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Potential Human Health Effects Associated with Pathogens in Urban Wet Weather Flows

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Abstract

High concentrations of pathogens and indicator organisms found in urban receiving waters are a common cause of concern. Though some question the actual public health risk associated with exposure to these organisms, large amounts of resources are spent attempting to identify and correct their source. This paper contains a summary of recent work describing the potential human health effects associated with pathogens and common indicator organisms found in urban stormwater and the receiving waters they feed, as well as a brief discussion of the development of water quality standards for pathogens. This information will enable the reader to more effectively consider the level of risk that may actually be present locally. Future phases of the U.S. Environmental Protection Agency research that supported these initial investigations will develop and test methods communities may use to assess local risk to humans and the environment associated with exposure to urban stormwater and receiving waters (Lalor and Pitt 1998 and Easton 2000).

Key Words

Bacteria, pathogens, epidemiology, urban stormwater.

Introduction

Urban receiving waters have many beneficial uses, including: stormwater conveyance (flood prevention), biological uses (warm water fishery, aquatic life uses, biological integrity, etc.), non-contact recreation (linear parks, aesthetics, boating, etc.), contact recreation (swimming and fishing), and water supply. Pollutants entering these receiving waters by way of urban stormwater conveyance systems, or wet weather sewage overflows, may adversely impact many of the desired uses. Urban runoff or wet weather flows include not only precipitation and washoff from lawns and landscaped areas, buildings, roadways and parking lots, but often separate sewer overflows or discharges resulting from inflow and infiltration (Lalor and Pitt 1998).

Water Environment & Technology (1996a) reported that the latest National Water Quality Inventory released by the U.S. Environmental Protection Agency (U.S. EPA) showed only a slight improvement in the attainment of beneficial uses in U.S. receiving waters. Bacteria and nutrients were cited as leading problems, and urban runoff was cited as a leading source of these problems. Bacteria, in particular, are associated with limiting human recreational and drinking water use. Recent epidemiological studies have shown significant health effects associated with pathogens in stormwater contaminated marine swimming areas (Haile, *et al*. 1999). Pathogens found in stormwater from separate storm drainage systems are a significant public health concern, as are pathogenic protozoa associated with likely sewage-contaminated stormwater (Ellis 1985; Oliveiri 1989; Bryan 1999; LeChevallier, et al. 1991, 1995, and 1995).

Over the years, numerous studies have investigated microorganisms in stormwater (such as Ellis and Wang 1995, Field, et al. 1976, Geldreich 1965, Geldreich, et al. 1968, and Olivieri, et al. 1977). Probably the most comprehensive early characterization study was the Nationwide Urban Runoff Program (NURP) (EPA 1983) conducted at many locations throughout the United States. Almost 220 NURP monitoring stations had reported about one-half million analyses, including more than 1,600 fecal coliform urban runoff observations from 70 test catchments over a one to three year period. These test catchments ranged in size from less than one acre to more than 10,000 acres. Most of these catchments were of residential land use, but almost all land uses in urban areas were included (commercial, industrial, open space, etc.). The fecal coliform observations had an overall range of ten to 270,000 organisms/100 mL. The average of the site means was about 20,000 fecal coliform organisms/100 mL. The overall range of observations for fecal coliform indicator bacteria in urban waters is therefore very large. However, the typical values observed, and especially the occasional extremely high values, are of great concern when they are compared to existing water quality standards and criteria for recreational use water.

There are several exposure pathways through which contaminated stormwater can cause potential human health problems. These include exposure to stormwater contaminants at swimming and recreational areas affected by stormwater discharges, drinking water supplies contaminated by stormwater discharges, and the consumption of fish and shellfish that have been contaminated by stormwater pollutants.

Isolating the risks associated with stormwater alone can be a difficult task. Watersheds are often very large and the receiving waters are affected by many sewage and industrial point discharges, and upstream agricultural nonpoint discharges, in addition to the local stormwater discharges. Even in waters receiving only stormwater discharges, inappropriate sanitary and other wastewaters may be discharging through the storm drainage system (Pitt, et al. 1993). These multiple sources make it especially difficult to identify specific cause and effect relationships associated with stormwater discharges alone. Therefore, much of the human risk assessment associated with stormwater exposure has been determined using theoretical evaluations, which rely on stormwater characteristics and laboratory studies in lieu of actual population studies. However, some site investigations, especially related to swimming beach problems associated with nearby stormwater discharges (Haile 1996 and Haile 1999), have been conducted, and recently, in-stream studies of the fate and transport of pathogens and indicator organisms have been carried out (Easton 2000).

Traditionally, indicator bacteria have been used to evaluate potential health risks of contaminated water (Geldreich and Kenner 1969; Geldreich 1976). These indicator bacteria have been used as surrogates for the actual pathogens of concern due to the lack of technology, lack of expertise, and high cost of detecting and/or enumerating the pathogens. Recently, indicator bacteria data used to evaluate health risk due to pathogens have been shown to be inadequate (Kay and Fricker 1997). In particular, the low infectious dose and high persistence of viral and protozoan pathogens confounds the use of indicator bacteria as predictors of health risk (NRC 1994). The relationship is further complicated by the fact that indicator bacteria and pathogens do not share identical sources.

Unfortunately, most microbiological water quality standards are based on indicator bacteria, not pathogens. Recent improvements in technology have enabled detection and enumeration of the pathogens actually generating the health risk. It would seem prudent, therefore, to begin assessing the health risks using these new methods, and subsequently to base the standards, at least partly, on the pathogen measurements (as opposed to indicator) associated assessments of risk.

Sewage Contamination as a Source of Pathogens in Urban Wet Weather Flows

Urban stormwater runoff includes waters that find their way into storm drainage systems from many sources in addition to precipitation. In many cases, these non-stormwater sources may account for the majority of the annual discharges for some pollutants of concern from the storm drainage system. This was one of the issues which emerged from the individual projects of the U.S. EPA’s Nationwide Urban Runoff Program (NURP) (EPA 1983). Concerns regarding illicit connections to storm drainage systems were summarized as follows in the Final Report of the NURP executive summary:

> A number of the NURP projects identified what appeared to be illicit connections of sanitary discharges to stormwater sewer systems, resulting in high bacterial counts and dangers to public health. The costs and complications of locating and eliminating such connections may pose a substantial problem in urban areas, but the opportunities for dramatic improvement in the quality of urban stormwater discharges certainly exist where this can be accomplished. Although not emphasized in the NURP effort, other than to assure that the selected monitoring sites were free from sanitary sewage contamination, this Best Management Practice (BMP) is clearly a desirable one to pursue.

The illicit discharges noted during NURP were especially surprising because the monitored watersheds were carefully selected to minimize factors other than stormwater. Presumably, illicit discharge problems in typical watersheds would be much worse. Illicit entries into urban storm sewerage were identified by flow from storm sewer outfalls following substantial dry periods. Such flow could be the result of direct “illicit connections” as mentioned in the NURP final report, or could result from indirect connections (such as contributions from leaky sewerage infiltrating to the separate storm drainage). Many of these inappropriate dry-weather flows are continuous and would therefore also occur during rain-induced runoff periods (Pitt, et al. 1993).

The EPA funded an early research project to develop tools to assess and identify inappropriate discharges into storm drainage (Pitt, et al. 1993; Lalor 1993). This project developed simple field screening methods, heavily based on successful experience elsewhere, that were found to be highly reliable in residential and commercial test areas. In recent years, numerous screening tools have also been proposed to identify sources of contaminants found in urban drainage waters. Pitt, et al. (2000) reviewed many of these tools for application to inappropriate dry weather discharges into separate storm drainage.

In many cases, sanitary sewage is an important component of dry weather discharges from storm drainage systems. The effects these discharges have on the receiving waters are highly dependent on many site specific factors, including frequency and quantity of sewage discharges and the creek flows. In many urban areas, the receiving waters are small creeks in completely developed watersheds. These creeks are most at risk from inappropriate discharges, as base flows may be predominately dry weather flows from the drainage systems.

The presence of pathogens from raw, or poorly treated sewage, in urban streams, presents a potentially serious public health threat. Even if the receiving waters are not designated for water contact recreation, children are often seen playing in small city streams. From a human health perspective, it may not require much raw or poorly treated sewage to cause a receiving water problem due to pathogens.

Inadequacy of Indicator Bacteria

Numerous studies have been conducted that show increased health risk from exposure to recreational waters containing high levels of indicator bacteria, including an excellent recent review by Prüss (1998). The intention of this article is not to review these indicator studies, but to advocate the collection of pathogen data in future studies and the use of this data to conduct better risk assessments.

The traditional studies have used indicator bacteria such as coliforms, *E. coli*, and Enterococci. Coliforms are found in human and animal feces; however, not all of them are of human fecal origin (Bitton 1994). Animal sources can contribute to high levels of indicator bacteria in receiving waters, but these waters may or may not contain pathogens that pose a significant health risk to humans. *E. coli* has been found in pristine sites in a tropical rain forest, suggesting that they too may not be a reliable indicator of human fecal contamination (Bermudez and Hazen 1988). Members of the genus Streptococcus such as Enterococci (fecal streptococci) are present in the intestinal tract; however, one species, Enterococcus faecalis, has been found on some plants in addition to other habitats (Madigan, et al. 1997).

Additional evidence for the inadequacy of indicators comes from the published climatological or regional differences found in epidemiology studies. Different indicators correlate with disease outcome depending upon whether or not the study was conducted in fresh or marine waters. In a freshwater French study (Ferley *et. al*. 1989), fecal streptococci were better indicators for gastrointestinal disease than fecal coliforms; while in a marine

Australian study (Corbett *et. al*. 1993), fecal coliforms were better predictors than fecal streptococci. Indeed, even when comparing similar environments (marine), but for studies conducted in different geographical areas, analogous inconsistencies are noted. A British study (Fleisher *et. al*. 1993) found a relationship between fecal streptococci and gastroenteritis, and no association with fecal coliforms; while a Hong Kong study (Cheung *et. al*. 1990) found *E. coli* (a fecal coliform) was the best indicator. In contrast, it is expected that numbers of a given pathogenic microorganisms will correlate quite well (and consistently) with its associated disease outcome.

As mentioned previously, recent technological advances have made laboratories increasingly more capable of enumerating pathogens. For instance, a study using these new methods was conducted to evaluate the decay rates of Cryptosporidium, Giardia, and *E. coli* O157:H7 in an urban stream in Alabama (Easton 2000). Data such as these can be used to develop more accurate risk assessments, and subsequently better standards.

Epidemiological Studies and Effects of Human Exposures to Stormwater

Epidemiology can be defined as the study of the occurrence and causes of disease in human populations and the application of this knowledge to the prevention and control of health problems. Much of the information that is used in developing environmental regulations designed to protect human health originates with epidemiological studies. Routinely used to assess risks associated with contaminants in drinking waters, epidemiology has, more recently, also been used to investigate human health risks associated with swimming in waters contaminated by stormwater.

Recently published epidemiology studies have described the increased health risks and problems associated with contact recreation in contaminated water, including water affected by stormwater, although most historical studies have focused on waters contaminated by sanitary sewage. However, as seen above, separate stormwaters are likely contaminated with sewage and therefore possibly contain similar pathogens, although the indicator conditions can vary greatly. In most cases, the levels of pathogens (see Craun, et al. 1997; O'Shea and Field 1992a and 1992b; Kay 1994) causing increased illness during these epidemiological studies were well within the range found in urban waters only affected by stormwater. These studies are therefore important as they indicate the risks associated with water contact recreation in receiving waters contaminated with the pathogens found in stormwater.

Before reviewing these studies, it should be noted that the results of environmental epidemiology studies have provoked controversy. An excellent review article by Craun, *et al*. (1996) on epidemiology applied to water and public health discusses many of these problems and offers suggestions to enable better interpretation of existing studies and better design of future studies.

Hong Kong Swimming Beach Study

Swimming beach studies were conducted in Hong Kong during the summers of 1986 and 1987 (Cheung, *et al*. 1990). This was one of the first major epidemiological investigations to be conducted in subtropical waters. More than 18,700 responses were obtained from beachgoers on nine beaches. Water samples were collected every two hours at the nine beaches under study. The samples were analyzed for *E. coli*, *Klebsiella* spp., fecal streptococci, fecal coliforms, staphylococci, *Pseudomonas aeruginosa*, *Candida albicans*, and total fungi. *E. coli* only represented 57% of the fecal coliforms (much lower than reported elsewhere). Beachgoers were recruited on selected weekends and given initial interviews. Follow-up telephone interviews were obtained 7 to 10 days afterwards. The beachgoers spent an average of 3.5 hours at the beach, and swimmers spent an average of 1.3 hours in the water (much longer than reported in colder climates). The individual beaches studied were affected to varying degrees by nearby submarine sewage outfalls, agricultural runoff (pig farming) or by storm drains discharging across the beaches.

The overall symptom rates for gastrointestinal, ear, eye, skin, respiratory, fever, and total illness were significantly higher for swimmers than for non-swimmers. The increased risk of swimmers developing highly credible gastrointestinal illness (HCGI) was 5 times greater than for non-swimmers. The increased risk for swimmers of developing gastrointestinal (GI), eye, skin, and total illness was 2 to 4 times greater than for non-swimmers. The incubation period for the gastrointestinal symptoms in Hong Kong were similar to those reported for the U.S., indicating a possible similar causative agent (Norwalk virus and rotavirus virus originating from human sewage being suspected). Children under 10 years of age were also found to have significantly higher symptom rates for GI, HCGI, skin, respiratory, fever, and total illness than older swimmers. *Escherichia coli* was found to be the best indicator of swimmer illness (especially gastroenteritis and skin symptoms). Staphylococci measurements were recommended as a supplement to *E. coli*, especially for ear, respiratory and total illness. Researchers contrasted this finding with typically better correlations between Enterococci and health risks at U.S. beaches, and concluded that it may not be appropriate to adopt another country's water contact recreation water quality criteria, especially if they are vastly separated geographically. Differences may be due to differences in the immune state of the populations and the indicator-illness relationships. Geometric mean densities of 180 *E. coli* per 100 mL and 1,000 staphylococci per 100 mL were found to be the thresholds for differentiating "barely acceptable" and "relatively unpolluted" beaches. Many of the rates were also higher at "barely acceptable" beaches than at "relatively unpolluted" beaches. These observations were used to develop new swimming beach standards for Hong Kong, as shown in Table 1. This new classification scheme was in place in 1988.

Table 1. Classification of Hong Kong Beaches Based on Swimming Associated Health Risk Levels

Rank	Swimming associated gastroenteritis and skin symptom rate (per 1,000 swimmers)	Seasonal geometric mean *E. coli* density (per 100 mL)	Number of swimming beaches in category during 1988
Good	0	24	9
Acceptable	10	180	19
Barely acceptable	15	610	7
Unacceptable	>15	>610	7

Cheung, *et al*. 1990.

Sydney Beach Users Study

This study examined problems associated with sewage contaminated swimming beaches (from CSO discharges and ocean outfalls of treated sewage) (Corbett, *et al*. 1993). The research team interviewed almost 3,000 beach goers at 12 beaches during 3 months in late 1989 and early 1990. Follow-up telephone interviews were conducted about a week later concerning incidence of illness. During the 41 days of sampling, 461 samples were analyzed for fecal coliforms and fecal streptococci. Of these samples, 67% failed to meet New South Wales Department of Health water quality criteria.

Swimmers were almost twice as likely as nonswimmers to report symptoms, but the prevalence of respiratory symptoms in people aged 15 to 25 was high, irrespective of swimming status or pollution level. The incidence of respiratory, fever, eye, ear, and other problems increased with increasing bacterial counts. Fecal streptococci counts were worse predictors of the swimming risk than the fecal coliform counts. Gastrointestinal symptoms were not related to either the fecal coliforms or fecal streptococci counts monitored. Those who swam for longer than 30 minutes were more than 4 times as likely to develop gastrointestinal symptoms compared to nonswimmers or those who swam for shorter periods.

Table 2 shows the percentages of swimmers who reported various illness symptoms after swimming in waters having varying bacterial contamination levels. Increasing levels of contamination increased the health risks for all symptoms, except for gastrointestinal symptoms. Table 3 shows the odds ratios (and associated 95% confidence intervals) for illness at different levels of fecal coliform contamination. Above 1,000 cfu/100 mL fecal coliforms, the associations for these illnesses are all strong, while they are at least moderate for all levels shown, compared to the nonswimmers. However, most of the confidence intervals were quite large, indicating large variability in the observations, as expected.

Table 2. Percentages of Beachgoers Reporting Symptoms (Corbett, *et al*. 1993)

Illness	Did not swim (n=915)	Swam, low pollution (n=1770)	Swam, high pollution (n=154)	Total sample (n=2839)
Vomiting	0.9	1.0	0.6	0.9
Diarrhea	2.2	3.7	3.2	3.2
Cough, cold, flu	10.2	17.3	23.4	15.3
Ear infection	1.3	3.9	5.8	3.2
Eye infection	1.0	2.4	3.9	2.0
Fever	1.1	1.8	5.2	1.7
Other	4.7	8.0	13.0	7.2
Any condition reported	16.5	26.9	35.7	24.0
Attended a doctor	3.5	4.3	8.4	4.3
Took time off work	2.6	4.6	6.5	4.0

Table 3. Odds Ratios (OR) of Swimmers Reporting Health Problems for Different Levels of Fecal Coliform Bacteria (Corbett, *et al*. 1993)

Illness	10 – 300 cfu/100 mL		300 – 1000 cfu/100 mL		1000 – 3000 cfu/100 mL		>3000 cfu/100 mL	
	OR	CI of OR	OR	CI of OR	OR	CI of OR	OR	CI of OR
Any symptom	2.9	1.7 – 5.1	3.8	2.1 – 7.1	5.2	1.7 – 16.0	5.9	3.0 – 11.5
Cough	2.4	1.5 – 3.8	2.0	0.9 – 4.4	4.2	1.2 – 14.6	6.9	3.3 – 14.1
Ear symptoms	4.3	1.1 – 16.2	8.6	1.7 – 43.2	8.5	0.8 – 97.6	7.4	1.3 – 43.3
Eye symptoms	6.3	1.3 – 30.8	9.7	1.5 – 63.7	8.7	1.0 – 72.8	na	na
Fever	2.1	0.6 – 7.0	4.7	1.0 – 22.5	9.0	1.9 – 43.5	na	na
Any gastrointestinal symptom	4.6	1.9 – 4.9	3.1	0.7 – 13.0	3.4	0.7 – 18.0	na	na

UK Swimmer/Sewage Exposure Study

Another recent swimmer/sewage exposure study was conducted in the UK, reported by Kay, *et al*. (1994) and by Fleisher, *et al*. (1996). This study was unique in design and was able to develop dose-response relationships and critical exposure levels for a few illnesses associated with swimmer exposures to sewage contaminated waters. Adult volunteers (1528 study participants) were studied over four seasons from 1989 through 1992. After arriving at the beach, healthy volunteers were randomly separated into bather and nonbather groups with the duration and place of individual exposure being rigorously controlled. All of the study locations met European Community mandatory bacteriological marine bathing water quality criteria and were therefore not excessively contaminated.

The researchers found a clear dose-response relationship between increasing levels of fecal streptococci and increased risk of acquiring acute febrile respiratory illness. Only bathers exposed to the highest quartile of exposure (51 to 158 FS /100 mL) showed a statistically significant increase in risk compared to the non bathers. The odds ratio (OR) was 2.65 (moderate association), with a 95% confidence interval of 1.19 – 5.48 for acute fibrile respiratory illness and fecal streptococci. There was a clear dose-response relationship among the bathers. In addition, exposure to increased levels of fecal coliform organisms was found to be predictive of ear ailments among bathers. Numerous studies have repeated the strong relationship with fecal streptococci or Enterococci, such that the EU (European Union), among other regulatory agencies, intends to move to Enterococci standards from fecal coliforms.

Thresholds of exposure to indicator organisms, below which bathers were at no excess risk of illness relative to nonbathers, were estimated to be 60 fecal streptococci organisms/100 mL for febrile respiratory illness and 100 fecal coliform organisms/100 mL for ear ailments. These threshold levels are quite low and are commonly exceeded in most urban streams. No dose-response relationships or threshold levels were found for any of the indicator organisms (total coliforms, fecal coliforms, fecal streptococci, total staphylococci and *Pseudomonas aeruginosa*) and eye or skin ailments. They concluded that the use of a single illness or indicator organism for establishing swimming criteria in marine waters is incorrect.

Exposure to Pathogens in Stormwater – The Santa Monica Bay Project

This study was the first large-scale epidemiological study in the U.S. to investigate possible adverse health effects associated with swimming in ocean waters affected by discharges from separate storm drains (SMBRP 1996). This was a follow-up study after previous investigations found that human fecal waste was present in the stormwater collection systems (*Water Environment & Technology* 1996b, *Environmental Science & Technology* 1996, and Haile, et al. 1996).

During a four month period in the summer of 1995, about 15,000 ocean swimmers were interviewed on the beach and during telephone interviews one to two weeks later. They were queried concerning illnesses since their beach outing. The incidence of illness (such as fever, chills, ear discharge, vomiting, coughing with phlegm, and credible gastrointestinal illness) was significantly greater (from 44 to 127% increased incidence) for ocean goers who swam directly off the outfalls, compared to those who swam 400 yards away, as shown on Table 4. Disease incidence dropped significantly with distance from the storm drain. At 400 yards, and beyond, upcoast or downcoast, elevated disease risks were not found. The results did not change when adjusted for age, beach, gender, race, socioeconomic status, or worry about health risks associated with swimming at the beach.

Table 4. Comparative Health Outcomes for Swimming in Front of Storm Drain Outfalls, Compared to Swimming at least 400 Yards Away (from SMBRP 1996)

Health Outcome	Relative Risk	Rate Ratio	Estimated Association	Estimated No. of Excess Cases per 10,000 Swimmers (rate difference)
Fever	57%	1.57	Moderate	259
Chills	58%	1.58	Moderate	138
Ear discharge	127%	2.27	Moderate	88
Vomiting	61%	1.61	Moderate	115
Coughing with phlegm	59%	1.59	Moderate	175
Any of the above symptoms	44%	1.44	Weak	373
HCGI-2	111%	2.11	Moderate	95
SRD (significant respiratory disease)	66%	1.66	Moderate	303
HCGI-2 or SRD	53%	1.53	Moderate	314

These interviews were supplemented with indicator and pathogen bacteria and virus analyses in the waters. The greatest health problems were associated with times of highest concentrations (*E. coli* >320 cfu/100 mL, Enterococcus > 106 cfu/100 mL, total coliforms >10,000 cfu/100 mL, and fecal coliforms > 400 cfu/100 mL). Bacteria populations greater than these are common in urban runoff and in urban receiving waters. Symptoms were found to be associated with swimming in areas where bacterial indicator levels were greater than these critical counts. Table 5 shows the health outcomes associated with swimming in areas having bacterial counts greater that these critical values. The association for Enterococcus with bloody diarrhea was strong, and the association of total coliforms with skin rash was moderate, but nearly strong.

Table 5. Heath Outcomes Associated with Swimming in Areas having High Bacterial Counts (from SMBRP 1996)

Indicator (and critical cutoff count)	Health Outcome	Increased Risk	Risk Ratio	Estimated Association	Excess Cases per 10,000 Swimmers
E. coli (>320 cfu/100mL)	Ear ache and nasal congestion	46% 24%	1.46 1.24	Weak Weak	149 211
Enterococcus (>106 cfu/100 mL)	Diarrhea w/blood and HCGI-1	323% 44%	4.23 1.44	Strong Weak	27 130
Total coliform bacteria (>10,000 cfu/100 mL)	Skin rash	200%	3.00	Moderate	165
Fecal coliform bacteria (>400 cfu/100 mL)	Shin rash	88%	1.88	Moderate	74

The ratio of total coliform to fecal coliform was found to be one of the better indicators for predicting health risks when swimming close to the storm drain. When the total coliforms were greater than 1,000 cfu/100 mL, the strongest effects were generally observed when the total to fecal coliform ratio was 2. The risks decreased as the ratio increased. In addition, illnesses were more common on days when enteric viruses were found in the water. The percentage of survey days exceeding the critical bacterial counts were high, especially when closest to the storm drainage, as shown on Table 6. High densities of *E. coli*, fecal coliforms and Enterococcus were observed on more than 25% of the days, however, there was a significant amount of variability in observed counts in the water samples obtained directly in front of the drains. The variability and the frequency of high counts dropped considerably with distance from the storm drains. Upcoast bacteria densities were less than downcoast densities probably because of prevailing near-shore currents.

Table 6. Percentages of Days when Samples Exceeded Critical Levels (from SMBRP 1996)

Bacterial Indicator	0 yards	1 to 100 yards upcoast	1 to 100 yards downcoast	400+ yards upcoast
E. coli (>320cfu/100 mL)	25.0%	3.5%	6.7%	0.6%
Total coliforms (>10,000 cfu/100 mL)	8.6	0.4	0.9	0.0
Fecal coliforms (>400 cfu/100 mL)	29.7	3.0	8.6	0.9
Enterococcus (>106 cfu/100 mL)	28.7	6.0	9.6	1.3
Total/Fecal coliform ratio ≤5 (and total coliforms >1,000 cfu/100 mL)	12.0	0.5	3.9	0.4

The SMBRP (1996) concluded that less than 2 miles of Santa Monica Bay's 50 mile coastline had problematic health concerns due to the storm drains flowing into the Bay. They also concluded that the bacterial indicators currently being monitored do help predict risk. In addition, the total to fecal coliform ratio was found to be a useful additional indicator of illness. As an outcome of this study, the Los Angeles County Department of Health Services planned to post new warning signs advising against swimming near the outfalls ("Warning! Storm drain water may cause illness. No swimming"). These signs will be posted on both sides of all flowing storm drains in Los Angeles County. In addition, county lifeguards will attempt to warn and advise swimmers to stay away from areas directly in front of storm drain outlets, especially in ponded areas. The county is also accelerating their studies on sources of pathogens in stormwater.

Development of Bathing Beach Bacteriological Criteria and Associated Epidemiological Studies

Current microbiological standards seldom have clear scientific basis and regulatory authorities cannot be confident that compliance with standards currently in force will ensure appropriate levels of public health protection. Human health standards for body contact recreation (and for fish and water consumption) are based on indicator organism monitoring. Dufour (1984a) presents an excellent overview of the history of US indicator bacterial standards and water contact recreation, summarized here. Total coliforms were initially used as indicators for monitoring outdoor bathing waters, based on a classification scheme presented by W.J. Scott in 1934. Total coliform bacteria refers to a number of bacteria including *Escherichia*, *Klebsiella*, *Citrobacter*, and *Enterobacter* (DHS 1997). They are able to grow at 35^{o}C and ferment lactose. They are all gram negative asporogenous rods and have been associated with feces of warm blooded animals. They are also present in soil. Scott had proposed four classes of water, with total coliform upper limits of 50, 500, 1,000, and >1,000 MPN/100 mL for each class. He had developed this classification based on an extensive survey of the Connecticut shoreline where he found that about 93% of the samples contained less than 1,000 total coliforms per 100 mL. A sanitary survey classification also showed that only about 7% of the shoreline was designated as poor. He therefore concluded that total coliform counts of <1,000 MPN/100 mL probably indicated acceptable waters for swimming. This standard was based on the principle of attainment, where very little control or intervention would be required to meet this standard.

In 1943, the state of California independently adopted a total coliform standard of 10 MPN/1 mL (which is the same as 1,000 MPN/100 mL) for swimming areas. This California standard was not based on any evidence, but it was assumed to relate well with the drinking water standard at the time.

H.W. Streeter used an analytical approach to develop a standard for bathing water quality in 1951. He used an equation which included both *Salmonella* and total coliforms, the number of bathers exposed, the approximate volume of water ingested by bathers daily, and the average total coliform density. Streeter concluded that water containing <1,000 MPN total coliforms/100 mL would pose no great *Salmonella typhosa* health hazard.
Dufour points out that it is interesting that all three approaches in developing a swimming water criterion resulted in the same numeric limit.

One of the earliest bathing beach studies to measure actual human health risks associated with swimming in contaminated water was directed by Stevenson (1953), of the U.S. Public Health Service's Environmental Health Center, in Cincinnati, Ohio, and was conducted in the late 1940s. They studied swimming at Lake Michigan at Chicago (91 and 190 MPN/100 mL median total coliform densities), the Ohio River at Dayton, KY (2,700 MPN/100 mL), at Long Island Sound at New Rochelle and at Mamaroneck, NY (610 and 253 MPN/100 mL). They also studied a swimming pool in Dayton, KY. Two bathing areas were studied in each area, one with historically poorer water quality than the other. Individual home visits were made to participating families in each area to explain the research program and to review the calendar record form. Follow up visits were made to each participating household to insure completion of the forms. Total coliform densities were monitored at each bathing area during the study. More than 20,000 persons participate in the study in the three areas. Almost a million person-days of useable records were obtained. The percentage of the total person-days when swimming occurred ranged from about 5 to 10 percent. The number of illnesses of all types recorded per 1,000 person-days varied from 5.3 to 8.8. They found an appreciably higher illness incidence rate for the swimming group, compared to the nonswimming group, regardless of the bathing water quality (based on total coliform densities). However, a significant increase in gastrointestinal illness was observed among the swimmers who used one of the Chicago beaches on three days when the average coliform count was 2,300 MPN/100 mL. The second instance of positive correlation was observed in the Ohio River study where swimmers exposed to the median total coliform density of 2,700 MPN/100 mL had a significant increase in gastrointestinal illness, although the illness rate was relatively low. They suggested that the strictest bacterial quality requirements that existed then (<1,000 MPN/100 mL, based on Scott's 1934 work) might be relaxed without significant detrimental effect on the health of bathers.

It is interesting to note that in 1959, the Committee on Bathing Beach Contamination of the Public Health Laboratory Service of the UK concluded that "bathing in sewage-polluted seawater carries only a negligible risk to health, even on beaches that are aesthetically very unsatisfactory" (Cheung, *et al*. 1990 and Alexander, *et al*. 1992).

Dufour (1984a) pointed out that total coliforms were an integral element in establishing fecal coliform limits as an indicator for protecting swimming uses. Fecal coliform bacteria are a subgroup of the total coliform group. They grow at 44.5^{o}C and also ferment lactose. They are restricted to the feces of warm blooded animals and can be used to separate bacteria of soil and animal origin (DHS 1997). They do survive for variable periods of time in fecal contaminated soil and water, however. As a result of the Stevenson (1953) study, reported above, a geometric mean fecal coliform level of 200 MPN per 100 mL was recommended by the National Technical Advisory Committee (NTAC) of the Federal Water Pollution Control Administration in 1968 and was adopted by the U.S. Environmental Protection Agency in 1976 as a criterion for direct water contact recreation (Cabelli, *et al*. 1979). This criterion was adopted by almost all states in the U.S. by 1984. It was felt that fecal coliform levels were more specific to sewage contamination and had less seasonal variation than total coliform levels. Since fecal coliform exposures at swimming beaches had never been linked to disease, the NTAC reviewed the USPHS studies, as published by Stevenson (1953). The 2,300 MPN/100 mL total coliform count association with gastrointestinal disease was used in conjunction with a measured ratio of fecal coliform to total coliform counts (18%) obtained at the Ohio River site studied earlier. It was therefore assumed that a health effect could be detected when the fecal coliform count was 400 MPN/100 mL (18% of 2,300 = 414). Dufour (1984a) pointed out that a detectable health effect was undesirable and that the NTAC therefore recommended a limit of 200 MPN/100 mL for fecal coliforms. Although likely coincidental, the 1968 proposed limit for fecal coliforms (200 MPN/100 mL) was very close to being theoretically equivalent to the total coliform limit of 1,000 MPN/100 mL that was being replaced (200/0.18 = 1100).

Dufour (1984a) lists the ideal characteristics of bacterial indicators of fecal contamination, as presented by various authors. The authors were in agreement concerning many of the criteria (correlation to pathogens, unable to grow in aquatic environments, more resistant to disinfection than pathogens, and easy to isolate and enumerate), but two important aspects were seldom mentioned, namely that the indicator should have a direct relationship to fecal contamination, and that the indicator density should correlate with health hazards. Many of the follow-up studies conducted since the mid 1970s examined these additional criteria. *E. coli*, a member of the fecal coliform group, has been recently used as a better indicator of fresh fecal contamination. Table 7 indicates the species and subspecies of the Streptococcus and Enterococcus groups of bacteria that are used as indicators of fecal contamination (DHS 1997).

Table 7. Streptococcus Species used as Indicators of Fecal Contamination

Indicator organism	Enterococcus group	Streptococcus group
Group D antigen		
Streptococcus faecalis	X	X
S. faecalis subsp. *liquifaciens*	X	X
S. faecalis subsp. *zymogenes*	X	X
S. faecium	X	X
S. bovis		X
S. equines		X
Group Q antigen		
S. avium		X

Source: DHS (1997)

Fecal streptococci bacteria are indicators of fecal contamination. The Enterococcus group is a subgroup that is considered a better indication of human fecal contamination. S. bovis and S. equinus are considered related to feces from non-human warm blooded animals (such as from meat processing facilities, dairy wastes, and feedlot and other agricultural runoff), indicating that Enterococcus may be a better indication of human feces contamination. However, *S. facealis* subsp. *liquifaciens* is also associated with vegetation, insects, and some soils (DHS 1997).

The Cabelli, *et al*. (1979) study was undertaken to address many remaining questions pertaining to bathing in contaminated waters. Their study examined conditions in New York (at Coney Island beach, designated as barely acceptable, and at Rockaway beach, designated as relatively unpolluted). About 8,000 people participated in the study, approximately evenly divided between swimmers and nonswimmers at the two beaches. Total and fecal coliforms, *Escherichia*, *Klebsiella*, *Citrobacter-Enterobacter*, Enterococci, *Pseudomonas aeruginosa*, and *Clostridium perfringens* were evaluated in water samples obtained from the beaches during the epidemiological study. The most striking findings were the increases in the rates of vomiting, diarrhea, and stomach ache among swimmers relative to nonswimmers at the barely acceptable beach, but not at the relatively unpolluted beach. Ear, eye, nose, and skin symptoms, as well as fever, were higher among swimmers compared to nonswimmers at both beaches. They concluded that measurable health effects do occur at swimming beaches that meet the existing health standards. Children, Hispanic Americans, and low-middle socioeconomic groups were identified as the most susceptible portions of the population.

Cabelli, *et al*. (1982) presented data from the complete EPA sponsored swimming beach study, conducted in New York, New Orleans, and Boston. The study was conducted to address issues from prior studies conducted in the 1950s (including Stevenson's 1953 study noted above) that were apparently contradictory. They observed a direct, linear relationship between highly credible gastrointestinal illness and Enterococci. The frequency of gastrointestinal symptoms also had a high degree of association with distance from known sources of municipal wastewater. Table 8 shows correlation coefficients for total gastrointestinal (GI) and highly credible gastrointestinal (HCGI) symptoms and mean indicator densities found at the New York beaches from 1970 to 1976. The best correlation coefficients were found for Enterococci. In contrast, the correlation coefficients for fecal coliforms (the basis for most federal and state guidelines) were poor. Very low levels of Enterococcus and *E. coli* in the water (about 10 MPN/100 mL) were associated with appreciable attack rates (about 10/10,000 persons).

Table 8. Correlation Coefficients between Gastrointestinal Symptoms and Bacterial Densities at New York City Beaches (Cabelli, *et al*. 1982)

Indicator	HCGI correlation coefficient	GI correlation coefficient	Number of observations
Enterococci	0.96	0.81	9
Escherichia coli	0.58	0.51	9
Klebsiella	0.61	0.47	11
Enterobacter-Citrobacter	0.64	0.54	13
Total coliforms	0.65	0.46	11
Clostridium perfringens	0.01	-0.36	8
Pseudomonas aeruginosa	0.59	0.35	11
Fecal coliforms	0.51	0.36	12
Aeromonas hydriphila	0.60	0.27	11
Vibrio parahemoylticus	0.42	0.05	7

Regressions of swimming associated gastrointestinal symptom rates (swimmer rates minus nonswimmer rates) against the mean Enterococcus and *E. coli* densities of the water samples clearly showed that the risk of gastrointestinal symptoms associated with swimming in marine waters contaminated with municipal wastewater is related to the quality of the water, as indicated by the Enterococcus density of the water. There was a strong case for causality between Enterococci and gastrointestinal symptoms, based on the good association, the consistency at the different locations over different years, the reasonable nature of the relationship between enteric disease and fecal contamination, and the coherent association based on observations of waterborne disease transmission during prior outbreaks.

Cabelli concluded that swimming in even marginally polluted marine bathing water is a significant route of transmission for observed gastrointestinal illness. The gastrointestinal illness was likely associated with the Norwalk-like virus that had been confirmed in 2,000 cases at a shellfish associated outbreak in Australia and at several outbreaks associated with contaminated drinking water.

Fleisher (1991) reevaluated this marine swimming beach data and concluded that the limitation for Enterococci promulgated by the EPA in 1986, based on the Cabelli, *et al*. (1982) study, (35 per 100 mL, geometric mean for 5

equally spaced samples over a 30-day period, for both fresh and saline water) was too severe, due to minor adjustments of the observed data. He was also especially concerned with the use of a single criterion based on pooled data, while the data from the individual sites indicated very different probabilities of gastroenteritis among swimmers at Boston compared to New York and Lake Pontchartrain (which were similar). He also reported that previous studies found bacteria indicator, and possibly pathogen, survival to be inversely correlated with salinity. He therefore concluded that any relation between Enterococci and disease causing pathogens may be site specific, possibly related to water salinity. This EPA Enterococci criterion for swimming waters was based on an "acceptable" rate of gastroenteritis of 19 cases per 1,000 swimmers, the same rate upon which the fecal coliform criterion (200 MPN/100 mL) was based. It is interesting to note that Fleisher later participated in additional epidemiological studies in the UK and concluded that 33 fecal streptococci (essentially Enterococci)/100 mL was the threshold of increased risk for gastrointestinal illness for swimmers (Kay, *et al*. 1994).
Dufour (1984a) also reviewed a series of studies conducted at freshwater swimming beaches from 1979 to 1982, at Tulsa, OK, and at Erie, PA. Only Enterococci, *E. coli*, and fecal coliforms were monitored, based on the results of the earlier studies. Table 9 shows the correlation coefficients for these three bacterial parameters and gastrointestinal disease.

Table 9. Correlation Coefficients for Bacterial Parameters and Gastrointestinal Disease (Fresh Water Swimming Beaches)

	HCGI	Total Gastrointestinal Illness	Number of Study Units
Enterococci	0.774	0.673	9
E. coli	0.804	0.528	9
Fecal coliforms	-0.081	0.249	7

These results are quite different than the results from the marine studies, in that both Enterococci and *E. coli* had high correlation coefficients between the bacterial levels and the incidence of gastrointestinal illness. However, the result was the same for fecal coliforms, in that there was no association between fecal coliform levels and gastrointestinal illness. Dufour (1984b) concluded that Enterococci would be the indicator of choice for gastrointestinal illness, based on scientific dependability. *E. coli* could also be used, if only fresh waters were being evaluated. Fecal coliforms would be a poor choice for monitoring the safety of bathing waters. However, he concluded that numeric standards should be different for fresh and saline waters because of different dieoff rates for the bacteria and viruses for differing salinity conditions.

Other studies examined symptoms other than gastrointestinal illness associated with swimming in contaminated water, and identified additional potentially useful bacterial indicators. Seyfried, *et al*. (1985), for example, examined swimming beaches in Toronto for respiratory illness, skin rashes, plus eye and ear problems, in addition to gastrointestinal illness. They found that total staphylococci correlated best with swimming associated total illness, plus ear, eye and skin illness. However, fecal streptococci and fecal coliforms also correlated (but not as well) with swimming associated total illness. Ferley, *et al*. (1989) examined illnesses among swimmers during the summer of 1986 in the French Ardèche river basin, during a time when untreated domestic sewage was entering the river. They examined total coliforms, fecal coliforms, fecal streptococci and *Pseudomonas aeruginosa* and *Aeromonas Spp*, but only two samples per week were available for each swimming area. The total morbidity rate ratio for swimmers compared to nonswimmers was 2.1 (with a 95% confidence interval of 1.8 to 2.4), with gastrointestinal illness the major illness observed. They found that fecal streptococci (FS) was the best indicator of gastrointestinal illness. A critical FS value of 20 MPN/100 mL indicated significant differences between the swimmers and nonswimmers.
Skin ailments were also more common for swimmers than for nonswimmers and were well correlated with the concentrations of fecal coliforms, *Aeromonas Spp* and *Pseudomonas aeruginosa*. They noted that a large fraction (about 60%) of the fecal coliforms corresponded to *E. coli*, and that their definition of fecal streptococci essentially was what North American researchers termed Enterococci.

Koenraad, *et al*. (1997) investigated the contamination of surface waters by *Campylobacter* and its associated human health risks. They reported that campylobacteriosis is one of the most frequently occurring acute gastroenteritis diseases in humans. Typical investigations have focused on the consumption of poultry, raw milk, and untreated water as the major sources of this bacterial illness. Koenraad, *et al*. (1997) found that human exposures to *Campylobacter* contaminated surface waters is likely a more important risk factor than previously considered. In fact, they felt that *Campylobacter* infections may be more common than *Salmonella* infections. The incidence of campylobacteriosis due to exposure to contaminated recreational waters has been estimated to be between 1.2 to 170 per 100,000 individuals. The natural habitat of *Campylobacter* is the intestinal tract of warm-blooded animals (including poultry, pigs, cattle, gulls, geese, pigeons, magpies, rodents, shellfish, and even flies). It does not seem to multiply outside of its host, but it can survive fairly well in aquatic environments. It can remain culturable and infective for more than 2 months under ideal environmental conditions. Besides runoff, treated wastewater effluent is also a major likely source of *Campylobacter* in surface waters. Sanitary wastewater may contain up to 50,000 MPN of *Campylobacter* per 100 mL, with 90 to 99% reductions occurring during typical wastewater treatment.

Many of the available epidemiological studies have been confined to healthy adult swimmers, in relatively uncontaminated waters. However, it is assumed that those most at risk would be children, the elderly, and those chronically ill, especially in waters known to be degraded. Obviously, children are the most likely of this most-at-risk group to play in, or by, water. Alexander, *et al*. (1992) therefore specifically examined the risk of illness associated with swimming in contaminated sea water for children, aged 6 to 11 years old. This study was based on parental interviews for 703 child participants during the summer of 1990 at Blackpool beach, UK. Overall, 80% of the samples at the Blackpool Tower site and 93% of the samples at the South Pier site failed to meet the European Community Standards for recreational waters. All of the 11 designated beaches in Lancashire (including Blackpool beach), in the northwest region of England, continually fail the European directive imperative standards for recreational waters. During this study, statistically significant increases in disease were found for children who had water contact, compared to those who did not. Table 10 shows the prevalence and rate ratios for these symptoms. Diarrhea and loss of appetite had strong associations with the water contact group, while vomiting and itchy skin had moderate associations. No other variables examined (household income, sex of the child, sex of the respondent, general health, chronic or recurring illness in the child, age of the child, foods eaten, including ice cream, other dairy products, chicken, hamburgers, shellfish, or ice cubes, acute symptoms in other household members, presence of children under 5 in the household, and other swimming activities) could account for the significant increases in the reported symptoms for the children who had water contact.

Table 10. Illness Symptoms for Children Exposed to Sewage Contaminated Sea Water (Alexander, *et al*. 1992)

	Prevalence for water contact group, n=455 (%)	Prevalence for non-water contact group, n=248 (%)	Rate Ratio	Strength of Association
Vomiting	4.2	1.6	2.6	Moderate
Diarrhea	7.9	2.4	3.3	Strong
Itchy skin	5.1	2.8	1.8	Moderate
Loss of appetite	4.0	1.2	3.3	Strong

Other risk factors, in addition to exposure to sewage contaminated swimming waters, were investigated by Fleisher, *et al*. (1993). People visiting beaches for recreation are frequently exposed to additional risks for gastroenteritis disease, especially related to foods that are eaten. Picnic lunches and food purchased at swimming beaches may contain improperly prepared or inadequately stored foods, including food that may be especially risky such as eating sandwiches having mayonnaise, chicken, eggs, hamburgers, and hot dogs. They found that non-water related risk factors confounded the relationships between gastroenteritis and fecal streptococci densities. They also found that fecal coliform and fecal streptococci densities changed rapidly in time and location at swimming beaches, requiring many more water sample evaluations than are typically obtained during most epidemiological studies.

1986 U.S. EPA Guidance for Recreational Waters, Water Supplies, and Fish Consumption

A recreational water quality criterion can be defined as a “quantifiable relationship between the density of an indicator in the water and the potential human health risks involved in the water's recreational use.” From such a definition, a criterion can be adopted which establishes upper limits for densities of indicator bacteria in waters that are associated with acceptable health risks for swimmers.

The U.S. Environmental Protection Agency, in 1972, initiated a series of studies at marine and fresh water bathing beaches which were designed to determine if swimming in sewage-contaminated marine and fresh water carries a health risk for bathers; and, if so, to what type of illness. Additionally, the EPA wanted to determine which bacterial indicator is best correlated to swimming-associated health effects and if the relationship is strong enough to provide a criterion (EPA 1986).

Many of the above described U.S. studies were conducted as part of these EPA sponsored research activities. The quantitative relationships between the rates of swimming-associated health effects and bacterial indicator densities were determined using standard statistical procedures. The data for each summer season were analyzed by comparing the bacteria indicator density for a summer bathing season at each beach with the corresponding swimming-associated gastrointestinal illness rate for the same summer. The swimming-associated illness rate was determined by subtracting the gastrointestinal illness rate in nonswimmers from that for swimmers.

The EPA’s evaluation of the bacteriological data indicated that using the fecal coliform indicator group at the maximum geometric mean of 200 organisms per 100 mL, as recommended in *Quality Criteria for Water* would cause an estimated 8 illness per 1,000 swimmers at freshwater beaches.

Additional criteria, using *E. coli* and Enterococci bacteria analyses, were developed using these currently accepted illness rates. These bacteria are assumed to be more specifically related to poorly treated human sewage than the fecal coliform bacteria indicator. The freshwater equations developed by Dufour (1984b) were used to calculate new indicator densities corresponding to the accepted gastrointestinal illness rates.

It should be noted that these indicators only relate to gastrointestinal illness, and not other problems associated with waters contaminated with other bacterial or viral pathogens. It is likely that common swimming beach problems associated with contamination by stormwater could also include skin and ear infections caused by the large concentrations of *Pseudomonas aeruginosa* and *Shigella* found in stormwater (Pitt 1983).

U.S. bacteria criteria have been established for contact with bacteria and are shown in

Table 11. State standards usually also exist for fecal coliform bacteria.

Water Environment & Technology (1997) reported the new EPA BEACH (Beaches Environmental Assessment, Closure, and Health) program to help states strengthen recreational water quality monitoring programs. During the summer of 1995, state and local governments reported closing or issuing warnings for 4,000 beaches because of suspected dangerous conditions associated from wastewater and stormwater contamination of swimming areas. A new testing method for *Escherichia coli* and Enterococci bacteria was introduced that gives results in 1 day instead of the typical 2 days testing period. They also reported that these bacteria better correlate with human health risks. The EPA will survey state and local health and environmental directors about the quality of freshwater and marine recreational areas and post the results on a new Beach Watch Web site.

Table 11. U.S. EPA Water Quality Criteria for Swimming Waters

	Marine Waters	Fresh Waters
Main EPA research reference	Cabelli, et al. 1982	Dufour 1984b
Acceptable swimming associated gastroenteritis rate (per 1,000 swimmers)	Increase of 19 illnesses per 1,000 swimmers	Increase of 8 illnesses per 1,000 swimmers
Comparable fecal coliform exposure	200 fecal coliforms/100 mL	200 fecal coliforms/100 mL
Steady state geometric mean indicator density	35 Enterococci/100 mL	33 Enterococci/100 mL, or 126 *E. coli*/100 mL
Single sample limits:		
Designated bathing beach area	104 Enterococci/100 mL	61 Enterococci/100 mL, or 235 *E. coli*/100 mL
Moderate full body contact recreation	124 Enterococci/100 mL	89 Enterococci/100 mL, or 298 *E. coli*/100 mL
Lightly used full body contact recreation	276 Enterococci/100 mL	108 Enterococci/100 mL, or 406 *E. coli*/100 mL
Infrequently used full body contact recreation	500 Enterococci/100 mL	151 Enterococci/100 mL , or 576 *E. coli*/100 mL
EPA 1986		

New California Recreational Area Bacteria Standards

California Assembly Bill AB-411 was implemented in July 1999 for southern California areas. The regulations specifically only apply to beaches having over 50,000 annual visitors that receive runoff from a storm drain or natural creek and apply from April 1 to October 31 of each year. However, most of the local agencies have implemented the regulations at all beaches. These criteria are heavily based on the Santa Monica Bay study described above and recognize the danger that urban runoff presents. They recommend that recreational use of waters within stormwater drains (including manmade conveyances and also natural drains such as creeks and streams), in ponds or pools that form because of stormwater drainage, and in the immediate surf zone into which stormwater drains, should be prohibited at all times. The criteria documents state that:

> a protocol should be developed that sets forth procedures for closing recreational waters and beach areas whenever significant amounts of rainfall results in urban runoff that enters recreational waters and beach areas.
>
> Ocean beaches that are subject to urban runoff should be closed for a minimum of 72 hours following significant rain to allow wave action to dissipate microbiological contamination, unless sampling and analysis indicates that earlier reopening is appropriate, or local health agencies have ample data and experience with the location to determine appropriate actions.
>
> Other beaches that are subject to significant urban runoff (e.g., via storm drains) should be closed until sampling by and/or experience of local health agencies indicate reopening is appropriate.

> Bays or other ocean water areas with poor water circulation may require a longer time to recover." (DHS 1997)

Similar wording was also provided relating to swimming in freshwaters contaminated by urban runoff. Indicator organisms should include total and fecal coliform bacteria, at a minimum. Enterococci can also be added as an indicator. They felt that monitoring for specific pathogens (such as *Giardia* or *Cryptosporidium*) is costly and doesn't appear to be reliable. They could be monitored if done in conjunction with the other required monitoring efforts, especially in response to specific needs.

Reopening of a closed recreational area is appropriate when two successive samples taken at least 24 hours apart are below the closure levels. If a swimming area is closed due to contamination by urban stormwater runoff, the following wording for warning signs is suggested: "Warning! Closed to swimming. Beach/swimming area is contaminated by stormwater runoff/sewage and may cause illness." In areas that are chronically contaminated by stormwater, the following wording for permanent signs is suggested: "Warning! Storm drain water may cause illness. No swimming in storm drain water."

WHO Guidelines for Recreational Use of Water

The World Health Organization (WHO) has been concerned with the health aspects associated with the recreational use of water for many years. In 1994, with the urging of the WHO Regional office for Europe, WHO developed *Guidelines for Safe Recreational-Water Environments*. A joint WHO and USEPA meeting was held in 1998 and the *Annapolis Protocol* (WHO 1999) was developed. The Annapolis Protocol report contains an excellent summary of health aspects of recreational waters, including standards from throughout the world and guidance for assessing the health risks for numerous discharge conditions. Separate storm drains are described as having low significance to public health, although of increasing importance if contaminated with sanitary wastewater.

Tables 12 and 13, summarized from the *Annapolis Protocol*, show example categories for recreational waters and selected bacteria standards from various counties for primary contact recreation. The *Annapolis Protocol* (WHO 1999) also specifically outlines bathing beach monitoring strategies. WHO also developed a code of good practice for monitoring recreational waters recently.

Table 12. Examples of Categories of Microbial Indicator Levels by Water Source

Water Source	Indicator(s)	Category	95th Percentile (number/100 mL)
Temperate freshwater	Fecal Streps Enterococci(1)	A	<10
		B	11-50
		C	51-200
		D	201-1000
		E	>1000
	E. coli	A	<35
		B	36-130
		C	131-500
		D	501-1000
		E	>1000
Alternative for tropical marine water and optional for tropical marine freshwater	Sulfite reducing Clostridia *Clostridium perfringens*	A	<1
		B	1-10
		C	11-50
		D	51-80
		E	>80

(1) these are the same categories and percentile values for temperate marine water
Source: from WHO 1999

Conclusions

The bacterial quality of urban receiving waters is usually of great interest because of the very high levels of indicator microorganisms that occasionally are detected, and the elevated levels that are commonly detected. There is little evidence to support a workable relationship between indicator organisms and pathogens in stormwater, however, there is now limited epidemiological evidence that has associated swimming in stormwater contaminated receiving waters with increased disease. There is also increasing evidence of elevated levels of human pathogens in stormwaters, possibly from sanitary sewage contamination. Therefore, even though the traditional indicators of pathogenic contamination are not likely valid for stormwaters, pathogens may still be commonly present in stormwaters and urban receiving waters, at least associated with inadvertent contamination.

The history of the development of receiving water use guidelines and standards for contact recreation, as briefly outlined in this paper, indicates how indicators and pathogens at levels commonly found in urban waters may increase disease. Again, this is becoming apparent through epidemiological studies that have examined waters contaminated with separate stormwaters and with no obvious sanitary sewage sources. It has become increasingly possible to directly monitor microorganisms that are thought to be more specifically related to fecal contamination, and to directly measure pathogens in receiving waters. It is therefore important that additional data be collected and that sources of pathogens, along with their fates, be identified in urban waters so that accurate risk assessments and control strategies can be developed. This is especially critical as children are the ones most likely to be exposed to these contaminated waters during casual play activities.

Table 13. Microbiological Quality of Water, Guidelines and Standards from Several Countries for Primary Contact Recreation (number/100 mL)

	Total Coliforms	Fecal Coliforms	Other	References
Brazil	80% <500m	80% <1000m		Brazil Ministerio del Interior 1976
Colombia	1000	200		Colombia, Ministerio de Salud 1979
Cuba	1000[a]	200[a] 90% <400		Cuba, Ministerio de Salud 1986
EEC[b], Europe	80% <500[c] 95% <10,000[d]	80% <100[c] 95% <2000d	Fecal strep. 100[c] Salmonella 0/L[d] Enteroviruses 0 PFU/L[d] Enterococci 90% <100	EEC 1976 CEPPOL 1991
Ecuador	1000	200		Ecuador, Ministerio de Salud Publica 1987
France	<2000	<500	Fecal strep. <100	WHO 1977
Japan	1000			Japan, Environmental Agency 1981
Mexico	80% <1000[f] 100% < 10,000[k]			Mexico, SEDUE 1983
Peru	80% <5000f	80% <1000[f]		Peru, Ministerio de Salud 1983
Poland			*E. coli* <1000	WHO 1975
Puerto Rico		200[h] 80% <400		Puerto Rico, JCA 1983
United States, California	80% <1000[ij] 100% <10,000[k]	200[aj] 90% <400[l]		California State Water Resources Board
United States, EPA			Enterococci 35 (marine) 33 (fresh) *E. coli* 126 (fresh)	EPA 1986 Dufour and Ballentine 1986
Former USSR			E. coli <100	WHO 1977
UNEP/WHO		50% <100[n] 90% <1000[n]		WHO/UNEP 1978
Uruguay		<500[n] <1000[o]		Uruguay, DINAMA 1998
Venezuela	90% <1000 100% <5000	90% <200 100% <400		Venezuela 1978

Notes:
a. logarithmic average for a period of 30 days of at least 5 samples
b. minimum sampling frequency: every two weeks
c. guide
d. mandatory
e. monthly average
f. at least 5 sampler per month

g. minimum of 10 sampler per month
h. at least 5 samples taken sequentially from the waters in a given instance
i. period of 30 days
j. within a zone bounded by the shoreline and a distance of 1000 ft from the shoreline or the 30 ft depth contour, whichever is further from the shoreline
k. not a sample taken during the verification period of 48 hrs should exceed 10,000/100 mL
l. period of 60 days
m. "satisfactory" waters, samples obtained in each of the preceding 5 weeks
n. geometric mean of at least 5 samples
o. not to be exceeded n at least 5 samples

Source: from WHO 1999, adapted from Salas 1998

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