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HISTORY AND APPLICATION OF MICROBIOLOGICAL WATER QUALITY STANDARDS IN THE MARINE ENVIRONMENT

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TABLE OF CONTENTS

FIGURES

TABLES

1. ABSTRACT

The history and application of microbiological water quality standards in the marine environment for primary contact recreation and shellfish harvesting are presented. Special note is taken of investigations conducted in the U.S.A. which concluded that enterococci, as an indicator organism, provided the best correlation with gastrointestinal symptoms attributed to swimming in contaminated waters. The linear relationship developed between mean enterococcus density per 100 ml and swimming associated rate for gastrointestinal symptoms per 1000 persons is presented along with the U.S. Environmental Protection Agency adaptation of enterococcus as the primary indicator organism in lieu of total and fecal coliforms.

After an extensive review of 37 epidemiological investigations conducted in marine waters worldwide, the World Health Organization (WHO) has presented Guidelines for Safe-Recreational-Water-Environments in 1998 using fecal streptococcus as the indicator organism. These guidelines are based primarily on the controlled randomized epidemiological trial studies conducted in the coastal waters of the United Kingdom.

Existing international, national and local microbiological guidelines and standards in the marine environment are presented to provide a range for the water quality planner. The simple adaptation of a particular set of standards is considered inappropriate without a thorough review of local circumstances and local/national economic factors. Also, caution should be exercised in directly applying quantitative relationships between health risk and indicator organism in other areas where the general health and immunity of the local population may be different.

2. KEY WORDS

Microbiological recreational and shellfish guidelines and standards; total and fecal coliform; enterococci; streptococci, marine environment, bathing beaches.

3. INTRODUCTION

A recreational water quality criterion is defined as a quantifiable exposure-effect relationship based on scientific evidence between the level of some indicator of the quality of the water concerned and the potential human health risks associated with the recreational use of that water. A water quality guideline derived from such a criterion is a suggested maximum density of the indicator in the water which is associated with unacceptable health risks. The concept of acceptability implies that social, cultural, economic and political, as well as medical factors are involved. A water quality standard obtained from the criterion is a guideline fixed by law.

4. HISTORICAL REVIEW

Historically, the first evaluations concerning contact recreation and the incidence of disease were conducted by the USA American Public Health Association with studies in the early nineteen twenties to ascertain the prevalence of infectious diseases, which may be conveyed by means of swimming pools and other bathing places (Simons, *et al*, 1922). As reported by Moore (1975), the actual application of bacterial guidelines to sea water can be traced back to the cautious suggestion by Winslow and Moxon (1928), in a pollution study of New Haven Harbor, U.S.A., where typhoid fever was attributed to bathing in grossly polluted water, that the coliform count of samples from bathing waters should not exceed 100/100 ml. However, no logical basis for this figure was provided. Coburn (1930) suggested a maximum permitted coliform count of 10000 per 100 ml and quoted a bathing area where counts where consistently higher than this without apparently causing ill-health in bathers. Ludwig (1983) notes that the California, U.S.A. Coliform Standard, of 1000 MPN/100 ml, which has been adopted in many other areas, was developed during the nineteen forties based entirely on aesthetic considerations, in that investigators found that when total coliform counts remained consistently (more than 80% of the time) below 1000 MPN/100 ml, the beaches remained aesthetically satisfactory with no visual evidence of sewage pollution.

Cabelli, *et al.* (1983) reports that the U.S. total coliform limit of 1000/100 ml "apparently developed from two sources: the predicted risk of salmonellosis as obtained from calculations made by Streeter (1951) on the incidence of Salmonella species in bathing waters and attainability as determined by Scott (1951) from microbiological surveys conducted at Connecticut bathing beaches." This Connecticut Standard was then adopted by many other U.S. State agencies.

As noted by the Committee on Bathing Beach Contamination of the Public Health Laboratory Service (1959), Garber (1956), reported on an inquest of different public health and control agencies in the United States concerning "how bacteriological standards were determined and why they were decided upon". The most frequent reply was that there was no analytical background for the limits set other than the fact that epidemiological experience under the given standards had been satisfactory. This argument was used for standards ranging from a median coliform count of less than 2400/100 ml down to a requirement that no coliform organisms should be present.

Major epidemiological studies, aimed directly at assessing the health risk of bathing in polluted waters, were conducted during the years 1948-1950 by the United States Public Health Service. The findings (Stevenson, 1953) were that statistically significant epidemiologically detectable health effects at levels of 2300 and 2700 Coliforms/100 ml were demonstrated by the studies on Lake Michigan at Chicago in 1948 and on the Ohio River at Dayton, Kentucky in 1949, respectively. The third study conducted in 1950 in the saline tidal waters of Long Island Sound at New Rochelle and Mamaroneck, New York, showed no relationship between total coliform levels and swimming related diseases. Subsequent work in the same stretch of the Ohio River indicated that the fecal coliforms represented 18% of the total coliforms (Cabelli, *et al.*, 1983) and therefore would indicate that detectable health effects would occur at a fecal coliform level of about 400 MPN/100 ml. Applying a factor of safety, in that water quality should be better than that which would cause a health effect, the National Technical Advisory Committee (NTAC, 1968) to the U.S. Federal Water Pollution Control Administration developed in 1968 a national fecal coliform guideline of 200 MPN/100 ml for fresh and marine waters which was based primarily on the two fresh water studies of Stevenson (1953).

However, in 1972, the Committee on Water Quality Criteria of the National Academy of Sciences of the U.S.A. (1972), in an USEPA funded project, came to the following conclusion: "No specific recommendation is made concerning the presence or concentration of microorganisms in bathing water because of the paucity of valid epidemiological data." Subsequently in 1976, the USEPA (1976) presented fecal coliform guidelines which were essentially those presented in the NTAC (1968) document. Notwithstanding, the primary rationale was based on the relationship of fecal coliform densities to the frequency of Salmonella isolations in surface waters and the findings of the Stevenson (1953) studies were essentially abandoned as a rationale. The final guideline proposed by the USEPA (1976) was as follows: "based on a minimum of not less than five samples taken over not more than a 30-day period, the fecal coliform content of primary contact recreational waters shall not exceed a log mean of 200/100 ml, nor shall more than 10% of total samples during any 30-day period exceed 400/100 ml."

Based on a three-year (1973-1975) study conducted at New York City beaches, Cabelli, *et al.* (1983) concluded that Enterococci (analytical procedures presented in USEPA, 1985), as an indicator organism, provided the best correlation with gastrointestinal (vomiting, diarrhea, nausea or stomachache) symptoms attributed to swimming in contaminated waters. Other indicators evaluated included total coliforms and their component genera (Escherichia, Klebsiella, Citrobacter-Enterobacter), fecal coliforms, Escherichia coli (E. Coli), Pseudomonas aeruginosa, Clostridium penfringens, Aeromonas hydrophila, Vibrio parahaemolyticus and Salmonella. Subsequent U.S. studies confirmed the superiority of enterococci as an indicator organism and Cabelli (1983) developed a linear relationship between mean enterococcus density/100 ml and swimming associated rate for gastrointestinal symptoms per 1000 persons as presented in Figure 1.

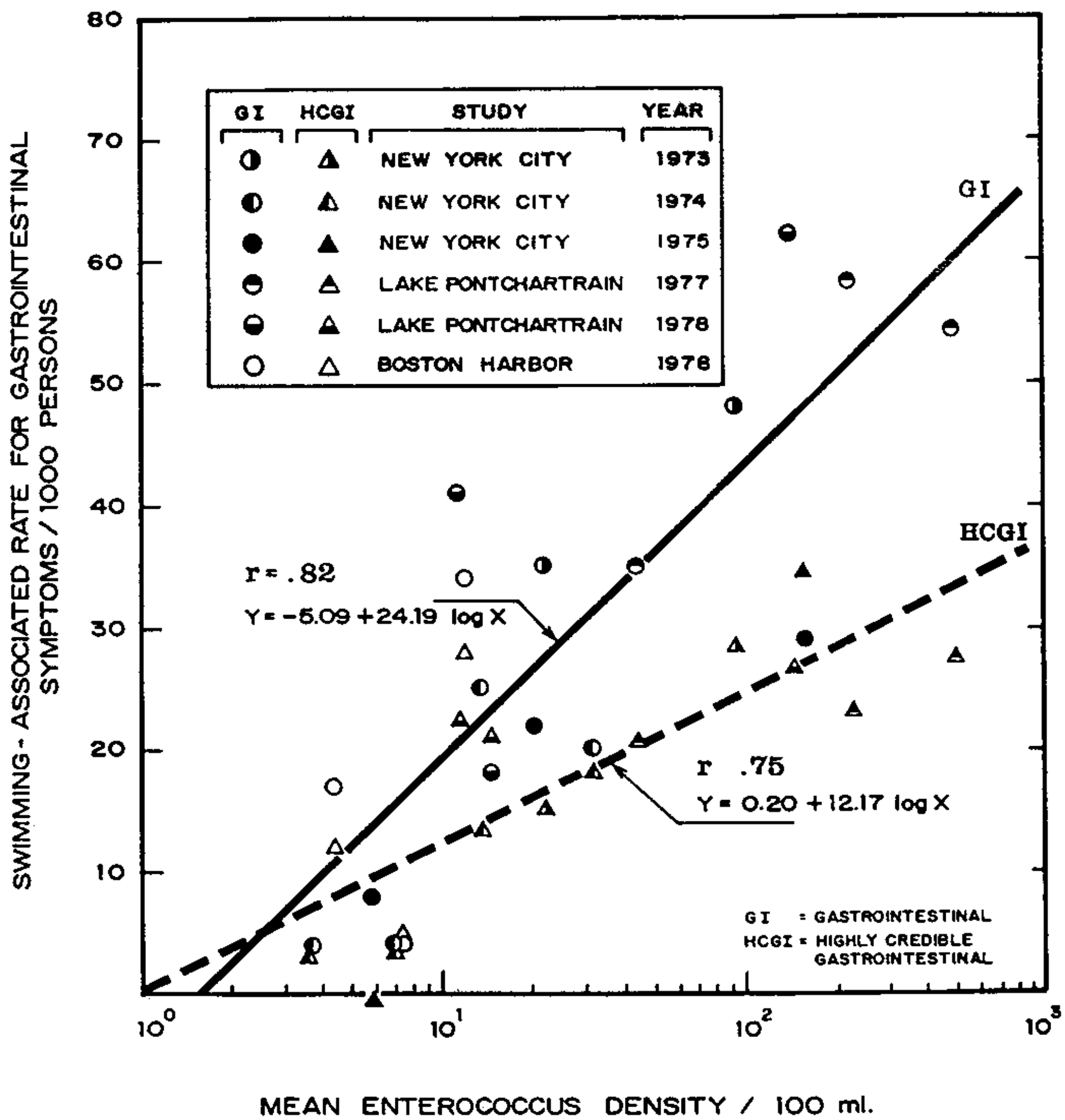

Figure 1. Swimming associated rates for gastrointestinal symptoms against mean enterococcus densities in marine waters (Cabelli, 1983)

In 1974, the World Health Organization (WHO) convened a Working Group of European experts on Guides and Criteria for Recreational Quality of Beaches and Coastal Waters (WHO, 1975) in Bilthoven, Netherlands, which "agreed that the recommended upper limits for indicator organisms should be expressed in broad terms of orders of magnitude rather than rigidly stated specific numbers. Highly satisfactory bathing areas should, however, show E. Coli counts consistently less than 100 per 100 ml and to be considered acceptable, bathing waters should not give counts consistently greater than 1000 E. Coli per 100 ml". Subsequently, in 1977 a group of Experts jointly convened by WHO and UNEP in Athens, (WHO, 1977) concluded that there was no basis for recommending changes in the conclusions reached by the WHO Working Group in Bilthoven in 1974.

Silva & Helmer (1990) report that, in 1983, UNEP/WHO (1983) proposed that the Mediterranean governments adopt interim criteria for coastal recreational waters using, as a basis, the 1974 Bilthoven conclusions extrapolated to Mediterranean conditions using the results of the WHO organized pilot project on coastal water quality control within the framework of the UNEP-sponsored MED POL program (carried out between 1976 and 1981). These criteria were based on concentrations of both fecal coliforms and fecal streptococci. The part of the proposal concerning fecal coliform concentration limits, that is, 100 per 100 ml in at least 50% of the samples and 1000 per 100 ml in at least 90%; minimum of 10 samples, were subsequently adopted in 1985 by the Mediterranean states on a joint basis as an interim measure (UNEP, 1985).

The European Economic Community (EEC) (1976) published Quality Requirements (microbiological) for Bathing Waters as follows:

	Microbiological parameter	Guide[1]	Mandatory[2]	Minimum sampling Frequency
1.	Total coliforms / 100 ml	500	10,000	Fortnightly
2.	Fecal coliforms / 100 ml	100	2,000	Fortnightly
3.	Streptococci fecal / 100 ml	100	-	(*)
4.	Salmonella / litre	-	0	(*)
5.	Enteroviruses PFU/10 litres	-	0	(*)

1 80% of samples less than.
2 95% of samples less than.
(*) Concentration to be checked by the competent authorities when an inspection in the bathing area shows that the substance may be present or that the quality of the water has deteriorated.

The present water quality requirements for bathing waters of the European Economic Community (WHO, 1996) are as follows:

	Microbiological Parameter	Guide[1]	Mandatory[2]	Minimum Sampling Frequency
1.	E. Coli / 100 ml	100	2,000	Fortnightly
2.	Fecal Streptococci / 100 ml	100	400	Fortnightly*
5.	Enteroviruses PFU/10 liters	-	0	Monthly*

1 80% of samples less than.
2 95% of samples less than.
(*) Concentration to be checked by the competent authorities when an inspection in the bathing area shows that the substance may be present or that the quality of the water has deteriorated.

The Caribbean Environment Programme (CEPPOL) held Regional meetings in 1991 and 1993 on Monitoring and Control of Sanitary Quality Bathing and Shellfish-Growing Marine Waters in the Wider Caribbean. Due to the economic dependence of the Caribbean on tourism, both the bacteriological and aesthetic water quality are very important. It was concluded at these meetings that Member Countries should adopt EEC, WHO or USEPA (prior to 1986) standards and guidelines for bacteriological quality of bathing waters until sufficient information is available, based on future epidemiological studies conducted in the Caribbean, to modify the current standards (CEPPOL and UNEP, 1991).

One school of thought, whose primary spokesmen has been B. Moore (1959, 1975), indicated that swimming in moderately contaminated waters does not constitute a significant public health risk and, as such, coliform guidelines/standards are irrelevant and the beach contamination problem should be more properly treated as an aesthetic concern. However, epidemiological investigations conducted in the 80's and 90's indicate the contrary.

Conversely, another group, whose initial principal advocate was V. Cabelli (1979, 1983), staunchly insists that there is epidemiological evidence that clearly supports the application of contact recreational guidelines and standards to protect public health. Cabelli (1983) has concluded that enterococci is the superior indicator organism in lieu of total or fecal coliforms or E. Coli in that the enterococci better mimic the survival characteristics of the etiological agent which Cabelli (undated) concluded to be the human rotavirus with regard to gastroenteritis.

The USEPA (1984) first presented the recommendation that, enterococci be adapted by the States as the primary indicator organism for primary contact recreations in lieu of the indicators applied at that time (primarily total and fecal coliforms). The USEPA indicated that "by using the existing criterion of 200 fecal coliform bacteria per 100 ml, risk levels of 15 gastrointestinal illnesses per 1000 population in marine waters and 6 per 1000 population in fresh waters has been unknowingly accepted". The USEPA proposed that future risk levels be equal to those previously accepted for fresh and marine waters and were therefore as follows:

Freshwater - 20 enterococci/100 ml or 77 E. Coli/100 ml
Marine water - 3 enterococci/100 ml"

These guidelines were based in studies conducted by Dufour (1984) and Cabelli (1983) applying the empirical equations developed for highly credible gastrointestinal symptoms (HCGI) associated with swimming in fresh and marine waters, respectively.

After review of 51 comments to the above proposal submitted by public health officials, treatment plant officials and allied engineering firms, and university and government scientists and a recalculation of the data, the USEPA (1986) adopted the following new criteria:

Freshwater: E. Coli- not to exceed 126/100 ml, or
Enterococci - not to exceed 33/100 ml

Marine water: Enterococci - not to exceed 35/100 ml

These criteria are calculated as the geometric mean of a statistically sufficient number of samples, generally not less than five samples equally spaced over a thirty-day period. Single sample maximum allowable densities were also promulgated based on beach use and are presented in Table 1 taken from Dufour and Ballentine (1986).

These values were based on risk levels of 8 and 19 gastrointestinal illnesses per 1000 swimmers at fresh water and marine beaches (see Figure 1), respectively, which were estimated to be equivalent to the risk levels for 200/100 ml fecal coliform criteria.

Notwithstanding, it must be recognized that the pathogen to indicator organism ratio is variable due to its dependence on the overall health of the discharging population. As noted by Cabelli (1983), the swimming associated outbreak of Shigellosis on the Mississippi River below Dubuque, Iowa, U.S.A. (Rosenburg, 1976) , appears to represent an instance where, although the 200/100 ml fecal coliform guideline was probably exceeded for some time, the outbreak did not occur until there was a large enough number of ill individuals and carriers in the discharging population. Also, comparisons made by Cabelli (1983, undated) of epidemiological studies conducted in Egypt with those conducted in the U.S. suggest the important role of population immunity in that gastrointestinal illness rates in the U.S. studies were associated with bathing in waters with relatively much lower enterococci densities. These studies also demonstrated that swimming-associated gastrointestinal symptomatology was much more prevalent among children (10 years of age and under) with lesser developed immune systems than adults. This further suggests the importance of immunity in the epidemiology of the observed swimming-associated gastroenteritis. These factors imply that caution should be exercised in directly applying the relationships developed in other areas to the Latin American context.

As reported by Saliba and Helmer (1990), prospective cohort epidemiological studies similar to that conducted by Cabelli (generally referred to as "Cabelli style studies") were carried out in a number of countries between 1982 and 1989. Saliba and Helmer state that "practically all studies showed higher morbidity among bathers as compared to non-bathers, but correlation between specific symptoms and bacterial indicator concentrations varied considerably". Furthermore, they conclude that although difficult to quantify "the evidence clearly indicates that health risks do exist and are most pronounced in areas directly exposed to pollution by untreated sewage".

Table 1. Criteria for indicator for bacteriological densities

	Acceptable Swimming Associated Gastroenteritis Rates per 1000 swimmers	Simple Sample Maximum Allowable Density (4), (5)				
		Steady-State Geometric Mean Indicator Density	Designed Beach Area (upper 75% C.L.)	Moderate Full Body Contact Recreation (upper 82% C.L.)	Lightly Used Full Body Contact Recreation (upper 90% C.L.)	Infrequently Used Full Body Contact Recreation (upper 95% C.L.)
Freshwater						
Enterococci	8	33[(1)]	61	89	108	151
E. Coli	8	126[(2)]	235	298	406	576
Marine Water						
Enterococci	19	35[(3)]	104	124	276	500

(1) Calculated to nearest whole number using equation:
$$\text{(mean enterococci density)} = \text{antilog}_{10} \frac{\text{illness rate/1000 people} + 6.28}{9.40}$$

(2) Calculated to nearest whole number using equation:
$$\text{(mean } E.\ Coli \text{ density)} = \text{antilog}_{10} \frac{\text{illness rate/1000 people} + 11.74}{9.40}$$

(3) Calculated to nearest whole number using equation:
$$\text{(mean enterococci density)} = \text{antilog}_{10} \frac{\text{illness rate/1000 people} - 0.20}{12.17}$$

(4) Single sample limit = antilog_{10} { log indicator geometric + factor determined from areas under x ($\log_{10}$ standard deviation) }
mean density/100 ml) the normal probability curve for the assumed level of probability (see below)

The appropriate factors for the indicated one sided confidence levels are:
75% C.L. - .675
82% C.L. - .935
90% C.L. - 1.28
95% C.L. - 1.65

(5) Based on the observed log standard deviations during the USEPA studies: 0.4 for freshwater E. Coli and enterococci; and 0.7 for marine water enterococci. Each jurisdiction should establish its own standard deviation for its conditions which would then vary the single sample limit.

C.L. Confiability level

Taken from Dufour and Ballentine (1986)

The World Health Organization (WHO) has proposed world guidelines for "Safe-Recreational-Water Environments". WHO has convened several experts' meetings, the last of which were held in Bad Elster, Germany in June 1996 and St. Helier, Jersey, Channel Island, United Kingdom in May 1997, and Farnham, United Kingdom in April 1998, the latter for the development of a Code of Good Practice for monitoring. The preliminary publication of the guidelines was made in 1998 (WHO, 1998). As part of this process, Pruss (1998) has summarized the epidemiological studies conducted worldwide. Of the 37 studies evaluated, 22 qualified for inclusion in the evaluation. Figure 2 presents the relation between indicator organism density and illness risk for marine waters. Of the 22 studies selected, 18 were prospective cohort studies, two retrospective cohort studies and two were randomized controlled trials, as summarized in Table 2.

WHO concluded that the controlled randomized trial studies were the most accurate and the WHO Experts' Committee based the new guidelines for marine waters on the only study of this type for enteric illness, reported by Kay & Fleisher, *et al.* (1994), in the United Kingdom. It is noted that these are temperate waters and not characteristic of the tropical waters of most of Latin America and the Caribbean.

The WHO guidelines are presented in Figure 3 and the explanation of the guideline values are given in Table 3.

5. EXISTING WATER QUALITY STANDARDS

Table 4 presents international, national and local guidelines and standards for various water quality indicators in bay or ocean environments and these can provide a reference point for planning. Similarly, Table 5, taken from Cabelli (1983), presents the standards as of 1978 for primary contact recreation in the States of the United States of America. These standards vary widely, and thus, reflect different philosophies and/or levels of water use protection. The principal factor responsible for the range of standards is the origin of the supporting criteria be it epidemiological, aesthetic, or ecological.

It is noted that except for Brazil and Peru, most of the countries in the Region which have promulgated national standards have adopted them directly, with minor modifications, from those applied in the U.S.A. prior to 1986 with perhaps minimal considerations given to economic realities and development priorities. Developing nations of Latin America differ from the industrialized nations where most of the criteria research is conducted, in that the developing country must allocate limited financial resources to a greater number of basic public works and economic development projects. It is important that the planner conduct a thorough review of the prevailing local water quality guidelines/standards (if any exists) to insure that local economic development priorities are reasonably accounted for. Control systems, such as ocean outfalls, are among the most capital intensive means of wastewater disposal although life time costs will be considerably less in comparison to secondary wastewater treatment with on shore disposal. Consequently, the decision to design the system for other than minimum water quality standards, should be supported by demonstrated need, or a stated local/national policy decision.

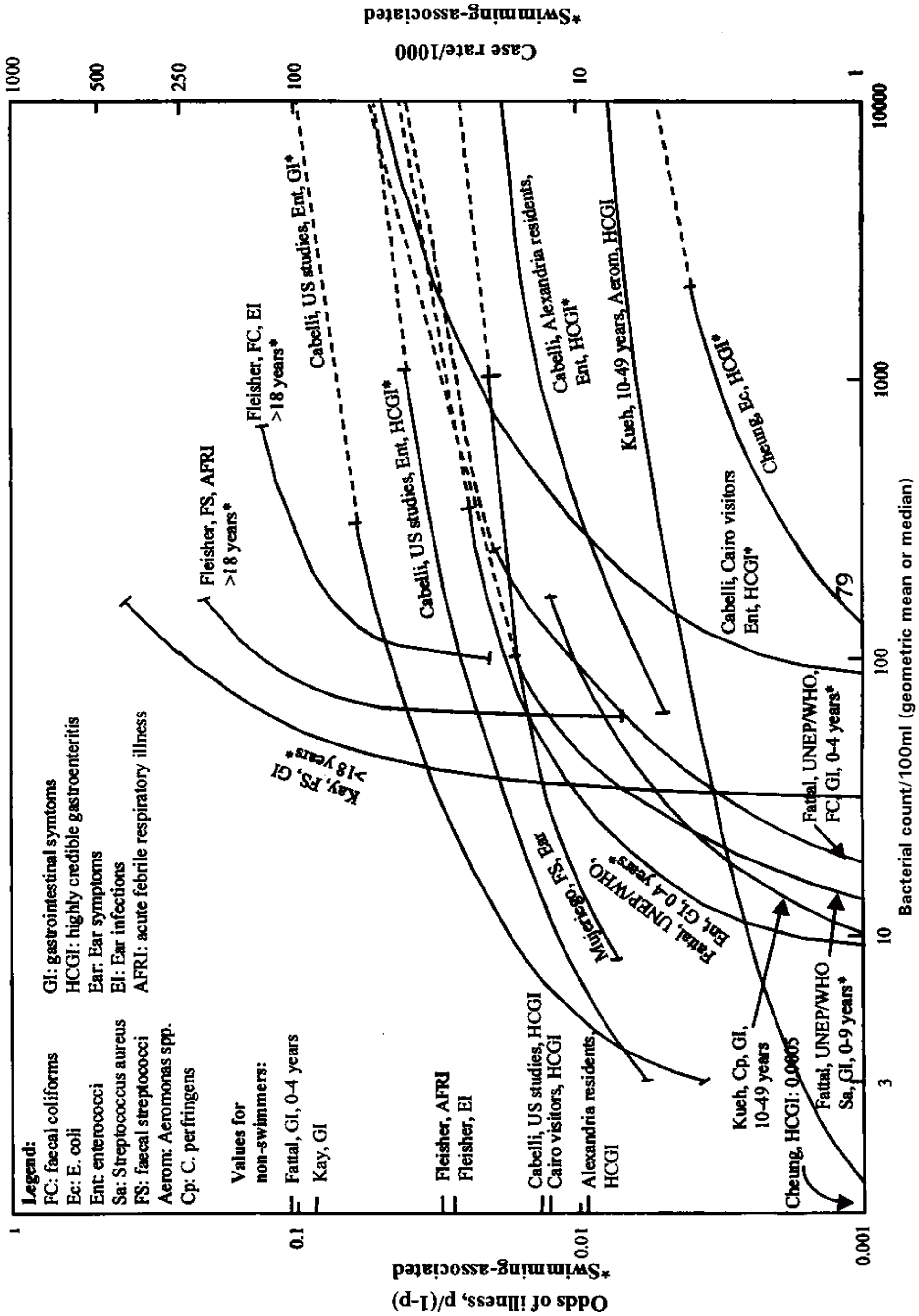

Figure 2. Risks of illness in swimmers against bacteria count in marine waters

Source: WHO (1998), *Guidelines for safe recreational-water environments.*

Table 2. List of selected studies

First author	Year	Country	Study design	Water	Comments
Fleisher	1996	UK	Randomized controlled trial	marine	d
Haile	1996	US	Prospective cohort	marine	
Van Dijk	1996	UK	Prospective cohort	marine	c
Bandaranayake	1995	New Zealand	Prospective cohort	marine	d
Kueh	1995	Hong Kong	Prospective cohort	marine	b
Medical Research Council	1995	South Africa	Prospective cohort	marine	a, c
Kay	1994	UK	Randomized controlled trial	marine	d
Pike	1994	UK	Prospective cohort/**	marine	a, b, c
Corbett	1993	Australia	Prospective cohort	marine	a, d
Fewtrell*	1992	UK	Prospective cohort	fresh	d
UNEP/WHO no 46	1991	Israel	Prospective cohort	marine	b, d
UNEP/WHO no 53	1991	Spain	Prospective cohort	marine	a, b, d
Cheung1	1989	Hong Kong	Prospective cohort	marine	a, b
Ferley1	1989	France	Retrospective cohort	fresh	a, b, c
Lightfoot1	1989	Canada	prospective cohort	fresh	
Fattal, UNEP/WHO no 20	1987	Israel	prospective cohort	marine	b, d
Seyfried	1985	Canada	prospective cohort	fresh	
Dufour	1984	US	prospective cohort	fresh	a, b
Cabelli	1983	Egypt	prospective cohort	marine	a, b, c
Cabelli	1982	US	prospective cohort	fresh & marine	a, b
Mujeriego	1982	Spain	retrospective cohort**	marine	b, a
Stevenson, 3-day study	1953	US	prospective cohort	fresh	b, c, d

a: Only use of seasonal mean for analysis of association with outcome reported.
b: Control for less than three counfounders reported, or no reporting at all.
c: Exposure not defined as head immersion/head splashing/water ingestion.
d: <1700 bathers and 1700 non-bathers participating in the study.
* Exposure is white-water canoeing; similar to swimming, water intake is likely, while turn-over or through ingestion or inhalation of droplets.
** Cross-sectional study.

Remark: Two studies analyze the same data sets [5,10] but come to different conclusions.

Source: WHO (1998), *Guidelines for safe recreational-water environments.*

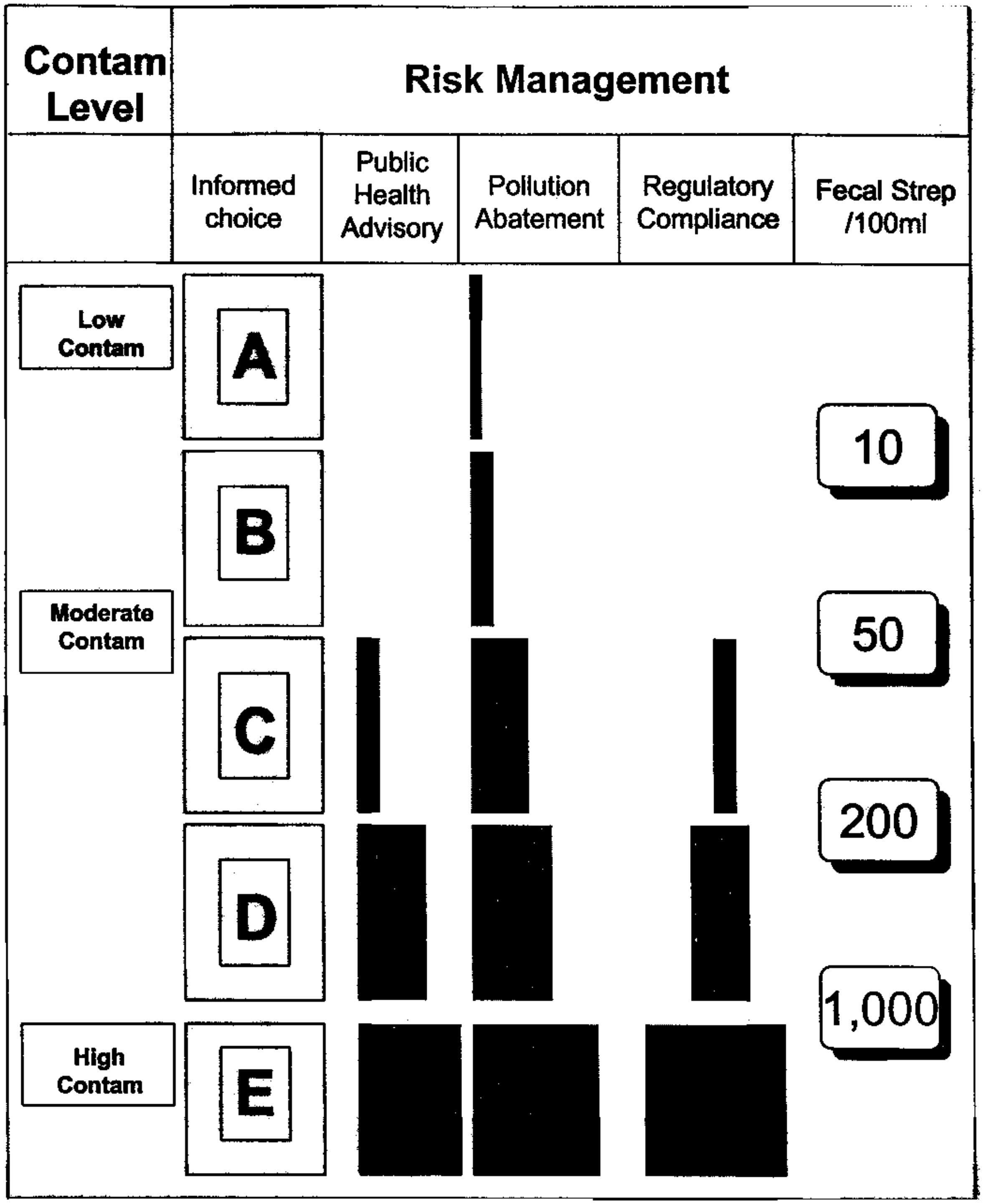

Figure 3. WHO Guidelines

Source: WHO (1998), *Guidelines for safe recreational-water environments.*

Table 3 . Guideline values for microbiological quality (fecal streptococci/100ml)

95 percentile value of faecal streptococci per 100 ml	Basis of derivation	Estimated disease burden
10	This value is below the no-observed adverse effect level (NOAEL) in most epidemiological studies that have attempted to define a NOAEL.	Using the indicator level/burden of disease relationship it corresponds to the 95 percentile value which is associated with less than a single excess incidence of enteric symptoms for a family of four healthy adult bathers having 80 exposures per bathing season (rounded value), over a 5 years period. Making a total of 400 exposures.
50	This value is above the threshold and lowest-observed-adverse-effect level (LOAEL) for gastro-enteritis in most epidemiological studies that have attempted to define a LOAEL.	Using the indicator level/burden of disease relationship it corresponds to the 95 percentile value that is associated with a single excess incidence of enteric symptoms for a family of four healthy adult bathers having 80 exposures per bathing season (rounded value).
200	This value is above the threshold and lowest –observed-adverse-effect level for all adverse health outcomes in most epidemiological studies.	Using the indicator level/burden of disease relationship it corresponds to the 95 percentile value that is associated with a single excess incidence of enteric symptoms for a healthy adult bather having 20 exposures per bathing season (rounded value).
1000	Derived from limited evidence regarding transmission of typhoid fever in areas of lowlevel typhoid endemicity and of paratyphoid. These are used in this context as indicators of severe health outcome.	The exceedence of this level should be considered a public health risk leading to immediate investigation by the competent authorities. Such an interpretation should generally be supported by evidence of human faecal contamination (e.g. a sewage outfall).

Footnotes

1. This table would produce protection of “healthy adult bathers” exposed to marine waters intemperate north European waters.
2. It does not relate to children, the elderly or immuno-compromised who would have lower immunity and might require a greater degree of protection. There are no available data with which to quantify this and no correction factors therefore applied.
3. Epidemiological data on fresh waters or exposures other than bathing (e.g. high exposure activities such as surfing or white water canoeing) are currently inadequate to present a parallel analysis for defined reference risks. Thus a single guideline valve is proposed, *at this time,* for all recreational uses of water because insufficient evidence exists at present to do otherwise. However, it is recommended that the severity and frequency of exposure encountered by special interest groups (such as body, board and windsurfers, subaqua divers, canoeists and dinghy sailors) are taken into account (chapter 1).
4. Where disinfection is used to reduce the density of indicator bacteria in effluents and discharges the presumed relationship between faecal streptococci (as indicators of faecal contamination) and pathogen presence may be altered. This alteration is, at present, poorly undestood. In water receiving such effluents and discharges faecal streptococci counts may not provide an accurate estimate of the risk of suffering from mild gastrointestinal symptoms.
5. The values calculated here assume that the probability on each exposure is additive.

Source: WHO (1998), *Guidelines for safe recreational-water environments.*

This author has been unable to find any epidemiological investigations which were used as a basis for the promulgation of the Brazilian standard for primary contact recreation which is essentially five times that of the USEPA guideline for fecal coliforms which was applied until 1986 (see Table 4). It is reasonable to conclude that the Peruvian standard which is identical to that of Brazil, was highly influenced by the latter. In 1987, the "Companhia de Tecnologia de Saneamento Ambiental of Sao Paulo (CETESB)" (García Agudo, 1991) embarked on an epidemiological study to ascertain the relationship between swimming associated illnesses and microbiological indicators for Brazil (publication pending). A similar epidemiological study was conducted during 1991-1993 in Trinidad Tobago (CEPPOL/UNEP, 1991).

As can be seen in Tables 4 and 5, the microbiological standards are frequently expressed as a permissible mean concentration and a maximum value that should not be exceeded a given percent (90% is common) of the time. However, the relationship between these two criteria should be evaluated. For example, Kay, *et al.* (1990), show that the EEC pre-1996 mandatory criteria, that 95% of the samples be less than 2000 fecal coliforms/100 ml is more strict than the geometric mean of 200/100 ml used by the USEPA prior to 1986. This analysis assumes a log normal distribution with a standard deviation of 0.7 ($\log_{10}$) that implies that for a mean of 200/100 ml, 95% of the samples would have to be less than 2834/100 ml. However, it is noted that the pre-1986 USEPA guidelines also specified that 90% of the samples be less than 400/100 ml which translates to a geometric mean of about 50 fecal coliforms/100 ml utilizing the some assumptions of Kay, *et al.* (1990).

The establishment of water quality objectives (standards) is dependent on existing or planned water uses in an area, and as such, is a site specific issue. The discussions in this paper have been and will continue to be limited to the presentation of the historical development of criteria and the adaptation of guidelines and standards to protect different water uses.

Coliform levels, floatables and grease and oil are generally key parameters in the design of municipal control systems; whereas toxicants and temperature are often more important for industrial discharges. Other parameters such as nutrients and dissolved oxygen will not usually be a major concern unless the sewage is discharged to a shallow, poorly flushed coastline or embayment.

6. SHELLFISH STANDARDS

The most stringent coliform and toxicant criteria are associated with shellfish harvesting areas. Certain shellfish such as oysters, clams, mussels and scallops, etc. feed by filtering water, and consequently, tend to concentrate contaminants, providing a favorable environment for the continued growth of harmful organisms. It has been demonstrated that water containing a relatively small number of harmful microbes can produce shellfish containing pathogen concentrations which will transmit disease. As reported by Wood (undated), the transmission of enteropathogenic diseases by polluted mollusks was first documented for typhoid fever in the latter part of the nineteenth century. Since then, Wood (undated) reports, contaminated shellfish have been associated with the transmission of a wide range of diseases including paratyphoid fever, cholera, viral hepatitis and many other gastro-enteric conditions.

Table 4. Microbiological Quality of Water Guidelines/Standards 100 ml

Country			Primary contact recreation			Protection of indigenous		References
	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Other	Total Colif.	Fecal Colif.	
USEPA, United States		14[a] 90% < 43			Enterococci 35[a] (see Table 1)			USEPA (1986) Dufour y Ballentine (1986)
California, United States	70[e]		80% <1000[i,j] 100%<10000[k]	200[a,j] 90% < 400[1]				Cal. Sta. Water. Res. Board (undated)
EEC[b], Europe			80%<500[c] 95%<10,000[d]	80%<100[c] 95%<2,000[d]	Fecal estreptococci 100[c] Salmonella 0/liter [d] Enteroviruses 0 PFU/liter[d] Enterococci 90%<100			EEC (1976) CEPPOL (1991)
UNEP/WHO		80% < 10 100%< 100		50% <100[n] 90% <1000[n]				WHO and UNEP, 1978
Brazil			80% <5000[m]	80% <1000[m]				Brazil. Ministerio del Interior. (1976)
Colombia			1000	200				Colombia. Ministerio de Salud. (1979).
Cuba			1000[a]	200[a] 90% < 400				Cuba. Ministerio de Salud. (1986)
Ecuador			1000	200				Ecuador. Ministerio de Salud Pública. (1987).
Mexico	70[e] 90% < 230		80%<1000[f] 100%<10,000[k]			10,000[e] 80% <10,000 100% <20,000		Mexico. SEDUE. (1983)
Peru	80% < 1000	80% < 200 200%<1000	80% < 5000[f]	80% < 1000[f]		80% <20000	80% < 4000	Perú. Ministerio de Salud. (1983)
Puerto Rico	70[h] 80% < 230			200[h] 80% < 400				Puerto Rico. JCA. (1983)
Venezuela	70[a] 90% < 230	14[a] 90% < 43	90% < 1000 100% < 5000	90% < 200 100% < 400				Venezuela. (1978)

Table 4. Microbiological Quality of Water Guidelines/Standards 100 ml

Country	Shellfish harvesting		Primary contact recreation			Protection of indigenous organisms		References
	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Other	Total Colif.	Fecal Colif.	
France			< 2000	< 500	Fecal Estreptococci < 100			WHO (1977)
Israel			80% < 1000[g]					Argentina. INCYTH. (1984)
Japan	70		1000			1000		Japan. Environmental Agency. (1981)
Poland					E. Coli < 1000			WHO (1975)
U.R.S.S.					E. Coli < 100			WHO (1977)
Yugoslavia			2000					Argentina, INCYTH (1984)
People's Republic of China	Coli index <50[n]	14		<200[i]	Coli index <1000[i]			SEPA (1998)

a. Logarithmic average for a period of 30 days of at least 5 samples
b. Minimum sampling frequency - fortnightly
c. Guide
d. Mandatory
e. Monthly average
f. At least 5 samples per month
g. Minimum 10 samples per month
h. At least 5 samples taken sequentially from the waters in a given instance
i. Period of 30 days
j. Within a zone bounded by the shoreline and a distance of 1000 feet from the shoreline or the 30 foot depth contour, whichever is further from the shoreline
k. Not a sample taken during the verification period of 48 hours should exceed 10,000/100 ml
l. Period of 60 days
m. "Satisfactory" waters, samples obtained in each of the preceding 5 weeks
n. Maximum permitted value in unit item determination
i. Sampling frequency no less than once a month. More than 95% of the samples in a year should accord with the standard.

State Environmental Protection Administration, SEPA (1998).
Selected environmental standards of the People's Republic of China (1979-1997), December 1998.

Table 5. Total and Fecal Coliform Standards for Primary Contact Recreational Waters as of 1978 - (Cabelli, 1983)

State[a]	Year Rev[b]	Water Type[c]	Total Coliform Limit per 100 ml			Fecal Coliform Limit per 100 ml		
			Average	Percentile	One Sample	Average	Percentile	One Sample
Alabama[1,2,3]	77	SW				LM[d] 100		
	77	SW				LM 200		
Alaska	79	ALL				Mean 20	90% ≤ 40	
Arizona	73	FW				USEPA	USEPA	
Arkanzas	77	FW				USEPA	USEPA	
California	78	SW	Ave 1000	80%≤1000		USEPA	USEPA	
	76	FW	Med[e] 240		≤10,000	Med 50	90% ≤400	
Colorado	75	FW				USEPA	USEPA	
Connecticut[4,5,6]	76	SW	Med 700	90%≤2300		USEPA[f]	90%≤500[g]	
	76	FW	Med 1000	80%≤2400		USEPA[f]	90%≤500[g]	
Delaware	75	ALL				USEPA		
Dist. of Columbia	Pro[h]	ALL		USEPA	USEPA			
Florida	74	ALL	LM 1000	80%≤1000	≤2400	USEPA	USEPA	≤800
Georgia[1,2]	77	SW				LM 100[26]		
	77	FW				LM 200		
Hawaii	74	ALL	Med 1000	90%≤2400		USEPA	USEPA	
Idaho	Pro	FW				LM 50	90%≤200	≤500
Illinois	75	FW				USEPA	USEPA	
Indiana[7]	78	FW				USEPA		≤400[a,i]
Iowa[8]	77	FW				USEPA	USEPA	
Kansas	78	FW				USEPA	USEPA	
Kentucky[9,10]	76	FW	Ave 1000	80%≤1000	≤2400	USEPA[11]	USEPA[11]	
Louisiana	77	ALL				USEPA	USEPA	
Maine	77	SW	Med 70	90%≤230		Med 1000	90%≤200	
	77	FW				NTE 200[g,j]		
Maryland[12]	74	ALL				USEPA	USEPA	
Massachussetts[13]	78	SW	Med 700	90%≤1000				
	78	FW				USEPA	USEPA	
Michigan[27]	73	FW				USEPA		
Minessota[14]	77	FW				USEPA	USEPA	
Mississippi	77	ALL				USEPA	USEPA	
Missouri[8,15]	77	FW				USEPA	USEPA	
Montana	78	FW				USEPA	USEPA	
Nebraska	77	FW				USEPA	USEPA	
Nevada	74	FW				USEPA	USEPA	
New Hampshire[9]	77	ALL			240			
New Jersey[6]	74	ALL				USEPA		
New Mexico[16]	77	FW				LM 100	90%≤200	
New York[9,17,18]	74	ALL	Med 2400	80%≤5000		USEPA		
N.Carolina[19,20]	77	ALL				USEPA[16]	80%≤400	
North Dakota	77	FW				USEPA	USEPA	
Ohio[21]	78	FW				USEPA	USEPA	
Oklahoma	76	FW				USEPA	USEPA	
Oregon[22]	Pro	SW	Ave 240	80%≤ 240				
		FW	Ave 1000	80%≤2400				
Pennsylvania	Pro	ALL				USEPA		
Rhode Island	77	SW	Med 700	90%≤2300		Med 50		90%≤500
	77	FW	Med 100	80%≤2400		Med 200[g]		80%≤500[g]
South Carolina	77	ALL				USEPA	USEPA	
South Dakota	78	FW				USEPA	80%≤200	≤400
Tennessee[1,23,24]	77	FW				USEPA		≤1000
Texas[6]	76	ALL				USEPA	USEPA	
Utah	78	FW	LM 1000			USEPA		
Vermont	78	FW	NTE 500			NTE 200		
Virgina	77	ALL				USEPA	USEPA	
Washington	77	SW				Med 14	90%≤43[25]	
	77	FW				LM 100	90 ≤200[16]	
West Virginia	77	FW	Ave 1000	80%≤1000	≤2400	USEPA	USEPA	
Wisconsin[28]	78	FW				USEPA	USEPA	
Wyoming	78	FW				USEPA	USEPA	
Puerto Rico	76	ALL				USEPA	80%≤400	
Virgin Islands	73	ALL				LM 70		
Trust Territory	73	ALL				USEPA	USEPA	
American Samoa	73	ALL				Ave 100	90%≤200	
Guam[9]	76	ALL				Ave 200	USEPA	

Table 5 (Cont.)

a. Does not include all the caveats, special requirements, limitations, etc.
b. Year of latest revision
c. SW - seawater (estuarine and coastal); FW - freshwater
d. Log mean
e. Median
f. Geometric mean not to exceed 200/100 ml
g. Guideline
h. Proposed
i. In one month
j. Not to exceed

1. Waters in the vicinity of STP outfall not suitable
2. Designated as "coastal" and "all other recreational waters".
3. If standard exceeded, waters considered acceptable if a second sanitary survey and evaluation indicates no significant public health risk.
4. For listed rivers, disinfection of STP effluents required; and standards only apply between months of May through September.
5. "Coliform bacteria ... are related to the probability of contamination by undisinfected sewage. High results may be due to soil bacteria or bacteria from the feces of warm-blooded animals which are not of sanitary significance".
6. Sanitary surveys required.
7. Applies only from April through October.
8. Applies from 1 April through 31 October.
9. Unless naturally occurring.
10. If TC exceeded, then FC is used.
11. Only applicable from May through October.
12. Waters exceeding standard acceptable only if sanitary survey shows no significant public health risk.
13. Except as provided in Regulation 2.1.
14. Standards relate only to intrastate waters.
15. Except when affected by stormwater runoff.
16. Varies with body of water; standard as given used in most cases, USEPA guideline used in a few.
17. Applies only when disinfection is practiced.
18. For "International Boundary Waters" under Great Lakes Water Quality Agreement of 1972, log mean TC 1000/100 ml and FC 200/100 ml.
19. Applicable only during May through September.
20. Not applicable during or immediately following periods of rainfall.
21. Where there are no lifeguards and/or bathhouse facilities, log mean of 1000/100 ml and 90% $\leq$ 2000/100 ml apply.
22. Bacterial pollution or other conditions deleterious to waters used for ... bathing ... or otherwise injurious to public health shall not be allowed.
23. $\leq$ 1/100 ml set as 1/100 ml in calculating log mean
24. Individual samples cannot be collected within 12 hours of each other.
25. Standard given is for Class A (Excellent) waters which "...shall meet or exceed the standards for all or substantially all uses ..." Class AA (Extraordinary) fresh water standard is a median TC of 50/100, 90% $\leq$ 100/100 ml. Class B (Good) for fresh water is median FC of 200/100 ml, 90% $\leq$ 400/100 ml; for sea waters, the standard is the same as that for Class A fresh waters.
26. If water quality and sanitary surveys show 200/100 ml exceeded occasionally due to "natural causes", log mean of 300/100 ml in lakes and reservoirs and 500/100 ml in free flowing FW streams becomes the limit.
27. Limits may be exceeded if due to "uncontrollable non-point sources".
28. Sanitary survey to assure protection is chief criterion; bacterial limits are guidelines.

An ancient reference concerning the danger of eating certain marine animals is found in the Bible, where Moses in Deutoronomy alerts his people that "Of all creatures living in the water, you may eat any that have fins and scales. But anything that does not have fins and scales you may not eat; for you it is unclean" (Deut. 14:9-10).

The USEPA (1976) recommended that the "evaluation of the micro-biological suitability of waters for recreational taking of shellfish should be based upon the fecal coliform bacterial levels. When possible, samples should be collected under those conditions of tide and reasonable rainfall when pollution is most likely to be a maximum in the area to be classified. The median fecal coliform value should not exceed an MPN of 14 per 100 ml and no more than 10 percent of the samples should exceed an MPN of 43." As stated in the USEPA (1976) report, the primary source of these guidelines was the internationally accepted microbiological criterion for shellfish water quality of 70 total coliforms per 100 ml, using a median MPN, with no more than 10 percent of the values exceeding 230 total coliforms per 100 ml. The fecal coliform guidelines recommended were simply derived from the fecal to total coliform ratios (approximately 20%) based on more than 3500 sets of data measured in the USA. Other shellfish standards are presented in Table 4.

The above mentioned internationally accepted total coliform standard was originally established in 1925 (Committee on Evaluation of Safety of Fishery Products, 1991) based on typhoid epidemiological investigations conducted from 1914 to 1925 by the states and the Public Health Service of the USA. It was believed that typhoid fever would not normally be attributed to shellfish harvested from water in which "not more than 50% of the 1 cc portions of water examined were positive for coliforms" (FDA, 1989). This equates to 70 MPN total coliforms/100 ml, which is equivalent to the fecal material from one person diluted in 8 million cubic feet (226,700 m^3) of coliform-free water. Later, these standards were extrapolated to fecal coliforms on the basis that fecal coliforms were more accurate indicators of fecal contamination.

Table 4 shows that most Latin American countries have adopted this internationally accepted criterion with the exception of Peru that has a standard that 80% of samples be less than 200 fecal coliforms per 100 ml and 100% less than 1000 in shellfish harvesting waters.

The WHO/UNDP current criterion on shellfish harvesting waters is that 80% of samples should be less than 10 fecal coliforms per 100 ml and 100% less than 100 fecal coliforms per 100 ml (Helmer *et al.,* 1991).

7. MIXING ZONE STANDARDS

In the design of ocean outfalls for final sewage disposal, consideration should be given to defining a separate set of standards within a limited region surrounding the outfalls' diffuser section. The purpose of this <u>mixing zone</u> is to allocate a limited region for complete effluent mixing with ocean water. As such, the mixing zone is a region of non-compliance and limited water use. It normally encompasses a volume extending 50-600 meters on all sides of the initial dilution zone. Mixing zone standards are generally limited to water quality variables for acute toxicity protection (usually determined by bioassays) and to minimize visual impacts. Mixing zone standards for coliform organisms are normally not imposed unless the diffuser is located in close proximity to shellfish harvesting areas or water contact recreational uses. Such standards are not usually applied to BOD, dissolved oxygen, and nutrients.

8. CONCLUSIONS

The information presented in Tables 4 and 5 provide a range for the water quality planner principally for total and fecal coliforms as indicator organisms. However, although more than 80 years have passed since their first application, a world-wide range of three orders of magnitude continues to exist. The quantity of epidemiological studies that justify these total and fecal coliform standards is very limited, although the application of these standards can result in significant costs for control systems. As such, the simple adaptation of a particular set of standards is inappropriate without a thorough review of their origin and the local socio-economic circumstances.

The Cabelli (1983) studies provided for the first time a quantitative relation between health risk and indicator organisms (enterococci) level, although factors such as the general health and immunity of the local population imply that caution should be exercised in directly applying the relationships developed in other areas. Furthermore, in epidemiological studies conducted after those of Cabelli, correlation between sickness symptoms and bacterial indicator concentrations varied considerably.

As such, it is recommended that the countries, especially in developing countries where priorities often must be established for projects of first necessity in the context of limited economic resources, conduct local epidemiological studies directed at establishing the relationship between health risk and indicator organisms. There is significant controversy concerning the type of study that should be adopted. The majority of studies conducted to date are prospective cohort studies (Pruss, 1998) as were the Cabelli (1983) studies (protocol available in WHO, 1986). However, in the recent WHO efforts, only controlled randomized trial studies have been considered by the experts' group as more accurate (Pruss, 1996) and the only study of this type conducted by Kay, Fleisher, *et al.*, (1994) in the United Kingdom, has been used as the basis for developing the WHO guidelines for recreational marine waters for enteric illness. The application of these guidelines to the tropical waters of most of our Region is of concern.

At any rate, the cost of epidemiological studies is justifiable in the context of the large potential capital expenditures associated with control systems. Also, the adaptation of a particular risk level for human health should be based on the local socio-economic situation if it is to be viable.

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