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# *Thalassogenic diseases*

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# PREFACE

With the growing concern for the quality of the marine environment the diseases associated with bathing attracted the justified attention of holidaymakers and public health officials. While avoiding bathing in waters polluted by municipal and industrial effluents made undisputable common sense, the public health officials were confronted with the difficult task to define what should be considered as "safe" or "acceptable" quality of bathing waters. Aside from the aesthetic quality of a beach, the health risk associated with bathing was obviously the most important criterion, but it proved to be difficult to obtain statistically significant data linking the quality of bathing waters with the incidence of illnesses which could be directly related to that quality. This led to the variety of national regulations and standards, which were often based more on beliefs and feelings of those who originated them, than on hard scientific evidence.

The Regional Seas Programme of the United Nations Environment Programme (UNEP)[1/] was confronted with the need to provide the Contracting Parties to the numerous regional conventions developed in the framework of that Programme, with a sound, scientifically based advice on commonly acceptable environmental quality criteria which could be translated into national regulations. The definition of criteria for acceptable quality of bathing beaches was among the first priorities.

The review prepared by Professor H.I. Shuval was commissioned by UNEP as a contribution to clarify our present understanding of the problem.

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1/ The Regional Seas Programme at present covers ten regions (Mediterranean, Kuwait Action Plan Region, Caribbean, West and Central Africa, Red Sea and Gulf of Aden, South Asian Seas, Eastern Africa, East Asian Seas, South Pacific and South-East Pacific) with more than one hundred and twenty participating coastal States.

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## INTRODUCTION

This review shall deal only with those forms of thalassogenic infections[1/] associated with microbial contamination of the sea resulting from the disposal of wastewater into the sea and/or microbial contamination directly from the bodies of bathers in restricted coastal bathing areas. Such exposure to contaminated sea water, containing human pathogens, may lead to infection and disease among bathers who ingest some sea water while bathing. Fish or seafood, particularly bivalves (mullosks) which are found in such water may become contaminated and cause infection in humans who consume such sea products raw, partially cooked, or processed in a way which inadequately inactivates the pathogens. Greater detail of specific thalassogenic infections resulting from the above routes of infection will be presented in later sections.

However, other forms of infection and disease are associated with sea-contact and can cause confusion with the above sources of infections. These can include the following: certain human infections, associated with the consumption of raw or partially cooked fish and seafood are caused by pathogenic microorganisms, such as Vibrio parahaemolyticus and Clostridium botulinum (type E), whose native habitat is the sea (WHO, 1974). Others, less common, are associated with - nemotodes such as Anisakis and Angiostrongylus cantonensis, whose normal hosts are apparently fish-eating mammals, birds and possibly preditory fish. These pathogens can cause disease in man from consuming infected fish or seafood served raw, undercooked, pickeled or smoked (WHO, 1974).

Another category of infections often associated with bathing, may be caused by microorganisms such as Staphylococcus aureas, Clostridium welchi, Pseudomonas aeraginos and Candida Albicans which are often present in man, but may give rise to disease when, the resistance of the individual who harbors them is lowered, as might occur in the case of extended periods of bathing in cold water (Mood and Moore, 1976). These same organisms may also cause infection as a result of being forced into breaks or tears in delicate membranes in the ear or nose resulting from the trauma associated with diving into water. While all the above four species of bacteria may also be found in polluted water, Mood and Moore (1976) caution that the suggestion that a bather suffering from infection with one of these organisms has acquired it from polluted water, "must be treated with reserve, unless there is strong supporting evidence to the contrary".

Other risks to health (although not infections), associated with recreational contact with the sea may be quite serious and include, injury from striking submerged rocks while diving, drowning, and in some areas even fatal attacks by sharks. On the shore-contact side, there is always the danger of severe sunburn and food poisoning from poor food sanitation at beach-side eating establishments and vendors. Another example of a potential danger to swimmers health is the report of erosion of dental enamel among competitive swimmers in a chlorinated pool in Virginia (MMWR, 1983). In this study, 15 per cent of 452 frequent pool swimmers reported symptoms of enamel erosion compared to 3 per cent among 295 infrequent and non-swimmers. The investigators attributed this pathology to extended exposure to extremely low pH of 2.7 in the swimming pool which was chlorinated. Proper procedures to neutralize the acid effects of the gas chlorination were not followed.

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1/ Definition of thalassogenic infections: Thalassogenic infections have been defined by Mosley (1974) as human infections whose source is the sea (Greek: thalass = the sea + genesis = source).

## GOALS OF REVIEW

The goal of this paper is to present a critical review of the epidemiological studies correlating thalassogenic infections - with the microbial quality of marine bathing waters, shellfish growing waters and shellfish. Such studies are essential to provide an epidemiological basis for establishing a criterion for health risks associated with bathing in marine waters of varying microbial qualities or of eating shellfish grown in marine waters of varying microbial quality. Health effects, recreational water criteria, guidelines, and standards will be discussed in detail later.

Many, if not most coastal beaches, recreational and fishing areas are in the vicinity of urban areas. The disposal of urban wastewater, laden with pathogenic microorganisms, into the sea, in the vicinity of such beaches and fishing areas, has always been of some concern to public health authorities as a possible route of infection, either by exposure of bathers to pathogens of wastewater origin at bathing beaches, or exposure of fish and shellfish to those same pathogens in fishing and shellfish growing areas. Attempts to control or regulate such risks may be by reducing or removing sources of pollution and by treatment of wastewater prior to sea disposal. Such engineering control measures usually require some sort of environmental achievement guideline or standard to enable designers to aim for a defined goal in reducing pollution. As a result, marine water quality standards have been developed.

Such standards have at times been based on pragmatic engineering and economic considerations, such as technical feasibility or attainability, or on visual esthetic considerations. However, it is the purpose of this review to evaluate the epidemiological basis for establishing quantitative microbial guidelines and standards for marine waters.

## CRITERIA, GUIDELINES AND STANDARDS

### Definition of terms

There are varying definitions of the terms criteria, guidelines and standards as applied to environmental quality management. The Webster Dictionary definition for criterion "a standard for comparison or judgement" and that given for standard - "a basis of comparison; a criterion; measure", while providing little differentiation between the two terms, presents the usual lay understanding of these words.

### Definitions of the European Communities

The Official Journal of the European Communities (E.C., 1973) provides a detailed definition of "Environmental Protection Terminology" as follows:

### Criteria

1. The term "criterion" signifies the relationship between the exposure of a target to pollution or nuisance, and the risk and/or the magnitude of the adverse or undesirable effect resulting from the exposure in given circumstances.

2. "Target" means man or any component of the environment actually or potentially exposed to pollution or nuisance.

3. The "exposure" of a target, envisaged in this relationship, should be expressed as numerical values of concentration, intensity, duration or frequency.

4. "Risk" is the probability of occurence of adverse or undesirable effects arising from a given exposure to one or more pollutants or nuisances considered alone or in combination with others.

5. The "adverse or undesirable effect" envisaged in this relationship may be a direct or indirect, immediate or delayed, simple or combined action on the target. The risk and the magnitude of this effect should be expressed, whenever possible, in quantitative terms.

6. The methods of evaluating the parameters describing exposure and adverse or undesirable effects should be harmonized to ensure compatability of the results from studies and research on criteria.

Quality objectives

1. The "quality objective" of an environment refers to the set of requirements which must be fulfilled at a given time, now or in the future, by a given environment or particular part thereof.

2. In setting this objective, the following are taken into account:

   a) a "basic protection level" so that man or another target is not exposed to any unacceptable risk.

   b) a "no-effect level" so that no identifiable effect will be caused to the target.

These two levels are determined on the basis of the criteria described above. Due allowance is also made for the specific regional conditions, the possible effects on neighboring regions, and the intended use.

Environmental protection standards

"Standards" are established in order to limit or prevent the exposure of targets and can thus be a means of achieving or approaching quality objectives. The standards are directly or indirectly addressed to the responsible individuals or bodies; they establish limits for pollution or nuisance that must not be exceeded in an environment, target, product, etc. They may be established by means of laws, regulations or administrative procedures or by mutual agreement or voluntary acceptance.

These standards include "Environmental quality standards" which, with legally binding force, prescribe the levels of pollution or nuisance not to be exceeded in a given environment or part thereof.

WHO definitions

For the purpose of completeness, we shall note the specific definitions relating to recreational water quality suggested by WHO, which are quite close to those of the EEC.

Health effects water quality indicator

Any microbial (including parasitic worms) or chemical systems used to index pollution-associated hazards of infectious disease (as well as biotoxemia or allergy to microorganisms) coinciding with recreational use of marine waters. Faecal indicators, on the other hand, should be expected to index only those risks associated with pathogens in the faecal wastes of man and other warm-blooded animals. Pathogens may be water quality indicators.

Water quality criterion

A set of facts or data concerning health hazards associated with pollution upon which a decision or judgement may be based. Ideally, it is a relationship of illness or disease among swimmers to some measures of quality of the bathing water.

Water quality guidelines

Suggestions, based upon water quality criteria, by which policy measures may be formulated, implemented or translated into action for the attainment of one or more health objectives or goals. Guidelines should be based upon prevailing technical, economic, social cultural and political conditions for that time and should be reviewed and revised periodically.

Water quality standards: Guidelines fixed in law.

## Evolution of health effects water quality guidelines

The early water quality indicators were generally related to chemical characteristics such as tubidity, chlorides and the presence of nitrogenous compounds based on the assumption that abnormal appearance of these parameters in water indicated the presence of human body wastes.

Escherich in 1885 had found that E. coli was a normal non-pathogenic habitant of the human and mammalian intestine and the more broad spectrum coliform test, but less specific, developed by Theobold Smith in 1893 was adopted as a convenient and sensitive method for indicating what was felt to be the degree of faecal contamination in water, because it was both quantitative and comparatively easy (Kabler, 1961). Official interest in the use of the bacterial indicator E. coli was shown as early as 1895 in the American Public Health Association report on pollution of water supplies (APHA, 1895). However, apparently the first official use of the coliform organism as a legally binding standard in the United States was not until 1941, with the publication of the first U.S.P.H.S. Drinking Water Standards.

In 1918, the American Public Health Association organized a Committee on Bathing Places which carried out a questionnaire survey sent to State Health officers and practicing physicians on the prevalence of infections associated with bathing places. This study led to a tentative proposal that total bacterial counts and coliform counts be used as water quality indicators in the health evaluation of bathing places (Simons et al., 1922). The APHA then formally recommended the establishment of total bacterial counts and coliform counts as water quality guidelines for the operation of swimming pools and entertained the recommendation of applying them to natural bathing places. However, a number of years later the same committee reported that there is "dearth of epidemiological information" on the subject and that it was "unconvinced that bathing places are a major health problem", however, it nonetheless proposed a classification scheme based on the average coliform count for rating bathing waters (APHA, 1936).

Many of bathing water quality guidelines and standards that have meanwhile been promulgated in the United States were apparently based on a study by W.J. Scott (1932) of Connecticut shore beaches, in which he correlated the results of bacteriological analysis for coliforms with the finding of a sanitary survey. His recommendations, based on feasibility or attainability, are presented in Table 1 and helped establish the total coliform count as the most widely accepted health effects water quality indicator for bathing places despite the fact that they made no claim to a direct relationship to health effects.

Table 1: Recommended bacteriological water quality guidelines for bathing waters as established by Scott (1932)

| Class | Coliforms/100 ml | Sanitary Description |
|---|---|---|
| A+ | 0 - 10 | Excellent |
| A- | 11 - 50 | Good |
| B | 51 - 500 | Fair |
| C | 501 - 1000 | Satisfactory |
| D | over 1000 | Unsatisfactory |

The first definitive Federal bathing water quality guideline promulgated in the United States was published in 1968 by the Federal Water Pollution Control Agency, U.S. Department of Interior (1968). A geometric (log) mean of 200 faecal coliform organisms per 100 ml was recommended as a limiting value that under normal circumstances should not be exceeded in water intended for bathing and swimming. This guideline also requires that no more than 10 per cent of the samples in a given month shall exceed 400 faecal coliforms/100 ml. This guideline was adopted by the U.S. EPA and most of the states. This guideline was based on a number of studies which indicated that tests using faecal coliforms were more specific indicators of the possible presence of enteric pathogenic microorganisms from human sources or other warm blooded animals than the coliform group of organism. These studies also indicated that a geometric mean of 200 faecal coliforms was approximately equivalent to a total coliform count of 2400/100 ml.

However, in the E.P.A. Water Quality Criteria (EPA, 1973) the faecal coliform guideline was dropped. The conclusion published stated "no specific recommendation is made concerning the presence or concentration of micro-organisms in bathing water because of the paucity of valid epidemiological data". In justifying this conclusion, the report stated "there may be some merit to the faecal coliform index as an adjunct in determining the acceptability of water intended for bathing and swimming, but caution should be exercised in using it.... The index is a measure of the "sanitary cleanliness" of the water and may denote the possible presence of untreated or inadequately treated human wastes. To use the faecal coliform index as the sole measure of "sanitary cleanliness", it would be necessary to know the maximum "acceptable" concentration of organism; but there is no agreed-upon value that divides "acceptability" from "unacceptability".

Nonetheless, the report does state in a footnote that if an arbitrary value for faecal coliform index is desired, consideration may be given to a density value expressed as a geometric mean of samples collected during a given period. A maximum faecal coliform value of 1000/100 ml is suggested for possible consideration. However, in 1976, the EPA reestablished the 1968 guidelines of 200 faecal coliforms mentioned above (USEPA, 1976).

## Current microbial guidelines and standards

Microbial standards or guidelines for bathing beaches, shellfish growing areas and for shellfish fish have been established by a number of countries, by the E.E.C., and by the WHO/UNEP MED-POL programme under the Mediterranean Action Plan. Whether or not such current standards and guidelines are based on sufficient epidemiological evidence or are needed at all has been widely debated (Moore, 1974; Shuval, 1974; Cabelli, 1983).

Within the Mediterranean basin alone microbial standards for recreational waters vary greatly from the strictest requirement in Italy, that bathing water quality is considered satisfactory only if 80 per cent of the samples are equal to or less than 100 E. coli/100 ml, to the most liberal in Yugoslavia which requires that 100 per cent of the samples be equal to or less than

20,000 total coliforms/100 ml. Many of the Mediterranean states have upper limits of 1000 E. coli/100 ml (UNEP, 1983). The European Economic Community (EEC, 1976) has recommended that 80 per cent of the samples be equal to or less than 10,000 faecal coliforms/100 ml. A guideline of no more than 100 faecal streptoccoci is also recommended. Thus, in the Mediterranean basin three different indicator organisms with a wide range of numerical limits and varying forms of statistical interpretation are currently in use with little consensus as to the most appropriate indicator organism or the required numerical limits.

Most existing recreational water guidelines are maximum allowable upper limits for the density of the selected indicator organisms in seawater or shellfish meat which at best may relate to some known detectable health risk. Other standards, as mentioned above, have been frankly based on technological feasible or attainable water quality levels which do not necessarily correlate with known negative health effects.

Cabelli (1983) has recommended that the proper way of setting such upper limits should be first to establish a criterion defined as "a quantifiable relationship between the density of the most appropriate microbial indicator organism in the seawater and the potential human health effects involved in the water's use for recreational purposes". Such a criterion is a set of facts or a relationship upon which a judgement can be made. The criterion is established by extensive epidemiological studies.

According to Cabelli (1983) a water quality guideline (or standard) derived from the criterion is a suggested upper limit for the density of the selected indicator organism which is associated with unacceptable health risks. The concept of acceptability implies that there are social, cultural, economic, and political as well as medical considerations in establishing such a level.

Cabelli's (1983) conceptual graphic presentation of the type of epidemiological data correlating water quality indicator density (on the absicca) to swimming associated illness rate (on the ordinate) that should be used to establish a criterion is shown in Fig. 1.

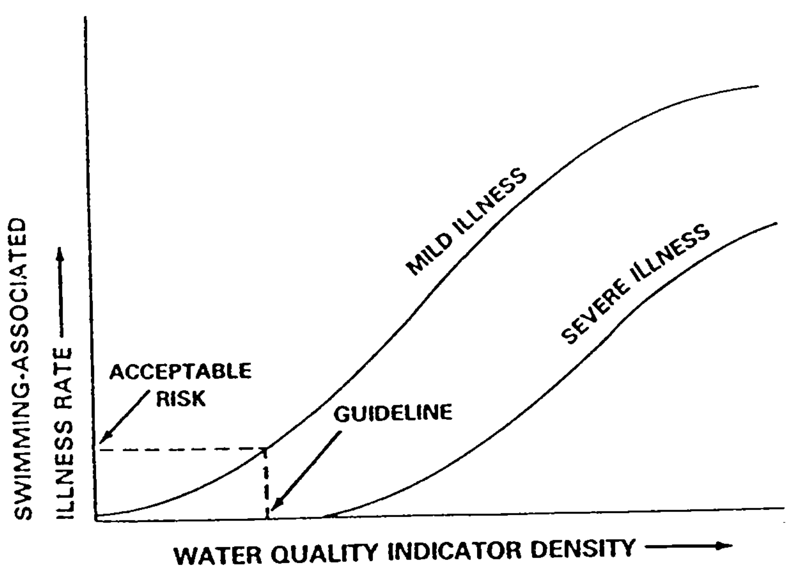



Figure 1. Graphic representation of the desired recreational water quality criteria. It is assumed that only an extremely small risk of "serious" illness will be accepted.

(From Cabelli, 1983)

If such a criterion is available, the derivation of a guideline or maximum allowable standard requires a decision as to the level of health risk which is economically and socially acceptable. In the example shown, there is some detectable mild swimming associated illness even at the guideline level indicated, as well as at density levels below that, however, there would be no severe health effects.

Indicative of the differing views concerning the concept of "acceptable risk", Mood and Moore (1976) argue that "with regard to the real or postulated risks to good health and well-being which may be encountered in coastal areas, it should be acknowledged that with most recreational activities, such as mountain climbing, skiing, horse-back riding, etc., there are risks to good health which the holiday maker or vacationer will encounter. These may be considered to be calculated risks which are taken as a matter of course. Unless the risk to good health is significant, it may not be in the best interest to health and well being to deny people the use of coastal areas as places of recreation".

On the other hand, it can be argued, that while there are indeed certain unavoidable risks associated with all forms of sports and recreation, people have a right to expect that publicly operated and supervised recreational areas, particularly those recognized as tourist resorts, be provided with amenities, controls, and proper supervision so as to reduce, avoidable risks to a reasonable minimum. For instance, at ski resorts the public has every right to expect that ski lift equipment is regularly inspected and meets all safety requirements. Thus, health risks associated with improper disposal of wastewater into the sea in the vicinity of recreational areas should not be viewed as part of the normal risks to health that sportmen and vacationers should accept as a matter of course.

## SOURCES OF EVIDENCE ON THE ROUTE OF TRANSMISSION THALASSOGENIC INFECTIONS

Information on thalassogenic infections and/or disease in relation to microbial contamination of the sea can be obtained from two primary sources: a) reports of investigations of disease outbreaks associated with microbial contamination of the seas or fresh water bathing places and, b) retrospective or prospective epidemiological investigations whose specific aim is to determine the relationship between thalassogenic infections and/or disease and microbial quality of seawater or shellfish.

A third possible route to provide information as to the risks of thalassogenic infection associated with microbial contamination of the sea has been through the use of deductive reasoning based on minimal infectious dose, amount of sea water ingested, immune status and other possible environmental and host variables (Streeter, 1951; Shuval, 1974).

We shall first present a review of the known reported outbreaks of thalassogenic disease associated with bathing at wastewater contaminated beaches or with consuming seafood from contaminated waters. Important information is also provided from studies on fresh-water bathing areas and shall be included in this review for the sake of completeness.

### Outbreaks associated with bathing in contaminated water

#### Typhoid Fever

Apparently, the earliest recorded outbreak of a thalassogenic infection associated with microbial contamination of bathing water was published by Pfuhl, in 1888. He reported an outbreak of 49 cases of typhoid fever associated with swimming in the sewage polluted Elbe River in Germany. Reece (1909) described an outbreak of typhoid fever at a royal Marine Camp at Walmer on the coast of Kent in southeast England. The outbreak was traced to swimming in an enclosed heated swimming pool which was filled periodically with seawater on a rising tide through an inflow pipe. The pool was subject to gross pollution with sewage carried by sea currents from two adjacent sewer outfalls, one of which received the untreated sewage of a communicable disease isolation hospital.

An outbreak of typhoid fever at a boys camp near New Haven, Connecticut in the U.S.A. was traced by Campolini, in 1921, to bathing in sewage polluted seawater.

In 1929, Winslow and Moxon reported on suspected transmission of typhoid among those who bathed in the polluted waters of New Haven Harbor. A similar report on suspected typhoid transmission by bathing in polluted areas of New York Harbor was published in 1932 (N.Y. city Dept. of Health). Mood and Moore express one opinion that both of these reports were "poorly documented".

A typhoid fever outbreak involving 10 cases in western Australia associated with bathing in a wastewater polluted coastal area near a broken outfall sewer was reported by Snow (1959). A number of persons in Alabama, U.S.A. became sick with typhoid fever as a result of swimming in a heavily sewage contaminated drainage ditch with a faecal coliform concentration of 10/100 ml (C.D.C., 1972). In Louisiana, a typhoid fever outbreak at Covington State Park was associated with swimming in heavily polluted river water down-stream from the flow of a broken sewer line (C.D.C., 1963). Cabelli (1983) reported that four cases of typhoid fever detected in Alexandria, Egypt were all associated with swimming at a heavily polluted beach immediately impacted with raw sewage. The District Medical Officer of Health in Tel Aviv, Israel, attributed a number of cases of typhoid fever among children to the contact of faecal material on a heavily contaminated stretch of beach adjacent to a raw wastewater outfall sewer (Shuval, 1972). The beach itself was posted as an area where bathing was prohibited.

Virus disease

Concerning the transmission of virus disease by bathing in polluted water the evidence is mixed. The possible transmission of poliomyelitis by bathing in wastewater contaminated water was investigated intensively when that disease was still a major problem in the United States. Mosley (1974) states that the few published studies alleging such a relationship have been inconclusive. Moore (1954) in the U.K. did not find evidence of higher rates of poliomyelitis among bathers than among non-bather controls.

A number of reports have dealt with the isolation of specific enteroviruses from different types of recreational waters in association with human infections. The earliest report involves an outbreak of disease of Coxsackievirus B1 etiology, an agent which had been undetected in the study area for the previous 14 years (McLean et al., 1964). This virus was concomitantly recovered from a city wading pool. A similar situation was described in Berlin in which virologic surveillance of the city swimming pool during one summer resulted in the recovery of Coxsackievirus B3 from 20 per cent of the water samples. This virus was also the predominant agent recovered from clinical specimens obtained from children primarily manifesting meningitis or encephalitis (Liebscher, 1969). A report dealing with swimming pools indicated that Coxsackievirus B1 was recovered from the children's section of two Moscow swimming pools during a period of two months with concomitantly proven human infections with this agent during the same period (Osherovich and Chasovnikova, 1969).

A small outbreak of Coxsackievirus A16 illness in five children occurred some days after they had been bathing in a lake (Denis et al., 1974). Coxsackievirus A16 was isolated from a 10-liter sample of lake water and from rectal swabs of two patients. A somewhat larger outbreak with accompanying isolation of the etiologic agent from a lake was reported by Hawley et al., in 1973. This outbreak involved 21 identified cases of acute viral illnesses in children at a summer camp located on the shores of Lake Champlain. Coxsackievirus B5 was isolated from 62 per cent of the clinical cases and 17 per cent of sampled asymptomatic individuals. The same virus was also recovered from the water of the beach along the lakeshore which the camp used for its swimming activity. However, epidemiologic analysis of the outbreak fairly conclusively indicated that the principal mode of transmission was person-to-person, in that all but four cases were clustered in one cabin.

The lack of evidence of waterborne transmission in the Lake Champlain outbreak is similar to the findings of a summer camp study where virologic surveillance of the campers and environment was considerably more systematic (Paffenbarger et al., 1959). Over the course of the summer, 37 of 681 participating campers had virus isolates. None of the environmental samples, including those taken from the camp swimming pool on a weekly basis, resulted in the isolation of a virus. As in the Lake Champlain study, virus spread was shown to be primarily or solely by direct transmission, in that specific viruses tended to concentrate in groups of boys living in the same cabins. There was no apparent transmission of illnesses by swimming or by any other environmental exposures.

It is clear that recreational waters not receiving sewage effluent can be contaminated with enteroviruses and that the serotype found in the water is likely to be the same one predominating in concomitant human infections. Thus, bathing waters so contaminated, by the bathers themselves, may at times serve as an effective route of transmission of some viral diseases. As an illustration of the inadequacies of many such investigations, Mosley (1974) points to the investigation of the epidemic of Coxsackie B5 virus at a boys summer camp, previously mentioned, which was reported to have been associated with swimming in a contaminated bathing area (Hawley et al., 1973). While the virus was detected in one of two water samples from the bathing area, the samples were taken after the epidemic was in progress and may have been excreted by the cases themselves and no bacteriological samples were taken. No investigations were made as to possible routes of sewage contamination of the bathing area. Mosley concludes that "such incomplete investigations are of little help".

As mentioned above, Denis et al., (1974) reported on an outbreak of Coxsackie A16 infection presumably associated with bathing in contaminated lake water and Bryan et al., (1974) also suggested that the evidence indicated that an outbreak of Hepatitis A was associated with swimming in a polluted lake. Cabelli, 1983 states that the evidence for the above two outbreaks as well as the Coxsackie B5 outbreaks mentioned above (Hawley et al., 1973) is questionable.

The largest reported bathing associated outbreak occurred, in 1979, when during a three day period, in July, 187 individuals developed gastroenteris within three days from swimming at two lakes within a park in Michigan (C.D.C., 1979). Although the etiological agent was not at first identified, the short incubation period, the relatively mild gastroenteritis with short duration was suggestive of the human rotavirus, Norwalk agent and/or parvolike viruses. The CDC (1983) has recently reported on two additional outbreaks of swimming associated disease, definitely caused by Norwalk agent in Minnesota Parks. Cabelli (1983) feels strongly that the findings of his own studies suggest this fact.

D'Alessio et al., (1980) carried out a study of virus transmission in swimming waters at beaches, at fresh water lakes and swimming pools in Madison, Wisconsin. The retrospective study consisted of a surveillance of recent swimming activities and clinical histories of 3,774 children who visited a pediatric clinic. Children, with clinically apparent acute viral infections, were tested for virus infection in the laboratory. The unique feature of this study was that its aim was supposedly to test the hypothesis that recreational waters that are not exposed to contamination by sewage effluent can serve as a medium for transmission of virus diseases, particularly enteroviruses. According to the report, no sewage effluent is discharged into the lake in the vicinity of the bathing areas.

The researchers conclusions are as follows:

1. That children who visited swimming sites consistently reported more illness of apparent viral etiology, both respiratory and gastrointestinal, than those who refrained from those activities, i.e. a statistically significant association between swimming activities and entroviral illness was demonstrated.

2. There was no apparent association between the frequency of visits to swimming sites and illness.

3. The data suggests that water served as the enterovirus transmission medium, although this study does not provide direct evidence on this point.

4. The results suggest, although less strongly, that the risk of acquiring enteroviral illness may be greater at beaches, than at swimming pools.

It must be noted that at these so called pollution free beaches, the mean faecal coliform counts for 1976 were 24/100 ml, and for 1977, 39/100 ml with numerous counts over 1000. There were even a few individual enterococci and E. coli counts over 10,000/100 ml. The report states that "the origin of the faecal coliforms and enterococci, which repeatedly has lead to the closing of the individual beaches for short periods, is not clear despite considerable investigation". Suspicion that some of the bathing waters were indeed exposed to external sources of sewage pollution does make it difficult to accept the authors assumption that the only source of viruses was from the bathers' bodies. Considering these serious limitations in the study design, it is difficult to evaluate the findings of this study.

The researchers hypothesize that since the enteroviruses that caused the excess infection among swimmers were not introduced into the water by external sources of sewage flows, that virus excreted by the bathers themselves from the respiratory tract or intestinal tract were the source of the contamination of the water. The authors also consider the possibility that the virus diseases were transmitted by person-to-person contact at the swimming site rather than through the medium of the bathing water.

This study suffers from two cardinal weaknesses both recognized by the researchers themselves. Firstly, the actual swimming activities of the subjects were not known. It was only known if the subjects "visited" the bathing sites. Secondly, the microbiological quality of the water was not monitored by the researchers but by the City of Madison on a weekly basis. The quality of the bathing waters as determined by tests for faecal coliforms and enterococci varied widely during the study period. The geometric mean for enterococci for all beaches during the study was 71/100 ml in 1976 and 108 in 1977, with numerous individual tests above 1000/100 ml. Thus, transmission of virus disease by bathing in sewage contaminated water or water contaminated directly by other bathers is a decided possibility.

Ear, eye, nose and respiratory disease

One of the first systematic attempts to collect information on communicable disease in relation to bathing was made in 1921 when a committee of the American Public Health Association (Simons et al., 1922), sent out 2,000 questionnaires to specialists in eye, ear, nose and throat disease and to health officers, asking for opinions and information on bathing as a factor in the transmission of disease. From 571 responses in which at least one question was answered, the committee concluded that certain outbreaks could reasonably be ascribed to swimming, including 7 outbreaks of conjunctivitis, 2 of middle ear infection, 2 of pharyngitis and tonsillitis and 1 of sinusitis.

It was apparently assumed from the above findings, that certain upper respiratory, ear and eye infections are caused by organisms from wastewater polluted bathing water. According to Mood and Moore (1976) no evidence for this conclusion can be found in the literature. They conclude that "In man, middle ear sinus infections are usually caused by organisms from the patients nasopharyns, which may be mechanically introduced into the paranasal cavities in the course of swimming and diving".

In 1955, Bell et al., published the first epidemiological study of pharyngoconjunctival fever, a then recently recognized disease entity caused by what are now known as adenoviruses. This was a highly infectious acute disease characterized by high fever, pharyngitis and conjunctivitis.

Spread was most rapid from person-to-person in affected households, but the pattern of spread in camps suggested that contaminated swimming pool water might have been "a possible source of infection accessory to a person-to-person mode of spread". Later work has shown that the conjunctival route is a very efficient one of the transmission of adenovirus infection. Swimming-pool outbreaks have also been described as occurring during periods of defective chlorination (Foy et al., 1968). Adenoviruses are readily destroyed by chlorine. A higher incidence of pharyngoconjunctival fever in bathers when chlorination was ineffective, suggestive of a graded dose-response relationship, would, therefore, support the view that bathing caused the disease (Mood and Moore, 1976).

Mood and Moore (1974) are of the opinion that whatever the relative importance of person-to-person spread and swimming pool water transmission in this disease is, it is quite clear that pharyngoconjunctival fever is an upper respiratory tract infection, the incidence of which bears no logical relationship to sewage pollution of bathing water. However, it is a disease which may be transmitted by bathing, the route of the infectious agent being bather-water-bather.

In 1981, Calderon and Mood published a report of two studies of otitis externa among swimmers. Otitis externa is an inflammation of the outer ear canal, characterized by pain, swelling, drainage and occasional fever. This disease is sometimes known as swimmers ear. One, was a prospective study conducted in the summer of 1979 comparing boy scouts at camp who swam in a fresh water lake with boy scouts at another camp who swam in a chlorinated swimming pool. The other was a retrospective study conducted at Yale University during the summer of 1980. In the prospective study, 3 per cent of the children reported ear complaints in the week following camp, but none had otitis externa confirmed by a physician: the retrospective study compared 29 cases with 29 controls which were matched by age and sex.

In the prospective study a higher relative humidity at the camp where the boy scouts swam in a chlorinated pool was associated with a greater degree of abnormal flora colonization of the ear (Gram-negative bacteria and S. aureus). In the retrospective study, positive association was demonstrated with cases of otitis externa for ambient air temperatures, water temperature, less than 18 years of age, being female, swimming, and length of time spent swimming. There was no association between cases of otitis externa and water quality as measured by faecal coliforms, enterococci and P. aeruginosa or between abnormal flora colonization of the ear and bacterial indices of water quality.

The authors drew the following conclusions from these two studies:

1. Otitis externa appears to be a disease associated primarily with people under 18 years of age. Otitis externa in adults does occur, but was not found in these studies.

2. Hot and humid air appears to be associated with otitis externa. This association may be indirect rather than direct. Hot and humid air may affect a person's swimming habits during such periods of extreme weather.

3. Swimming appears to be associated with otitis externa but, more importantly, it seems to be associated with the amount of time spent actually swimming.

4. Otitis externa does not appear to be associated with bacterial indicators of recreational water quality, such as faecal coliforms, enterococci, or P. aeruginosa. This suggests that bacterial indices involving these organisms as measures of recreational water quality may be of little use in evaluating the potential risk of acquiring otitis externa in swimmers bathing in these waters.

5. While P. aeruginosa may be the most commonly isolated organism from cases of otitis externa, the role of other organisms as etiological agent, such as Acinetobacter, Klebsiella, Enterobacter and Staphylococcus, should not be excluded when studying otitis externa.

One of the limitations of this study is that the researchers apparently did not collect information on swimming intensity and, in particular, on diving which, as we shall see, is a crucial intervening variable in ear infections.

Another recent study, on the association of ear infections and bathing in swimming pools of various water qualities, was carried out by Simchen et al., (1984) among young children in Kibbutzim (communal settlements) in Israel. This study concentrated on the detection of otitis externa among 346 children, aged 3-6, at swimming pools in 11 different kibbutzim. The children bathed almost every day for the summer months and were followed up clinically by the local medical personnel. They were closely observed, as to whether they dived or not, by their teachers who accompanied them every day.

A limited number of microbiological tests for total coliform, faecal coliforms and total bacterial count, and chlorine residual were carried out during the course of the study. Thus, only very limited information was available as to the actual microbial quality of the water in which the children swam prior to the detection of illness.

The results indicated that while otitis externa was quite common among swimmers there appeared to be a positive association with the concentration of total coliforms, faecal coliforms and total bacterial counts.

However, controlling for diving activity, a stronger statistically significant excess of otitis externa was found among children who swam in the pools of poor microbial quality. However, among divers the rate of otitis externa was high regardless of water quality.

This study confirms the earlier findings that ear infections are swimming associated. However, they provide firm evidence that they are exacerbated by diving. This study does provide some evidence, when controlling for diving, that pools showing high coliform counts present a higher risk of ear infection. Presumably no sewage pollution in such swimming pools occurred and the increase in coliform counts is indicative, in a general way, of increased microbial flora from body contact including increases in the density of possible causative microbial agents of the ear infections. This study suffered from the fact that only coliforms were used as microbial indicators rather than other microorganisms that might represent mouth, nose, ear or eye excretions and body contact contamination. Also, the number and frequency of bacteriological tests were insufficient to obtain a proper evaluation of the water quality.

Shigellosis

One of the best investigated outbreaks which provides valuable information on the transmission of enteric disease (Shigellosis) to persons bathing in sewage contaminated water occurred in 1976 on an 8 km stretch of the Mississippi River below Dubuque, Iowa (Rosenberg et al., 1976). Of 45 culture-positive cases studied, 43 (96%) of the individuals consulted a physician and 18 (4%) were hospitalized. Twenty-three individuals had a history of swimming in the area within three days of the onset of symptoms. Thirteen of them were swimming at a park area which, when sampled periodically during the month following the end of the outbreak, had a mean faecal coliform density of 17,500/100 ml. Shigella sonnei, the same antibiogram and colicin type as the isolates from seven swimmers, also was recovered from these waters. A case-control analysis and a retrospective, cohort analysis of an additional 262 individuals revealed a statistically significant association of gastrointestinal illness with swimming (p .001) but not with drinking well-water or with food consumption. The illness was defined as diarrhea with fever and cramps occurring within three days. The rate among swimmers at the park was 12 per cent. Of the swimmers, the highest attack rate and the best correlation to illness was among individuals who took water in their mouths while swimming and among children and adolescents (less than 20 years of age).

These findings have some limitations since water quality measurements could be obtained only after the end of the outbreak and since the source of the Shigella and indicator organisms in the water could not be unequivocally established. Cabelli (1983), states that, nevertheless, the report documents a consequential outbreak of illness clearly associated with swimming in water polluted with faecal wastes. More important, it would appear that the health effects occurred in the absence of aesthetic deterioration which was sufficient to deter individuals from swimming in the area.

This is the first study to clearly implicate swimming in sewage polluted water with the transmission of Shigellosis. Studies have shown that the disease can be caused by the ingestion of as few as 10 to 100 organisms. In this study, only swimmers who reported that they actually held water in their mouths or swallowed it had a significant risk of illness, suggesting that swallowing a small volume of contaminated bathing water is indeed sufficient to cause disease.

The level of faecal coliform detected in the Mississippi of 17,500/100 ml is some 20 times higher than the U.S. EPA upper recommended limit for swimming of 200/100 ml, but only some 9 times higher than the EEC limit of 2,000/100 for faecal coliforms.

Two additional outbreaks of Shigellosis, associated with swimming in contaminated fresh water, were reported by the CDC in 1983.

Gastroenteritis of unidentified etiology

Dr. B. Moore, in an unpublished draft memorandum prepared for the WHO refers to a study by two Russian workers (Gorodetskij and Raskin, 1960). Moore's analysis of that study follows:

Two Russian workers reported that until June 1956 crude sewage from the Black Sea resort of Yalta was discharged from an outfall on the shore. A new sewer then came into use which now carries the town sewage some 200 m out to sea and discharges it at a depth of 10 m below the surface. The consequent improvement in the appearance of the Yalta beaches prompted a study of morbidity figures for gastrointestinal disease before and after the new sewer was installed. The index used was the overall morbidity/10,000 inhabitants from gastrointestinal disease, obtained by combining notifications for dysentery, gastroenteritis and enteric fever.

In addition, the authors compared the morbidity figures for Yalta during the years 1953-59 with corresponding figures for another Crimean resort, Eupatoria, a town of roughly similar population. The towns were also alike in various other respects. At both, the summer population was inflated 242-fold. Both towns had good water supplies and regular refuse collection. In Yalta, however, 96 per cent of the population was connected to the main sewerage system, whereas Eupatoria had not yet completed a municipal sewerage scheme and because of this had no beach pollution problem.

According to Moore, the authors' claim rests entirely on two text diagrams. The first of these purpots to show a significant fall in monthly incidence of gastroenteritis when data for the 4 summers after the installation of the new sewer outfall were averaged and compared with those obtained for the 3 summers beforehand. Even ignoring the difficulties of achieving adequate notification of gastorenteritis in seaside resorts and joining several categories of illness, it is clearly impossible to distinguish in the diagram between a falling time-trend in gastroenteritis and any change referable to the new outfall.

Moore feels that the argument in the second diagram is even more nebulous. The authors suggest that, as the graph shows a greater relative increase in gastroenteritis at Yalta during the summer than in Eupatoria, the greater increase at Yalta must be due to the factor known to be different there, i.e. the presence of a sewer.

In conclusion, Moore states that on neither ground does the authors' claim stand up to scrutiny, but the attempt to associate changes in disease incidence with some intervention in the environment is right in principle and might have applications elsewhere.

Outbreaks associated with consumption of shellfish

In case of direct human exposure to pathogens in seawater during bathing limited ingestion, dilution and die-away of the pathogens are major protective mechanisms. This is much less the case as far as edible bivalves, such as oysters, clams, mussels, and cockles are concerned. They, as filter feeders, pump large volumes of seawater through their systems and filter out, concentrate and protect the microplankton, together with attached or suspended particles including the pathogens in the sea. These types of shellfish are usually consumed raw or partially cooked.

Typhoid fever

According to Mosley (1974), although one epidemic of oyster-associated typhoid fever was reported from France as early as 1816, it was not until the 1890's and early 1900's that the importance of this mechanism was recognized. The large proportion of cases in some parts of Britain at that time was found to be due to consumption of contaminated oysters, mussels, and cockles. Epidemics of shellfish-associated typhoid were also described at the turn of the century in the United States (Soper, 1905 and Stiles, 1912), although they do not appear to have been so numerous or extensive as in Britain because shellfish were less widely consumed. The recognition of shellfish as a vehicle for enteric agents resulted in some modifications of sewage disposal, with lessening of marine pollution, and there was an inception of shellfish sanitation as a public health activity. The presumed impact of relatively simple measures upon the incidence of typhoid in Brighton between 1895 and 1907 is illustrated in Fig. 2 (from Mosley, 1974).

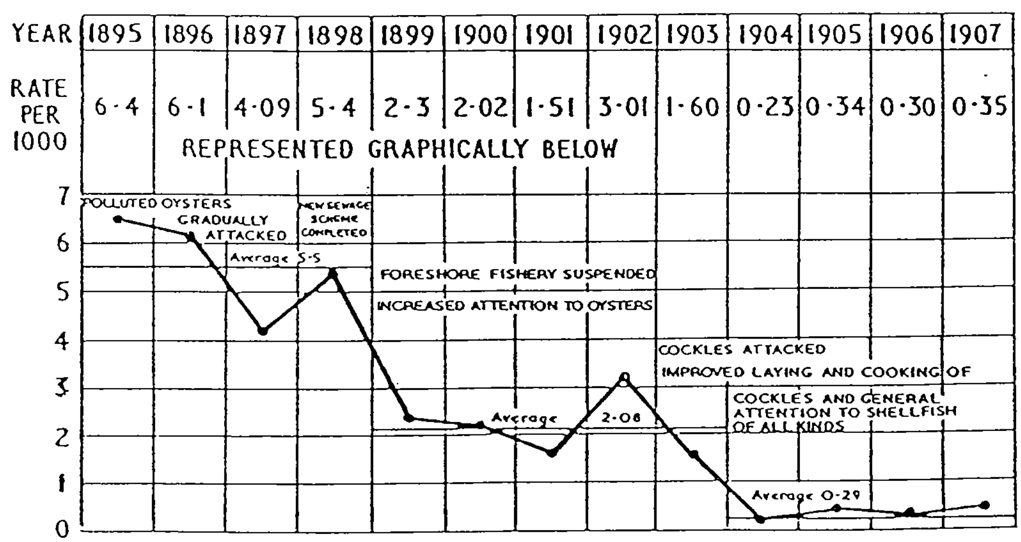



Figure 2: Incidence of typhoid fever in Brighton, England, between 1895 and 1907 (prepared by Nash in 1909) showing impact of various shellfish sanitation measures.

It is questionable whether the contention that the reduction in typhoid fever rates in Brighton, between 1895 and 1907, was exclusively brought about by improved sanitary conditions in the shellfish growing areas is fully justified, since typhoid fever was also on the decline in many inland cities as a result of improved water supplies and generally improved hygienic conditions. In the 1920's, a number of major typhoid fever epidemics were traced to contaminated shellfish in the United States. Brooks (1916), reported on an outbreak of typhoid attributed to infected oysters, Lundsen et al., (1924) described a typhoid fever epidemic in 1924 caused by oyster borne infection. There also was a major typhoid epidemic in Chicago in 1925 apparently due to oysters (Bundesen, 1925).

The clear risk of transmission of typhoid fever by bivalves growing in sewage contaminated water was well established during the early years of this century and served as the basis for the establishment of shellfish sanitation programs in the U.K. and in the United States based on approved, clean harvesting areas and programs of shellfish self-purification in clean-water holding tanks called "depuration" by the Americans. The disappearance of epidemics of typhoid fever transmittted by shellfish may partially be a result of the success of the programs, but may also be explained by the general reduction in typhoid fever during the period 1920 to 1940 as a result of improvements in water treatment, general sanitation, surveillance of food handlers and supervision of known typhoid carriers (Mosley, 1974).

The fact that since then, numerous major outbreaks of infectious hepatitis type A (IHA) were clearly identified as being transmitted by mollusks grown in wastewater contaminated beds indicates that the simple sanitary improvements of the early years of the century did not completely block this route of transmission of thalassogenic disease.

Infectious hepatitis and other virus diseases

Mosley (1974) has reviewed the epidemiological aspects of transmission of infectious hepatitis (IHA) and other virus diseases by shellfish, the main findings of which are presented below.

The Swedish oyster-associated IHA epidemic of 1955-56 (Roos, 1956) was regarded in the United States as an epidemiologic curiosity until 1962. In that year, an oyster-associated IHA outbreak in the southern United States in Mississippi and Alabama involving 84 cases (Mason and Lean, 1962) and a clam-associated epidemic centered in New Jersey involving 459 cases (Doughtery and Attman, 1962) made it evident that the absence of shellfish-associated typhoid fever was not synonymous with absence of contamination by sewage. Two additional clam-associated epidemics, involving hundreds of cases followed in 1964 (Ruddy, et al., 1969; Hepatitis Surveillance Unit, 1964), and an outbreak of major proportion was reported in 1973 (C.D.C., 1973). In addition, there is an "endemic" background of sporadic cases that may total as many as several hundreds each year.

Outside the United States, there has been little interest in mollusk-associated type A hepatitis. Since the Swedish report in 1965, only one investigation has been reported in the literature. Stille and co-workers (1972) indicated that consumption of contaminated mollusks accounted for an estimated 19 per cent of type A hepatitis in Frankfurt. The German cases were mainly attributable to eating oysters and mussels on the Mediterranean littoral, especially southern France and Italy.

The occurrence of shellfish-associated hepatitis is not confined to mollusks eaten raw, because steaming as usually practiced fails to raise the internal temperature sufficiently to inactivate the viral agent (Koff and Sears, 1967).

A recent question is that of transmission of type B hepatitis by accumulation of hepatitis B virus (IHB) in oysters and clams (Mahonly et al., 1974). The only demonstration of mollusk contamination, however, was in samples taken from a bed adjacent to a hospital's sewage outfall. Many other samples along the coast were negative for IHB. Mosley feels that seafood is not a significant route of transmission of type B hepatitis (IHB), since occurrence of the agent in faeces is doubtful, and oral infection of serum is low. Mosley (1974) argues that disposal by pouring down a sink of one or several units of IHB contaminated blood at a hospital, however, could conceivably result in an occasional infection. However, Mosley neglects to mention that blood from menstruation normally reaches the sewage systems, providing a continuous source of contaminated IHB virus.

Metcalf and Stiles (1967) demonstrated enteroviruses in oysters harvested from contaminated waters closed to harvesting and Denis (1973) reported recovery of Coxsackie A viruses in market samples taken in France.

The designation "shellfish" includes not only mollusks but also crustaceans. Mollusks are frequently eaten raw and the entire animal is consumed including the gastrointestinal tract. This fact, in addition to their ability to concentrate particulate matter, is very relevant to their frequent implication as vehicles of enteric infection. Crustaceans, on the other hand, are commonly eaten after removal of the gastrointestinal tract and other viscera, and cooked to a degree that would seem adequate to kill any organisms that might be present. Crustaceans also do not have the same efficiency of concentrating small organic particles from seawater as do mollusks. Recently, however, DiGirolamo and co-workers (1972a) have demonstrated that West Coast (United States) shore crabs accumulated polio-virus both in artificially contaminated seawater and when allowed to feed on virus-contaminated mussels. In another experiment, they demonstrated phage uptake into the edible flesh of the crab and its persistence after cooking in boiling water for as long as 20 minutes.

A later review of transmission of virus disease by shellfish was published by Goldfield (1976) in which he lists 13 published reports of common source outbreaks of hepatitis A, associated with shellfish ingestion (see Table 2). He concludes that the 1,612 cases of shellfish-associated IHA recognized in the 13 outbreaks represent but a small proportion of those that actually occurred. Koff et al., (1967) have provided evidence suggesting that ingestion of raw clams and oysters may also account for a small but significant fraction of sporadic cases of IHA during non-epidemic periods. Mosley (1974) shares this view.

Table 2: Common source outbreaks of hepatitis associated with shellfish ingestion

| Year | Source | Place | No. of cases |
|---|---|---|---|
| 1953 | Oysters | Oregon | 30 |
| 1955 | Oysters | Sweden | 629[18,19] |
| 1961 | Oysters | Mississippi & Alabama | 84[20] |
| 1961 | Clams | New Jersey | 459[21] |
| 1961 | Clams | Connecticut | 15 |
| 1962 | Clams | New York | 3 |
| 1963-4 | Clams | New Jersey & Pennsylvania | 252 |
| 1963-4 | Clams | Connecticut | 123[22] |
| 1964 | Oysters | North Carolina | 3 |
| 1964 | Oysters | British Columbia | 2 |
| 1966 | Clams | Massachusetts | 4[23] |
| 1967 | Clams & Oysters | Texas | 3 |
| 1971 | Clams | Massachusetts | 5 |

(From Goldfield, 1976)

Goldfield (1976) also reports on five outbreaks of gastroenteritis of unknown etiology in which shellfish including clams and oysters were implicated. He suggested that some of these outbreaks of "non-bacterial" etiology may have been caused by parvoviruses. The first clear-cut shellfish-associated epidemic caused by the norwalk-like virus was a massive gastroenteritis outbreak in all areas of Australia in which some 2,999 cases were reported. This outbreak was associated with the consumption of raw shellfish harvested from wastewater contaminated areas (Murphy et al., 1979). One estimate suggests that possibly 10 to 20 times that number of people were actually infected in the outbreak.

There is now ample evidence that shellfish, particularly mollusks grown in sewage polluted water are very effective carriers (and concentrators) of IHA virus and norwalk-virus, and have on numerous occasions caused infection in humans.

Cholera

There had been only limited opportunity to study the possibility of Vibrio cholerae transmission by mollusks until that disease became pandemic in 1970 and shellfish growing areas in Europe were exposed to wastewater carrying V. cholerae organisms from cases or carriers of the relatively mild El Tor form of the disease.

In 1973, it became amply clear as a result of a major cholera epidemic in Italy that contaminated mollusks can be a very effective vector of the disease (Baine et al., 1974).

Whether the cholera vibro laden wastewater was derived from ships in the harbor carrying hidden cases of the disease as hypothesized by some of the investigators or from recently arrived subclinical cases using the city sewerage system, which discharges raw wastewater directly into the harbour, is immaterial.

The fact remains that the mollusks were grown and harvested in sewage contaminated water containing cholera vibrios and successfully concentrated the vibrios, which survived long enough and in high enough concentrations to result in a massive epidemic.

Studies indicate that the minimum infective dose for cholera is around 1,000 organisms. The cholera epidemic in Naples, the coastal regions of Campania and Puglia and in Sardinia, resulted in grave health effects with 278 confirmed cases, probably many more non-laboratory confirmed cases, and 25 fatalities. There were, as well, staggering economic losses due to the loss of tourism and trade which resulted from the compulsory international quarantine notification of the outbreak to all countries of the world.

It should be noted, that prior to the much publicized Naples outbreak, there was an explosive outbreak of cholera in the Philipines in 1961, in which Joseph et al., (1965) identified the consumption of raw shrimps as the main mode of transmission. Laboratory studies have indicated that V. cholera persists in fish and shellfish at room temperatures for 2-5 days and under refrigerated conditions for 1-2 weeks (Ardoz, 1970).

With El Tor cholera pandemic and the possibility of tourists or crew members suffering from subclinical cases flying in from an epidemic zone to a country free of cholera in a matter of hours, the case of Naples could reoccur almost anywhere, particularly in areas where shellfish growing areas are exposed to raw wastewater flow from adjacent cities. It can be estimated that one single person infected with cholera may excrete as many as $10^{13}$ vibrios in one day, which is sufficient to contaminate a shellfish bed near a small raw sewage outfall. Since the Naples outbreak, other shellfish borne outbreaks of cholera have been reported.

## PREDICTIVE MODELS BASED ON INDUCTIVE REASONING

Due to the paucity of quantitative epidemiological data relating health risks of bathing in contaminated seawater to the concentration of microbial indicator organisms, a number of efforts have been made to develop predictive mathematical models based on inductive reasoning. These models have used as input experimental and field data on such factors as: minimal infective dose; ratio of pathogens to indicator organisms; expected amount of water ingested by a swimmer; and levels of immunity.

The Streeter model

The first such effort was made by Streeter in 1951 basing his calculations on the anticipated risk of ingesting a typhoid bacterium (Salmonella typhi) on the earlier studies of Kehr and Butterfield (1943). In that study they developed an estimated ratio of total coliforms to typhoid bacteria in sewage and surface waters as a function of the typhoid fever morbidity rate in the community.

For example, according to their estimates, if the typhoid morbidity rate is 10 cases/10,000 then the Salmonella typhi: total coliform ratio would be $8:10^6$. They assumed that the coliform concentration in a community wastewater remains more or less constant, but that the pathogen concentration is a function of the morbidity rate, i.e. the relative number of persons excreting the pathogen. The total coliform standard of 1,000/100 ml adopted by many authorities in the United States in the 1950's was based partially on Streeter's analysis and partially on the "attainability" concept of Scott (1951).

Cabelli (1983) has criticized such models as unproductive, in general, and the Streeter analysis in particular, since it was based on the assumption of a minimal infective dose of one salmonella organism for typhoid fever. This is several orders of magnitude less than the dose obtained from human volunteer studies (Hornick et al., 1970). In any event, today with the almost total disappearance of typhoid fever in most developed countries, there is little point in attempting to evaluate the health risks of bathing in contaminated seawater in connection with that disease.

The Shuval model

We have made our own attempt by deductive reasoning of arriving at an evaluation of the risk to health, based on bathing in contaminated marine water (Shuval, 1974). Some of the variables that must be considered in this approach and our conclusions are presented in the following paragraphs:

Minimum infective dose

A number of studies have indicated that for certain enteric viruses the minimum infective dose for humans is as low as one tissue cultural infective dose (Plotkin and Katz, 1967; Kowal et al., 1982; Shiff et al., 1984). Cabelli (1983) has concluded that the most probable etiological agents of the gastrointestinal infections associated with bathing detected in his studies were human rotavirus and/or the Norwalk agent viruses. Although no definitive studies are available, it is assumed that these agents excreted in very high concentrations are highly virulent and have a low minimal infective dose. In our initial estimate, we assumed that only 1 person in 10 who ingests a single virion will become infected and of those only 1 in 10 will develop a clinically detectable form of disease. Thus, we assumed that only 1 per cent of those who ingest a minimal infective dose will actually develop disease. With a virulent pathogenic virus and for the highly susceptible younger age group (10 years) this may be an overly conservative assumption. Thus, it is not unreasonable to assume that 1 in 10 who ingest a minimal infective becomes ill.

Ratio of pathogens to indicator organisms

The pathogen concentration in the wastewater stream is a function of the number of ill or subclinical cases excreting the specific pathogenic organism. In the case of diseases that appear in communities infrequently, in epidemic cycles, there can be considerable variation in the ratio of pathogens to indicator. However, in the case of more common endemic virus diseases such as those caused by some enteroviruses, Norwalk agent and human rotavirus in larger communities, it is not unreasonable to assume that the shedding rate of the specific pathogens is more or less constant during the bathing season year after year. It is assumed that the ideal indicator organism has more or less a constant concentration in the original wastewater stream and has a die-away pattern parallel to the pathogens. We, however, have shown that total coliforms have a much more rapid die-away rate in seawater than do enteroviruses. Thus, if the initial enterovirus to total coliform ratio in the raw sewage was 1:100,000, or 1:10,000, it could be increased to 1:1,000 or less at a beach 1.5 km down current from a marine outfall sewer (Fattal et al., 1983; Shuval, 1970) due to the more rapid differential die-away rate of the coliforms. In our original estimate, we assumed a ratio of the specific virus etiological agents of bathing associated illness to total coliforms of 1:100,00. With essentially no virus die-away in a few hours of transport in the sea, but with a reduction in total coliforms by a die-away factor of about 100 the ratio would be increased to 1:1,000 at the bathing area near the shore line.

In light of today's advancement of knowledge, different assumptions would be made for more promising indicators such as E. coli or enterococci. The initial concentration of enterococci in fresh wastewater is lower and is often only about 1 per cent of the total coliforms. Assuming parallel die-away with the virus pathogen, it might be estimated that the specific pathogen to enterococci ratio in seawater bathing areas would also be 1:1,000. However, Cabelli (1983) is of the opinion that the concentration of the virulent rotavirus in wastewater and marine water could be quite high and close to that of enterococci, thus, a ratio of 1:100 or 1:10 might also occur.

Volume of water ingested by swimmers

While it can be safely assumed that most individuals will consume about 1 liter of drinking water per day, if not more, in hot dry climates, no such simple assumption can be made as to bathers. Mechalas et al., (1972) suggested that 10 ml is the average amount ingested by swimmers per exposure period while Steiniger (1954) reports on a survey made among physical education physicians, in Germany, who found 50 ml to be a good estimate for active swimmers in high quality fresh water. Of course, there will be individual differences and differences due to climate. For example, a child spending the day at a warm Mediterranean beach resort may spend as many as 2-4 full hours in the water and ingest 100 ml of sea water during the day, while a bather at a colder Scandinavian beach will spend much less time in the water and can thus be expected to ingest much less water. For the purposes of this discussion, it is assumed that bathers ingest about 10 ml per bathing day. It is felt that this assumption is a conservative one.

Hypothetical risk of becoming sick

Based on the above assumptions, it is possible to calculate the range of the hypothetical risk of becoming infected and/or sick by a single exposure to a contaminated bathing area with any given concentration of indicator organism.

Assuming marine water with an enterococci concentration of 100/100 ml; a ratio of virulent virus pathogens to enterococci of 1:100; a minimal infective dose of 1; that 10 per cent of those in the susceptible age group up to 10 who ingest a minimal infective dose became ill; and that, on the average, bathers ingest 10 ml of seawater; it can be calculated that on the average there will be one virus infective dose per 100 ml of marine water and that one out of 10 persons will ingest an infective dose. Of those only 10 per cent will become ill. In other words, according to this model and under this assumption, 1 per cent of the swimmers (up to the age of 10) would become ill as a result of a single days exposure to bathing in water with an enterococci concentration of 100/100 ml. If it is assumed that the ratio of virus to enterococci is 1:10, rather than 1:100 as assumed in the first calculation, then 10 per cent of the swimmers would become ill as a result of a single day contact. From the above hypothetical calculation, it is possible to suggest that the risk of children becoming ill after a single bathing exposure to seawater with 100 enterococci/100 ml is in the range of 1-10 per cent. Depending on the assumptions, it might be somewhat greater or less than the above range.

All of the above, are only hypothetical calculations and risk estimates but, based on methods of inductive reasoning and assumptions such as those presented above, it is possible to arrive at the general conclusion that, if the above assumptions are more or less correct, that there is a quantifiable health risk associated by bathing in wastewater contaminated seawater and that risk can be correlated to the concentration of a reliable bacterial indicator organism. Validation of this assumption was not available when we originally published it in 1974 but it is today, as we shall show later on.

Predictive models such as that presented above do indeed have limitations but lacking firm field epidemiological evidence, they did play a role in helping to evaluate whether or not a health risk is involved in bathing in wastewater polluted seawater and whether a quantitative microbial standard could be useful in evaluating or reducing that risk.

## EPIDEMIOLOGICAL STUDIES DESIGNED TO CORRELATE HEALTH RISK WITH MICROBIAL INDICATORS

Only a very limited number of epidemiological studies were designed with the intention of determining whether there is a correlation between health risks (i.e. thalassogenic disease) and the concentration of specific microbial pollution indicator organisms. In the final analysis only from carefully designed studies of this type, is it possible to determine the true extent of health risk associated with bathing in sewage contaminated water and the efficiency of indicator organisms as monitoring systems.

### The Stevenson - U.S. Public Health Service Study (1953)

The first systematic prospective epidemiological study dealing with recreational water-borne disease in which microbial indicator organism concentration was used as a key intervening variable was carried out by Stevenson (1953) and his associates in the U.S. Public Health Service.

There were three studies. The first was conducted at two beaches on Lake Michigan in the vicinity of Chicago. The second examined illness rates among individuals at two locations, a swimming pool in Kentucky and a nearby stretch of polluted beach on the Ohio River. The third study was conducted at two marine beaches on Long Island Sound, one in New Rochelle, New York and other in Mamaroneck, New York.

A household diary method to record symptoms was used in all three studies. The main conclusion was that there was a statistically significant excess (P=0.01) of disease among bathers at fresh water bathing sites at Chicago and along the Ohio River with total coliform concentrations of about 2,400/100 ml. In addition, the researchers detected an excess of disease, particularly ear, nose and throat infections among swimmers over non-swimmers regardless of bathing water quality. The authors explained this later finding by stating "water is an abnormal habitat for man regardless of its bacterial quality" (Stevenson, 1953).

Moore (1974) in his detailed critique of the Stevenson study has made the following points:

"The Chicago results can certainly not stand up to serious scrutiny. On the evidence given, the survey tables were inspected and two groups of swimmers chosen because their three-day illness incidence rates of 12.2 and 8.5 per 100 swimmers respectively showed an apparent excess of illness in those who bathed in the more contaminated bathing water. Opposite findings in the other surveys were ignored. Secondly, all the illnesses reported were lumped together. It would be manifestly absurd to compare the incidence of skin irritations in bathers on the cleaner days with the frequency of diarrhea in those who swam on the other days, but there is no way of knowing to what extent this might have been done. Thirdly the comparability of the two swimming groups in other material respects is not discussed. Fourthly, the inclusion of all illnesses reported during the week after a bath makes the association of these ailments with the bathing episode more tenuous. With all these doubts, the emphasis placed on a rather marginal level of statistical significance as an index, not only of association between bathing and illness but of cause-and-effect relationship between the two, is difficult to justify".

"The Ohio River study findings are equally unsatisfactory in this respect. Significance is attached to an incidence of gastro-intestinal disease in Ohio River swimmers in excess of that suffered by swimmers in a fresh-water pool with recirculation and filtration by a margin that could occur by chance once in twenty trials. The difference was accounted for by gastro-intestinal complaints reported by 13 river swimmers out of a total of nearly 1,000. Here again, the multiple aetiology of minor gastro-intestinal complaints makes it difficult to assess to what extent the comparisons made between the two swimming groups and tested by statistical tests of significance have any real validity."

Cabelli (1983) in his critique of this important study has pointed out that swimming was not defined rigorously enough so that any subsequent illnesses could be attributed exclusively to contact of the upper body orifices with polluted water as opposed to consumption of food at the beach, personal contact between beachgoers, aerosols potentially generated by toilet facilities, etc. Secondly, because the trials we conducted over the entire summer, the effects of day-to-day fluctuations in the pollution levels at the beaches were not eliminated. The consequence of this was that the mean indicator densities and, hence, the illness rates at the paired beaches in the first and third studies were not significantly different from each other. A third problem was that measurements were reported only for one indicator, total coliform bacteria.

In the first study, symptom rates among the beachgoers at the South Beach were no different than those at the North Beach. However, a statistically significant difference (P=0.01) was obtained in the rate of total symptoms among individuals who were at the South Beach during three "high" coliform density days compared to those there during three "low" days. This was not true at the North Beach. The mean indicator density during the high days at the South Beach was 2,300 total coliforms/100 ml. In the Ohio River study, the rate for total symptoms was higher among people at the chlorinated swimming pool than those at the polluted beach on the Ohio river. However, the age adjusted rate for gastrointestinal symptoms was higher for the individuals at the river beach than those at the swimming pool. The mean coliform density in the stretch of the Ohio River was 2,700/100 ml. In the third study, conducted at the marine beaches in the vicinity of New York City, no differences in symptom rates could be obtained even when illness rates during "high" days and "low" days were compared.

Cabelli (1983) states that aside from problems in the experimental design there are a number of problems with the analyses of the data and the conclusions drawn thereof. First of all, Stevenson concluded that swimming per se resulted in a higher rate of illness. Because of the experimental design, it can only be concluded that going to the beach results in a higher illness rate. Second, the comparison of illness rates for three high days versus three low days during the Lake Michigan study has been criticized in that the differences were shown for only one set of high versus low days, and no data are given for all the other possible combinations. Third, in the first study, the differences were reported for total symptoms, while in the second, they were for gastrointestinal symptomatology; yet, both sets of data were used identically in the derivation of the guidelines. Cabelli (1983) feels that "because of the limitation in the experimental design and analysis, one could conclude the positive results were spurious and that there was no effect of swimming in sewage-polluted waters. Alternatively, the limitations in design and analysis notwithstanding, it might be argued that the findings described a reality obtained with a relatively insensitive epidemiological instrument".

Despite the above noted limitations, which were not all recognized at the time, the National Technical Advisory Committee (NTAC) to the Federal Water Pollution Control Administration (FWPCA), which was the predecessor of the EPA concluded as follows (NTAC, 1968):

"The studies at the Great Lakes (Michigan) and the Inland River (Ohio) showed an epidemiologically detectable health effect at levels of 2,300-2,400 coliforms per 100 ml. Later work on the stretch of the Ohio River where the study had been conducted indicated that the faecal coliforms represented 18 per cent of the total coliforms. This would indicate that "detectable" health effects may occur at a faecal coliform level of about 400/100 ml; a factor of safety would indicate that the water quality should be better than that which would cause a health effect ... The Santee project correlated the prevalence of virus with faecal coliform concentrations following sewage treatment. Virus levels following secondary treatment can be expected to be 1 Plaque-Forming-Unit (PFU) per milliliter with a ratio of 1 virus particle per 10,000 faecal coliforms. A bathing water with 400 faecal coliforms per 100 ml could be expected to have 0.02 virus particles per 100 ml (1 virus particle per 5,000 ml)."

Based on this analysis, they recommend as follows:

- "Faecal coliforms should be used as the indicator organism for evaluating the microbiological suitability of recreational waters. As determined by multiple-tube fermentation or membrane filter procedures and based on a minimum of not less than five samples taken over not more than a 30 day period, the faecal coliform content of primary contact recreational waters shall not exceed a log mean of 200/100 ml, nor shall more than 10 percent of total samples during any 30-day period exceed 400/100 ml."

The U.S. EPA (1976) later adopted this recommendation despite an earlier evaluation by a panel of the National Academy of Science in 1972, which concluded that "no specific recommendation is made concerning the presence or concentration of microorganisms in bathing water because of the paucity of valid epidemiological data". Basically by that statement the National Academy of Science panel had rejected the validity of the Stevenson study.

<u>The Moore - U.K. Public Health Laboratory Services Study - (1959)</u>

Mood and Moore (1976) have summarized the study as follows:

Between the years 1953 and 1959, the British Public Health Laboratory Service, under the leadership of Dr. Brandon Moore (1959), carried out an extensive bacteriological and epidemiological study of bathing in sewage-contaminated coastal waters. The committee recorded 4 cases of paratyphoid fever, out of a total of over 3,000 cases of this disease notified during the years in question, where the evidence pointed to infection having been acquired by children playing on two grossly polluted beaches of the more than 40 beaches examined during the study. At one of the two grossly polluted beaches, a total of 348 samples were collected and examined. The median presumptive coliform counts for these samples were 24,000 per 100 ml and the median faecal coli count was 7,000 per 100 ml. At the other grossly polluted beach, 51 samples were collected and examined. The median presumptive coliform counts for this group of samples was 12,000 per 100 ml and the median faecal coli count was 7,000 per 100 ml. The committee concluded that "bathing in sewage-polluted seawater carried only a negligible risk to health, even on beaches that are aesthetically unsatisfactory", and that this risk was probably associated with chance contact with intact aggregates of faecal material that happened to have come from infected persons.

The Committee also mounted a case-control study of whether or not poliomyelitis could be related to bathing, at a time when this disease was very prevalent in Britain. The study was carried out during the years of 1957 and 1958. When, in any coastal district, a local resident child under 15 contracted poliomyelitis, a careful record was made of the bathing history. As a matched control for each patient, the local medical officer of health chose from the birth register or the school register, the name of a healthy child. This child, it was agreed must not live in the same house as the patient but should be of the same sex, as nearly as possible of the same age as the ill child, and should preferably live on the same street but certainly in the same administrative area. A bathing history was taken from the control child also and the records kept for later analysis.

In all, 150 paired records were collected during the two years that remained before the advent of mass polio vaccination precluded any continuation of the study. The cases and controls were first shown to be well matched for age, sex, and social class. Bathing histories were analyzed in two ways. First, they were tabulated according to whether there was a history of sea bathing at any time three weeks prior to the onset of symptoms in the patients. The bathing histories of the two groups proved remarkably similar. Thus, 45 of the 150 poliomyelitis patients had bathed during the three weeks before the onset of symptoms, as compared to 44 of the health control children. Therefore, the evidence indicated that the proportion of bathers in the poliomyelitis group was simply the proportion that one would expect in children living in a seaside town. There was no indication that any special significance should be attached to the history of bathing as regards the causation of this disease. The bathing histories of the two groups also failed to show any difference when analyzed in terms of the time intervals between dates of bathing and the onset of symptoms in the index cases.

Cabelli (1983) in his detailed critique of the Moore et al. studies (1959) has pointed out that there were a number of problems with the experimental design used: (1) swimming was not defined rigorously; (2) the time span between the actual swimming experience and the query as to its occurrence was protracted in many cases; (3) it was difficult to establish a relationship to the quality of the water in which the individuals bathed; (4) of necessity with this type of analysis in contrast to that used by Stevenson, there was a presumption as to which diseases were "important", poliomyelitis and salmonellosis; and (5) this type of analysis is rather insensitive except when conducted during an outbreak situation. In their report, Moore and his associates noted some of these limitations and pointed out that, "A survey of this type could clearly not prove that poliomyelitis was never caused by bathing, and in any case such a presumptive finding might be contradicted by future events, but the results of the survey give no indication that further investigation along those lines is likely to be fruitful except in the negative sense recorded."

Nevertheless, Cabelli cautions that their findings do not warrant the conclusions drawn: that there is little if any, risk of enteric disease from swimming in sewage-polluted waters unless aggregate faecal material is found therein and that aesthetic consideration will limit beach usage long before there is a significant risk of swimming-associated enteric disease. However, with regard to the two specific diseases in question, Cabelli felt that Moore's conclusions were probably correct since, even in the period subsequent to his report, there have been no outbreaks or cases of poliomyelitis shown to be associated with the recreational use of water, and there has only been one outbreak of this disease even remotely associated with any of the waterborne routes.

Earlier, Moore's methodology and conclusions were criticized primarily because information was not available concerning whether so-called "bathers" actually entered the water sufficiently to submerge their heads and, thus, become truly exposed to the only real risk associated with bathing, that is the ingestion of water (Shuval, 1974). It was pointed out that, "Exposure to risk varies greatly among visitors at bathing beaches since some may swim energetically for hours, ingesting considerable volumes of water, while others may hardly wet their ankles".

Let us assume that those defined as bathers in the U.K. study did in fact become exposed to risk by immersing their heads and did not in fact show any excess of typhoid fever or poliomyolytis. The question remains whether Moore and his colleagues were justified in recommending to the public at large: "That bathing in sewage polluted seawater carries only a negligible risk to health even on beaches that are aesthetically very unsatisfactory" (P.H.L.S., 1959) and that in the final analysis....."microbial standards for bathing waters as usually proposed have little scientific validity" and that "...the allocation of resources needed to check conformity to an imposed standard cannot be justified on public health grounds". (Moore, 1974).

These far reaching conclusions and recommendations, from such an eminent public health official, had a considerable impact in many countries. They led to a reduced support for regulation and control of wastewater pollution of bathing beaches. In one case, in which I was personally involved, the Mayor of a major city in Israel successfully used Moore's recommendations in his battle to prevent the Ministry of Health from implementing restrictions on public bathing at a number of heavily polluted beaches within his city.

It is questionable whether Moore's conclusions, even if correct for the specific diseases studied and for the special situation existing at the relatively cool bathing beaches in the U.K., were transferable to polluted beaches in more temperate climates such as the Mediterranean. At bathing beaches in such temperate or tropical areas, very young, highly susceptible bathers often spend hours in the water with the chance of ingesting considerable volumes of water. Such an intensive exposure rarely occurs at the often chilly bathing beaches in Britain.

Since the publication of the U.K. report (Moore, 1959) which cast serious doubt as to the existence of health risks associated with sewage contaminated seawater and totally challenged the validity of any microbial standards for recreational bathing waters there has been a great deal of uncertainty within the public health community. All concerned felt that only a well designed, definitive and large scale epidemiological study of all the questions concerned could finally resolve the great debate on this vital issue.

## The Cabelli - U.S. EPA study (1983)

In 1972, Cabelli and his colleagues at the U.S. EPA initiated a large scale prospective epidemiological-microbiological study which included both salt water and fresh water beaches. The study which spanned a six year period, eventually included some 26,000 subjects at 3 locations in the United States - New York City (New York); Lake Pontchartrain, New Orleans (Louisiana) and Boston Harbor (Massachusetts). An additional study was conducted in Alexandria, Egypt. All U.S. studies used essentially identical methodology designed to overcome many of the weaknesses revealed in the Stevenson and Moore studies mentioned previously.

Cabelli (1983) has described the design characteristics which made their study unique as follows:

In response to the perceived deficiencies in the Stevenson studies, the calendar approach was not used. Rather, the participants were recruited at the beach and queried some 7-10 days later by phone or personal interview (mail questionnaires were tried and found to be unsatisfactory) concerning symptomatology which developed subsequent to the swimming experience. Other features of the design were as follows:

1. Only individuals whose upper body orifices were exposed to the water were classified as swimmers, and subjects were queried on the nature and duration of swimming activity. The more rigorous definition of swimming allowed for a beach-going but non-swimming control group and thereby eliminated the bias from non-swimming associated illnesses..

2. Beach interviews were conducted only on weekends. Exposure was limited to a single day, or at most two successive days on a weekend. This was accomplished by eliminating individuals who swam in midweeks before and after the weekend trials from the study. The use of weekends maximized the size of the study population but limited the illness observation period to 8-10 days. This feature of the study facilitated the analysis of the data "by days", thereby obviating the effect of day-to-day variability in pollution levels. However, it eliminated from consideration illnesses with incubation periods exceeding nine days, notably infectious hepatitis (this was examined in the portion of the Egyptian study which dealt with Cairo visitors to Alexandria beaches).

3. The impact of within-day variability in pollution, primarily attributable to tidal effects, could not be eliminated. However, in the first two years of the New York City study, an attempt was made to minimize this effect by choosing test and control beaches which were markedly different in the pollution levels reaching them. There also was an attempt to select trial dates when minimal tidal effects coincided with peak beach usage periods (usually 11 a.m. to 5 p.m.).

4. Demographic effects, which could assert themselves as differences in susceptibility to infection, in swimming activity and in the reliability of respondent information, were minimized. This was done by selecting test and control beaches whose populations were demographically similar and by obtaining age, sex, ethnic, and SES information that could be used in isolating and identifying the influence of these factors.

5. The respondents were asked whether they remained home, remained in bed or sought medical advice because of the symptoms. This information was used to indicate disability.

6. A system was devised for validating gastrointestinal (GI) symptomology. Highly credible GI symptoms (HCGI) were defined as: (1) vomiting, (2) diarrhea with a fever disabling enough for the individual to remain home, remain in bed or seek medical advice, or (3) stomachache or nausea accompanied by a fever. The rates for HCGI symptoms were calculated and compared to those for total GI symptoms in order to determine if the trends were the same.

7. The illness questionnaire solicited information on irritations and disturbances of the skin, upper respiratory tract, eyes and ears. This was done not only against the possibility of pollution-associated infectious processes but also against the possibility of toxic and hypersensitive conditions attributable to chemical pollution and to pollution-associated changes in marine biota.

Water samples were collected in sterile bottles from just below the surface of the water, at "chest-high depth", and periodically during the time when people were in the water. They were collected at 2-3 locations along the beach; and, in general, 3-4 samples were collected between the hours of 11 a.m. - 5 p.m., the period of maximum swimming. The samples were "iced" and returned to the laboratory for assay within six hours of collection.

Assays of the water samples were performed to determine the densities of number of potential microbial indicator systems. The microbial indicators tested included: coliforms, _E. coli_, _Klebsiella_ enterococci; _C. perfringens_; Bifido-bacteria; Coliphage; _C. albicans_; _P. aeruginosa_; _A hydrophila_; _V. parahaemolyticus_; _Salmonella_ and Enteropathogenic _E. coli_. A chemical indicator of faecal matter coprostanol, was also tested.

The findings of the main Cabelli EPA report (1983) have been summarized succinctly by Cabelli _et al._, (1983) elsewhere as follows:

"The results clearly show that the risk of gastroenteritis associated with swimming in marine waters impacted with municipal wastewaters is related to the quality of the water as indexed by the mean enterococcus density in the water. Moreover, the risk is detectable at extremely low levels of pollution. According to the criteria suggested by Hill (1965), there is a strong suggestion of casuality. First, the association is a good one; in some trials, the swimming-associated gastroenteritis rate was three to four times greater than the non-swimming rate. Second, there was a consistency in the association in that it was observed at multiple locations over multiple years. Third, the association between enteric disease and faecal contamination is a reasonable one by its very nature. Fourth, the association is a coherent one since there is a precedent for such a relationship by other waterborne routes of transmission, i.e., in shellfish and potable water.

"It was also understandable that, of the indicators examined, enterococcus densities in the water correlated best with the rates for the swimming- associated gastroenterits. The two salient indicator characteristics required for the specific association obtained are a consistent faecal source and 'good' survival during sewage treatment and transport in the aquatic environment. Of the indicators examined, enterococci and _E. coli_ best satisfy the first requirement: and, of the two, enterococci have the best survival characteristics, although their densities in raw or treated sewage are 1-2 orders of magnitude less than those of _E. coli_."

There are two implications from the findings of rather high gastroenteritis rates (1%) associated with the ingestion of one to five enterococci (the accidental ingestion of 10-15 ml of water whose enterococcus density was about 10/100 ml). The first is that even enterococci may not survive as well as the etiologic agent for gastroenteritis. The second is that the agent must be present in the bathing waters and, hence, municipal wastewaters in very large numbers, be highly infectious, survive very well in the marine environment or most probably, a combination of all three.

The correlation coefficient for the New York beach studies between highly credible gastrointestinal (HCGI) symptoms and the concentration of enterococci in the bathing water was r=.96 (P 0.001) while the coefficient for the other potential indicators was as follows E. coli -.58; total coliforms -.65; and faecal coliform -.51. The data for all U.S. studies gave an r=0.75 for enterococcus and r=0.54 for E. coli. The widely used faecal coli indicator proved to be a relatively poor predicator of G.I. disease.

In 1979, Dufour (1984) of EPA, initiated another series of studies at Tulsa, Oklahoma and Erie, Pennsylvania. These studies were completed in 1982. The methods of these additional fresh water bathing area studies, were the same as that used in the marine studies. As in the previous studies a strong correlation between HCGI symptoms and enterococcus (r=.774) and E. coli (r=.804) was found. There was again no association between faecal coliforms and swimming associated gastroenteritis (r=.081).

Based on the findings of these extensive and carefully controlled epidemiological studies Cabelli et al., (1983) have developed a generalized relationship between enterococci densities in marine water and health effects from which can be developed a quantitative criterion for marine recreation waters. This is shown in Fig. 3.

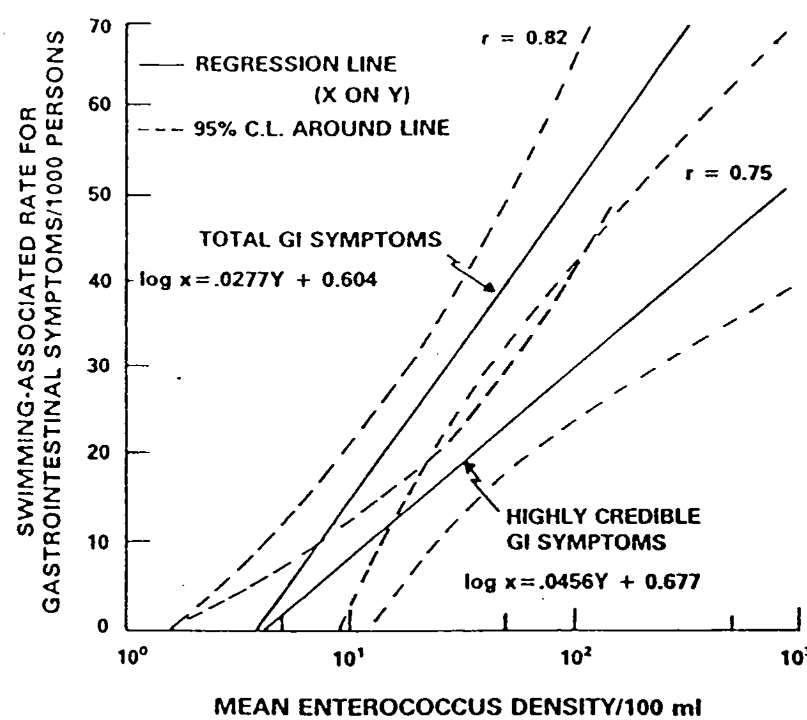



Figure 3: Health effects criteria for marine recreational waters developed by the USEPA epidemiological-microbiological program. Criteria are X on Y regression lines of the mean enterococcus density in the water against the swimming-associated rate of gastrointestinal symptoms.

(from Cabelli, 1983)

From this figure, it is seen that the regression lines for swimming associated gastrointestinal symptoms and enterococci densities approach zero for illness rates before enterococci densities reach zero. Cabelli (1983) interprets this to mean that the pathogens either disappear or are at concentrations lower than the minimal infections dose before the enterococci are no longer detectable in a 100 ml sample. This is not true for E. coli.

Although the Cabelli (1983) studies are not without flaws resulting from a variety of problems that arose during the field work phase, they are by far, one of the most carefully designed and executed epidemiological studies of the relationship of environmental pollution indicators and illness to have been carried out ever. One of the problems is found in the various reports and papers on the project. The numerical findings vary between one publication and another and some are hard to follow. But in the final analysis, this study has provided highly credible and sound results, which provide a firm basis for arriving at operational conclusions and recommendations.

Other relevant epidemiological studies

Alexandria - Egypt

The USEPA sponsored a study based on Cabelli's methods and under his supervision at the beaches in Alexandria, Egypt, in cooperation with Egyptian scientists. The EPA was interested in locating some more heavily polluted beaches than those available for study in the United States, so as to be able to determine the nature of the dose response curve at the higher dose levels.

Some of the beaches included in the study were exposed to nearby outfall sewers and heavily polluted with enterococcus and E. coli densities reaching $10^4$/100 ml. Other beaches were acceptable according to EPA guidelines. The study population included both Alexandria residents and summer visitors coming from Cairo. It was assumed that the visitors from Cairo had lower levels of immunity to the diseases endemic in Alexandria.

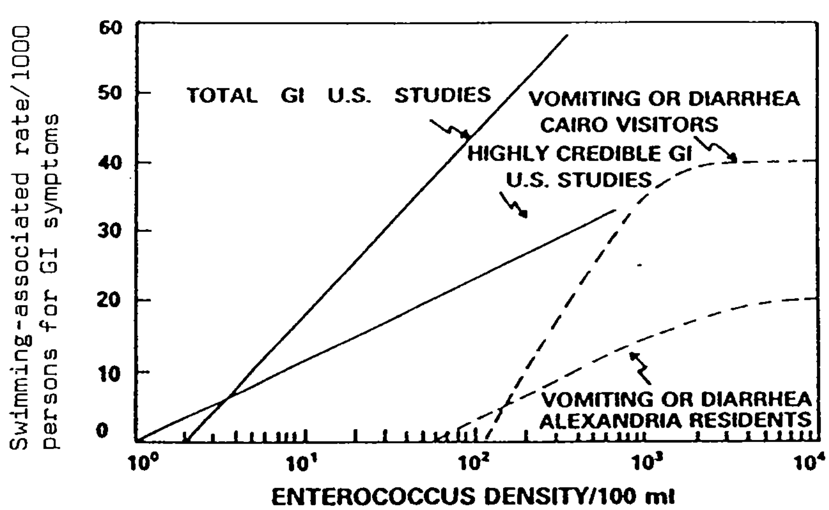



**Figure 4: Comparison of the illness-indicator relationship obtained from the U.S. studies with those for the Cairo visitors and Alexandria residents in the Egyptian studies.**

**(From Cabelli, 1983)**

The main findings were essentially similar to those of the New York city beach study, i.e. a strong association of HCGI symptoms and enterococcus (r=.88) densities as well as for E. coli densities (r=.89). However, at equivalent entrococci densities disease rates were lower in Egypt. This is probably due to higher levels of immunity in the local population. This finding is to be expected in an area where enteric diseases are highly endemic and a high portion of the older children and adults are immune. Fig. 4 shows the regression lines for swimming associated rates for vomiting and diarrhea against the mean enterococcus density of the water for the Egyptian study as compared to the U.S. Studies. A report on certain aspects of this study has been made by El Sharkawi et al. (1982). In their report they state that there is a significant risk of contracting typhoid from bathing in polluted seawater at Alexandria and that the young age group was found to be most susceptible. The proximity of outfalls which carried solid faecal matter to bathing areas was felt to be the main cause of the infections detected.

Tel Aviv - Israel

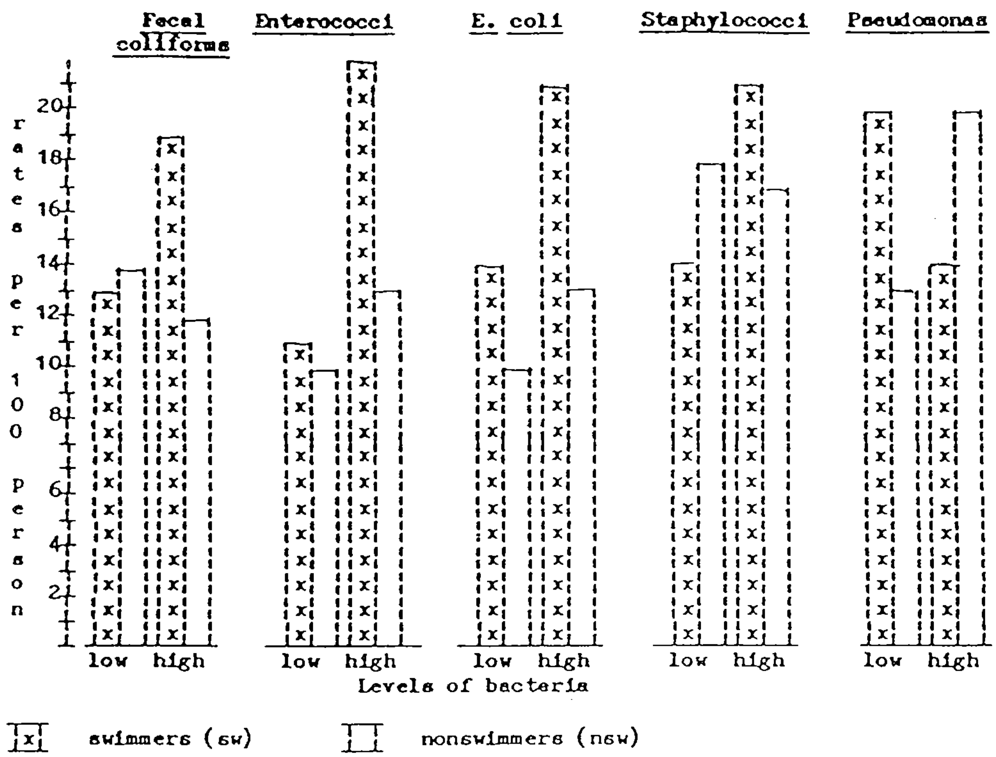
During the year 1983, WHO sponsored a pilot, prospective epidemiological study in Israel, carried out at bathing beaches in the Tel Aviv area. Fattal et al. (1986) designed the study following the basic methodology developed by Cabelli who served as a consultant to the project. The study was carried out at 3 beaches having varying degrees of exposure to sewage pollution. The study encompassed 2,231 swimmers and non-swimmers (32% in the 0-4 age group) and was considered by the researchers as a pretest of the methodology under Israeli conditions. The indicators used were faecal coli, enterococcus, E. coli, staphylococci aureus and pseudomonas. The main finding was a significant ($P<0.03$) excess of enteric symptoms (gastrointestinal disease) among swimmers in the 0-4 age group in water with higher concentrations of entrococcus or E. coli. Faecal coliforms and pseudomonas did not appear to be as good predicators of swimming-associated enteric disease (See Table 3 and Fig. 6).

Table 3: "Low" and "high" levels of three bacterial indicator concentrations in seawater for morbidity analysis.

| Bacterial indicator | Range of bacterial concentrations (CFU*/100ml) "low" | | "high" | |
|---|---|---|---|---|
| | Median | min.- max. | median | min. - max. |
| Faecal coliforms | 9 | 0 - 50 | 138 | 51 - 650 |
| Enterococci | 7 | 0 - 24 | 49 | 25 - 410 |
| E.coli | 5 | 0 - 24 | 49 | 25 - 268 |

* - CFU - colony forming units

TEL AVIV STUDY
Fattal et al., 1985




Population (swimmers and nonswimmers) and significance of differences between incidence rates in Fig. 2

| | Population by levels of bacteria | | | | Significance of differences[1] | |
|---|---|---|---|---|---|---|
| | "low" | | "high" | | sw vs nsw | "high" vs "low" |
| Bacteria | sw | nsw | sw | nsw | for "high" | for sw |
| Fecal coliforms | 106 | 51 | 184 | 108 | NS | NS |
| Enterococci | 131 | 76 | 172 | 101 | * | ** |
| E. coli | 149 | 81 | 154 | 96 | * | * |
| Staphylococci | 91 | 48 | 99 | 36 | * | NS |
| Pseudomonas | 138 | 75 | 23 | 5 | NS | NS |

1 - * - significant at P<0.05 level; ** - significant at P<0.005 level.
No significant differences were found between swimmers and nonswimmers at "low" bacterial levels, or between nonswimmers at "high" vs "low" bacterial levels.

Figure 6: Incidence of enteric symptoms per 100 persons among bathers of the 0 to 4-year-old-age group according to "low" and "high" levels of bacteria.

This study provides another important independent confirmation of the relationship between swimming associated disease and enterococci concentrations in bathing water under Mediterranean conditions. The role of staphylo as an indicator of faecal pollution is not clear since this organism is most likely associated with body contamination of bathers from wastewater pollution.

Malaga and Tarragona - Spain

Mujeriego et al. (1982) carried out an epidemiological study at 24 beaches in Malaga and Tarragona, Spain during the summer of 1979. A total of 20,219 persons were interviewed based on a fixed questionnaire which served as the primary source of data. The authors' own summary of their findings state that the following conclusions can be drawn:

1. Sea-water transparency and the presence of floatable materials, are the two major factors that determine the opinion of recreationists about the aesthetic quality of coastal waters.

2. Useful empirical criteria was obtained, relating the aesthetic quality with the microbiological quality of coastal waters.

3. There appears to be a real public health hazard associated with recreation in coastal waters of unsatisfactory microbiological quality.

4. The most frequent health ailment observed among recreationists are skin infections, with a morbidity rate of 2 per cent, followed by ear and eye infections with a morbidity rate close of 1.5 per cent.

5. Intestinal infections have morbidity rates below 1 per cent, and are not the main public health concern in the coastal areas studied.

6. The habit of immersing the head in the water when bathing is significantly associated with ear and eye infections.

7. Microbiological limits in terms of faecal coliforms do not seem to provide consistent public health protection, in the presence of comparable concentrations of faecal streptococci.

The authors carried out microbiological tests on 19 of the beaches studies during the summer but not necessarily in close association with the dates that persons were interviewed. They plotted regression lines between reported morbidity rates of ear infections at each specific beach and the median faecal streptococci concentration at that specific beach. Although the coefficient of correlation was positive the confidence limits were very wide making it difficult to put much weight in that finding.

Due to lack of adequate controls and total dependence on the interviewees' memory of swimming and illness experiences, this study cannot be considered as providing quantitative eqidemiological information on the relationship of thalassogenic disease and microbial indicator organisms, although the study does supply some suggestive evidence as to the value of enterococci as an indicator of marine pollution.

France

Foulon et al. (1983) performed a study on 5 beaches in France. The method used was a beach interview, followed by an answer card given to the inter- viewee with the listed symptoms occurring within the first 30 days after returning home. Four thousand nine hundred twenty one (4921) individuals were questioned on the beach and 1532 individuals returned an answer card. Water samples were collected and bacteriological analyses of total coliforms, faecal coliforms and faecal streptococci were performed. The results of this study indicate that there was a difference between 1) incidence of conjuctivitis and skin infections among bathers and non-bathers; 2) in the incidence of colds, abdominal discomfort, nausea and pruritis between those who immerse the head in water and those who do not; 3) the difference between polluted and non-polluted beaches were not important. The weaknesses of this study are: the high refusal rate - 19 per cent on the beach, no information on morbidity for 69 per cent of the population interviewed on the beach, and that there was no daily follow-up of the bacterial water quality.

Canada

During the summer of 1980, Seyfried et al. (1985 I & II), carried out a major study of swimming associated disease on a sample of 8000 persons selected from 10 fresh water beaches in Ontario. Only data, obtained from 4537 telephone follow-up interviews, were considered reliable enough for analysis.

The main findings were: significantly higher morbidity rates for respiratory, gastrointestinal, ear and skin symptoms for swimmers than non-swimmers. (69:6/1000 for swimmers versus 24:5/1000 for non-swimmers).

Morbidity among swimmers was shown to correlate with staphylococcal, to faecal coliform levels and somewhat less strongly to streptococcal counts. The authors conclude that in the fresh water situation studied total staphylococci appeared to be the more consistent indicator for predicting total morbidity rates among swimmers.

These findings differ from those of Dufour (1984) and Cabelli (1983) in fresh water bathing areas exposed to sewage contamination.

One possible explanation of these differences is the suggestion that the study beaches in Ontario may have been heavily contaminated with staphylococci bacteria from the bodies of bathers, particularly due to heavy bather load and poor water exchange at the beaches. Thus, staphylococci organisms may indeed be a possible indicator organism of body contact pathogens of non-sewage origin.

To confirm this hypothesis, a special research situation, free of external contamination from sewage sources, would be required. The whole question of swimming associated non-enteric disease and its etiology requires additional study.

## WHO/UNEP GUIDELINES FOR EPIDEMIOLOGICAL STUDIES

In 1977, a group of experts jointly convened by the WHO and UNEP in the framework of the coordinated Mediterranean Pollution Monitoring and Research Program (MED POL), (WHO/UNEP, 1977) proposed guidelines for the conduct of epidemiological-microbiological studies for developing recreational water quality criteria. Prof. V.J. Cabelli, who served as rapporteur played a key role in drafting those guidelines based on his experience in developing the prospective epidemiological studies on this subject for the USEPA. The main objective was to develop a methodology which would provide definitive epidemiological data for developing a recreational water quality criteria that overcame the flaws in previous studies.

That meeting recommended that a number of epidemiological-microbiological studies be initiated in the Mediterranean area to help develop criteria specifically appropriate for that area. These guidelines were updated and modified at the WHO/UNEP consultation meeting on correlation between coastal water quality and health effects held at Follonica, Italy in October, 1985.

## USEPA PROPOSED CRITERIA

While the Cabelli (1983) study developed data for regression lines for both total G.I. symptoms and "highly credible" G.I. symptoms (HCGI) (i.e. nausea, vomiting, diarrhea and stomachache) (see Fig. 3), only the data for the latter were used by the EPA in developing the regression line used in the proposed criteria diagram (see Fig. 5). The researchers felt that there was greater credibility for those types of severe symptoms and the consequences of illness were of greater public health importance, and thus, more amenable to economic analysis.

In May 1984, the US EPA published a notification in the Federal Register requesting comments on the proposed draft criteria document which provides "guidance on ambient indicator bacteria densities which provide various levels of protection from risks of gastrointestinal disease from swimming in sewage polluted waters. When published, in final form, these criteria may form the basis for enforceable water quality standards".

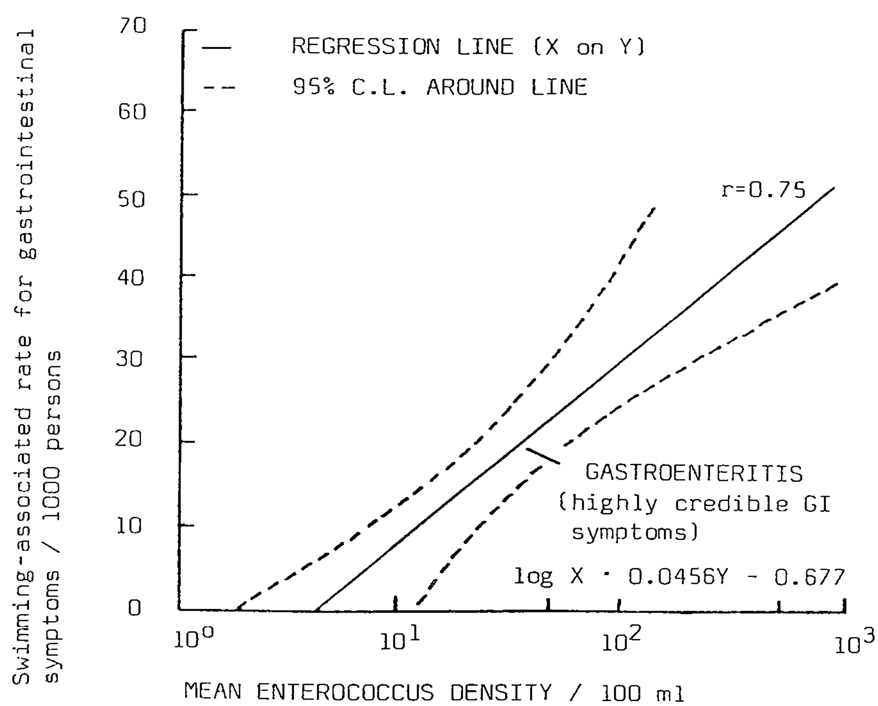



Figure 5: Recommended health effects criterion for marine recreational waters.

(From Cabelli, 1984)

The publication notes that the EPA studies have demonstrated that "enterococcus has a far better correlation with swimming associated illness in both marine and fresh waters than do faecal coliforms; and the E. coli has a correlation in fresh water equal to enterococcus, but does not correlate as well in marine water".

The publication further states that at the present U.S.A. criterion level of 200 faecal coliforms per 100 ml, risk levels of 15 cases of gastrointestinal disease per 1,000 swimmers in marine waters and 6 per 1,000 swimmers in fresh water have been "unknowingly accepted by EPA".

The proposed new criteria recommended by the US EPA are:

| | | |
|---|---|---|
| marine water | : | 3 enterococci / 100 ml |
| fresh water | : | 20 enterococci / 100 ml or |
| | | 77 E.coli / 100 ml |

With the publication of these new proposed specific quantitative guidelines for marine recreational water the US EPA has indicated its full acceptance of the results and recommendations of the Cabelli studies and has based its proposals firmly on them.

## CONCLUSIONS

Thus, after many years of uncertainty and active debate it now appears that there finally is a vast amount of firm data providing strong evidence that bathing in sewage polluted seawater, or fresh water, can cause a significant excess of credible gastrointestinal disease and that the disease rates show a high degree of correlation with enterococci and E. coli concentrations in the seawater. This finally provides a rational basis for establishing a marine recreational water criteria as well as guidelines and standards based on sound epidemiological evidence.

Similarly it is now possible to extrapolate from the results of these historic studies to establish new guidelines for shellfish growing waters and shellfish meat although no specific epidemiological studies were made on this subject.

## REFERENCES

American Public Health Association (1895). Report of A.P.H.A. Committee on pollution of water supplies. Proc. Amer. Pub. Health Assoc. 20-459.

American Public Health Association (1936). Bathing places. A.P.H.A. Year Book 1935-1936 p.209.

Araoz, J. de et al. (1970). Principles and practice of cholera control. World Health Organization Public Health Papers No. 40. WHO, Geneva.

Baine, W.B., A. Zampierc, M. Mazzotti, G. Angioni, D. Greco, M. Dibioia, F. Pocchiari, (1974). Epidemiology of cholera in Italy in 1973. The Lancet December 7, 1974. p.1370.

Bell, J.A., W.P. Rowe, J.I. Engler, R.H. Parrott, and R.J. Huebner, (1955). Pharyngoconjuctival fever: Epidemiological studies of a recently recognized disease entity. J. Am. Med. Assoc., 157:1083.

Brooks, P.B. (1916). Outbreak of typhoid attributed to infected oysters. J. Am. Med. Ass. 66:1445.

Bryan, J.A., J.D. Lehmann, I.F. Setiady, and M.H. Hatch, (1974). An outbreak of hepatitis A associated with recreational lake water. Amer. J. Epidemiol. pp 99:145.

Bundesen, H.N. (1925). Typhoid epidemic in Chicago apparently due to oysters. J. Am. Med. Ass., 84:641.

CDC - Center for Disease Control (Sept. 1984). Water related outbreaks, Annual Summary 1983.

Cabelli, V.J. (1983). Health effects criteria for marine recreational waters - R & D Report No. EPA-600/1-80-031. U.S. Environmental Protection Agency - Research Triangle Park, N.C. August 1983. p 98.

Cabelli, V.J., A.P. Du Four, L.J. McCabe, and M.A. Levin, (1984). A marine recreational water quality critrion consistent with indicator concepts and risk analysis. Jour. WPCF 55:1306-1314.

Calderon, R. and E.W. Mood, (1981). Epidemiological studies of otitis externa: Report of a prospective and of a retrospective study of otitis externa among swimmers - Project Summary - EPA-601/SI-81-053. August 1981 - HERL U.S. Environmental Protection Agency - Cincinnati, Ohio. 3 Pgs.

Campolini, E. (1921). A study of typhoid fever incidence in the health center district of New Haven. Unpublished report.

CDC - Center for Disease Control (Nov. 1963). Typhoid fever at Covington State Park, Louisiana. In: Salmonella Survellance CDC No. 18.

CDC - Center for Disease Control (August, 1972). Epidemiologic notes and reports. Typhoid fever - Alabama. Morbidity and Mortality Weekly Reports. USDHEW/PHS Vol. 21 No. 32.

CDC - Center for Disease Control (1973). Follow-up on shellfish-associated hepatitis. Morbid. Mortal, Wkly. Rep. 22:388.

CDC - Center for Disease Control (1979). Gastroenteritis associated with lake swimming - Michigan Morbidity and Mortality Weekly Reports. USDHEW/PHS Vol. 28 No. 35. p. 413.

D'Alessio, J., T.E. Mino, D.B. Nelson, C.I. Allen, A.A. Tsiatis, (1980). Epidemiological studies of virus transmission in swimming waters. E.P.A. Research Report #EPA-60011-80-006, January, 1980 - United States Environmental Protection Agency, Cincinnati, Ohio - p. 61.

Denis, F.A. (1973). Coxsackie group A in oysters and mussels. Lancet. i:1262.

Denis, F.A., E. Blanchovin, F. Poitiers, et al. (1974). Coxsackie A16 infection from lake water. J. Am. Med. Ass. 228:1370-1371.

DiGirolamo, R., L. Wiczynski, M. Daley, and F. Miranda, (1972). Preliminary observations on the uptake of poliovirus by West Coast Shore crabs. Appl. Microbiol. 23:170.

Doughtery, W.J. and R. Altman (1962). Viral hepatitis in New Jersey. Am. J. Med. 32:704.

Dufour, A.P. (1984). Bacterial indicators of recreational water quality. Canadian Jour. of Public Health.

El-Sharkawi, F., and M.N.E.R. Hassan (1982). The relation between the state of pollution in Alexandria swimming beaches and the occurence of typhoid among bathers. Bull High Inst. pub. Hlth Alexandria 12:337-351.

Environmental Protection Agency (1973). Water quality criteria - 1972. Ecological Research Series - EPA R3-73-033. p. 30-32.

European Economic Community - EEC (1973). Environmental protection terminology - Official Journal of the European Community Annex I, 20 Dec 1973, No. C. 112/49-50.

European Economic Community - EEC (1976). Council directive of 8 December 1975 concerning the quality of bathing waters (76/160/EEC) Official Jour. of the European Communities No. L31/1-4.

Fattal, B. and H. Shuval, (1985). Tel Aviv bathing beach study - report to WHO.

Fattal, B., E. Peleg-Olevsky, T. Agurshy, and H.I. Shuval, (1986). The association between sea-water pollution as measured by bacterial indicators and morbidity of bathers at Mediterranean beaches in Israel. Chemosphere (accepted for publication).

Flynn, M.J. and D.K.B. Thirstlewayte, (1964). Sewage pollution and sea bathing. Second Int'l. Conf. on Water Pollution Res.

Foulon, G., J. Maurin, N. Quoi, G. Martin Boyer, (1983). Relationship between the microbial quality of bathing water and health effects. Rev. Française des Sciences de l'Eau. 2:127-143.

Foy, H.M., M.K. Cooney, and J.B. Hatlen, (1968). Adenovirus type 3 epidemic associated with intermittent chlorination of a swimming pool. Arch. Env. Health. 17:795.

Goldfield, M. (1976). Epidemiological indicators for transmission of viruses by water. In: Viruses in water. Editors G. Berg, H. Bodily, E. Lennette, J. Melnick, and T. Metcalf, - American Public Health Assoc., Washington, D.C. pp. 70-85.

Gorodetskij, A.S. and B.N. Raskin, (1958). Gigiena pribrezhnykh Morskikh Vod. (Leningrad) as quoted in unpublished Draft by B. Moore prepared for the WHO.

Hawley, H.B., D.P. Morin, M.E. Geraghty, J. Tomkow, and C.A. Phillips, (1973). Coxsackievirus B epidemic at a boys' summer camp: Isolation. J. Am. Med. Ass., 226:33-36.

Henderson, J.M. (1968). Enteric disease criteria for recreational waters J. San. Engr. Div., ASCE, 94, (No.SA6):1253.

Hepatitis Surveillance Unit (1964). Clam-associated epidemics of infectious hepatitis. Communicable Disease Center, Atlanta. Hepatitis Surveillance Rep. No. 18, p. 14.

Hill, A.B. (1965). The environment and disease: association or causation? Proc R Soc Med 58:295 -300.

Hornick, R.B., S.E. Graisman, T.E. Woodward, H.L. Dupont, A.T. Dawkins, and M.J. Snyder (1970). Typhoid fever, pathogenesis and immunologic control. New Eng. J. Med. 283:686.

Joseph, P.R. et al. (1965). Studies of cholera El Tor in the Philippines. A retrospective investigation of an explosive outbreak in Bacolod City and Talisay - Bull. Wld. Hlth. Org. 33:637-643.

Kabler, P.W. (1961). Bacterial parameters of water quality. In: Water Quality Measurement and Instrumentation. Tech Report W61-2 USPHS Robert Taft San. Eng. Cent. Cincinnati. p. 45.

Kehr, R.W. and C.T. Butterfield, (1943). Notes on the relationship between coliform and enteric pathogens. Publ. Hlth. Rep., Washington, 58:589-607.

Koff, R.S., G.F. Grady, T.C. Chalmers, J.W. Mosley, and B.L. Swartz, (1967). Viral hepatitis in a group of Boston hospitals, III. Importance of exposure to shellfish in a non-epidemic period. New England J. Med. 276-703-710.

Koff, R.S. and H.S. Sear, (1967). Internal temperature of steamed clams. New Engl. J. Med. 276:737.

Kowal, N.E. (1982). Viruses in health effects of land treatment. p. 26-39. U.S.E.P.A.., Cincinnati, Ohio.

Liebscher, S. (1969). Enteroviren im Schwimmbadwasser. Z. Gesamte Hyg. 16: 198-200.

Lundsen, L.L., H.E. Hasseltine, J.P. Leaky, and M.V. Velder, (1924). A typhoid fever epidemic caused by oyster borne infection. Publ. Hlth. Rep., Washington, Suppl. No. 50.

Mahoney, P., G. Fleischner, B.S. Blumber, I. Millman, W.T. London, and I.M. Arias, (1974). Australian antigen: Detection and transmission in shellfish. Science, N.Y. 183:80.

Mair, L.W.D. (1909). The aetiology of enteric fever in Belfast in relation to water supply, sanitary circumstances, and shellfish. Proc. R. Soc. Med. 2:187.

Mason, J.O. and W.R. McLean, (1962). Infectious hepatitis traced to the consumption of raw oysters. Am. J. Hyg., 75:90.

McLean, D.M., R.P.B. Larke, G.A. McNaughton, et al. (1965). Enteroviral syndromes in Toronto, 1964, Can. Med. Ass. J. 92:658-661.

Mechalas, B.J., K.K. Hekimian, L.A. Schinazi, and R.H. Dudley, (1972). An investigation into recreation water quality. Office of Research and Monitoring. 'Water quality criteria data book'. U.S. Environmental Protection Agency, Washington, D.C., Vol. 4, p. 256.

Metcalf, T.G. and W.C. Stiles, (1967). Viral pollution of shellfish in estuary waters. Am. J. Epidemiol. 88:3.

Metcalf, T.G., J.M. Vaughn, and W.C. Stiles, (1972). The occurence of human viruses and coliphages in marine water and shellfish. In: Marine Pollution and Sea Life. Ed. M. Ruivo, pp. 570-574. Fishing News Books, Surrey, U.K.

MMWR (1983). Erosion of dental enamel among competitive swimmers, Virginia. Morbidity and Mortality Weekly Report - Center for Disease Control - Atlanta, Georgia. July 22, 1983 Vol. 32 No. 28, pp. 361-362.

Mood, E.W., and B. Moore, (1976). Health criteria for the quality of coastal bathing waters. Unpublished mimio draft document - Yale University School of Medicine, New Haven, Connecticut - March 30, 1976. p. 39.

Moore, B. (1959). Sewage contamination of coastal bathing waters. Bull. Hyg., London, 29:689.

Moore, B. (1974). The case against microbial standards for bathing beaches; In: Discharge of Sewage from Sea Outfalls - Proceedings of an International symposium, - London (1974). Edit. A.L.H. Gamesson, Pergamon Press Oxford. pp. 103-109.

Mosely, J.W. (1974). Epidemiological aspects of microbial standards for bathing beaches, In: Discharge of Sewage from Sea Outfalls - Proceedings of an International Symposium - London (1974) - Edit. A.L.H. Gamesson, Pergamon Press, Oxford. pp. 80-93.

Mujeriego, R., J.M. Bravo, and M.T. Feliu, (1982). Recreation in coastal waters: public health implications. Vier Journee Etud. Pollutions, Cannes, CIESM. pp. 585-594.

Murphy, A.M., G.S. Grohmann, P.J. Christopher, et al. (1979). An Australia-wide outbreak of gastroenteritis from oysters caused by norwalk virus. Med. J. Aust. 2:329-333.

Nash, J.T.C. (1909). In: Discussion following paper by Mair (1909).

National Technical Advisory Committee (1968). Water quality criteria. Federal Water Poll. Control Adm., Dept. of the Interior, Washington, D.C., p. 7

New York City Dept. of Health (1932). Typhoid fever from bathing in polluted waters (1932). Weekly Bull. N.Y. city Dep. Hlth. 21:257.

New York City Dept. of Health (1932). See pg. 44.

Northrop, R.L., G.R. Brenniman, S.H. Rosenberg, R.B. Byington, and C.S. Hesse, (1981). Recreational water quality and health. Project Summary.EPA-600/SI-81-059. Sept. 1981 - HERL U.S. Environmental Protection Agency, Cincinnati, Ohio. 3 pgs.

Osherovich, A.M., G.S. Chasovnikova, (1969). Some results of a virologic investigation of environmental sources. Hyg. Sanit. 34:424-427.

Paffenbarger, R.S., G. Berg, N.A. Clarke, et al. (1959). Viruses and illness in a boys' summer camp. Amer. J. Hyg. 70:254-274.

Pfuhl (1888). Deutsche Med. Zeitschr. Vol. 17, p. 9 (as quoted in Coliform Standards for Recreational Areas, Jour. San. Eng. Div. Proc. A.S.C.E. 89: 57-94 Aug. 1963.

Plotkin, S.A. and M. Katz (1967). Minimal infective doses of viruses for man by the oral route. In: Transmission of viruses by the water route (Ed. G. Berg). Wiley-Interscience, New York. pp. 151-166.

Reece, R.J. (1909). 38th Annual Report to Local Government Board, 1908-9 Suppl. with rept. of Med. Officer for 1908-9. Appendix A, No.6:90

Roos, B. (1956). Hepatitis epidemic conveyed by oysters. Svenska Lakartidn., 53:989.

Rosenberg, M.L., K.K. Hazlet, J. Shaefer, J.G. Wells, R.C. Pruneda, (1976). Shigellosis from swimming. JAMA 236-1849-1852.

Ruddy, S.J., R.F. Johnson, J.W. Mosley, J.B. Atwater, M.A. Rossetti, and J.C. Hart, (1969). An epidemic of clam-associated hepatitis. J.Am. Med. Ass. 208:649.

Schiff, G.M., G.M. Stefanovic, B. Young, and J.K. Pennekamp, (1984). Minimum human infectious dose of enteric virus (echovirus 12) in drinking water. Monogr. Virol. 15:222-228 - Karger - Basle.

Scott, W.J. (1932). A study of Connecticut shore bathing waters. Amer. Jour. Pub. Health 22:316.

Scott, W.J. (1951). Sanitary study of shore bathing waters. Bull Hyg. 33:353.

Seyfried, P.L., R.S. Tobin, N.E. Brown, P.F. Ness, (1985). A prospective study of swimming related illness I and II. Am. J. Public Health 75:1068-1075.

Shuval, H.I. (1972). WHO document EP/WP72:4.

Shuval, H.I. (1974). The case for microbial standards for bathing beaches; In: Discharge of Sewage from Sea Outfalls - Proceedings of an International Symposium - London (1974) - Edit. A.L.H. Gamesson, Pergamon Press, Oxford. pp. 95-101.

Simchen, E., D. Franklin, and H.I. Shuval, (1984). "Swimmer's Ear" among children of kindergarten age and water quality of swimming pools in 11 Kibbutzim. Israel Journal of Medical Sciences 20:584-588.

Simons, G.W., Jr., R. Hillscher, H.F. Ferguson, and S. de M. Gage, (1922). Report of the committee on bathing places. Am. J. Public Health 12:121.

Snow, D.J.R. (1959). Typhoid and city beach. Western Australia. Report of the Commissioner of Public Health for the year 1958, :52.

Soper, G.A. (1905). Typhoid fever at Lawrence, N.Y. due to oysters. Med. News 86:241.

Steiniger, F. (1954). Aus der Freihandbiologie der Salmonellen. Dt. Med. Zeitschr. 79:1118-1120.

Stevenson, A.E. (1953). Studies of bathing water quality and health. Am J. Public Health, 43:529.

Stiles, G.W. (1912). Sewage-polluted oysters as a cause of typhoid and GI disturbances. Chem. Bull, 156:16.

Stille, W., B. Kunkel, and K. Nerger, (1972). Austern-Hepatitis. Dt. Med. Zeitschr. 97:145.

Streeter, H.W. (1951). Bacterial quality objectives for the Ohio River. A guide for evaluation of sanitary condition of waters used for potable supplies and recreational uses. Ohio River Valley Water Sanitation Commission, Cincinnati, Ohio.

UNEP/WHO (1983). Assessment of the present state of microbial pollution in the Mediterranean Sea and proposed control measures. Report of the second meeting of the working group for scientific and technical cooperation - Athens 21-25 November 1983 - MED POL - PHASE II United Nations Environment Programme in cooperation with the World Health Organization. p. 46.

USEPA (1976). Quality Criteria for Water. U.S.E.P.A., Washington D.C.

USEPA (1984). Water quality criteria: Request for comments. U.S. Federal Register Vol. 49 No. 102 (Thursday, May 24, 1984). pp.21987-8.

USEPA (1984). Draft criteria for recreational water quality - U.S. Federal Register May 1984.

Vickery, K. (1973). Coxsackie group A in oysters and mussels. Lancet, i:1385.

WHO (1977). Health criteria and epidemiological studies related to coastal water pollution. WHO - Regional office for Europe, Copenhagen.

WHO (1974). Fish and Shellfish Hygiene - Report of a WHO Expert Committee in cooperation with FAO. Technical Report Series 550. World Health Organization, Geneva. 62 pgs.

Winslow, C.E.A. and D. Moxon, (1928). Bacterial pollution of bathing beach waters in New Haven Harbor. Am. J. Hyg. 8:299.

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