APPENDIX C - WATER QUALITY MONITORING IN THE MB UA: SUPPORT FOR MCMS #1 AND #2

The SMS4s of the Myrtle Beach Urbanized Area continue to partner in water quality monitoring programs that help fulfill MCM #1 for outreach, MCM #2 for public engagement and MCM #3 for illicit discharge detection and elimination. The monitoring data can also provide insight into long-term water quality trends, and hence, help evaluate progress in MCM #5 for post construction discharges. Some of these programs are staffed by volunteers and others are conducted by CCU's Environmental Quality Laboratory (EQL) that is certified by SC DHEC.

To address MCM #1, all monitoring data are accessible through public websites. The URLs for these website are presented in collated form at: http://www.coastal.edu/wwa/datasets.html, and advertised via program-specific business cards. Web counters are used to document traffic at these sites. The results are included in the CWSEC biannual reports to the SMS4s.

Data are uploaded semiannually to the national STORET Data warehouse using the US EPA's Water Quality Exchange (WQX) portal. The uploaded data are available to the public via US EPA's WATERS GeoViewer (https://www.epa.gov/waterdata/waters-geoviewer) and the National Water Quality Monitoring Council's Water Quality Portal (http://www.waterqualitydata.us/index.jsp).

The monitoring programs in the Myrtle Beach UA and their data have been described in the proceedings of the SC Water Resource Conference, StormCon, the SC Environmental Conference, SCASM, and the SC Water Resources Journal, as well as at several of the National Water Quality Monitoring Council's biennial National Monitoring Conferences.

In 2016, the South Carolina Sea Grant Consortium established a data portal, the South Carolina Coastal Water Monitoring Network (SCCWMN) to provide a map-based depiction of locations of long-term water monitoring and monitoring in response to events such as flooding in coastal South Carolina. All of the monitoring programs conducted in the Myrtle Beach Urbanized Area are featured at this data portal. In addition to site locations, metadata provide information on monitoring frequency, what is measured and how to access the data. The portal URL is: https://scseagrant.maps.arcgis.com/apps/webappviewer/index.html?id=34eafc714c8e4007ad7b9d891386888f

The monitoring data continue to be used in presentations to municipal councils and committees. Use of the data for IDDE is facilitated through production of biweekly provisional reports, and in the case of beach monitoring, weekly. These reports highlight findings of regulatory exceedances of water quality criteria and comparisons to site-specific norms. The latter are based on annually updated percentile rankings developed from each sampling site's historical dataset. This rapid reporting was the subject of a talk presented in May 2016 at the National Water Quality Monitoring Council's 10th National Monitoring Conference.[1] A presentation on how the volunteer monitoring data are being used in concert with other data (USGS sensors, EQL certified monitoring data, rain data) to improve water quality was delivered at the biennial South Carolina Water Resources Conference held in October 2018.[2]

In most of the programs, datasets are now long enough to conduct statistical tests for long-term trends. These have been performed using the same tests that SC DHEC uses for its watershed water

[1]Libes, Susan (2016) Rapid provisional reporting in long-term monitoring programs for detection of illicit discharges by NPDES SMS4 communities. 10th National Monitoring Conference, National Water Quality Monitoring Council, held in Tampa, Florida, May 2-5, 2016 (oral).

[2] Libes, Susan (2018) Leveraging time-series water-quality data from volunteer, USGS, and regulatory monitoring programs to detect illicit discharges and long-term trends in the Waccamaw and Sampit Rivers. 2018 South Carolina Water Resources Conference held in Columbia, South Carolina on October 16-18, 2018. (oral).

quality assessment reports, i.e. the seasonal Mann-Kendall test for monotonic trends.

To address MCM #2, Horry and Georgetown Counties, the City of Conway, and the Town of Surfside Beach support volunteer water quality monitoring programs run collaboratively with CCU's Waccamaw Watershed Academy (WWA) and field leaders listed in Table 1.

To address MCM #3, CCU's WWA produces provisional reports and potential IDDE reports that are sent to the relevant stormwater managers. These reports compare measurements to state water quality standards, site-specific norms established by the program data, and US EPA recommended water quality thresholds. A more rapid reporting is used when findings suggest a new acute illicit discharge has been detected. In these cases, the volunteers and EQL staff alert the program coordinator immediately. After a rapid review, this information is transmitted to the relevant stormwater manager. The volunteers and staff are equipped with copies of the site specific norms to enable them to make a rapid assessment of whether a measurement is unusual. If so, this finding is texted, emailed or called in. Several such cases have led the stormwater managers to engage in site reconnaissance efforts to try to find the source of the potential illicit discharge. In other cases, the volunteers have engaged in such an effort

More details on each of the monitoring programs along with highlights from 2018, such as the IDDE investigations, are provided below.

Volunteer Water Quality Monitoring

Three volunteer monitoring water quality monitoring programs are being supported in the MB UA. Details are provided in Table 1.

Sampling is conducted biweekly year round and data are posted within two weeks of collection at http://bccmws.coastal.edu/volunteermonitoring/. These websites include rain data from CoCoRaHs (Community Collaborative Rain, Hail and Snow Network) volunteer monitoring program. NOAA's NERRS Central Data Management Office is also providing areal estimates of daily rainfall by sub-watershed.

Management meetings are held with the field leaders. With some exceptions, each program conducts an annual data conference for the public and a luncheon for its volunteers. Presentations from these events are posted at the program websites (http://www.coastal.edu/wwa/vm/).

Table 1 - Volunteer Water Quality Monitoring Programs in the Myrtle Beach Urbanized Area

Monitoring Program	Field Leader	Sampling Sites	Number of Volunteers	Start Date	Funding Partners
Waccamaw River	Waccamaw Riverkeeper	6 in NC 12 in SC	54	2006	Georgetown & Horry Counties, Conway
Murrells Inlet	Murrells Inlet 2020/Robert Steffens	8	18	2008	Georgetown & Horry Counties
Surfside Beach	Ken Harth	2	6	2010	Surfside Beach
CCU Campus	Waccamaw Riverkeeper	3	5	2011	CCU's WWA & QEP Program

These programs are included in the: (1) Volunteer Water Quality Monitoring National Water Resource Project's listing of Volunteer Water Quality Monitoring and Master Naturalist Programs (http://www.usawaterquality.org/volunteer/VolunteerMonPrograms/index.html); (2) US EPA's National Directory of Volunteer Monitoring Programs: http://yosemite.epa.gov/water/volmon.nsf/Home?OpenForm; and (3) National Water Quality Monitoring Council's Volunteer

Water Quality Monitoring Program Directory: http://acwi.gov/monitoring/vm/programs/vm_map.html.

An inventory of the water quality measurements made to date in each of the programs is provided in Table 2. These collectively represent about 104,000 independent measurements.

Table 2 - Water quality measurements made to date in the volunteer monitoring programs of the Myrtle Beach UA

Program	*Site*	*Samplings*	*Measurements per sampling event*	*Total independent measurements*
Waccamaw River since June 2006	Maple Street	157	11	1,727
	Canal Cove	157	11	1,727
	Big Creek	157	11	1,727
	LAWA Dam	157	11	1,727
	Babson's Landing	124	11	1,364
	Pireway Landing	124	11	1,364
	Highway 9 Landing	291	11	3,201
	Reaves Ferry	280	11	3,080
	Murrells Landing	2197	17	37,349
	Sterritt Swamp	265	11	2,915
	Conway Waterfront	290	11	3,190
	Pitch Landing	289	11	3,179
	Peachtree Landing	254	11	2,794
	Enterprise Landing	289	11	3,179
	Bucksport Landing	294	11	3,234
	Wachesaw Landing	292	11	3,212
	Hagley Landing	290	11	3,190
	Sampit River	286	11	3,146
			Total =	81,305
Murrells Inlet since May 2008	Woodland Drive Pond	248	11	2728
	Point Drive Canal	248	11	2728
	Rum Gully Creek	248	11	2728
	Marina Colony Pond	248	11	2728
	HS	248	11	2728
	BHR	248	11	2728
	Bike Bridge	248	11	2728
	Oyster Landing Beach	248	11	2728
			Total =	21,824
Surfside Beach since May 2010	Lake Dogwood	195	11	2145
	Myrtle Lake	195	11	2145
			Total =	4,290
Campus Volunteer Monitoring since Oct 2011	501 West	200	11	2196
	544 East	2	11	22
	544 West	196	11	2156
	Wall Pond Bridge	184	11	2024
	Wall Pond East	2	11	22
	Wall Pond West	17	11	187
			Total =	6,607

All datasheets and QA/QC paperwork continue to be bound annually using a uniform format. The binders are maintained in an archive room in the EQL that requires users to sign out the binders. Hard copies of the volunteer training records are kept in individual folders. Records are reviewed quarterly to insure that retraining is performed annually for each activity that a volunteer is qualified to conduct.

In 2018, the following initiatives were undertaken to enhance data quality: (1) Retraining of volunteers to ensure correct counting of E. coli fluorescence when halos overlap. An OEM production issue with the plates also had to be resolved. Surveillance continues of nonfluorescing blue colonies. (2) Surveillance continues for nitrate strip contamination issues. Updated SOP and datasheets to correct computation of nitrate from Hach test strips, (3) Upgrade in volunteer training documentation and SOP. The latter was important as many new volunteers were trained in 2018, (4) New inventory sheet for inspection of off-site gear (incubator, black light, NIST thermometer, sampling pole) that is not returned as part of quarterly kit maintenance, (5) Production of quick instruction sheets. An overhaul of webpages was necessitated by an upgrade in CCU's web content management platform, TERMINALFOUR.

Field leaders for the programs are as follows:

- Murrells Inlet: Meredith Millen continues as Executive Director of Murrells Inlet 2020. Robert Steffens continues to perform as the field leader.
- Surfside Beach: Ken Harth continues as Field Leader.
- Waccamaw River: Cara Schildtknecht, Waccamaw Riverkeeper, continues as the field leader.
- Campus Monitoring: Kaley Towns continued as the graduate student teaching assistant. She graduates in May 2019 and is cross training her replacement.

Additional details on each of the volunteer monitoring programs and highlights from 2018 are provided below. Due to the

dedication of the volunteers and their high quality of work, we have a very low rate of missing data. Due to Hurricane Florence one sampling was missed for Surfside and Murrells Inlet (9/11/18). Two samplings were missed on the Waccamaw River due to sustained flooding (9/12/18 and 9/26/18).

Murrells Inlet

Eight sites have been monitored since 2008 by 18 volunteers. Robert Steffens has continued to serve as the field leader. In 2017, Murrells Inlet 2020 (MI2020) relocated their weather station to a site near their offices. It reports continuous data to Weather Undergrround as station "Murrells Inlet 2020" (KSCMURRE111). The rain data from this station are incorporated into the volunteer monitoring program's database and displayed with the water quality data to document when stormwater runoff was likely occurring.

The watershed-based plan for Murrells Inlet, approved by SC DHEC in August 2014, is being implemented by a steering committee that includes CCU's WWA, Murrells Inlet 2020, and the stormwater managers of Horry and Georgetown Counties.

In 2016, SC DHEC funded a first round of grants to support installation of stormwater BMPs recommended in the Murrells Inlet Watershed-based Plan. These included Filtrexx™ SiltSoxxs®, floating wetlands and a created wetlands each of which is located upstream of a volunteer monitoring site. Aeration fountains were also installed at a fourth site. In 2017-2018, the volunteers performed upstream sampling at two of these sites (Woodland Drive Pond and HS) to assist in assessing the effectiveness of the new BMPs (a floating wetlands and Filtrexx™ SiltSoxx®, respectively). This work was funded by MI2020 and Horry County Stormwater. A final report was produced by CCU and submitted to the funding agencies in January 2019. Continued downstream sampling at these sites and at the BB site (downstream of a created wetlands) serve as ongoing assessment of the BMPs.

Robert Steffens has continued as the field leader in coordination with Meredith Millen, the Executive Director of MI 2020. The latter provides outreach services. This includes posting information in their printed newsletters and emailed updates. These venues have also been used to recruit new volunteers.

In 2018, 10 King Tides occurred bringing saline water into WDP, which had adverse effects on the floating wetland BMP, BHR and BB. Rain since the historic drought of 2002 to 2012 ended, has led to a continued trend of decreasing salinity at RGC and OLB. The percent saturation of DO continues an upward trend seen at all but the two pond sites. At BHR, turbidity exceeded the Class SFH water quality criteria once as compared to 4 times in 2017. HS exceeded this criteria twice. Both sites have Filtersoxx installed upstream. As shown in Table 3, sites with continued frequent contraventions of the E. coli water quality criteria include Woodland Drive Pond, HS and BHR. Median E. coli levels in 2018 were less than the 2008 to 2018 median at each of these sites with the largest decline observed at HS.

Table 3 - Median E. coli concentrations and trends at the Murrells Inlet Volunteer Monitoring sites.

Site Name	***5/20/18 to 1/1/18***	***1/1/18 to 1/1/19***	***Decrease***
Woodland Drive Pond	500	400	-100
Point Drive Canal	67	33	-34
Rum Gully Creek	0	0	0
Marina Colony Pond	67	67	0
HS	600	400	-200
BHR	1400	1350	-50
Bike Bridge	200	133	-67
Oyster Landing Beach	0	0	0

A joint volunteer appreciation luncheon was held on 3/21/18 at CCU's Burroughs and Chapin Center for Marine and Wetland Studies during which the Surfside, Murrells Inlet and Waccamaw River volunteers compared their findings. A presentation was also delivered regarding resolution of methods issue with nutrient testing strips and E. coli dual confirmation media.

Waccamaw River

Twelve sites in South Carolina have been monitored since 2006 and six sites in North Carolina since 2011. This bi-state effort engages 54 volunteers and has generated close to 75,000 independent measurements, providing the basis for identifying spatial and temporal trends. The Waccamaw Riverkeeper serves as the field leader for this program.

The annual volunteer appreciation luncheon was held on March 21, 2018. The purpose of the luncheon is to recognize and provide an update to our volunteers. This meeting was a joint effort that brought together volunteers from all the programs to compare results from their bacteria monitoring and socialize across programs. This included a presentation on recent illicit discharge detections and source investigations in each of the programs.

Data generated from this program is presented at an Annual Data Conference that was held on November 9th 2018 at CCU's Burroughs & Chapin Center for Marine and Wetland Studies. Particularly well received was a presentation recapping management uses of the volunteer monitoring data in each of the programs. A guest presentation was delivered by a representative of American Rivers to discuss their current efforts in the Waccamaw River.

The Waccamaw RIVERKEEPER® Program oversees the volunteer monitoring effort in North Carolina in partnership with Lake Waccamaw State Park with financial support provided by grants from International Paper, Columbus County and Z. Smith Reynolds Foundation. CCU's WWA provides pro bono support for this effort. Efforts continue to secure a sustainable funding source for this program.

Presentations from the volunteer appreciation luncheon and the annual data conference have been posted at https://www.coastal.edu/wwa/vm/waccamawriver/presentationspublications/.

Information from the Waccamaw River Volunteer Monitoring Program is also presented at the annual Waccamaw Conference, a public education event hosted by the Waccamaw Riverkeeper. The 2018 Waccamaw Conference was held on February 10th.

Interpretation of the data is enhanced by the USGS's continuous sensors that measure water quality, flow and weather at several of the volunteer water quality monitoring sites. In addition, the USGS water quality data are used to validate the volunteer data. Other important data include rain accumulations from NOAA's CoCoRAHS volunteer rain monitoring program that is run through the SC State Climatology Office. These data are incorporated into the Waccamaw River volunteer monitoring program's web app.

The major event in 2018 was historic flooding from Hurricane Florence. Sampling was cancelled in September 2018 due to inaccessibility of all the sampling sites with the exception of Murrells Landing. Data for this site are collected every other day. Results from this site documented extraordinarily low oxygen in the surface waters from 9/20/18 to 10/21/18 (31 days) during which hypoxic conditions were continuously present. Anoxic conditions were present from 9/25/18 until 10/11/18 (16 days).

Several sites, and especially at Hagley, have long-term evidence in support of algal blooms, having elevated pH and oxygen saturation while conductivity was site normal. At Hagley, ammonia continues to be frequently detected. The surface-water oxygen concentrations measured by the volunteers are typically 0.5 to 1 ppm higher than the bottom-water concentrations measured by the USGS's continuous sensors – another indicator of ongoing

algal blooms. This site also has elevated chlorophyll levels (median 3.2 ppb)

Sterritt Swamp has been a site of concern since 2013 due to episodic concurrent elevations in turbidity and conductivity. This site has been the subject of an IDDE effort undertaken by the Horry County Stormwater and the Waccamaw Riverkeeper in communication with SC DHEC. The latter performed several site investigations of the landfill. Some issues with sediment retention ponds were identified and the SWA was asked to address them.

The overall median turbidity at Sterritt Swamp (2007-2018) is 3.8 NTU (265 samples). In 2018, all data exceeded this median, but only two samples exceeded 7.5 NTU (16 NTU on 4/11/18 and 5/9/18). This was a marked reduction as compared to 2013-2017.

E. coli concentrations have notably declined at Sterritt Swamp since 2013. As shown in the following table, the percentage of samples exceeding the SC DHEC water quality criteria from declined from 9% (2008-2013) to 3% (2013-2018). This is one of only two sites on the Waccamaw River 303(d) listed for fecal bacteria impairments. The percentage threshold for 303(d) listing is 10% of the past 5 years of data.

Table 4 - Rate of E. coli impairments at the Sterritt Swamp volunteer water quality monitoring sites as compared to the SC DHEC Class FW E. coli recreational water quality criteria (SCDHEC 2016) and the EPA's recommended criteria (EPA 2012).

Date range	Sample count	>349 CFU/100 mL		>235 CFU/100 mL	
		count	% exceeding	count	% exceeding
2008-2013	113	10	9%	13	12%
2013-2018	124	4	3%	6	5%

Sterritt Swamp is also 303(d) listed for DO. Since 2013, this site has seen rising Oxygen Saturation, pH, and conductivity suggesting the increasing presence of a less swamp-like water source.

Of particular concern on the North Carolina end of the Waccamaw River is a continuing trend in elevated turbidity at the two sites immediately upstream of the NC/SC state line whose source is thought to be from logging operations. These turbid waters flow into South Carolina, and thus, pose a threat to water quality downstream. During 2018, only one excessively high turbidity was reported, i.e. 16 NTU on 10/24/18 at Pireway Landing. Excessively high conductivity (90 µS/cm) was reported at both Pireway and Babson's Landing on 1/9/18 and 2/28/18. These were the second highest reports out of 118 measurements to date since sampling started in June 2013. The overall median based on 118 measurements is 65 µS/cm.

Surfside Beach

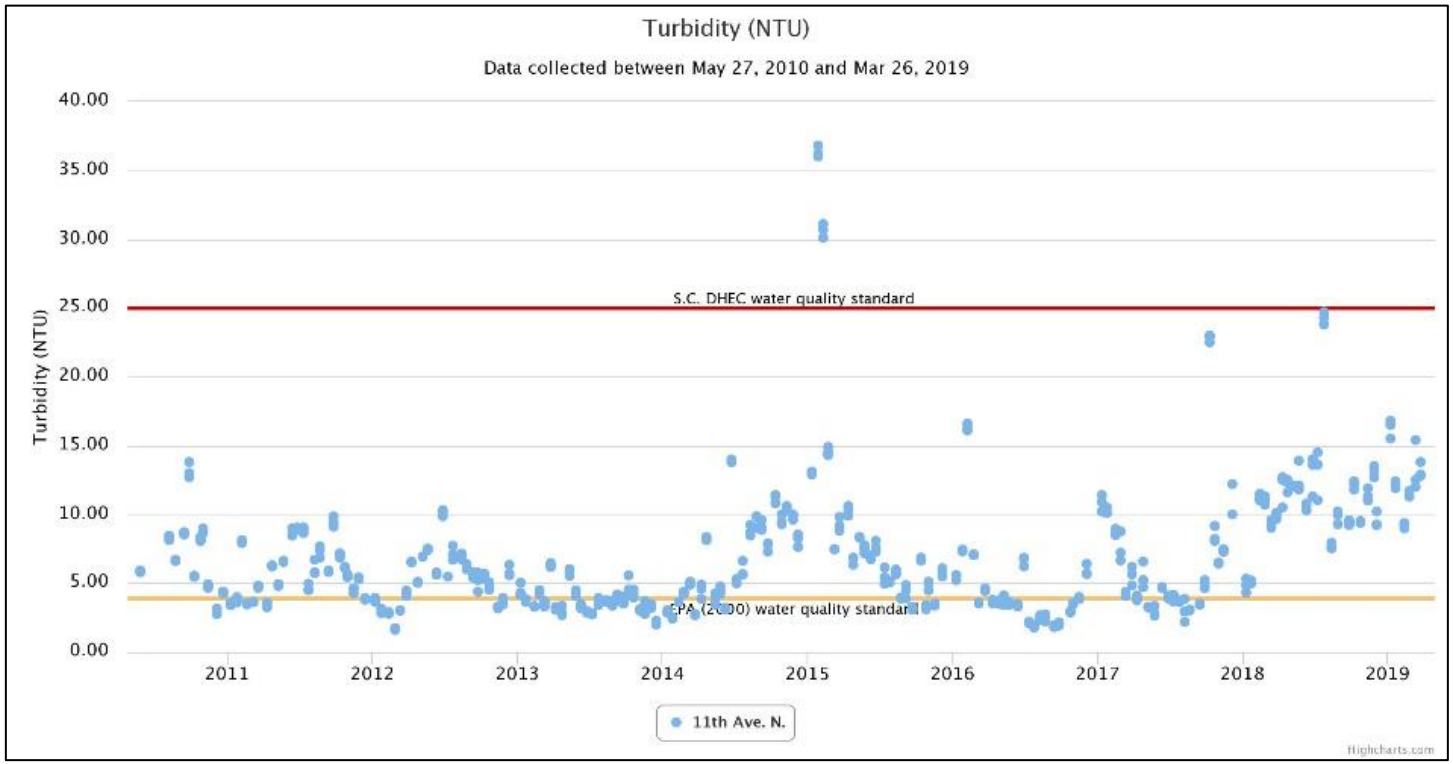
Two sites have been monitored since 2010 by 6 volunteers. Ken Harth has continued to serve as the field leader. Carol Harth continues to provide rain data as a NOAA CoCoRAHs volunteer rain observer. Two of the volunteers (Ron Mask and Al Beck) also serve on the town's stormwater committee.

Water quality reports were presented at quarterly meetings of the Town's Stormwater Committee to summarize the volunteer water quality monitoring data and SC DHEC's beach monitoring data. Electronic copies were provided for posting online at the town's stormwater webpages (http://www.surfsidebeach.org/stormwater-committee).

A requested public outreach presentation was delivered on April 9, 2018 to describe the activities and findings of the volunteer monitoring program.

Starting in 2015, the volunteers have detected periodic spikes in turbidity in Lake Dogwood that were traced back to illicit discharges. Although these discharges were halted, turbidity in 2018 continues to be elevated as shown in the following graph. This lake, which provides stormwater retention services, is due to be dredged to remove sediment that has settled onto the bottom, causing water depths to become shallow.

Figure 1 - Turbidity (NTU) in Lake Dogwood, Surfside Beach, SC from 2010 to present



E. coli levels in Lake Dogwood have been increasing since July 2018, with several water quality contraventions being reported. Myrtle Lake continues to frequently contravene water quality criteria. Levels were also unusually high during the Summer of 2018. Unusually high levels of Enterococcus were also observed downstream at many of the SC DHEC beach monitoring sites ending a period of improved water quality. This phenomenon was seen across the Grand Strand and has been attributed to a high frequency of rain events during the Summer of 2018.

Since 2015, oxygen levels have been rising at both sampling sites and is attributable in part to mechanical aeration. Lake Dogwood also frequently has evidence of algal blooms (supersaturated %DO and elevated pH).

Long Bay Hypoxia Monitoring Consortium

Horry County and the cities of Myrtle and North Myrtle Beach are collaborators in the Long Bay Hypoxia Monitoring Consortium (LBHMC). The goal of the consortium is to monitor water quality and meteorology at three fishing piers. The monitoring data are used to characterize normal conditions for oxygen, salinity, temperature, pH, turbidity and chlorophyll in the coastal waters of Long Bay and to detect the occurrence of hypoxia and

eutrophication. Water quality data are collected every 15 minutes from the surface and bottom waters and meteorological data every 5 minutes about 10 m above sea level. CCU's EQL is responsible for technical support and data management.

Data are made available to the public at the Hydromet Cloud website: http://hydrometcloud.com/hydrometcloud/logincontroller?action=login&username=user&password=user. Live data feeds are displayed on large screen monitors at each of the piers (http://www.coastal.edu/pierdata). CCU maintains a data portal at http://scmss.coastal.edu/project/lbhmc that includes another live presentation of the past month of weather data and the past week of water quality data as part of the Long Bay Observing System: http://bccmws.coastal.edu/lbos. The portal also houses static versions of the historical data and links to peer-reviewed publications.

The data are being harvested for deposit into regional and national databases, namely the Integrated Ocean Observing System's Southeast Coastal Ocean Observing Regional Association (SECOORA) at https://portal.secoora.org/ and the National Weather Service's Meteorological Assimilation Data Ingest System (MADIS) via US Mesonet. These data have "really helped our situational awareness of winds and temperatures for coastal Horry County" (pers. comm. from Tim Armstrong, Meteorologist & Climate Program Leader, National Weather Service Wilmington, NC).

The data collected are notable, as they represent the only continuous water quality information on pH, turbidity and chlorophyll being collected in the coastal waters of South Carolina. The pH data are of particular interest to national initiatives, such as the Southeast Ocean and Coastal Acidification Network (SOCAN), directed at studying impacts of acidification in coastal waters.

The data are also being used to support assessments required in SC DHEC OCRM permits issued for ocean outfall pipes in the cities of North Myrtle Beach and Myrtle Beach. The rain data are also used for interpretation of the weekly beach monitoring data and are presented online with the *Enterococcus* monitoring data at http://bccmws.coastal.edu/enteroview/ .

Education outreach is provided at the piers via signage that provides the URL and QR code to HydrometCloud and large screen displays of the real-time data. The URL and QR codes are also provided on business cards that describe the program and how to access the data. Tours are given to K-12 classes. Program metadata are presented at the South Carolina Coastal Water Monitoring Network (SCCWMN).

Low oxygen continues to be episodically observed during summer months in the bottom waters at all three piers concurrent with low pH, high turbidity and chlorophyll. Spectral analysis performed by Troup et al. (2017) suggests that these episodes are related to vertical temperature stratification that limits mixing in the nearshore waters. The resulting inshore currents are substantially different from those more than ½ mile offshore.[3]

In 2018, hypoxic concentrations (<2 mg/L) were episodically present from late May to early October at all three piers. Concentrations less than 4 mg/L were present from late-April to mid-October. The most pronounced period of sustained very low oxygen occurred from 9/24/18 to 9/30/18 during which concentrations fell to 0.2 mg/L at the Cherry Grove Pier. This was likely a consequence of runoff from Hurricane Florence. Salinities were depressed at all the piers, but most dramatically at Cherry Grove where levels as low as 20 ppt were observed in the bottom

[3] Troup, M.L., D.B. Fribance, S.M. Libes, R. Gurka and E.F. Hackett. 2017. Physical Conditions of Coastal Hypoxia in the Open Embayment of Long Bay, South Carolina: 2006–2014. ***Estuaries and Coasts***, V. 40, p. 1576–1591. DOI 10.1007/s12237-017-0246-x.

waters. Salinities continued to be seasonally low at all three piers through the end of 2018. Inputs of flood waters from the Cape Fear River and Hog Inlet are the likely sources. This is supported by the spatial trend in salinity with lowest values observed at Cherry Grove and the highest at Second Avenue. During the flooding, the surface waters at Cherry Grove were notably tea-colored and clear and to a lesser degree at the Apache and Second Avenue Piers. Surprisingly, marine fish were abundant at all three piers during this period despite the depressed salinity.

Surface waters exhibited supersaturated oxygen concentrations through this spring and summer with maximal levels of 135% at Second Ave on 6/10/18 and 143% at Apache on 6/1/18. These levels were seen during the day. During the night, concentrations declined to levels similar to the bottom waters. Surface water oxygen concentrations were sporadically below 4 mg/L at all three piers during June through July and during mid-October. The lowest surface water concentrations in 2018 were 2.4 mg/L at the Second Ave (6/14/18), 1.7 mg/L at Apache Piers (6/24/18) and 1.4 mg/L at the Cherry Grove Pier (7/6/18).

The lowest sustained bottom-water pH's were 7.6 to 7.7 and occurred during the period of Hurricane Florence flood water impacts in late September. The lowest single reported value was 6.8 (surface water at Second Ave). As in years past, the highest surface water pH (8.3) were observed during periods of supersaturated %DO and elevated chlorophyll, suggesting an algal bloom was present.

The chlorophyll sensors are groundtruthed against lab-based measurements. In years past, the spring plankton bloom starts in mid-May and reaches maximum chlorophyll concentrations in mid-June and mid-July. A small fall bloom typically occurs in October. In 2018, surface water concentrations reached maximal values in mid-August at around 20 to 30 ppb, which is unusually high. The October bloom occurred during the week of 10/7 with sustained concentrations of 10, 20 and 30 ppb at the Second Ave, Apache and Cherry Grove Piers, respectively. These unusually high surface chlorophyll concentrations likely reflect continuing influence of nutrient loading from the Hurricane Florence flood waters. As in years past, temporal variations in bottom-water chlorophyll concentrations track the surface water but at much higher levels. Maximal concentrations of 100 ppb were again observed at all three piers.

Bottom turbidities were highest in July and October. No impact from the beach renourishment in Myrtle Beach in early October was present. Maximum concentrations were 426, 1586 and 1724 NTU at the Second Ave, Apache and Cherry Grove piers, respectively. Average concentrations were 30, 26 and 45 NTU. These were s a bit lower than last year. In the surface waters, turbidity reached maximum levels in early March to mid April, probably from the spring bloom, and in mid-June. Maximum concentrations were 94, 45 and 583 NTU at the Second, Apache and Cherry Grove piers, respectively. Averages were 12, 8 and 11 NTU, pretty similar to last year.

Larval recruitment studies have continued and annual reports are available upon request. The goal of this work is to document biological impacts from water quality conditions at the piers, including episodes of low oxygen, low salinity, high turbidity and chlorophyll. Radon work was halted at the end of 2017. The data record up through that period documented that episodes of low oxygen are associated with high radon levels. The latter are from submarine groundwater discharge pinned to the coast by upwelling conditions that inhibit lateral mixing and promote the

development of hypoxic conditions. This was discussed further in Peterson et al. (2016).[4]

The only substantial widespread data outage in 2018 took place from 9/10/18 to 9/24/18 when equipment was removed in advance of Hurricane Florence. Isolated outages were as follows: (1) 10/11 to 10/31 at the Apache Pier due to Hurricane Michael damage and (2) 6/11/18 to 7/5/18 at the Cherry Grove pier due to two successive lightning strikes that depleted the back-up equipment. Insurance covered some of the repair costs.

In 2017, renewal of the five year contracts that fund the LBHMC's monitoring program were completed. The City of Myrtle Beach has renewed for two years ending 6/30/20. The Cherry Grove and Apache Piers are funded through 6/30/23. This enabled replacement of water quality equipment with YSI's current generation of datasondes (EXO's) and an upgrade on the Vaisala weather stations (WXT536). The EXO's were deployed at Cherry Grove on 7/17/17, at Apache on 11/28/17 and at Second Avenue on 4/11/18 (surface) and 5/2/18 (bottom). This also include a redesign of the surface sonde deployment to eliminate the need of an expensive copper sled that was prone to deterioration and cable fouling. The new weather station installation was completed in July 2018. We had anticipated some data outages at the Second Avenue pier for repairs from Hurricane Matthew damage but these are still pending.

Beach Monitoring

Enterococcus data collected at 61 sites along the Grand Strand since 1997 by SC DHEC and the cities of Myrtle Beach and North Myrtle Beach are made available to the public at a website (http://bccmws.coastal.edu/enteroview/) constructed and maintained by CCU's EQL. This is a pro bono effort designed to support development of TMDL's, microbial source tracking projects, and to meet other needs for temporal and spatial trend analysis such meeting SC DHEC OCRM permit requirements for the Main Street Ocean Outfall in the City of North Myrtle Beach and the 4th Ave. N Ocean Outfall in Myrtle Beach.

The EQL continues to coordinate sampling with SC DHEC during the summer beach season to minimize the number of additional samples needed following reports of contraventions. In 2014, the EQL began issuing weekly potential IDDE reports for samples that contravened the *Enterococcus* water quality standards. The reports compare the weekly results to site-specific norms for *Enterococcus* and salinity using data collected since 2008 – this is date at which the current monitoring protocol was initiated. Samples with unusually low salinity suggest that elevated bacterial levels could be due to stormwater runoff. Samples with normal salinity suggest that an illicit discharge could be the cause of the elevated bacteria levels. In 2016, at the request of SC DHEC, we added evaluation of swash sampling sites against site-specific norms. These norms are updated annually using the 90th, 95th and 99th percentiles for *Enterococcus* and the 10th and 25th percentiles for salinity.

In 2018, several special sampling events were undertaken at the request of individual SMS4s to investigate sewer line breaks or overflows.

CWSEC partnered on delivery of a Water Quality Communication interactive webinar on 7/2/18. The webinar was targeted at Grand Strand tourism / hospitality establishments and businesses who frequently interact with the public to help them learn more about coastal water quality, how the water is tested, and what resources are out there to help them. The session had 21 participants. The webinar was interactive so the participants were able to answer

[4] Peterson, R.N., W.S. Moore, S.L. Chappel, R.F. Viso, S.M. Libes and L.E. Peterson (2016) A new perspective on coastal hypoxia: The role of saline groundwater, *Marine Chemistry*, 179(1), 1-11.

questions. A copy of the webinar was posted on the CWSEC website.

River Gauge Monitoring

Since January 2008, Horry and Georgetown Counties and the City of Conway have been partnering with CCU's EQL and the USGS to maintain a monitoring program at eight sites in the Waccamaw River and one site in Pee Dee River. The work is being performed under a SC DHEC approved Quality Assurance Project Plan.

Grab sampling is conducted at sites where the USGS is maintaining real-time water quality sensors for parameters that cannot be measured in-situ. The EQL also performs in-situ measurements to provide a back-up source of data for interpreting the grab samples. These data are being collated to provide a statistical comparison with the USGS real time data. The former have been certified by the SC DHEC, but not the latter so this comparison provides confirmation of the USGS data. When a lack of agreement is observed, the EQL notifies the USGS who then follows-up to investigate a possible sensor failure.

The USGS real-time data are made available to the public at http://waterwatch.usgs.gov/wqwatch/map?state=sc&pcode=00010. The EQL's results are posted within one month of sampling at: http://bccmws.coastal.edu/river_gauge/.

The results are transmitted to the stormwater managers in provisional reports. A first report is sent within one to two days following sampling. The rest of the results can take as much as a month to generate, so a follow-up report is sent. As with the volunteer monitoring reports, these provisional reports compare the observations to regulatory standards, US EPA recommended levels and site-specific norms. The latter have been established from the entire dataset. Sampling is generally conducted on alternating weeks from the volunteer monitoring program to increase the temporal resolution of the monitoring data. About 2 to 4 times a year, sampling is done during the same week, providing a comparison results between the two programs.

The most recognized water quality impairment in the Waccamaw River, besides mercury in fish tissues, are low oxygen levels. A TMDL was approved in 1999 for the river downstream of Conway. The TMDL is implemented through BOD discharge permits granted to WWTPs. The river's naturally low levels of oxygen are due to the BOD contributed by organic matter exported from the adjacent floodplain wetlands. In an effort to distinguish this natural BOD from anthropogenic sources, the River Gage Monitoring program measures dissolved organic carbon (DOC) and true color in all samples. True color is a proxy for the DOC originating from the adjacent floodplain wetlands. Statistical relationships are used to identify samples in which BOD seems to have a large anthropogenic contribution.

Now that the program has generated 10 full years of data, seasonal trends can be identified. These include seasonal trends in nutrients, DOC, turbidity and BOD. Even the nitrogen-to-phosphorus ratio exhibits a seasonal trend, suggesting a seasonal difference in sources of these elements to the Waccamaw and Pee Dee Rivers. Many seasonal trends detected by the volunteer monitoring program are also seen in the River Gaging data, confirming the accuracy of the volunteer's results. In some cases, the River Gaging data are corroborating findings by the volunteers. For example, indirect evidence of algal blooms from the volunteer pH, conductivity and oxygen saturation measurements is often supported by elevated chlorophyll levels reported from the River Gaging Program.

E. coli measurements have been conducted since 2012 following a transition from fecal coliform as the regulatory microbial indicator. In 2018, SC DHEC's *E. coli* water quality standard was contravened at least once at all sites except at Bucksport and Hagley. As shown in Table 5, three sites contravened the SC DHEC water quality criteria in more than 10% of the samples, i.e. at the two tributaries, Crabtree Canal (Swamp) and Buck Creek and immediately downstream of the latter at Highway 9. Based on the entire 6-year dataset (2012-2018), only two sites have been

Table 5 - E. coli trends at River Gaging Monitoring Sites

Site Name	2018					2012-2018				
	Total	>349 CFU/100 mL		>235 CFU/100 mL		Total	>349 CFU/100 mL		>235 CFU/100 mL	
		count	% exceeding	count	% exceeding		count	% exceeding	count	% exceeding
Buck Creek	23	3	13%	5	22%	109	9	8%	19	17%
Highway 9	23	3	13%	5	22%	109	11	10%	13	12%
Reaves Ferry	23	2	9%	3	13%	109	4	4%	7	6%
Crabtree Swamp	22	5	23%	6	27%	108	32	30%	36	33%
Conway Marina	24	1	4%	3	13%	110	4	4%	7	6%
Bucksport	23	0	0%	0	0%	109	0	0%	0	0%
Hagley Landing	23	0	0%	0	0%	109	2	2%	2	2%
Galivants Ferry	23	1	4%	2	9%	109	5	5%	9	8%

exceeding the 10% threshold, i.e. Highway 9 (barely) and Crabtree Swamp. A microbial source tracking project was conducted in Crabtree Swamp in 2017-2018 to identify the geographic and host animal source causing this *E. coli* impairment.

The decadal dataset has revealed other multiyear trends. For example, conductivity and BOD have been declining at all sites since 2013 except for Crabtree. This likely reflects a long-term recovery from an historic drought that ended in 2012.

As reported in prior years, Hagley Landing has been notable for having the second highest median oxygen saturation levels after Buck Creek and the second highest median turbidity after Crabtree Canal. TP and chlorophyll concentrations at this site are much higher than at all the other sites and generally the surface day-time water oxygen levels are significantly elevated over the bottom water. This likely reflects: (1) influence from discharge from the Pee Dee River, (2) tidal flushing, and (3) impacts from WWTP discharges immediately upstream.

The decadal dataset has illustrated significant differences in pollutant levels between the tributaries (Buck Creek and Crabtree Canal) and the main stem of the river into which they discharge. The tributaries have elevated BOD, TP, and *E. coli* compared to the main stem, which is not surprising given the higher degree of human land use in the catchments that drain into these tributaries. The tributaries also have lower true color, DOC and TN as compared to main stem, probably reflecting a strong groundwater source due to continued dredging.

In 2018, record low oxygen levels were observed following Hurricane Florence (9/11/18) with hypoxic conditions sustained from 9/20/18 to 10/21/18 (31 days). Anoxic conditions were present in the surface waters from 9/25/18 to 10/11/18 (16 days). These observations are from grab sampling at Murrells Landing as part of the volunteer monitoring program as the USGS continuous sensors were nonoperational from 9/19/18 to 10/25/18 (36 days).

The Daphnia toxicity test was positive on 10/4/18 at Bucksport, Conway Marina and Reaves Ferry. Concurrent positives at three sites is highly unusual and likely due to toxic organo-sulfur compounds generated under anoxic conditions on the newly submerged organic-rich floodplains. This was suggested by the unusual odor present during the period of anoxia. SC DNR reported fish kills as follows:

…With the flooding being so extensive it was nearly impossible to get (an) estimate, but easily tens of thousands of fish died. At any rate, it wasn't a complete die off and we plan to monitor the situation this summer to get an idea on the magnitude of the kill. (pers. comm. J. Marsik, SC DNR).

collectively responded to several dozen media requests. Some emergency sampling was also performed in response to flooding of the Conway WWTP.

Table 6 - Eutrophication indicators during post Hurricane Florence flooding

Site	Chlorophyll (ppb)			TN (ppm)			TP (ppm)			Molar TN/TP		Oxygen (ppm)		
	EPA threshold 0.4 ppb			EPA threshold 0.87 ppb			EPA threshold 0.05 ppb			Algae = 20 to 50		SC DHEC WQS 4 ppm		
	10/4/18	10/18/18	*MAX*	10/4/18	10/18/18	*MAX*	10/4/18	10/18/18	*MAX*	10/4/18	10/18/18	10/4/18	10/18/18	*MIN*
Buck Creek	4.3	1.5	*62.8*	0.8	0.5	*3.5*	0.06	0.05	*0.23*	28	27	**2.66**	6.17	*2.18*
Highway 9	**2.7**	**3.8**	*51.1*	**1.7**	**1.8**	*2.3*	**0.11**	**0.08**	*0.17*	**34**	49	**1.37**	**2.41**	*0.87*
Reaves Ferry	**22.4**	7.9	*22.4*	**1.7**	**1.8**	*1.8*	**0.16**	0.08	*0.16*	**24**	48	**0.05**	**1.70**	*0.15*
Crabtree Swamp	NC	**43.8**	*53.5*	NC	**1.0**	*2.5*	NC	**0.13**	*0.27*	NC	18	NC	**1.34**	*0.11*
Conway Marina	**13.0**	**11.3**	*13.0*	**1.3**	**1.6**	*2.0*	**0.16**	**0.09**	*0.16*	**18**	41	**0.07**	**1.26**	*0.07*
Bucksport	1.6	**8.4**	*9.3*	**1.1**	**1.6**	*1.6*	**0.12**	**0.09**	*0.12*	**22**	37	**0.05**	**0.46**	*0.05*
Hagley Landing	0.6	3.1	*3.2*	**1.1**	**1.4**	*1.5*	**0.13**	**0.14**	*0.24*	18	23	**0.27**	**2.55**	*0.27*
Galivants Ferry	0.2	0.3	*6.2*	**1.6**	**1.3**	*1.8*	**0.16**	**0.13**	*0.18*	22	22	**3.09**	**4.06**	*3.09*

Site	Oxygen (ppm)			DOC (ppm)			Color (PtCo)			BOD5 (ppm)		
	SC DHEC WQS 4 ppm			Eutrophic >30 ppm			>275 PtCo highly colored			Eutrophic > 2 ppm		
	10/4/18	10/18/18	*MIN*	10/4/18	10/18/18	*MAX*	10/4/18	10/18/18	*MAX*	10/4/18	10/18/18	*MAX*
Buck Creek	**2.66**	6.17	*2.18*	10.2	8.3	*30.5*	58.0	45.0	*259.0*	2.3	1.2	*6.7*
Highway 9	**1.37**	**2.41**	*0.87*	**41.0**	**42.2**	*42.2*	**429.0**	**413.0**	*432.0*	2.5	1.9	*7.8*
Reaves Ferry	**0.05**	**1.70**	*0.15*	**36.6**	**42.0**	*42.0*	**361.0**	**413.0**	*416.0*	**6.0**	2.3	*6.0*
Crabtree Swamp	NC	**1.34**	*0.11*	NC	15.1	*27.5*	NC	**126.0**	*303.0*	NC	**3.4**	*14.9*
Conway Marina	**0.07**	**1.26**	*0.07*	28.0	**38.7**	*38.7*	280.0	**417.0**	*470.0*	**5.6**	2.3	*11.0*
Bucksport	**0.05**	**0.46**	*0.05*	24.7	**36.8**	*36.9*	**287.0**	**386.0**	*386.0*	**3.6**	2.4	*5.7*
Hagley Landing	**0.27**	**2.55**	*0.27*	**24.9**	**21.9**	*25.4*	**265.0**	**233.0**	*304.0*	**2.5**	1.7	*5.0*
Galivants Ferry	**3.09**	**4.06**	*3.09*	**39.0**	**29.0**	*39.0*	**441.0**	**298.0**	*441.0*	1.8	1.3	*6.1*

NC = not collected due to flooding. **Record high (or low for N/P)** >90th percentile (based on approximately 260 samples)

EPA threshold from "US EPA (2000) Ambient Water Quality Criteria Recommendations Information Supporting the Development of State And Tribal Nutrient Criteria For Rivers And Streams In Nutrient Ecoregion XIV, EPA 822-B-00-022"

For the first time, the local media was very interested in the potential water quality impacts of flooding. The Director of the Waccamaw Watershed Academy and the Waccamaw Riverkeeper

Nutrient loading from the flood led to unusually high TN and TP concentrations through 11/15/18. As shown in Table 6, concentrations were highest in the sampling results from 10/4/18

and 10/18/18. This flood pulse of nutrients supported a widespread algal bloom as documented by elevated chlorophyll detected on 10/4/18 and 10/18/18. The flood also led to unusually elevated Color, DOC and BOD5. Numerous results exceeded the 90th percentile of the entire monitoring program's dataset with several records set, i.e. Chlorophyll (1), TN (2), TP (3), Oxygen (4), DOC (3) and Color (1).

Since 2017, samples have been collected for the USGS to test the hypothesis that modest but sustained increases in turbidity and oxygen deficits following flood events were caused by leaching of reduced metals, sulfide and methane from saturated soils into the shallow groundwater. Once in the river, oxidation of these metals in oxic river water would generate particulate metals, raising turbidity and would account for the low oxygen saturations also observed. Oxidation of the sulfide and methane would also contribute to the oxygen deficits. Such events occurred in 2015 and 2016 following Hurricanes Joaquin and Matthew. A post-flood elevation in turbidity was not observed after Hurricane Florence.

CCU Campus Monitoring

The goal of CCU's Campus Monitoring Program is to provide an assessment of water quality conditions in the stormwater ditches and retention ponds on campus, all of which eventually send waters off campus towards the Waccamaw River. This program was started in 2009 to help meet the requirements of a wetlands permit issued to enable construction of Wall Pond. Data collected since 2011 are made available to the public at: http://bccmws.coastal.edu/ccum/index.html. A web page with a program description and portal to the data is located at: https://www.coastal.edu/wwa/datasets/campus/.

In its current incarnation, CCU undergraduate students can participate by enrolling for 1 credit under MSCI 399Q or volunteering in a non-credit role. The data are being used to evaluate whether water quality is improving or degrading over time at some or all of the sites using a watershed approach. CCU's Waccamaw Watershed Academy provides technical support. The Waccamaw Riverkeeper serves as the field leader and ensures that the data are relayed to CCU's Building and Grounds staff for follow-up on potential illicit discharges. Both organizations are providing pro bono assistance in this effort. A graduate student intern serves as the teaching assistant responsible for training the students, organizing logistics and uploading the data.

In 2018, CCU's QEP program was awarded another round of funding to support this program. A request has been submitted to continue funding into 2019. This funding has helped support acquisition of a Hanna multimeter for in-situ measurements. CCU also began providing an assistantship to a graduate student who serves as the teaching assistant. The graduate student trains the undergraduates, supervises sampling and analyses, maintains the sampling equipment and performs the first layer of data review.

In 2018, the students generally sampled weekly at three locations (501 West, Wall Pond, 544 West) bringing the number of independent measurements to a total of 6,607 since the program commenced on October 13, 2011.

At the end of each semester, the students and Riverkeeper hold a data conference to review their results. In 2018, these conferences were held on April 26th and December 6th. The graduate student intern presented a poster presentation about the program at the 2018 SC Water Resources Conference on 10/17/18. As in years past, biweekly sampling was conducted during the summer by EQL student workers.

A notable gap in all the volunteer monitoring programs has been measurement of phosphate. To address this two honors program students validated a lab-based method that was adopted in Spring 2017. This work has seen been continued as a coordinated independent study project. The data suggest phosphate is elevated at the most downstream site where E. coli concentrations are most frequently very high.