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Development of the Recreational Water Quality Indicator Report

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INTRODUCTION

The State of Delaware Surface Water Quality Standards for waters with primary contact recreation among their designated uses require that waters meet the single sample value of 104 *Enterococcus* colonies/100 mL of marine water (DNREC 2004). The long term Primary Contact Recreation is defined as "any water-based form of recreation, the practice of which has a high probability for total body immersion or ingestion of water (examples include but are not limited to swimming and water skiing)". *Enterococcus* bacteria are commonly found in the guts of warm blooded animals and their presence is used to indicate the occurrence of potentially harmful bacteria and pathogens in water. When water is fouled by waste from warm blooded animals, the risk to swimmers of ingesting disease causing organisms and getting sick, particularly with gastroenteritis, becomes elevated. The above standard is based on epidemiological studies used by the EPA to develop national water quality criteria for bacteria (USEPA 1986). The standards were enacted in part to provide a scientific assessment of public health risk. The risk estimated is that approximately 19 out of 1,000 swimmers (or just under 2%) will become ill as a result of swimming in waters with counts above the standard. Additional epidemiological studies have confirmed that risk of illness is elevated by 1.34 times for waters above the standard especially for those who swim for longer periods of time and for those that submerge their heads (Wade et al. 2003, Wade et al. 2006).

The Inland Bays are designated by the State as waters of Exceptional Recreational and Ecological Significance and provide opportunities unrivaled in the State for primary contact recreation such as swimming, kiteboarding, wading, and wind surfing. As the population and tourism industry surrounding the Bays grows, so does the likelihood of increased water use. Crowded beaches and increased interest in ecotourism appear to be turning (or returning) residents and tourists to the Bays for activities like swimming and kayaking. By ensuring that the risk of bacteriological illness to swimmers is low, the enjoyment of the Bays may be promoted with confidence in turn benefitting overall bay health and the local economy. To meet this goal, the State of Delaware passed a Total Maximum Daily Load regulation for bacteria that mandates a reduction of bacteria loads to the Inland Bays by 23% from the 2000-2005 baseline level (Delaware State Code 2006). The recreational water quality indicator was developed to communicate to the public and decision makers the levels of the indicator organism *Enterococcus* in Bay waters, and attempt to determine any changes in levels over time. Recommendations for research and choices that residents can make to reduce bacteria loads are provided.

METHODS

Data Collection & Analysis

The University of Delaware Citizen Monitoring Program (UDCMP) and the Delaware Division of Natural Resources and Environmental Control (DNREC) test waters for levels of *Enterococci*. Volunteer monitors from the UDCMP collect data from over 30 sites at beaches, docks, and bridges twice a month during May through September. DNREC also monitors frequently two bay beaches, certain boat ramps and marinas, and ocean beaches.

The location of test sites is based primarily on the availability of volunteers, and thus does not qualify as a random sampling design allowing inference to the entire estuarine system. However, care is taken by the UDCMP to secure volunteers from a variety of water types resulting in a fair distribution of sites among types, and some level of generalization about differences between water types is possible.

Samples are processed at the University of Delaware College of Earth, Ocean, and Environment using Enterolert™ test kits and the Quanti-Tray®/2000 enumeration method developed by IDEXX Laboratories Inc. Levels of bacteria are determined by culturing water samples in the lab for 24 hours and detecting the number of colonies using ultraviolet light. Both UDCMP and DNREC conduct their studies following EPA approved Quality Assurance Project Plans.

Adequacy of Indicator Organism

The adequacy of *Enterococcus* as an indicator organism has received attention. *Enterococcus* has been found to correlate only weakly or not at all with the presence of certain disease causing organisms. However, *Enterococcus* remains widely regarded as a satisfactory indicator of human health risk for marine waters considering the current capacity of most monitoring programs. Currently, the EPA is developing new recreational ambient water quality criteria that they intend to publish in 2012 (USEPA 2007). The research path to support these new criteria is designed to examine the affects of different sources of bacteria on health risks.

Indicator Development

The author coordinated input for the development of the indicator through a workshop and individual consultations with UDCMP, DNREC, and University of Delaware College of Earth, Ocean, and Environment (UDCEOE) scientists. Effort was made to include water user groups in the workshop but they were unable to attend.

Waters are assessed for bacteriological quality by DNREC using both the single sample standard of 104 and the long term geometric mean standard of 35 *Enterococcus* colonies/100ml. The single sample standard is higher in order to accommodate the inherent high level of variation in *Enterococcus* concentrations and thus to avoid requiring unnecessary advisories or closures of swimming areas. Calculating the geometric mean standard controls for this level of variation.

The decision to express the recreational water quality as the level of exceedance of the single-sample standard rather than using geometric means was made for a number of reasons. First, most sites did not have the 5 samples over a 30 day period needed to meet EPA guidance on reporting. Reporting frequency of exceedance also provided what was felt to be an increased resolution of risk for someone making a decision on whether to swim. It also helped to communicate that most waters were occasionally over instantaneous standards, perhaps naturally so. Furthermore, a review of epidemiological studies suggested that relative risk to swimmers did not continue to increase above the 104 cfu/100 mL standard (Wade et al. 2003). The geometric mean long term standard of 35 cfu/100 mL of marine water was expressed on a graph of two more frequently monitored DNREC sites.

The EPA criteria, upon which State standards are based, are expressed with multiple single sample standards that are recommended for application to different swimming areas based on their intensity of use (USEPA 1986). "Designated swimming areas" are assigned the single sample criteria of 104 cfu/100mL while "moderately used swimming areas" are assigned 158 cfu/100mL. The single sample criteria levels are based on the upper confidence level around the geometric mean concentration of 35 cfu/100mL. These levels were arbitrarily assigned by the EPA. The lower standards have lower upper confidence bounds to reduce the risk that the single sample value reflects a higher illness rate than allowed by the geometric mean standard.

Much of the Inland Bays may be considered infrequently used for primary contact recreation, suggesting that perhaps the less stringent single sample EPA standards should be used for the indicator. In fact, DNREC has assigned the single sample standard of 158 cfu/100mL to certain sites. However, little guidance was available on what differentiates heavily used from moderately used and use in the Inland Bays was considered to be highly variable. It was decided that the most cautious single sample swimming standard would be employed to maintain simplicity and clarity of communication. It was decided that this level of caution would be expressed in the indicator publication.

The period June through September was selected for analysis because it was felt that the most people would be swimming during this time. Sites that had at least one year of data with at least five individual samples per year from 2004 to 2009 were included in analysis. Sites were categorized as Bays (n = 13), Residential Canals or Marinas (n=11), and Tributaries (n = 9) to help direct research and management attention. The CMP site categorization was recategorized using the scheme in Table 1. CMP Site names were altered slightly to for presentation to a public audience. The Town of South Bethany had multiple sites and these were averaged when calculating the mean frequency of exceedance resulting in n = 4 for residential canals and marinas.

Table 1. Recategorization scheme for Citizen Monitoring Program Sites

Old Category	New Category
Lower Tributary	Bay
Inland Bay	Bay
Lower Dead End Canal	Residential Canal or Marina
Marina	Residential Canal or Marina
Upper Dead End Canal	Residential Canal or Marina
Open Canal	Tributary
Upper Tributary	Tributary

Results

Results are presented mapped as Figure 1 and in Table 2. On average, Open Bay sites exceeded standards 13% of the time, residential canals and marinas exceeded standards 19% of the time, and tributaries exceeded standards 43% of the time. Certain sites of each type had relatively higher levels of *Enterococcus* suggesting site-specific sources. Upper tributaries had the highest levels of *Enterococcus*. This is likely due to their proximity to watershed bacterial sources and lower salinities which are more hospitable for their survival (Mallin et al. 1999, Mallin et al. 2000). The open bay site Pot Nets Seaside Pier never exceeded the standard over five years of sampling. Dirikson Creek and Upper Guinea Creek had the highest levels of exceedence at 80 and 87%. Table 3 shows the geometric average concentrations by site.

A visual analysis of the grand geometric average concentration over the sample years did not suggest any significant trend for the site types (Figure 3). The year 2009 had relatively high concentrations for all site types and was the highest year for tributaries and canals and marinas. An examination of total rainfall amounts for June through August for the sample years using interpolated Standard Precipitation Index (National Drought Mitigation Center 2010) values did not indicate any above average rainfall for 2009 that could have contributed to higher concentrations.

The longer sampling period for two DNREC monitored sites permitted an initial analysis of trends for Tower Road Bayside and Holts Landing (Figure 2). Both sites showed weak and insignificant correlations between geometric mean *Enterococcus* concentrations and year. More data is needed to determine any trends or lack thereof for these sites with acceptable confidence.

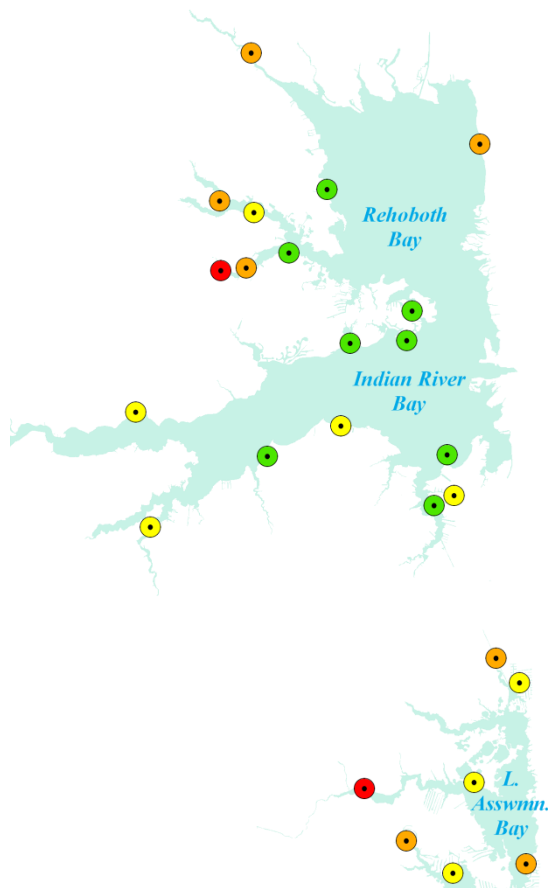

Figure 1. Map illustrating the percentage of samples that exceeded the single sample primary recreational water contact standard of 104 Enterococcus cfu/100 mL in the Inland Bays from 2004 to 2009. Legend: Green = 0 – 10%, Yellow = 10-25%, Orange = 25-75%, Red = 75-100%. Map does not show one site, the Lewes and Rehoboth Canal indicated as green.

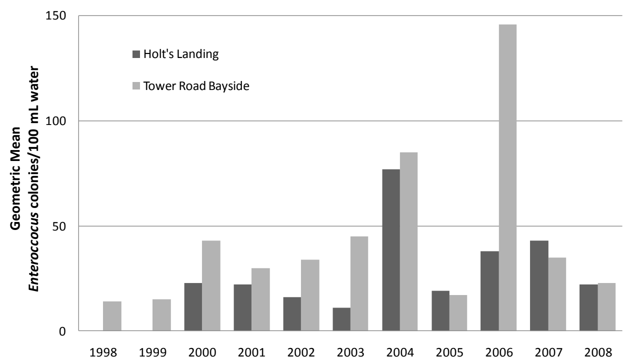

Figure 2. Geometric mean *Enterococcus* concentrations for two Open Bay sites from 1998 to 2009. Holt's Landing had no data for 1998 and 1999. Long term primary contact standard for marine waters is 35 cfu/100 mL.

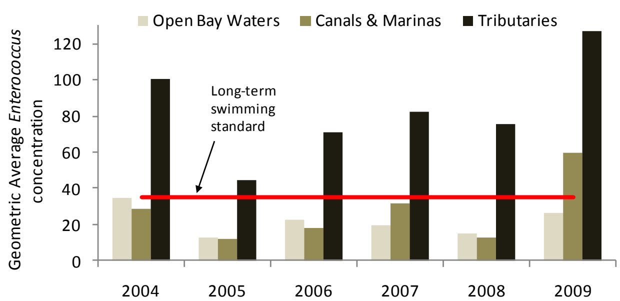

Figure 3. Grand geometric average *Enterococcus* concentrations by site type from 2004 to 2009. Long term primary contact standard for marine waters is 35 cfu/100 mL.

Table 2. Percentage of samples that exceeded the primary recreational water contact standard of 104 *Enterococcus* cells/100 mL for 31 sites in the Delaware Inland Bays from 2004 to 2009.

Waterbody Type / Site Name	2004	2005	2006	2007	2008	2009	2004 -2009
Open Bay Waters							
Pots Nets Seaside Pier	0	0	0	0	0	0	**0**
Massey's Landing	20	0	0	0	0	0	**3**
Boathouse Pond Entrance		0	0	14	0	0	**3**
Warwick Cove	43	0	0	0	0	29	**12**
Mulberry Landing	29	14	0	14	0	14	**12**
West Bay Park	20	13	14	0	13	0	**10**
Keenwick at Roy Creek	29	13	0	29	0	0	**12**
James Farm Pasture Point	0	0	33			0	**8**
Fenwick Island Bayside		13	29	29		83	**38**
Holts Landing	60	0	21	15	19	10	**21**
Tower Road Bayside	33	7	64	14	19	35	**29**
Average	**26**	**5**	**15**	**12**	**6**	**16**	**13**
Tributaries							
Vines Creek					0	29	**15**
Mouth of Guinea Creek	11	0	0	14	0	0	**4**
Lewes - Rehoboth Canal	0	0	0	13	13	0	**4**
Herring Creek	29	0	0	0		67	**19**
Mid Guinea Creek			40				**40**
Love Creek	43	38	71	57	57	71	**56**
Assawoman Canal Bridge				67	50	100	**72**
Burton Prong	57						**57**
Dirickson Creek	57	50	100	100	75	100	**80**
Upper Guinea Creek	100	75	100	100	75	71	**87**
Average	**42**	**27**	**44**	**50**	**39**	**55**	**43**
Canals & Marinas							
Bethany Marina	14	0	0				**5**
Bay Colony	14	0	14	14	0	17	**10**
Holly Terrace Acres - End	0	13	29	29	0	43	**19**
Keenwick Sound - Entrance	43						**43**
South Bethany Averge			0	0	7	57	**16**
Anchorage Canal Rt. 1					0	100	**50**
Anchorage Canal Elbow				0	0		**0**
Petherton Canal Rt. 1					38	57	**47**
Layton Canal			0	0	0	14	**4**
Carlisle Canal					0		**0**
Russell Canal					13		**13**
Jefferson Canal					0		**0**
Average	**18**	**4**	**11**	**14**	**2**	**39**	**19**

Table 3. Geometric average *Enterococcus* cells/100 mL for 31 sites in the Delaware Inland Bays from 2004 to 2009. Geometric averages for years 2004-2009 by site and for sites by year to minimize influence of a few sites with high values. Arithmetic averages (grand average) are reported in italics for all geometric averages of all sites from 2004 – 2009.

Waterbody Type / Site Name	2004	2005	2006	2007	2008	2009	2004 -2009
Open Bay Waters							
Pots Nets Seaside Pier	13	9	11	15	7	7	**10**
Massey's Landing	22	7	7	7	9	9	**9**
Boathouse Pond Entrance		9	16	14	28	18	**16**
Warwick Cove	68	10	12	9	21	77	**22**
Mulberry Landing	54	13	11	21	10	21	**18**
West Bay Park	19	15	16	9	22	12	**15**
Keenwick at Roy Creek	73	22	18	37	12	16	**24**
James Farm Pasture Point	7	5	30			9	**10**
Fenwick Island Bayside		27	105	71		955	**117**
Holts Landing	77	19	38	43	22	25	**33**
Tower Road Bayside	85	17	146	35	23	64	**47**
Geometric Avg.	**34**	**12**	**23**	**20**	**15**	**26**	***29***
Tributaries							
Vines Creek					26	54	**37**
Mouth of Guinea Creek	14	11	14	15	10	14	**13**
Lewes - Rehoboth Canal	22	17	20	19	23	15	**19**
Herring Creek	36	13	8	18		107	**24**
Mid Guinea Creek			73				**73**
Love Creek	87	72	174	115	169	195	**127**
Assawoman Canal Bridge				169	219	941	**326**
Burton Prong	105						**105**
Dirickson Creek	691	171	542	452	242	845	**426**
Upper Guinea Creek	1440	272	557	574	249	352	**472**
Geometric Avg.	**100**	**44**	**71**	**82**	**75**	**127**	***162***
Canals & Marinas							
Bethany Marina	9	6	6				**7**
Bay Colony	19	15	23	27	5	14	**15**
Holly Terrace Acres - End	14	21	32	66	16	107	**32**
Keenwick Sound - Entrance	283						**283**
South Bethany Averge			25	18	26	149	**36**
Anchorage Canal Rt. 1					18	280	**71**
Anchorage Canal Elbow				14	14		**14**
Petherton Canal Rt. 1					94	149	**118**
Layton Canal			25	22	13	18	**19**
Carlisle Canal					13		**13**
Russell Canal					17		**17**
Jefferson Canal					14		**14**
Geometric Avg.	**29**	**12**	**18**	**32**	**13**	**60**	***75***

DISCUSSION

The data show that Open Bay waters have low levels of bacteria that rarely exceed swimming standards. Residential canals and marinas also have low levels but exceed standards more frequently. Tributaries regularly exceed standards and often have high levels of bacterial indicator organisms. Certain sites have consistently higher levels of bacteria than others, suggesting local pollution sources.

Sources of Bacteria

Likely sources of bacteria in the Inland Bays include malfunctioning septic systems, pet waste, waterbirds, poultry manure, and even bottom sediments. Over 18,000 septic systems were permitted in the Inland Bays watershed as of May 2008 (DNREC 2008). Approximately 50% of these may not meet current regulations for onsite disposal, and many are assumed to be malfunctioning. Septic systems can contribute to elevated bacteria levels in coastal waters (Scandura and Sobsey 1997, Cahoon et al. 2006, Line et al. 2008, Meeroff et al. 2008). Contributions are likely higher when seasonal human populations are present, when systems are improperly maintained, when groundwater tables are higher, and when soils are sandy. All of these circumstances may apply to areas around the Inland Bays. Since 1990, over 13,000 systems were converted to central sewer systems and more are scheduled to be converted and upgraded as detailed in the Inland Bays Pollution Control Strategy (DNREC 2008).

Waterbirds

During the spring and summer, high numbers of waterbirds utilize the open waters, marshes, and beaches of the Inland Bays. Gulls nest on marsh islands along back barrier islands and often congregate along estuarine beaches used for recreation such as at Tower Road on Rehoboth Bay. Their presence is speculated as contributing to relatively high levels of bacteria at this site. Studies from other coastal areas indicated high contributions from waterbirds that have been shown to follow seasonal patterns (Weiskel et al. 1996, McDonald et al. 2006). A bacteria source tracking study on a Delaware Bay beach found that waterbirds were contributing to elevated bacteria levels (Mike Bott, DNREC, personal communication July 2009). The importance of this source is likely a function of the density of birds and the flushing of a particular area of water. Because of their congregational nature, waterbirds may serve to be an important localized contribution of bacteria relative to more dispersed surface water inputs from the watershed. They have the potential to confound sampling schemes by congregating around beaches, docks or piers, and marinas, where many samples are collected.

Poultry Manure
It is estimated that nearly 250,000 tons of poultry litter were applied in Sussex County in 2005[1], much of that occurring within the Inland Bays watershed (Hansen et al. 2005, Sims et al. 2008). Animal manure is undoubtedly a source of bacteria (Lu et al. 2003, Gerba and James E. Smith 2005), but the extent to which bacteria survives in transport from fields to the Inland Bays is unknown. Transport of bacteria from land applied poultry manure has been demonstrated (Soupir et al. 2006, Mishra et al. 2008). An experimental study found edge-of-field *Enteroccocus* concentrations averaging 280,000 colony forming units/100 ml of water following a simulated rain event. The authors concluded poultry litter application on cropland based on agronomic requirements can be a significant source of bacteria loading if rainfall occurs shortly after manure application. In areas where ditch density is high, such as the southern part of the Inland Bays watershed, transport of bacteria from fields after rain events will be enhanced. Less is known about the fate of microbes percolating into ground water from manure though it is likely dependant on soil type; with sandier soils, soils with lower organic matter content, and macropores increasing transport. Little is known about survival of bacteria and pathogens through the soil column (Mawdsley et al. 1995).

Wild and domestic bird waste as well as human waste are known to be sources of *Enterococcus faecalis*, a bacterium that can sometimes cause infections in humans. Kuntz et al. (2004) found high prevalence of *Enterococcus faecalis* in broiler feces but almost no E. *faecalis* was found in broiler litter from five Georgia counties. This suggests that broiler litter is an unlikely source of this particular species of *Enterococcus* to the environment. Hartel (2000) also found very low levels of fecal coliforms in poultry litter, particularly in that which had been stacked. Processes such as drying and heating within the litter piles could deactivate the bacteria. Poultry litter contains other potentially harmful bacteria and pathogens (Lu et al. 2003) but their survival in transport to surface water and risk to swimmers appears unknown.

Impervious Surfaces
Impervious surfaces can be strongly correlated with increased waterborne bacteria levels because they speed delivery of bacteria to waters and prevent its filtration through soils (Weiskel et al. 1996, Mallin et al. 2000, Mallin et al. 2001). Other studies have not demonstrated significant correlations between watershed impervious surface coverage and bacteria levels (Cahoon et al. 2006, Line et al. 2008). These differences in association may be explained by the amount and distribution of impervious coverage in a watershed, and the relative contribution of other sources of bacteria which could mask contributions from impervious surfaces.

Wastewater Treatment Plants
Wastewater treatment plants are likely not a major source in the Inland Bays because their discharges are disinfected to meet the geometric mean concentration limit of 10 colony forming units/100 mL of water. The two major remaining point sources are required to be expeditiously removal from the Inland Bays.

Waterusers
Other swimmers and boat users are potential local sources of bacteria. Young children in particular may defecate in the water, and special diapers can be used to prevent this. Boaters who improperly dispose of waste into the Bays are another possible source. Educational efforts may reduce this potential source.

Environmental Factors
Environmental factors also affect bacteria levels. Tides and winds affect suspension of bacterial cells attached to sediments. An inverse relationship has been demonstrated between tide stage and bacterial levels in tidal tributaries (Mallin et al. 1999), but this may not hold up in densely urbanized areas with intense local sources (Scarlatos 2001). Release from muddy sediments has been documented (Weiskel et al. 1996). Where underwater grasses like eelgrass are not present, this may be expected to increase. Estuarine sediments have been shown to provide a favorable environment for *Enterococcus faecalis* (Hueiwang et al. 2005), and are a likely source to the water column. Precipitation is commonly cited as a factor increasing bacterial concentrations, however, this is likely site-specific and influenced by interactions with local sources such as near-surface septic leachate and animal waste deposited just above normal the high tide line. Other smaller scale environmental factors that may affect *Enterococcus* concentrations include nutrient levels, temperature, sediment type, light levels, and the life cycle of individual bacteria.

Risk Associated with Human vs. Non-Human Sources of Bacteria

Conventional wisdom dictates that waters contaminated by fecal material from human sources put swimmers at greater risk than waters contaminated by non-human sources. However, waste from wild and domestic birds and humans share pathogenic bacteria and viruses such as *Enterococcus faecalis* and *Salmonella* (Lu et al. 2003,

[1] Derived from estimates within Sims et al. 2008 and Hansen et al. 2005.

Ishii and Sadowsky 2008). In a review of health and water quality implications of E. coli, Ishii and Sadowsky (2008) declared that a main assumption of studies that inform water use advisories is that fecal contamination originating from human sources is indicative of greater health risks than is contamination originating from animals and the environment. However, this hypothesis, they state, has not been adequately tested. A USEPA Experts Scientific Workshop (2007) also identified the need for research on differences in risk associated with human and non-human sources.

Recommendations

1. Caution should always be used when making decisions about swimming in the Inland Bays, particularly when the likelihood of ingesting water is high.
2. The tributaries of the Inland Bays regularly exceed standards, particulary in their upper reaches. An enhanced level of caution should be used when making decisions about swimming in tributaries, particulary when tides are low and after rain events.
3. Monitoring of *Enterococcus* should continue with a focus on the tributaries. Consideration should be given to sampling tributaries during outgoing near-low tides to capture periods of highest risk.
4. Microbial source tracking to quantify levels of bacteria or viruses from multiple sources should be considered a high research priority in the tributaries of the Inland Bays.
5. Effort should continue to educate residents and tourists concerning individual behaviors that can reduce bacterial loading such as a) cleaning up pet waste, b) refraining from feeding waterbirds, c) properly maintaining septic systems, and d) supporting legislation and voluntary efforts (such as the Inland Bays Pollution Control Strategy) that limit impervious surfaces and promote the implementation of water quality buffers.

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LINKS TO FURTHER INFORMATION

DNREC's Recreational Water Monitoring Program
http://apps.dnrec.state.de.us/RecWater/

UD Citizen's Monitoring Program
http://citizen-monitoring.udel.edu/

For Summary Information on bacteriological water quality of Delaware's Ocean beaches and others across the nation, the National Resources Defense Council publishes an annual report.
http://www.nrdc.org/water/oceans/ttw/titinx.asp

State Water Quality Standards
http://www.dnrec.state.de.us/DNREC2000/Divisions/Water/WaterQuality/WQStandard.pdf

USEPA Ambient Water Quality Criteria for Bacteria - 1986
http://www.epa.gov/waterscience/beaches/files/1986crit.pdf

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