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 SCDHEC.

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 SMS4's.

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 Conference.

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 similar presentation was delivered at the biennial South Carolina Water Resources Conference held in October 2016.

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

[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)

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 2017, 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	137	11	1,507
	Canal Cove	137	11	1,507
	Big Creek	137	11	1,507
	LAWA Dam	137	11	1,507
	Babson's Lndg	105	11	1,155
	Pireway	105	11	1,155
	Hwy 9	269	11	2,959
	Reaves Ferry	259	11	2,849
	Murrells Lndg	2023	17	34,391
	Sterritt Swamp	244	11	2,684
	Conway	269	11	2,959
	Pitch Landing	269	11	2,959
	Peachtree	233	11	2,563
	Enterprise	269	11	2,959
	Bucksport	270	11	2,970
	Wachesaw	272	11	2,992
	Hagley	269	11	2,959
	Sampit	265	11	2,915
			Total =	74,497
Murrells Inlet since May 2008	Woodland Drive Pond	226	11	2486
	Point Drive Canal	226	11	2486
	Rum Gully Creek	226	11	2486
	Marina Colony Pond	226	11	2486
	HS	226	11	2486
	BHR	226	11	2486
	Bike Bridge	226	11	2486
	Oyster Landing Beach	226	11	2486
			Total =	19,888
Surfside Beach since May 2010	Lake Dogwood	173	11	1903
	Myrtle Lake	173	11	1903
			Total =	3,806
Campus Volunteer Monitoring since Oct 2011	501 West	181	11	1991
	544 East	17	11	187
	544 West	181	11	1991
	Wall Pond Bridge	181	11	1991
	Wall Pond East	2	11	22
	Wall Pond West	2	11	22
			Total =	6,204

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 2017, the following initiatives were undertaken to enhance data quality: (1) Upgrade in Micrology Easygel media by OEM in response to findings from the EQL of low fluorescence, (2) Continued monitoring of fluorescence performance of new media, (3) Upgrade in Hach nitrate test strips by OEM that resulted in performance issues as documented by the EQL. This required instituting a chain of custody tracking procedure for each bottle of test strips. (4) Addition of orthophosphate measurements to the campus monitoring program.

On the field leader front, personnel changes included:

- Murrells Inlet: Meredith Millen was hired as the new Executive Director of Murrells Inlet 2020. Robert Steffens continues to perform the field leader.
- Waccamaw River: Cara Schildtknecht was hired as the Waccamaw Riverkeeper and is now serving as the field leader.
- Campus Monitoring: Kaley Towns was appointed as the next graduate student teaching assistant whose primary duties are to run the campus monitoring program.

Additional details on each of the volunteer monitoring programs and highlights from 2017 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.

Murrells Inlet

Eight sites have been monitored since 2008 by 18 volunteers. Bob 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. The new station name is "Murrells Inlet 2020" and the new station ID is 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 SCDHEC 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 BMP's recommended in the Murrells Inlet Watershed-based Plan. These included Filtrexx socks, 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, the volunteers began performing additional sampling at two of these sites to assist in assessing the effectiveness of the new BMPs.

Robert Steffens has continued as the field leader. Meredith Millen took over from Renee Williamson as Executive Director of MI2020 and in that capacity has continued to serve the program by providing outreach through her organization. This includes posting information in their printed newsletters and emailed updates. These venues have also been used to recruit new volunteers. Meredith assisted with logistics associated with the joint data conference held in October 2017 described further below.

In 2017, rain was so frequent that many sampling events were performed shortly afterwards, leading to numerous reports of elevated turbidity and bacteria. Most notable were a series of high turbidity reports from BHR, four of which exceeded the Class SFH water quality criteria, leading to an illicit discharge investigation conducted by Georgetown County's stormwater department. This site has typically exhibited the highest *E. coli* levels, but levels were unusually low in 2017 with the annual median being 800 CFU/100 mL as compared to 1833 CFU/100 m for the period from July 2009 through December 2016.

A joint data conference was held with Surfside Beach's volunteer water quality monitoring program on October 3rd 2017. This joint meeting enabled a discussion of the watershed connection between the two communities and a comparison of water quality trends. For example, both programs have documented a multiyear trend of increasing oxygen levels at most of their sampling sites, leading to improved water quality

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 April 9, 2017. 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. Particularly well received was a Water Quality 101 presentation that featured a CSI-style description of how illicit discharge investigations are performed using the volunteer water quality data.

Data generated from this program is presented at an Annual Data Conference that was held on November 16th 2017 at CCU's Center for Marine and Wetland Studies. A guest presentation was delivered by the organizers of SCDHEC's new Adopt-A-Stream program that will eventually support volunteer water quality

monitoring statewide. A data conference for the North Carolina volunteers was held on December 6, 2017 at the Lake Waccamaw State Park.

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.

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.

Presentations from the volunteer appreciation luncheon and the annual data conference have been posted at http://www.coastal.edu/wwa/vm/wr/publications.html.

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 2017 Waccamaw Conference was held on February 11th.

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.

In 2017, numerous samplings were performed shortly after rain had fallen, so this year's data reflect impacts of stormwater runoff on the river. Most notable were repeatedly high levels of turbidity. Geographically widespread occurrences of *E. coli* contravening the water quality criteria were reported on 8/9/17 and 10/25/17. This is highly unusual for the Waccamaw River. Due to a relatively warm winter, oxygen levels were unusually low in January and February. Due to flooding in August and September, oxygen levels were again unusually low and below the SCDHEC water quality criteria. This flooding was caused by a total of 12.5" rain that fell during August and September, half of which came from Potential Tropical Cyclone Ten on 8/28/17 and Hurricane Irma on 9/11/17.

Turbidity was elevated from January to August in 2017 following Hurricane Matthew (October 2016). This was similar to a sustained elevation observed in 2016 several months after Hurricane Joaquin (September 2015). The degree of elevation was a factor of 2.1 in 2016 and about 1.8 in 2017. A possible cause was hypothesized to be leaching of reduced metals, sulfide and methane from the saturated soils into the shallow groundwater. Once the groundwater drained into the river, oxidation of these metals in oxic river water should generate particulate metals, raising turbidity and accounting for the low oxygen saturations also observed. To test this hypothesis, Horry County requested that the USGS undertake some trace metal sampling, which was conducted during 2017 as part of the River Gaging program and is described further below.

Several sites, and especially at Hagley, had 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.

The March 22nd sampling was particularly notable for having oxygen saturations somewhat-to-unusually high at all the river sites. At the Sampit River site, the saturation level was 100%,

which is unusually high for a blackwater river. Similar observations were reported from the new continuous water quality sensors in Winyah Bay operated by the NI-WB NERR. Upstream at the five sites located near USGS continuous sensors, four had higher surface oxygen levels as compared to the bottom-water levels, ranging from 0.1 to 0.5 mg/L higher. Therefore, it appears sampling captured a widespread spring algal bloom on that day.

During 2016, an IDDE investigation was continued at Sterritt Swamp in response to continued episodic elevations in turbidity and conductivity. Not all of these coincided with rain events and some of the turbidity measurements exceeded the state water quality criteria of 50 NTU. In 2017, a record high turbidity (78 NTU) was reported in January. Elevated values were reported four more times during routine sampling with additional samples collected to track the length of some of these events. Horry County engaged with SCDHEC seeking the source of the sediment by conducting site investigations upstream and downstream of the Horry County Solid Waste Authority (SWA) landfill. The Waccamaw Riverkeeper had several discussions with SWA. SCHDEC performed several site investigations of the landfill. Some issues with sediment retention ponds were identified and the SWA was asked to address them. Concurrently, a new PUD constructed near Clear Pond upstream of the landfill was completed at approximately the same time. The last high turbidity level was reported on August 9, 2017 suggesting the illicit discharge issue has been resolved.

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.

In 2017, at the request of the stormwater manager, volunteers performed additional investigative work to document oxygen levels in the Lakes, including Palmetto Lake, to assess the effectiveness of new aeration pumps. At the routine monitoring sites, oxygen levels continue to exhibit a multiyear trend of increasing levels, leading to improved water quality.

Water quality reports were presented at quarterly meetings of the Town's Stormwater Committee to summarize the volunteer water quality monitoring data and SCDHEC's beach monitoring data.

A requested public outreach presentation was delivered on March 16th 2017 to educate committee members on the sources of nonpoint source pollution in Surfside and steps that residents and tourists can use to minimize this. Another requested public outreach presentation was delivered on October 20th 2017 to describe the town's volunteer water quality 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 2017 was overall higher than the mean from 2010 to 2016 (exclusive of the illicit discharge). 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.

In September 2017, the volunteers detected the presence of salty waters in Lake Dogwood due to overwash from Hurricane Irma. The outer bands of Nate in October also transported sediment and fecal bacteria into Lake Dogwood, leading to high levels of turbidity and *E. coli* that persisted through the entire month. Otherwise *E. coli* levels continued to be very low in this lake, whereas Myrtle Lake continued to exhibit elevated *E. coli* with a median in 2017 of 400 CFU/100 mL. In contrast, beach monitoring performed by SC DHEC found few cases where any of the town's sampling sites had exceeded the SC DHEC water quality standards for the saltwater fecal indicator bacteria, *Enterococcus*. This continues a multi-year trend of improving water quality.

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 SutronWin website: http://sutronwin.com/sutron/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. The data have also been ingested into the Intelligent Rivers database and are to be displayed at https://www.intelligentriver.org/data.

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 directed at studying impacts of acidification in coastal waters.

The data are also being used to support assessments required in SCDHEC 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 SutronWin 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.[2]

In 2017, hypoxic concentrations (<2 mg/L) were episodically present from late May to late August at all three piers. Concentrations less than 4 mg/L were present from mid-April to

[2] 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.

mid-October. A period of sustained very low oxygen occurred from 5/30/17 to 6/29/17 during which concentrations fell to less than 0.2 mg/L at the Second Ave and Apache Piers. Another period of pronounced low oxygen occurred in mid-October that is attributed to beach renourishment. Surprisingly, the anoxic conditions did not lead to fish kills or dead invertebrates washing up on the beach. Condition reports were emailed out to the SMS4's, SCDHEC and SC DNR on a weekly basis.

As in years past, the low oxygen levels were associated with upwelling favorable conditions (winds blowing out of the southwest for at least a day followed by a period of wind speeds less than 10 mph). This produces vertical stratification in temperature and salinity with low temperature and high salinity water reported by the bottom datasonde as compared to the surface. Bottom water turbidity and chlorophyll concentrations are much elevated over the surface waters. pH's are lower due to release of CO_2 from microbially driven aerobic respiration that is responsible for the removal of the O_2. As in years past, the phytoplankton present at bloom concentrations was *Rhizosolenia*, a diatom. Another species in large abundance was *Proboscia* (G. Boneillo, personal communication).

In Cherry Grove, anoxic conditions were present from 10/11/17 to 10/24/17. This was attributed to the after effects of beach renourishment. Surprisingly, this was accompanied by very low bottom water salinities (24.5 psu) overlain by higher salinity surface water. Bottom turbidity was very high probably because the bottom sonde was suspended in a slurry of sediment created by winnowing from the beach renourishment fines. Bottom water oxygen concentrations were also impacted at the Second Ave and Apache Piers, but to a lesser extent with lowest concentrations of 2.3 and 1.9 mg/L being reported on 10/11/17 and 10/12/17, respectively.

Surface waters exhibited supersaturated oxygen concentrations through this spring and summer with maximal levels of 135% at Second Ave on 6/10/17 and 143% at Apache on 6/1/17. 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 Jun through July and during mid-October. The lowest surface water concentrations in 2017 were 2.4 mg/L at the Second Ave (6/14/17), 1.7 mg/L at Apache Piers (6/24/17) and 1.4 mg/L at the Cherry Grove Pier (7/6/17).

The lowest bottom-water pH's were 7.6 to 7.7 reported from 6/24 to 6/26 at all three piers. The highest surface water pH was 8.3, reported from 5/29/17 to 6/1/17, suggesting an algal bloom was present. The chlorophyll sensors are groundtruthed against lab-based measurements. As in years past, the spring plankton bloom starts in mid-May and reaches maximum chlorophyll concentrations in mid Jun and mid Jul. A small fall bloom occurred in October. In 2017, bottom-water concentrations reached maximum concentrations of 100 ppb at all three piers. In the surface waters, diurnal and biweekly periodicity was present with maximum concentrations of 30 ppb. Surface-water oxygen concentrations and pH also exhibited diurnal periodicity, especially during periods of low bottom-water oxygen, suggesting an ongoing surface phytoplankton bloom.

Bottom turbidities were highest in June and July. Maximum concentrations were 1210, 1390 and 4487 at the Second Ave, Apache and Cherry Grove piers, respectively. Average concentrations were 31, 29 and 54 NTU. In the surface waters, turbidity reached maximum levels in early March to mid Apr, probably from the spring bloom, and in mid-June. Maximum concentrations were 590, 900 and 490 NTU at the Second, Apache and Cherry Grove piers, respectively. Averages were 15, 12 and 10 NTU.

Salinities continue to be highest during the summer when upwelling draws shelf water closer to the coast and typically range from 36 to 37 psu. Wintertime salinities are typically 34 to 35 psu. Salinities can drop as low as 31 to 32 psu following rain events.

Cherry Grove is particularly prone to 2 to 3 psu drops immediately following rain events.

Another multi-year trend is a shallowing of Secchi depths in 2017 from 140 to 120 cm at the Cherry Grove Pier, 180 to 160 cm at the Apache Pier and 180 to 150 cm at the Second Ave N pier. This suggests an increase in surface water turbidity in 2017. The surface sondes are deployed about 100 cm below the sea surface.

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).[3]

The only substantial data outage in 2017 took place from 9/8/17 to 9/21/17 when equipment was removed in advance of Hurricane Irma. A lightning strike on 8/24/17 damaged equipment at the Cherry Grove Pier, leading to an insurance claim that covered repairs to the data sondes.

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. With this second five-year cycle, we will be migrating to YSI's current generation of datasondes (EXO's) and switching from Vaisala weather stations to one's from Gill Instruments. This has been completed at the Cherry Grove and Apache Piers. We do anticipate some data outages at the Second Avenue pier while repairs from Hurricane Matthew damage are undertaken. The timing of this is unknown.

Beach Monitoring

Enterococcus data collected at 61 sites along the Grand Strand since 1997 by SCDHEC 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 SCDHEC 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 SCDHEC 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 SCDHEC, 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.

[3] 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.

In 2017, several special sampling events were undertaken at the request of individual SMS4's to investigate sewer line breaks or overflows. Final reports were also submitted for microbial source tracking work performed within the city of North Myrtle Beach and in Hog Inlet.

CWSEC partnered on delivery of a Water Quality Communication workshop on 2/7/17 at the Myrtle Beach Area Chamber of Commerce. The goal of the workshop was to provide guidance to hospitality staff on communicating risks from recreational exposure to elevated levels of *Enterococcus* bacteria. The session was well attended and covered by the press. After the meeting, the EQL met with SCDHEC to discuss coordination for the upcoming 2017 beach season.

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 SCDHEC 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 SCDHEC, 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, USEPA 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 WWTP's. 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.

In 2017, sampling was frequently conducted soon after rain events, similar to the volunteer monitoring sampling. Effects of stormwater runoff were most notably on 2/16/17, 4/6/17, 4/20/17 and 12/14/17, during which elevated *E. coli* and turbidity were widespread in both rivers. For most of these events, the USGS gages in the Waccamaw River enabled visualization of a turbid plume that moved out of the two tributaries, Buck Creek and Crabtree Canal, and then were tracked downstream as the plume moved past the sensors at Highway 9, Reaves Ferry and Conway.

In 2017, SCDHEC's *E. coli* water quality standard was contravened at least once at all sites except at Bucksport and Hagley. Some of the water quality impairments observed in 2017 represented record high concentrations, including TN and TP in Crabtree Canal. The record concentrations all followed rain events. The Daphnia toxicity tests generated positive results following two rain events: (1) 2/16/17 at Highway 9, Reaves Ferry, Conway, and Bucksport and (2) 12/14/17 at Reaves Ferry and Hagley Landing.

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.

The decadal dataset has also revealed multiyear trends. For example, oxygen saturation has been declining since 2013 at most of the main stem sites, i.e., Reaves Ferry, Conway, Bucksport and Hagley Landing. This likely reflects a long-term recovery from an historic drought that ended in 2012. In contrast, oxygen saturation has been rising in Buck Creek.

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) WWTP discharges immediately upstream.

In 2017, samples were 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 flood events occurred in 2015 and 2016 following Hurricanes Joaquin and Matthew.

In 2017, a new microbial source tracking effort was commissioned by the city of Conway and Horry County for Crabtree Canal in response to continuing episodic elevations of *E. coli* that greatly exceed the state water quality criteria. This work got underway in October 2017 with sample collect to occur at a rate of one storm per month for one year.

CCU Student Monitoring

Three monitoring programs are being conducted by CCU's undergraduate students to provide data for the SMS4's. This includes: (1) ground and lake water levels in Briarcliffe Acres, (2) survival of native trees and shrubs planted as part of a floodplain restoration along Crabtree Canal, and (3) water quality monitoring on CCU's campus. As noted below, these efforts are being

supported by the SMS4s and CCU. CCU's boundaries lie within the SMS4 jurisdictions of Conway and Horry County.

Briarcliffe Acres Groundwater

Since June 2012, Horry County and the town of Briarcliffe Acres have been partnering on a monitoring program to characterize lake and groundwater levels. The goals of this program are to provide insight into: (1) how to manage limited water resources during times of drought and (2) the frequency and timing of high water tables that have the potential to intercept septic tank flow fields. These data are to be used to engage the local community in water stewardship efforts.

The data are collected from three groundwater wells and two lakes. They are downloaded monthly and posted at a public website: http://bccmws.coastal.edu/bagw/. Project presentations and reports are also posted. This project was designed to engage students by having them perform the data download. Since the first three years of funding reached completion in 2015, CCU sought and obtained grant funding to support replacement of all equipment. Horry County has agreed to continued support of travel and undergraduate student salary. This grant funding supports student enrollment for credit in a section of independent study to enable experiential learning under CCU's QEP program.

Monitoring was halted in 2017 due to lack of staffing in the EQL. The lab had a hard time recovering from the vandalism that occurred in 2016, specifically not having the technical expertise in house to re-establish vertical elevation benchmarks to the accuracy needed. Continuing construction at one of the sites also made equipment maintenance impractical. A CCU student plans to work up the final data collected in 2017 during the fall 2018 semester. These data will then be uploaded to the project website along with a final report.

On a positive note, the data were used to provide feedback on a draft "Resolution to Establish the Briarcliffe Acres Floodplain Improvement District". This resolution was approved by the town and is being used to address long standing issues with fecal bacteria contamination in Briarcliffe Swash and the nearby surf zone.

A microbial source tracking project was conducted in the Briarcliffe and White Point swashes in 2015 at the request of Horry County that demonstrated significant contamination emanating from both swashes. Beach monitoring data continue to demonstrate impaired conditions where the two swashes merge and discharge into the surf zone with 9 of the 73 samples (12%) collected by the EQL and SCDHEC in 2017 exceeding the recreational water quality criteria.

Crabtree Canal Floodplain Restoration

Restoration of a channelized swamp, Crabtree Canal, was initiated in 2009 by the City of Conway and Horry County following identification as a top priority action in the Kingston Lake Watershed Management Plan. Assessment work has been performed to demonstrate restoration of floodplain structure and function. The US FWS provided funding for the restoration and assessment work. The latter was conducted by CCU students who performed annual tree counts to track survival rates and downloaded water-level logger data for use by Clemson University to infer floodplain inundation activity. Clemson University was also monitoring channel and floodplain bathymetry and topography. Water monitoring ended in July 2015 due to lack of funding. The tree surveys were suspended by mutual agreement of the Crabtree Restoration working group in light of the relative stability of the restored vegetation.

In 2016, the USACOE has entered into a formal agreement with Horry County to study how they can support additional restoration work. Flooding in 2015 and 2016 from Hurricanes Joaquin and Matthew did not cause significant damage, suggesting the design of the restoration has created a sustainable floodplain.

In 2017, the City of Conway and Horry County commissioned the EQL to undertake a microbial source tracking project along the

segment of Crabtree Canal that runs from Oak Street to Long Avenue. Samples are being collected over a 12-month period following significant rain events. The primary objective of this work is to determine whether human-sourced fecal bacteria are present and contributing to a recent spate of very high *E. coli* levels reported from the River Gage monitoring program. Levels were so elevated that results were frequently off scale. To address this, additional dilutions are now routinely performed with financial support from Horry County. The results of this work were presented at several meetings of the Crabtree Canal Floodplain Restoration Working group and led to a collaborative development of the sampling design for the microbial source tracking project.

Due to the elevated *E. coli* results that have been detected during the ongoing microbial source tracking project, the City of Conway and Horry County have undertaken several illicit discharge investigations during which evidence for sewer manhole overflows have been documented.

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: http://www.coastal.edu/wwa/datasets/coastalcarolinauniversitycampusmonitoring/

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.

In 2017, CCU's QEP program was awarded another round of funding to support this program. A request has been submitted to continue funding into 2018. 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 2017, the students generally sampled weekly at three locations (501 West, Wall Pond, 544 West) bringing the number of independent measurements to a total of 6204 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 2017, these conferences were held on April 27th and December 7th. Biweekly sampling is conducted during the summer by EQL work-study students.

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 and provides a more advanced opportunity for upper-level students to engage in the monitoring program.

In 2017, the following poster presentations were delivered by the students about their campus monitoring data: (1) CCU's Undergraduate MSCI Departmental Poster Symposium (11/28/17), (2) CCU's Campus and Community Research Collaborative (10/12/17), (3) Winyah River Foundation's Annual Waccamaw Conference (2/11/17) and (4) CCU's Undergraduate Research Symposium held on 4/11/17. The poster presented at the Waccamaw Conference won the "Best in Show" award.