Recreational Water Quality at Three Coastal Municipal Parks:

Racine, WI

2010-2012

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RACINE ON THE LAKE

City of Racine, Wisconsin

Great Lakes RESTORATION

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Executive Summary

Good water quality is critical in order to protect public health and catalyze sustainable development. Prior to this study, the City of Racine had three coastal recreational areas, some officially designated as public bathing beaches by the WI DNR, that had been historically unmonitored or under monitored: Michigan Boulevard, Samuel Myers and Carre-Hogle. In 2009, a single years worth of data had been collected to determine baseline water quality and potential sources of impairment at these sites in preparation for further grant funded research. The goal of this study, funded by the Great Lakes Restoration Initiative (GLRI), was to further refine and/or identify potential pollution sources resulting in degraded water quality at these coastal areas. The detection of excess fecal indicator bacteria (FIB) in recreational waters, via routine monitoring, only reveals impairments are present, but not the source(s). Without properly identifying sources and characterizing their interactions with surface water, any mitigation strategy is speculative. By properly indentifying sources of FIB and their relative contributions to poor water quality, mitigation strategies are more likely to be effective and economically feasible.

In order to identify likely sources of pollution, sanitary surveys were conducted four times per week at all three sites during the summer of 2010 and once weekly in 2011 and 2012. In brief, surface water samples were collected from three to six open water sites per beach with additional weekly, biweekly or event dependent samples collected from potential sources of fecal contamination (i.e. adjacent stormwater outfalls, beach sands, algae or other site specific locations). *E. coli* concentrations were determined in each water sample collected. Ambient environmental and physical beach conditions, occurring at the time of sample collection, were qualified and quantified whenever possible. At Samuel Myers (2010 and 2012 only) surface water samples were collected from multiple depths at each sampling transect to determine the geospatial distribution of bacteria (*E. coli*) resulting in water quality impairments. Bacteria concentrations observed in surface waters were compared to environmental and physical conditions at each beach and to adjacent potential sources of impairment.

E. coli concentrations exceeded US EPA recommended water quality standards in at least one of the three study years at each site: Michigan Boulevard Beach (2010), Samuel Myers Beach (2010 and 2011), and Carre-Hogle Beach (2010, 2011 and 2012). Physical and environmental factors associated with elevated *E. coli* concentrations at Michigan Boulevard Beach were rainfall, stormwater discharge from Wolff Street Outfall (in combination with a northern longshore current), wave heights in excess of 0.5 meters, and turbid water. At both Samuel Myers and Carre-Hogle, sources of pollution primarily originated from the shoreline and included: wildlife, submerged algae (*Cladophora*) and shoreline sediments (beach sands). Environmental conditions associated with elevated *E. coli* concentrations at Samuel Myers Beach were southern winds, a northern longshore current, and precipitation. At Carre-Hogle Beach, rainfall, high waves, and high wind speeds, particularly from the north and east directions, created favorable conditions for elevated *E. coli* concentrations. At all three beaches, public usage was low due to a combination of limited access, degraded water quality and aesthetic issues.

General and site-specific recommendations were formulated based upon these study results. General recommendations that can be applied to all three beaches include the incorporation of best

management practices such as vegetated swales or encouraged dunes between paved surfaces and/or turf grass areas and the shoreline, installing/maintaining litter bins (including pet waste receptacles), beach grooming and reducing wildlife loafing behavior through habitat modifications and harassment techniques. Site-specific recommendations at Michigan Boulevard Beach include designating the northern half of the beach, away from the adjacent stormwater outfall, as the primary swim area and improving public access. At Samuel Myers Beach, invasive *Phragmites* should be removed and a management and control plan developed. An appropriate grade should be achieved through beach nourishment to simultaneously reduce the pooling of water on the beach and provide infiltration. The direct launch of boats from vehicles should be eliminated to preserve the steeper grade of the beach and prevent rutting and an offshore swim zone should be established (in deeper water, where water quality consistently meets standards for recreation). Further, to increase active (walking, picnicking, canoeing and kayaking) and passive uses (such as bird watching), additional points of public access (including a carry in canoe and kayak launch), green space improvements, amenities such as picnic tables and benches, and coastal habitat restoration (to include replacing invasive with native species) should be implemented as part of proposed beach redesign plans. At Carre-Hogle Beach, options should be explored to improve public access and reduce loafing birds through determents such as habitat modification. Further, until sources of fecal contamination and excess debris on the beach are addressed, swimming should be banned at this location. Many of these general and site-specific recommendations will have the ancillary benefit of improving beach aesthetics.

The following report discusses water quality and public health, potential sources of fecal contamination, current beach monitoring practices, the relationship between FIB concentrations and recreational water quality advisories, sources of FIB and applications of sanitary survey data for remediation. Data from each beach was analyzed to determine sources of fecal contamination and potential mitigation strategies to reduce fecal loading. This report summarizes the data and findings of the GLRI beach sanitary survey research initiative conducted by the City of Racine Health Department Laboratory during the summers of 2010 – 2012.

Introduction

One of the main goals of the Clean Water Act is to make all water bodies fishable and swimmable (FWPCA, 2002). Preventing contamination of recreational water bodies and community water supplies is necessary in order to safeguard public health (Simpson et al, 2002). From 1971 to 2000, the Centers for Disease Control (CDC) reported over 7,500 cases of illness, associated with 116 disease outbreaks, attributed to exposure to ponds and lakes. However, it is suspected that large numbers of cases went unreported (Craun et al, 2005). Some diseases associated with recreational water contact include gastroenteritis, dermatitis and respiratory infections (Craun et al, 2005; Seyfried et al, 1985), resulting from pathogens including *Cryptosporidium, Giardia, Shigella* and *Salmonella* amongst others (Coupe et al, 2006; Keene et al, 1994; Koopman et al, 1982; Makintubee et al, 1987). Increased contact with water, particularly submersion of the head, can enhance an individual's risk of illness (Seyfried et al, 1985). Once exposed, the risk of developing an illness is dependent upon a variety of factors including the presence and concentration of pathogens in the water, the strength of an individual's immune system and type of exposure.

Due to the expense and elusiveness of pathogens in the environment, direct measurement is not currently employed (Field, 2008). Instead, fecal indicator bacteria (FIB) are measured as surrogates for pathogens and the presence of recent fecal contamination. *E. coli* and enterococci have been shown to correlate with increased risks of gastro-intestinal illnesses and are currently the best indicators of fecal contamination in freshwater systems (Dufour, 1984; US EPA 1986; US EPA, 2012). Wisconsin has a 2-tiered system for regulating recreational water quality based on an *E. coli* standard. An advisory is issued, suggesting patrons may want to avoid water contact, when *E. coli* concentrations exceed 235 colony forming units per 100 milliliters (CFU/100ml). Swimming is prohibited when *E. coli* concentrations reach or exceed 1,000 CFU/100ml.

Sources of Fecal Indicator Bacteria

Multiple sources and portals of entry exist whereby *E. coli* and pathogens may be transported into recreational waters. *E. coli* and pathogens are present in the digestive tract of warm-blooded animals, including humans, and are excreted in feces. Once excreted, bacteria can be transported to local waterways via direct contributions, tributaries, surface runoff (both agricultural and urban), stormwater infrastructure and sewage overflows (Gannon and Busse, 1989). Other sources of FIB include nearshore sediments (including beach sands) (Alm et al, 2003); filamentous green algae (*Cladophora*) (Byappanahalli et al, 2009), wildlife and domesticated animals (Fogarty et al, 2003). When examining potential sources of contamination affecting water quality, both point and non-point sources must be considered. Sanitary survey tools have been developed to aid local beach managers in the determination of these sources and are one of a suite of tools that can be employed as part of a rigorous investigative process (Kinzelman and McLellan, 2009).

Stormwater and Surface Runoff. Stormwater in urban and rural environments has been found to contain FIB concentrations exceeding primary recreational standards regardless of surrounding land use (Clary et al, 2008; Novotny et al, 1985). Rainfall flows over land and conveys pollutants, including bacteria, previously deposited on terrestrial surfaces, towards receiving bodies of water. Pollutants transported into local water bodies via overland flow, stormwater infrastructure or tributaries can pose a threat to public health. Urban areas are especially susceptible to poor water quality due to impervious surfaces altering natural hydrology and decreasing infiltration. *E. coli* concentrations are often elevated in runoff due to the mobilization of non-point source pollution deposited onto impervious surfaces. For example, in Madison, WI, water samples collected during precipitation events from a variety of terrestrial surface areas (i.e. lawns, streets, driveways and parking lots in residential, commercial and industrial locations) all exceeded a geometric mean of 1,500 CFU/100 ml fecal coliforms (Bannerman et al, 1993). Samples collected from residential areas had the highest geometric means with 34,000, 42,000 and 56,000 CFU/100 ml fecal coliforms in samples collected from driveways, lawns and streets respectively. Pervious surfaces, such as forested land and green areas, can absorb larger amounts of water, reducing runoff volumes and associated pollutants. Land use, population density and the percentage of impervious surface within a watershed have all been positively associated with the amount of FIB observed in tributaries (Mallin et al, 2009). Runoff from agricultural areas can also pose a risk to water quality. Sources of FIB from agricultural areas include manure deposited on pastures, manure slurry applied to fields (either injected or surface application), animal feeding operations (AFOs and CAFOs), fields, barns, drainage tiles and soil erosion (Abu-Ashour and Lee, 2000; Heinonen-Tanski and Uusi-Kämppä, 2001; Jamieson et al, 2002; Gerba and Smith, 2005). Agricultural soils, even in temperate climates, have the ability to serve as a reservoir for *E. coli* with runoff mediated erosion and field tiles being a major delivery mechanism (Jamieson et al 2002, Ishii et al, 2006).

Sediments. Sediments are an important reservoir for FIB. *E. coli* concentrations in sediments have been observed ranging from three to 38 times higher in the top layer of sediments than *E. coli* concentrations in adjacent surface water samples (Alm et al, 2003). Sediments provide an ideal environment for bacteria because they are protected from inactivation due to sunlight, protozoan grazing and are provided with nutrients (Davies et al, 1995; Alm et al, 2003). Indicator bacteria can survive at high concentrations in beach sands throughout the swimming season and it is suspected that bacteria reproduce to some degree inside sediments (Obiri-Danso and Jones, 1999; Beversdorf et al, 2007). Fecal indicator bacteria in sediments can be transferred to adjacent waters following precipitation events or during periods of intense wave activity (Kinzelman et al, 2004). Others have modeled sediment transfer of bacteria to surface water as a function of bed shear stress and wave run up (Ge et al, 2010). Sediments may also interact with nearshore waters via Aeolian deposition (windblown) and runoff during large rain events, although it is unclear how much bacterial transfer may occur under these scenarios. Although no current regulatory standards exist, beach sediments even in the absence of water exposure may pose a health risk (Heaney et al, 2009). Pathogens in sediments can be transferred to ones hand and may later be ingested resulting in illness (Whitman et al, 2009). In a study examining the impact of bacteria in sediments on human health, beach patrons with significant exposure to beach sand had a 20- 50% greater risk of developing gastrointestinal illness compared to individuals who were not exposed (Heaney et al, 2009). Actual risk of illness depends on a variety of factors including the type of exposure, the strength of one's immune system and the presence/concentration of pathogens in beach sand.

Algal Blooms (Cladophora). In recent years, *Cladophora,* branching, filamentous green algae found naturally inside the Great Lakes, has re-emerged as an annual problem. Massive *Cladophora* blooms impacted the Great Lakes during the 1950's through the 1970's, largely due to excess phosphate loading. Removing phosphate from laundry detergents and more stringent wastewater regulation largely alleviated this problem. However, *Cladophora* blooms have returned as a problem in recent year, believed to be caused, in part, by the introduction of quagga (*Dreissena bugensis*) and zebra (*Dreissena polymorpha)* mussels into the Great Lakes basin. Since the introduction of *Dreissenid* mussels, water clarity has improved significantly. This has lead to an increase in the euphotic zone, increasing photosynthesis and promoting greater plant growth. It is hypothesized that *Dreissenid* mussels transfer nutrient rich (particularly phosphorous) feces and pseudo-feces to the benthic zone, which further increases algal growth (Heckey et al. 2004).

Cladophora frequently occupies the nearshore areas of Lake Michigan and washes ashore onto beaches. Whether submerged in the water or stranded on the beach, large amount of algae can negatively impact water quality. Once washed ashore, algae and associated invertebrates begin to decay creating a smell that some mistake for sewage. Stranded algal mats attract wildlife that feed on invertebrates and insects that inhabit mats. *Cladophora* can harbor both pathogens and FIB deposited by wildlife as part of the feeding process, which have the potential to survive for months, as well as reproduce, inside mats (Whitman et al, 2003; Byappanahalli et al, 2009; Byappanahalli et al, 2007). *E. coli* has been observed at densities of over 100,000 CFU per gram dry weight of algae (Vanden Heuvel et al. 2010). Pathogens and FIB associated with algal mats can be released into the water column during periods of intense wave action, resulting in beach closures (Englebert et al, 2008).

Wildlife and Domesticated Animals. Local wildlife and domestic animals can directly contribute fecal matter to recreational water or load sediments as an intermediary (i.e. transported to surface waters via runoff following precipitation events or through intense wave action). One of the most prevalent avian species in the nearshore environment are ring billed (*Larus delawarensis*) and herring gulls (*Larus argentatus*). From 1976 through 1990, ring billed gull populations increased from 56,000 to 283,000 breeding pairs along the Canadian portion of the lower Great Lakes (Blokpoel and Tessier, 1991). This rise in population is believed to be caused by increases in anthropogenic food sources (such as landfills or uncovered waste containers) and the increased availability/use of urban nesting sites (Dwyer et al, 1996). Gull feces contains $10^5 – 10^9$ CFU *E. coli* per gram; this gives gulls the ability to produce a staggering amount of FIB when considering the number of resident gulls a beach may attract and the amount of waste each gull can produce per day (Fogarty et al, 2003). In Quebec, at a pristine location without gulls, birds were baited to a beach with food to determine their impact on water quality. Within two days after attracting gulls, water quality was impaired beyond published standards (Lévesque et al, 1993). In addition to gulls, geese have the potential to adversely impact water quality. However, while the average fecal dropping of geese weighs 15 times more than gull droppings, they contain smaller amounts of fecal coliforms (Alderisio and DeLuca, 1999). These studies demonstrate that wildlife, in particular avian species, can adversely impact water quality. However, it is difficult to attribute the amount of FIB at a beach to the presence of wildlife alone. In a Door County, Wisconsin, study, *E. coli* densities in water did not correlate to the density of gull fecal matter observed on the beach or the number of gulls present at most locations (Kleinheinz et al, 2006). Therefore, the impact gulls may have on recreational water may be dependent on multiple factors, including: beach sediment grain size/uniformity, topography and the presence of a suitable mechanism of transport.

Bacteria Die Off. In addition to understanding sources, reservoirs, and factors influencing the release of bacteria into the aquatic environment, mechanisms that control bacteria die off or disappearance are just as important. Sunlight (Fujioka et al, 1981), sedimentation (Schillinger and Gannon, 1985), filtration, dilution and disinfection mechanisms (bacteriophage attacks, predation and toxins produced by macrophytes) are natural processes within the beach environment which reduce the presence of FIB (Schuler and Holland, 2000). Environmental factors may attenuate or exacerbate the impact FIB has on water quality. For instance, turbid waters may decrease the amount of bacteria that are deactivated due to sunlight, but may increase the amount of bacteria that are removed through sedimentation. Bacteria die off mechanisms are complex and may vary depending upon the number and types of macrophytes present, water clarity, the propensity for sedimentation to occur (low energy or high energy environment) in addition to other factors.

Beach Sanitary Surveys

With so many potential sources, pollution pathways, and complex interactions occurring in the nearshore zone, the majority of instances with poor water quality are unexplained. Within the Great Lakes approximately 90% beach advisories and closures are attributed to unknown sources (Kovatch, 2006). Beach sanitary surveys are a low cost technique designed to determine sources and variables associated with excess FIB in recreational waters. Sanitary surveys are a unified, reliable and replicable data collection method. Ambient environmental and beach conditions that have the potential to impact beach water quality are recorded using a routine on site sanitary survey form at each beach visit (Appendix A). Conditions recorded at the time of sample collection include: wind speed, wind direction, rainfall amount, rainfall intensity, amount of cloud cover, air/water temperature, the amount of algae present in water or stranded ashore, alongshore current direction, wave height, water clarity, the amount/type of wildlife present, the amount of people at the beach (and their activities), and the presence of beach litter. In addition to examining environmental parameters, local infrastructure may be evaluated, i.e. stormwater outfalls or other potential point sources. Variables recorded when conducting beach sanitary surveys describe sources of bacteria, conditions that may increase the amount of bacteria introduced from non-point sources, environmental conditions that can alter bacteria die off rates and factors that affect the transportation of bacteria once in the nearshore environment. Other supportive information, collected on an annual basis, includes: topographical characteristics, the location of infrastructure such as stormwater outfalls, surrounding land use and the location/condition of sanitary facilities near the beach. The use of sanitary surveys along with other source tracking methods has been effective at identifying sources of contamination and guiding remediation efforts (Kinzelman and McLellan, 2009). The collection of this information may also used to create predictive models that can empirically estimate water quality conditions before laboratory results are available. The results of which can be used to trigger beach closures or advisories before water quality results are available through traditional analytical techniques. More rapid public notification prevents unnecessary exposure of the beach going public to degraded water quality which carries a higher risk of illness.

Previous Monitoring and Current Study Purpose

In the 1970's, a beach existed at the terminal end of 14th Street in Racine, WI (Fourteenth Street Beach). It was divided from the open waters of Lake Michigan by a series of two breakwaters, neither connected to the adjacent land mass (Pershing Park). In the 1980's, the northernmost breakwater was extended and connected to the land in order to reduce bluff erosion which would, in time, compromise infrastructure located at the south end of Main Street. The change in circulation patterns caused by filling in the breakwater resulted in scouring of existing sand deposits, eliminating Fourteenth Street Beach and accreting sediments below the revetment at Sam Myers Park and along the shoreline to the north at Carre-Hogle Park. Previous monitoring by the Racine Health Department (RHD) determined that the coastal waters off Sam Myers Park were unsafe for swimming and a sign was placed at the entrance to the park in the 1990's permanently prohibiting swimming. In 2000, the WI DNR conducted walking assessments of the entire coast of WI, in response to the BEACH Act, and designated areas as beaches. The accumulated sand at Sam Myers Park was included as a beach, in spite of the posting and against the recommendation of the City of Racine, as was an area to the north of the Racine Zoo located below Michigan Boulevard Park; Carre-Hogle was not officially classified as a beach.

A decade later (2009), the RHD conducted pilot sanitary survey studies to determine beach usage and water quality.

Michigan Boulevard. Recreational standards were exceeded in 17 percent of samples collected in 2009, with a greater number of failures occurring at the southernmost sample collection location (adjacent to the Wolff Street Outfall) compared to other locations (Kinzelman et al, 2009). Higher surface water *E. coli* concentrations, frequently exceeding recreational standards, were associated with rainfall and the Wolff Street stormwater outfall was identified as a likely point source of contamination. The outfall was also noted as having dry weather discharge, a red flag for potential sanitary infiltration into the stormwater conveyance system. Beyond poor water quality, a lack of safe public access was noted as an additional problem. More monitoring was recommended to further investigate causes of water quality exceedances at this beach (Kinzelman et al, 2009).

Samuel Myers Beach. *E. coli* levels exceeded recreational standards 35 percent of the available "swim dates" in 2009. Elevated *E. coli* concentrations were associated with wildlife, precipitation, increased wave height and turbid water. High amounts of submerged and stranded algae were also frequently observed, reducing the aesthetic appeal of the park. Beach visitors averaged one or two people per day, but were generally not observed in the water. Additional monitoring was recommended to further refine the sources of water quality impairment (Kinzelman et al, 2009).

Carre-Hogle Beach. Carre-Hogle Park, as part of the contiguous coast including Sam Myers Park, was also monitored by the RHD in 2009. Water quality was poor and recreational standards were exceeded for a third or more of the swimming season at all six sampling transects (CH1 – CH6, 33 – 53%) (Kinzelman et al, 2009). High amounts of submerged and stranded algae, large flocks of waterfowl, pooling of water on the beach and high waves were all associated with poor water quality. As with

Samuel Myers and Michigan Boulevard, additional monitoring was recommended to further refine sources of water quality impairment.

As a result of data collected during this 2009 sanitary survey process, Sam Myers and Michigan Boulevard were deemed inaccessible and removed from the WI DNR list of monitored public swimming beaches (2012).

GLRI Study Purpose. The intended purpose of the 2010 – 2012 Great Lakes Restoration Initiative grant was to refine and/or identify additional potential pollution sources resulting in degraded water quality at these coastal areas located in City of Racine municipal parks. The US EPA routine and annual beach sanitary surveys were the primary assessment tools employed. A determination of pollution sources impacting water quality, public accessibility and utility of these spaces will aid the city in maximizing recreational opportunity/economic potential while protecting public health at Carre-Hogle, Samuel Myers and Michigan Boulevard Parks.

Potential Point Source Pollution Sources

Prior to the start of this study, walking assessments of the three parks/beaches were conducted by the project team in order to identify potential point sources, develop a study design and determine appropriate sampling locations (transects).

Michigan Boulevard Beach. The Wolff Street Outfall, a large concrete stormwater structure, is located 15 m southwest of the beach area. The Wolff Street Outfall discharge pipe is approximately 1.5 m in diameter (Figure 1). The outfall drains 4.55 km^2 (1,125 acres) of urban land which includes an industrial park and Racine Batten Airport (Figure 2). Several retention ponds in the vicinity of the industrial park and airport delay the immediate release of stormwater following precipitation but also generate dry weather flow. No other point sources were identified in the immediate beach area.

Figure 1: Wolff Street Outfall at south end of Michigan Boulevard Beach

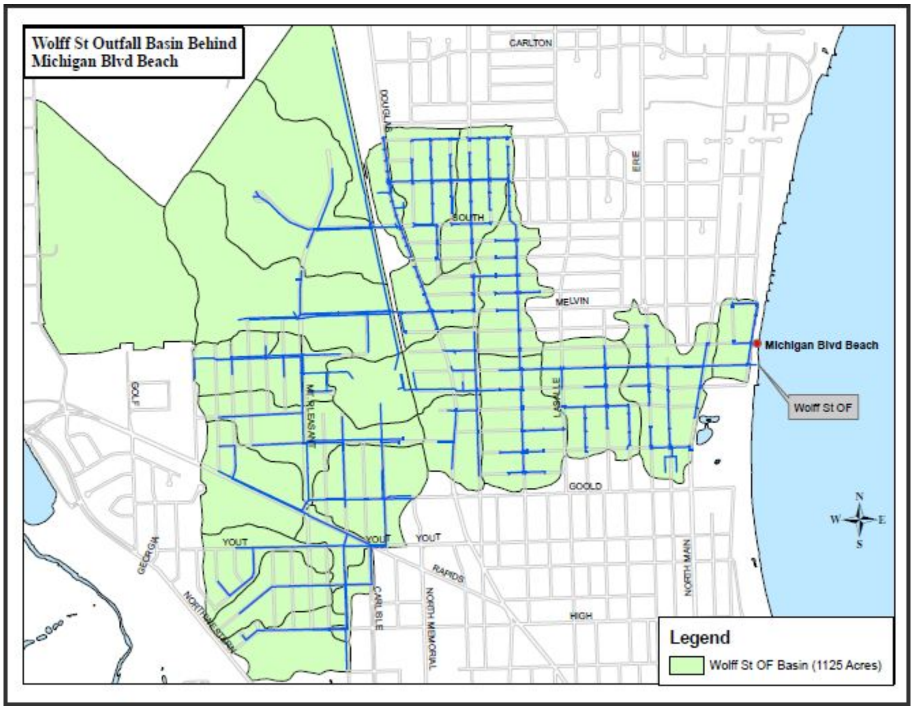

Figure 2: Wolff St. Outfall basin map showing discharge location in relation to Michigan Boulevard Beach (4.55 km^2). Map courtesy of Jason Herzog, City of Racine, Department of Public Works (Engineering).

Samuel Myers Beach. Four municipal stormwater outfalls are located at the ends of 14th, 15th, and 16th (n=2, north and south) Streets, adjacent and to the west of Samuel Myers and north of Carre-Hogle beaches. These outfalls discharge into the embayment in which Samuel Myers and Carre-Hogle Beaches are located. The four drainage basins and their surrounding neighborhoods are shown in Figure 3. The size of the drainage basins vary, from 0.0006 km^2 (1.6 acres) (16th St. South OF) to 1.5 km^2 (360 acres) (16th St. North OF). The Fifteenth St. OF has two different basins draining into it for a combined basin size of 0.5 km^2 (134 acres). The 14th St. OF drains an area of approximately 0.02 km^2 (six acres).

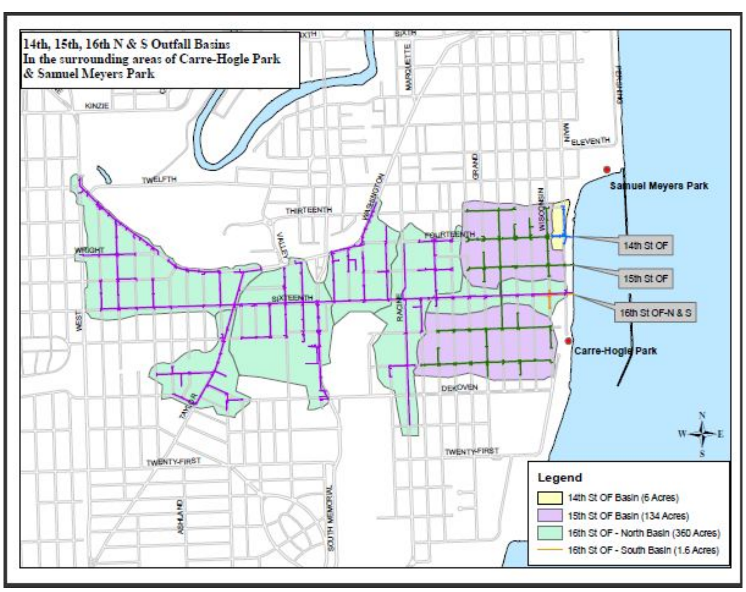

Figure 3: 14th St., 15th St., 16th St.-N, and 16th St.-S outfall basins and discharge locations in relation to Samuel Myers and Carre-Hogle Beaches. Map courtesy of Jason Herzog, City of Racine Department of Public Works (Engineering).

The Racine Wastewater Treatment Plant is located 0.75 km south of Carre-Hogle and 1.6 km south of Samuel Myers Beaches. The City of Racine separated sanitary and stormwater infrastructure, thus making sanitary sewage overflows from the wastewater treatment plant rare. No overflows from the plant occurred during the study period.

Carre-Hogle Beach. Carre-Hogle is located just south of Samuel Myers, within the same embayment, thus the same potential point sources for Samuel Myers Beach also apply to Carre-Hogle.

Methods

The routine, on-site sanitary survey was completed each day that sampling occurred to evaluate environmental conditions and potential point and non-point pollution sources associated with poor water quality. The annual beach sanitary survey form was completed once annually during the sampling season. The following section provides a brief description of the study area, sample collection methods, enumeration methods, and other methods used to collect and interpret data.

Study Sites

Michigan Boulevard Beach. Michigan Boulevard Beach is located 2.3 km north of the mouth of the Root River within the Wind Point Watershed (Figure 4). It is oriented in a north-south configuration, parallel to Michigan Boulevard, between the terminal ends of Wolff Street and Melvin Avenue. Land use is primarily high-density residential housing. At 176.8 m above sea level, Michigan Boulevard sits lower than the surrounding neighborhood (189 m above sea level).

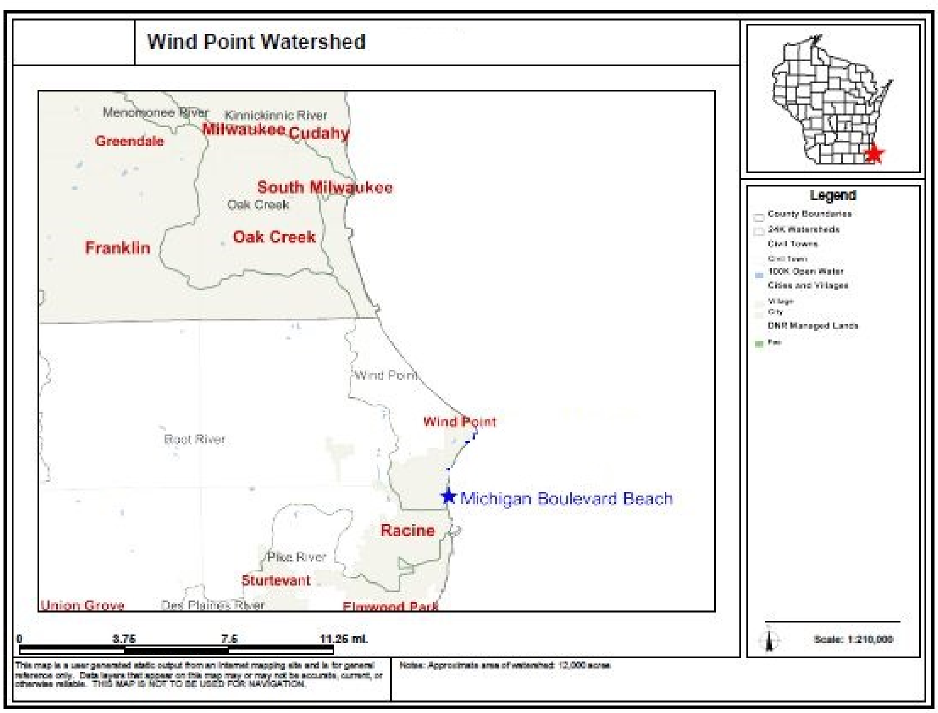

Figure 4. Michigan Boulevard Beach. Source: Wisconsin Department of Natural Resources

Michigan Boulevard Beach is located at the base of a steep, forested 26 m bluff leading up to Michigan Boulevard. Boulders/shore armor separates the beach from the bluff. There are two foot paths extending down from Michigan Boulevard that provide limited access to the beach. The main path is 37 m long, moderately steep, comprised of dirt/rocks/tree roots and winds through the forested area before reaching the beach. The second path is steeper, about 24-m in length and comprised of dirt. Both paths become slippery when wet.

To the north, a groin composed of riprap separates the northern end of Michigan Boulevard Beach from a private residential beach. Approximately one-half of the groin sits in the lake. To the south, a 42 m pier separates the southern edge of the beach from the Wolff Street Outfall discharge location, but still allows water to move freely underneath. Approximately two-thirds of this pier sits in the lake.

Samuel Myers Beach. Samuel Myer's Beach is located within the Pike River Watershed and is oriented in an east-west direction (Figure 5). It is bounded to the north by a park/Gateway Technical Institute, to the east by a breakwater, to the west by a partially wooded bluff and opens onto an embayment to the south. Surrounding land use is high density residential housing, businesses and parkland. At 176.8 m above sea level, Samuel Myers sits lower than the surrounding neighborhood.

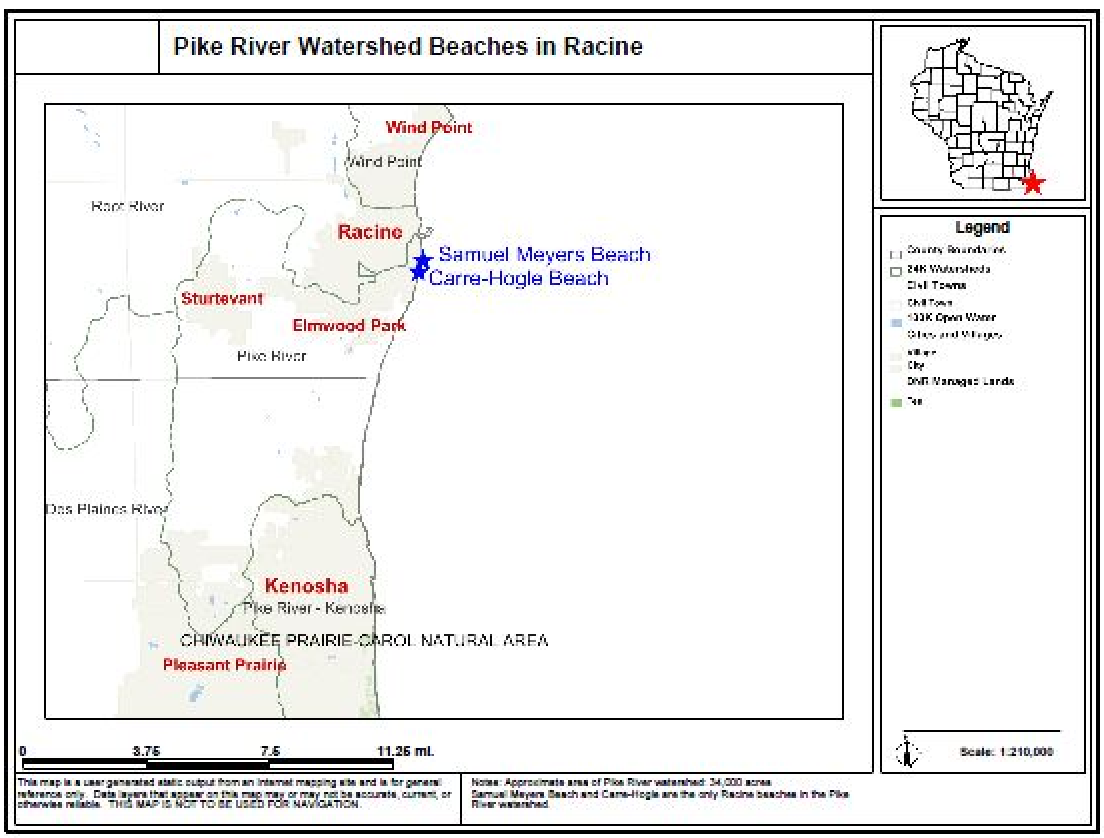

Figure 5: Samuel Myers and Carre-Hogle Beaches lie within in the Pike River Watershed. Source: Wisconsin Department of Natural Resources.

On the northeast side of the beach, an 18 m sloped metal grate boat launch extends onto the beach, approximately 80 m from the shoreline. Above the boat ramp is a gravel parking lot, bike path and Samuel Myers Park. Flanking the boat launch are two patches of wetland, consisting of willows, dogwood, cottonwood and overrun with large amounts of invasive *Phragmites* species. The western wetland area is 0.014 km^2 (3.55 acres) and the eastern wetland is 0.002 km^2 (0.55 acres).

Figure 6: Location of Samuel Myers Beach, 14^{th}, 15^{th}, 16^{th} St.-N, and 16^{th} St.-S OFs, Carre-Hogle Beach, and the Racine Wastewater Treatment Plant. Image: Google Earth.

The bluff to the west of the beach has been fortified with 0.63 km of rip rap to prevent coastal erosion. Municipal stormwater infrastructure exits the riprap at four locations between Samuel Myers and Carre-Hogle Beaches (Figure 6). Samuel Myers sits on the northern end of a south facing embayment formed by a series of two breakwaters, also installed to prevent coastal erosion. The northern one, directly east of Samuel Myers and attached to the shore, is 0.40 km in length. The southern breakwater runs north to south parallel to the shoreline for two-thirds of its length (0.32 km) and the remaining third (0.23 km) angles south-westward towards Carre-Hogle; these breakwaters are separated by a 0.26 km opening. These breakwaters have altered the coastal hydrology and limit circulation and exchange with the open waters of Lake Michigan.

Carre-Hogle Beach. Carre-Hogle lies 0.8 km to the south-southwest of Sam Myers Beach at the terminal end of South Main Street, also inside the Pike River Watershed (Figure 5). A peninsular spit formation, Carre-Hogle is surrounded to the north, east, and south by the waters of Lake Michigan and immediately to the west by parkland and high density residential housing (Figure 6). At 176.8 m above sea level, Carre-Hogle sits lower than the surrounding neighborhood.

From the terrestrial (western) side, Carre-Hogle is located at the base of a bluff which has been fortified with riprap to prevent coastal erosion. Municipal stormwater infrastructure exits the riprap at four locations between Carre-Hogle and Samuel Myers, to the north. Approximately 0.69 km of riprap extends south from Carre-Hogle towards the Racine Wastewater Treatment Plant and an additional 0.08 km of riprap separates the beach area from the park above. A small gravel parking lot is located above the beach, to the northwest. Access to the beach is via a makeshift trail originating from the parking lot. The slope is steep at various points and can be slippery under both dry (due to gravel) and wet (due to mud) conditions.

Sampling Locations

Michigan Boulevard Beach. Water samples were collected at three transects in 2010 and two transects in 2011 and 2012 (Table 1). Transects M1 and M2 were located at the south end of the beach, within 27 and 88.4 meters of the Wolff Street Outfall, respectively. They traverse approximately one-quarter (68 m) of the total beach length (Figure 7). Transect M3 was located at the far north end of the beach, approximately 205 m north of transect M2. Transect M2 was eliminated after 2010. Stormwater samples were collected directly from Wolff Street Outfall for the duration of the study, when flowing.

Figure 7: Transects M1-M3 and the Wolff St. Outfall (WSOF) at Michigan Boulevard Beach. Image: Google Earth

Michigan Boulevard Beach SAMPLING LOCATIONS (2010-2012)				
Transect Name (ID)	**GPS Location**	**Site Description**	**Sampling Frequency**	**Time of Sample Collection**
2010 - 2012 Sampling Locations				
Michigan Boulevard-1 (M1)	N 42.753055, W -87.780640	Most southern sampling point on beach, 4.5 m north of WSOF pier.	2010: 4x/wk 2011-2012: 1x/wk	10:05 AM
Michigan Boulevard-3 (M3)	N 42.755513, W -87.780305	Most northern sampling point on beach, 2.7 m south of rock groin.	2010: 4x/wk 2011-2012: 1x/wk	10:13 AM
Wolff Street Outfall (WSOF)	N 42.752900, W -87.780921	Large outfall infrastructure, 15 m southwest of southern edge of beach.	2010: 33x 2011-2012 1x/wk	10:16 AM
Additional 2010 Sampling Location				
Michigan Boulevard-2 (M2)	N 42.753699, W -87.780582	Middle sampling point 81 m from southern edge of beach	4x/wk	10:10 AM

Table 1: Michigan Boulevard Beach transect designations, GPS locations, site descriptions, sampling frequency, and time of sample collection (2010-2012).

Samuel Myers Beach. Water samples were collected at three transects in 2010 and two transects in 2011 and 2012 (Table 2). Transect SM1 was located at the west end of the beach, approximately 122 m from the breakwater, transect SM2 was located south of the boat launch, 54.5 m from the breakwater, and transect SM3 was located at the east end of the beach, 7.1 m from the breakwater (Figure 8). Transect SM2 was eliminated after the 2010 sampling season. Samples were also collected from 14^{th} St., 15th St., 16th St.-North, and 16^{th} St.-South outfalls in 2010.

Samuel Myers Beach SAMPLING LOCATIONS (2010-2012)				
Transect Name (ID)	**GPS Location**	**Site Description**	**Sampling Frequency**	**Time of Sample Collection**
2010 - 2012 Sampling Locations				
Samuel Myers-1 (SM1)	N 42.71800, W -87.77954	125 m west of breakwater	2010: 4x/wk 2012: 1x/wk	10:30am
Samuel Myers-3 (SM3)	N 42.718479, W -87.77837	7.1 m west of breakwater	2010: 4x/wk 2012: 1x/wk	10:40am
Additional 2010 Sampling Locations				
Samuel Myers-2 (SM2)	N 42.718265, W -87.77834	54.5 m west of breakwater	4x/wk	10:35am
14th St. OF (0.32 km away from SM2)	N 42.715493, W -87.78184	Terminal end of 14th Street	1x/wk (when flowing): Thursday	10:20am
15th St. OF (0.48 km away from SM2)	N 42.714058, W -87.78187	Terminal end of 15th Street	1x/wk (when flowing): Thursday	10:10am
16th St.-N-OF (0.64 km away from SM2)	N 42.712592, W -87.78180	Terminal end of 16th Street - north	1x/wk (when flowing): Thursday	9:55am
16th St.-S-OF (0.64 km away from SM2)	N 42.712566, W -87.781798	Terminal end of 16th Street - south	1x/wk (when flowing): Thursday	9:50am

Table 2: Samuel Myers Beach transects designations, GPS locations, site descriptions, sampling frequency, and time of sample collection (2010-2012).

Figure 8: Transects SM1-SM3 at Samuel Myers Beach. Image: Google Earth.

Carre-Hogle Beach. Water samples were collected at six transects in 2010 and three transects in 2011 and 2012 (Table 3). Transects CH1, CH2, and CH3 were spread equidistantly across the north face of the beach, transect CH4 was located off the point of the spit, transect CH5 was located at the midpoint on the southern side of the beach and transect CH6 was located on the southern side of the beach, six meters from the shoreline (Figure 9). Transects CH1, CH3, and CH6 were eliminated after the 2010 sampling season.

Carre-Hogle Beach SAMPLING LOCATIONS (2010-2012)				
Transect Name (ID)	**GPS Location**	**Site Description**	**Sampling Frequency**	**Time of Sample Collection**
2010 - 2012 Sampling Locations				
Carre-Hogle-2 (CH2)	N 42.710340, W -87.78194	Midpoint on north face of beach	2010: 4x/wk 2011-2012: 1x/wk	9:23am
Carre-Hogle-4 (CH4)	N 42.710179, W -87.78145	Directly off the end of the spit	2010: 4x/wk 2011-2012: 1x/wk	9:29am
Carre-Hogle-5 (CH5)	N 42.710137, W -87.78172	Midpoint on south face of the beach	2010: 4x/wk 2011-2012: 1x/wk	9:32am
Additional 2010 Sampling Locations				
Carre-Hogle-1 (CH1)	N 42.710481, W -87.78210	West end of north side, 6 m from the rocks	4x/wk	9:20am
Carre-Hogle-3 (CH3)	N 42.710269, W -87.78167	North side, 2/3 the distance from the shore	4x/wk	9:26am
Carre-Hogle-6 (CH6)	N 42.710118, W -87.78191	West end of south side, 6 m from the rocks	4x/wk	9:35am

Table 3: Carre-Hogle Beach transects designations, GPS locations, site descriptions, sampling frequency, and time of sample collection (2010-2012).

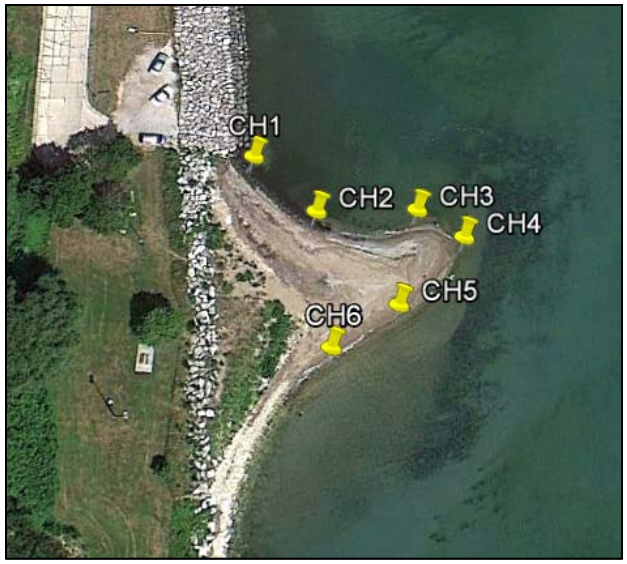

Figure 9: Transects CH1-CH6 at Carre-Hogle Beach. Image: Google Earth.

Physical (Topographical) Characteristics

The on-shore slope/grade, length, and width were measured at Michigan Boulevard (2010-2012), Samuel Myers (2010-2012), and Carre-Hogle (2010 only) beaches. On-shore slope, and width were measured at each of the designated sampling transects, each year. Results within a given year, and across multiple years, were averaged together for each measurement type. Due to the continuously shifting nature of the Carre-Hogle Beach, beach width and on-shore slope measurements were only taken at transects CH2, CH4, and CH5; as representative of the north, east, and south beach faces.

Beach length and width were measured using a digital surveying wheel (Keson, Aurora, IL). Beach length was defined as the measure of the dimension of the beach parallel to the shoreline. Beach width, the measure of the dimension of the beach perpendicular to the shoreline, was measured from the current position of the berm crest (on the days the site was assessed) to the edge of the beach. The change in elevation along the beach width was measured using a pair of poles, line levels, and a high-tension string. One pole was placed at the back of the beach and the other pole was placed at the ordinary high water mark. The high tension string was attached to both poles and pulled taut. The height of the string was adjusted until the string was deemed level (using line levels). The distance between the beach surface and the height of the string was measured on each wooden pole. The difference between the height of the string on the pole at the high water mark and the height of the string on pole at the back of the beach represented the change in elevation (i.e. the slope).

Sediment Sample Collection

When/where beach width allowed, sediment samples were collected from three positions; the berm crest (the top of the swash zone), the middle beach (10 meters inland from berm crest), and the back beach (20 meters inland from berm crest).

Michigan Boulevard Beach. Sediments were collected bi-weekly in 2010 (n = 7 events) from five sampling locations: M1-Berm Crest (M1-BC), M2-Berm Crest (M2-BC), M3-Berm Crest (M3-BC), M1-Middle Beach (M1-MB), and M2-Middle Beach (M2-MB).

Samuel Myers Beach. Sediments were collected bi-weekly (n = 7 events) in 2010 from five beach sampling locations and once in 2012 from nine beach sampling locations. In 2010 the locations were: SM1-Berm Crest (SM1-BC), SM2-Berm Crest (SM2-BC), SM3-Berm Crest (SM3-BC), SM2-Middle Beach (SM2-MB), and SM2-Back Beach (SM2-BB). In 2012, sediments were collected at these locations as well as at SM1-Middle Beach (SM1-MB), SM3-Middle Beach (SM3-MB), SM1-Back Beach (SM1-BB), and SM3-Back Beach (SM3-BB). The additional middle and back beach locations were due to a substantial drop in lake water levels in 2012. A single set of submerged sediments were also collected at in 2012; transects SM1, SM2, and SM3 at in water depths of 0.3, 0.6, and 0.9 m.

Carre-Hogle Beach. Sediments were collected bi-weekly (n = 7 events) in 2010 from eight sampling locations: CH-1 Berm Crest (CH1-BC), CH-2-Berm Crest (CH2-BC), CH-3-Berm Crest (CH3-BC), CH-4-Berm Crest (CH4-BC), CH-5-Berm Crest (CH5-BC), and CH6-Berm Crest (CH6-BC), CH-4-Middle Beach (CH4-MB), and CH4-Back Beach (CH4-BB).

***Sediment Sample Collection Method*.** Sediment cores were collected using an AMS stainless steel slotted soil recovery probe (Art's Manufacturing and Supply, American Falls, Idaho, US) with a 2.8 cm bore and sterilized butyrate liners with end caps. The sterilized butyrate liners were pre-labeled at the laboratory using removable tape, one for each sample to be collected, and placed in clean Ziploc bags (S. C. Johnson, A Family Company, Racine, WI). At the site of collection, a liner was removed from the Ziploc bag and placed within the soil recovery probe whose interior had been previously coated with a light layer of silicone spray to aid in the successful removal of the liner. The sample was collected by holding the apparatus parallel to the beach sand, firmly pressing the soil recovery probe into the sediment and then removing it in the same manner. Submerged sediment samples were collected in the same manner as foreshore sediments, except the apparatus was held parallel to the water and submerged until reaching the sediment bed. At this point, the apparatus was firmly pressed into the sediment. Special care was taken not to disturb the bed sediments prior to sample collection.

After sample collection, the liner was extracted by removing the handle and grasping the exposed exterior edge of the liner being careful not to disturb the core or contaminate the sample. Once a sufficient portion of the liner had been withdrawn from the probe an end cap was placed on the exposed end, the probe up-ended and the liner withdrawn completely and capped on the opposite end. The soil recovery probe was then rinsed with water and the procedure repeated once for each sample to be collected. All samples were obtained between 6:30am and 12:00 pm, maintained at 4 °C in a cooler on ice packs and returned to the laboratory within one hour of collection. Analysis for *E. coli* concentrations in sediments was conducted within three hours of receipt by the laboratory. Sediment cores were analyzed for the following: *E. coli,* grain size and uniformity.

Surface Water Sample Collection

Routine monitoring samples. Routine surface water samples were collected in sterile Whirl-Pak™ bags (Nasco, Ft. Atkinson, WI) at a depth of 0.6 – 0.75 m (approximately between knee and hip depth). Being careful not to disturb bottom sediments or algae, the technician faced parallel to the direction of the alongshore current, removed the seal, opened the bag using tabs located on the side of bags, and collected a water sample from approximately 0.3 m below the water surface. After collection, the Whirl-Pak™ bag was sealed, maintained at 4 °C in a cooler on ice packs, transported to the lab and held at 4 °C until sample analysis occurred, generally within four hours of collection.

Multi-depth samples. Multi-depth, open water sampling occurred simultaneously for each corresponding beach transect bi-weekly at all three beaches in 2010 (sampling = 8 events per beach), and at Samuel Myers only in 2012 (n = 6 events). In order to accomplish simultaneous sample collection, four field technicians waded out to depths of 0.3, 0.6, 0.9 and 1.2 m of water, facing parallel to the direction of the alongshore current in the same manner as the daily surface water samples. Upon the signal of one of the technicians, all technicians would collect a water sample from 0.3 m below the surface simultaneously (except for the 0.3 meter depth where a sample was collected at approximately 0.15 m below the surface). After collection, the Whirl-Pak™ bag was sealed, maintained at 4 °C in a cooler on ice packs, transported to the lab and held at 4 °C until sample analysis occurred, generally within four hours of collection.

Stormwater outfalls. Direct stormwater discharge samples were collected from the Wolff St. (2010 – 2012), 14th Street, 15th Street, 16th Street-North and 16th Street-South Outfalls (2010 only), when flowing. For all locations, grab samples were aseptically collected directly into a sterile Whirlpak™ bags, the bags were sealed, maintained at 4 °C in a cooler on ice packs, transported to the lab and held at 4 °C until sample analysis occurred, generally within four hours of collection.

Human-specific Bacteroides Marker

Microbial source tracking tools were used to determine the origin of fecal contamination at some locations during the course of the study.

Sample collection. In 2011, samples for *Bacteroides* (total and human specific) were collected four times from the Wolff Street outfall and twice from the 15th St. and 16th St.-South outfalls using the same sample collection and handling techniques as for general stormwater outfall samples.

Sample filtration. Two 100-ml aliquots (sub-samples) of the stormwater grab sample were filtered through sterile 0.45-micron; 47 mm nitrocellulose filters placed on a filter funnel assembly (Millipore Corporation, Billerica, MA) by applying a vacuum. Sample filters were aseptically removed from the filter funnel base, rolled with the exposed side inwards, placed into DNAse free micro-centrifuge tubes, capped and frozen at -80 °C until transport on ice to the University of Wisconsin-Milwaukee School of Freshwater Science (Dr. Sandra McLellan) for quantification of total and human-specific *Bacteroides* genetic markers.

Result interpretation. Two *Bacteroides* results thresholds triggered further investigation for potential sanitary sewage infiltration in the stormwater conveyance system: 1) a human-specific

Bacteroides copy number (CN/100 ml) greater than 5000 and 2) a ratio of human-specific *Bacteroides* to total *Bacteroides* marker greater than 5.1% +/- 2.93% (Sauer et al, 2011). NOTE: More recently, the analyzing laboratory has transitioned away from this threshold designation and is now using a single, higher threshold of 10,000 CN/100 ml human-specific *Bacteroides* to trigger further investigation. However, these interpretive guidelines were not yet in force at the time of this study and the former interpretive guidelines were used.

Beach Sanitary Surveys (BSS)

In order to identify sources of bacterial contamination, and provide replicable and consistent data, routine sanitary surveys were employed each time a water sample was collected (Online: http://water.epa.gov/type/oceb/beaches/sanitarysurvey_index.cfm) (Appendix A). Beach conditions described and quantified when possible included: outfall discharge data (sewage and stormwater), precipitation amounts/intensity, amount/type of wildlife/domestic animals, the amount of algae present (both washed ashore and submerged in the water), air/water temperature, wind speed/direction, water clarity, wave height, wave intensity, alongshore current direction, cloud cover, odors, the number/activities of people at the beach and the amount/type of beach litter. Methods for collecting beach sanitary survey data are available online in the Great Lakes Beach Sanitary Survey User Manual (http://water.epa.gov/type/oceb/beaches/upload/2008_05_29_beaches_sanitarysurvey_user-manual.pdf). All sanitary survey data was entered into the Wisconsin's Beach Health website (www.wibeaches.us) and later retrieved for data analysis. The annual beach sanitary survey form was completed once during each sampling season using the US EPA annual beach sanitary survey tool (http://water.epa.gov/type/oceb/beaches/upload/2008_05_29_beaches_sanitarysurvey_survey-annual.pdf).

Wildlife, including domestic animals, can be a potential source of bacterial contamination. The location, species, and number of animals observed were enumerated and recorded as actual numbers present. The presence of dog feces was also noted.

Algae may serve as a preferential growth and survival media for FIB. The color, type, presence, condition, and amount of algae in the nearshore water (submerged) and washed ashore (stranded) was described. The color of the algae was denoted as either light green, bright green, dark green, yellow, brown, other, or any combination thereof. The amount of algae submerged in water was quantified as percent surface coverage near the sampling location and described as low (1-20% coverage), moderate (21-50% coverage), or high (>50% coverage). The amount of algae stranded ashore was also quantified as low (1-20% coverage), moderate (21-50% coverage), or high (>50% coverage) based upon surface area coverage on the berm crest.

Precipitation for the 24 and 48 hour periods prior to sample collection was obtained daily from the Racine Wastewater Treatment Plant rain gauge (7 km south of the beach) in inches and converted to centimeters (cm).

Wave height increases the interaction between sediments, shoreline wrack, and the water column. Field technicians estimated wave height by averaging the height (measured from trough to crest) of the three largest out of ten waves.

Water clarity was described as clear, slightly turbid, turbid, or opaque. For statistical analysis purposes, this data was converted into ordinal values (i.e. clear=1, slightly turbid=2, turbid=3, opaque=4).

Wind speed and direction at the time samples were collected was obtained through a National Weather Service anemometer located at Batten International Airport (3 km west of the beach). Wind direction data was reported in cardinal directions (e.g. north, north east, east, etc.) and speed to the closest mile per hour (mph). Wind speed data were converted to kilometers per hour (kph).

The ***longshore current direction***, the direction that water and associated pollutants travel parallel to the direction of the shoreline, was determined primarily through observing wave angles. For example, if one section of a wave broke to the north first, then towards the south, the longshore current direction would be towards the south. If this method of determining longshore current was indeterminate, an object was tossed into the water and the direction the object travelled parallel to the shore would be recorded as north or south. For statistical analysis purposes, this data was converted into binary values for separate north and south data categories (i.e. present=1, absent=0).

Cloud cover can attenuate the presence of FIB in the nearshore environment. Cloud cover was estimated upon initial arrival at the site and was described as sunny (no cloud coverage), mostly sunny (⅛ to ¼ cloud coverage), partly sunny (⅜ to ½ cloud coverage), mostly cloudy (⅝ to ⅞ cloud coverage), or cloudy (total cloud coverage).

Air temperature was measured upon arrival at the site using a calibrated alcohol thermometer. Air temperature measurements were taken in the shade or in lieu of shade, in the shadow generated by the technician's body. Temperature was expressed in degrees Celsius (°C).

Water temperature was measured by placing a calibrated alcohol thermometer in the water adjacent to, but down current, from where water samples were collected. Special care was taken to avoid potential contamination issues. Water temperatures were expressed in degrees Celsius (°C).

The ***number of people*** at the beach and in the water was recorded as actual numbers present at the time of sample collection. The type of activity people were engaged in (e.g. swimming, sunbathing, boating, walking, etc.) was also recorded.

Debris amounts in the water and on the beach was estimated based upon percent surface coverage and categorized as low (1-20% coverage), moderate (21-50% coverage), or high (>50% coverage). Classification of waste types included: street litter, food-related, medical items, sewage-related, building materials, fishing-related litter, household waste or other types of waste.

E. coli **Enumeration**

***E. coli* enumeration in surface water.** *E. coli* was quantified using IDEXX Colilert - 18® or IDEXX Colilert® (IDEXX, Inc., Westbrook, ME), selective cultural identification methods utilizing bacterial enzymatic activity and differential substrates, for the detection of *E. coli* according to previously established laboratory protocols. In brief, samples processed either undiluted (100 ml) or diluted, 1:10 (10 ml of sample + 90 ml sterile distilled water), or 1:100 (1.0 ml sample + 99 ml of sterile distilled water) based on visual inspection of the sample (using sample cloudiness as an estimation of gross turbidity). The sample was then mixed with reagent and sealed in a Quanti-Tray/2000 according to manufacturer's instructions (Colilert or Colilert-18® product insert, IDEXX Laboratories, Westbrook, ME, US). After incubation at 35 ºC ± 0.5 ° C for 18 hours (or 24 hours for Colilert®), Quanti-Tray wells were read for yellow color indicating onitrophenyl ß-D-galactopyranoside (ONPG) hydrolysis (confirmatory for the presence of total coliforms) and fluorescence, indicating 4-methyl-umbelliferyl ß-D-glucuronide (MUG) cleavage (confirmatory for the presence of *E. coli*), with the aid of a UV light box (366 nm). Wells producing fluorescence in the absence of yellow color were determined to be false readings (*E. coli* would be classified as a total coliform and therefore should be detected by this method as such, according to the manufacturer). The number of wells producing fluorescence was compared to the MPN table provided by the manufacturer to enumerate *E. coli* as MPN/100 ml (Most Probable Number of *E. coli* per 100ml). *E. coli* concentrations below the detection limit were treated as half the detection limit for statistical calculation purposes, i.e. <10 MPN/100 ml became 5 MPN/100 ml. Quality control organisms (positive = *E. coli* ATCC #25922, negative = *P. aeruginosa* ATCC # 10145) were run once per box of reagent to validate (qualitative) test performance.

***E. coli* enumeration in sediments.** Sediment cores were weighed (expressed in grams) and measured (in cm) upon arrival at the laboratory. After measuring the weight and length, the entire sediment core was aseptically transferred into a sterile container. Immediately following this step, 99 ml of sterile phosphate buffer with $MgCl_2$ (Hardy Diagnostic or Hach®, pH 7.2 +/- 0.2) was passed through the sterile butyrate liner to remove any residual sediment particles adhering to the sides. Samples were mechanically agitated for 30 seconds to suspend sediment attached *E. coli* into the phosphate buffer solution. Serial dilutions of the phosphate buffer solution with suspended *E. coli* (1 to 5ml depending on sample location and conditions) were diluted to 100 ml total volume using sterile deionized water and filtered through sterile 0.45-micron, 47 mm nitrocellulose filters (Millipore Corporation, Billerica, MA). Filters were placed onto modified m-TEC agar (US EPA Method 1603) and dry incubated at 35 °C (+/- 0.5 °C) for two hours to resuscitate stressed organisms, then transferred to a 44.5 °C (+/- 0.2 °C) degree water bath for 22 (+/-2) hours. After incubation, the numbers of red or magenta colonies that formed on the filters were counted with the aid of a Quebec Colony Counter ®, multiplied by the dilution factor employed, and divided by the sediment core weight to express *E. coli* concentration as CFU (colony forming units) per gram of sediment wet weight. The CFU/gram wet weight was then divided by a factor determined by desiccating each individual sample to complete dryness in order to express the *E. coli* density as colony forming units (CFU)/gram dry weight of sand.

Quality control and quality assurance measures were maintained throughout the analytical process. Media, sterilization process controls (pre- and post-analysis), and positive (*E. coli* ATCC # 25922) and negative (*Enterococcus faecalis* ATCC #29212) quality control organisms were included with each day's membrane filtration run to insure sterility of sampling equipment, dilution agents, analytical equipment and confirm the ability of the media to exhibit the appropriate chromogenic response. The sterility of the butyrate liners was also insured through the inclusion of sterility control with each batch of prepared liners (100mL of the sterile phosphate buffer as previously described).

Sediment Grain Size and Uniformity

Grain Size. The sediment grain-size analysis was conducted at University of Wisconsin-Parkside Geology Laboratory using the American Standards Testing and Materials standard test method for sieve analysis of fine and course aggregates (10.1520/C0136-05.5) (ASTM, 2006). Samples were composited into one sample per location for grain-size analysis (mechanical sieve shaker). Once composited, sediment grain size analysis was conducted using method ASTM C 136-05 (ASTM, 2006) at the University of Wisconsin-Parkside Geosciences Department Laboratory. In brief, samples were placed into a stack of progressively finer sieves that would allow sediments finer then 8, 4.76, 1, 0.5, 0.21, 0.125, 0.074 millimeters to pass through. This stack of sediments sieves was then placed onto a mechanical shaker for at least three minutes to separate sediments into separate size fractions. Following mechanical agitation, the fraction of sediments remaining on each sieve was weighed. The mean grain diameter and uniformity coefficient were calculated using standard graphical techniques based on the proportion of sediments retained on each sieve (Folk and Ward 1957, Hazen 1900). Mean grain size was determined using equation Eq (1), where Φ (phi) was determined by Eq (2). In Eq (2), D represents the diameter of a particle in millimeters. Φ_{16}, Φ_{50} and Φ_{84} were determined through graphical methods. Φ_{16}, Φ_{50} and Φ_{84} represent the phi size of the particles distributed at the 16th, 50th and 84th percentile.

Uniformity Coefficient. The uniformity coefficient (C_u) was determined using equation Eq (3). D_{60} and D_{10} represent the diameter of particles for which 60 and 10% of particles are finer then. A C_u less than four is considered a well-sorted sediment sample and a C_u greater than six is considered a poorly-sorted sediment sample. Combined sediment samples were further described using the Unified Soil Classification System.

$$Eq(1) Mean\ grain\ size\ (\phi) = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

$$Eq(2) \phi = -log_2(D)$$

$$Eq(3) C_u = \frac{D_{60}}{D_{10}}$$

Statistical Analysis

A number of basic statistical analyses were conducted to determine conditions impacting water quality. The majority of *E. coli* concentration data was log-normalized and expressed as log-transformed variables unless stated otherwise to partially satisfy statistical conditions of normality and equal variance. All qualitative variables, such as "sunny", or "odor present" were converted into ordinal (i.e. given a ranking) or binary values (1 = present or 0 = absent).

Microsoft® Office Excel data analysis ToolPak was used to calculate descriptive statistics. Minimum significant *r* values ($\alpha < 0.05$, $p < 0.05$) were identified for every pair of variables based upon the degree of freedom present in the analysis. Trend analysis was accomplished through the generation of scatter plots and the application of linear regression analysis, in particular targeting variables with significant *r* values. If any variable appeared to be explanatory for total *E. coli* concentrations, SPSS® (IBM, Armonk, NY) was used to determine if the means were significantly different, applying normality tests such as the Shapiro-Wilk test and equal variance tests to determine if parametric or non-parametric tests were indicated based upon data distribution. P values of <0.05 were considered significant, unless otherwise noted. Mean comparisons were conducted through independent sample t-tests and analysis of variance (ANOVA). If log-transformed data was not normal, then distributions were tested through Mann-Whitney or Kruskal-Wallis non-parametric tests. Tests for normalcy and equal variance were used to determine post-hoc treatments to be employed, including: Tukey-Kramer Method, Bonferroni-Dunn test, and Games-Howell, for example.

NOTE: The reduction in the number of samples collected in 2011 (n=9 per year) and 2012 (n = 14 per year) versus the larger amount in 2010 (n = 45 per year) may contribute to statistical bias in the analysis of inter-annual data at all three beaches. The probability of capturing a wide range of environmental conditions also decreases with a smaller population. Whenever possible, comparative data was analyzed within a single year, rather than across study years, in order to reduce bias.

Results

The following section examines the results of monitoring data collected from 2010-2012 at Michigan Boulevard, Samuel Myers, and Carre-Hogle Beaches. Potential explanatory variables were compared to water quality data in order to determine sources and factors associated with poor water quality.

Michigan Boulevard Beach

Topographical (Physical) Measurements. Beach length, onshore slope, and width were measured at transects M1, M2, and M3. Beach length, width and slope were determined once each year (Table 4). The average length of the beach was 296 m from the southern pier to the northern rock groin.

In-water measurements were only assessed in 2010. Measurements indicated a relatively similar bathymetry across the three sampling transects, with transect M2 dropping off the quickest and transect M3 having the most gradual decline (Table 4). A sand bar was present just beyond the 0.6 m depth at transect M2, which increased the distance from the shoreline to achieve a water depth of 0.9 m.

Michigan Boulevard Beach TOPOGRAPHICAL MEASUREMENTS (2010-2012)				
2010-2012 Average	**M1**	**M2**	**M3**	**Mean**
Beach Width (m)	11.2	11.3	6.2	9.6
Beach Slope (%)	6.4	11.6	7.5	8.5
2010 In-Water Measurements from Berm Crest to:				
0.3 m	8.5	3.7	8.8	7.0
0.6 m	16.3	11.7	15.4	14.5
0.9 m	25.1	31.3	31.8	29.4
1.2 m	36.0	38.0	39.4	37.8

Table 4: Topographical Measurements at Michigan Boulevard Beach (2010-2012).

Water quality – routine monitoring. One hundred and eighty-four water samples were collected from Michigan Boulevard Beach throughout the study period: 2010 (n=138), 2011 (n=18), and 2012 (n=28) (Table 5). Log-transformed *E. coli* data at each transect from all years failed normality tests (Shapiro Wilk, $p<0.05$), thus precluding parametric statistical analysis. Statistical tests revealed a difference in *E. coli* concentration between sampling locations in 2010 (Kruskal-Wallis, n=46, p=0.048), but post-hoc tests failed to identify where the differences occurred (Dunn's 1964 procedure with a Bonferroni correction, M3-M2, p=1.00; M3-M1, p=0.06; M2-M1, p=0.183). After 2010, transect M2 was eliminated due to redundant data and sampling events were decreased to once per week. No significant differences were found in *E. coli* concentrations between transects M1 and M3 in either 2011 or 2012 (Kruskal-Wallis, p>0.05).

Michigan Boulevard Beach RECREATIONAL WATER QUALITY EXCEEDANCES (2010-2012)						
Transect/ Full Beach	**n**	**Median (MPN/100 ml)**	**Minimum (MPN/100 ml)**	**Maximum (MPN/100 ml)**	**Exceedances (> 235 MPN/100 ml)**	**Exceedance Rate (%)**
2010						
M1	46	86	<10	6,488	13	28
M2	46	41	<10	5,492	10	22
M3	46	36	<10	3,282	8	17
Full Beach	138	52	<10	6,488	31	22
2011						
M1	9	30	10	256	1	11
M3	9	<10	<10	169	0	0
Full Beach	18	20	<10	256	1	6
2012						
M1	14	<10	<10	738	2	14
M3	14	<10	<10	722	1	7
Full Beach	28	<10	<10	738	3	11

Table 5: Number of samples, median, minimum, and maximum *E. coli* concentrations (MPN/100 ml), exceedances (*E. coli* concentrations above 235 MPN/100 ml) and exceedance rate at Michigan Boulevard Beach sampling transects and full beach from 2010-2012.

Overall, 22 (n=31/138), six (1/18) and 11 (3/28) percent of samples exceeded water quality standards in 2010, 2011, and 2012 respectively (Table 5). Transect M1 accounted for the highest percentage of exceedances in every year of the study (2010 - 28%; 2011 - 11%; 2012 - 14%) and in 2011, was the only transect with a water quality exceedance. Although transect M1 had a higher number of water quality violations overall, *E. coli* concentrations were not significantly higher at any one transect in 2011 (p=0.161), or 2012 (p=0.424). However, *E. coli* concentrations in 2010 at transects M1 and M3 were significantly higher than corresponding concentrations in 2012 at the same locations (M1: Kruskal-Wallis, p=0.021, post-hoc test: p=0.046) (M3: Kruskal-Wallis: p=0.013, post-hoc test: p=0.029). Samples collected in 2011 did not differ significantly from samples collected in 2010 or 2012 (all Kruskal-Wallis, 2010 vs. 2011: M1 p=0.213, M3 p=0.176; 2011 vs. 2012: M1 p=1.00, M3 p=1.00).

Water quality – multi-depth samples. Ninety-six water samples were collected during eight sampling events at depths of 0.3, 0.6, 0.9, and 1.2 m at transects M1, M2, and M3 in the summer of 2010 (Table 6). Log-transformed *E. coli* concentrations were normally distributed (n=8, p>0.05). *E. coli* concentrations at all depths and transects were significantly correlated (n=8, r value range: 0.907 – 1.000, p=0.01 or less). Furthermore, *E. coli* concentrations did not differ significantly by depth at any transect (ANOVA, n=8, p=0.995).

Michigan Boulevard Beach *E. COLI* CONCENTRATION BY DEPTH (2010)												
Date of Sample Collection	**M1**				**M2**				**M3**			
	Depth (m)				**Depth (m)**				**Depth (m)**			
	0.3 m	**0.6 m**	**0.9 m**	**1.2 m**	**0.3 m**	**0.6 m**	**0.9 m**	**1.2 m**	**0.3 m**	**0.6 m**	**0.9 m**	**1.2 m**
6/28	231	301	98	85	51	52	52	31	269	41	20	41
7/12	20	10	10	20	<10	<10	20	10	<10	<10	<10	<10
7/26	41	52	97	<10	10	<10	<10	<10	20	41	10	<10
8/9	8,664	5,172	3,448	3,255	3,076	1,041	1,211	1,597	1,585	1,576	2,489	1,467
8/23	97	108	120	86	158	146	98	171	51	97	41	52
9/2	1,450	657	262	246	1,467	437	382	785	231	298	90	111
9/14	31	10	<10	10	10	<10	10	20	41	10	10	20
9/28	<10	<10	<10	10	<10	20	<10	<10	10	41	31	<10
Median	*69*	*80*	*98*	*53*	*31*	*36*	*36*	*26*	*46*	*41*	*26*	*31*

Table 6: *E. coli* concentrations (expressed as MPN/100 ml) by depth (in meters) at which the sample was collected; Michigan Boulevard-1 (M1), Michigan Boulevard-2 (M2), and Michigan Boulevard-3 (M3) (2010). Median concentrations were calculated from eight multi-depth sampling events conducted bi-weekly from 6/28/2010 to 9/28/2010. [Orange-shaded and pink-shaded cells indicate days when recreational water quality advisory and closure thresholds were exceeded, respectively]

Water quality - Wolff Street Outfall. The Wolff Street Outfall was sampled in 2010 (n=33), 2011 (n=8), and 2012 (n=13). All log–transformed data were normally distributed (Shapiro-Wilk, p>0.05). *E. coli* concentrations in 2010 (mean=3.22, σ=0.62, n=33) were significantly higher (ANOVA, p=0.025; Tukey post-hoc, p=0.047) than concentrations in 2012 (mean=2.67, σ=0.95, n=13), but neither were significantly different compared to 2011 concentrations (mean=2.69, σ=0.53, n=8) (p>0.05). The percentage of samples with *E. coli* concentrations over 235 MPN/100 ml decreased each year from 91 percent in 2010 (n=30/33) to 75 percent in 2011 (n=6/8) to 62 percent in 2012 (n=8/13).

The relationship between precipitation events and the amount of *E. coli* present in Wolff Street Outfall stormwater discharge varied by study year. In 2010, Wolff Street Outfall *E. coli* concentrations were significantly correlated with 24-hr, 48-hr, and 72-hr rainfall (Table 7). During sampling events in 2011, only one event occurred following a 24-hr rain event, thus precluding statistical analysis. Although 2012 had rain events on 35.7 percent (n=5/14) of sampling days, Wolff Street Outfall *E. coli* concentrations were not significantly associated with antecedent precipitation during any time period (24-hr, 48-hr, and 72-hr prior to the sampling event) (all p>0.05).

Michigan Boulevard Beach CORRELATION COEFFICIENTS - WOLFF ST. OUTFALL *E. COLI* VS. BEACH *E. COLI* AND RAINFALL (2010-2012)			
	WSOF *E. coli*		
	2010	***2011***	***2012***
M1 *E. coli*	0.602**	0.602	0.705**
M3 *E. coli*	0.502**	0.913**	0.579*
24-hr rain	0.640**	0.577	0.229
48-hr rain	0.663**	0.577	0.108
72-hr rain	0.506**	0.421	0.425
**. Correlation is significant at the 0.01 level (2-tailed).			
*. Correlation is significant at the 0.05 level (2-tailed).			

Table 7: Spearman's rho correlation coefficients between *E. coli* concentrations at Wolff St. Outfall (WSOF), and transects M1 and M3; and correlation between WSOF E. coli concentrations and 24-, 48-, and 72-hr rainfall from 2010-2012.

Wolff Street Outfall *E. coli* concentrations (medians=1,274; 384; 309 MPN/100 ml, n values=33; 8; 13) were significantly higher than concentrations at transects M1 and M3 (combined) in each year (all Mann-Whitney, all p=0.0005). Additionally, Wolff Street Outfall *E. coli* concentrations were significantly correlated with surface water concentrations at transect M1 in 2010 and 2012 (but not 2011) and transect M3 (2010 – 2012) (Table 7). On days with a northern alongshore current in 2010, combined *E. coli* concentrations from all transects (median=52.5 MPN/100 ml, n=75) were significantly higher than when a southern alongshore current was present (median=20 MPN/100 ml, n=51) (Mann-Whitney, p=0.018). This trend was not present in 2011 (Mann-Whitney, p=0.515, N LSC n=8, S LSC n=10) or 2012 (Mann-Whitney, p=0.061, N LSC n=8, S LSC n=16); this may be due to the decreased numbers of samples collected.

Human-specific* Bacteroides *marker testing was conducted on water samples collected from the Wolff Street Outfall on four dates in 2011 (8/12, 8/26, 9/1, and 9/19). On 8/12, 8/26, and 9/19, human-specific *Bacteroides* marker were found in copy numbers greater than 5,000 per 100 ml: 7,776, 12,729, and 10,568 CN/100 ml, respectively. A lesser amount was noted on 9/1 (374 CN/100 ml). All four dates had human-specific *Bacteroides* to total *Bacteroides* species ratios above the average (5.1 +/- 2.9%) found in sewage (68.4%, 8.4%, 40.7%, and 9.8% on 8/12, 8/26, 9/1, and 9/19, respectively).

Sediments - E. coli concentration. Sediment samples were collected bi-weekly at the berm crest location of all transects and at middle beach locations at transects M1 and M2 only in 2010 (Table 8). Dog tracks were observed within 0.3 m of M2-Berm Crest (M2-BC) and were the only evidence of a pollution source (e.g. bird feces, algae, animal tracks) noted near sediment collection areas. *E. coli* concentrations did not differ significantly across beach transects (Kruskal-Wallis, p=0.579). Berm crest *E. coli* concentrations were significantly higher (1.1 to 985.1 times higher) than concentrations in paired surface water samples (median =10 MPN/100 ml, n=21) (Mann-Whitney, p=0.0005). This corresponds to a median *E. coli* value in sediments 22 times higher than in surface water samples. Although higher concentrations were present in sediments than paired water samples, sediment *E. coli* levels were not significantly correlated with fluctuations in surface water quality results (Spearman's rho, $p>0.05$).

Michigan Boulevard Beach MEDIAN *E. COLI* CONCENTRATIONS IN BEACH SAND (2010)							
	E. coli (CFU/100 g)						Key
Date	M1-BC	M1-MB	M2-BC	M2-MB	M3-BC	Median by Date	
7/7/10	427	343	2,416	30	984	427	trash
7/21/10	189	422	544	3,125	59,053	544	algae
8/4/10	886	223	92	60	4,925	223	bird feathers
8/18/10	170	483	436	26	542	436	bird feces
8/31/10	2,264	182	38	93	29	93	bird tracks
9/14/10	862	116	329	30	102	116	animal feces
9/28/10	169	313	64	4,410	34	169	other
Median by Site	427	313	329	60	542	313	

Table 8: Median *E. coli* concentration (CFU/100 g) in berm crest (BC) and mid-beach (MB) sands at Michigan Boulevard Beach sampling transects M1, M2, and M3 (2010). Potential polluting sources (Key) were in sample or within 0.3 m."Other" on 8/31/10 at M2-BC is dog tracks.

Sediments - grain size. Sediment grain size analysis at Michigan Boulevard Beach indicated a mostly sandy beach (0.08 – 2.0 mm) with the inclusion of some coarse/very coarse pebbles (16-64 mm) and cobble (64-256 mm) at the berm crest (M1, M2, and M3). The mean grain size was 0.85 mm at berm crest locations and 0.27 mm at middle beach sampling locations. Berm crest sediments were generally classified as coarse sand (0.5 - 1.0 mm). Middle beach sediments were classified as medium grain sand (0.25 – 0.50 mm). M2-BC had the largest mean grain size diameter, 1.18 mm, which was categorized as very coarse sand.

Sediments - uniformity. The sediment composition was classified as well-sorted sand (< 4.0) at all sampling locations except for at M2-BC, which was poorly-sorted (> 6.0). Uniformity coefficients at M1-BC, M1-Middle Beach, M2-Middle Beach, and M3-BC were all below 3.1. M2-BC had a uniformity coefficient of 9.0.

Sanitary Survey Data

Wildlife. The number and type of wildlife (including domestic animals), alive and dead, observed on the beach were recorded in all years (Table 9). The number of total wildlife was less than 100 for each species. In addition to animals, dog feces was occasionally observed on the beach (approximately once per week). *E. coli* concentrations from each year during 2010-2012 did not vary significantly as a function of wildlife numbers or species (Spearman's, $p>0.05$).

Michigan Boulevard Beach TOTAL NUMBER AND TYPE OF WILDLIFE PRESENT BY YEAR (2010 – 2012)													
Year	**Gulls**		**Geese**		**Dogs**		**Ducks**		**Dead Birds (All Types)**		**Dead Fish**	
	No.	**Days**	**No.**	**Days**	**No.**	**Days**	**No.**	**Days**	**No.**	**Days**	**No.**	**Days**
2010	45	15	0	0	21	11	0	0	0	0	4	4
2011	8	3	0	0	1	1	3	2	0	0	12	4
2012	2	2	0	0	4	2	24	3	1	1	1	1
TOTAL	55	20	0	0	26	14	27	5	1	1	17	9

Table 9: Number (No.) of wildlife (dead or alive) and dogs observed at Michigan Boulevard Beach by type and number of days observed (Days) per study year (2010 – 2012).

Algae. Algae (*Cladophora*) amounts submerged in the nearshore water and stranded on the beach were recorded each day that sample collection occurred (Table 10). The amount of algae was most frequently described as absent or low (submerged = 80.9% of 68 observations and stranded = 92.6% of 68 observations). High amounts of submerged (6.5% of 46 observations) and stranded algae (2.2% of 46 observations) were noted in 2010 only. In 2010-2011, no or low amounts of submerged algae (median=52 MPN/100 ml, n=42) corresponded with significantly higher *E. coli* concentrations in surface water at transect M3. There was no indication this result was an artifact of covariance; artifacts of covariance examined included Wolff Street Outfall *E. coli* concentrations, precipitation, wave height and alongshore current direction. No significant associations between surface water *E. coli* concentrations and submerged or stranded algae were noted during any other timeframe or at any other transect during the study period (Mann-Whitney, Kruskal-Wallis, p>0.05).

Michigan Boulevard Beach AMOUNT OF TYPE OF *CLADOPHORA* (2010-2012)						
Year	**Submerged/Stranded**	**Not Present**	**Low**	**Moderate**	**High**	**TOTAL (n)**
2010	Submerged	6	28	9	3	46
	Stranded	9	33	3	1	46
2011	Submerged	5	4	0	0	9
	Stranded	4	4	1	0	9
2012	Submerged	0	12	1	0	13
	Stranded	2	11	0	0	13
TOTAL	Submerged	11	44	10	3	68
	Stranded	15	48	4	1	68

Table 10: Number of beach sanitary survey dates with no, low, moderate, and high amounts of algae submerged in the water and stranded ashore and total number of days when any algae was observed at Michigan Boulevard Beach (2010 – 2012).

Precipitation. Rainfall events of 0.01 cm or greater occurred 24 hours prior to sample collection on 36.2 (n=17/46), 11.1 (n=1/9), and 35.7 percent (n=5/14) of days in 2010, 2011, and 2012, respectively. Only one 24-hr, two 48-hr and two 72-hr antecedent rain events occurred in 2011.

However, no significant differences were noted in the total seasonal amount of rainfall between 2010, 2011, or 2012 (Kruskal-Wallis, $p>0.05$).

E. coli concentrations at all transects were significantly higher post-rainfall in 2010, 2011, and 2012. In 2010, all antecedent rain events greater than 0.01 cm (24-hr, 48-hr, and 72-hr) yielded higher *E. coli* concentrations in surface water (all transects combined) than when no rainfall occurred prior to sample collection. Median *E. coli* concentrations were 263.5, 110, and 85 MPN/100 ml following 24-, 48-, or 72-hr precipitation respectively and 31, 20, and 20 MPN/100 ml with no rain (Mann-Whitney, all $p=0.0005$). Since very little precipitation fell in 2011, only two events could be used for statistical analysis. Rainfall within the 24-hour period prior to sample collection was correlated with significantly higher *E. coli* concentrations in surface water (median=212.5 MPN/100 ml, n=2).

Wave Height. Observed wave heights at Michigan Boulevard during 2010 (median=0.20 m, n=46), 2011 (median=0.20 m, n=9), and 2012 (median=0.15 m, n=14) did not differ significantly (Kruskal-Wallis, $p=0.971$). *E. coli* concentrations in 2010 and 2011 were not significantly associated with wave height (Spearman's rho, $p>0.05$). Estimated wave height was positively correlated with *E. coli* concentrations at transects M1 (rho=0.762) and M3 (rho=0.742) (both n=14, Spearman's, $p=0.01$) in 2012.

Water Clarity. Water clarity descriptions were available at transects M1 and M3 on 69 dates (2010-2012), and transect M2 on 46 dates (2010 only) (Table 11). *E. coli* concentrations did not differ significantly as a function of water clarity at transect M1 (2010 – 2012, Kruskal-Wallis, $p=0.115$) but did at transects M2 and M3. At transect M2, the median *E. coli* concentration when water was described as turbid was 360 MPN/100 ml (n=8) compared to 20 MPN/100 ml (n=30) on dates when it was described as clear (Kruskal-Wallis, $p=0.017$; Pair wise Comparison, $p=0.017$). At transect M3, the median *E. coli* concentration was 96 MPN/100 ml (n=11) when water was turbid versus 10 MPN/100 ml (n=26) when clear (Kruskal-Wallis, $p=0.001$, Pair wise Comparison, $p=0.001$).

Michigan Boulevard Beach WATER CLARITY (TURBIDITY) VERSUS MEAN *E. COLI* DENSITY BY YEAR (2010-2012)										
Year	**Transect**	**Field-Estimated Water Clarity**								No. of Sampling Days
		Clear		**Slightly Turbid**		**Turbid**		**Opaque**		
		***E. coli* (MPN/100 ml)**								
		median	***n***	***median***	***N***	***median***	***n***	***median***	***n***	*N*
2010 - 2011	***M1***	36	*28*	52	*15*	234.5	*10*	1952	*2*	*55*
	M2	20	*30*	79.5	*8*	360.5	*8*	-	*0*	*46*
	M3	10	*30*	20	*13*	96	*11*	< 10	*1*	*55*
2012	***M1***	42	*4*	< 10	*7*	110	*3*	-	*0*	*14*
	M3	< 10	*4*	< 10	*7*	86	*3*	-	*0*	*14*

Table 11: Water clarity (turbidity) versus median *E. coli* concentration (MPN/100 ml) from 2010-2012 at Michigan Boulevard Beach. [*n* = number of observations, *N* = total number of sampling events per study year]

In 2010-2011, wave height was correlated with ordinal water clarity descriptors at all transects; M1 (rho=0.662), M2 (rho=0.581) and M3 (rho=0.687) (Spearman's, n=55, p=0.01). In 2012, ordinal water clarity descriptors correlated positively with wave height at transect M3 (rho=0.759, p=0.001), but not at transect M1 (rho=0.207, p=0.463).

Wind Speed and Direction. Wind speeds and directions were available on all sampling dates from 2010 through 2012. Surface water *E. coli* concentrations did not correlate with, or vary, based upon wind direction or wind speed (p>0.05 for all tests) in any study year.

Longshore Current Direction. Detectable longshore currents were present on 93, 100, and 86 percent of sampling dates in 2010, 2011, and 2012. Northern longshore currents accounted for 56, 44, and 29 percent of sampling days in 2010, 2011, and 2012; southern longshore currents accounted for 38, 56, and 57 percent of sampling days in those same years. In 2010, *E. coli* concentrations at all transects (combined data) were significantly higher in the presence of a northern longshore current or no detectable current (median=52 MPN/100 ml, n=81) versus a southern longshore current (median=20 MPN/100 ml, n=51) (Mann-Whitney, p=0.008). In 2011-2012, the opposite was observed. *E. coli* concentrations were significantly higher when a southern longshore current was present (median=26.5 MPN/100 ml, n=26) versus northern or absent (median=<10 MPN/100 ml, n=20) (Mann-Whitney, p=0.018).

Cloud Cover. Cloud cover data war available on all sampling dates from 2010 - 2012. Surface water *E. coli* concentrations did not correlate with, or vary based upon, cloud cover (p>0.05 for all tests).

Air Temperature. The average air temperature recorded on sampling days was 22.9 (σ=2.5, n=47), 21.8 (σ=5.1, n=9), and 24.5 °C (σ=5.2, n=14) in 2010, 2011, and 2012, respectively. No significant correlations were found between air temperature and surface water *E. coli* concentrations during any year of the study (all Spearman's rho, p>0.05).

Water Temperature. The average water temperature recorded on sampling days was 18.0 (σ=2.3, n=138), 18.8 (σ=4.2, n=18), and 19.0 °C (σ=4.4, n=28) in 2010, 2011, and 2012, respectively. No significant correlations were found between water temperature and surface water *E. coli* concentrations in any of the study years (Spearman's rho, p>0.05).

Beach Usage. The number of people at the beach and in the water was recorded each day that sample collection occurred. An average of one, zero to one, and one person were observed at the beach in 2010, 2011, and 2012. Of the people observed, zero to one, zero, and zero to one people were in the water, either wading or swimming (2010, 2011, and 2012 respectively). The number of people observed at the beach may not be representative of overall beach use due to the time of sample collection (10:00am – 12:00pm). These times do not represent peak beach usage, which generally occurs in the mid-afternoon and on weekends. Given the low number people observed in the water, bather-shed *E. coli* was not considered a significant factor affecting water quality.

Debris. The amount and type of beach debris was recorded each day that sample collection occurred. Beach debris was present at low levels for 100, 100, and 93 percent of the sampling season in 2010, 2011, and 2012, respectively. During the remaining sampling days in 2012, no beach debris was observed. Household waste, street litter and food-related litter constituted the type of debris observed. Floatables were observed only once on September 2nd, 2011.

Samuel Myers Beach

Topographical (Physical) Measurements. Beach length, on-shore slope, and width measurements were taken at transects SM1, SM2, and SM3 during each study year (Table 12). The average length of the beach was 122 m from the eastern breakwater extending across approximately two-fifths across the shoreline (the area most likely to be utilized by the public). The beach width was greatest at transect SM2, likely due to vehicular traffic from the boat launch which prevented the spread of vegetation (primarily invasive *Phragmites*).

Samuel Myers Beach TOPOGRAPHICAL MEASUREMENTS (2010-2012)				
2010-2012 Average	**SM1**	**SM2**	**SM3**	**Mean**
Beach Width (m)	9.2	18.3	10.3	12.6
Beach Slope (%)	5.4	2.4	2.6	3.5
2010 In-Water Measurements from Berm Crest to:				
0.3 m	12.2	13.0	11.0	12.1
0.6 m	91.4	95.3	87.5	91.4
0.9 m	146.3	142.7	147.0	145.3
1.2 m	190.5	193.1	190.2	191.3

Table 12: Topographical Measurements at Samuel Myers Beach from 2010-2012.

In-water measurements were made in 2010 only. Measurements indicate a relatively similar in-water bathymetry across the three sampling transects. The distance from the shoreline to achieve a depth of 0.3, 0.6, 0.9 and 1.2 m water depth was approximately 10, 90, 140 and 190 meters respectively.

Water quality – routine monitoring. One hundred and eighty-four water samples were collected from Samuel Myers Beach over the course of the study: 2010 (n=138), 2011 (n=18), and 2012 (n=28) (Table 13). After 2010, transect SM2 was eliminated due to redundant data and sampling events were decreased to once per week. No significant differences were observed between surface water *E. coli* concentrations across transects SM1, SM2 or SM3 in 2010 (ANOVA, n=46, $p>0.05$), which justified the removal of transect SM2 in subsequent years. Log-transformed *E. coli* data from 2010 and 2011 were normally distributed, but 2012 data failed normality tests (Shapiro-Wilk, $p<0.05$), thus precluding parametric statistical analysis between years.

Samuel Myers Beach RECREATIONAL WATER QUALITY EXCEEDANCES (2010-2012)						
Transect/ Full Beach	n	Median (MPN/ 100 ml)	Minimum (MPN/ 100 ml)	Maximum (MPN/ 100 ml)	Exceedances (> 235 MPN/100 ml)	Exceedance Rate (%)
2010						
SM1	46	67	< 10	3,967	8	17
SM2	46	58	< 10	1,223	7	15
SM3	46	74	< 10	2,098	9	20
Full Beach	138	68	< 10	3,967	24	17
2011						
SM1	9	216	< 10	749	4	44
SM3	9	63	< 10	1,119	2	22
Full Beach	18	98	< 10	1,119	6	33
2012						
SM1	14	10	< 10	309	1	7
SM3	14	< 10	< 10	193	0	0
Full Beach	28	< 10	< 10	309	1	4

Table 13: Number of samples, median, minimum, and maximum *E. coli* concentrations (MPN/100 ml), exceedances, and percentage of exceedances at Samuel Myers Beach sampling transects from 2010-2012.

E. coli concentrations exceeded water quality standards 17 (n=24/138), 33 (n=6/18), and four (n=1/28) percent of the time in 2010, 2011, and 2012 respectively (Table 13). In 2012, only one water quality standard exceedance occurred, at transect SM1 (7% of 14 samples), likely the result of drought conditions. Average *E. coli* concentrations were not significantly different (p>0.05) across beach transects during 2010-2011. However, in 2012, *E. coli* concentrations were significantly higher at transect SM1 (the site furthest away from the breakwater) than at transect SM3 (p=0.031). *E. coli* concentrations were higher in 2010 and 2011 compared to 2012 (Table 13).

Water quality – multi-depth samples. One-hundred and forty-four samples were collected during 14 sampling events at depths of 0.3, 0.6, 0.9, and 1.2 m at transects SM1, SM2 (2010 only), and SM3 in the summers of 2010 and 2012 (Table 14). Log-transformed *E. coli* concentrations from 2010 were normally distributed (Shapiro-Wilk, all n=8, p>0.05), but concentrations from 2012 were not, which precluded parametric statistical analysis for that year (Shapiro-Wilk, n=8, p>0.05).

Samuel Myers Beach MEDIAN *E. COLI* CONCENTRATION BY DEPTH (2010 and 2012)				
	Depth (m)			
Year	**0.3 m**	**0.6 m**	**0.9 m**	**1.2 m**
SM1				
2010	*563*	*85*	*58*	*25*
2012	*83*	*21*	*<10*	*8*
SM2				
2010	*297*	*26*	*36*	*25*
SM3				
2010	*1173*	*154*	*20*	*26*
2012	*15*	*<10*	*10*	*15*

Table 14: Median *E. coli* concentrations (expressed as MPN/100 ml) by depth (in meters) at which samples were collected; Samuel Myers-1 (SM1), Samuel Myers-2 (SM2), and Samuel Myers -3 (SM3) (2010). Median concentrations were calculated from eight multi-depth sampling events conducted bi-weekly from 6/28/2010 to 9/28/2010. [Orange-shaded and pink-shaded cells indicate means/medians exceeding recreational water quality advisory and closure thresholds, respectively].

In 2010, there was a significant difference between all individual sampling locations (ANOVA, n=8, p=0.005), but follow-up tests failed to identify where differences occurred (Levine's Test for Homogeneity of Variances, p=0.026; Games-Howell, p>0.05). The central tendency (median) of transects SM1, SM2, and SM3 at a water depth of 0.3 m in 2010 all exceeded water quality standards (Table 14). When grouped together, log-transformed *E. coli* concentrations at 0.3 m depths (mean=2.64, σ=1.06, n=24) were significantly higher than *E. coli* concentrations from all other depths combined (mean=1.67, σ=0.82, n=72) (t-test, p=0.0005).

E. coli concentrations in 2010 (median=74 MPN/100 ml, n=64), at all depths of sampled transects were significantly higher than in 2012 (median=10 MPN/100 ml, n=48) (Mann-Whitney, p=0.0005). While 2010 *E. coli* concentrations at a water depth of 0.3 m had median concentrations above water quality standards, only one instance occurred at each depth of transect SM-1 in 2012. In 2012, *E. coli* concentrations did not vary significantly different across beach transects or depths (Kruskal-Wallis, all n=6, p=0.688 and Mann-Whitney, p>0.05).

Stormwater Outfalls. Stormwater samples from the four outfalls located at the terminal ends of 14th, 15th, and 16th Streets were evaluated, when flow was present, on nine (weekly) occasions in 2010 (Table 15).

Water Quality - 14th Street Outfall. Discharge from the 14th St. OF (basin size=0.02 km^2) was never observed (under both wet and dry conditions) and therefore samples were never collected (Table 15). Due to lack of flow, this outfall was not deemed a potential source of fecal loading.

Water Quality - 15th Street Outfall. Flow from 15th St. OF (basin size=0.5 km^2) was steady and at a moderate discharge rate (approximately 300 ml/sec). Fifty-six percent (n=5/9) of samples had *E. coli* concentrations that exceeded water quality standards for safe swimming however they were not significantly higher than samples collected from the surface water sampling locations at Samuel Myers (p=0.090-0.288) (Table 15). *E. coli* concentrations in the effluent from this outfall were not significantly correlated with 24-, 48-, or 72-hr precipitation (all Pearson's, n=7, all p>0.05). Human-specific *Bacteroides* genetic marker testing was conducted for 15th St. OF on two dates in 2011, 9/1 and 9/19. The sample collected on 9/1, after 0.00 cm of 72-hr precipitation, exceeded the threshold necessary to trigger a need for further investigation into potential sanitary infiltration (111,049 CN/100ml and a ratio of human-specific *Bacteroides* to total *Bacteroides* species of 6.1%). However, it should be noted that stormwater samples collected from the 15th St. OF were diluted by lake water intruding into the low-lying pipe and therefore *E. coli* concentrations could be higher than what is presented in this report.

Carre-Hogle Beach and Samuel Myers Beach MEDIAN *E. COLI* CONCENTRATIONS AT 14TH - 16TH ST OUTFALLS				
Date	**14th St. OF**	**15th St. OF**	**16th St.-N OF**	**16th-St. S OF**
	***E. coli* concentration (MPN/100 ml)**			
7/1/10	No Flow	10	< 10	110
7/8/10	No Flow	708	< 10	1,782
7/15/10	No Flow	833	< 10	1,187
7/22/10	No Flow	1,726	< 10	5,492
8/5/10	No Flow	354	< 10	31
8/12/10	No Flow	20	< 10	30
8/19/10	No Flow	173	< 10	10
8/26/10	No Flow	246	148	< 10
9/3/10	No Flow	10	< 10	1,178
Median	*N/A*	*246*	*< 10*	*110*

Table 15: Median *E. coli* concentrations at 14th, 15th, and 16th St. North (N) and South (S) Outfalls in 2010. [Orange-shaded and pink-shaded cells indicate means/medians exceeding recreational water quality advisory and closure thresholds, respectively].

Water Quality - 16th Street North Outfall. Stormwater discharge volume and flow rate at 16th St.-North OF (basin size=1.5 km^2) was consistently high, approximately 3,000 ml/sec. Eighty-nine percent (n=8/9) of samples from 16th St. N OF had *E. coli* concentrations below the limit of detection (<10 MPN/100 ml); the remaining sample had a concentration of 148 MPN/100 ml (Table 15). The majority of discharge from this outfall can be attributed to process water. Due to the consistently low *E. coli* concentrations at the time of the assessment, it was considered an unlikely source of *E. coli* loading to the embayment.

Water Quality - 16th Street South Outfall. The amount and rate of stormwater discharge at the 16th St. South OF (basin size = 0.0006 km^2) was consistently low, approximately 3ml/sec. Forty-four percent (n=4/9) of water samples exceeded water quality standards, with results above 1,000 MPN/100 ml, however these values were not significantly higher than *E. coli* concentrations observed in open water sampling locations at Samuel Myers (M1: p=0.248) (M2: p=0.426) (M3: p=0.353)(Table 15). Twenty-four (r=0.76, p=0.02) and 48-hr rainfall amounts (r=0.77, p=0.01) were correlated with *E. coli* concentrations in stormwater discharging from the 16th St. South OF (all Pearson's, n=7). Human-specific *Bacteroides* genetic marker testing was conducted on samples from 16th St.-South OF on two dates in 2011 (9/1 and 9/19). The sample collected on 9/19, after 1.51 cm of rainfall within the last 24-hrs, had a human-specific *Bacteroides* copy numbers/100 ml of 284 but a ratio of 5.3%; these values suggest that this outfall merits further investigation. Sixteenth St. South OF *E. coli* concentrations were significantly correlated with concentrations in 2010 at transect SM1 (Pearson's, r=0.79, p=0.02) but not SM2 or SM3 (p>0.05).

***Sediments - E. coli concentration*.** Sediment samples were collected bi-weekly at all three berm crests locations and at transect SM2 middle and back beach locations on seven occasions in 2010 (Table 16). Additional sediment samples were collected in 2012 from all three onshore transects, positions (berm crest, middle and back beach), as well as submerged samples at depths of 0.3, 0.6, and 0.9 m (Figure 10). As part of the sampling regimen, potential pollution sources were noted at each sampling location, 2010 and 2012. Evidence of six potential pollutant sources (algae, feathers, bird feces, bird tracks, dog tracks, and tire tracks) were observed within 0.3 m of sediment sampling locations in 2010. Algae were present during all sampling events at SM2-BC and greater than half (n=4/7) of all sampling events at SM3-BC, but only once at SM1-BC. *E. coli* concentrations were significantly higher at the berm crest position of transect SM2 than at the middle (Pairwise Comparison: p=0.004) or back beach locations in 2010 (Pairwise Comparison: p=0.004) (Table 16). *E. coli* concentrations at the berm crest were significantly higher than paired surface water samples across all beach transects [(SM1: median=10, n=7), (SM2: median=41 MPN/100 ml, n=7) (SM3: median=74 MPN/100 ml, n=7); Kruskal-Wallis, p=0.0005]. Although higher *E. coli* concentrations were present in berm crest sediments, they were not correlated with elevated levels in surface water samples (Spearman's, p>0.05).

Samuel Myers Beach MEDIAN *E. COLI* CONCENTRATION IN BEACH SAND (2010)							
Date	*E. coli* (CFU/100 g)						
	SM1-BC	SM2-BC	SM2-MB	SM2-BB	SM3-BC	Median by Date	Key
7/7	44	78	680	52	2,727	78	trash
7/21	4,244	50,710	1,282	1,812	14,037	4,244	algae
8/4	3,379	52,755	895	194	60,322	3,379	feathers
8/18	663	52,265	69	33	14,417	663	bird feces
8/31	6,940	24,813	202	135	11,850	6,940	bird tracks
9/14	1,278	25,789	40	80	110,132	1,278	animal feces
9/28	242	19,324	752	37	12,743	752	other
Median by Site	1,278	25,789	680	80	14,037	1,282	

Table 16: Median *E. coli* concentrations (CFU/100 g) at berm crest (BC), mid-beach (MB), and back beach (BB) sampling locations at Samuel Myers Beach (2010). Potential polluting sources (Key) were either in the sample or within 12". "Other" in this case was tire tracks and dog tracks.

Figure 10: September 6, 2012 sediment results (CFU/100 g) at submerged (blue pins) and beach locations at Samuel Myers Beach. [Submerged samples: SM1, SM2, SM3 at 0.3, 0.6, and 0.9 m water depth; sediment samples= SM1, SM2, SM3 Berm Crest (BC), Middle Beach (MB), and Back Beach (BB); a value of "0" designates a concentration below the limit of detection]

In 2012, *E. coli* concentrations were also highest at the berm crest compared to other locations, with a range of 16,311 – 40,558 CFU/100 g. *E. coli* concentrations ranged from below the detection limit to 1,600 CFU/100 g at the middle and back beach positions. The lowest bacteria concentrations were found in the submerged sediments (below the detection limit to 1,252 CFU/100 g) (Figure 10). In all, five out of the nine submerged sediment samples had *E. coli* levels below the detection limit.

Sediments – grain size. Sediments at Samuel Myers were classified as medium to coarse grain sand (0.08 – 2.0 mm) with trace amounts of very fine pebbles (2.0-4.0 mm). Average mean grain size was 0.60 mm. SM2- MB (0.36 mm), SM2-BB (0.45 mm) and SM3-BC (0.45 mm) had mean grain size diameters classified as medium sand, whereas SM1-BC (0.63 mm) and SM2-BC (0.90 mm) had mean grain size diameters classified as coarse sand.

Sediments – uniformity. Sediments were classified as well to poorly sorted sand based on position. The average uniformity coefficient for the entire beach was 5.6 (>6=poorly-sorted, <4=well-sorted), with middle and back beach samples at 2.1 and 2.9, respectively, and berm crest locations registering 5.5, 12.5, and 5.0 at transects SM1, SM2, and SM3, respectively.

Sanitary Survey Data

Wildlife. This beach and surrounding park was frequently the site for many different types of migrating birds. The number and type of wildlife (alive and dead) was counted on each day that sample collection occurred (Table 17). A total of 371 gulls, 179 ducks, and 164 geese were recorded. When geese were observed, they were commonly observed on the western side of the beach, beyond transect SM1. In 2010, *E. coli* concentrations were higher at transect SM1 on days with geese present (mean=2.30, σ=0.70, n=21) compared to days with no geese (1.64, σ=0.68, n=26) (T-test, p=0.023). The presence of other wildlife types were not correlated with surface water quality ($p>0.05$).

Samuel Myers Beach TOTAL NUMBER AND TYPE OF WILDLIFE PRESENT BY YEAR (2010 – 2012)												
Year	Gulls		Geese		Dogs		Ducks		Dead Birds (All Types)		Dead Fish	
	No.	Days	No.	Days	No.	Days	No.	Days	No.	Days	No.	Days
2010	209	21	115	7	5	3	81	11	27	17	15	14
2011	100	1	0	0	0	0	49	3	3	3	6	4
2012	62	7	49	3	10	4	49	8	7	6	10	6
TOTAL	371	29	164	10	15	7	179	22	37	26	31	24

Table 17: Number (No.) of wildlife (dead or alive) and dogs observed at Samuel Myers Beach by type and number of days observed (Days) per calendar year (2010 – 2012).

In 2010, dead birds, animals, and fish were frequently observed. A total of 27 dead gulls were found over 17 days, including 11 on the same day (9/17/10) (Figure 11). Many of the gulls were found in or around algae and/or runny fecal matter. Large dead fish were found washed up along the entire beach during all three years. After large storms, dead animals were often found, including raccoons, opossums, squirrels, and a muskrat, possibly flushed out of the stormwater outfalls.

Figure 11: One of eleven dead sea gulls found at Samuel Myers Beach (9/17/10).

Algae. The amount of algae (*Cladophora*) submerged in the nearshore water and stranded on the beach were recorded on each day that sample collection occurred (Tables 18 and 19). High levels of stranded and submerged algae were more common in 2010 compared to other years. During all study years, submerged and stranded algae accumulated in higher amounts near transect SM3, the easternmost sampling location (Figure 12). Transect SM3 had the highest percentage of dates with moderate and/or high amounts of submerged algae noted [2010 (high: 73% (n=33/45)), 2011 (moderate and high: 67% (n=6/9)), and 2012 (moderate and high: 43% (n=6/14)]. In 2010-2011, ordinal submerged algae levels were higher when a northern alongshore current was present (median=2.66, n=29) versus when absent (median=2.00, n=26) (Mann-Whitney, p=0.008).

Samuel Myers Beach AMOUNT OF SUBMERGED *CLADOPHORA* (2010-2012)						
Year	**Transect**	**Not Present**	**Low**	**Moderate**	**High**	**TOTAL (n)**
2010	SM1	0	14	20	11	45
	SM2	0	7	10	28	45
	SM3	0	7	5	33	45
2011	SM1	3	2	2	2	9
	SM3	2	1	4	2	9
2012	SM1	0	8	6	0	14
	SM3	0	8	5	1	14

Table 18: Numbers of beach sanitary survey dates with none, low, moderate, and high amounts of algae submerged in the water and total number of days when any algae was observed at Samuel Myers Beach from 2010-2012.

Samuel Myers Beach AMOUNT OF STRANDED *CLADOPHORA* (2010-2012)						
Year	**Transect**	**Not Present**	**Low**	**Moderate**	**High**	**TOTAL (n)**
2010	SM1	0	34	9	2	45
	SM2	0	2	17	26	45
	SM3	0	10	14	21	45
2011	SM1	2	5	1	1	9
	SM3	2	3	3	1	9
2012	SM1	0	5	8	1	14
	SM3	0	2	9	3	14

Table 19: Numbers of beach sanitary survey dates with no, low, moderate, and high amounts of algae stranded ashore and total number of days any algae was observed at Samuel Myers Beach from 2010-2012.

Figure 12: High amounts of submerged algae (foreground) entrapped near breakwater by transect SM3 at Samuel Myers Beach (7/15/10).

Higher *E. coli* concentrations were associated with moderate and high amounts of submerged algae in all study years. In 2010 and 2011, higher surface water *E. coli* concentrations were associated with moderate to high levels of submerged algae at transects SM2 and SM3 [(SM2: log mean=1.89, σ=0.53, n=37) (SM3: log mean=1.99, σ=0.60, n=41)] but not in 2012 (T-test, p>0.05). A similar relationship between *E. coli* density and submerged algae was not observed at transect SM1 in 2010 or 2011, but was in 2012 (Mann-Whitney, p=0.020); an opposite relationship to the other two transects. Surface water *E. coli* concentrations did not vary based upon the amount of stranded algae on the beach during any year or at any transect (ANOVA, Mann-Whitney and Kruskal-Wallis, p>0.05).

Precipitation. Rainfall events of 0.01 cm or greater occurred within the 24-hour period prior to sample collection on 40 (n=18/45), 11 (n=1/9), and 36 (n=5/14) percent of sampling days in 2010, 2011, and 2012 respectively. No significant differences were noted in the seasonal amount of rainfall between 2010, 2011, or 2012 (Kruskal-Wallis, p>0.05). Precipitation was a significant factor influencing surface water *E. coli* concentrations in 2010 at transect SM1 [>0.01 cm 24-hr rainfall: (mean=2.03, σ=0.73, n=17); 0.00 cm rainfall (mean=1.57, σ=0.67, n=29) (T-test, p=0.038)], but was not significant for any other transect during any other year of the study (p>0.05).

Wave Height. The maximum wave height observed during the study period was 0.61 m, which occurred twice, on 6/23/10 and 7/1/11. All other wave heights were between zero and 0.15 m. Wave heights of 0.00 m were observed 68 (n=32/47) percent of the time in 2010, zero (n=0/9) percent of the time in 2011, and 21 (n=3/14) percent of the time in 2012. Waves above zero up to 0.15 m in height comprised 30 percent (n=14/47) of wave height estimates in 2010, 89 percent (n=8/9) of estimates in 2011, and 79 percent (n=11/14) of estimates in 2012. Wave height was not correlated with *E. coli* concentrations in surface water samples in any year or at any transect (p>0.05).

Water Clarity. Water clarity descriptors were available at transects SM1 and SM3 on 69 dates. Water clarity data was available for 46 dates at transect SM2 (2010 only) (Table 20). Log-transformed surface water *E. coli* concentrations at transect SM1 (2010 – 2011) were significantly higher when water clarity was described as turbid (mean=2.68, σ=0.96, n=4, Tukey's, p=0.005) or slightly turbid (mean=2.21, σ=0.63, n=11, Tukey's, p=0.012,) compared to when it was described as clear (mean=2.68, σ=0.63, n=39) (ANOVA, p=0.001). This relationship did not occur at other transects from 2010 to 2011 or at any transect in 2012 (Mann-Whitney, p>0.05).

From 2010 to 2011, water clarity, when assigned ordinal values, was significantly correlated with other explanatory variables, including: wave height (r=0.625, p=0.0005), southern winds (r=-0.392, p=0.01), wind speed (r=0.514, p=0.0005), and 48-hr rainfall amounts (r=0.347, p=0.009) (all Pearson's, n=46). In 2012, wave height (r=0.588, p=0.027) and 24-hr rainfall (r=0.626, p=0.017) were significantly associated with water clarity (all Spearman's, n=14).

Samuel Myers Beach WATER CLARITY (TURBIDITY) VERSUS MEAN *E. COLI* DENSITY BY YEAR (2010-2012)										
Year	**Transect**	**Field-Estimated Water Clarity**								**No. of Sampling Days**
		Clear		**Slightly Turbid**		**Turbid**		**Opaque**		
		***E. coli* (MPN/100 ml)**								
		median	***n***	***median***	***N***	***median***	***n***	***median***	***n***	***N***
2010 - 2011	***SM1***	31	*39*	210	*11*	278	*4*	369	*1*	*55*
	SM2	41	*33*	227	*10*	98	*3*	-	*0*	*46*
	SM3	73	*39*	85	*11*	135	*4*	226	*1*	*55*
2012	***SM1***	10	*8*	60	*6*	-	*0*	-	*0*	*14*
	SM3	< 10	*8*	< 10	*6*	-	*0*	-	*0*	*14*

Table 20: Water clarity (turbidity) versus median *E. coli* concentration (MPN/100 ml) from 2010-2012 at Samuel Myers Beach. [*n* = number of observations, *N* = total number of sampling events per study year]

Wind Speed and Direction. Wind speeds and directions were available on all dates between 2010 through 2012. From 2010 to 2011, surface water *E. coli* concentrations at transect SM3 were significantly higher when a southern wind was present (135° - 225°) (mean=2.18, σ=0.60, n=17) compared to days with a northern wind (315° – 45°) (mean=1.25, σ=0.56, n=11) (T-test, p=0.0005). A significant relationship between wind direction and surface water *E. coli* concentrations at transects SM1 and SM2 was not observed (T-tests, p>0.05). *E. coli* concentrations did not vary significantly as a function of east (45° - 135°) or west winds (225° - 315°), all transects, all years (T-tests; Mann-Whitney; p>0.05). A significant relationship was not found between *E. coli* concentrations and wind speed during any study year (all Spearman's, p>0.05).

Longshore Current Direction. An longshore current was detected on 91, 89, and 86 percent of sampling dates in 2010, 2011, and 2012, respectively. There was no discernible longshore current detected on the remainder of the sampling days. Northern longshore currents were noted on 54, 44, and 29 percent of days and southern currents on 37, 44, and 57 percent of sampling days in 2010, 2011, and 2012, respectively. In 2010 and 2011, surface water *E. coli* concentrations at transect SM3 were significantly higher when a northern longshore current was present (mean=2.11, σ=0.60, n=29) (T-test, $p=0.001$). This relationship was not present at other transects in 2010 or 2011 (T-test, $p>0.05$) or at any transect in 2012 (all Mann-Whitney, $p>0.05$).

Cloud Cover. Cloud cover data was available on all dates that sample collection occurred throughout the study period. *E. coli* concentrations in surface water did not correlate with, or vary based upon, the degree of cloud cover ($p>0.05$ for all tests).

Air Temperature. The average air temperature recorded on sampling days was 22.6 (σ=2.6, n=47), 22.7 (σ=4.7, n=9), and 25.1 °C (σ=5.2, n=14) in 2010, 2011, and 2012, respectively. Air temperature did not vary significantly across study years (Levine's, $p=0.018$; Robust Tests of Equality of Means, $p=0.285$).

Air temperatures were significantly and positively correlated with log-transformed surface water *E. coli* concentrations at transects SM2 ($r=0.30$, $p=0.041$) and SM3 ($r=0.43$, $p=0.001$) in 2010 and 2011. No significant correlations were found between air temperature and surface water *E. coli* concentration at transect SM1 during the same time frame or at any transects in 2012 (all Pearson's and Spearman's rho, $p>0.05$).

Water Temperature. The average water temperature recorded on sampling days was 18.6 (σ=2.2, n=135), 19.6 (σ=4.7, n=18), and 21.4 °C (σ=4.7, n=28) in 2010, 2011, and 2012, respectively. Water temperatures in each year were normally distributed (Shapiro-Wilk, $p>0.05$) and 2012 water temperatures were significantly higher (mean=21.4, σ=4.6, n=28) than 2010 temperatures (mean=18.6, σ=2.2, n=135) (ANOVA, $p=0.0005$; Games-Howell Pair wise Comparison, $p=0.01$). In 2010, significant correlations were found between water temperatures and surface water *E. coli* concentrations at transects SM1 and SM2 (SM1: $r=0.33$, $p=0.027$, n=45) (SM2: $r=0.30$, $p=0.049$, n=45). No other significant correlations were found between water temperatures and corresponding surface water *E. coli* concentrations by transect or year (2011 and 2012, $p>0.05$).

Beach Usage. The number of people at the beach and in the water was recorded each day that sample collection occurred. An average of one to two, zero to one, and two to three people were observed at the beach in 2010, 2011, and 2012 respectively. Of the people observed, no more than two people were observed in the water, either wading or swimming (2010, 2011, and 2012). The number of people observed at the beach may not be representative of overall beach use due to the time of sample collection (10:00am – 12:00pm). These times do not represent peak beach usage, which generally occurs in the mid-afternoon and on weekends. Due to the low observation of people on the beach at the time of the sanitary surveys, bathers were not considered a significant source of bacterial contamination.

Debris. The amount and type of beach debris was recorded on each day that sample collection occurred. In 2010, beach debris was observed during 20 (n=9/47), 45 (n=21/47), 34 (n=16/45), and two (n=1/47) percent of sampling days at high, moderate, low and absent levels respectively. The only day that beach debris was not observed was following clean-up prior to the Midwest Dragon Boat Festival in 2010. Beach debris was observed at moderate and low levels for 100 percent of sampling days in 2011 and 2012. All categories of debris from the daily beach sanitary survey were represented (street litter, food-related litter, medical items, sewage-related, building materials, and fishing-related). Floatables were observed during 57 (n=27/47), 56 (n=5/9), and zero (n=0/14) percent of days in 2010, 2011, and 2012, respectively. No significant differences or correlations between surface water *E. coli* concentrations and beach debris or floatables were found, any year ($p>0.05$).

Carre-Hogle Beach

Topographical (Physical) Measurements. Beach length, on-shore slope, and width were measured at transects CH2, CH4, and CH5 on September 17th, 2010. The length of the shoreline around the peninsula which represents the beach was 113 m. Average width was 18.8 m (Table 21). In-water beach measurements indicate relatively similar bathymetry between the three sampling transects, but with a more rapid drop-off at the end of the peninsula, transect CH4.

Carre-Hogle Beach TOPOGRAPHICAL MEASUREMENTS (2010)				
	CH2	**CH4**	**CH5**	**Mean**
Beach Width (m)	12.2	27.5	16.8	18.8
Beach Slope (%)	3.8	3.8	5.4	4.3
In-Water Measurements from Berm Crest to:				
0.3 m	6.4	8.5	7.5	7.5
0.6 m	12.3	9.8	11.4	11.2
0.9 m	16.8	12.9	24.2	18.0
1.2 m	28.0	16.4	32.0	25.5

Table 21: Topographical Measurements at Carre-Hogle Beach (2010).

Water quality – routine monitoring. Three hundred and thirty-nine water samples were collected from Carre-Hogle Beach in 2010 (n=270), 2011 (n=27), and 2012 (n=42) (Table 22). No significant differences were found in *E. coli* concentrations across beach transects in 2010 (ANOVA, n=45, p<0.05), justifying the condensing of transects from six (CH1 – CH6) to three (CH2, CH4, and CH5) in subsequent years. After 2010, sampling events were also decreased to once per week.

E. coli concentrations were not significantly different between transects or study years (all ANOVA, p>0.05), therefore allowing for inter-year comparison between transects CH2, CH4, and CH5. *E. coli* concentrations at all transects exceeded water quality standards 33 (n=88/270), 22 (n=6/27), and 40 (n=15/42) percent of the time in 2010, 2011, and 2012 respectively (Table 22). Log-transformed surface water *E. coli* data, all transects and all study years, were normally distributed (Shapiro-Wilk, p<0.05), thus allowing parametric statistical analysis between years.

Carre-Hogle Beach RECREATIONAL WATER QUALITY EXCEEDANCES (2010-2012)						
Transect/ Full Beach	**n**	**Median (MPN/100 ml)**	**Minimum (MPN/100 ml)**	**Maximum (MPN/100 ml)**	**Exceedances (>235 MPN/100 ml)**	**Exceedance Rate (%)**
2010						
CH1	45	160	< 10	9,139	18	40
CH2	45	110	< 10	3,968	16	36
CH3	45	134	10	2,851	13	29
CH4	45	121	10	1,071	18	40
CH5	45	86	< 10	2,489	13	29
CH6	45	109	< 10	1,722	10	22
Full Beach	270	108.5	< 10	9,139	88	33
2011						
CH2	9	189	41	482	3	33
CH4	9	52	< 10	703	1	11
CH5	9	63	< 10	909	2	22
Full Beach	27	122	< 10	909	6	20
2012						
CH2	14	256	< 10	17,329	8	57
CH4	14	118	10	8,664	3	21
CH5	14	52	10	3,873	4	29
Full Beach	42	103	< 10	17329	15	40

Table 22: Number of samples, median, minimum, and maximum *E. coli* concentrations (MPN/100 ml), water quality exceedances, and exceedance rate at Carre-Hogle Beach sampling transects and full beach from 2010-2012.

Water quality – multi-depth samples. One-hundred and ninety-two samples were collected during eight sampling events from all six transects, at the depths of 0.3, 0.6, 0.9, and 1.2 m, during the summer of 2010 (Table 23). Log-transformed *E. coli* concentrations from all transects were normally distributed (Shapiro-Wilk, all n=8, p>0.05). No significant differences in *E. coli* concentrations existed between any of the sampling transects (all ANOVA, n=48, p>0.05), which allowed a single depth across all transects to be combined for statistical analysis. Surface water *E. coli* concentrations were highest close to the shoreline and decreased significantly with greater depth (all ANOVA, n=48, p=0.0005). The mean *E. coli* concentration at the 0.6 m depth was also significantly higher than at the 0.9 m (Tukey's, p=0.042) and 1.2 m depths (Tukey's, p=0.001), but there was no significant difference between the 0.9 m and 1.2m depths (Tukey's, p=0.536).

Carre-Hogle Beach *E. COLI* CONCENTRATION BY DEPTH (2010)									
Mean/ Median	**Depth (m)**				**Mean/ Median**	**Depth (m)**			
	0.3 m	**0.6 m**	**0.9 m**	**1.2 m**		**0.3 m**	**0.6 m**	**0.9 m**	**1.2 m**
CH1					**CH4**				
Median	*438*	*98*	*47*	*47*	Median	*251*	*193*	*69*	*80*
CH2					**CH5**				
Median	*242*	*304*	*69*	*52*	Median	*239*	*92*	*69*	*74*
CH3					**CH6**				
Median	*269*	*178*	*63*	*47*	Median	*230*	*135*	*103*	*79*

Table 23: Median *E. coli* concentration (expressed as MPN/100 ml) by depth (in meters) at which the sample was collected; transect Carre-Hogle-1 (CH1), Carre-Hogle-2 (CH2), Carre-Hogle-3 (CH3), Carre-Hogle-4 (CH4), Carre-Hogle-5 (CH5), Carre-Hogle-6 (CH6) (2010). Medians were calculated from eight multi-depth sampling events conducted bi-weekly from 6/28/2010 to 9/28/2010. [Orange-shaded and pink-shaded cells indicate means/medians when recreational water quality advisory and closure thresholds were exceeded, respectively].

Stormwater Outfalls. Water sample collection was attempted once weekly (n = 9 weeks) for each outfall located adjacent to the beach in 2010 (Table 15, Page 35). This was a concurrent effort with pollution source investigation at Samuel Myer's beach.

Water Quality - 14th Street Outfall (See page 35). Discharge from the 14th St. OF was never observed and samples were not collected.

Water Quality - 15th Street Outfall (See page 36). *E. coli* concentrations in stormwater samples collected from the 15th St. Outfall were not significantly higher than those observed at the open water sampling locations of Carre-Hogle beach (p=0.773). Transects on the northern side of Carre-Hogle (n = 8), were significantly correlated with 15th St. OF (all Pearson's, n=8).

Water Quality - 16th Street Outfall North (See page 36). *E. coli* concentrations in the 16th St.-North OF stormwater discharge were consistently low during all sampling events.

Water Quality - 16th Street Outfall South (see page 36). *E. coli* concentrations in stormwater samples collected from the 16th St. Outfall South were not significantly higher than concentrations observed at open water locations of Carre-Hogle (p=0.852). Sixteenth St. S OF stormwater *E. coli* concentrations were not significantly correlated with surface water *E. coli* at any of the Carre-Hogle transects.

Sediments -E. coli. Sediment samples were collected bi-weekly on seven occasions in 2010 at all six berm crests locations (transects CH1-CH6). Sediments were also collected at middle and back-beach locations at transect CH4 (Table 24). This transect was the only one with sufficient depth to accommodate a middle and back beach sample (Table 21). Evidence of five potential pollutant sources (trash, algae, bird feathers, bird feces, bird tracks, and dog tracks) were observed within 0.3 m of the sediment sampling locations. Along the northern shoreline (transects CH1-CH3), it was primarily algae and trash. At the middle and back beach locations, bird artifacts such as feces, feathers, and tracks were present for the majority of sampling events. Combined sediment *E. coli* concentrations did not correlate with the presence of potential pollutant sources such as the number of gulls, geese, dogs, dead fish, or dead birds encountered on the beach on sediment sampling days (all Pearson's, n=7, p>0.05).

Carre-Hogle Beach MEDIAN *E. COLI* CONCENTRATION IN BEACH SAND (2010)										
	E. coli (CFU/100 g)									
Date	**CH1-BC**	**CH2-BC**	**CH3-BC**	**CH4-BC**	**CH4-MB**	**CH4-BB**	**CH5-BC**	**CH6-BC**	Median by Site	**Key**
7/7	362	7,950	21,786	2,222	8,306	1,314	7,259	2,261	4,760	trash
7/21	122,549	32,216	4,565	14,545	15,963	26,036	5,994	10,522	15,254	algae
8/4	14,116	7,621	3,855	3,076	19,019	6,242	9,692	386	6,931	feathers
8/18	72,222	14,947	3,833	7,940	21,307	1,131	3,284	750	5,886	avian feces
8/31	1,230	14,466	40,678	3,650	37,258	6,511	11,658	1,090	9,084	bird tracks
9/14	52,256	3,226	6,982	4,028	18,772	26,738	2,006	1,242	5,505	animal feces
9/28	1,268	20,537	5,774	3,234	3,277	6,200	3,808	100,465	4,791	other
Median by Site	14,116	14,466	5,774	3,650	18,772	6,242	5,994	1,242	6,746	

Table 24: Median *E. coli* concentrations (CFU/100 g) in berm crest (BC), mid-beach (MB), and back beach (BB) sands at Carre-Hogle Beach transects CH1-CH6 (2010). Potential polluting sources (Key) were either in the sample or within 12". "Other" in this case is dog tracks.

Log-transformed sediment results were normally distributed (Shapiro-Wilks, p>0.05), allowing for parametric statistical analysis. *E. coli* concentrations did not differ based upon sampling transect or location within each transect (Robust Tests of Equality of Means, n=7, p=0.129). *E. coli* concentrations in berm crest sediments (mean=3.78, σ=0.60, n=42) were significantly higher than in adjacent surface water (mean=1.71, σ=0.60, n=42) (T-test, p=0.0005). However, *E. coli* concentrations in sediments and surface water were not significantly correlated (Pearson's, p>0.05).

Sediments – grain size. Carre-Hogle was a mostly sandy beach (0.08 – 2.0 mm) with trace amounts of very fine pebbles (2.0-4.0 mm). The average mean grain size was 0.85 mm for the entire beach. CH1-BC was the only location that was primarily comprised of very fine pebbles.

Sediments – uniformity. Sediment composition was classified as well-sorted (a low variety of grain sizes) at the berm crest of transects CH2, CH3, and CH6. Samples from the berm crest of transects CH4 and CH5 were in between well- and poorly-sorted (4.31 – 4.45). Berm crest sediments at CH1-BC were described as poorly-sorted (10.88). The middle and back beach positions of CH4 were classified as well sorted.

Sanitary Survey Data

Wildlife. The number and type of wildlife (alive and dead) observed on the beach were recorded at the time of sample collection (Table 25). A total of 3,482 gulls, 884 geese, and 538 ducks were counted over the course of the study; gulls and geese consistently occupied the beach in high numbers (Figure 13). Gulls, geese, or ducks were present for 84 (n=58/69), 64 (n=44/69), and 42 (n=29/69) percent of sampling events in 2010, 2011, and 2012 respectively. In addition, fresh indicators of birds, such as feces, feathers, and tracks (Figure 14) were prominent on all sampling days. Waves were frequently observed washing across the beach face (Figure 15), which could act as a mechanism to deliver fecal pollution into the nearshore water. However, surface water *E. coli* concentrations did not differ significantly based upon the type or number of wildlife present (p>0.05).

Carre-Hogle Beach TOTAL NUMBER AND MEAN PER DAY OF WILDLIFE TYPE PRESENT, BY YEAR (2010 – 2012)												
Year	Gulls		Geese		Dogs		Ducks		Dead Birds		Dead Fish	
	No.	χ	No.	χ	No.	χ	No.	χ	No.	χ	No.	χ
2010	2,422	53	527	11	3	0	303	7	0	0	1	0
2011	739	82	142	16	0	0	91	10	0	0	5	1
2012	321	23	215	15	3	0	144	10	5	0	1	0
2010-2012	3,482	50	884	13	6	0	538	8	5	0	7	0

Table 25: Number (No.) and mean per day (χ) of wildlife (dead or alive) type and dogs observed at Carre-Hogle Beach per study year (2010 – 2012).

Figure 13: Gulls and geese loafing on Carre-Hogle Beach (7/6/10).

Figure 14: Gull and geese tracks and potential fecal matter (6/24/10).

Figure 15: Water washing across Carre-Hogle Beach near tip and pooling in middle beach area (7/22/10).

Algae. Algae (*Cladophora*) amounts submerged in the nearshore water and stranded on the beach were recorded each day that sample collection occurred (Tables 26 and 27*).* Algae, submerged and stranded ashore, were present on the north side of the beach (transects CH1, CH2, and CH3) for 97.1 and 95.6 percent of sampling events respectively (Figure 16). Submerged and stranded algae were present on the south side of the beach; inclusive of transect CH4, on 91.7 and 83.4 percent of days respectively. Algal blooms were often present in higher amounts on the north side of the beach. When algal amounts were assigned ordinal values, transect CH2 had a significantly higher amount of submerged (median=moderate, n=68) and stranded algae (median=low, n=68) than transect CH4 (submerged: median=not present, n=68, p=0.0005; stranded: median=not present, n=68, p=0.0005) and transect CH5 over the course of the study (submerged: median=not present, n=68, p=0.0005; stranded: median=not present, n=68, p=0.0005, all Kruskal-Wallis). *E. coli* concentrations did not vary significantly based upon the amount of stranded or submerged algae at any transect over the study period (all ANOVA, n=68, p>0.05).

Carre-Hogle Beach AMOUNT of SUBMERGED *CLADOPHORA* (2010-2012)							
Year	**Transect**		**Not Present**	**Low**	**Moderate**	**High**	**TOTAL**
2010-2012	**CH2**	**n**	2	9	19	38	68
		%	*2.9*	*13.2*	*27.9*	*55.9*	*99.9*
	CH4	**n**	8	36	22	2	68
		%	*11.8*	*52.9*	*32.4*	*2.9*	*100*
	CH5	**n**	7	29	21	11	68
		%	*10.3*	*42.6*	*30.9*	*16.2*	*100*

Table 26: Number and percentages of beach sanitary survey dates with none, low, moderate, and high amounts of algae submerged in the water from 2010-2012 at Carre-Hogle Beach transects CH2, CH4, and CH5. Note: totals do not add up to 100% due to rounding.

Carre-Hogle Beach AMOUNT OF STRANDED *CLADOPHORA* (2010-2012)							
Year	**Transect**		**Not Present**	**Low**	**Moderate**	**High**	**TOTAL**
2010-2012	**CH2**	**n**	3	17	25	23	68
		%	*4.4*	*25.0*	*36.8*	*33.8*	*100*
	CH4	**n**	12	49	7	0	68
		%	*17.6*	*72.1*	*10.3*	*0.0*	*100*
	CH5	**n**	12	46	7	3	68
		%	*17.6*	*67.6*	*10.3*	*4.4*	*99.9*

Table 27: Number and percentages of beach sanitary survey dates with none, low, moderate, and high amounts of algae stranded ashore from 2010-2012 at Carre-Hogle Beach transects CH2, CH4, and CH5. Note: totals do not add up to 100% due to rounding.

Figure 16: Algal buildup on northwest corner of Carre-Hogle Beach, near transects CH1 and CH2 (7/6/10).

Precipitation. Rainfall events of 0.01 cm or greater occurred within 24 hours prior to sample collection on 40 (n=18/45), 11 (n=1/9), and 36 (n=5/14) percent of sampling days in 2010, 2011, and 2012 respectively. One 24-hr rain event (1.12 cm on 6/10/11) and two 48-hr and 72-hr rain events occurred in 2011. However, significant differences were not noted in the amount of rainfall in each year (Kruskal-Wallis, p>0.05).

In 2010, higher *E. coli* concentrations were associated with precipitation in the 24 hours prior to sample collection at transects CH1 (p=0.022), CH2 (p=0.02) and CH3 (p=0.035). Significant differences were not associated with precipitation events during any other precipitation time frames, during any other years or at any other transects (p>0.05).

Wave Height. Observed wave heights at Carre-Hogle were similar across study years (Kruskal-Wallis, p>0.05). Wave height values were not normally distributed, thus precluding parametric statistical analysis (Shapiro-Wilk, p>0.05). The median, minimum, and maximum wave heights over the 2010-2012 study period were 0.08 m, 0.00 m, and 0.61 m, respectively. Wave height estimates were significantly correlated with *E. coli* concentrations over the duration of this study at transects CH2 (r=0.442, p=0.0005), CH4 (r=0.386, p=0.001), and CH5 (r=0.377, p=0.002) (all Pearson's, n=68). In 2010, transects CH1 (r=0.427, p=0.003) and CH3 (r=0.352, p=0.018) were also significantly correlated with wave height, but this relationship was not observed at transect CH6 (p>0.05) (all Pearson's, n=45).

Water Clarity. Water clarity descriptors were available at transects CH2, CH4, and CH5 on 68 dates from 2010 to 2012 and at transects CH1, CH3, and CH6 on 45 dates (2010 only) (Table 28). *E. coli* concentrations were significantly higher when water clarity was described as opaque (mean=2.99, σ=0.81, n=7, Tukey's, p=0.0005) or turbid (mean=2.45, σ=0.57, n=21, Tukey's, p=0.006) versus when described as clear at transect CH2 (mean=1.84, σ=0.58, n=24) (ANOVA, p=0.0005). In 2010, transects CH1 and CH3 had significantly higher *E. coli* concentrations when surface water was described as turbid or opaque compared to when it was clear (all ANOVA, p>0.05). Ordinal water clarity descriptors were significantly correlated with wave height (r=0.661, p=0.0005) and wind speed (r=0.527, p=0.0005) (both Pearson's, n=68).

Carre-Hogle Beach WATER CLARITY (TURBIDITY) VERSUS MEAN *E. COLI* DENSITY BY YEAR (2010-2012)							
Field-Estimated Water Clarity	***E. coli* density (MPN/100 ml)**	**2010 - 2012**			**2010**		
		CH2	***CH4***	***CH5***	***CH1***	***CH3***	***CH6***
Clear	***mean***	1.84	1.82	1.58	1.83	1.91	1.83
	Σ	0.58	0.58	0.77	0.65	0.45	0.65
	N	*24*	*25*	*26*	*20*	*20*	*21*
Slightly Turbid	***mean***	2.11	1.96	2.06	2.50	2.13	1.65
	Σ	0.57	0.49	0.72	0.51	0.48	0.32
	N	*16*	*17*	*17*	*7*	*7*	*5*
Turbid	***mean***	2.45	2.34	2.04	2.64	2.34	1.90
	Σ	0.57	0.65	0.70	0.86	0.57	0.76
	N	*21*	*23*	*22*	*15*	*15*	*16*
Opaque	***mean***	2.99	2.59	2.46	3.06	2.94	2.55
	Σ	0.81	0.38	0.69	1.03	0.79	0.41
	N	*7*	*3*	*3*	*3*	*3*	*3*
TOTAL	*N*	*68*	*68*	*68*	*45*	*45*	*45*

Table 28: Water clarity (turbidity) versus log-transformed mean *E. coli* concentrations (MPN/100 ml) from 2010-2012 at transects CH1-CH6 at Carre-Hogle Beach. [*σ*=standard deviation, *n*=number of observations]

Wind Speed and Direction. Wind speeds and directions were available for all dates on which sample collection occurred. Over the entire study period, *E. coli* concentrations at transect CH2 were significantly correlated with wind speed (r=0.276, p=0.023, n=68, Pearson's). This relationship was not present at any other transects (all Pearson's, p>0.05). Also over the course of this study, *E. coli* concentrations at transect CH5 were significantly higher when east winds were present (45° - 135°) (mean=2.29, σ=0.84, n=13) compared to days with west winds (225° – 315°) (mean=1.71, σ=0.71, n=35) (T-test, p=0.0020). This relationship was also present at transect CH6 in 2010 (T-test, p>0.05), but not at other transects during any timeframe (all T-test, p>0.05). In 2010, transect CH1 had higher mean surface water *E. coli* concentrations when north winds (315° - 360°, 0° - 45°) were present compared to days with south winds (135° - 225°) (T-Test, p>0.05). *E. coli* concentrations did not vary at any other transect as a function of north or south winds during any of the three study years (T-test, p>0.05).

Longshore Current Direction. *Longshore* currents were detected on 98, 89, and 86 percent of sampling dates in 2010, 2011, and 2012 respectively. There was no detectable longshore current on the remaining sampling dates. Northern longshore currents were present on 54, 44, and 29 percent of sampling events in 2010, 2011 and 2012 respectively and southern longshore currents comprised 37, 44, and 57 percent of sampling events in the same years. *E. coli* concentrations did not correlate with longshore current direction throughout this study (all ANOVA, n=68, p>0.05).

Cloud Cover. Cloud cover data were available on all dates that sample collection occurred between 2010 through 2012. *E. coli* concentrations did not correlate with, or vary based upon, the percent cloud cover (p>0.05 for all tests).

Air Temperature. The average air temperature recorded on sampling days was 22.8 (σ=3.1, n=45), 22.3 (σ=5.9, n=9), and 24.6 °C (σ=5.5, n=14) in 2010, 2011, and 2012, respectively. No significant difference was found between mean air temperatures in any year (ANOVA, p=0.289). Surface water *E. coli* concentrations were not significantly correlated with air temperature at any transect, any year [Pearson's, p>0.05, n=45 (2010), n=67 (2010-2012)].

Water Temperature. Mean daily water temperature results at Carre-Hogle did not differ between 2010 (median=18.1 °C, n=45), 2011 (median=20.0 °C, n=9), and 2012 (median=21.3 °C, n=14) (ANOVA on Ranks, p=0.051). No significant correlation was found between surface water *E. coli* concentrations at any transect during any year (all Spearman's, p>0.05).

Beach Usage. The number of people at the beach and in the water was recorded each day that sample collection occurred. An average of zero to two people were observed at the beach. Of the people observed, zero or one persons were observed in the water, either wading or swimming (2010, 2011, and 2012). The number of people observed at the beach was likely not representative of overall beach use due to the time of sample collection (10:00am – 12:00pm). These times do not represent peak beach usage, which occurs in the mid-afternoon and on weekends at other local beaches. Due to the low number of people observed in the water, bather shedding bacteria was not considered a significant source of fecal loading to the nearshore water of Lake Michigan.

Debris. The amount and type of beach debris was recorded each day that sample collection occurred. In 2010, beach debris was observed at high, moderate, low or absent levels during 16 (n=7/45), 53 (n=24/45), 31 (n=14/45), and zero (n=0/45) percent of sampling days, respectively. Beach debris was observed at moderate levels for 100 percent of the beach season in both 2011 and 2012. The majority of beach debris and floatables were observed on the northern side of the beach, particularly in the northwest corner (Figure 17). All categories of debris from the daily beach sanitary survey were encountered (street litter, food-related litter, medical items, sewage-related, building materials, and fishing-related). Floatables were observed during 50 (n=22/44), 44 (n=4/9), and 14 (n=2/14) percent of days in 2010, 2011, and 2012. There was no significant correlation between surface water *E. coli* concentrations and the amount or type of beach debris or floatables present (p>0.05).

Figure 17: Debris and trash buildup on northwest side of Carre-Hogle Beach, near transects CH1, CH2, and CH3 (6/16/10)

Discussion

The following section discusses the results of routine monitoring and beach sanitary survey data for the determination of site-specific characteristics and potential pollution sources impacting Lake Michigan surface water quality at the three study sites.

Recreational Water Quality. Recreational water quality guidelines were exceeded for more than 15 percent of samples in select years at Michigan Boulevard (2010), Samuel Myers (2010 and 2011) and Carre-Hogle (2010-2012) beaches. Mean *E. coli* concentrations did not differ based upon transect location at Michigan Boulevard; however, the water quality exceedance rate, maximum, and median *E. coli* concentration was higher at transect M1 compared to other locations suggesting possible variations in sources of impairment across the beach. At Samuel Myers Park, *E. coli* concentrations only differed significantly by transect in 2012. However, there was only one water quality exceedance, at transect SM-1, and less than 15% of total samples exceeded recreational water quality standards. At Carre-Hogle, there were no significant difference in FIB concentrations across beach transects, yet the exceedance rates and median *E. coli* concentration was greater on the north side of the beach compared to the south side.

Multi-Depth samples. Recreational water quality did not vary significantly with increased sample depth (0.3 – 1.2 m) at Michigan Boulevard Beach, but higher *E. coli* concentrations were present close to the shoreline at Samuel Myers and Carre-Hogle Beaches. At Samuel Myers Beach (2010), *E. coli* concentrations were significantly higher near the shoreline, at the 0.3 m depth, compared to deeper water (0.6, 0.9, 1.2 m depths); as water depth increased, median *E. coli* concentrations decreased. This relationship was not observed in data collected in 2012. This may be a statistical artifact, due to a fewer number of multi-depth samples collected in this year compared to the 2010. At Carre-Hogle Beach, *E. coli* concentrations were highest closest to the shore and decreased significantly out to a depth of 0.9 m. The decrease in *E. coli* concentrations with increased depth, and by proxy distance from the shoreline, suggests that localized sources at the shoreline contribute to observed *E. coli* concentrations. *E. coli* concentrations did not decrease with respect to sample depth at Michigan Boulevard Beach. This does not mean that shoreline sources could not adversely impact water quality, but rather, conditions may have not been environmentally favorable to observe such a relationship when multi-depth samples were collected or greater mixing occurs between the nearshore area and the open waters of Lake Michigan at this site limiting the presence of a significant bacteria gradient.

Stormwater Outfalls (Point Sources)

One stormwater outfall was located immediately adjacent to Michigan Boulevard Beach, the Wolff Street Outfall, and four outfalls were located within the same embayment containing Samuel Myers and Carre-Hogle Beaches.

Wolff Street Outfall. Stormwater collected directly from the Wolff Street Outfall had significantly higher *E. coli* concentrations than surface water samples at Michigan Boulevard Beach during all years of the study, rendering it a potential pollutant source. Surface water samples at Michigan Boulevard Beach from all years, except transect M1 in 2011, were significantly correlated with outfall *E. coli* concentrations. In 2010, the most sample intensive season, higher *E. coli* concentrations were associated with northern alongshore currents compared to southern alongshore currents. A northern alongshore would provide favorable hydrodynamics to promote mixing between discharge from this outfall and Lake Michigan surface water at Michigan Boulevard. The close proximity of transect M1 to this outfall may explain higher median *E. coli* concentrations at this location compared to the rest of the beach. Elevated *E. coli* concentrations in effluent from the Wolff Street Outfall were driven by wet weather (24-, 48-, and 72-hr rainfall) in 2010, but not in later years. In 2011, only one rain event occurred, thus limiting statistical significance, and in 2012, outfall *E. coli* concentrations were significantly lower than concentrations in 2010, likely a result of drought conditions. Human specific *Bacteroides* results from 2011 (only year with *Bacteroides* testing) indicate that sanitary sewage infiltration may be causal for some dry- (and wet-) weather discharge associated *E. coli* as copy number and human specific *Bacteroides* to *Bacteroides* species ratios results were great enough to warrant further investigation.

14th Street Outfall. The Fourteenth St. Outfall consistently lacked flow and therefore was not considered a likely source of *E. coli* loading at either Samuel Myers or Carre-Hogle Beaches. However, it should be monitored if flow conditions change.

15th Street Outfall. The outlet of the 15th Street outfall was partially submerged on all dates. Due to this, samples from this outfall were likely diluted with lake water, lowering observed *E. coli* concentrations. The majority of samples collected (55.5%) exceeded recreational water quality standards (>235 MPN/100ml). Flow volumes were moderate, approximately 300 ml/s. *E. coli* concentrations in effluent from the 15th St. Outfall correlated with concentrations observed at open water locations on the north side of Carre-Hogle Beach (transects CH1-3) but not at Samuel Myers. This, along with frequently elevated *E. coli* concentration in the effluent from this outfall, indicates it could behave as a potential contamination source for Carre-Hogle Beach. However, the distance between the 15th St. Outfall and the north side of Carre-Hogle Beach was 430 meters, which allows for substantial dilution of effluent prior to entry into the beach's swimming areas. Dilution, along with multi-depth results showing higher impairment potential from the shoreline, indicates the outfall may not be the only/most potent pollutant source adversely impacting surface water quality at Carre-Hogle Beach. Source tracking results from 2011 also indicated that sanitary sewage may supply dry-weather *E. coli* to the outfall as human-specific *Bacteroides* exceeded thresholds which warrant further investigation.

16th Street Outfall-North. *E. coli* concentrations were consistently low and below recreational water quality standards in stormwater discharge from this outfall. Therefore, the Sixteenth St. – North Outfall was not a likely source of impairment to either Sam Myers or Carre-Hogle Beaches.

16th Street Outfall-South. *E. coli* concentrations in stormwater discharge from the 16th St.-South Outfall were typically above 1,000 MPN/100ml following precipitation. Conversely, samples collected during dry weather generally had low *E. coli* concentrations (<235 MPN/100ml). *E. coli* concentrations in effluent from this outfall were correlated with surface water samples collected at transect SM1 in 2010. In 2010, *E. coli* concentrations at transect SM1 were also correlated with rainfall. The correlation between *E. coli* concentrations in surface water and stormwater discharge was likely an artifact of covariance between the two sites rather than indicative of a causal relationship (e.g. *E. coli* concentrations in surface water samples and effluents both varied based upon precipitation). Human-specific *Bacteroides* source tracking results from 2011 indicate the potential for sanitary sewage infiltration, which may be supplying the outfall with elevated levels of dry- and wet-weather *E. coli*. It should be noted that this stormwater outfall is 640 m from the Samuel Myers Beach, and the flow was extremely low, thus allowing for substantial dilution of effluent with lake water prior reaching transect SM1; actual counts may be higher than stated in this report.

Non-point Sources

Sediments. Sediment *E. coli* concentrations were higher at the berm crest compared to paired surface water samples at all three beaches and therefore could be a potential pollution source. Statistically, surface water samples were not significantly correlated with sediment *E. coli* concentrations at any beach. The lack of correlation suggests that the release of bacteria from sediments into surface waters may be transient. Previously published articles indicate wave action or wave run up aid in the transfer of bacteria between these two media (Kinzelman et al, 2004; Ge et al, 2010). If there was little or variation in wave action occurring at the time of sample collection, correlations between *E. coli* concentrations in these two media could be biased. Additional sampling is necessary to determine the exact relationship and loading potential. Further, multi-depth analysis at Samuel Myers and Carre-Hogle Beach indicated shoreline sources; sediments, shoreline algae, wildlife, and/or combinations thereof, were a source of impairment. At Samuel Myers Park, the highest levels of *E. coli* were in berm crest sediments; with lower concentrations observed in submerged, back and middle beach sediments. This suggests shoreline sediments have the greatest potential to influence water quality due to higher concentrations and the greater presence of direct wave action washing attached bacteria into the nearshore water. Higher sediment *E. coli* concentrations close to the shoreline are consistent with Skalbeck et al (2010) where *E. coli* concentrations were generally four times higher along the shoreline (berm crest) compared to back or middle beach samples.

Wildlife. Wildlife (alive and dead) were not associated with elevated *E. coli* densities at Michigan Boulevard Beach, but were at Samuel Myers and Carre-Hogle beaches. At Michigan Boulevard, the number of observed wildlife was low and thus insufficient to be a major source of impairment at this beach. Dogs were occasionally observed on the beach and at times, dog feces were noted as well, but neither was correlated with higher *E. coli* concentrations. In 2010, the presence of geese was found to be significantly correlated with higher *E. coli* concentrations at Samuel Myers Beach. This correlation occurred at the westernmost transect (SM1), closest to where geese commonly loafed. Dead animals and fish were an aesthetic and potential health problem at Samuel Myers, particularly in 2010 when 11 dead gulls were found on one sampling date, near runny fecal matter. Speculatively, the large number of dead birds on the beach may be related to avian botulism or other communicable avian diseases. The animals did not appear to be consumed in any way, suggesting their deaths were not caused by predation.

At Carre-Hogle, wildlife was not statistically correlated with higher *E. coli* concentrations. However, high numbers of birds frequented the beach and bird feces were observed during every sampling event. A 2011 study found gull genetic markers were nearly ubiquitous at all depths of water where gulls frequented and the presence of gull markers was positively associated with higher *E. coli* counts (Lu et al, 2011). Kleinheinz et al (2006) suggested physical wildlife counts, or even the density of wildlife droppings, was a poor indicator of the effect wildlife has on surface water quality. A 2009 study at Grant Park Beach in South Milwaukee, WI suggested that bacteria can be transferred from gulls into the water using sediments as an intermediate (Koski and Kinzelman, 2009). Lake water was observed washing across the spit at this beach which may have been able to dislodge *E. coli* from bird fecal matter left on the sediment. It was likely avian sources, particularly gulls and geese, impaired water quality at Carre-Hogle Beach due to the large number consistently observed.

Algae. At Michigan Boulevard, neither submerged or stranded algae mats were associated with elevated *E. coli* concentrations. At Samuel Myers, *E. coli* concentrations positively correlated with submerged algae levels. In 2010 and 2011, this relationship was noted at transects SM2 and SM3, where submerged algae would frequently become trapped next to the breakwater. In 2012, this relationship was observed at transect SM1. Lower amounts of algae were present at Samuel Myers in 2012 than in 2010 which may explain why a lower percentage of water quality exceedances occurred in this year compared to years previous. Although there were frequent correlations between submerged algae amounts and *E. coli* concentrations at Sam Myers, there was no association between FIB and stranded algae. Beyond water quality, algal blooms were noted to detract from beach aesthetics.

At Carre-Hogle, submerged and stranded algae was not found to be significantly associated with higher *E. coli* levels, although high amounts of algal biomass was frequently observed on the north side of the beach throughout all study years. Higher *E. coli* concentrations were found in berm crest sediments and at the 0.3 m surface water sampling depth. Algae tended to accumulate in these areas and may have contributed to observed *E. coli* concentrations. Large amounts of submerged and stranded algae detracted from aesthetics at this beach.

Environmental Factors

Precipitation. Precipitation was significantly associated with elevated *E. coli* concentrations at select beach transects, all sites, for all or some years of the study period. At Michigan Boulevard, *E. coli* concentrations correlated with 24, 48, and 72-hr rainfall amounts in 2010. This relationship was also observed with 24-hr rainfall at select transects of Samuel Myers (transect SM1). These relationships were not present at either beach in 2011 or 2012. Only one rain event occurred prior to sampling events in 2011, and anecdotally 2012 was a drought year in Southeastern Wisconsin which may have biased this relationship. At Carre-Hogle, a significant relationship between *E. coli* concentrations and 24-, 48-, and 72-hr rainfall was observed on the north side of the beach (transect CH2, all years) (CH1 and CH3, collected in 2010 only) for the full study period (2010 – 2012). On the east side of the beach, this relationship was present for just 48- and 72-hr rainfall (Transect CH4) and not present on the south side of the beach (transects CH5, CH6). Rainfall may generate runoff that transfers *E. coli* from beach sediments, bird fecal matter, and/or algae, directly into the shallow waters at these beaches. Additional rain-mediated processes that may adversely impact water quality include increased stormwater discharge and surface runoff from adjacent impervious surfaces and turf grass.

Wave Height. A significant correlation was observed between increased wave height and elevated surface water *E. coli* concentrations at Michigan Boulevard and Carre-Hogle beaches, but not at Samuel Myers. At Michigan Boulevard, *E. coli* concentrations increased when waves of 0.5 m or greater occurred (2012, but not 2010 or 2011). The lack of association between wave height and surface water *E. coli* levels at Sam Myers was likely due to the almost complete lack of waves higher than 0.15 m at this beach. At Carre-Hogle, *E. coli* concentrations varied based upon wave height for the full study period at all beach transects (except for transect CH6 in 2010). Large waves serve to suspend/re-suspend shoreline sources into the water column. The short distance between the berm crest and surface water sampling points may facilitate the easy dispersion of shoreline bacteria/wrack into the nearshore waters adjacent to the sampling locations.

Water Clarity. Higher *E. coli* concentrations were associated with turbid water at all beaches. At Michigan Boulevard, water clarity was associated with higher *E. coli* concentrations in all years and at all transects, except for transect M1 (2010 and 2011). At Samuel Myers Beach, south winds and rainfall were frequently associated with turbid waters. At Carre-Hogle, higher wind speeds were associated with turbid waters. In addition to these environmental variables, turbid waters were closely/significantly associated with increased wave heights at all beaches. Larger waves serve to suspend coastal sediments and other shoreline sources into the nearshore water, reducing water clarity. Therefore, the presence of turbid waters was indicative of shoreline stress.

Wind Speed and Direction. Wind direction was significantly associated with increased *E. coli* concentrations at Samuel Myers and Carre-Hogle Beaches, but not at Michigan Boulevard Beach. At Samuel Myers, higher *E. coli* concentrations were associated with winds having a southern component. Southern winds were associated with a northern alongshore current, a variable associated with higher surface water *E. coli* concentrations and algae at this beach. At Carre-Hogle, winds with a northern component were associated with higher surface water *E. coli* concentrations at transect CH2 in 2010. A significant relationship was also observed between surface water *E. coli* concentrations and winds with an eastern component at transects on the south side of the beach, CH5 (2010-2012) and CH6 (2010). Higher wind speeds also corresponded with higher *E. coli* concentrations at Carre-Hogle, but not the other two beaches. Greater sustained wind speeds and onshore wind directions increase the interaction between the shoreline and nearshore waters. The relationships between these variables may be indicative of non-point shoreline sources.

Longshore Current Direction. Longshore current directions were associated with *E. coli* concentrations at Michigan Boulevard and Samuel Myers Beaches, but not at Carre-Hogle Beach. At Michigan Boulevard (2010), *E. coli* concentrations were higher when a northern longshore current was observed. A northern longshore current likely supports the transport of effluent from Wolff St. Outfall along the beach face. Environmental conditions were not favorable in 2011 to support detection of high *E. coli* concentrations in the Wolff Street Outfall discharge; only one wet weather monitoring event occurred. Drought conditions were present in 2012 and effluent concentrations were lower in the Wolff Street Outfall than previous years. Due to this, a southern longshore current was associated with higher *E. coli* in 2011 and 2012. At Samuel Myers, *E. coli* concentrations increased with a northern current (onshore) at transect SM3 in 2010 and 2011. An onshore component in the longshore current increases shoreline stress and was likely indicative of shoreline sources. No other longshore current relationships existed at Samuel Myers or Carre-Hogle for the full study period.

Cloud Cover. *E. coli* concentrations did not vary based upon cloud cover at any beach.

Air and Water Temperature. *E. coli* concentrations did not vary based upon air or water temperature at Michigan Boulevard or Carre-Hogle beaches. However, at Samuel Myers, there was a positive correlation between bacteria concentrations and air temperature in 2010 and 2011 (transects SM2 and SM3) and with water temperature at the westernmost transect (SM1) in 2010.

Beach Usage. Michigan Boulevard, Samuel Myers, and Carre-Hogle averaged few visitors at the time of sampling for all three study years. Unless usage was significantly higher at other times of the day, these numbers were low enough to negate bather shedding *E. coli* as a likely source of impairment at these beaches.

Debris. Excessive debris was not an issue at Michigan Boulevard, but was consistently observed at Samuel Myers and Carre-Hogle beaches. A significant relationship between debris and surface water *E. coli* concentrations was not found at any of the study beaches. However certain types of debris, for example food-related items, may attract wildlife and indirectly influence water quality. Pervasive debris was an aesthetic issue and can detract from the overall appeal of a recreational area.

Conclusions and Recommendations

Michigan Boulevard Beach had poor water quality in 2010, but had *E. coli* exceedance rates below 15% in 2011 and 2012. Transient periods of poor water quality at this beach were associated with rainfall, the presence of stormwater discharge from the Wolff St. outfall in conjunction with a northern alongshore current, wave heights above 0.5 m, and turbid water, indicating the likely influence of both point and nonpoint pollution sources. Although the number of bathers observed throughout the study period was low, there was evidence to indicate that this beach was utilized by the community for swimming and other coastal recreation activities. However, poor access to this location limits its recreational value. As of 2012, Michigan Boulevard Beach was designated by the WI DNR as "Inaccessible." It is recommended that it remain so listed until public access is improved. Any improvements or modifications to public access must also account for bluff stability. Infrastructure integrity within the Wolff St. stormwater basin should be investigated.

Samuel Myers Beach had poor water quality in 2010 and 2011, but the percentage of samples that exceeded standards was below 15% in 2012. Periods of poor water quality at this beach were associated with shoreline sources of *E. coli* including: high amounts of submerged algae, a significant fecal burden in foreshore sediments, and wildlife (primarily geese). Environmental variables such as turbidity, northern alongshore currents, southern winds, and 24-hr rainfall served as indicators of, or delivery mechanisms for, the transfer of bacteria to the nearshore water. This beach was rarely used by the community for swimming, most likely due to a combination of the current posting by the Racine Health Department which prohibits swimming and poor beach aesthetics. At present this is an underutilized municipal park. During the study, Samuel Myers appeared to be frequently used for launching small, motorized watercraft, as evidenced by the deep tire ruts in the beach area. As of 2012, Samuel Myers Beach was designated by the WI DNR as "Inaccessible" (WI DNR, 2013) due to its overall poor quality and the unlikelihood of improvement in the absence of full scale remediation. This site has great recreational potential and a full scale restoration, including the management/control of invasive *Phragmites,* is recommended.

Carre-Hogle Beach had poor water quality during the entirety of this study, with recreational standard exceedances rates above 15% during all years. Poor water quality at this beach was associated with shoreline sources of *E. coli*, including sediments and bird fecal matter. Environmental conditions that promoted elevated *E. coli* concentrations included rainfall, high waves, turbid water, and northern or eastern winds. Furthermore, high amounts of algae, particularly on the north end of the beach, detract from aesthetics. Beach usage was low, particularly for swimming, most likely due to a combination of limited access and poor aesthetics. Historically, and as of 2012, Carre-Hogle Beach was not designated by the WI DNR as an official public bathing beach. Without improvements in water quality and access, it is recommended that this beach remain off the list of official bathing beaches.

Although these beaches have water quality and accessibility issues, actions can be taken to maximize the utility of these public spaces, improve aesthetics and to improve surface water quality. Some remedial actions or best management practices are applicable to all locations. Wherever possible, vegetated swales or buffers should be placed at the interface of impervious surfaces and turf grass, and turf grass and sandy areas, to reduce direct surface runoff onto beaches. Beach grooming and the placement of additional litter bins would reduce waste and increase aesthetic appeal. Proper beach grooming techniques have been shown to decrease sediment *E. coli* concentrations (e.g. deep grooming) likely through the desiccation of bacteria (Kinzelman et al, 2003; Kinzelman et al, 2004b). However, poor access at Michigan Boulevard and Carre-Hogle prevents the use of beach groomers and the large size of Michigan Boulevard makes hand grooming impractical and economically unfeasible.

The current boat launch would provide a feasible point of ingress/egress for a small beach groomer at Sam Myers Beach and the routine use of this equipment at this site should be seriously explored.

Efforts should be made to reduce the wildlife population that loafs on or near all three beaches, but especially at Carre-Hogle and Samuel Myers Park. Although significant correlation between the presence of wildlife and surface water *E. coli* was only observed at one transect at Samuel Myers Beach in 2010, wildlife likely influences water quality due to the large amounts of *E. coli* in their feces, their close proximity to the water and variety of delivery mechanisms available (stormwater discharge, surface runoff and wave action). Loafing wildlife can be reduced through harassment techniques or habitat modifications. The use of Border Collies has been successful in reducing *E. coli* concentrations at other beaches (Converse et al, 2012). Habitat modifications have also been shown to be effective; this technique typically employ dunes and other vegetation to create areas that could potentially harbor predators. The threat of predation deters wildlife from loafing on the beach. Establishing dunes along the shoreline at Samuel Myers and in the back beach area at Carre-Hogle would discourage bird loafing and subsequent fecal matter deposition. These techniques have been used at airports to reduce avian plane collisions and at other Great Lake beaches to improve water quality (Washburn and Seamans, 2004; GLSLCI, 2009). Habitat modification techniques may result in a reduction of usable space. Depending upon the level of integration necessary with existing park master plans, and the amount of open areas required, naturalized engineering control measures are viable options at all sites.

Further investigation of the Wolff St., 15th St., and 16th-St.-South outfall basins for sanitary infiltration into the stormwater conveyance system is recommended. The identification of illicit or cross-connections will determine where infrastructure improvements can be made to decrease sewage contributions. To combat wet weather runoff in these three basins, implementation of bio-retention best management practices (BMP) within the surrounding neighborhoods could improve water quality. Residents could be encouraged to use rain barrels, rain gardens, and buffer strips. Rain gardens and riparian buffer strips can reduce the volume and/or delivery of storm water runoff from impervious and shallow-rooted terrestrial surfaces (e.g. turf grass), potentially improve water quality by increasing groundwater infiltration, stabilizing creek banks and reducing erosion (USEPA, 2012b). Rain barrels capture downspout runoff from roofs and can provide water for gardening and lawn care. Other stormwater infiltration BMP options that may be viable long-term include the use of permeable pavers.

Aesthetic issues such as algae and debris at Samuel Myers and Carre-Hogle beaches need to be addressed. Algae and debris will likely continue to accumulate on these beaches due to their location within a semi-enclosed basin with low current speeds. More frequent, and consistent, clean-up efforts are needed to keep these beach areas clean.

Specific recommendations to improve use and safeguard public health at each beach:

<u>Michigan Boulevard Beach</u>

- Establish a swimming area in the northern half of the beach, away from Wolff St. Outfall. A sign at the southern end of the swimming area should warn swimmers about the likelihood of higher exposure levels to potential pathogens in the Wolff St. Outfall discharge area.

- Expand monitoring within the Wolff St. Outfall basin to assess infrastructure integrity.
- Install a "Grab a Bag, Leave a Bag" dispenser on Michigan Boulevard prior to the middle beach path entrance for picking up pet waste.
- Investigate options to improve public accessibility.
- Continue weekly water quality monitoring in designated swimming area during summer months to protect public health.

Samuel Myers Beach

- Remove the invasive *Phragmites* species and establish dune grasses and native wetland plants in the beach area and native trees and shrubs in the park area, thereby improving coastal/migratory bird habitat, and reducing loafing wildlife.
- Re-grade the middle and eastern parts of the beach to establish steeper slopes, reduce pooling of water/surface runoff on the beach and increase infiltration capacity.
- Eliminate direct watercraft launches via automobiles to preserve the steeper re-graded shoreline and utilize this area as a non-motorized craft launch.
- Create the possibility for alternative active and passive uses of the beach area through a naturalized area that will maximize green space at Samuel Myers Park and Beach.
- Establish a designated offshore swimming area beyond the 0.3 and 0.6 m depths, away from shoreline pollutant sources. This may be used by Lake Michigan boaters and small watercraft users in the basin.
- Monitor the offshore swimming area once weekly during summer months to safeguard public health.

Carre-Hogle Beach

- Investigate options to improve public accessibility.
- Investigate best management practices to reduce avian sources (habitat modifications).
- Ban swimming from the shoreline until bird, algal, and debris issues are addressed.

Samuel Myers Park has been chosen as one of four sites in Southeastern Wisconsin for a conceptual beach redesign with the goal of promoting water quality, maximizing utility and improving access (Appendix-B, Page 73). Redesign plans should encourage passive uses, alternative recreational/educational opportunities, as well as enhanced/handicapped access. Due to the inconsistent water quality near the shoreline, swimming should be encouraged in deeper area where water quality was often better. Furthermore, to improve water quality, surface runoff should be infiltrated, where possible, and habitat should be modified to reduce loafing geese and gulls.

Michigan Boulevard, Samuel Myers, and Carre-Hogle beaches in the City of Racine are lakefront areas that have previously been underutilized by the public due to water quality, access, and aesthetic issues. This three-year study has researched these issues to determine the causes of recreational water quality exceedances and to evaluate future uses of these public areas based upon the water quality and beach use results. The specific recommendations listed in this report for all three beaches can optimize public use and economic investment, while protecting public health and improving the environmental conditions of Racine's coastal lakefront.

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APPENDIX A

GREAT LAKES BEACHES ROUTINE ON-SITE SANITARY SURVEY

Name of Beach:	Date and Time of Survey:
Beach ID:	Surveyor Name(s):
Sampling Station(s)/ID:	Surveyor Affiliation:
STORET Organizational ID:	

PART I – GENERAL BEACH CONDITIONS

Air Temperature: ________ °C or °F | Wind: Speed (mph) ____________
Direction (e.g., E or 90°) ________ (From which direction the wind is coming)

Rainfall: ☐ <24 hours ☐ <48 hours ☐ <72 ☐ >72 hours since last rain event and ______ inches or ______ cm rainfall measured

Rain Intensity: ☐ Misting ☐ Light Rain ☐ Steady Rain ☐ Heavy Rain ☐ Other

Weather Conditions:

Sky Condition	☐ Sunny	☐ Mostly Sunny	☐ Partly Sunny	☐ Mostly Cloudy	☐ Cloudy
Amount of cloud coverage	No Clouds	1/8 to 2/8	3/8 to 1/2	5/8 to 7/8	Total Coverage

Wave Intensity: ☐ Calm ☐ Normal ☐ Rough Wave Height: ________ ft ☐ Estimated or ☐ Actual

Longshore current speed and direction (cm/sec, S or 180°):

Comments/Observations

PART II – WATER QUALITY

Bacteria Samples Collected (list samples collected from beach water and potential pollution sources, if applicable—see Part IV)

Sample Point	Sample #	Parameter (*E. coli*, enterococci, etc.)	Comments:

Water Temperature: ________ °C or °F Change in Color? ☐ yes ☐ no If yes, describe ____________

Odor: ☐ None ☐ Septic ☐ Algae ☐ Sulfur ☐ Other ____________

Turbidity: ☐ Clear ☐ Slightly Turbid ☐ Turbid ☐ Opaque or NTU:

Comments/Observations

PART III – BATHER LOAD

Total number of people in the water: ____________ Total number of people out of the water: ____________

Total number of people at the beach: ____________

List of Activities Seen (optional):

Type of Activity				
Number of People				

Comments/Observations

1 5/20/08

PART IV – POTENTIAL POLLUTION SOURCES

Sources of Discharge:

Type	River(s)	Pond(s)	Wetland(s)	Outfall(s)	Other (specify):
Name(s) of Source(s)					
Amount (H, M, L)					
Flow Rate (M/sec)					
Volume					
Characteristics					

Did you collect any bacteria samples from the sources listed in the table above? ☐ yes ☐ no

If "Yes", did you list the samples in the table in Part II, Water Quality? ☐ yes ☐ no

Floatables present: ☐ yes ☐ no Please circle the following floatables if found:

Type	Street litter	Food-related litter	Medical items	Sewage-related	Building materials	Fishing related	Household waste	Other:
Example	Cigarette filters	Food packing, beverage containers	Syringes	Condoms, tampons	Pieces of wood, siding	Fishing line, nets, lures	Household trash, plastic bags	

Amount of Beach Debris/Litter on Beach: ☐ None ☐ Low (1-20%) ☐ Moderate (21-50%) ☐ High (>50%)

Type of Debris/Litter Found (please circle)

Type	Street litter	Food-related litter	Medical items	Sewage-related	Building materials	Fishing related	Household waste	Tar	Oil/ Grease	Other:
Example	Cigarette filters	Food packing, beverage containers	Syringes	Condoms, tampons	Pieces of wood, siding	Fishing line, nets, lures	Household trash, plastic bags	Tar balls	Oil slick	

Amount of Algae in Nearshore Water: ☐ None ☐ Low (1-20%) ☐ Moderate (21-50%) ☐ High (>50%)

Amount of Algae on Beach: ☐ None ☐ Low (1-20%) ☐ Moderate (21-50%) ☐ High (>50%)

Circle the types of algae found

Type	Periphyton	Globular	Free floating	Other
Description	Attached to rocks, stringy	Blobs of floating materials	No obvious mass of materials	Please describe

Circle the color of algae found

Light green	Bright green	Dark green	Yellow	Brown	Other

Presence of Wildlife and Domestic Animals

Type	Geese	Gulls	Dogs	Other (specify)
Number				

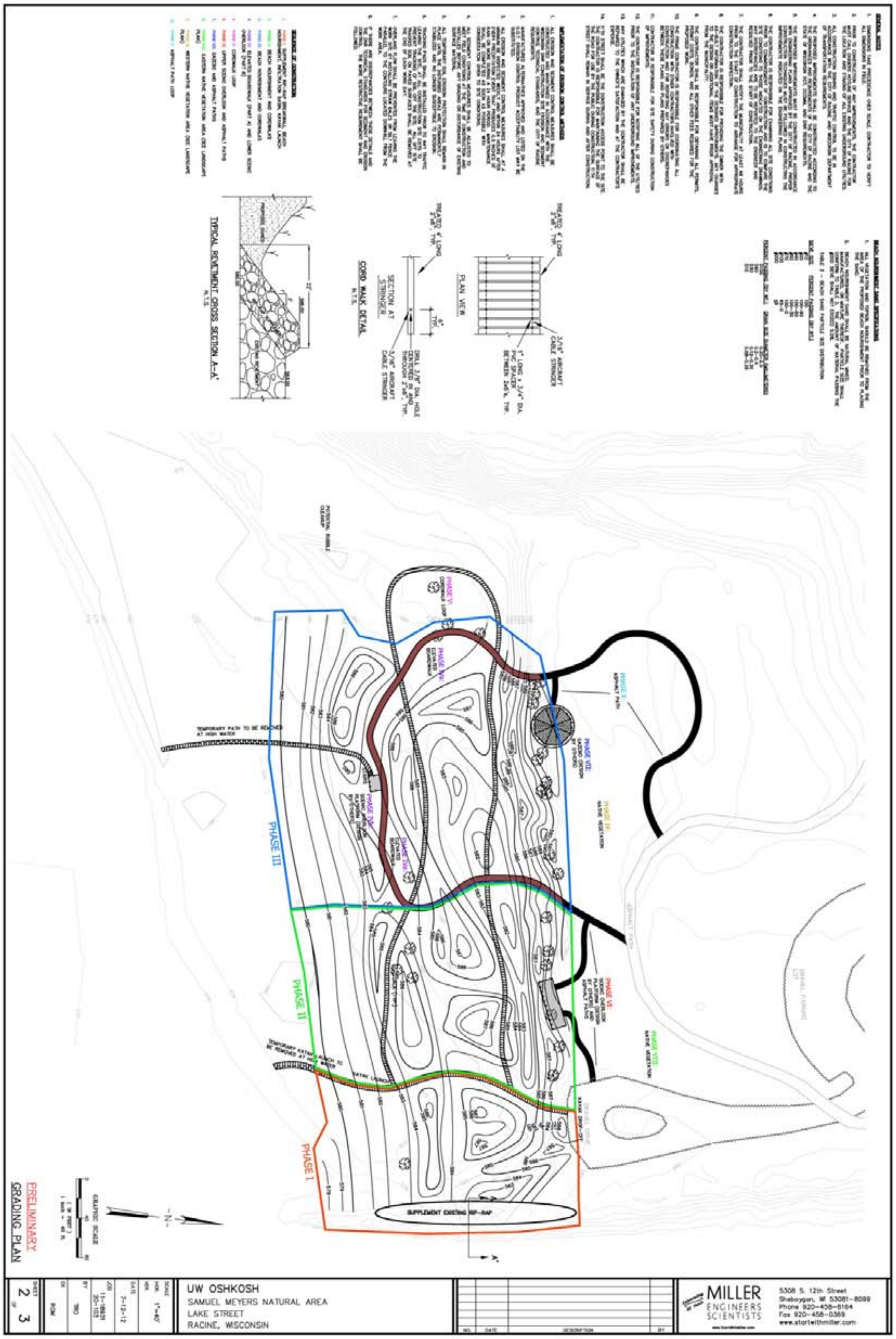
List the number of each species of bird found dead on the beach

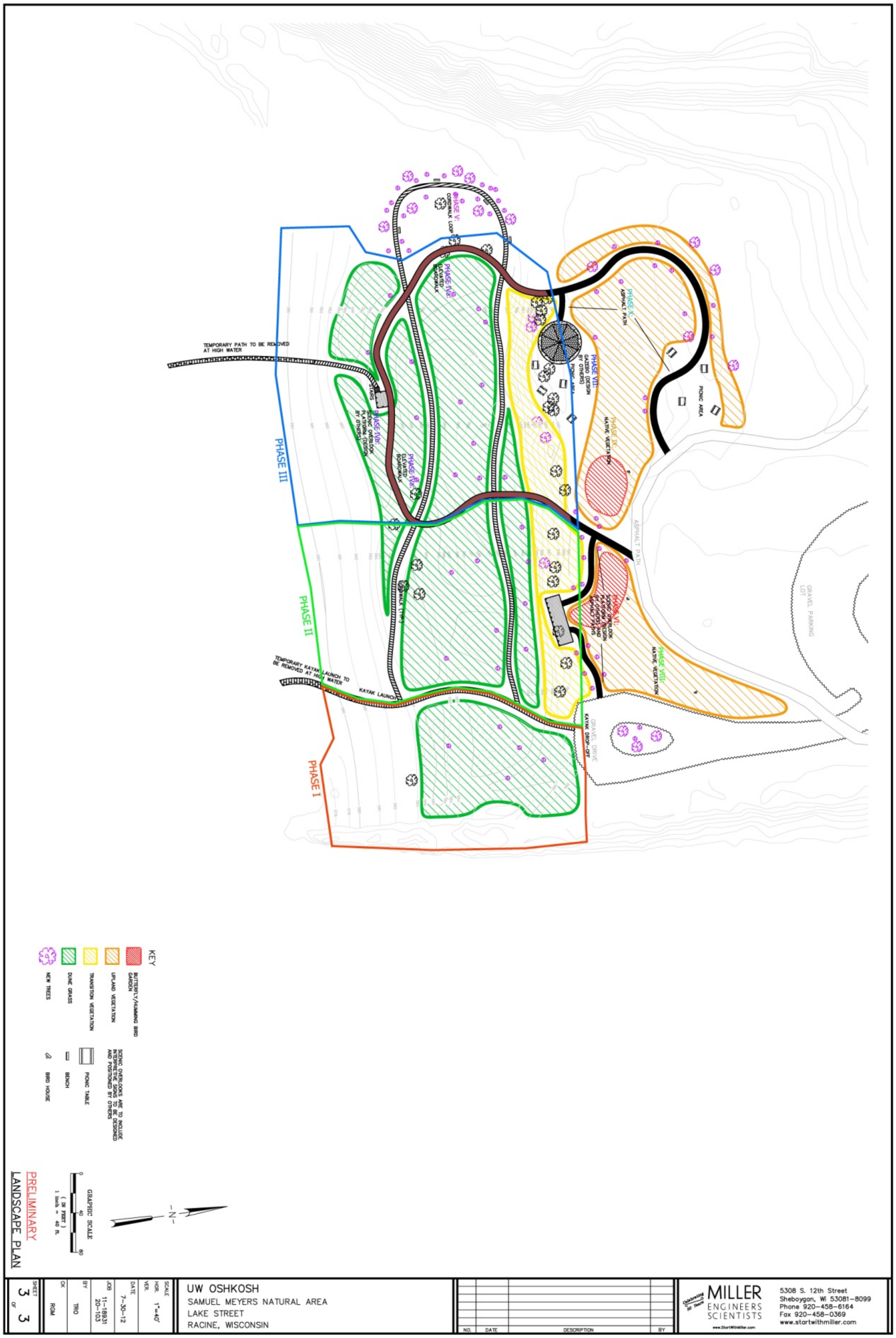
Type	Common loons	Herring gulls	Ring-billed gulls	Double crested cormorants	Long-tailed ducks	White-winged scoter	Horned grebes	Red-necked grebes	Other
Number found dead									

Number of dead fish found on the beach: ____________

Comments/Observations (continue on back if necessary):

APPENDIX B


UW OSHKOSH
SAMUEL MEYERS NATURAL AREA
LAKE STREET
RACINE, WISCONSIN
MILLER
ENGINEERS
SCIENTISTS
5308 S. 12th Street
Sheboygan, WI 53081-8099
Phone 920-458-6164
Fax 920-458-0369
www.startwithmiller.com
PRELIMINARY
GRADING PLAN
PHASE I
PHASE II
PHASE III
SUPPLEMENT EXISTING RIP-RAP
TYPICAL REVETMENT CROSS SECTION A-A'
CORD WALK DETAIL
PLAN VIEW
SECTION AT STRINGER


PHASE I
PHASE II
PHASE III
TEMPORARY PATH TO BE REMOVED AT HIGH WATER
TEMPORARY KAYAK LAUNCH TO BE REMOVED AT HIGH WATER
KAYAK LAUNCH
KAYAK DROP-OFF
GRAVEL DRIVE
ASPHALT PATH
GRAVEL PARKING LOT
PICNIC AREA
KEY
BUTTERFLY/HUMMING BIRD GARDEN
UPLAND VEGETATION
TRANSITION VEGETATION
DUNE GRASS
NEW TREES
SCENIC OVERLOOKS ARE TO INCLUDE INTERPRETIVE SIGNS TO BE DESIGNED AND POSITIONED BY OTHERS
PICNIC TABLE
BENCH
BIRD HOUSE
GRAPHIC SCALE
(IN FEET)
1 inch = 40 ft.
PRELIMINARY
LANDSCAPE PLAN
UW OSHKOSH
SAMUEL MEYERS NATURAL AREA
LAKE STREET
RACINE, WISCONSIN
SCALE HOR. 1"=40'
DATE 7-30-12
JOB 11-18931 20-103
BY TRO
CK RGM
SHEET 3 OF 3
NO. DATE DESCRIPTION BY
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