REGIONAL SEAS

UNITED NATIONS ENVIRONMENT PROGRAMME OCTOBER 1995

Statistical methods for the evaluation of results from monitoring the quality of coastal recreational and shellfish areas

Reference Methods For Marine Pollution Studies No. 55 (Rev.1)

Prepared in co-operation with

WHO

UNEP 1995

This document has been prepared by the World Health Organization (WHO) and issued by the International Atomic Energy Agency, Marine Environment Laboratory (IAEA-MEL) and the United Nations Environment Programme (UNEP) under the project FP/ME/5101-93-03(3033).

For bibliographic purposes this document may be cited as:

UNEP/WHO: Statistical methods for the evaluation of results from monitoring the quality of coastal recreational and shellfish areas. Reference Methods for Marine Pollution Studies No. 55, Rev. 1. UNEP, 1995.

REGIONAL SEAS

UNITED NATIONS ENVIRONMENT PROGRAMME OCTOBER 1995

Statistical methods for the evaluation of results from monitoring the quality of coastal recreational and shellfish areas

Reference Methods For Marine Pollution Studies No. 55 (Rev.1)

Prepared in co-operation with

WHO

UNEP 1995

PREFACE

The Regional Seas Programme was initiated by UNEP in 1974. Since then the Governing Council of UNEP has repeatedly endorsed a regional approach to the control of marine pollution and the management of marine and coastal resources, and has requested the development of regional action plans. The Regional Seas Programme at present includes 12 regions and has over 140 coastal states participating in it (1), (2).

One of the basic components of the action plans sponsored by UNEP in the framework of the Regional Seas Programme is the assessment of the state of the marine environment and of its resources, and of the sources and trends of the pollution, and the impact of pollution on human health, marine ecosystems and amenities. In order to assist those participating in this activity, and to ensure that the data obtained through this assessment can be compared on a world-wide basis and thus contribute to the Global Environment Monitoring System (GEMS) of UNEP, a set of Reference Methods and Guidelines for marine pollution studies is being developed as part of a programme of comprehensive technical support which includes the provision of expert advice, reference methods and materials, training and data quality assurance (3). The methods are recommended to be adopted by Governments participating in the Regional Seas Programme.

The methods and guidelines are prepared by, or in cooperation with, the relevant specialized bodies of the United Nations system as well as other organizations, and are tested by a number of experts competent in the field relevant to the methods described.

In the description of the methods and guidelines the style used by the International Organization for Standardization (ISO) is followed as closely as possible.

The methods and guidelines, as published in UNEP's series of Reference Methods for Marine Pollution Studies, are not considered as final. They are planned to be periodically revised taking into account the development of our understanding of the problems, of analytical instrumentation and the actual need of the users. In order to facilitate these revisions, the users are invited to convey their comments and suggestions to:

WHO/EURO Project Office
Coordinating Unit for the Mediterranean Action Plan
48 Vassileos Konstantinou
P.O. Box 18019
GR-11610 Athens
GREECE

which is responsible for the development and preparation of microbiological and other health-related Reference Methods.

---

(1) UNEP: Achievements and planned development of the UNEP's Regional Seas Programme and comparable programmes sponsored by other bodies. UNEP Regional Seas Reports and Studies No. 1, UNEP, 1982.

(2) P. HULM: A strategy for the Seas. The Regional Seas Programme: Past and Future, UNEP 1983.

(3) UNEP/IAEA/IOC: Reference Methods and Materials: A Programme for comprehensive support for regional and global marine pollution assessments. UNEP, 1990.

This revised issue of Reference Methods for Marine Pollution Studies No. 55 was prepared by the World Health Organization on the basis of a review of the Method during expert meetings and comments from individual scientists who tested the method. The assistance of all those who contributed to this revised issue of the Reference Method is gratefully acknowledged.

CONTENTS

1. INTRODUCTION

The original version of this part of the Guidelines was prepared by the World Health Organization within the framework of the Long-term Programme of Pollution Monitoring and Research in the Mediterranean Sea (MED POL Phase II) and issued by the United Nations Environment Programme as Reference Method for Marine Pollution Studies No. 55 within UNEP's Regional Seas Programme Activity Centre's series.

The present version constitutes a re-issue of the original within the framework of the new overall guidelines for health-related monitoring of coastal recreational and shellfish areas.

2. SCOPE AND FIELD OF APPLICATION

The method described is suitable for the evaluation and interpretation of microbiological data from coastal and shellfish-growing waters in temperate and tropical seas, and is designed to be used in the sanitary surveillance of bathing and shellfish-growing waters.

Microbial indicators exhibit a highly variable concentration at a given sampling station, depending, among other factors, on the sampling time of the day and the day of sampling. Compliance with national and international criteria and standards requires an estimation of the "microbial concentration not exceeded" on a defined percentage of the samples collected, and it is therefore of interest to use a systematic method for data evaluation that, in addition to giving the microbial concentrations associated with the established percentages, helps to understand the temporal variation of the microbiological quality of a coastal water, and provides some insight into the type and relative importance of the factors affecting it.

3. PRINCIPLES

The evaluation and interpretation method described is based on a statistical model and has to be applied to a homogeneous series of experimental concentrations, obtained at a sampling station, over a continuous period of time, and expressed in terms of a specified microbial indicator.

The concentration of microbial indicators present in the water samples collected at a sampling station, over a continuous period of time, has been shown to approximate to a lognormal probability distribution. In other words, the natural logarithm of the microbial concentrations appears to follow a normal probability distribution quite closely.

The lognormal probability distribution that most closely fits an experimental set of microbial concentrations can be obtained through a graphical interpolation technique, which allows the direct estimation of the microbial concentrations not exceeded in any given percentage of the samples, as well as providing several statistical parameters that are useful in understanding the factors affecting the microbiological quality of the coastal waters studies.

This statistical method for evaluating and interpreting microbiological data can also be applied numerically, using appropriate computer programmes.

4. METHODOLOGICAL COMPARISONS

Compliance with national and international criteria and standards of microbiological quality usually requires the determination of the microbial concentration not exceeded in a given percentage of the water samples analyzed. A subsequent comparison between the resulting microbial concentrations and those established by the criteria or standards provides the basis for assessing the microbiological quality of the water with respect to the criteria or standards considered.

Although most of the existing criteria and standards for microbiological water quality are expressed in terms of two concentrations of a specified microbial indicator, which should not be exceeded in two corresponding percentages of the samples, very few of the criteria or standards give explicit indications on how to derive the appropriate microbial concentrations from the set of experimental data.

As an illustration, the WHO/UNEP interim criteria on the recreational waters (WHO, 1979) specify that the faecal coliform concentrations of at least 10 water samples collected during the bathing season should not exceed: (a) 100 faecal coliforms per 100 ml in 50% of the samples; and (b) 1000 faecal coliforms per 100 ml in 90% of the samples.

4.1 The Ranking Method

The method most frequently used for deriving the microbial concentrations required for water quality evaluation involves the ranking of the experimental concentrations, in increasing order, and the subsequent selection of the microbial concentration having an order number equal to that resulting from the product of the total number of samples considered and the percentage specified by the criteria or standards. Assuming the number of concentrations available was n = 20, the microbial concentrations of concern when applying the WHO/UNEP interim criteria would be those with order numbers n50 = 20 x 0.50 = 10 and n90 = 20 x 0.90 = 18 respectively.

This ranking method has the following features.

1. It is very simple to perform, as it involves simple ordering and multiplication operations, making unnecessary the use of any complex formula or laborious graphical analyses.

2. It frequently leads to the practical difficulty of having to interpret order numbers which are not integers. Unless the number of experimental results available "n" is appropriate, determination of its product by the corresponding percentage of compliance will result in a real number, with the subsequent difficulty of having to associate it with one of the integers representing the order number of the experimental set. As an example, assuming the number of concentrations available was n = 12, the order numbers of interest when applying the WHO/UNEP criteria concentration would be n50 = 12 x 0.50 = 6 and n90 = 12 x 0.90 = 10.8 respectively. While the former number is an integer, the latter is a real number and does not correspond with any of

the 12 integers representing the same number of ranking positions of the experimental concentrations.

This difficulty is usually solved by rounding off the fraction, thus converting the real number into an integer, which can then be used for identifying the desired microbial concentration. The most commonly used rounding-off criterion consists in adding 0.5 units to the real number and then dropping the fraction part of the resulting number. According to this criterion, the previously obtained real number n90 = 10.8 would be converted into the integer n90 = 11.

3. The precision of the microbial concentration thus selected is quite variable and fairly low, being mainly determined by its relative ranking position within the ordered series of available results. Any concentration included within the range defined by the concentrations immediately above and below that associated with a specified percentage could have been chosen as corresponding to the same order number of the concentration actually selected.

4. The method does not take into account the absolute values of any of the experimental results, other than those associated with the percentages specified by the criteria or standards.

5. As the method concentrates on selecting one or two specific microbial concentrations out of a set of experimental values, it does not provide any insight into the temporal variation of the microbiological quality of the water at the sampling station considered.

Appendix 1 illustrates the process of evaluation of the microbiological quality of a coastal water in the Mediterranean according to the WHO/UNEP interim criteria, using the ranking method previously discussed.

4.2 Lognormal Distribution Method

The statistical method proposed for the evaluation and interpretation of microbiological results is based on the observed property of the microbial concentrations, measured at a sampling station, to follow a lognormal probability distribution. The method involves determination of the normal distribution that most closely fits the natural logarithms of the experimental results. The adjustment procedure may be performed either graphically or numerically, both alternatives being capable of producing identical results, provided the calculation steps are adequately specified.

The following characteristics of the lognormal probability distribution method should be noted.

1. The procedure is slightly more elaborate than the ranking method. Although it does not involve complex formulae, it demands some knowledge of geometry and certain skills in graphical treatment of data. Strict adherence to the procedure and a minimum of practical training will ensure its successful performance by any skilled technician.

2. There are no practical difficulties concerning the total number of results available. Any set of experimental results can be evaluated, although the benefits of this technique

become more evident with higher numbers of microbial concentrations. Data sets containing more than 10 experimental results provide the best interpretation conditions.

3. The precision of the method can be statistically ascertained and is generally superior to that of the ranking method.

4. The method takes into account the absolute values of all the microbial concentrations considered, which results in a more precise estimation of the concentration not exceeded in any percentage of the samples.

5. The method entails determination of the lognormal probability distribution that most closely fits the experimental results and thus provides very helpful insight concerning the temporal variation of the microbiological quality at the sampling station considered, as well as the relative variation between two or more stations.

5. TECHNICAL MATERIALS

The preparation of the graphical plot from a set of microbial concentrations, as required by the lognormal distribution method, involves the use of the items:

5.1 A calculator capable of furnishing natural logarithm values. As an alternative, either a logarithmic table or a graphical logarithmic scale can be used.

5.2 A sheet of either normal probability paper or lognormal probability paper. The sheets of normal and lognormal probability paper give two coordinate axes, one of them having a non-linear scale, corresponding to the normal probability distribution, and the other having either an arithmetic scale or a logarithmic scale respectively.

Figures 1 and 2 show these two types of probability paper.

The specific property of normal probability paper is that a set of experimental values belonging to a normally distributed population will fit a straight line when plotted.

As the microbial concentrations obtained from a sampling station are considered to follow a lognormal probability distribution, their graphical analysis makes it necessary either to calculate the natural logarithms of the data and then plot them as normal probability paper or, more simply, to plot the data directly on lognormal probability paper.

Where no type of probability paper is available, the probability scales shown in Figures 1 and 2 may be used.

5.3 A transparent drawing rule, approximately 30 cm long.

5.4 Auxiliary drawing tools, such as pencils and eraser.

5.5 The appropriate data recording forms, from which to obtain the experimental data and on which to record the statistical parameters derived from the evaluation process.

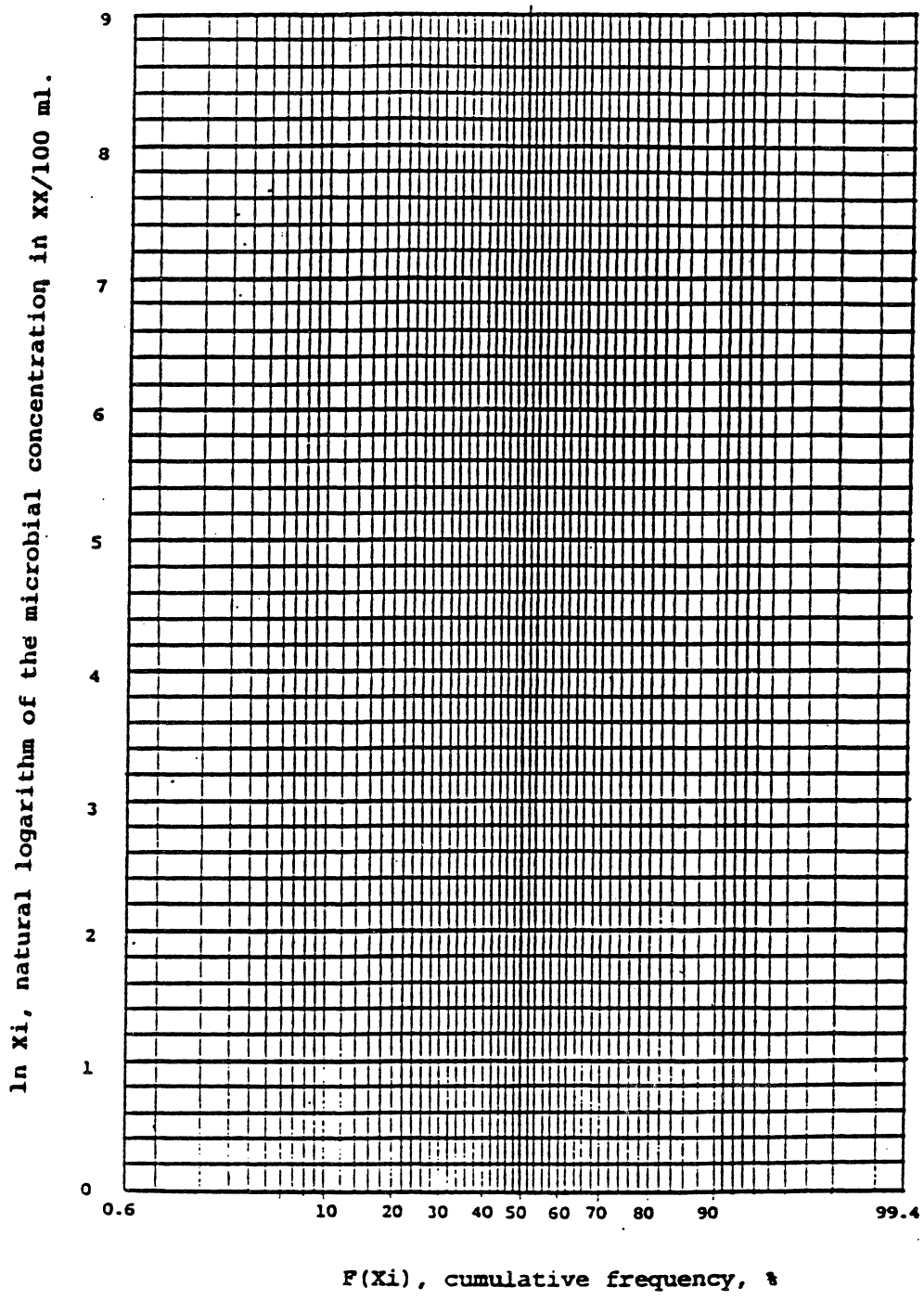

Figure 1. Normal probability paper for evaluation of microbiological data.

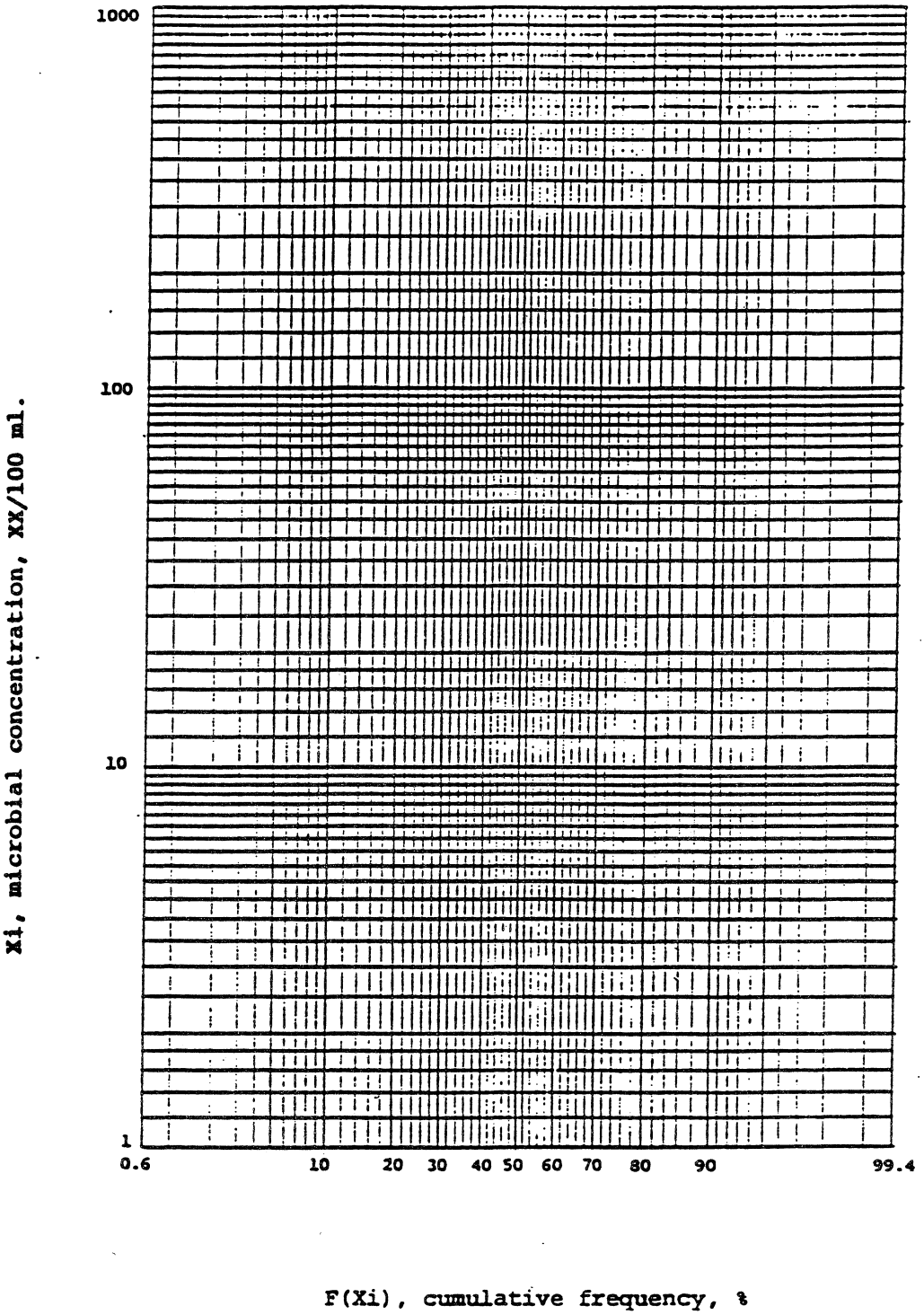

Figure 2. Lognormal probability paper for evaluation of microbiological data.

6. OPERATION PROCEDURES

The procedure for application of the lognormal distribution method is described below and illustrated in Appendix 2.

The following steps are necessary in order to construct a lognormal probability plot from a set of microbial concentrations.

6.1 From the laboratory recording forms, obtain the set of consecutive microbial concentrations that, corresponding to a specified microbial indicator, covers the time period of interest.

6.2 Rank the experimental results in increasing order of magnitude and obtain a new set of microbial concentrations in which every value is smaller than or equal to that following it.

6.3 Prepare a sheet of probability paper. When normal probability paper is available, the previously ordered set of microbial concentrations has to be converted to natural logarithms. This transformation can be performed either numerically, using a calculator or a logarithmic table, or graphically, using a logarithmic scale taken from the ordinates axis of Figure 2.

When lognormal probability paper is available, there is no need for transformations, as the microbial concentrations will be plotted directly in a coordinate system such as that appearing in Figure 2.

6.4 Calculate the expected cumulative frequency, F(Xi), associated with each of the previously ordered microbial concentrations, using the expression:

$$F(Xi) = \frac{i}{n+1} \times 100$$

where:

Xi	=	microbial concentration in the i-th position;
F(Xi)	=	cumulative frequency associated with the data value in the i-th position;
i	=	order number of each microbial concentration;
n	=	total number of microbial concentrations in the set.

6.5 When normal probability paper is available, plot the log-transformed values, in Xi, versus the corresponding cumulative frequencies, F(Xi).

When lognormal probability paper is available, the microbial concentrations, Xi, should be plotted directly in relation to the corresponding cumulative frequencies, F(Xi).

The coordinate axis used for plotting the log-transformed data is usually referred to as the observational scale and the coordinate axis for plotting the F(Xi) as the cumulative axis. Whether the observational or cumulative axis appears on the abscissa is irrelevant and depends on the way the plotting paper has been prepared.

6.6 The lognormal probability distribution that best fits the experimental results will now be obtained by graphical interpolation of a straight line to the previously plotted points. A detailed discussion of the interpolation methods appears in section 7.

This straight line represents the cumulative probability distribution of the microbial concentrations not exceeded in a certain percentage of the cases.

6.7 The microbial concentration not exceeded in a given percentage of the set of concentrations considered can be obtained graphically by finding the concentration associated (through the previously drawn straight line) with the percentage of interest.

A convenient notation for the microbial concentration not exceeded in, for example, 50% of the samples would be XX50, where XX designates the two initials of the microbial indicator considered.

As an illustration, TC50 = 2480 TC.100 ml would mean that 50% of the total coliform concentrations considered are smaller than or equal to 2480 total coliforms per 100 ml, at the selected water sampling station, and during the time period specified.

6.8 Calculate the standard deviation of the lognormal probability distribution. The standard deviation is a direct measure of the scattering of the experimental results from their mean value, and thus gives a clear indication of the variation, within the time period considered, of the microbiological quality of the water at the sampling station surveyed.

The standard deviation of a lognormal probability distribution is defined by the expression:

$$s = \ln XX84 - \ln XX50 = \ln XX50 - \ln XX16$$

where:

s = standard deviation of the lognormal probability distribution;
XX84, XX50, XX16 = microbial concentrations derived from the interpolated probability distribution, which are not exceeded in 84%, 50% and 16% of the samples respectively.

The above definition of the standard deviation must always be borne in mind, when using either normal or lognormal probability paper, to prevent any confusion arising from the type of scale used for plotting microbial concentrations.

The standard deviation of a lognormal probability distribution is directly related to the geometrical slope of the straight line representing the lognormal probability distribution. The higher the standard deviation of the probability distribution, the closer the straight line to the vertical position.

6.9 The confidence interval of the set of microbial concentrations can be obtained directly from the probability distribution previously drawn.

The confidence interval of the (1-α) x 100 percentage is defined by the following limits:

$$(XX (\alpha/2) ; \; XX (1-\alpha/2))$$

where:

XX	=	initials of the microbial indicator;
α	=	level of significance.

As an illustration, the 90% confidence interval of the concentrations measured at a sampling station would be defined by the two concentrations:

$$(XX05 ; \; XX95)$$

where XX05 and XX95 are the concentrations of the microbial indicator denoted by XX, which were not exceeded in 5% and 95% of the samples, as estimated from the graphically interpolated lognormal distribution.

6.10 The confidence interval of the median microbial concentration, XX50, at a given sampling station is defined by the following two limits:

$$\left(\exp \left(\ln XX50 - \frac{s}{\sqrt{n}} t_{1-\alpha/2,\, n-1} \right); \exp \left(\ln XX50 + \frac{s}{\sqrt{n}} t_{1-\alpha/2,\, n-1} \right) \right)$$

where:

XX50	=	median microbial concentration estimated from the lognormal probability distribution, XX/100 ml;
s	=	standard deviation of the lognormal probability distribution;
$t_{1-\alpha/2,\, n-1}$	=	value of the cumulative student's t distribution with n-1 degrees of freedom;
α	=	level of significance;
(1-α)100	=	confidence interval, %;
n	=	number of microbial concentrations included in the data set.

Appendix 3 illustrates the most frequently used values of student's t distribution, as contained in Table 18 of the **Guidelines for health related monitoring of coastal water quality** (WHO/UNEP, 1977a).

6.11 The lognormal probability distribution previously obtained defines all the statistical parameters necessary for further hypothesis testing, both for the distribution itself and for comparisons of this distribution with others obtained at the same or different sampling stations.

7. INTERPOLATION TECHNIQUES

The recommended criterion for interpolating a straight line to a set of plotted points involves visually drawing a straight line such that the areas defined on each side, by the virtually polygonal line connecting consecutive points, are approximately equal.

Although more exact interpolation techniques can be used, such as the least squares method, practical experience from interpolation of numerous sets of microbial concentrations shows that an experienced analysts can produce straight-line interpolations of comparable precision to those achieved with more elaborated numerical methods.

Practical difficulties encountered when trying to interpolate a straight line, through a scattered cloud of data points, should be considered as an indication of the lack of adjustment to the proposed lognormal distribution model - a condition which would not be improved by the precise interpolation that can be performed by complex numerical methods.

8. PRACTICAL CONSIDERATIONS

Visual examination of the experimental data points appearing in a lognormal probability plot is a practical and direct method for testing whether or not the results follow such a distribution. The closer the plotted points fit a straight line, the better the experimental data follow a lognormal probability distribution.

Data points located at both tails of the distribution frequently diverge from the overall linear tendency of the other points. Practical experience shows that a close fir of the majority (from 70% to 90%) of the central points can be considered a strong indication of the validity of the proposed statistical model.

Although samples with zero microbial concentration cannot be logarithmically transformed, and thus cannot be plotted on probability paper, they should be taken into account for all practical purposes during the data-ordering process. Only when applying a statistical test for goodness-of-fit should they be considered, being located at the far bottom of the cumulative frequency axis, under their corresponding F (Xi) value.

When the plotted points cannot be adjusted to a straight line, it is most likely that the variation among the microbial concentrations cannot be interpreted by the lognormal probability distribution model proposed in this document.

However, a visual inspection of the pattern followed by the plotted points may give some clues with regard to what other models could be used for interpreting the data or to the appropriateness of adopting a certain subdivision of the data set considered, as they may appear to follow two distinct lognormal distributions.

A detailed analysis of the data sets which do not follow a lognormal distribution model can provide very valuable insight to the data analyst, as well as helping to improve interpretation skills.

9. INTERPRETATION

From the straight line that most closely fits the set of experimental points drawn in the probability paper, the following parameters can be directly obtained:

XX50 = microbial concentration not exceeded in 50% of the samples;
XX84 = microbial concentration not exceeded in 84% of the samples;
XX90 = microbial concentration not exceeded in 90% of the samples.

Similarly, any other microbial concentration not exceeded in a given percentage of the samples can be read from the probability plot.

The standard deviation of the lognormal distribution can be obtained by the expression:

$$s = \ln XX84 - \ln XX50 = \ln XX50 - \ln XX16$$

which requires calculation of the natural logarithms of the concentrations previously obtained.

The confidence interval of the set of microbial concentrations and the confidence interval of the median concentration can be obtained by the expressions appearing in sections 6.9 and 6.10 respectively.

Appendix 2 illustrates the calculation procedure for processing microbiological data from a water sampling station on the Mediterranean coast.

10. COMPLIANCE WITH STANDARDS

To determine whether or not the microbial concentrations measured at a given sampling station comply with the applicable criterion or standard, it is necessary only to compare the microbial concentrations specified in the criterion or standard with the corresponding microbial concentrations derived from the lognormal distribution model.

When the criterion or standard applicable contains two concentration limits for a given microbial indicator, the proposed model provides further insight into the degree of compliance at the sampling station considered, through visual comparison of the probability distribution derived from the experimental data, and that defined by the criterion or standard itself.

11. EVALUATION REPORT

The reporting form for the evaluation and interpretation of the microbiological quality at a sampling station should include information on the following items.

11.1 The identification code of the sampling station.

11.2 The microbial indicator considered.

11.3 The microbiological method used.

11.4 The time period covered.

11.5 The total number of data available.

11.6 The number of samples with zero microbial concentration.

11.7 The criterion or standard of microbiological quality considered.

11.8 The high or low degree of adjustment of the experimental data to the lognormal distribution model.

Only when the adjustment to the proposed model is adequate should information on the following items be determined from the probability distribution derived from graphical interpolation of the data points.

11.9 The microbial concentrations not exceeded in the percentages of the samples specified by the criterion or standard.

11.10 The standard deviation of the distribution, s.

11.11 The 95% confidence interval of the microbial concentrations.

11.12 The 95% confidence interval of the median microbial concentration.

11.13 The evaluation of the microbiological quality according to each of the concentration limits specified by the criterion or standard considered.

11.14 The overall evaluation of the microbiological quality of the sampling station according to the criterion or standard considered.

11.15 The lack of adjustment of the data to the lognormal distribution model, as well as the relative microbial concentrations defined by the experimental lognormal distribution and the values imposed by the criterion or standard.

Table 2.2 in Appendix 2 gives an example of a report on an evaluation of the microbiological quality of a Mediterranean coastal water according to the WHO/UNEP interim criteria, using the lognormal probability distribution method.

APPENDIX 1

EVALUATION OF THE MICROBIOLOGICAL QUALITY OF A MEDITERRANEAN COASTAL WATER BY THE RANKING METHOD

Table 1.1 Faecal coliform concentrations at a water sampling station on the Mediterranean coast, summer 1982.

Date	FC.100 ml
16 June 1982	92
23 June 1982	1600
30 June 1982	36
7 July 1982	0
14 July 1982	140
21 July 1982	4
28 July 1982	0
4 August 1982	36
11 August 1982	4
18 August 1982	8
25 August 1982	0
14 September 1982	32

Table 1.2 Microbiological quality of a coastal water: arrangement of experimental data when using the ranking method.

Order number	Microbiological concentration FC/100 ml
1	0
2	0
3	0
4	4
5	4
6	8
7	32
8	36
9	36
10	92
11	140
12	1600

The evaluation of the microbiological quality of this coastal water, according to the WHO/UNEP interim criterial for recreational waters, requires the selection of the concentrations not exceeded in 50% and 90% of the samples.

The order numbers associated with those percentages are:

$$n50 = 12 \times 0.50 = 6$$
$$n90 = 12 \times 0.90 = 10.8$$

respectively.

Considering that the order numbers appearing in Table 1.2 are integers, the previous value n90 = 10.8 has to be rounded off and transformed into an integer. The commonly used criterion for rounding off numbers transforms the n90 = 10.8 value into n90 = 11, which can then be identified in Table 1.2.

The faecal coliform concentrations not exceeded in 50% and 90% of the samples can be obtained from Table 1.2, i.e. those associated with the order numbers n50 = 6 and n90 = 11, and are:

FC50 = 8.0 FC/100 ml
FC90 = 140.0 FC/100 ml

From the results shown in Table 1.3, it can be concluded that the microbiological quality of the coastal waters surveyed does not exceed either of the two microbial limits, and consequently can be considered satisfactory according to the WHO/UNEP interim criteria.

Table 1.3 Microbiological quality of a recreational coastal water in the Mediterranean: comparison of limits specified by the WHO/UNEP interim criteria and observed values.

Water quality parameter	Microbial concentrations FC/100 ml	
	Specified by criteria	Observed
FC50	100	8
FC90	1000	140

As discussed in the description of the ranking method, the values in Table 1.2 illustrate that any experimental concentration falling within the range from 92 to 1600 FC/100 ml would have been ranked in the eleventh position, assuming the other results were unchanged, thus illustrating the low precision of this method and underlining the strong implications that it has for the final outcome of the evaluation procedure.

If instead of the 140 FC/100 ml concentration a value above 1000 FC/100 ml had been observed, the water sampling station would have been classified an unsatisfactory according to the WHO/UNEP interim criteria.

APPENDIX 2

EVALUATION OF THE MICROBIOLOGICAL QUALITY OF A MEDITERRANEAN COASTAL WATER BY THE LOGNORMAL PROBABILITY METHOD

The following table illustrates the ordering and calculation procedures necessary for applying the lognormal probability model to the set of faecal coliform concentrations appearing in Table 1.1 of Appendix 1.

Table 2.1 Microbiological quality of a coastal water: evaluation by the lognormal probability method.

Order number	Cumulative frequency % F(Xi)	Microbial concentration FC/100 ml Xi	Log-transformed microbial concentration 1n Xi
1	8	0	-
2	15	0	-
3	23	0	-
4	31	4	1.39
5	38	4	1.39
6	46	8	2.08
7	54	32	3.47
8	62	36	3.58
9	69	36	3.58
10	77	92	4.52
11	85	140	4.94
12	92	1600	7.38

As an illustration, two graphical analyses will be performed, depending on whether normal probability paper or lognormal probability paper is used. In both cases the evaluation method requires plotting the microbial concentration Xi versus the corresponding cumulative frequencies F(Xi), as they are listed in Table 2.1. Figures 2.1 and 2.2 illustrate the graphical analyses conducted on the two types of probability paper.

The data points shown in Figures 2.1 and 2.2 have been interpolated with a straight line, following the criterion recommended in Section 7.

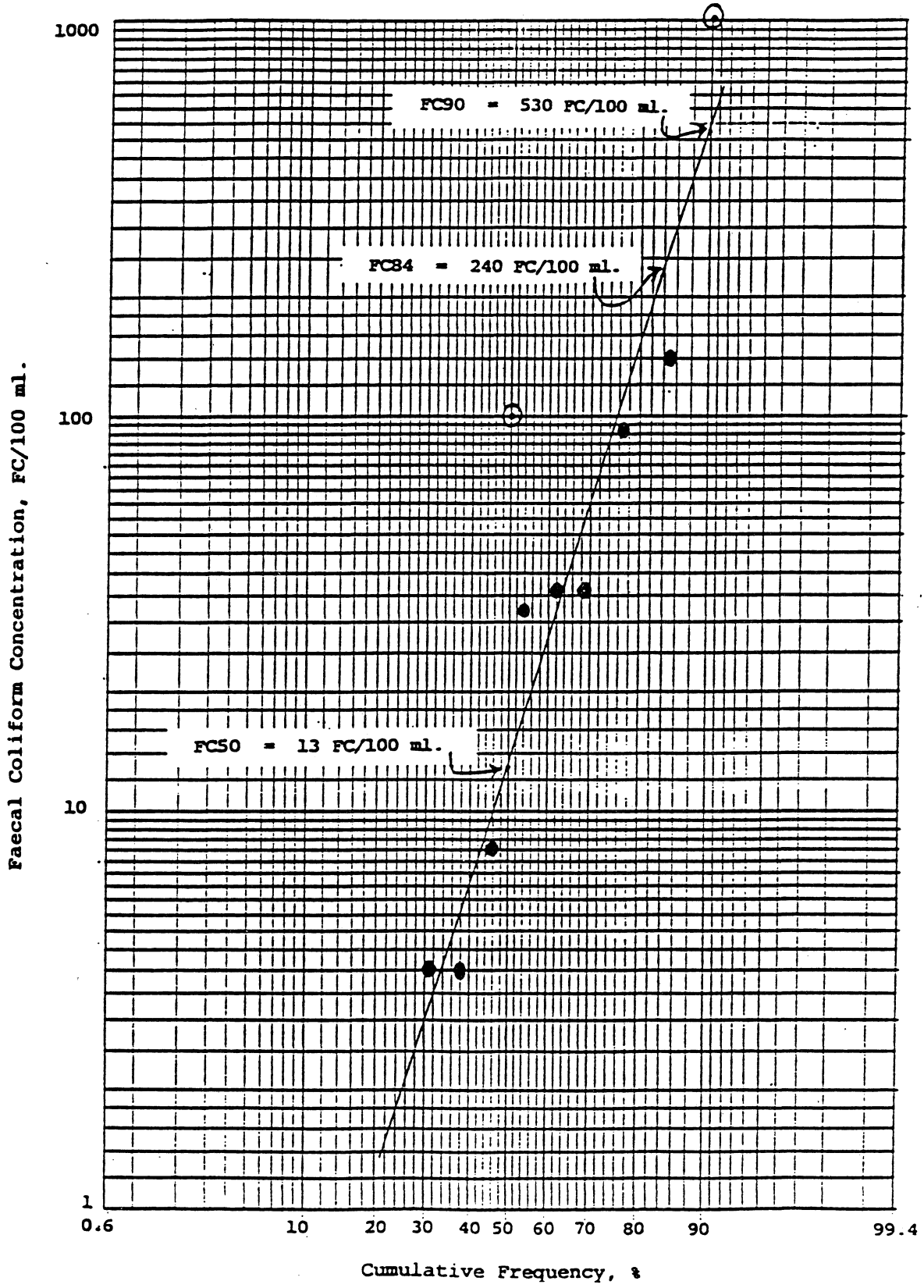

Figure 2.1 Interpretation of the microbiological quality of a coastal water in the Mediterranean, by the lognormal probability model, and evaluation according to the WHO/UNEP interim criteria (o).

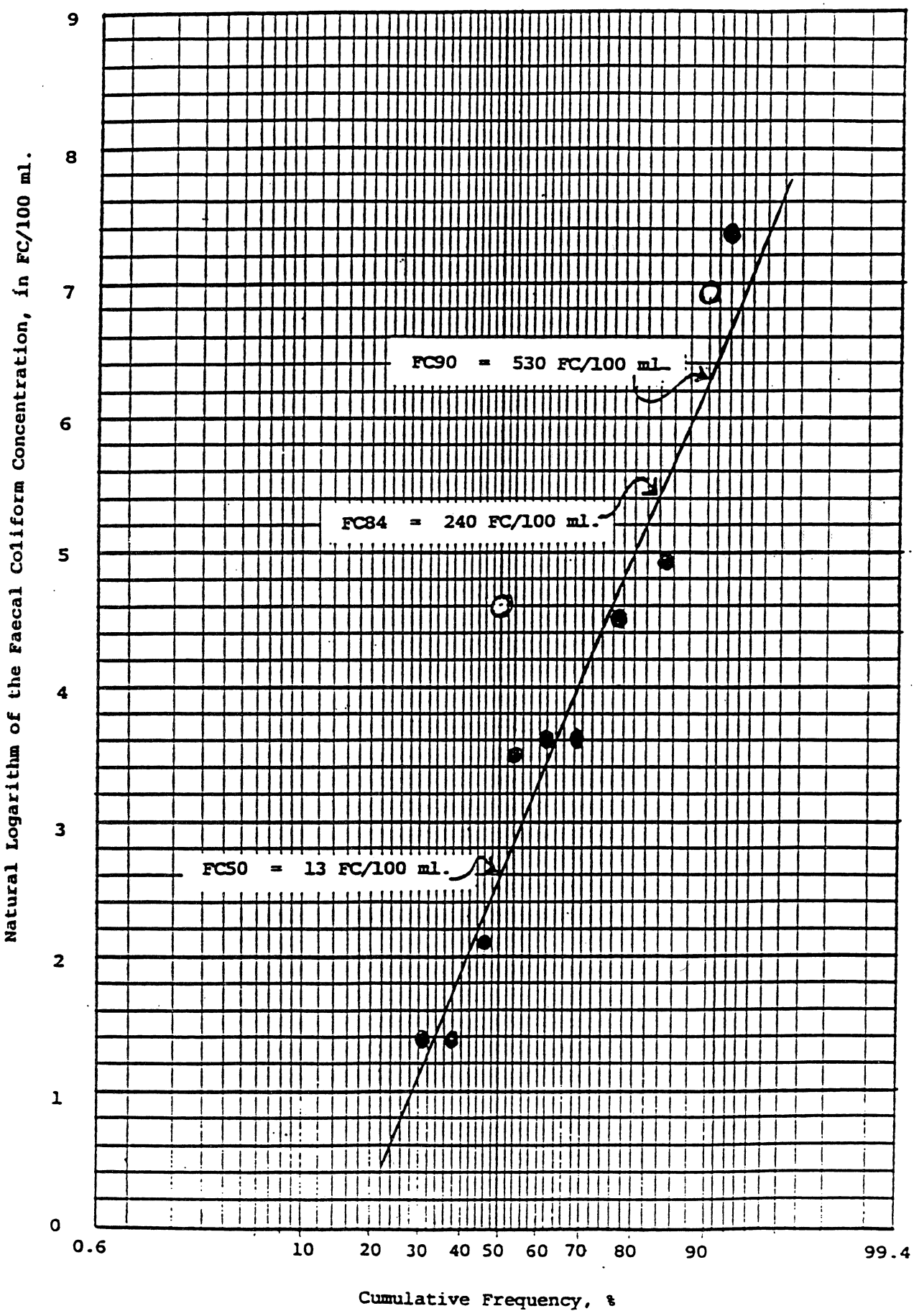

Figure 2.2 Interpretation of the microbiological quality of a coastal water in the Mediterranean by the normal probability model, and evaluation according to the WHO/UNEP interim criteria (o).

A visual examination of Figures 2.1 and 2.2 indicate a good agreement between the data points and the probability model proposed. From the probability distribution obtained in both Figures, the faecal coliform concentrations not exceeded in 50% and 90% of the samples have been estimated and appear in Table 2.2. Furthermore, the faecal coliform concentration not exceeded in 84% of the samples has been estimated for use in subsequent calculations.

Obviously, the value of the statistical parameters derived from both probability plots have to be the same, within the limits of error incurred during the graphical procedure for interpolating and estimating microbial concentrations.

The standard deviation of the probability distribution has been obtained using the expression:

$$s = 1n\ XX84 - 1n\ XX50 = 1n\ 240 - 1n\ 13 = 5.48 - 2.56 = 2.92$$

The 95% confidence interval of the set of faecal coliform concentrations is defined by the concentrations associated with the 2.5% and 97.5% cumulative frequencies, which are:

(1 CF/100 ml, 3700 CF/100 ml)

This confidence interval means that if a considerable number of similar series of concentrations had been collected, 95% of the concentrations of faecal coliforms observed would be in the interval between 1 and 3700 FC.100 ml. This interval is thus a measure of the most likely values of the concentrations expected to occur at the sampling station studied.

The 95% confidence interval of the median faecal coliform concentration can be calculated by the expression appearing in section 6.10. In this case, considering that:

$$\begin{aligned} 1n\ FC\ C0 &= 1n\ 13 = 2.56 \\ s &= 2.92 \\ n &= 12 \\ t_{0.975.11} &= 2.201 \end{aligned}$$

The 95% confidence interval of the median concentration is defined by

(2 FC/100 ml; 83 FC/100 ml)

This confidence interval means that if a considerable number of similar series of concentrations had been collected, and its corresponding median value derived for each of them, 95% of these values would be in the interval from 2 to 83 FC/100 ml. This confidence interval is thus a measure of the most likely values of the median concentration expected to occur at the sampling station studied.

Table 2.2 summarizes a report on an evaluation of the microbiological quality of the Mediterranean coastal water considered, using the lognormal probability method and taking the WHO/UNEP interim quality criteria as a reference.

Table 2.2 Evaluation of the microbiological quality of water at a sampling station on the Mediterranean coast according to the WHO/UNEP interim criteria, using the lognormal probability method.

Item	Value
Station code	
Microbial indicator	Faecal coliform
Analytical method	Membrane Filtration
Period covered	June - September 1982
Number of samples	12
Number of zeros	1
Model agreement	Satisfactory
WHO/UNEP interim quality criteria	FC50 = 100 FC/100 ml FC90 = 1000 FC/100 ml
Experimental concentration	FC50 = 13 FC/100 ml FC90 = 530 FC/100 ml
Standard deviation	s = 2.92
95% confidence interval of sample	(1 FC/100 ml, 3700 FC/100 ml)
95% confidence interval of median concentration	(2 FC/100 ml, 83 FC/100 ml)
Quality evaluation	Below FC50 limit Below FC90 limit
Overall quality evaluation	Satisfactory

As can be seen in Figure 2.1, the combined influence of all the microbial concentrations observed results in an estimate for the concentration not exceeded in 90% of the samples of FC90 = 530 FC/100 ml, which is much higher than that shown in Table 1.3.

The agreement between the experimental data and the proposed method is satisfactory and reveals a temporal variation of the microbiological quality of the water that is slightly higher than that defined by the WHO/UNEP interim criteria.

Any general deterioration of the microbiological quality at the sampling station studied would move the probability distribution upwards and presumably parallel to itself, causing the upper limit of the criteria to be exceeded. The water quality at the sampling station would therefore be classified as non-satisfactory according to the WHO/UNEP interim criteria.

APPENDIX 3

RECAPITULATION OF THE MOST FREQUENTLY USED VALUES OF STUDENT'S t DISTRIBUTION *
WHO/UNEP, 1977a

Degrees of freedom n	Prob ($t_n < t_{1-\alpha, n}$) = 1 - α	
	0.950	0.975
1	6.314	12.71
2	2.920	4.303
3	2.353	3.182
4	2.132	2.776
5	2.015	2.571
6	1.943	2.447
7	1.895	2.365
8	1.860	2.306
9	1.833	2.262
10	1.812	2.228
11	1.796	2.201
12	1.782	2.179
13	1.771	2.160
14	1.761	2.145
15	1.753	2.131
16	1.746	2.120
17	1.740	2.110
18	1.734	2.101
19	1.729	2.093
20	1.725	2.086
30	1.697	2.042
40	1.684	2.021
50	1.676	2.009
100	1.660	1.984

* Source: Guidelines for health related monitoring of coastal water quality. Report of a Group of Experts jointly convened by WHO and UNEP (Rovinj, 1977). WHO Regional Office for Europe, Copenhagen, 1977a (Table 18).

12. REFERENCES

Benjamin, J.R. & Cornell, C.A. Probability, statistics and decisions for civil engineers. New York, N.Y., McGraw Hill, 1970.

Hahn, G.J. & Shapiro, S.S. Statistical models in engineering. New York, N.Y., John Wiley & Sons, 1967.

IAWPRC, Progress in water technology. Oxford, Pergamon Press, 1980, Vol. 12.

ICSEM/UNEP, Pollution of the Mediterranean: report on a workshop (Cagliary, 1980). ICSEM, Monaco, 1981.

WHO/UNEP Guidelines for health-related monitoring of coastal water quality: report on a group of experts jointly convened by WHO and UNEP (Rovinj, 1977). Copenhagen, WHO Regional Office for Europe, 1977a.

WHO/UNEP Health criteria and epidemiological studies related to coastal water pollution: report on a group of experts jointly convened by WHO and UNEP (Athens, 1977). Copenhagen, WHO, Regional Office for Europe, 1977b.

WHO/UNEP Coastal monitoring of recreational and shellfish areas (MED VII): report on a meeting of principal investigators jointly convened by WHO and UNEP (Rome, 1979). Copenhagen, WHO Regional Office for Europe, 1979.

WHO/UNEP Coastal water quality control in the Mediterranean: final report on the joint WHO/UNEP coordinated pilot project (MED VII) 1976-1980. Copenhagen, WHO Regional Office for Europe, 1981.

Issued by

Oceans and Coastal Areas Programme Activity Centre
United Nations Environment Programme

Additional copies of this publication
can be obtained from:

Oceans and Coastal Areas Programme Activity Centre
United Nations Environment Programme
P.O. Box 30552
Nairobi
KENYA

or from:

Marine Environmental Studies Laboratory
International Atomic Energy Agency
Marine Environment Laboratory
B.P. No. 800 - MC 98012
MONACO CEDEX