Water-Quality Comparison Data from 2011-12 CBIBS Buoy Visits

—Peter Bergstrom, NOAA Chesapeake Bay Office, September 2014

Executive Summary

This report summarizes some of the results of a comparison study of continuous water-quality monitoring data collected by two different types of monitors in Maryland's tidal Chesapeake Bay waters. One type is the WET Labs Water Quality Monitor (WQM) used in the most of the Chesapeake Bay Interpretive Buoy System (CBIBS) buoys deployed by the National Oceanic and Atmospheric Administration Chesapeake Bay Office (NCBO), and the other is the YSI 6600 monitor that are used in all of the Maryland Department of Natural Resources (DNR) Eyes on the Bay deployments. The YSI monitors are also used in one CBIBS buoy, at Gooses Reef. Both types of monitors record water-quality data for multiple parameters once per hour, but since they use slightly different technology, we performed this study to assess the comparability of their measurements.

To make a direct comparison of their measurements, we put a YSI monitor in one of the CBIBS buoys that already had a WQM monitor in it, just outside the Annapolis harbor. The two monitors were about 3 feet apart at about the same depth, so they were measuring essentially the same water. They were deployed from April-November in 2011 and 2012.

The results reported here are all from regular visits to the buoy by a field crew from MD DNR, usually every two weeks. We also examined data from post-calibration procedures done in the lab for both YSI and WQM monitors a few days after each swap, but we could not compare those data, because for the WQM they were collected after cleaning the instrument, and for the YSI they were collected before cleaning. Thus, the post-calibration data were not comparable. This report also does not examine the agreement of the hour-by-hour measurements made by the two monitors in the Annapolis buoy. Those results may be compared in a separate future report for 2012 data; the 2011 data had too many timing issues to analyze this way. While those hour-by-hour results have a much larger sample size, they only compare two measurement results, while there were up to five different results to compare during the field visit data analyzed here.

The results from the field visits were used to calculate the Coefficient of Variation (CV), a unitless measure of variability. This is the standard deviation (SD) divided by the mean, calculated over all the different measurements on a particular day during the field visit. Smaller is better (closer agreement). We also graphed the CV data from the different sensors by date.

The data reported here addressed two questions:

1. *From the field visit data, how closely did the measurements from the different sensors agree with each other, by parameter and over time?* Three parameters, DO (Dissolved Oxygen), SALIN (Salinity), and WTEMP (Water Temperature), had good agreement in both years, with low mean Coefficient of Variation (CV), 15% or less. However, for two parameters that use optical sensors, TURB (Turbidity) and CHLA (Chlorophyll a), mean CV was much higher (37-59%), and thus agreement was much worse. Agreement for TURB and CHLA did improve (lower CV) in 2012 compared to 2011, but it was still much worse than for the other three parameters in 2012.
2. *When the measurements did not agree closely, could we determine any likely reasons why?* The disagreement (mean CV) during field visits was probably higher (worse) for TURB and CHLA for two reasons: 1) they use optical sensors which are subject to fouling, even though they have automatic wipers on them; and 2) both parameters are more variable in space and time than the others measured because both involve particulate matter that can be patchy. (YSI DO also uses an optical probe, but it does not appear to be as subject to fouling as TURB & CHLA.)

These results are being used to identify and prioritize possible actions to improve agreement of results.

Background

In January 2011, Maryland Department of Natural Resources (MD DNR) and the Chesapeake Research Consortium (CRC), representing the National Oceanic and Atmospheric Administration Chesapeake Bay Office (NCBO), agreed that MD DNR would provide field maintenance services for five NCBO Chesapeake Bay Interpretive Buoy System (CBIBS) buoys in the Maryland portion of the Chesapeake Bay. These five buoys collect continuous physical (current and weather) and water-quality (dissolved oxygen, temperature, fluorescent chlorophyll a, salinity, and turbidity) measurements from water sites in the Chesapeake Bay. The goal of the agreement was to forge a partnership that would foster the use of CBIBS data for Chesapeake Bay Program (CBP) water-quality criteria assessments and as long-term sentinel data.

The location of the CBIBS buoys offers an opportunity to provide crucial insights into criteria attainment in open-water environments near a channel, in the mainstem Bay or a large tidal tributary. In contrast, MD DNR and its partners have collected continuous water-quality data at shallow nearshore sites throughout the Bay, mainly in tidal tributaries, through the Shallow Water Quality Monitoring Program (SWQMP). The SWQMP has existed for more than 10 years, with reliable quality assurance/quality control (QAQC) protocols established for the YSI 6600 monitors used to collect the continuous data. The CBIBS program began operating in 2007, using WET Labs WQM monitoring equipment.

Scientists from NCBO and MD DNR agreed that differences in water-quality parameter readings may exist between the WQM and YSI monitors, and that these differences should be documented to:

1. Provide direct comparison among all continuous water-quality data collected from the Maryland portion of the Bay,
2. Provide data to be used in the development of QA/QC protocols for WET Labs WQM monitoring data, and
3. Make recommendations for steps that could be taken to improve agreement of the results from the two types of sensors, where the largest and most consistent differences were found.

The purpose of this document is to describe a comparison study of continuous monitoring data between WET Labs WQM and YSI 6600 monitors. Durability during extended field deployments is documented for both instruments (Orrico et al. 2007, YSI 2011). An analysis conducted by MD DNR comparing dissolved oxygen (DO) at the MD DNR continuous monitor at Havre de Grace, Maryland, and the CBIBS buoy in the Susquehanna Flats in 2009 showed some marked differences, especially at the end of the deployment. However, these two stations were roughly 1 km (0.6 mi) apart, and the monitors in the CBIBS buoys are now changed more often than they were in 2009.Therefore, NCBO and MD DNR scientists decided to undertake a comparative study at a single site by deploying both types of monitor next to each other.

This side-by-side monitor comparison was attempted in April and May 2010 at the MD DNR continuous monitor at Fort Smallwood Park on the south shore of the Patapsco River. NCBO staff built a tube in which their WQM floated next to DNR's YSI monitor that was already placed there. However, because the site was much shallower at low tide than we thought it was when the tube was built (1.3 m rather than about 3 m) and the NCBO tube did not include the "bottom stop" that is used in the DNR tubes, the WQM repeatedly hit bottom (which was hard) and had to be repaired. The comparison was tried again at the same site with the WQM adjusted higher to try to avoid it hitting bottom, but it hit bottom again, and the comparisons had to be abandoned at the end of May 2010. Plans were made to put a YSI monitor on a CBIBS buoy in 2011 and 2012, to avoid the problems we encountered in 2010.

On April 7, 2011, MD DNR field personnel deployed a YSI 6600 monitor on the NCBO CBIBS buoy near the mouth of the Severn River (38.9631ºN, -76.4475ºW). This allowed direct, time-matched comparison of the WET Labs WQM and YSI 6600 data until the YSI monitor was removed on November 2, 2011. In addition, MD DNR field personnel collected grab water samples for lab analysis of chlorophyll a and total suspended solids (which can be converted to turbidity) at all of the CBIBS buoys in Maryland during most of the servicing visits to the buoys, and also collected profile data with a hand held YSI during those visits, so there are more limited comparison data for all of the CBIBS buoys in 2011. In 2012, the YSI monitor was added to the Annapolis buoy on 3/22/12, and removed on 11/5/12, and a similar sampling protocol was followed during the field visits.

Methods

All of the data reported here are comparison data from field visits to the CBIBS buoys, and post-calibration data from the lab. Other analysts may compare the hour-by-hour data from the two monitors in the Annapolis buoy in 2012 in the future.

The continuous monitoring instruments used are referred to as "monitors" that have various "sensors" in them to measure specific water-quality parameters. The two monitors compared here, the WET Labs WQM (in most of the CBIBS buoys) and YSI 6600 (used in tubes attached to pilings by MD DNR for their Eyes on the Bay network, by NOAA NERRS sites, and in the Gooses Reef CBIBS buoy), measure the same parameters, except the WET Labs WQM does not measure pH. The WQM is available with a pH sensor, but NCBO staff did not order it due to concerns over being able to calibrate it accurately when salinity is changing. Another sensor difference was that the WET Labs WQM uses a Seabird SBE43 DO sensor with a Clark polarographic membrane, while the YSI 6600 uses an optical DO probe. While the Clark membrane is older technology, Seabird redesigned it to improve performance. The WET Labs WQM has more anti-fouling measures than the YSI 6600, including bleach injection, which is why the WQMs are swapped once a month, and the YSI 6600 every 2 weeks. The CBIBS buoys also measure a variety of meteorological parameters, but those results are not compared here because the YSI 6600 only measures water quality.

Although the two monitors were in the same buoy, they were about 1 meter apart horizontally, and there were differences in probe depth and in data collection timing. All YSI 6600 probes are oriented downward, while some of the probes are oriented upward on the WQM. Therefore, not all parameters collected by the WQM are at the 1 meter depth specified for the Annapolis CBIBS buoy, and used for the YSI monitors. However, they are no more than half a meter apart. There were also temporal differences in sampling. The WQM takes one reading per second over five minutes from 53 to 58 minutes after the hour, and averages those readings. The YSI starts taking its reading at the top of the hour and averages 2 readings per second over three different intervals: over four seconds for WTEMP, SALIN, and pH; over 12 seconds for DO and TURB; and over 24 seconds for CHLA. We had no way to adjust for these temporal differences in this analysis, but they do represent an uncontrolled source of differences in the results when values are changing rapidly.

The DNR field crew that serviced all of the CBIBS buoys, visiting them usually monthly (or twice a month if they had YSI monitors), usually collected grab samples for lab analysis, and used a hand held YSI to collect profile data. The number of monitors, and thus the number of comparison values per visit, and the number of visits per year are listed in Table 1.

The sensor readings from those field visits were compared two ways:

1. For the Annapolis buoy, we graphed Coefficient of variation (CV) by parameter and date for all sensor values to get a general idea of relative agreement among parameters. It essentially measures disagreement, since the ideal CV is 0%. We did not include lab data since it was not available on all dates with sensor data. CV is the Standard Deviation divided by the mean, to make it more comparable among parameters, so it has no units, and is expressed as a percentage. CV has one drawback—it can get high when the mean value is very low (less than 1), since the mean is in the denominator. However, none of the means were low enough to cause this problem. CV values were graphed by parameter and date in line graphs (Figs. 1-2), and mean CV was graphed by parameter and year in a bar graph (Fig. 3).

2. We made time series plots (line graphs) of both sensor and (when available) lab CHLA data from Annapolis for all parameters (Figs. 4-10 and 13-15). We graphed the results by date to see if one sensor, or the lab value, was consistently low or high compared to other values. We graphed data from the sensor used before the swap (=old) and the one used after the swap (=new) to be able to compare these values. There was no “new” value for the WQMs, since they were not connected to a readout device during the swaps.

Table 1. Water-quality monitors in the buoy, and comparison data collected, in 2011 and 2012.

	Annapolis buoy (XGF7832**)**
Monitors	Both WQM & YSI monitors, April-November, 2011-2012 (this buoy normally only has WQM)
Comparison data from swaps	Up to 5 values per visit: old WQM, old YSI, new YSI, hand held YSI, and the lab value for CHLA. All collected at the same time; 14 visits each year.
Number of swaps with lab data	5 with CHLA from April 7-November 2, 2011; 7 with CHLA from March 22-September 10, 2012.

Unfortunately, the lab measured total suspended solids (TSS), not turbidity (measured in NTU by the WQM and the YSI). We looked for a local regression that related lab TSS to meter NTU in Chesapeake Bay, but could not find one, so we could not use the Lab TSS data to compare to turbidity values.

Since there seemed to be sporadic low salinity values from the WQM in the Annapolis buoy in 2011 and 2012, we also included a time series plot of those data from the CBIBS web site, showing only the WQM data for the whole summer (Figs. 11 and 12).

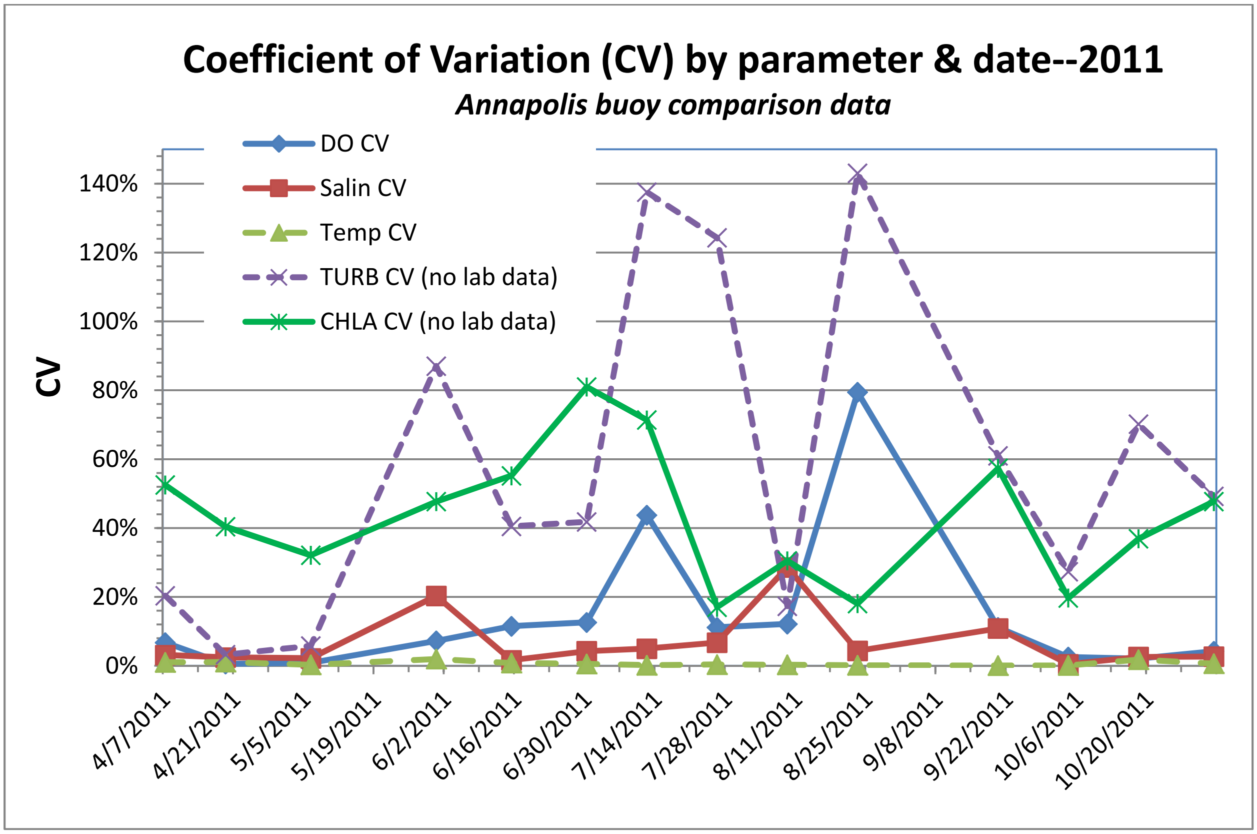
Note that for CV and the comparison graphs, they represent “worst case” agreement, assuming that the measurements by the sensors (the measuring devices within the monitor) drift over time while they are deployed. At each buoy visit, the “old” sensors have usually been in the water from two to four weeks, and their readings are compared to one or more “new” sensors that have just been calibrated, as well as a hand-held YSI meter that has not been left in the water. Presumably, agreement would be better with all new sensors.

Results

Variability over all sensor values, Annapolis buoy
The graph of Coefficient of Variation (CV) by parameter and date in 2011 (Fig. 1) for all the sensor values (no lab data) shows that in general, chlorophyll a (CHLA) and turbidity (TURB) had the highest CV values, and thus the lowest overall agreement in results. This is especially true for TURB. Thus, those two parameters are considered first in the results below.

A detailed examination of Fig. 1 shows that CHLA agreement (green line) got slightly better over time, probably because the WQM was no longer the lowest value after August 9 (see Fig. 4 below). CHLA CV (green line in Fig. 1) had two values over 60% and none were after July 12. TURB agreement (purple dashed line), however, was over 60% on six dates, with no obvious annual pattern. It was lowest from April through early May, and on August 9 and October 4, 2011.

Fig. 1 Coefficient of Variation (CV) for all parameters compared, Annapolis buoy data, 2011.



DO agreement (blue line) was OK (CV < 20%) except on two dates, July 12 and August 23. July 23 had both YSI and WQM monitors swapped, but both old and new WQM DO values were lower than any of the YSI values; August 23 had only the YSI swapped, and the YSI old value was very low that day (see Fig. 8). SALIN agreement (reddish line) was considered acceptable (less than 20%) except on July 12 (no WQM swap) and August 9 (WQM swap). TEMP agreement (light green dashed line) was excellent; CV was always 5% or less.

The patterns by parameter were similar in 2012 (Fig. 2). The high values continued through the year for TURB and CHLA, low values continued for TEMP, and SALIN and DO both had higher values in the summer (Fig. 2), as they also did on 2011 (Fig. 1). The higher SALIN and DO values in the summer are probably caused by fouling, which is worst in the summer; the CHLA and TURB sensors have wipers and tend to be less affected by fouling.

Fig. 2 Coefficient of Variation (CV) for all parameters compared, Annapolis buoy data, 2012.

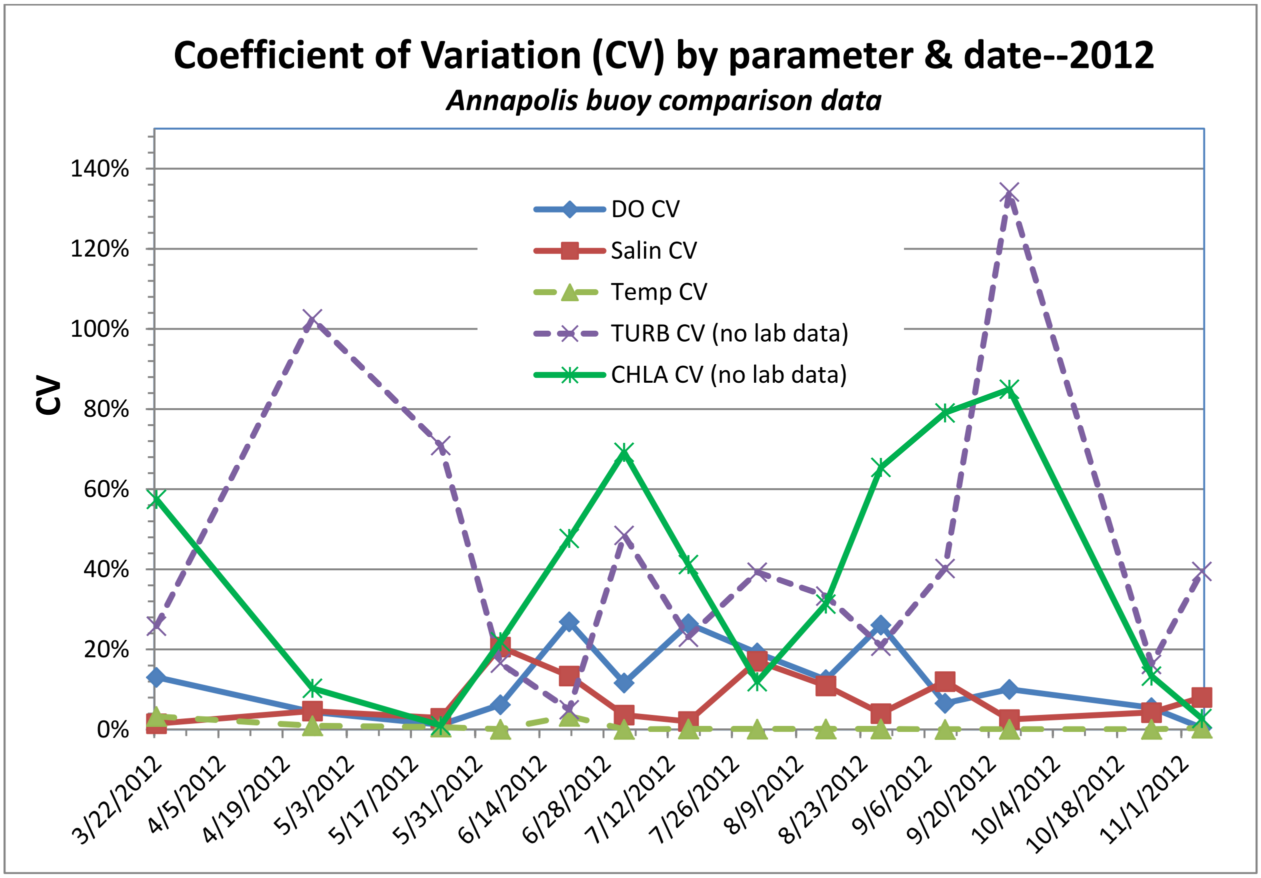


Table 2 and Fig. 3 summarize the CV patterns seen in Figs. 1 and 2. Fig. 3 graphs the same "Mean CV" data that are included in Table 2.

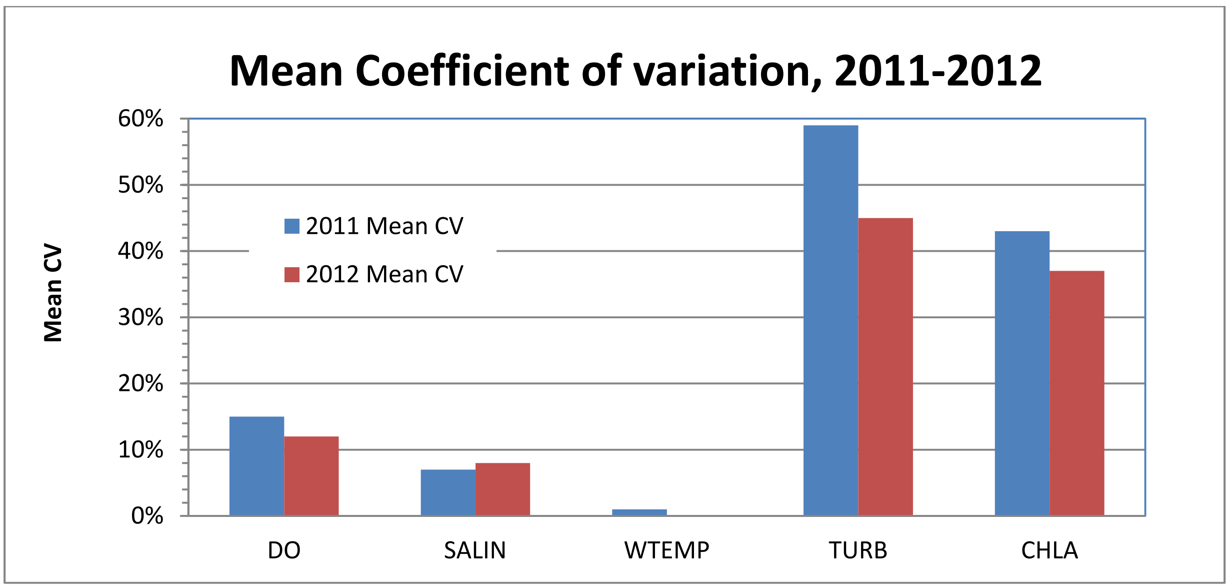
Both show that the first three parameters, DO (Dissolved Oxygen), SALIN (Salinity), and WTEMP (Water Temperature), all had good agreement in both years, with mean CV at 15% or less. However, for the two parameters that use optical sensors, TURB (Turbidity) and CHLA (Chlorophyll a), mean CV was much higher (37-59%), and thus agreement was much worse. Agreement for TURB and CHLA did improve (lower CV) in 2012 compared to 2011, but it was still much worse than for the other three parameters in 2012.

In Table 2, the cells shaded pink in 2011 (for Turbidity and Chlorophyll a) show that those two parameters had worse (higher) CV values (in both years) than the other three parameters (DO, Salinity, and Temperature). The cells shaded green in 2012, for DO, Turbidity and Chlorophyll a, show the parameters that improved (lower CV) in 2012 compared to 2011. The CV values for Salinity and Temperature were generally the lowest of the five parameters, and were about the same in 2011 and 2012.

Table 2. Patterns in Coefficient of Variation (CV) by parameter and year for Annapolis buoy comparison data. *Cells shaded pink in 2011 show which parameters had* ***worse (higher) values*** *than others; cells shaded green in 2012 show where there was* ***improved agreement*** *(lower CV values) compared to 2011.*

Year and metric	**DO**	**Salinity**	**Water Temperature**	**Turbidity**	**Chlorophyll a**
2011 Mean CV	15%	7%	1%	59%	43%
2011 High Values	2 of 14 values above 40%	0 of 14 values above 40%	Maximum CV was 2%	4 of 14 values above 80%	1 of 14 values above 80%
2012 Mean CV	12%	8%	0%	**45%**	**37%**
2012 High Values	**0 of 14 values near or above 40%**	0 of 14 values above 40%	Maximum CV was 3%	**2 of 14 values above 80%**	2 of 14 values near or above 80%

Fig. 3. Mean Coefficient of Variation (CV) for measurements by the different sensors during field visits to the Annapolis buoy, calculated over four to six measurements. Data used are in Table 2, first and third rows.



We are not sure why mean disagreement (CV) during field visits was so much worse (higher) for TURB and CHLA (Fig. 3). One reason is that they rely on optical sensors which are subject to fouling, even though they have automatic wipers on them. Another reason is that both parameters are more variable in space and time than the others measured, because both involve particulate matter that can be patchy. There were also some short periods of reduced agreement in DO and SALIN, especially in the summer, which appeared to be caused by fouling (see below). These periods of low agreement produced some individual CV values for DO over 40%, but there were not enough of them to raise the mean CV for DO to the levels seen for TURB and CHLA.

Chlorophyll a

In Fig. 4 (2011 data), the sensor values were all lower than lab values on two of the five dates with lab data, suggesting there may have been calibration issues. There were consistently low WQM values at start of year; the same monitor was in place from April 7 to May 31 and May 31-July 12, so the low values occurred with two different monitors. The WQM calibration protocol was changed in the summer to raise the WQM values, on the advice of WET Labs staff.

There was a spike in YSI old values on June 30, 2011, with two more high values right after that (Fig. 4), suggesting possible fouling, returning to the range of other values on August 9, 2011. There was a period of good agreement starting in August 2011, then a low value for the old WQM on September 20, 2011 (just before a swap—thus possible fouling).

Fig. 5, with 2012 CHLA data, shows that lab CHLA (seven values) was always a bit higher that the field-measured CHLA, except the YSI old value was the highest one in July and September. Since the YSI old sensor had not been calibrated for about two weeks, its higher values on those two dates were most likely due to drift (fouling).

Looking at patterns for chlorophyll over both years, two patterns are apparent:

- There were possible YSI fouling effects in June-July 2011 with YSI old sensor values that were much higher than any other values.
- The consistent differences seen in 2012 data (lab CHLA values usually higher) suggest that both the YSI and WQM monitors should be calibrated to read a bit higher in order to improve their agreement with lab CHLA.

Fig. 4. CHLA in 2011 at the Annapolis buoy, with data from YSI hand held monitor, YSI new and old monitors, WQM new and old monitors, plus lab data on five dates (filled round blue dots).

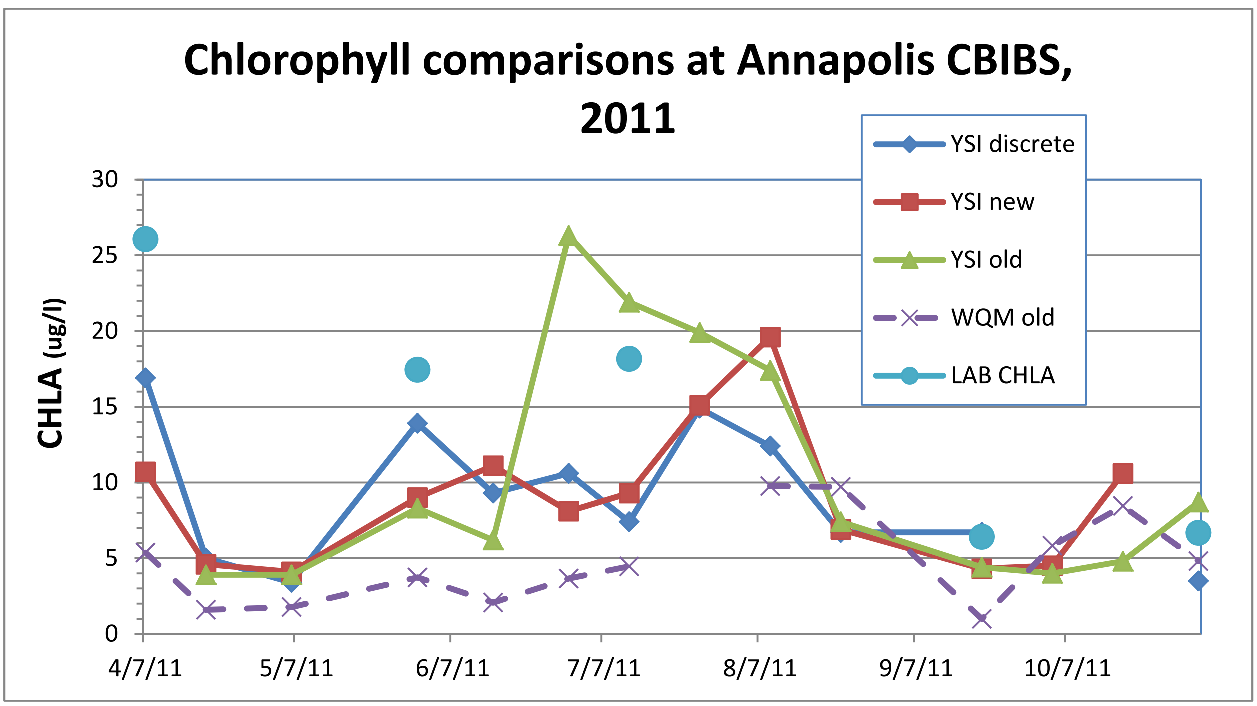
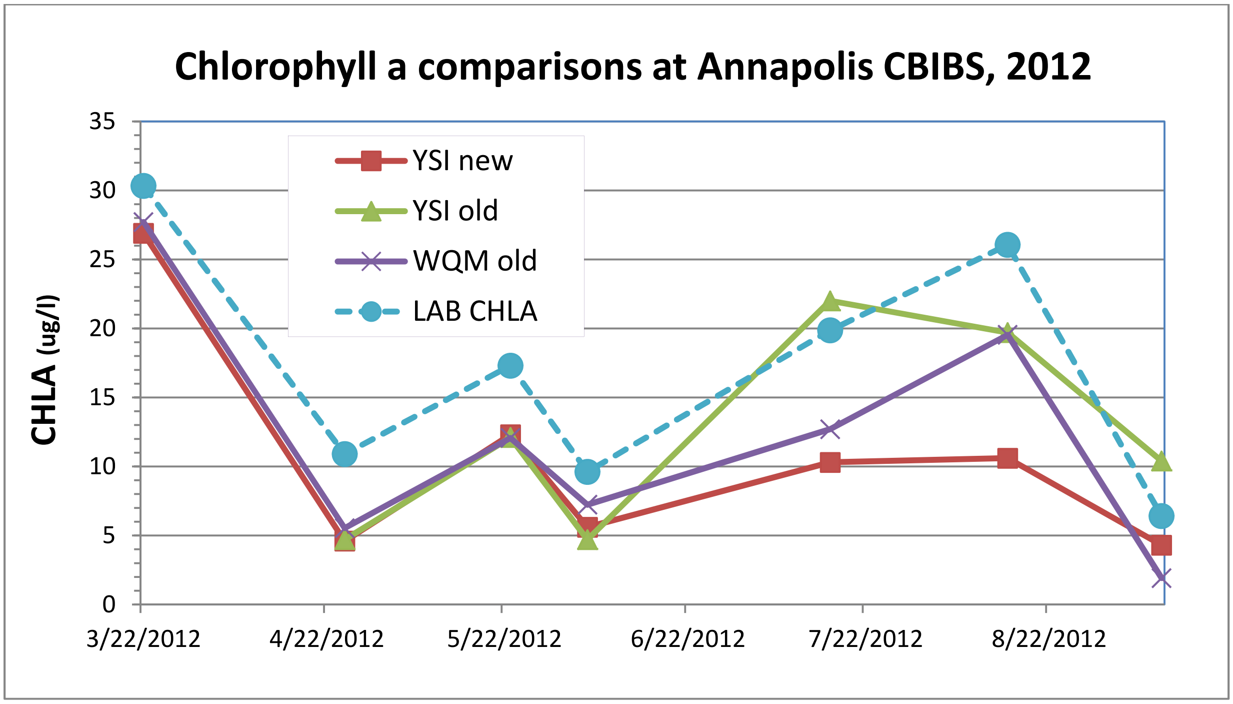
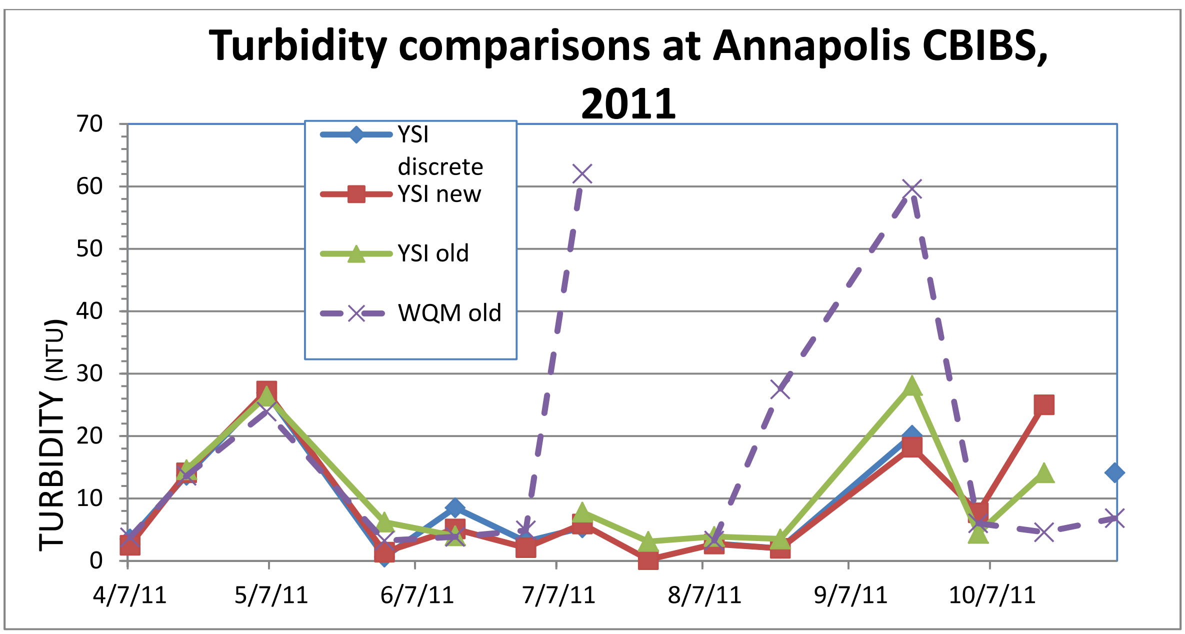


Fig. 5. CHLA in 2012 at the Annapolis buoy, with data from YSI new and old monitors, WQM new and old monitor, plus lab data on seven dates (filled round blue dots with dashed line).



Turbidity/Total suspended solids: In Fig. 6 (2011 data), overall the agreement was good. There were three dates in the summer when the WQM old value was higher than the YSI values, possibly from fouling. There were two dates when the YSI old value was higher than the YSI new value, also possibly from fouling, although the differences were smaller than the ones when WQM values were higher.

Fig. 6. Turbidity in 2011 at the Annapolis buoy, with data from YSI hand held monitor, YSI new and old monitors and WQM old monitor.

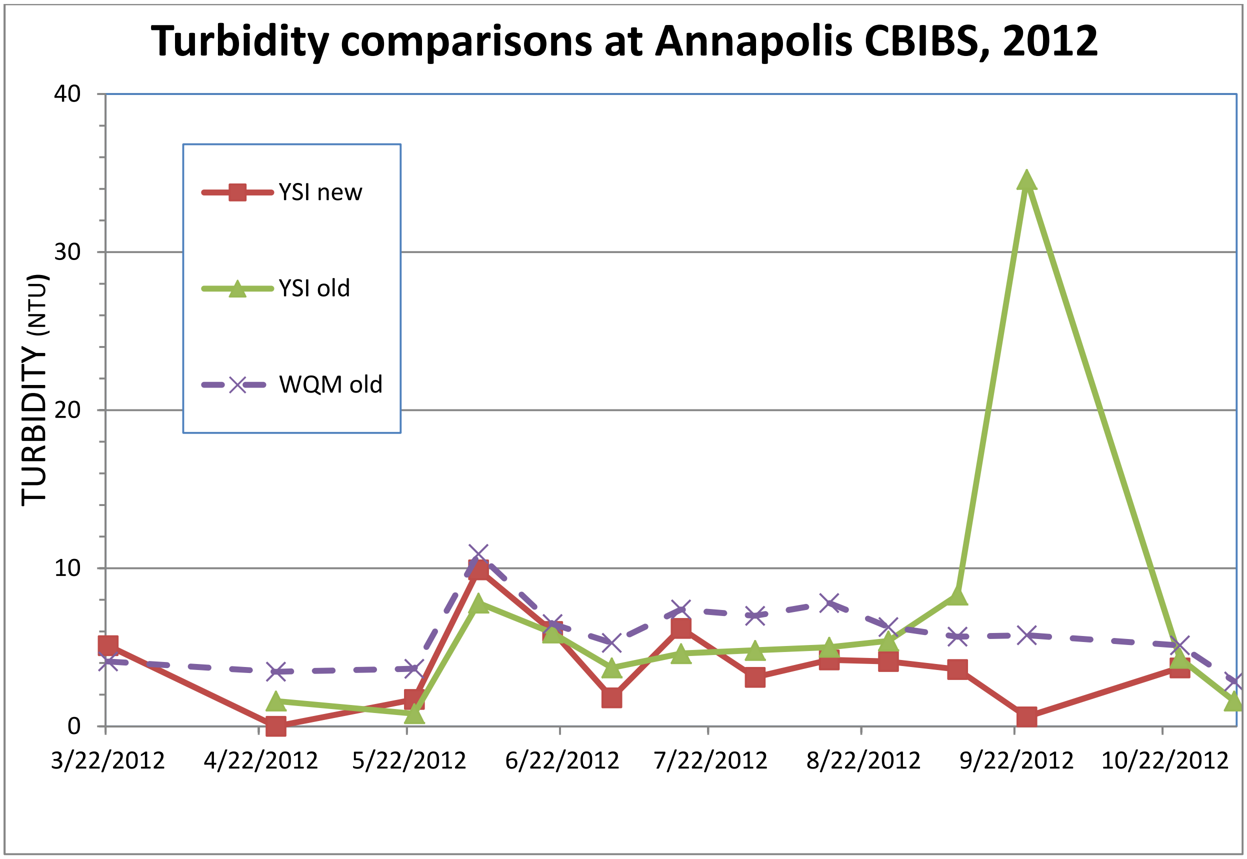


In Fig. 7 (2012 data), agreement was also generally good. There was one date (September 24, 2012) with a very high YSI old value, suggesting fouling.

Looking at patterns for turbidity over both years, two patterns are apparent:

- There were possible fouling effects with old sensor values that were higher than any other values in 2011, for the WQM monitors on 3 dates.
- Mean CV for TURB (Fig. 3) showed improved agreement among all of the sensor turbidity values in 2012 compared to 2011, but this could be due to less rainfall, and thus lower turbidity values, in 2012.

Fig. 7. Turbidity in 2012 at the Annapolis buoy, with data from YSI new and old monitors and WQM old monitor.



Dissolved oxygen

In the 2011 data from the Annapolis buoy (Fig. 8), both the WQM old and YSI old monitors had DO values lower than the YSI new values for much of the summer, when most fouling occurs (due to organisms growing on and in the sensors). There was also a general pattern of both YSI values being slightly higher than the WQM value, which was seen during all but the first and last month of data. We don't know which DO readings were more accurate, since there were no Winkler DO tests done in the field or lab for these samples. Some of the low WQM values occurred when specific instruments were deployed, however.

1. The old WQM DO values fell relative to YSI values during both of the spring deployments of two different monitors, April 7 through May 31 (WQM 15, low on May 31 only) and May 31 through July 12 (WQM 16, low that whole time), and WQM values were still low relative to YSI values on August 9 and August 23, which was also WQM 16. Agreement of WQM values with YSI values was much better starting on September 20, when WQM 153 was installed. Thus the low WQM DO may be due to

defective sensors on WQMs 15 and 16. Hour-by-hour comparisons would help us to understand this difference better.

2. The YSI old DO values started falling relative to the other YSI values on July 12 (matching one of the low WQM values that day) and were also low on July 26 and August 23 (DO from the old YSI was only 0.59 mg/l on August 23).

Fig. 8. Dissolved oxygen in 2011 at the Annapolis buoy, with data from YSI hand held (discrete) monitor, YSI new and old monitors, and WQM old monitor (no lab data).

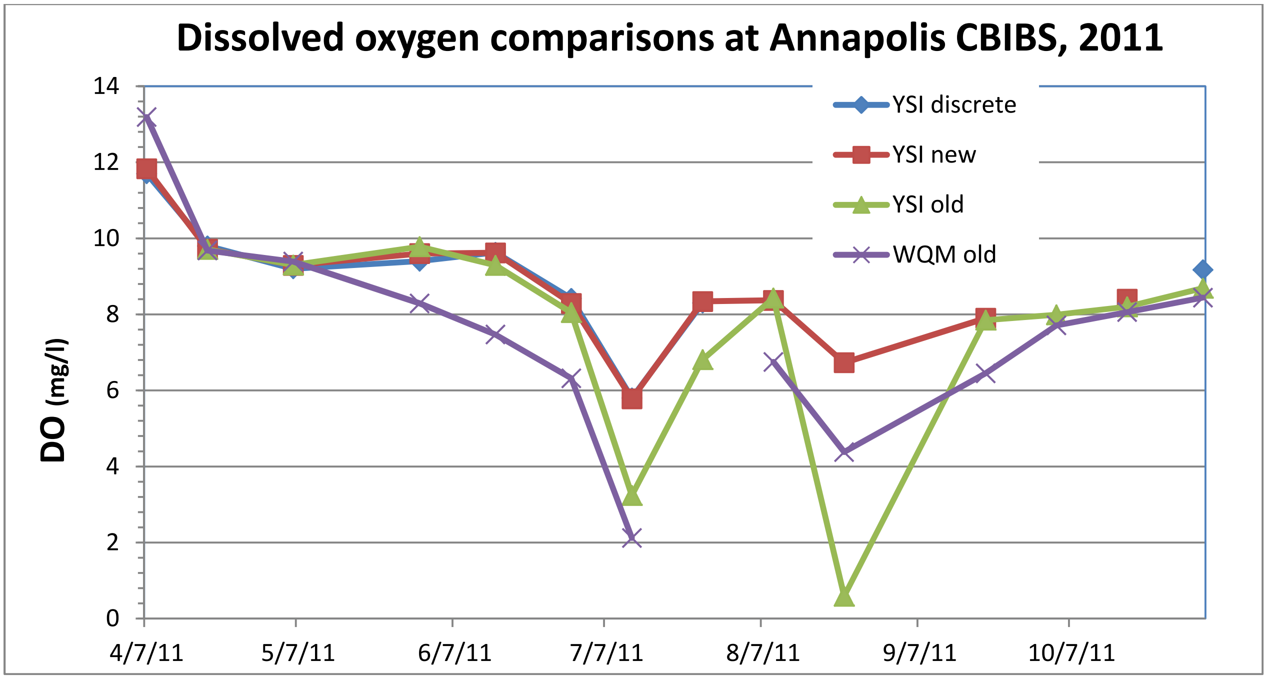
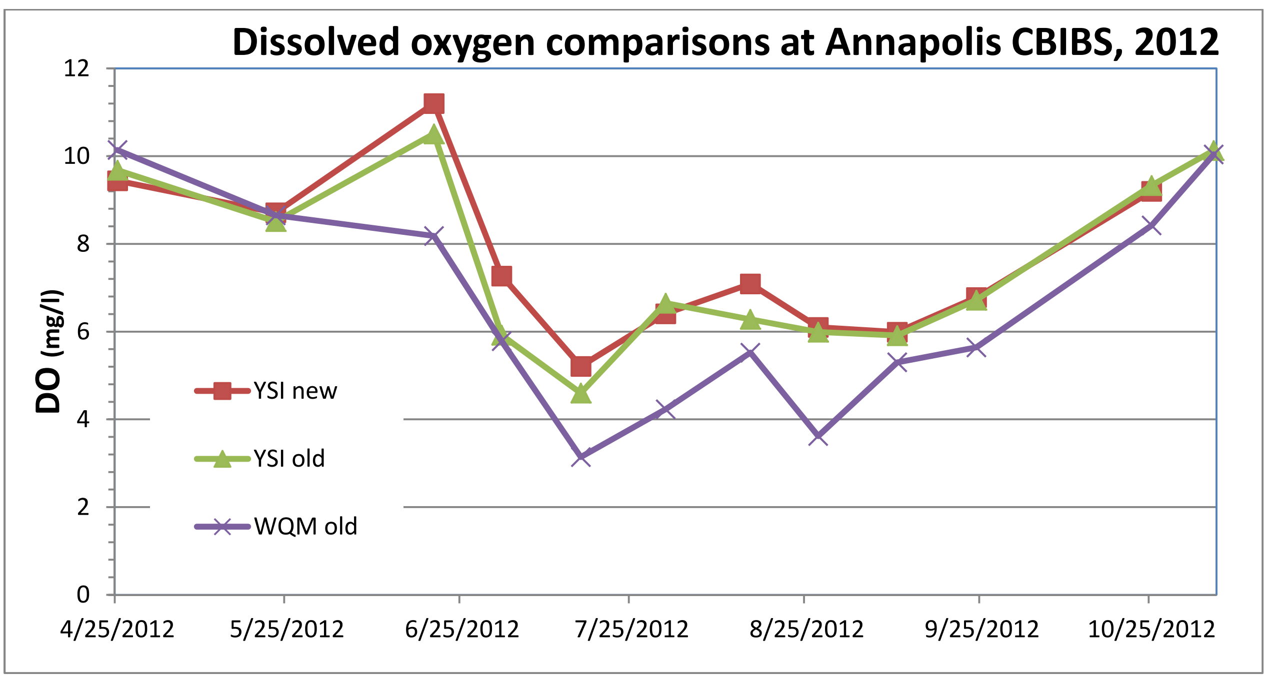


Fig. 9. Dissolved oxygen in 2012 at the Annapolis buoy, with data from YSI new and old monitors, and WQM old monitor (no hand held or lab data).



In the 2012 DO data (Fig. 9), both YSI DO values were usually slightly higher than both WQM DO values during all but the first and last month of data. There were fewer low values in the summer than in 2011, especially for the YSI, and the most extreme low values (about 3 mg/l) were all from the WQMs, with no values below 4.6 mg/l from the YSIs. As noted above for 2011, we don't know which DO readings were more accurate since there were no Winkler DO tests done.

Salinity

In the 2011 data from the Annapolis buoy (Fig. 10), there were two patterns noted:

1. YSI old values were low from June through September, and we generally see more fouling in summer.
2. WQM old was low on August 9, 2011.

Regarding the second pattern, it appears that short-term low WQM salinity values happened fairly often in summer 2011 at Annapolis (Fig. 11). A graph of two days of the same data from mid-August 2011 (Fig. 12) shows that most of the drops lasted 1-3 hours, followed by 1-2 hours at close to the previous higher value, and most drops had a fall of 2-3 salinity units in an hour. If this was an artifact, the problem may have been one or two sensors that were unstable, since WQMs 16 and 155 were used all summer in 2011. WQM 16 showed clearly erroneous low values of salinity during two deployments during the test period. The reason for these errors, where the 1-secod conductivity values would read as low as 25% of the (assumed) correct value for much of the 5 minute measurement interval, is still not clear, but being investigated further. The most likely reason is due to presence in the conductivity cell of matter with low conductivity - possibly air, large sediment particles, or fauna.

Fig. 10. Salinity in 2011 at the Annapolis buoy, with data from YSI hand held monitor, YSI new and old monitors, and WQM old monitor (no lab data).

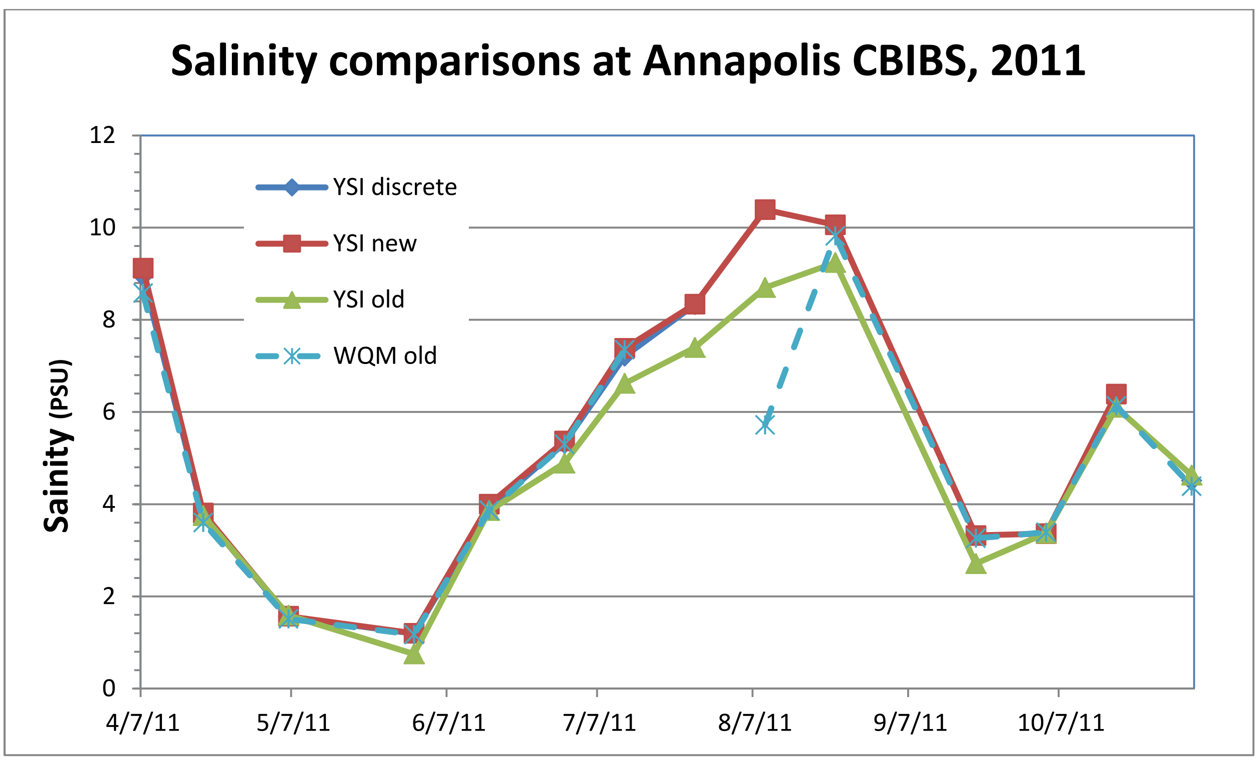


Fig. 11. Salinity values in 2011 at the Annapolis CBIBS buoy, WQM data only. Note frequent short drops (1-3 hrs. long) in June, July, and August.

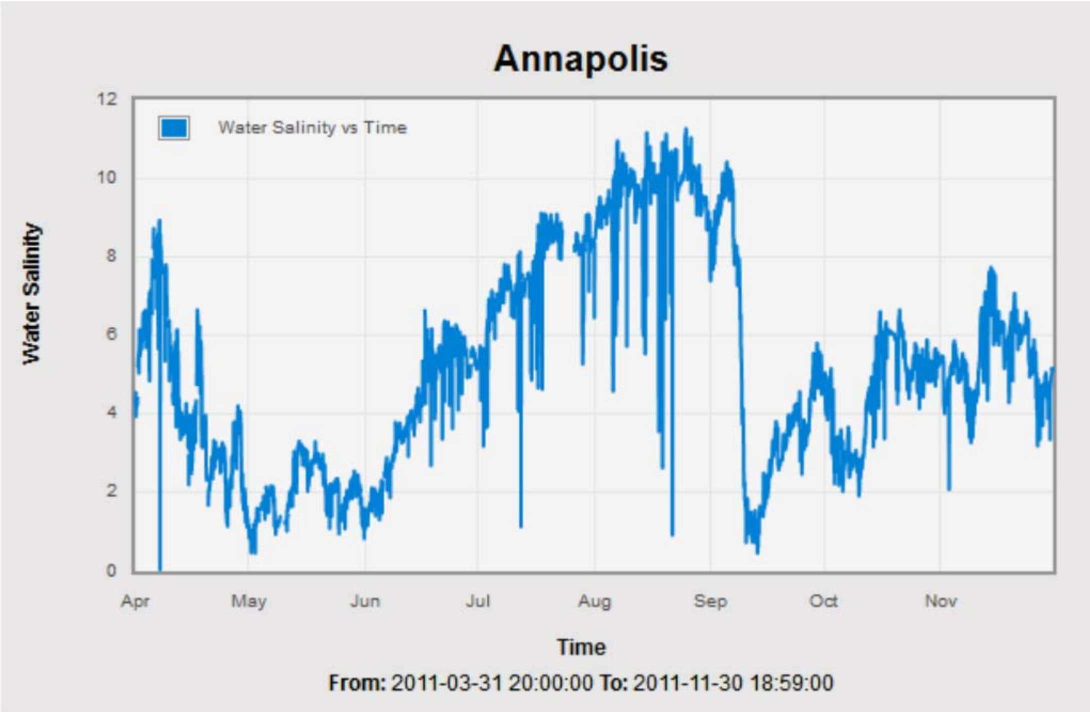
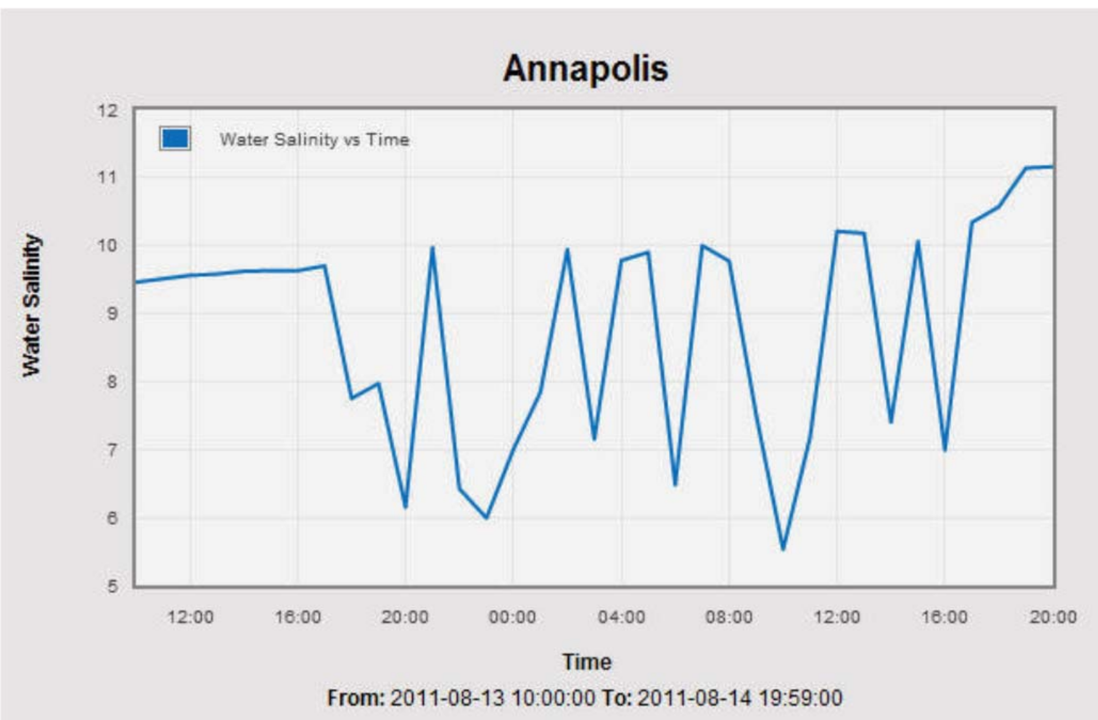


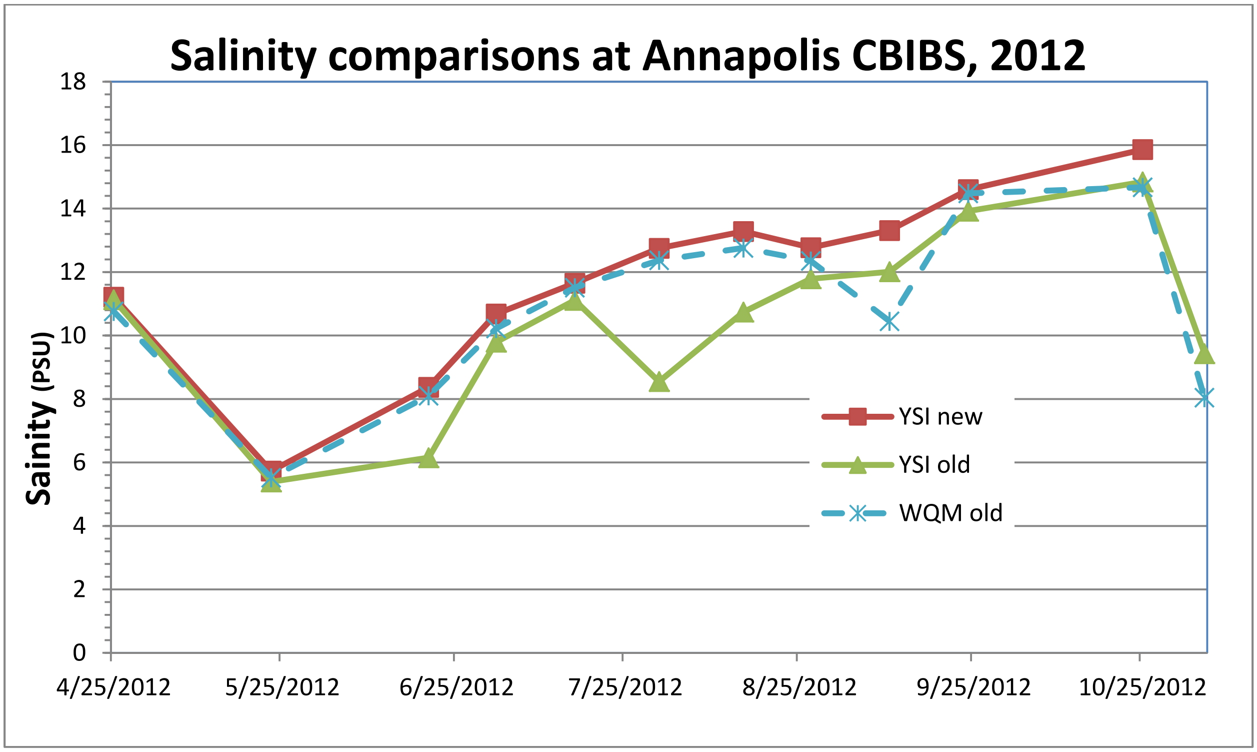
Fig. 12 Salinity values in mid-August 2011 at the Annapolis CBIBS buoy, WQM data only. Note that most of the drops lasted 1-3 hours, followed by 1-2 hours at close to the previous higher value.



In 2012, there were fewer large-scale variations in salinity during the year, due to less rainfall. There were still a few low salinity values in the summer during field visits, however (Fig. 13):

- The old YSI had 5 low values in a row the summer, July through September, just as it did in 2011. This suggests that low salinity values from fouling continued to be an issue for the YSI sensors in 2012.
- The old WQM also had one low value in September, possibly due to the short-term drops that continued in 2012 (see above).

Fig. 13. Salinity in 2012 at the Annapolis buoy, with data from YSI new and old monitors, and WQM old monitors (no hand held or lab data).



Water temperature

In the 2011 data from the Annapolis buoy (Fig. 14), agreement was much better for temperature than for any other parameters. A few minor differences between values were noted, each about 1-2 degrees C; no fouling effects were apparent. These differences only raised the CV values to 3-5% (from 0-1% on other dates) so they were minor.

Agreement was even better in 2012 (Fig. 15). The only date with any visible spread in the four values, June 20, 2012, still had a very low CV of 3%.

Fig. 14. Water temperature in 2011 at Annapolis buoy, with data from YSI hand held monitor, YSI new and old monitors, and WQM (old) monitor (no lab data).

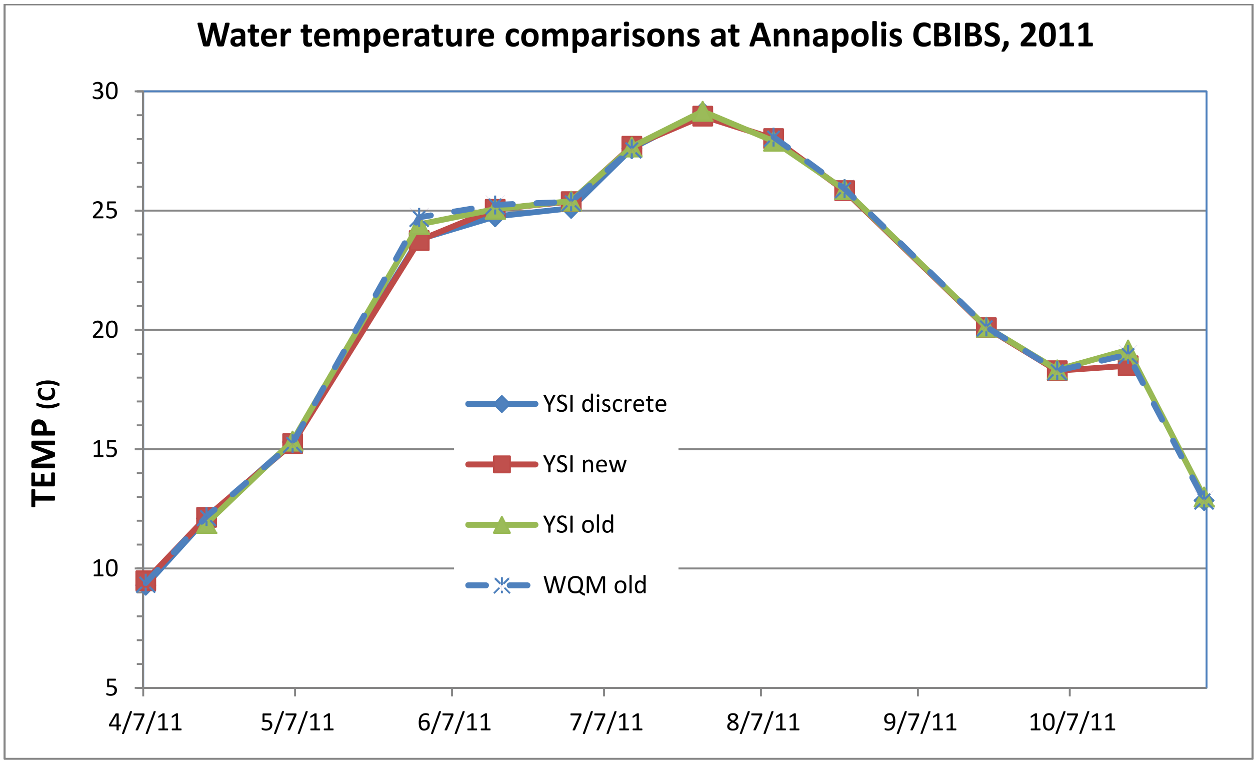
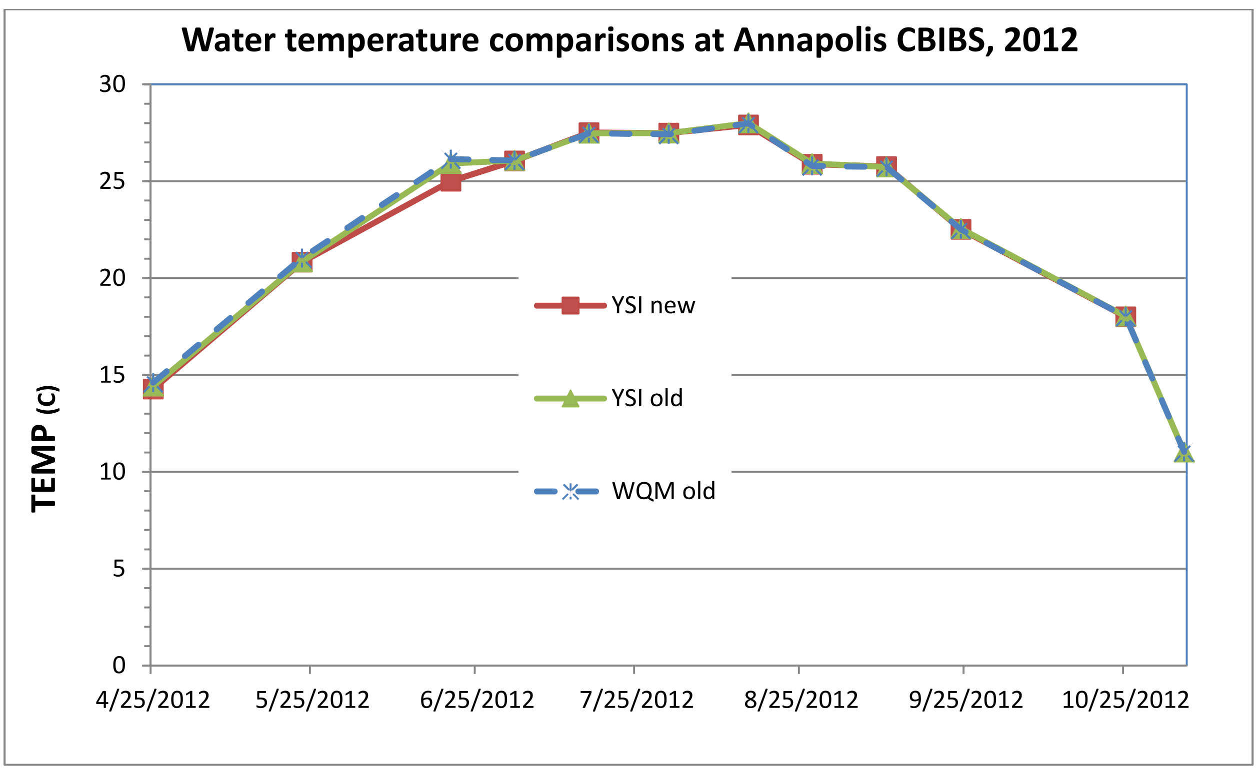


Fig. 15. Water temperature in 2012 at Annapolis buoy, with data from YSI new and old monitors, and WQM old monitor (no hand held or lab data).



Recommendations and Suggested Actions

These are preliminary recommendations based on incomplete analyses. It would help in deciding on actions to have the results of the hour-by-hour data comparisons, because they have a much larger sample size, and thus may show patterns not discernible in these “snapshot” comparisons from only a few points in time each year.

- Consider swapping YSI monitors weekly in the summer, as they do at VIMS to reduce fouling effects. The YSI in the Annapolis buoy had fouling issues for COND and DO in 2011, and for COND in 2012.
- Based on their high CV values (Figs. 1 and 2), agreement for TURB and CHLA seem to be an ongoing issue for both YSI and WQM sensors.
- Based on Fig. 5, both the YSI and WQM monitors should be calibrated to read a bit higher for CHLA (by about 5-10 µg/l) in order to improve their agreement with lab CHLA, at least in the ranges of data observed during these comparisons.
- Field crews should use a calibrated nephelometer to measure NTUs to compare to the TURB readings from the buoys, rather than collecting TSS samples, since the TSS data are not usable for comparison to NTU.
- The pattern of short WQM salinity drops over three years merits further investigation, to see if these drops are real, or an artifact of some sensor problem.

Table 3. Agreement issues and suggested actions by parameter.

Parameter	Agreement issues	Suggested Actions
Chlorophyll	Lab results often higher; WQM agreement got better when calibration changed in July 2011; possible fouling issues (high readings from old monitors)	Check calibrations for all sensors; try to account for the fact that standards are different from algae in response to light
Turbidity	Possible fouling issues (high readings from old monitors) for both YSI and WQM monitors in summer	Check calibrations for all sensors, look for TSS-turbidity regressions from tidal waters near our concentrations
Dissolved oxygen	Possible fouling effects leading to low readings by old YSI in summer 2011; also had low readings by old and new WQM in spring 2011	Monitors may need to be swapped more often, and/or anti-fouling measures improved (YSI). Check calibration methods (WQM).
Salinity	Sporadic low readings by WQM at Annapolis in 2011-3 (cause uncertain), and consistently low readings by old YSI in summer 2011 and 2012 (likely from fouling)	YSIs may need to be swapped more often in summer, and/or anti-fouling measures need to be improved. WQMs may need repair (low values are less common at other buoys).
Water temperature	Very minor; maximum CV was 5%	None

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