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# THE DETECTION AND DISINFECTION OF PATHOGENS IN STORM-GENERATED FLOWS

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## ABSTRACT

A recreational water's disease-producing potential is usually assessed by bacterial indicators of human fecal contamination, however many of these indicator bacteria also originate from soils, vegetation, and animal feces. Stormwater runoff can contain high densities of the nonhuman indicator bacteria and epidemiological studies of recreational waters receiving stormwater runoff have found little correlation between indicator densities and swimming related illnesses. In addition a number of non-enteric pathogens found in stormwater runoff have been linked to respiratory illnesses and skin infections, a risk which is not assessed by the present fecal indicators. Therefore, for receiving waters with predominantly stormwater discharges, the current bacterial indicators are not suited to accurately assess the water's total illness producing capacity. The intermittent and irregular nature of stormwater discharges causes unique disinfection requirements which are discussed in connection with present practices and developments. The need for epidemiological studies to assess the risk from nonhuman and non-enteric pathogens is recommended.

## KEYWORDS

Stormwater, disinfection, microorganisms, water-quality indicators.

## HISTORICAL PERSPECTIVE OF BACTERIAL INDICATORS

The difficulty and expense associated with the isolation and measurement of specific pathogens in water has resulted in the development of methods to monitor certain indicator organisms, i.e., microorganisms indicative of the presence of fecal contamination. Bacteria of the total coliform (TC) group became the generally accepted indicator for fecal pollution, but includes different genera which do not all originate from fecal wastes (e.g., *Citrobacter, Klebsiella,* and *Enterobacter).*

An improvement over the TC test is the more selective fecal coliform (FC) test, which selects primarily for *Klebsiella* and *Escherichia coli (E. coli)* bacteria. *E. coli* is the bacteria of interest because it is a consistent inhabitant of the intestinal tract of humans and other warm-blooded animals. The FC test though, is still not specific to enteric bacteria, and human-enteric bacteria in particular.

The most widely used bacteriological criteria in the United States is the maximum of 200 FC/100 ml. However, the following brief review illustrates, the lack of epidemiological evidence to support this criteria.

Studies of gastrointestinal (GI) illness in swimmers in the early 1950s found that TC densities between 2,300 and 2,400/100 ml caused a significantly higher incidence of symptoms. Later, as FC became the favored indicator for sanitary wastewater, early TC data collected on the Ohio River were reevaluated to determine a

FC/TC ratio of approximately 0.18. This ratio, plus a safety factor of 0.5, was applied to the TC densities known to produce health effects, and an average criterion of 200 FC/100 ml was generated. This value was believed to provide bathers adequate protection from pathogenic contamination and was recommended by the U.S. Public Health Service in 1968.

In a 1976 report (U.S. Environmental Protection Agency 1976) the EPA reinforced the original 1968 criteria of 200 FC/100 ml for recreational waters despite numerous criticisms of its deficiencies. The 1976 report acknowledged that epidemiological evidence to support the criterion was lacking but concluded that FC levels remained the best measure of microbiological water quality because of problems associated with the detection of other indicators or pathogenic microorganisms.

In the early 1980s, the EPA conducted two studies of marine (Cabelli 1983) and freshwater (Dufour 1984) which aimed to determine the relationship between GI swimming disorders and densities of FC, enterococci, and *E. coli.*

The marine study concluded that enterococci would be superior to *E. coli* as an indicator of fecal pollution at ocean beaches. The freshwater study found that both enterococci and *E. coli* densities displayed an excellent relationship to GI illness rates, *E. coli* exhibited the higher correlation coefficient and a lower standard error. Additional factors favoring *E. coli* as the indicator of choice for freshwater included: 1) its often higher density than enterococci both in human feces and sanitary wastewater effluent, and 2) its apparent hardiness in freshwater, relative to that of enterococci.

The results of both studies clearly confirmed that the rate of GI illness increased with fecal contamination. However, in statistically evaluating the relationship between FC densities and GI disorders, both studies found that FC densities were unrelated to swimming associated gastroenteritis. The implication of these results was best summarized in the freshwater report which states: "Bacteria from sources other than the gastrointestinal tract of man and other warm-blooded animals, which fit the definition of fecal coliform...are present at densities high enough to sufficiently eliminate the usefulness of fecal coliform as an indicator of fecal contamination of surface waters."

A 1986 EPA publication (U.S. Environmental Protection Agency 1986) recommended that states "begin the transition process to the new (*E. coli* and enterococci) indicators." However despite the lack of correlation between TC and FC levels and swimming related illness and this recommendation, many states still retain the TC and FC criteria first recommended in 1986.

## STORMWATER QUALITY AND ITS RELATIONSHIP TO HUMAN-DISEASE POTENTIAL

Receiving waters contaminated by discharges of sanitary wastewater alone or in combination with stormwater present a potential health hazard, and the choice of either FC or TC densities as an indicator of pathogens may be satisfactory.

The extent of contamination of receiving waters by separate stormwater discharges will be heavily influenced by watershed characteristics (e.g., rural or urban) and the degree of storm drain contamination by non-stormwater entries (e.g., sanitary wastewater cross-connections).

Regardless of the extent of stormwater contamination it could be argued that stormwater discharges present little threat to swimmers because: stormwater generally has low densities of pathogenic microorganisms; these are further diluted on reaching the recreational waters; and large infective doses of bacteria are required to be ingested for infection. However there are still health hazards from pathogens such as *P. aeruginosa, Salmonella Typhosa, Shigella,* or enteroviruses that either do not require ingestion for infection, or require very low infective doses.

Several studies (Geldreich *et al.* 1968; Geldreich 1978; Fukushima and Gomyoda 1991; Madore *et al.* 1987; Pitt 1983) have isolated animal associated enteric viruses and bacteria that can be transmitted to humans, (e.g., *Yersinia, Cryptosporidium,* and *Salmonella.*) in stormwater or surface waters in urban, rural, and agricultural watersheds. These findings indicate that the disease-causing potential of these sources cannot be neglected. However, few epidemiological studies have attempted to correlate incidence of GI or total illness with FC densities arising primarily from non-human sources as found in stormwater runoff uncontaminated by sanitary wastewater. Such studies, undertaken for a variety of watershed types, are necessary to insure that the continued reliance upon coliform indicators to determine water quality criteria for recreational waters receiving stormwater does not erroneously hinder their recreational usage.

To date, only one well documented study (Calderon *et al.* 1991) has been conducted that has addressed diseases which may result from direct contact with bathing waters whose sole source was rainwater runoff from a forested watershed. This study used epidemiological data to compare the health status of swimmers utilizing the waters during wet-weather periods with that of non-swimmers. The study site was a freshwater pond with no known source of human fecal contamination. Water samples were analyzed for *E. coli,* enterococci, *P. aeruginosa,* staphylococci, and FC. Data on rainfall, bather density, and the occurrence of GI illness among the monitored families were also collected.

Monitoring results indicated that the densities of *E. coli* and FC were over two times greater on rain days than on non-rain days, while for enterococci the ratio was four. These three fecal related indicators also exhibited significant correlation with each other, i.e., when one increased in density, the other two also increased. Conversely, staphylococci densities were related to bather density but not to any of the fecal indicator bacteria or to rainfall. No correlation was similarly observed between indicator bacteria levels and bather density. No association existed between the rate of GI illness and high fecal indicator bacteria, but GI illness rates were observed to be strongly associated with swimming. In addition, a significant association was observed between swimming associated illnesses and high densities of staphylococci or high densities of bathers. The authors concluded that the reported illnesses were probably due to agents transmitted from swimmer to swimmer, and were not related to wet-weather discharges. The high densities of the three fecal indicators, which could be correlated with daily rainfall levels, were attributed to the presence of warm blooded animals in the wooded areas surrounding the pond.

The results of this study are consistent with earlier work (Seyfried *et al.* 1985a, 1985b) that documented GI and total illness amongst 8400 swimmers and non-swimmers at 10 freshwater beaches in Ontario using total staphylococci, fecal streptococci, FC, heterotrophic bacteria, and *P. aeruginosa* as indicators. The findings indicated total staphylococci densities possessed the strongest dose-response relationship and proved to be the most consistent indicator of total illness as well as eye and skin disease.

It is important to note that the bacterial content of separate stormwater is predominantly from non-human sources. Also a significant portion of swimming related illnesses are associated with exposure to non-enteric pathogens, (e.g., staphylococcus, *Pseudomonas aeruginosa, Klebsiella* and adenoviruses) which can result in infections of the skin, ears, eyes, and upper respiratory tract.

Therefore the use of TC and FC tests, which were originally developed as indicators of human fecal contamination, may not be appropriate for receiving waters accepting separate stormwater inflows. The TC and FC tests are unlikely to adequately represent the actual human disease contraction potential, i.e., pathogenicity of a storm flow and its receiving water, causing a misguided concern over some disease hazards and the neglect of others.

## DISINFECTION

Storm generated flows in comparison to municipal wastewater effluents, require a different approach for disinfection treatment, because: the flows are intermittent; often high rate; and normally display wide variations both during and between storms of quantity, and pollutant and bacterial characteristics.

During the 1960s and 1970s the necessity for disinfecting stormwater discharges became increasingly apparent. Studies were undertaken to find cost effective and high rate disinfection practices which could adapt to intermittent use and varying dosages required to accommodate the unique characteristics of storm generated flows.

Studies included the use of Microstraining[R] for removal or fragmenting of particulate matter which shielded bacteria from chemical attack and so reduced chlorine demand and detention time. Other studies investigated stronger oxidants (e.g., ozone) and two stage addition of oxidants (e.g., chlorine followed by chlorine dioxide) to reduce detention times. The importance of maximizing mixing intensity to ensure dispersion of the disinfectant and increase the number of collisions between the bacteria and disinfectant was also confirmed.

The traditional approach to disinfection has been by use of elemental chlorine compounds, but impacts associated with the chemical reaction products of continuous chlorination has led to increasingly restrictive residual chlorine requirements. This has resulted in the necessity for dechlorination techniques, reduction in chlorine doses and increased contact times.

One disinfection technique that promises short detention times and the absence of toxic reaction products is the use of ultraviolet (UV) light irradiation. The effectiveness of the early systems was limited for water with high concentrations of solids which tended to attenuate the UV energy. Later systems emit higher intensity radiation for more effective treatment. Also more recently modulated UV light has been reported to reduce viable bacteria by approximately 100 fold compared to populations observed after similar exposure to UV light that lacked modulation (Bank *et al.* 1990).

## CONCLUSIONS AND RECOMMENDATIONS

Studies relating incidence of disease in recreational water users to instream densities of various indicator bacteria suggests that current criteria is inappropriate. This is especially true for those receiving waters complicated by storm-induced inflows. Water quality and disinfection criteria for pathogenic bacteria and viruses are clearly needed for stormwater. To develop water quality criteria, regulatory agencies must address the problems of choosing the most appropriate indicator(s) and their densities, but to be most effective, the criteria should be derived from direct pathogen and epidemiological analyses for relating risk to a given level of water contamination. Additional epidemiological case studies, from a variety of watershed areas, are needed to determine the true health risks associated with stormwater contact and to establish correlations between alternative bacterial or viral indicators and total illness rates.

Since the predominant bather associated risk has been reported to be infections of the skin, ear, eye, and upper respiratory system, epidemiological guidelines are also required which address the presence of non-enteric pathogens.

For separate storm drainage systems with human fecal contamination indicating illicit cross-connections, a serious effort should be directed towards tracing and eliminating these sanitary wastewater sources. Where these cross-connections are too numerous or too costly to be corrected, it may be advisable to classify the system as a combined sewer and apply end-of-pipe treatment.

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