PUBLIC HEALTH AND WATER QUALITY SIGNIFICANCE OF VIRAL DISEASES TRANSMITTED BY DRINKING WATER AND RECREATIONAL WATER

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Abstract

A review of the available information from case and outbreak reports and the results of prospective and retrospective studies revealed that the potential for the spread of viral diseases by the use of fecally contaminated drinking and recreational water has only been realized for infectious hepatitis and viral gastroenteritis. These two, however, are the most serious and prevalent, respectively, of the water-related diseases. A model is described for predicting the beach-specific, swimming-associated rates and annual number of cases of gastroenteritis. The inputs are the swimming-associated, gastroenteritis rate-bathing water enterococcus density regression equation developed from the USEPA prospective epidemiologic-microbiologic studies and the distribution of enterococcus density estimates and annual number of swimmers at the beach in question. In general, the gastroenteritis rates predicted from the enterococcus model were less than those from the corresponding E. coli model. Detectable rates at the 75 percentile level and rates approaching or exceeding 5/1000 swimmers at the 90 percentile level were predicted for 7 and 14, respectively, of the 87 sampling station-beach associations. All but one of the fourteen stations were potentially impacted by known municipal wastewater discharges and two of the associated beaches were posted as unsafe for swimming. The inapplicability of the model to beaches impacted with small, immediate sources of fecal wastes or stormwater run-off is noted. The limitations in the use of findings from the analysis of outbreak reports in the evaluation and establishment of water quality criteria and, hence, the need for prospective, drinking water and shellfish epidemiological studies is discussed. The need for such studies also derives from the results of the bathing beach study in that they suggest that cases of gastroenteritis are occurring with acceptable drinking and shellfish growing waters. The need for tissue culture enumerative methods for the viral gastroenteritis agents and methodology for determining the biological decay coefficients for these agents and their indicators is noted.
INTRODUCTION

A variety of viral pathogens have been recovered from human fecal wastes and municipal wastewaters (1). Potentially, all of these agents could be transmitted to man via his use of fecally contaminated drinking and recreational waters. In fact, as seen from epidemiologically well-documented, case and outbreak reports, there is scant evidence that any of the water-related routes of transmission have been significant in the transmission of viral diseases, with three exceptions; these are infectious hepatitis caused by hepatitis A virus, acute gastroenteritis caused by the Norwalk-like viruses and the human rotavirus, and a pharyngoconjunctivitis associated with the "use" of swimming pools and caused by adenovirus types 3 and 4 (2,3). There has been one small outbreak of poliomyelitis associated (albeit, poorly) with drinking water reviewed by Mosley (4) and two small swimming-associated outbreaks of disease (again, poorly documented with regard to the route of transmission), one due to coxsackie A virus (5) and the other to coxsackie B (6). The only other evidence comes from a recent report on swimming-associated enteroviral disease among children (7). Thus, there are virtually no hard data from case and outbreak reports or from the United States Environmental Protection Agency (USEPA) bathing beach epidemiological studies (8,9), showing water-related transmission of the recoverable enteroviruses. Moreover, Moore and his associates (10) could find no significant association of swimming in sewage polluted marine water to clinical poliomyelitis from the results of their retrospective epidemiological study. These epidemiological findings were at odds, as it were, with a notion long held by some investigators of the importance of these agents as inferred from their densities in sewage (11)--although in one study, at least, the densities in polluted marine waters were quite low (12)--, the very low human ID_{50} (< 10 TCID_{50}s) reported for poliomyelitis (13)--it was subsequently shown in a more realistic study to be somewhat higher (14)--, and the greater resistance to environmental stress of these agents relative to those of the coliform indicators (15-17).

An alternate hypothesis was set forth which seemingly reconciles the differences noted above (18,19). It is that there is low-level water-borne transmission of these agents followed by clinical disease in secondary contacts. The assumption is that, although the dosage is too small to produce clinical disease in the individuals exposed to the water, they are infected and there is sufficient replication and shedding of the enteroviral agents to produce clinical disease among secondary contacts. There are no data to support this theory for these specific viral agents and the primary transmission routes in question. Moreover, considering the very wide temporal and spatial variability in pollution levels and the highly infective nature of some of these agents (7), it would appear that, if the incidence of primary infections was high enough to produce an appreciable number of cases of secondary disease, there should be outbreaks of primary disease associated with the use of more polluted waters. Furthermore, over the years, one of these should have been recognized as such, at least for the recreational and shellfish routes of transmission. In fact, secondary transmission to family contacts from clinically ill individuals was documented in most of the 15 water-related Norwalk, and in one Norwalk-negative (20), gastroenteritis outbreaks reviewed by investigators at the Centers for Disease Control (CDC) and the National Center for Allergy and Infectious Diseases (21). Among the 15, were outbreaks by all three water-related routes, drinking water (eleven), swimming (two), and shellfish consumption (two). In one of the swimming-associated outbreaks (22), the secondary attack rate was 19 percent (56 percent among children < 10 years of age); and there was only one case (3%) among the family contacts of individuals who reported other than gastrointestinal illness. However, it appeared that secondary transmission only occurred from individuals who had the primary illness, although this could not be established statistically. If secondary transmission of one of the more serious reportable enteroviral diseases occurred at a comparable rate, it would seem that cases of this disease would have occurred coincidentally among family contacts during one of the sewage...
Public health and water quality significance

pollution-related water-borne disease outbreaks and, at least once, would have been recognized as such during the outbreak investigation. Thus, until substantiated by hard epidemiological evidence, "low-level viral transmission" must be treated at the very least as an unsubstantiated theory (23).

However, the foregoing is not meant to imply an insignificant role of viruses in the water-related transmission of infectious disease. To the contrary, at least in "developed" countries with fairly restrictive standards on the quality of drinking, recreational and shellfish growing waters and the control technology to achieve them, two of the three infectious diseases of greatest import are viral, infectious hepatitis and viral gastroenteritis (see references 24 and 25 for the rationale); the third is giardiasis. Excluded from consideration are infectious diseases not primarily spread by the fecal-oral route (e.g., by human pathogens autochthonous to aquatic environments). Also excluded are the situations to be described where water quality measurements have little, if any, predictability on the potential for infectious disease among the users (26).

For example, there were six swimming-related outbreaks of gastroenteritis reported by the CDC for 1980 (27), four due to shigellae and two of undetermined etiology. In five of the six outbreaks, the quality of bathing waters apparently met the USEPA fecal coliform guidelines. At first glance it would appear that guidelines were not restrictive enough to have prevented the outbreaks. In fact, the setting for each of the four outbreaks was a relatively small lake with no known sources of municipal wastewater discharges. For reasons given elsewhere (26), under such conditions, fecal indicator densities have no predictability and fecal indicator guidelines and standards are not applicable. For the same reason, the findings from an extremely well-investigated and documented outbreak of swimming-associated Norwalk gastroenteritis (22,28) can not be used in evaluating the guidelines. This is true of the large majority of water-related disease outbreaks (swimming- and shellfish-associated ones for the reason stated, shellfish-borne outbreaks also because of the possibility that illicitly harvested (bootlegged) shellfish were introduced into commercial channels, and drinking water outbreaks because most of them have been associated with breakdowns during treatment, disinfection, and distribution) (29). It would seem that such water quality criteria, guidelines and standards can best be developed and evaluated by prospective epidemiological studies, such as the one to be described.

An acute gastroenteritis is clearly the most prevalent disease by all three water-related transmission routes (30-32). In the U.S. in 1980, there were 33 reported outbreaks (15,134 cases) via drinking water (27), 5 outbreaks (137 cases) via shellfish consumption (30), and 2 outbreaks (83 cases) associated with recreational water use (27). Moreover, the numbers reported undoubtedly are gross underestimates of the actual incidence, first because of the passive water-borne disease surveillance system, especially for this non-reportable disease (27), and second because sporadic cases such as those observed in both the marine and freshwater prospective epidemiological programs (8,9,33) would either go undetected or could not be ascribed to a particular water-related transmission route. The disease in the large majority of such outbreaks can be further defined as an acute nonbacterial gastroenteritis since, historically, neither salmonellae nor shigellae could be isolated from the affected individuals and more recent attempts to isolate other bacterial pathogens (enteropathogenic E. coli, Yersinia enterocolitica and Campylobacter sp. for drinking water and Vibrio parahaemolyticus and non-O1 vibrios for shellfish outbreaks) have established a bacterial etiology only in a relatively small percentage of the outbreaks. With the greater availability of the reagents for serologic testing (radioimmunoassay and ELISA) and stool examination (immune electronmicroscopy) for the Norwalk-like viruses and the human rotavirus, the viral etiology of such outbreaks of acute nonbacterial gastroenteritis has increasingly been established. Seventy-four such outbreaks were reviewed recently for possible Norwalk virus etiology (21). Of 23 trans-
mitted via water-related routes, 65 percent were established as Norwalk outbreaks; another 4 percent were possibly due to the agent; and a total of 78 percent were associated with the presence of a 28 nm viral particle. Norwalk-like viruses have been implicated in drinking water outbreaks in the U.S. (21), England (20) and Japan (21), in shellfish-borne outbreaks in Australia (34), England (35) and the U.S. (36), and in a swimming-associated outbreak in the U.S. (22,28).

Human rotavirus gastroenteritis outbreaks in which drinking water has been implicated as the transmission mode have been reported from Sweden (37), Brazil (38), the U.S.S.R. (39) and the U.S. (R. Hopkins, personal communication). Moreover, the age specific rates for sporadic cases of acute gastroenteritis observed in the prospective bathing beach epidemiological studies and the presumed role of immunity in the differences in the attack rates in the U.S. and Egyptian studies (8), when examined against those for the Norwalk-like virus and rotavirus gastroenteritis (40) suggests the latter as the primary etiological agent (24). This raises the possibility that most of the reported water-related outbreaks are caused by the Norwalk-like viruses, at least 78 percent as seen from the CDC review (21), while most of the sporadic cases are caused by the human rotavirus. One explanation is that the pool of susceptible individuals to the rotavirus in the general population is generally too small to produce recognizable outbreaks. Its corollary is that the infective potential of the sewage polluted bathing waters in the prospective studies was generally less for Norwalk-like virus than rotavirus gastroenteritis, either because the Norwalk virus is less infective or because there is less of the agent in the sewage. The latter possibility is consistent with the reported relative shedding rates for the two viruses (41,42).

Recent trends in reported outbreaks and cases of water-related infectious hepatitis (IH) in the United States appear to provide some insights into the effectiveness of pollution control technology relative to the potential for this disease. There has been only one reported outbreak via the recreational (swimming) route (43), and it is poorly documented as regards the transmission mode. For reasons given earlier (8), the possibility of swimming-associated IH was not examined in the prospective bathing beach epidemiological studies conducted in the United States. However, this possibility was examined with negative findings for the Cairo tourists at the Alexandria beaches in the Egyptian study (8), possibly due to a high level of immunity in the swimming population. In the period from 1961-1973 there were 24 outbreaks and 1358 cases of shellfish-related IH, while from 1974 through 1980 there have only been two outbreaks with 11 cases reported (30). A similar decrease has occurred in the number of reported outbreaks via the drinking water route. From 1961-1973, there were 43 outbreaks and 1254 cases of drinking water-associated IH, while in the period from 1974-1980 there were only 3 outbreaks and 112 cases. In 1980, there was a single outbreak in a rural area from a well with treatment deficiencies (27).

There are a number of possible explanations which in combination could account for the reductions in the numbers of water-related IH outbreaks over the past 7-8 years. Included are a decrease in the number of individuals who shed the virus in their feces and a general upgrading in the treatment, disinfection and disposal/delivery of municipal wastewaters and drinking waters. The only microbiological water quality standards that were upgraded appreciably during this period were those for recreational waters. However, this can not be used as an explanation since there never were any well-documented IH outbreaks via this transmission route. On the other hand, the 1973 shellfish-borne outbreak (44) could very well be attributed to a defect in the coliform indicators on which the shellfish standards are based. Moreover, the standards are best evaluated from information on sporadic cases obtained in the course of prospective epidemiological studies; and such information is not available for infectious hepatitis for any of the three water-related routes.
Thus, as seen from outbreak reports and subject to the limitations noted above, it would appear that the risk of water-related infectious hepatitis has been reduced to an acceptable level and that the microbiological water quality standards are adequate with regard to this disease. Similar conclusions can not be drawn with regard to the potential for water-borne viral gastroenteritis. It follows then, that more restrictive microbiological water quality standards can be justified only by the unacceptability of the risks currently being accepted to this disease. The data bases required are mathematically expressible illness-indicator relationships which then can be used to predict these risks situation by situation. For the reasons given earlier and discussed elsewhere (26), the findings from the analyses of reported water-related disease outbreaks generally can not be used for this purpose, although there are fortuitous exceptions. They can be, and in one instance (8) have been, obtained from prospective epidemiological studies.

The results of the studies designed to define the indicator-illness relationship and develop health effects, water quality criteria for recreational waters were reported in earlier publications (8,9,24,45-47). One output from these studies was a regression equation relating the incidence of swimming-associated gastroenteritis to the mean enterococcus density in the bathing water (8,9). A second output was a health effects criterion which predicts the mean enterococcus density in the water from some acceptable incidence of the swimming-associated gastroenteritis (8,46). A third was a decision as to the "best" indicator of those examined, the one whose densities in the bathing waters were the best correlated to the swimming-associated gastroenteritis rates. The enterococcus group was by far the best indicator; Escherichia coli was a poor second; and fecal coliforms, the indicator most frequently used in the United States (25,48), was a relatively poor indicator by this definition (8,33,45). A fourth output was a strong indication that the etiological agent of the gastroenteritis was viral, probably the human rotavirus or one of the Norwalk-like viruses. This indication came from (i) the relatively high gastroenteritis rates (about 10/1000 swimmers) associated with very low enterococcus or E. coli densities (about 10/100 ml) suggesting that the etiological agent was highly infectious, present in sewage in large numbers relative to the two indicators, and/or relatively resistant to environmental stress, (ii) the short incubation period (14-48 hrs.) and acute onset, (iii) the short duration (2-3 days), and (iv) the importance of immunity as seen from the age distribution of the illness and the illness-indicator regression lines obtained in the U.S. studies as compared to those for the Alexandria residents and Cairo tourists in the Egyptian study (8,24).

The results obtained from the epidemiological studies were consistent with "common wisdom". First, enteric disease would be expected from the ingestion of sewage polluted waters, and an acute gastroenteritis of probable viral etiology from the analysis of reported outbreaks. Second, because of this, the best indicator should be the one that is the most specific for human fecal wastes and also approaches the viral agents in its survival characteristics. Enterococci, less so fecal streptococci, best satisfy these requisites for the reasons given earlier (25,26).

The availability of the regression equation permitted another step to be taken in "fine-tuning" control measures, as it were, against the potential for infectious disease arising from the use of sewage-impacted aquatic resources. It is the prediction of the beach-specific rates and seasonal numbers of cases of swimming-associated gastroenteritis. The additional inputs required are the frequency distribution of enterococcus densities and the seasonal number of swimmers at the beach in question. This report presents the results of a feasibility study designed to obtain these inputs and apply them in making the required predictions.
MATERIALS AND METHODS

Study sites and sample collection
The study sites were 78 sampling stations and the "associated" bathing beaches along the New York Bight extending north from Cape May, New Jersey and east to the Shinnecock Inlet on Long Island, New York. The water samples were obtained by helicopter at weekly intervals (this was not always possible due to logistic and weather considerations) during the summers (late May through early September) of 1980 and 1981. They were collected in Kemmerer samplers from just beyond the surf zone. Upon their return to the U.S. Environmental Protection Agency Laboratory in Edison, New Jersey, the "iced" samples were transshipped by air to the author's laboratory in Rhode Island.

Microbial Assays
Upon return of the water samples to the laboratory, they were assayed for enterococci using a modification (49) of the mE method (50) and for E. coli by the mTEC method (51).

Beach Usage
Bather usage was estimated by "head counts" from photographs taken by helicopter of the coastal beach areas along the New York Bight. Each beach was photographed between the hours of 10:00 A.M. and 5:00 P.M. at least twice, once on a week day and once on a weekend day. Between 2-20 photographs were taken of each beach, depending on its length and the spatial distribution of the bathers. The number of individuals "on the sand" and in the water per photograph(s) was multiplied by a correction factor to obtain an estimate of the total number at the beach, and the number obtained thusly was increased by 50 percent to account for individuals (beach-goers) who were at the beach sometime during the day but not at the specific time the photographs were taken. The number of swimmers was estimated at two-thirds the number of beach-goers from information obtained from the epidemiological studies (8).

Data Analysis
A predicted gastroenteritis rate (Y) was obtained from each enterococcus and E. coli density estimate (X) using the corresponding regression equation relating the swimming-associated rates for gastroenteritis (highly credible gastrointestinal symptoms) to the mean indicator density in the water (Fig. 1). The equations, obtained in the USEPA epidemiological program (8,9) for enterococci (r = 0.75) and E. coli (r = 0.56), respectively, were as follows:

\[ Y = 12.25 \log_{10} X + 0.073 \]  
\[ Y = 6.32 \log_{10} X + 5.71 \]  

Enterococcus densities ≥ 0.5/100 ml yielded negative gastroenteritis rates; these were recorded as "0"s. The cumulative frequency distributions for the rates derived from each indicator at each sampling station were obtained; and the 75, 90, and 95 percentile values were extracted to provide the predicted swimming-associated, gastroenteritis rates which would not be exceeded at the corresponding frequencies.

The predicted values for the annual numbers of gastroenteritis cases which would not be exceeded at each of the corresponding frequencies were obtained as follows: The annual number of swimmers at a given beach area was estimated by multiplying the average daily number of midweek swimmers by 46, multiplying the average daily
number of weekend swimmers by 18, and adding the two resultant values. Each beach
then was associated with one and, sometimes, two sampling stations; and the 75,
90, and 95 percentile gastroenteritis rates for the station, or the corresponding
averages for the two stations, were each multiplied by the annual number of
swimmers. This provided the predicted annual number of swimming-associated,
gastroenteritis cases at each of the three percentile values.

<table>
<thead>
<tr>
<th>E. COLI</th>
<th>ENTEROCoccus</th>
<th>STUDY</th>
<th>YR.</th>
</tr>
</thead>
<tbody>
<tr>
<td>⋅</td>
<td>⃦</td>
<td>NEW YORK CITY</td>
<td>1973</td>
</tr>
<tr>
<td>⋅</td>
<td>⃦</td>
<td>NEW YORK CITY</td>
<td>1974</td>
</tr>
<tr>
<td>⋅</td>
<td>⃦</td>
<td>NEW YORK CITY</td>
<td>1975</td>
</tr>
<tr>
<td>⋅</td>
<td>⃦</td>
<td>LAKE PONTCHARTRAIN</td>
<td>1977</td>
</tr>
<tr>
<td>⋅</td>
<td>⃦</td>
<td>LAKE PONTCHARTRAIN</td>
<td>1978</td>
</tr>
<tr>
<td>⋅</td>
<td>⃦</td>
<td>BOSTON HARBOR</td>
<td>1978</td>
</tr>
</tbody>
</table>

**FIG. 1.** Regression lines for swimming-associated highly
credible gastrointestinal symptoms (gastroenteritis)
against the mean indicator density in the bathing water.

**RESULTS**

Examples of the cumulative frequency distributions of enterococcus and E. coli
densities at some selected New Jersey and New York City (Staten Island and Coney
Island) sampling stations are shown in Fig. 2. The number of values for each
station varied from 17-26. However, at most of the New Jersey and Long Island
stations, many of the enterococcus and some of the E. coli densities were below
the sensitivity of the assay methods, 0.5 and 1.0 per 100 ml, respectively. This
made it difficult at times to fit straight lines to the distributions. It can be
seen that the E. coli densities were generally higher than those for the entero-
cocci, especially at the New York City stations. The cumulative frequency dis-
tributions of the corresponding gastroenteritis rates derived as described earlier
are shown in Fig. 3. With rare exceptions, the distributions of illness rates
predicted from the E. coli densities were higher than those predicted by the entero-
cocci. This observation can be attributed in part to the higher illness rates
associated with E. coli as compared to enterococcus densities in the range of
<10/100 ml (Fig. 1). However, most of the differences in the rates can be
ascribed to the generally higher E. coli than enterococcus densities, especially
at the New York City stations (compare Figs. 2 and 3).
FIG. 2. Cumulative frequency distribution of indicator densities at some selected New York Bight sampling stations.

FIG. 3. Cumulative frequency distribution of swimming-associated gastroenteritis rates predicted from indicator densities and illness indicator regression lines (Fig. 1); a - E. coli; b - enterococci.
Examples of the predicted 75, 90, and 95 percentile illness rates derived from the enterococcus densities are presented in Table 1. For instance, the prediction is that, at station J-93 near Wildwood, the gastroenteritis rate will not exceed 11.3/1000 swimmers more than 5 percent of the time, 6/1000 more than 10 percent of the time, and 0.0 more than 25 percent of the time. The comparison of the 75, 90, and 95 percentile values provides an idea of the relative slopes of the distributions and, hence, the constancy of the predicted rates at a given beach. This is best illustrated from the comparison of the predicted rates for Ocean Parkway and Manhattan Beach. Of the Coney Island beaches, the latter is the furthest east and, hence, the most distant from the major source of municipal wastewater, that passing through the Verrazano Narrows from Upper Hudson Bay; however, it also is the beach most subject to very infrequent pollution from Jamaica Bay to its east. The predicted rates, and thus the enterococcus density distributions from which they were derived, also reflect the diminishing impact of pollution from Raritan Bay and increasing impact of that from Lower Hudson Bay northward along the Staten Island beaches. The predicted 75 percentile rates exceeded 0.1/1000 swimmers at only seven stations; and the 90 percentile rates approached or exceeded 5.0/1000 swimmers at an additional seven (Table 1). All but one of these 14 stations was subject to known municipal wastewater discharges.

<table>
<thead>
<tr>
<th>Station</th>
<th>General location (beach area)</th>
<th>Rate/1000 swimmers at percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>J-97</td>
<td>Cape May City</td>
<td>3.38 9.39 11.19</td>
</tr>
<tr>
<td>J-93</td>
<td>Wildwood, North Wildwood</td>
<td>0.06 5.98 11.23</td>
</tr>
<tr>
<td>J-79</td>
<td>Longport</td>
<td>0.04 5.92 6.29</td>
</tr>
<tr>
<td>J-75</td>
<td>Atlantic City</td>
<td>0.00 4.95 5.92</td>
</tr>
<tr>
<td>SI-WP</td>
<td>Staten Isl., Wolfes Pond B.</td>
<td>0.00 4.08 7.07</td>
</tr>
<tr>
<td>SI-GK</td>
<td>Staten Isl., Great Kills Pk.</td>
<td>0.00 1.15 4.27</td>
</tr>
<tr>
<td>SI-OB</td>
<td>Staten Isl., Oakwood B.</td>
<td>0.00 0.00 3.71</td>
</tr>
<tr>
<td>SI-MB</td>
<td>Staten Isl., Midland B.</td>
<td>0.00 1.37 6.91</td>
</tr>
<tr>
<td>SI-GB</td>
<td>Staten Isl., Graham B.</td>
<td>0.00 7.28 12.88</td>
</tr>
<tr>
<td>SI-SB</td>
<td>Staten Isl., South B.</td>
<td>1.69 6.51 12.15</td>
</tr>
<tr>
<td>CI-35</td>
<td>Coney Isl., W. 35th St.</td>
<td>3.76 7.05 17.01</td>
</tr>
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<td>Coney Isl., W. 29th St.</td>
<td>1.69 8.04 16.57</td>
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<td>CI-20</td>
<td>Coney Isl., W. 20th St.</td>
<td>4.27 9.34 10.98</td>
</tr>
<tr>
<td>CI-8</td>
<td>Coney Isl., W. 8th St.</td>
<td>0.00 8.84 10.22</td>
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<td>Coney Isl., Manhattan B.</td>
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</tr>
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<td>L-2</td>
<td>Rockaways, Riis Park</td>
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<tr>
<td>L-4</td>
<td>Rockaways, 41st-92nd St.</td>
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</tr>
<tr>
<td>L-16</td>
<td>Cedar Island Beach</td>
<td>2.23 5.63 5.92</td>
</tr>
</tbody>
</table>

Abbreviations: B. - beach; Isl. - island; Pk. - park; St. - street

\[ Y = 12.25 \log_{10} X + 0.073 \]

Swimming-associated gastroenteritis rate (Y) for given percentiles; calculated from applying regression equation where X is the observed distribution (N = 17-26) of enterococcus densities/100 ml at indicated sampling station.

There were 27 New Jersey and 8 Long Island stations where no more than one positive Y value (predicted gastroenteritis rate) was obtained from the corresponding enterococcus densities. The disparity in the illness rates predicted from the densities of the two indicators can be seen from the following comparison of the mean 75, 90, and 95 percentile illness rates for these stations. The rates predicted from the E. coli density distributions were 6.4, 9.1, and 10.2 per 1000
swimmers, respectively, while those predicted from the enterococcus densities did not exceed 0.05/1000 swimmers.

A further analysis of the swimming-associated gastroenteritis rates at the Staten Island and Coney Island beaches illustrates the application of the information to the decision making process. Two of the beaches, Graham and South, are posted as being unsafe for swimming. Midland Beach was opened, as it were, several years ago. The data in Table 1 would certainly support this decision. On the other hand, it would seem inconsistent to post the two Staten Island beaches as unsafe and not post all but one of the Coney Island beaches as well. There are two justifications for doing just that. The first is the greater proximity of the two posted beaches to the pollution sources and, hence, the possibility of the ingestion of a "large" sewage particulate containing large numbers of an infective agent with a high ID50 (25). The second is that the need for the recreational resource overshadows the increased risk of this rather benign illness, and this justification is entirely consistent with risk assessment (26). There is a third justification which applies only to some of the Coney Island beaches. It is that, because of relatively low usage of these beaches, the seasonal numbers of cases generated are relatively small (Table 2).

<table>
<thead>
<tr>
<th>Station</th>
<th>General location (beach area)</th>
<th>Annual no.3</th>
<th>Annual no. of cases at perc.1</th>
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<tr>
<td>J-97</td>
<td>Cape May City</td>
<td>78.2</td>
<td>264</td>
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<td>J-93</td>
<td>Wildwood, North Wildwood</td>
<td>448.3</td>
<td>27</td>
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<td>J-79</td>
<td>Longport</td>
<td>142.8</td>
<td>6</td>
</tr>
<tr>
<td>J-75</td>
<td>Atlantic City</td>
<td>166.8</td>
<td>&lt;2</td>
</tr>
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<td>SI-WP</td>
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<td>7.1</td>
<td>&lt;1</td>
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<td>&lt;1</td>
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<td>Coney Isl., W. 8th St.</td>
<td>149.0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>CI-OP</td>
<td>Coney Isl., Ocean Parkway</td>
<td>147.2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>CI-MB</td>
<td>Coney Isl., Manhattan B.</td>
<td>187.1</td>
<td>&lt;2</td>
</tr>
<tr>
<td>L-2</td>
<td>Rockaways, Riis Park</td>
<td>110.7</td>
<td>&lt;1</td>
</tr>
<tr>
<td>L-4</td>
<td>Rockaways, 41st-92nd St.</td>
<td>81.2</td>
<td>181</td>
</tr>
<tr>
<td>L-16</td>
<td>Cedar Island Beach</td>
<td>75.5</td>
<td>168</td>
</tr>
</tbody>
</table>

Abbreviations: B. - beach; Isl. - island; Pk. - park; St. - street; no. - number; swim. - swimmers; perc. - percentile

1 Obtained by multiplying the percentile rates from Table 1 by the annual number of swimmers.

DISCUSSION

The beach specific, predicted, swimming-associated, illness rates and annual numbers of cases presented herein were meant to demonstrate the use of the model
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and present the reader with a general notion of the range of output information that can be expected from the model. The accuracy of the predictions was limited by the quality of the input data. First, the sampling stations were not chosen with regard to the spatial distribution of the swimmers at the beach; this was neither logistically feasible nor necessary in the present study. Second, depending on the length of the beach, two or more samples should have been collected; in some instances, at least, the samples could be pooled prior to assay. Third, at least 25 samples should have been collected from each sampling station. Finally, the input information on the annual number of beach-goers, as determined from the limited photographic tours, was too imprecise. However, all the above deficiencies can be rather easily corrected in a local effort of more limited geographic scope, especially since the membrane filter assay method for enterococci is relatively facile. Moreover, because of the nature of the gastroenteritis-enterococcus regression line, the assay sensitivity need not exceed 1/100 ml.

There are some additional constraints on the use of the model. Two of these, the number of individuals who contribute to the pollution source and the immune status of the users of the resource, are inherent to the use of fecal indicators. These have been considered earlier and discussed in more detail elsewhere (8,25,26). It is assumed from the results of the prospective epidemiological study and the trends in reported water-related outbreaks that, unless excessively high viral gastroenteritis rates are accepted, the risk of more serious enteric disease is negligible, except under unusual circumstances. These considerations emphasize the need for a sanitary survey and good public health surveillance as adjuncts to water quality guidelines and standards.

A third constraint relates to contamination of the water with lower animal fecal wastes from sewered (separate or combined) or unsewered stormwater run-off. Neither enterococci nor any of the other commonly used fecal indicators are human feces specific; and it may be reasonably assumed that the etiologic agents for the gastroenteritis and other "important" swimming-associated diseases are infrequently present or absent in lower animal wastes. Thus, to the extent that such sources contaminate the water, the risk of illness predicted from indicator densities will be overstated at times. This consideration impinges on the use of "wet weather data" and emphasizes the need for a human feces-specific indicator system. A fourth was noted earlier. It concerns the survival characteristics of the enterococci relative to viral pathogens in general and specifically the two presumed to be responsible for much, if not all, of the gastroenteritis reported in the epidemiological studies. There was an indication in one of the studies that this may have been a factor (24), and this suggests the desirability of a more environmentally resistant indicator system. However, as noted earlier, all four of these constraints or considerations are as or more relevant to the currently used coliform indicators.

The above notwithstanding, the model is a useful tool in evaluating the quality of bathing waters and a marked improvement over current classification standards in that it has a much greater epidemiological data base and employs a better indicator system. Secondly, both outputs are consistent with the acceptability rather than the detectability of risk. The first provides an individual with a general idea of the risk of illness he takes by swimming at a given beach, subject, of course, to his immune status and exposure (amount of bathing water he ingests while swimming). The second provides the manager of a specific recreational resource with a prediction of the annual number of cases of gastroenteritis. He may find the number acceptable. If not, he may restrict the use of the resource or, better yet, achieve an acceptable number by using the information as a feedback loop in modifying the treatment and disposal strategies for nearby wastewater discharges.
It was noted earlier that the incidence of gastroenteritis and possibly infectious hepatitis, as determined from case and outbreak reports, are undoubtedly underestimated for all three water-related transmission routes. This was confirmed with regard to swimming and can be inferred for the other two water-related routes as follows. The relatively high (about 10/1000 swimmers) gastroenteritis rate associated with rather low enterococcus and E. coli densities in the bathing water (about 10 CFU/100 ml) (9), especially when the relative quantities of water ingested per day via the two routes also is considered, supports this possibility. Moreover, it may be assumed that young children (ages 1-5) are more frequently exposed via the drinking water than the recreational route; and this age group would be the least likely to be immune to the etiologic agents (21,45). Similar calculations can be made for the consumption of raw shellfish with essentially the same inferences. Finally, as noted earlier, the Norwalk-like viruses have been increasingly shown to be the etiological agents in drinking water, swimming, and shellfish-associated disease outbreaks; and there have now been four reported outbreaks of drinking water-borne rotavirus gastroenteritis as well. Thus, there is an urgent need for the conduct of well-designed and controlled prospective epidemiological studies with both drinking waters and molluscan shellfish. One such study is in progress (39).

Another research need is information on the survival of the enterococci relative to the three important viral pathogens, hepatitis A virus, the Norwalk-like viruses, and the human rotavirus, during drinking water and wastewater disinfection and sewage effluent transport. This requires reasonably accurate methods for the enumeration of the "infective" virions. Ironically enough, while such methods are available for many of the enteroviruses, they are not for any of these three agents. Facile and inexpensive methods for concentrating these viruses from reasonable quantities of fresh and marine waters (10-30 liters) also are needed. This is especially relevant to the gastroenteritis agents since, if their prevalence in feces and sewage is as widespread as suspected, they are the only pathogens which may approach the requirements for a water quality indicator (26). Associated with these research needs is one for the development and evaluation of the technology required for obtaining biological decay coefficients with consideration to so-called "backyard" effects and without recourse to open water in situ studies. Clostridium perfringens spores appear to be an excellent conservative tracer for the conduct of such studies both as regards the water column and the sediments (53,54).

Finally, in the event that even the enterococci have to be replaced because their disinfection and transport survival characteristics do not sufficiently approach those of the three viral agents, an alternative indicator, or at least surrogate, should be waiting in the wings, as it were. The male-specific, single stranded RNA and DNA coliphages, f-2 (MS-2) (55,56) and f-1 (Fd), respectively, appear to be the best candidates, especially the latter because of its marked resistance to chlorination (57). The research on facile, accurate enumeration and concentration methods for these two phages should be expanded.

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