Module 3
Human Health Rish Assessments of Urban Wet Weather Flows

Abstract

High concentrations of likely pathogens and indicator organisms found in urban receiving waters is a common cause of concern. Large amounts of resources are spent attempting to identify and correct their source, while many question the actual public health concerns associated with exposure to these organisms. This paper contains a summary of the historical development of the U.S. water quality standards for pathogens and recent work describing the potential human health effects of stormwater, as contained in a recent EPA report prepared by Lalor and Pitt (1998). This information will enable the reader to more logically appreciate the actual local risks that may be encountered. Future phases of this EPA research will develop and test methods for communities to assess local risk to humans and the environment associated with exposure to stormwater and sewage-contaminated receiving waters.

Introduction

The main purpose of treating wet weather flow discharges is to reduce its adverse impacts on receiving water beneficial uses. Therefore, it is important in any urban wet weather flow study to assess the detrimental effects that runoff is actually having on a receiving water. Urban receiving waters may have many beneficial use goals, 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)
- water supply

With full development in an urban watershed and with no stormwater controls even in a separatly sewered area, it is unlikely that any of these uses can be satisfactorily obtained. With less development and with the application of stormwater controls, some uses may be possible. It is important that unreasonable expectations not be placed on urban waters, as the cost to obtain these uses may be prohibitive. With full-scale development and lack of adequate stormwater controls, severely degraded streams will be common. However, stormwater conveyance and aesthetics should be the basic beneficial use goals for all urban waters. Aquatic life uses should also be a goal, but with the realization that the natural stream ecosystem will be severely modified with urbanization. Certain basic controls, installed at the time of development, plus protection of stream habitat, may enable partial use of some of these basic goals in urbanized watersheds. Careful planning and optimal utilization of stormwater controls are necessary to obtain these basic goals in most watersheds. Water contact recreation, consumptive fisheries, and water supplies are probably not appropriate goals for most urbanized watersheds, however, due to the likely high concentrations of potential pathogens. However, these higher uses may be possible in urban areas where the receiving waters are large and drain mostly undeveloped areas.

Water Environment & Technology (1996a) reported that the latest National Water Quality Inventory released by the EPA only showed a slight improvement in the attainment of beneficial uses in the nations waters. Urban runoff was cited as the leading source of problems in estuaries, with nutrients and bacteria as the leading problems. Problems in rivers and lakes were mostly caused by agricultural runoff, with urban runoff the third ranked source for lakes, and the fourth ranked source for rivers. Bacteria, siltation, and nutrients were the leading problems in the nations rivers and lakes.

Pathogens found in stormwater from separate drainage systems are a significant concern potentially affecting human health. The use of indicator bacteria is controversial for stormwater, as well as the assumed time of typical exposure of swimmers to contaminated receiving waters. However, recent epidemiological studies has shown significant health effects associated with stormwater contaminated marine swimming areas. Protozoa pathogens, especially associated with likely sewage-contaminated stormwater, is also of public health concern.

There are several mechanisms where stormwater exposure can cause potential human health problems. These include exposure to stormwater contaminants at swimming 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. Understanding the risks associated with these exposure mechanisms is difficult and not very clear. Receiving waters where human uses are evident are usually very large and the receiving waters are affected by many sanitary sewage and industrial point discharges, along with upstream agricultural nonpoint discharges, in addition to the local stormwater discharges. In receiving waters only having stormwater discharges, it is well known that inappropriate sanitary and other wastewaters are also discharging through the storm drainage system. These “interferences” make it especially difficult to identify specific cause and effect relationships associated with stormwater discharges alone, in contrast to the many receiving water studies that have investigated ecological problems that can more easily study streams affected by stormwater alone. Therefore, much of the human risk assessment associated with stormwater exposure must use theoretical evaluations relying 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, have been conducted.

Evidence of Sewage Contamination of Urban Streams

Urban stormwater runoff includes waters from many other sources which find their way into storm drainage systems, besides from precipitation. There are cases where pollutant levels in storm drainage are much higher than they would otherwise be because of excessive amounts of contaminants that are introduced into the storm drainage system by various non-stormwater discharges. Additionally, baseflows (during dry weather) are also common in storm drainage systems. Dry-weather flows and wet-weather flows have been monitored during numerous urban runoff studies. These studies have found that discharges observed at outfalls during dry weather were significantly different from wet-weather discharges and may account for the majority of the annual discharges for some pollutants of concern from the storm drainage system.

Obviously, inappropriate discharges must be identified and corrected as part of any effort to clean up urban streams. If these sources are assumed to be non-existent in an area and are therefore not considered in the stormwater management activities, incorrect and inefficient management decisions are likely, with disappointing improvements in the receiving waters. Lalor (1993) and Pitt, *et al.* (1993) developed a strategy for the EPA to support the outfall screening activities required by the NPDES Stormwater Permit Program to identify and correct inappropriate discharges to storm drainage systems.

A number of issues emerged from the individual projects of the U.S. EPA’s Nationwide Urban Runoff Program (NURP) (EPA 1983). One of these issues involved illicit connections to storm drainage systems and was 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 BMP (Best Management Practice) 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 sanitary sewerage through infiltration to the separate storm drainage).

Many of these dry-weather flows are continuous and would therefore also occur during rain-induced runoff periods. Pollutant contributions from the dry-weather flows in some storm drains have been shown to be high enough to significantly degrade water quality because of their substantial contributions to the annual mass pollutant loadings to receiving waters.

In many cases, sanitary sewage is an important component (although not necessarily the only component) of dry weather discharges from storm drainage systems. From a human health perspective (associated with pathogens), it may not require much raw or poorly treated sewage to cause a receiving water problem. However, at low discharge rates, the DO receiving water levels may be minimally affected. The effects these discharges have on the receiving waters is therefore 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 the most at risk from these discharges as dry base flows may be predominately dry weather flows from the drainage systems. In Tokyo (Fujita 1998), for example, numerous instances were found where correcting inappropriate sanitary sewage discharges resulted in the urban streams losing all of their dry-weather flow. In cities that are adjacent to large receiving waters, these discharges likely have little impact (such as DO impacts from Nashville CSO discharges on the Cumberland River, Cardozo, *et al.* 1994). The presence of pathogens from raw, or poorly treated sewage, in urban streams, however, obviously 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.

Epidemiological Studies and 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. The general population often views epidemiology and associated risk assessments with skepticism when risks associated with seemingly everyday activities are quantified, especially when associated with periodic “food scares” that are typically exaggerated or misinterpreted in the press. Technical experts also may feel uncomfortable with the results of epidemiological studies because of the typically very low numbers of affected people in a study population. However, much of the information that is used in developing environmental regulations protecting human health originates with epidemiological studies and a more through understanding of the science of epidemiology would dispel much of the confusion associated with these studies.

Epidemiology has routinely been used to assess risks associated with contaminants in drinking waters. Epidemiology has also recently been used to investigate human health risks associated with swimming in waters contaminated by stormwater. However, Craun, *et al.* (1996) state that the results of environmental epidemiology studies (the assessment of human health effects associated with environmental contaminants, where indicators of disease are mostly studied instead of the disease itself) have provoked controversy. Their excellent review article 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.

Interpreting associations between disease and environmental conditions is based on examining the rate differences (RD), which is the absolute differences in the two rates (incidence rate of disease for the test, or exposed, group minus the incidence rate of disease for the control, or unexposed, group), or the rate ratio (RR), which is the ratio of the rates from the two groups. The odds ratio (OR) is the ratio of the odds of disease of the test group to the odds of disease of the control group, and is interpreted similarly to the rate ratio. If the RR or OR is close to 1.0, there is no association or increased risk between the two groups. If the ratio is 1.8, there is an 80 percent increased risk of disease for the exposed individuals, compared to the unexposed group. The confidence interval of the ratio is used to identify significance of the association. An example 95 percent confidence interval of 1.6 to 2.0 signifies a statistically significant estimate because the range does not include 1.0. The relatively narrow range also implies a precise estimate of the association. In contrast, an example 95 percent confidence interval of 0.8 to 14.5 does not signify a significant difference because the range includes the value of 1.0. In addition, the wide range also implies an imprecise estimate of the association. Craun, *et al.* (1996) presents Table 1 (from Monson 1980) indicating different rate ratios and strengths of associations. Weak associations (ratios of <1.5) are difficult to interpret. Very large range ratios are unlikely to be completely explained by unidentified or uncontrolled confounding characteristics. However, the magnitude of the rate ratio has no bearing on the likelihood that the association is attributed to bias, but causal association cannot be ruled out simply because of a weak association. In many environmental epidemiological studies, the rate ratio is frequently smaller than 1.5, causing speculation that the association may actually be caused by bias. Craun, *et al.* (1996) concluded that “high quality exposure and study design are important for interpreting risks of this magnitude.”

Table 1. Rate Ratios and Strengths of Associations for Epidemiological Studies (Monson 1980)

Rate Ratio, or Odd Ratio	Strength of Association

1.0	None
>1.0 to <1.5	Weak
1.5 to 3.0	Moderate
3.1 to 10.0	Strong
>10.0	Infinite

Water Contact Recreation and Urban Stormwater

There have been a few epidemiology studies recently published describing the increased health risks associated with contaminated dry weather flows affecting public swimming beaches. The following discussion presents an overview of the development of water quality criteria for water contact recreation, plus the results of several epidemiological studies that have specifically examined human health problems associated with swimming in contaminated water, including water affected by stormwater. In most cases, the levels of indicator organisms and pathogens (see O'Shea and Field 1992a and 1992b) causing increased illness were well within the range found in urban streams only affected by stormwater.

Development of Bathing Beach Bacteriological Criteria and Associated Epidemiological Studies

Human health standards for body contact recreation (and for fish and water consumption) are based on indicator organism monitoring. Monitoring for the actual pathogens, with few exceptions, requires an extended laboratory effort, is very costly and not very accurate. Therefore, the use of indicator organisms has become established. Dufour (1984a) presents an excellent overview of the history of 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 an arbitrary 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.

Dufour points out that a third method used to develop a standard for bathing water quality used an analytical approach adopted by H.W. Streeter in 1951. He used a ratio between *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). 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 (as indicated above, 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 by 1984. It was felt that fecal coliforms was more specific to sewage contamination and had less seasonal variation that total coliforms. 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. Dufour (1984a) points out that, 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 used as a better indicator of fresh fecal contamination. Table 2 indicates the species and subspecies of the Streptococcus and Enterococcus groups of bacteria that are used as indicators of fecal contamination (DHS 1997).

Table 2. 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. equinus		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 a Coney Island beach, designated as barely acceptable, and at a 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 3 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 *Escherichia coli* in the water (about 10 MPN/100 mL) were associated with appreciable attack rates (about 10/10,000 persons).

Table 3. 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. They also felt 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.

They concluded that swimming in even marginally polluted marine bathing water is a significant route of transmission for observed gastrointestinal illness. They felt that 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 4 shows the correlation coefficients for these three bacterial parameters and gastrointestinal disease.

Table 4. Correlation Coefficients for Bacterial Parameters and Gastrointestinal Disease (Fresh Water Swimming Beaches)

	Highly Credible Gastrointestinal Illness	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 additional illness symptoms associated with swimming in contaminated water, besides gastrointestinal illness, and identified other 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 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 5 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 5. 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, was 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 including 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.

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 a significant study in that it was one of the first major epidemiological investigations that has been conducted in subtropical waters. The Hong Kong swimming beach criteria, adopted in 1981, set the following objective: "The level of *E. coli* should not exceed 1,000 per 100 mL, calculated as the running median of the most recent five consecutive samples." Beaches that did not meet this objective for 60% of the time in any year were closed to swimming.

The results of this study can be compared to the more common temperate-area studies as an indication of the usability of recreation water quality criteria for a broader range of conditions. 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 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. Many of the rates were also higher at "barely acceptable" beaches than at "relatively unpolluted" beaches. The increased risk of swimmers developing highly credible gastrointestinal illness (HCGI) was 5 times greater than for non-swimmers. The increased risk for swimmers in 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. They contrasted this finding with typically better correlations between enterococci and health risks at U.S. beaches. They 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. These observations were used to develop new swimming beach standards for Hong Kong, as shown in Table 6. This new classification scheme was in place in 1988.

Table 6. 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). They 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. Luckily, children playing near and in urban streams are not likely to have such prolonged submerged exposures, and gastrointestinal problems may not be as serious as other water contact problems. The risk of respiratory, ear, and eye symptoms accounted wholly for the increases in illness observed. They reported that enteroviruses can cause respiratory symptoms and can persist in marine sediments and waters for many months.

Table 7 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 8 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 7. Percentages of Beachgoers Reporting Symptoms (Corbett, *et al.* 1993)

Illness	Did not swim (n=915)	Swam, low pollution (n=1770)	Swan, 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 8. 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 randomized 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.

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.

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: *Ambient Water Quality Criteria for Bacteria - 1986*, EPA 440/5-84-002, U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, DC., NTIS access #: PB 86-158-045).

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. Common swimming beach problems associated with contamination by stormwater include skin and ear infections caused by *Pseudomonas aeruginosa* and *Shigella*.
National bacteria criteria have been established for contact with bacteria and are shown in Table 9. State standards usually also exist for fecal coliform bacteria. Typical public water supply standards (Alabama's are shown) are as follows:

(i) Bacteria of the fecal coliform group shall not exceed a geometric mean of 2,000/100 mL; nor exceed a maximum of 4,000/100 mL in any sample. The geometric mean shall be calculated from no less than five samples collected at a given station over a 30-day period at intervals not less than 24 hours. The membrane filter counting procedure will be preferred, but the multiple tube technique (five-tube) is acceptable.

(ii) For incidental water contact and recreation during June through September, the bacterial quality of water is acceptable when a sanitary survey by the controlling health authorities reveals no source of dangerous pollution and when the geometric mean fecal coliform organism density does not exceed 100/100 mL in coastal waters and 200/100 mL in other waters. When the geometric mean fecal coliform organism density exceeds these levels, the bacterial water quality shall be considered acceptable only if a second detailed sanitary survey and evaluation discloses no significant public health risk in the use of such waters. Waters in the immediate vicinity of discharges of sewage or other wastes likely to contain bacteria harmful to humans, regardless of the degree of treatment afforded these wastes, are not acceptable for swimming or other whole body water-contact sports.

Standards for fish and wildlife waters are similar to the above standard for a public water supply, except part (i) has different limits: "Bacteria of the fecal coliform group shall not exceed a geometric mean of 1,000/100 mL on a monthly average value; nor exceed a maximum of 2,000/100 mL in any sample." Part (ii) is the same for both water beneficial uses.

The EPA full body contact recreation water quality criteria are as follows:

Marine waters: "Based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the enterococci densities should not exceed 35 per 100 mL." (EPA 1986)

Fresh waters: "Based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the bacterial densities should not exceed one or the other of the following (Note that only one indicator should be used. The regulatory agency should select the appropriate indicator for its conditions.):

E. coli, at a concentration of 126 per 100 mL, or
Enterococci, at a concentration of 33 per 100 mL." (EPA 1986)

Table 9. U.S. EPA Water Quality Criteria for Swimming Waters

	Marine Waters	Fresh Waters
Main EPA research reference	Cabelli 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

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.

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 10. As an example, the rate ratio (RR) for fever was 1.6, while it was 2.3 for ear discharges, and 2.2 for highly credible gastrointestinal illness comprised of vomiting and fever (HCGI). The approximated associations were weak for any of the symptoms, and moderate for the others listed. 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 10. 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 11 shows the heath 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 11. 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	46%	1.46	Weak	149
	nasal congestion	24%	1.24	Weak	211
Enterococcus (>106 cfu/100 mL)	Diarrhea w/blood and	323%	4.23	Strong	27
	HCGI-1	44%	1.44	Weak	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 12. 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 considerable with distance from the storm drains. Upcoast bacteria densities were less than downcoast densities probably because of prevailing near-shore currents.

Table 12. 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 will 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.

Proposed New California Recreational Area Bacteria Standards

In November of 1997, the State of California proposed new bacterial criteria for fresh and saltwater recreational areas (DHS 1997). 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. Levels indicating a need for additional attention (they suggested conducting sanitary surveys to identify and correct the sources of contamination) in both salt waters and freshwaters are:

Total coliforms: 1,000 per 100 mL (single sample), or
1,000 per 100 mL, in more than 20 percent of the samples at any sampling station, in any 30-day period [Title 17 California Code of Regulations, Section 7958]

Fecal coliforms: 200 per 100 mL, or
200 per 100 mL, based on the log mean of at least 5 equally spaced samples in a 30-day period (EPA 1986)

In addition, when the local health officer considers enterococcus monitoring for supplemental information, the following levels are also recommended:

Enterococcus (salt water): 35 per 100 mL (single sample), or
35 per 100 mL, based on the log mean of at least 5 equally spaced samples in a 30-day period.

Enterococcus (freshwater): 33 per 100 mL (single sample), or
33 per 100 mL, based on the log mean of at least 5 equally spaced samples in a 30-day period.

Freshwater swimming areas could also be monitored for *E. coli* to provide additional supplemental information. In that case, the following level indicating a need for more attention is also provided:

E. coli: 126 per 100 mL (single sample), or
126 per 100 mL (log mean of samples over a 30-day period (EPA 1986)

Salt water beach closure is recommended when sampling indicates any of the following conditions, when confirmed within 24 to 48 hours:

Total coliforms: 10,000 per 100 mL (17 California Code of Regulations, Section 7958)

Total coliforms: 5,000 per 100 mL, if the coliform index (the ratio of fecal to total coliform counts, times 100) is 20, or more

Fecal coliforms: 1,000 per 100 mL

When enterococcus monitoring is also used, the following closure level is recommended:

Enterococcus: 104 per 100 mL (EPA 1986)

Freshwater recreational areas should be closed whenever any of the following conditions are exceeded, when confirmed within 24 to 48 hours:

Total coliforms: 10,000 per 100 mL

Fecal coliforms: 400 per 100 mL (EPA 1986)

When enterococcus or *E. coli* monitoring is also used, the following closure level is recommended:

Enterococcus: 61 per 100 mL (EPA 1986)

E. coli: 235 per 100 mL (EPA 1986)

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.”

Other Human Health Risks Associated with Protozoa and other Microorganisms

Protozoa became an important public issue in the U.S. with the 1993 *Cryptosporidium*-caused disease outbreak in Milwaukee, Wisconsin, when about 400,000 people become ill from drinking contaminated water. Mac Kenzie, *et al*. (1994) prepared an overview of the outbreak, describing the investigation on the causes of the illness and the number of people affected. They point out that *Cryptosporidium*-caused disease in humans was first documented in 1976, but had received little attention and no routine monitoring. *Cryptosporidium* now is being monitored routinely at many areas and is the subject of much research concerning its sources and pathways. At the time of the Milwaukee outbreak, both of the city’s water treatment plants (using water from Lake Michigan) were operating within acceptable limits, based on required monitoring. However, at one of the plants (which delivered water to most of the infected people), the treated water experienced a large increase in turbidity (from about 0.3 NTU to about 1.5 NTU) at the time of the outbreak that was not being well monitored (the continuous monitoring equipment was not functioning, and values were only obtained every 8 hours). More than half of the residents receiving water from this plant became ill. The plant had recently changed its coagulant from polyaluminum chloride to alum and equipment to assist in determining the correct chemical dosages was not being used. The finished water had apparently relatively high levels of cryptosporidium because some individuals became ill after only drinking less than 1 L of water. *Cryptosporidium* oocysts have often been found in untreated surface waters, and it was thought that *Cryptosporidium* oocysts entered the water treatment supply before the increase in turbidity was apparent. Mac Kenzie, *et al.* (1994) point out that monitoring in the United Kingdom has uncovered sudden, irregular, community-wide increases in cryptosporidiosis that were likely caused by waterborne transmission. They also stated that the source of the *Cryptosporidium* oocysts was speculative, but could have included cattle feces contamination in the Milwaukee and Menomonee Rivers, slaughterhouse wastes, and human sewage. The rivers were also swelled by high spring rains and snowmelt runoff that may have aided the transport of upstream *Cryptosporidium* oocysts into the lake near the water intakes.

The Journal of the American Water Works Association has published numerous articles on protozoa contamination of drinking water supplies. Crockett and Haas (1997) describe a watershed investigation to identify sources of *Giardia* and *Cryptosporidium* in the Philadelphia watershed. They describe the difficulties associated with monitoring *Cryptosporidium* and *Giardia* in surface waters because of low analytical recoveries and the cost of analyses. Large variations in observed protozoa concentrations made it difficult to identify major sources during the preliminary stages of their investigations. They do expect that wastewater treatment plant discharges are a major local source, although animals (especially calves and lambs) are likely significant contributors. Combined sewer overflows had *Giardia* levels similar to raw sewage, but the CSOs were much less than the raw sewage for *Cryptosporidium*. LeChevallier, *et al*. (1997) investigated *Giardia* and *Cryptosporidium* in open reservoirs storing finished drinking water. This gave them an opportunity to observe small increases in oocyst concentrations associated from nonpoint sources of contamination from the highly controlled surrounding area. They observed significantly larger oocyst concentrations at the effluent (median values of 6.0 *Giardia*/100 L and 14 *Cryptosporidium*/100 L) in the reservoirs than in the influents (median values of 1.6 *Giardia*/100 L and 1.0 *Cryptosporidium*/100 L). No human wastes could influence any of the tested reservoirs and the increases were therefore likely caused by wastes from indigenous animals or birds, either directly contaminating the water, or through runoff from the adjacent wooded areas.

A Management Training Audioconference Seminar on *Cryptosporidium* and Water (MTA 1997) was broadcast in May of 1997 to familiarize state and local agencies about possible *Cryptosporidium* problems that may be evident after the EPA’s Information Collection Rule begins in July of 1997. This regulation will require all communities serving more than 100,000 people to monitor their source water for *Cryptosporidium* oocysts. If the source water has more than 10 *Cryptosporidium* oocysts per liter, then the finished water must also be monitored. It is likely that many source waters will be found to be affected by cryptosporidium. They reviewed one study that found the percentage of positive samples of *Cryptosporidium* in lakes, rivers, and springs was about 50 to 60% and about 5% in wells. In contrast, the percentage of samples testing positive for *Giardia* was about 10 to 20% in lakes and rivers, and very low in springs and wells.

Special human health concerns have also been recently expressed about *Pfiesteria piscicida*, a marine dinoflagellate that apparently is associated with coastal eutrophication caused by runoff nutrients (Maguire and Walker 1997). This organism has gathered much attention in the popular press, usually called the “cell from hell” (Zimmerman 1998). It has been implicated as causing symptoms of nausea, fatigue, memory loss, and skin infections in south U.S. Atlantic coastal bay watermen. *Pfiesteria* and *Pfiesteria*-like organisms have also been implicated as the primary cause of many major fish kills and fish disease events in Virginia, Maryland, North Carolina, and Delaware. In August of 1997, hundreds of dead and dying fish were found in the Pocomoke River, near Shelltown, Maryland, in the Chesapeake Bay, prompting the closure of a portion of the river. Subsequent fish kills and confirmed occurrences of *Pfiesteria* led to further closures of the Manokin and Chicamacomico Rivers. The Maryland Department of Health and Mental Hygiene also presented preliminary evidence that adverse public health effects could results from exposure to the toxins released by *Pfiesteria* and *Pfiesteria*-like organisms. The increasing numbers of fish kills of Atlantic menhaden (an oily, non-game fish) motivated Maryland's governor to appoint a Citizens *Pfiesteria* Action Commission. The Commission conveyed a forum of noted scientists to examine the existing information on *Pfiesteria.* The results of the forum were adopted by the Commission and included in its final report (available on the Maryland Department of Natural Resources' website).

Pfiesteria has a complex life cycle, including at least 24 flagellated, amoeboid, and encysted stages. Only a few of these stages appears to be toxic, but their complex nature makes them difficult to identify by nonexperts (Maguire and Walker 1997). *Pfiesteria* spends much of its life span in a nontoxic predatory form, feeding on bacteria and algae, or as encysted dormant cells in muddy sediment. Large schools of oily fish (such as the Atlantic menhaden) trigger the encysted cells to emerge and excrete toxins. These toxins make the fish lethargic, so they remain in the area where the toxins attack the fish skin, causing open sores to develop. The *Pfiesteria* then feed on the sloughing fish tissue. Unfortunately, people working in the water during these toxin releases may also be affected (Zimmerman 1998).

Researchers suggest that excessive nutrients (causing eutrophication) increase the algae and other organic matter that the *Pfiesteria* and Atlantic menhaden use for food. The increased concentrations of *Pfiesteria* above natural background levels increase the likelihood of toxic problems. Maguire and Walker (1997) state that other factors apparently involved include stream hydraulics, water temperature, and salinity. They feel that *Pfiesteria* is only one example of the increasing threats affecting coastal ecosystems that are experiencing increased nutrient levels. Most of the resulting algal blooms only present nuisance conditions, but a small number can result in human health problems (mostly as shellfish poisonings). The increased nutrient discharges are mostly associated with agricultural operations, especially animal wastes from large poultry and swine operations. In the Pocomoke River watershed, the Maryland Department of Natural Resources estimates that about 80% of the phosphorus and 75% of the nitrogen load is from agricultural sources. Urban runoff may also be a causative factor of eutrophication in coastal communities, especially those having small enclosed coastal lagoons or embayments, or in rapidly growing urban areas. Zimmerman (1998) points out that the Chesapeake Bay area is one of the country's most rapidly growing areas, with the population expected to increase by 12 percent by the year 2010.

Drinking Water Risks and Urban Stormwater

The National Research Council conducted an intensive review of the use of waters of impaired quality for groundwater recharge (Andelman, *et al.* 1994). Included in this book was a review of the use of stormwater to recharge groundwater for eventual use as a drinking water supply. Other potential source waters investigated for recharge included treated municipal wastewater and irrigation return flows. The following is a summary from that book, describing these potential human health risks associated with stormwater.

Various chemical and bacteriological health risks associated with stormwater were examined. The major risks were identified as originating from pathogenic organisms, disinfection byproducts for water that have undergone disinfection to reduce the threat from the pathogens, synthetic organic chemicals, and inorganic chemicals. Assessments are therefore needed to identify the potential risks associated with this reuse. These assessments contain four major components: hazard identification, dose-response assessment, exposure assessment, and risk characterization. The NRC committee reviewed available epidemiological studies that had investigated the use of degraded waters for recharge and as eventual drinking water supplies.

Table 13, summarized from the NRC report, lists the health effects of known chemicals found in urban stormwater. The health effects shown are not meant to be comprehensive, but are the problems that the drinking water standards are intended to protect against. The EPA carcinogen classifications are as follows:

A = sufficient evidence for humans
B1 = limited evidence for humans and sufficient evidence in experimental animals
B2 = inadequate/limited evidence for humans, sufficient evidence in experimental animals
C = limited evidence in experimental animals with no human data
D = inadequate or no data
E = sufficient evidence for noncarcinogenicity

The concentrations presented are summarized from the EPA's Nationwide Urban Runoff Program (NURP) (EPA 1983) and show the percentage of samples where the toxicant was detected and the range of the detected values. The maximum contaminant level (MCL) is the drinking water standard established by the EPA. Also shown (in parentheses) is the concentration associated with a cancer risk of 1 in a million, the generally recognized negligible risk level. The present background cancer occurrence rate in the U.S. is 25%. This 10^{-6} risk level, associated with a lifetime exposure to a chemical, will increase the risk of getting cancer from 250,000 in 1 million to 250,001 in 1 million (Andelman, *et al.* 1994). The reference dose is the estimated daily dose that is likely to be without an appreciable risk of deleterious effects during a lifetime (expressed as mg of ingested chemical per day per kg of body weight).

Most of the listed toxicants exceed the MCL limits and the negligible risk levels (highlighted in bold). However, most of the toxicants are associated with particulates and the MCL values are not directly applicable. In addition, drinking of undiluted, untreated stormwater is not likely.

Microorganisms of concern in drinking waters may include many different types of pathogens, including bacteria, viruses, and parasites. These are excreted from infected hosts and enter sanitary sewage. Stormwater and urban receiving waters can become contaminated with these pathogens, as noted earlier. Andelman, *et al.* (1994) reviewed waterborne disease outbreaks in the U.S. from 1971 through 1990. The most common identified causative agents were *Giardia*, chemical poisoning, and *Shigella* species. During this period, the causative agents in more than 50% of the outbreaks were not able to be identified. However, reviews of past outbreaks found that the Norwalk virus (causing acute nonbacterial gastroenteritis) was the likely cause of about 40% of the outbreaks from 1976 through 1980 that had no prior identified cause. The difficulty or inability to identify many of the viruses and parasites (such as *Cryptosporidium*) is the likely reason why they are not listed as a more common cause of illness from drinking contaminated water.

Dose-response information is usually determined by exposing volunteers to different doses of the microorganisms of interest. Normally, this data does not include special problems for special at-risk individuals. Table 14 (as reported in the NRC committee report) shows infective dose information for several pathogens. Table 15 shows the probability of infection of ingestion of 100 mL of water for various levels of contamination. The levels of these microorganisms in stormwater can be much greater than the values shown on this table (enterviruses of 100 to 3000 pfu/100 L, for example was reported by Olivieri, *et al.* 1977). Of course, ingestion of untreated or undiluted stormwater is rare.

Table 13. Health Effects of Toxicants Found in Stormwater (Andelman, *et al.* 1994 and EPA 1983)

Chemical	Health Effects: Human	Health Effects: Animal/In Vitro	EPA Carcinogen classification	Reported frequency of detection (%) and observed concentrations (μg/L) (EPA 1983, NURP)		Max. contaminant level (MCL) μg/L (10^{-6} cancer risk)	Reference dose (mg/kg/day)
Pesticides:							
Lindane		Morphological changes of kidney and liver cells	C	15	0.007 – 0.1	0.2	0.0003
Chlordane		Liver hypertrophy (regional)	B2	17	0.01 – **10**	0.2 (0.03)	0.00006
Polyaromatic hydrocarbons:							
Fluoranthene		Nephrapathy; increased liver weight; hematologic alterations; clinical effects (increased SGPT levels)		16	0.3 – 21	-	0.04
Other organics:							
Pentachlorphenol		Liver and kidney pathology, feto-maternal toxicity	B2	19	**1** – **115**	1 (0.3)	0.03
Inorganics:							
Antimony	Gastrointestinal effects	Liver and kidney effects	D	13	2.6 – **23**	6	0.0004
Arsenic	Skin (hyperpigmentation, keratosis); vascular complications; neurotoxicity; liver injury	Reproductive/developmental effects; chromosomal effects	A	52	**1** – **51**	50 (0.000002)	0.0003
Beryllium	Contact dermatitis; pulmonary effects	Skeletal effects; genotoxicity	B2	12	**1 – 49**	4 (0.008)	0.005

Cadmium	Pulmonary and renal tubular effects; skeletal changes associated with effects on calcium metabolism	Reproductive/teratogenic effects; effects on myocardium	D	48	0.1 – **14**	5	0.0005
Chromium	Renal tubular necrosis	Genotoxicity	D	58	1 – **190**	100	0.005
Cyanide	Nausea, confusion, convulsion, paralysis, coma, cardiac arrhythmia, respiratory stimulation followed by respiratory failure		D	23	2 – **300**	200	0.022
Mercury	Nervous system effects; kidney effects	Genotoxicity	D	10	0.6 – 1.2	2	0.0003
Nickel	Contact dermatitis	Reproductive effects; genotoxicity	D	43	1 – **182**	100	0.005
Selenium	Nail changes; hair loss; skin lesions; nervous system effects	Reproductive effects, genotoxicity		11	2 – **77**	50	0.005
Zinc	Gastrointestinal distress; diarrhea	Poor growth	D	94	10 - 2400	-	0.3

Table 14. Values Used to Calculate Risks of Infection, Illness, and Mortality from Selected Enteric Microorganisms (Andelman, *et al.* 1994).

	Probability of infection from exposure to one organism (per one million)	Ratio of clinical illness to infection (%)	Mortality rate (%)	Secondary spread (%)
Campylobacter	7,000			
Salmonella typhi	380			
Shigella	1,000			
Vibrio cholerae	7			
Coxsackieviruses		5 – 96	0.12 – 0.94	76
Echoviruses	17,000	50	0.27 – 0.29	40
Hepatitis A virus		75	0.6	78
Norwalk virus			0.0001	30
Poliovirus 1	14,900	0.1 – 1	0.9	90
Poliovirus 3	31,000			
Rotavirus	310,000	28 – 60	0.01 – 0.12	
Giardia lamblia	19,800			

Table 15. Probability of Infection from Ingestion of 100 mL of Water Contaminated with Viruses or Protozoa

Levels in ingested water (per 100 L)	Exposure per 100 mL	Estimated risk of infection in exposed population

Rotavirus		
0.01 pfu	1.0×10^{-5}	6.2×10^{-6}
0.13 pfu	1.3×10^{-4}	6.0×10^{-5}
Echovirus		
0.01 pfu	1.0×10^{-5}	2.0×10^{-8}
0.13 pfu	1.3×10^{-4}	2.7×10^{-7}
Giardia		
0.49 cysts	4.9×10^{-4}	9.8×10^{-6}
0.89 cysts	8.9×10^{-4}	1.88×10^{-5}
1.67 cysts	1.77×10^{-3}	3.3×10^{-5}
3.3 cysts	3.3×10^{-3}	6.6×10^{-5}
Cryptosporidium		
0.75 oocysts	7.5×10^{-4}	1.5×10^{-5}
5.35 oocysts	5.35×10^{-3}	1.1×10^{-4}

Craun, *et al.* (1997) conducted evaluations of waterborne disease outbreaks from public water supplies and found that coliform bacteria monitoring is likely adequate to protect against bacterial and viral illness, but not for protozoa associated illness. Coliform bacteria monitoring has been used for many years to assess the microbiological quality of drinking waters. Except for a few strains, coliforms are not considered pathogenic. They are not very specific to fecal contamination, as most species of coliforms are free-living in the environment. Tap water having no coliforms has generally been thought to be free of agents likely to cause waterborne disease. However, Craun, *et al*. (1997) found that disease outbreaks (especially associated with *Giardia* or *Cryptosporidium*) have occurred in water systems that have not violated the maximum contaminant levels for total coliforms. The 1989 Coliform Rule for drinking waters states that systems collecting fewer than 40 samples per month may have no more than one total coliform positive sample (per 100 mL of water) per month, systems collecting more samples must have fewer than 5% of their samples positive for total coliforms. When Craun, *et al.* (1997) reviewed information from reported waterborne disease outbreaks from 1983 to 1992, they found that coliforms were detected during most of the outbreaks that were caused by bacteria, viruses, and unidentified agents, but they were found only during few of the outbreaks caused by protozoa. As an example, the 1993 Milwaukee *Cryptosporidium* outbreak (the largest documented waterborne disease outbreak in the U.S., with 400,000 cases of illness reported) occurred even though the MCL for coliforms was not violated. It is known that total coliforms are more susceptible to disinfection during water treatment than some protozoa. They concluded that "microbiological monitoring alone (for total coliforms and other indicator organisms for pathogens) cannot safeguard the public against waterborne disease. Emphasis must also be given to source water protection (watershed control programs, better control of wastewater discharges, and wellhead protection programs) and adequate water treatment and operation. The 1989 coliform rule with its more stringent requirements (periodic sanitary surveys, procedures for *E. coli* testing, and extra samples to evaluate water quality after positive total coliform results) and other USEPA regulations (e.g. the Surface Water Treatment Rule, and the pending Enhanced Surface Water Treatment Rule) are all important for reducing the risks of waterborne disease."

Conclusions

There is evidence that water contact recreation in sewage contaminated reveiving waters causes significant increases in the incidence of various diseases. More recent epideomological studies have also shown increased risk in swimming in waters only affected by stormwater. Small and medium sized urban receiving waters typically have large concentrations of many indicator organisms. It is likely that important quantities of pathogens are also present. Inadverent or casual exposure, especually by children playing around and in urban waters, may be cause for increased illness.

The Department of Civil and Environmental Engineering at the University of Alabama is conducting a multi-phase research project for the U.S. EPA to develop and test an assessment strategy to identify inappropriate discharges to urban receiving waters. A number of experiments and field studies were conducted during the initial project phase. The methods developed included experiments of *in situ* bacteria/pathogen longevity, photosynthesis and respiration in sewage contaminated water, and the interaction between water column pollutants, contaminated sediments and interstitial waters. Methods were evaluated for the sampling of interstitial water, and the measurement of frequency, duration and magnitude of wet weather flow events. Laboratory methods were also developed or modified for organic extraction and analysis of urban stream sediments affected by SSOs, and for the detection and quantification of a variety of pathogens in sanitary sewage or polluted receiving streams. Initial field studies of SSO contaminated receiving waters in Birmingham, Alabama were also carried out to directly measure the fate and resultant exposure of pathogens (along with nutrients and toxicants).

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