WATERSHED-BASED PLANNING FOR MURRELLS INLET: SOURCE ASSESSMENT OF FECAL BACTERIA USING VOLUNTEER AND SHELLFISH SANITATION PROGRAM DATA

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ABSTRACT. A watershed-based plan was recently developed for Murrells Inlet, a moderately tidal, euhaline estuary located on the northern coast of South Carolina. One of the goals of this planning effort was to collate and analyze existing data to refine assessments of the sources of fecal coliform detected by SC DHEC's shellfish monitoring program. Coastal Carolina University's Waccamaw Watershed Academy (WWA) was engaged to lead this data analysis effort. The most important sources identified were urbanized wildlife and canines. Results from the data analyses were used to prioritize subwatersheds for remediation. This has led to proposed strategies that focus on interception and treatment of stormwater runoff as well as volume reduction, dredging of tidal creek sediments, and outreach education for pet waste control.

INTRODUCTION

Murrells Inlet is a moderately tidal, euhaline estuary located on the northern coast of South Carolina. The adjacent saltmarshes (3000 acres) are managed for oyster and clam harvesting. The watershed covers approximately 9,264 total acres (land and water) with 6,326 acres of land surface. The average elevation is 15 to 20 feet above MSL. A Total Maximum Daily Load (TMDL) was approved by SC DHEC in 2005 to address long-standing fecal coliform impairments observed under their shellfish management program at about 20 sampling sites monitored since the 1960's. A consequence of these impairments is that approximately 30% of the inlet is closed for shellfishing,

Various efforts have been undertaken to identify sources and transport pathways of the fecal bacteria. This has included: (1) an effort to develop an OCRM-funded Special Area Management Plan (2003-2005), (2) volunteer water quality monitoring (2008-present), (3) microbial source tracking using multiple antibiotic resistance and GIS modelling (Kelsey et al. 2003; Kelsey et al. 2004), and (4) spatial surveys conducted by SC DHEC, Georgetown County and Coastal Carolina University (since 2010). The latter included measurement of fecal bacteria in sediments.

In 2012, SC DHEC awarded the Waccamaw Council of Governments (COG) USEPA Section 319 funding to lead development of a watershed-based plan. The primary goal of the plan is to outline strategies for achieving fecal coliform load reductions. The COG developed this plan collaboratively with a steering committee comprised of stormwater managers from Horry and Georgetown counties, Murrells Inlet 2020 (a local community group), volunteer water quality monitors, Earthworks, Inc. and scientists from Coastal Carolina and Clemson University (Newquist 2014) and concerned members of the community. The plan includes a detailed list of prioritized fundable remediation projects designed to reduce fecal coliform loading to Murrells Inlet. These projects were developed from an understanding of fecal sources and transport pathways obtained from a comprehensive review of all existing data and prior microbial source tracking efforts.

PROJECT DESCRIPTION

Coastal Carolina University's Waccamaw Watershed Academy was engaged to lead this collation and data analysis effort. Bacteria concentration data from SC DHEC's shellfish monitoring program (1967-2011) and a local volunteer water quality monitoring program (2008-2012) were used to elucidate spatial and temporal trends in bacteria levels and their causative drivers. Other ancillary data included rain, salinity, watershed delineations, and land use-land cover information as described below.

Additional data was collected concurrently with the watershed planning effort via two independent projects. One was conducted by the volunteer water quality monitors who performed upstream source tracking under wet and dry conditions in several small tributaries that had consistently elevated fecal bacteria levels. The other was conducted by Horry County and Coastal Carolina University's EQL in the northern portion of the Inlet using genotypic and chemical tracers to identify host animal sources (Sturgeon et al. 2014).

The project's steering committee participated in selection of statistical tests, reasonable assumptions, and modes of data presentation including GIS mapping. This committee also reviewed the results and collaboratively crafted summary conclusions that were incorporated into the watershed-based plan. A technical advisory committee provided peer review of the data analyses.

METHODS

Data analyses were designed to answer the questions: (1) What is the ultimate source(s) and transport process(es) leading to the bacterial water quality impairments? (2) Why are some sites attaining water quality criteria and others not? (3) Are some impaired locations more problematic than others? (4) Where and why has the acreage of shellfish closures been changing?

Drivers of fecal coliform trends that were evaluated included: rain, i.e. transport via overland runoff due to stormwater flows, as well as tides, salinity, and changes in land use/land cover. In the case of rain, it was hypothesized that: (1) fecal bacteria concentrations would be higher in samples collected following rainfall as compared to antecedent dry periods, (2) fecal bacteria concentrations would be higher in samples collected during low tide as compared to high tide, and (3) fecal bacteria concentrations would be higher in samples collected during periods of lower salinity. Since the fecal bacteria data were not normally distributed, a Mann-Whitney U test was used to test the rain and tide hypotheses and a linear regression for the salinity hypothesis.

Spatial trends were examined by boxplotting and by ranking sites in terms of their frequency of water quality criteria exceedances. Two criteria are used in the National Shellfish Sanitation Program, i.e. the geometric mean of 36 samples collected during a rolling 3-year period and an estimated 90th percentile. These criteria are very tight, i.e. <14 and <43 MPN/100 mL, respectively, to provide human-health protection for raw shellfish consumption. In comparison, SCDHEC had used, until 2012, a recreational contact standard of 200 MPN/100 mL (based on a 30-d geometric mean). Both sets of criteria are found in South Carolina's R.61-68.

Another driver considered was changing land use as it was hypothesized that fecal bacteria levels would increase in response to increasing imperviousness. Changes in land-use over time were evaluated using a GIS-based model (Williams et al. 2014). Temporal trend analyses were performed using the Mann-Kendall test for monotonic trend with and without controls for short timescale rain events (Hirsch and Slack 1984). Ad-hoc linear regressions were used to confirm these results. Data were boxplotted to visualize interannual variability at each site as the Mann-Kendall test for trend assumes uniformity in short timescale variability.

Data sources. Watershed mapping was performed by Earthworks, Inc. This included delineation of 51 subwatersheds and analysis of land use-land cover change (Williams et al. 2014). Georgetown County performed peak flow determinations for design rain events using the TR-55 model that is designed for small urbanizing watersheds.

Statistical tests were performed on fecal coliform data from SC DHEC's National Shellfish Sanitation Program collected from 1967 to 2011 which is the entire period of record that SC DHEC was available to provide within the US EPA 319 project time frame. Data were provided by M. Pearson (SC DHEC). Younger data were used in some analyses as they became available. Ancillary data included salinity and tidal stage.

Statistical tests were performed on E. coli and total coliform data collected at eight sites by the Murrells Inlet volunteer water quality monitoring program from 2008 to 2012. Ancillary data included conductivity, as most of these sampling sites are located in freshwater tributary streams that discharge into saline tidal creeks.

To obtain a rain record back into the 1960's, the nearest NCDC site 20017384 was used. This site is located 1.5-mi inland in Brookgreen Gardens, Murrells Inlet, SC.

RESULTS & DISCUSSION

The results were collated in a map-based matrix that included subwatershed characteristics such as acreage and TR-55 estimated flows. This format was used to facilitate prioritization of subwatersheds for remediation via use of stormwater treatment practices. The spatial analyses illustrated that the sites located near commercial shellfish beds have high water quality, infrequently contravening water quality criteria. In contrast, most of the shellfish beds that are closed due to water quality impairments are on state grounds. The general driver behind these spatial trends is proximity to land with most of the approved beds being located in deeper portions of the estuary and the state grounds being located on the water frontage of the mainland.

In general, the highest fecal coliform levels are consistently observed at sites in tidal creeks with frontage on the mainland, suggesting a land-based source of the fecal bacteria. This was supported by statistical tests that found significantly higher fecal coliform levels under wet as compared to dry conditions at many sites and an inverse relationship with salinity. This suggests that stormwater runoff from the land is an important transport agent. The inverse relationship with salinity likely arises from several related processes: (1) periods of lower salinity are associated with less dilution and flushing by seawater, (2) less die-off occurs in low salinity waters due to less contact with saline seawater, and (3) a greater likelihood of resuspension of sediment to which bacteria are adsorbed following periods of stormwater runoff.

The sites with the highest levels of fecal coliform bacteria are located in the northern reach of the estuary, with statistically significant trends of increasing concentration. These sites are notable for reduced flushing caused by their distance from the mouth of the inlet and sedimentation infill that has reduced creek volumes. Statistical tests also found significantly higher fecal coliform concentrations during low tide at all sites. This further supports the role of reduced flushing in microbial contamination, although resuspension from marsh sediments at low tide could also be responsible.

The observations from the volunteer water quality monitoring program have identified two small tributaries as having consistently elevated *E. coli* levels during wet and dry conditions. Median concentrations at these sites are 1000 and 2000 CFU/100 mL (n =123). This is similar to median *E. coli* concentrations reported in the National Stormwater Quality Database (NSQD) for overall types of land use, i.e., 1750 MPN/100 mL (Maestre and Pitt 2005). The SC DHEC shellfish monitoring sites located immediately downstream are also consistently elevated suggesting these tributaries are a possible conveyance of fecal bacteria from the land into the Inlet. The level of significance cannot be evaluated as no flow data are available for these small tributaries. One of these tributaries is located in a subwatershed that was identified during the watershed planning process as a priority for remediation based on the elevated bacteria levels reported by both monitoring programs.

To summarize, much evidence was identified supporting the importance of land-based sources of fecal bacteria to Murrells Inlet, especially during wet weather, although legacy sediment contamination in the tidal creek bottoms could also be a contributor. Evidence for increasing fecal coliform concentrations was found only at a few sites and could be associated with changes in rainfall, land use, and reduced flushing. The latter being due to infill sedimentation in the tidal creeks. This process has a natural component to it as well as an anthropogenic influence as development mobilizes sediment from such processes as removal of vegetative buffers from stream and creek banks. Many of the near-shore sampling sites that exhibit the highest fecal coliform levels have been consistently exceeding the shellfish water quality criteria since at least the early 1980's and possibly earlier.

The most important bacterial sources identified were wildlife and canines. These conclusions were based, in part, on additional data collection conducted concurrently with the US EPA 319 project. These were funded by Georgetown and Horry Counties. They included efforts by the volunteers to track upstream sources (Young et al. 2014) and by CCU's Environmental Quality Lab to identify host animal sources using genotypic and chemical markers in the northern reaches of Murrells Inlet (Sturgeon et al. 2014). Genotypic source tracking efforts are pending for the middle and southern reaches.

The urbanized wildlife of greatest concern are raccoons and opossum. In urban settings, racoons are known to reach extraordinarily high population densities due to lack of predators, abundant food supply, and their problem-solving abilities (Prange et al. 2003). The relative contribution of fecal indicator bacteria by urbanized wildlife has likely been enhanced by land-use changes associated with increased development as this leads to increased overland flows, and hence less infiltration of runoff and associated removal of microbes from the waters discharging into Murrells Inlet. This increase in overland flow arises from increased imperviousness and from the associated ditching and piping that have traditionally been used to manage increased stormwater flows and prevent flooding.

DATA ANALYSIS LIMITATIONS

One of the most important outcomes of this collaborative data analysis was a better understanding of the SC DHEC shellfish monitoring data. This provided limits to how these data could be used to answer the original study questions. For example, sample sites have been relocated over time to better define the boundaries of closed shellfish beds and thereby reduce the area subject to closure. In other words, the sampling sites are not representatively spaced through the Inlet. Over time, their locations have become concentrated in contaminated regions. A very large proportion are located near land, close to the most likely source(s) of the fecal bacteria.

The NSQD provides a type of benchmark for evaluating the degree of fecal coliform contamination in the waters of Murrells Inlet, i.e. median values in urban stormwater runoff are 5091 MPN/100 mL (Maestre and Pitt 2005). But because the upper limit of SC DHEC's reporting range is 1600 MPN/100 mL, it is not possible to compare the NSQD results with levels in the receiving waters of Murrells Inlet. Another issue is that some of the SC DHEC monitoring data from the 1960s and 1970s could not be located for some of the sites.

To obtain a long enough time series of rain data required using daily observations from a site located 1.5-mi inland. The highly localized rainfall along the southeastern coast, especially during the summer, limits the usability of this source. The binning of data on a daily basis also creates limitations in interpreting the fecal coliform data.

Since only one fecal coliform sample is collected at each SC DHEC site per month, the potential exists for bias if rain days are over sampled. Efforts were made to check for this bias by comparing wet weather sampling frequency to rain frequency. No evidence was found to support bias over time scales of decades. The data did not support a higher resolution investigation. It is possible that rain could be causing a bias over short timescales. This could contribute to short timescale variability with the result being a short period of bed closures. For example, beds were reopened in the southern portion of the Inlet in 2013 after first having been closed in 2011. SC DHEC attributed the improvement in water quality to diminished rainfall in 2011-2012 (The 2013 report was based on data from 2010 to 2012). Thus any climate phenomena that contribute to rain variability have the potential to influence fecal coliform levels, such as the El Nino –Southern Oscillation that has periodicity of 2 to 7 years (MacMynowski and Tziperman 2007).

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