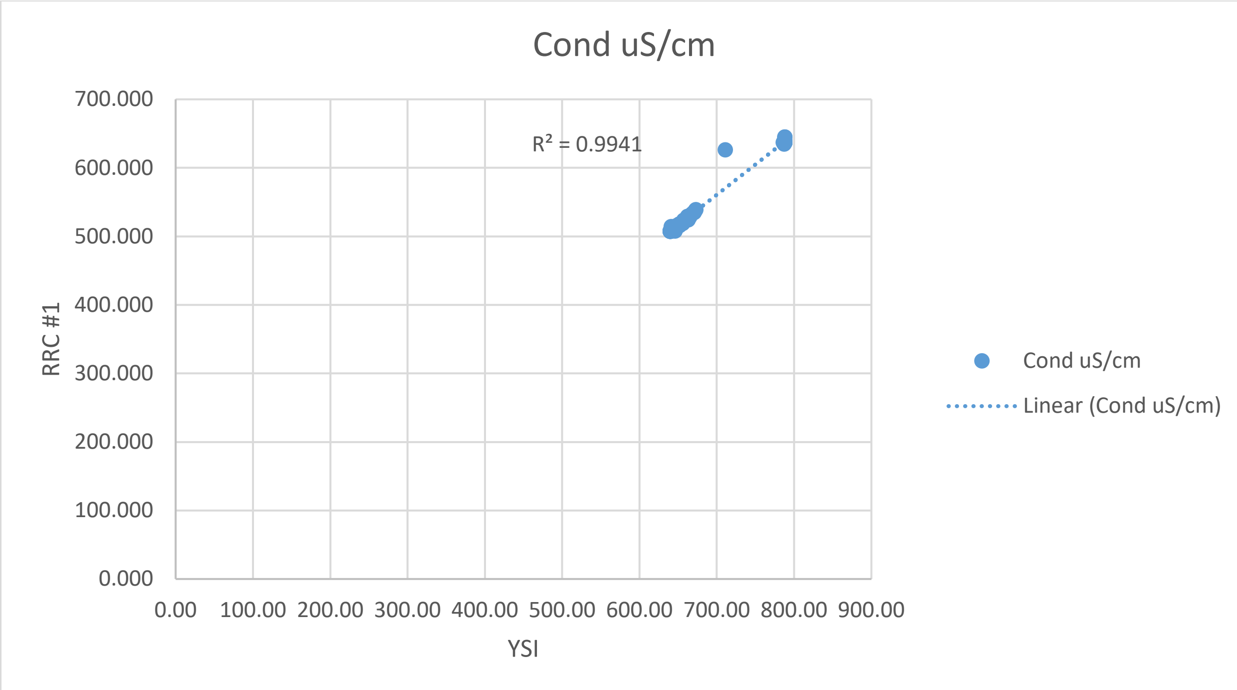


Figure 3. Scatterplots of paired samples for each parameter with trend line and R^2 values.

Given the relatively similar parameter values for the Bark and Rock Rivers, these plots do not reveal as much variation as would be helpful in better comparing the units across a broad range of conditions. For the sampled data, though, there is, again, relatively consistent measurements with respective R^2 values for temperature, dissolved oxygen, pH, and conductivity of 0.02, 0.89, 0.96, and 0.99. Overall, these high collinearity values confirm the similar trends visible in the profile graphs. Both units are measuring consistent changes in the rivers' waters. The low R^2 value for temperature is attributed to the sample resolution of the sensors and the non-linearity that resolution exhibits for the narrow range of temperatures sampled (a linear model may not be appropriate for this particular sample).

Discussion

This comparison of the Current/RRC array with a trusted, commercial multiparameter array, the YSI Professional Plus, revealed fairly consistent measurements between each. The pre- and post- measurement of calibration standards revealed that the Current/RRC unit was not as accurate as the YSI, showing around 2% drift by the end of the sample period. However, that's a relatively high-level of accuracy for a unit that is hand built and cost approximately a third of the YSI.

The relative values of each unit showed in the profile graphs and the scatterplot show a high degree of agreement between the two units. There were some indications that the relative velocity of the arrays in the water was influencing the pH and DO probes and these changes may warrant further investigation. In addition, the DO probe on the Current/RRC unit did exhibit a lag.

Raw absolute values between the two units were evident. The author does not have enough experience with arrays to determine whether or not these differences are significant. For spatial and/or temporal comparison between data sets, these differences could be important. The pre- and post-sample measurements of calibration standards could be used to create a linear correction for sample data throughout the series. Additionally, Crawford et al. (2016) have identified a mathematical correction technique in which the lag of a particular probe can be documented and accounted for.

Further use of the Current/RRC array and potential comparison with YSI (or other unit measurements) likely requires development of a set of corrections that incorporate calibration absolute value shifts, sensor drift, and lags/response times. While some relative velocity changes were noted, these would be difficult to model and correct for given the difficulty of measuring relative stream velocity either in the field or in post-processing.

References

Crawford, John T., Luke C. Loken, Emily H. Stanley, Edward G. Stets, Mark M. Dornblaser, and Robert G. Striegl. 2016. "Basin Scale Controls on CO2 and CH4 Emissions from the Upper Mississippi River." *Geophysical Research Letters* 43(5):1-7

Rounds, Stewart A., Franceska D. Wilde, and George F. Ritz. 2013. "Chapter A6 Field Measurements, Section 6.2 Dissolved Oxygen." In National Field Manual for the Collection of Water-Quality Data, 3.0, 55. USGS. http://water.usgs.gov/owq/FieldManual/Chapter6/6.2_ver3.pdf.