**Monitoring Bathing Waters - A Practical Guide to the Design and Implementation of Assessments and Monitoring Programmes**
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# Chapter 2*: DESIGN OF MONITORING PROGRAMMES

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Traditionally the primary reason for the assessment of the quality of an environment has been to verify suitability for intended uses. Monitoring has also evolved to determine trends in the quality of the environment and to determine how quality is affected by anthropogenic activities, including for example waste treatment operations (the latter is known as impact monitoring). Monitoring the background quality of recreational water environments is also now widely carried out to provide a means of assessing impacts and to check whether unexpected change is occurring. In regulatory monitoring programmes, factors such as sampling frequency, analytical methods, data analysis, interpretation and reporting, sample site selection and criteria for recreational water-use areas are generally defined by the regulatory agency.

General definitions for various types of environmental observation programmes have been proposed (e.g. Chapman, 1996) which may also be modified and interpreted in relation to recreational water use, as follows:

- *Monitoring.* Long-term, standardised measurement and observation of the environment in order to define status and trends.

- *Survey.* A finite duration, intensive programme to measure and observe the quality of the environment for a specific purpose.

- *Surveillance.* Continuous, specific measurement and observation for the purpose of management and operational activities.

Each of the above activities are often not clearly distinguished one from another and all may be referred to as “monitoring”, because they all involve collection of information at set locations and intervals. They do, nevertheless, differ in relation to their principal use in the recreational water quality assessment process.

## 2.1 Aims and objectives of monitoring

No assessment programme should be started without identifying the specific need(s) for information. Thus water quality assessment should take into account hydrological factors, water uses, economic development, policy and legislation, etc. The decisions that will result from the assessment programme determine whether emphasis should be put on concentrations or loads and on spatial or temporal distribution, as well as determining the most appropriate monitoring media. There are generally several competing beneficial uses of the recreational water-use area, and the monitoring activities should reflect the data needs of the various users involved.

The objectives of the assessments may focus activities on the spatial distribution of quality (a large number of sample stations), on trends (high sampling frequency), or on pollutants (in-depth inventories) (Box 2.1). Full coverage of all three requirements is virtually impossible and costly. Preliminary surveys are generally necessary in order to determine the appropriate focus of activities. Table 2.1 summarises the principal types of water quality operations in relation to their main objectives.

**Box 2.1 Setting objectives for microbiological monitoring of bathing areas**

The objectives of microbiological monitoring programmes can be diverse. However, microbiological monitoring of bathing areas is, in most cases, undertaken to comply with regulations and/or to establish the degree of microbiological pollution in order to protect public health and the environment. Those macro-objectives only answer the question: *Why?* More specific objectives need to be defined which will also tackle the question of *Where?* (location of bathing area, sampling points and frequency). Some aspects are fixed by the regulations. Others, such as the location of sampling points, are only generally defined and require preliminary screening. Such screening will establish the spatial and temporal variations of microbiological water quality to select the optimal sampling points and frequency to obtain data representative of those fluctuations. Questions of *What?* (variables or indicators to be determined) and *How?* (methodology of inspections and analysis) are sometimes only partially defined by the regulations. These variables must be those that are more representative of sewage pollution as a measure of health risk. Specific comparative studies of standardised indicators and procedures are advisable at each specific geographical area.

Public information and participation may be another objective included in the regulations. Microbiological results given to the public should include visual inspections for aesthetic factors that bathers will be confronted with and should be expressed in a clearly understandable ranking system.

Other specific objectives will assess the impact on the microbiological quality of river outlets at the sea bathing area and any discharges at inland reservoirs as well as the effects of rain. Spatial and temporal variations identified before will have to be taken into account and their impact assessed over a representative period so that remedial and/or preventative measures (such as indications of risk) can be encouraged.

Source: Based on the approach used by the Unit of Microbiology, Faculty of Medicine, University Rovira i Virgili, Spain

**Table 2.1** Types and objectives of principal water quality assessment operations

| Type of assessment | Major focus of water quality assessment |
|---|---|
| Multipurpose monitoring | Space and time distribution of water quality in general |
| Trend monitoring | Long-term evolution of pollution (concentrations and loads) |
| Basic survey | Identification and location of major problems and their spatial distribution |
| Operational surveillance | Water quality and related water quality descriptors (variables) for specific uses |
| Background monitoring | Background levels for studying natural processes; often used as reference point for pollution and impact assessments |
| Preliminary surveys | Inventory of pollutants and their space and time variability; usually prior to designing and establishing a routine monitoring programme |
| Emergency surveys | Rapid inventory and analysis of pollutants for rapid situation assessment following a catastrophic event |
| Impact surveys | Sampling limited in time and space, generally focusing on a few variables near pollution sources |
| Modelling surveys | Intensive water quality assessment limited in time, space and choice of variables to support, for example, eutrophication models or oxygen balance models |
| Early warning surveillance | At critical water use locations (continuous and sensitive measurements) |

Source: Bartram and Ballance, 1996

It cannot be overemphasized that the benefits of careful preliminary planning and investigation far outweigh the efforts spent during this initial phase. Mistakes and oversights during this part of the programme may lead to costly deficiencies, or overspending, during many years of routine monitoring.

## 2.2 Elements of recreational water quality assessment

Once objectives have been set, the scope of the monitoring programme should be defined. This includes definition of criteria for inclusion or exclusion of recreational water-use areas and the preparation of an inventory of areas included or excluded as recreational water-use areas. A review of existing data and the compilation of a catalogue of the basic characteristics of the area, supported by preliminary surveys, determines the monitoring design. The completed review and catalogue should be followed by recommendations to relevant authorities for management, pollution control and, eventually, the adjustment or modification of monitoring activities (Box 2.2).

**Box 2.2 Beach monitoring programme Lima, Peru**

The city of Lima, capital of Peru, is located on the coast of the Pacific Ocean and has a current population of about 8 million (1998). In spite of its tropical latitude of about 12° south, the marine waters of the area are relatively cold due to the Humboldt Current emanating from the polar ice cap waters of the South. During the summer months (December to March), the beaches within and near Lima are used extensively by the local population for recreational activities such as swimming.

Lima generates about 16.5 $m^3 s^{-1}$ of wastewater, the major part of which is discharged untreated directly or via the Rimac River to the coastal marine waters. There are no existing submarine outfalls although plans call for the construction of long sea outfalls with treatment during the next decade. Due to the arid climate of the region, the reuse of sewage for crop irrigation is practised to some extent and will increase in the future.

The water quality standards of Peru classify marine waters as safe for primary contact recreation when 80 per cent of five samples taken over one month period show less than 1,000 MPN per 100 ml of faecal coliforms and 5,000 MPN per 100 ml for total coliforms. This standard drives the frequency of measurement of the monitoring programmes described below.

Because of its proximity to populated areas as well as its accessibility by public transportation, Miraflores Bay is a very popular beach area referred to as the “Costa Verde”. A major trunk sewer discharges about 6-7 $m^3 s^{-1}$ of raw sewage directly to Chira Beach (not used by the public) approximately 4 km east (upstream) of the closest popular beach of Costa Verde. Predominate currents in this area are parallel to the coast from east to west.

For years the media attributed the contamination of the “Costa Verde” area to the Chira outfall. In 1986, the Environmental Health Division of the Ministry of Health initiated a beach vigilance monitoring programme with 21 stations sampled on a weekly basis during the summer in the Costa Verde area. The data clearly demonstrated that there was gross pollution in the vicinity of the Chira discharge and that this contamination was beginning to encroach on the popular beach areas of Costa Verde. However, the pockets of contamination observed on some of the most popular beaches of Costa Verde could only be attributed to local direct discharges from sanitary sewer overflows, restaurants and other installations. Bather density could also have been a contributing factor.

The monitoring programme was expanded to 24 stations in Costa Verde that were sampled weekly during the summer bathing season and monthly during the winter from 1987 to 1989. These data confirmed that local discharges rather than the Chira outfall caused the contamination at some popular beaches in Costa Verde. Management action was taken in 1991 with the construction of a small trunk sewer and six pumping stations in Costa Verde to transfer sewage to the main sewer system with subsequent discharge via the Chira outfall.

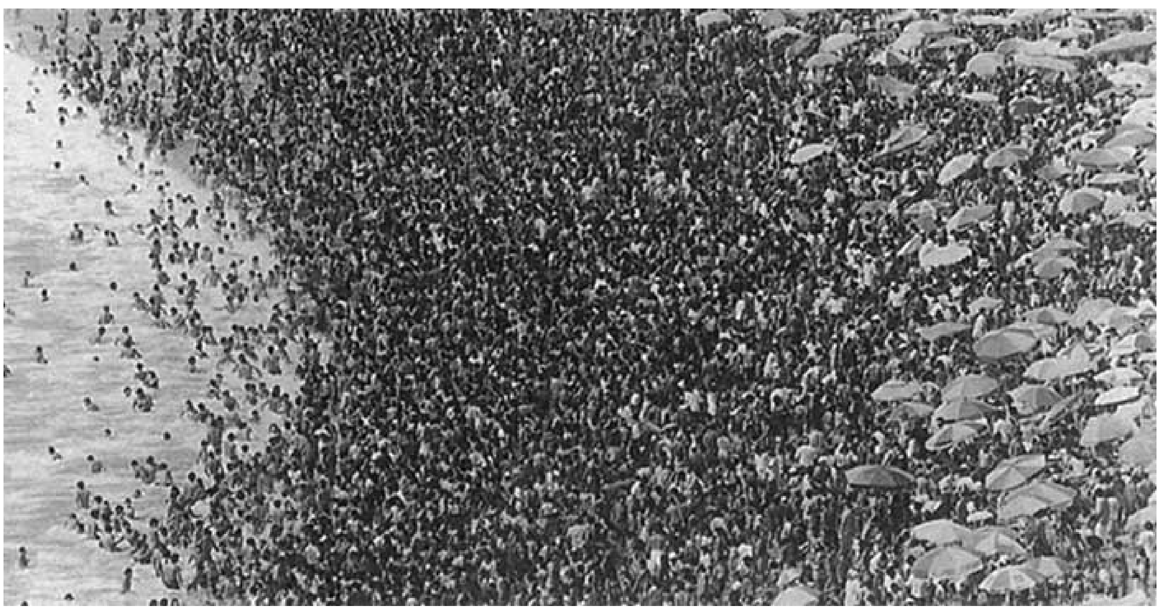
Budget cuts reduced the monitoring programme to as little as 10 stations in 1991 at the most contaminated beaches. In 1992 and 1993 weekly monitoring was resumed at the 24 Costa Verde stations during the summer. These data clearly demonstrated the water quality improvements at some beaches due to management action taken in 1991. The monitoring programme was even able to pick up the impact on beach water quality when the Costa Verde trunk sewer pumping stations were not operating during the energy blackouts caused by the drought of 1992.

In 1994 the monitoring programme was expanded to beaches to the north and south of Costa Verde which are also used by the Lima population. A total of 61 stations were sampled weekly in the summer and monthly in the winter.

The monitoring programme was expanded to national coverage in 1997. The programme presently takes samples at 148 stations: 77 stations at the beaches used by the Greater Lima Metropolitan Area population (these are sampled weekly in the summer and fortnightly in the winter) and 71 stations from Tumbes in the north to Tacna in the south (sampled weekly in the summer and monthly in the winter). In 1996, enterococci, *Escherichia coli* and *Vibrio cholerae* were added to the total and faecal coliform measurements at 46 stations. The programme conducts approximately 13,560 microbiological measurements per year.

The Lima monitoring programme was the key to ascertaining the real sources of the contamination of the popular Costa Verde beaches and instrumental in convincing the authorities, which in turn led to the implementation of sound management actions. The greater investment that would have been required to dispose of the sewage discharged properly via the Chira outfall would not have changed the situation at the popular Costa Verde beaches that were contaminated by small local sources. Nevertheless, if the monitoring approach described in this guidebook had been applied, action might have been taken sooner based on the information provided by the initial sanitary inspection. Furthermore, the sanitary inspection would have served to modify the monitoring programme to focus on those beaches where potential sources of pollution were identified, thus making the monitoring programme source-and use-driven as opposed to only use-driven.

**Bathers on the beach at Costa Verde, Peru. Photograph courtesy of “El Comercio”**



There are certain elements that are common to all water quality monitoring and assessment programmes. They are more, or less, extensively developed depending on the type of assessment required. These elements are:

- *Preliminary surveys.* Short-term, limited activities to determine the type of monitoring media and pollutants to be considered, and the technical and financial feasibility of a complete monitoring programme.

- *Monitoring design.* The selection of variables, station location, sampling frequency, sampling apparatus, etc. (Chapters 3, 8 and 12).

- *Field monitoring.* This includes *in situ* measurements, sampling of appropriate media, sample pre-treatment and conservation, identification, storage and shipment (Chapter 8).

- *Hydrological monitoring.* Measurements of water discharge, currents, tides, water levels, thermal profiles, etc. Hydrological data should always be related to the water quality assessment activities.

- *Laboratory activities.* These include concentration measurements, biological determinations, etc.

- *Data quality control.* This consists of analytical quality assurance within each laboratory and amongst all laboratories participating in the same programme (Chapter 4).

- *Data storage and treatment.* This is now widely computerised and involves the use of databases, for data storage reporting statistical analysis, trend determinations, multifactorial correlation, etc. together with presentation and dissemination of results in appropriate forms (graphs, tabulated data, data diskettes, etc.) (Chapters 3 and 8).

- *Data interpretation.* This involves the comparison of water quality data from different stations. For specific problems, and the evaluation of the environmental significance of observed changes, external expertise may be needed. Publication and dissemination of data and reports to relevant authorities, the public, and the scientific community is the necessary final stage of assessment activities (Chapter 6).

- *Water management.* Decisions will be taken at various levels involving local, national and international bodies, and by water authorities as well as by other environmental authorities. Important decisions concern the redesign of assessment operations in order to improve the monitoring programme and to make it more cost-effective (Chapter 5).

In recreational water quality investigations, the purpose of sampling is to obtain samples that are as representative as possible with respect to the microbiological, physicochemical and aesthetic properties of the area (Chapters 8, 9, 11 and 12). Sampling should be conducted during the bathing season, but is most appropriate when recreational waters are suspected of being contaminated or a source of waterborne disease. Historical data, combined with an annual environmental health assessment, may indicate that only occasional sampling is necessary. If deterioration in quality has occurred then monitoring of the area should be undertaken. Such an approach will allow health officials to concentrate their resources on beaches of questionable quality.

## 2.3 Data collection

### 2.3.1 Beach registration

In order to improve the quality of recreational water-use areas and to select beaches that can be developed as tourist areas, planners and managers may wish to keep a continuous record of selected information. The information necessary for selecting those parts of the coastline that will be used as bathing beaches now or in the near or distant future can be stored in a beach registration system. The aim of such a system is to establish a catalogue of all beaches, to use a checklist to collect the information needed to plan a monitoring programme and to decide if and how the beach will be developed in the future.

The checklist for the registration of beaches may be amended as required; for example, to assess the hazards present for swimmers in a particular area in order to develop the beach for tourism, and to prepare a beach management plan for the planning and co-ordination of all the resources related to providing a safe aquatic environment for the public. This approach could be especially useful when resources are not abundant and have to be employed as efficiently as possible (Chapter 3).

Beach registration is typically divided into four components:

- *Description of the surroundings.* The registration should include information on accessibility (roads, tracks, public transport, no access), hazard mitigating measures (information signs and information sources, lifeguards, showers, first aid posts, swimming and diving safety warnings) and facilities (restaurants, hotels, bars, toilets, drinking water, litter bins, car parks and camping grounds).

- *Description of the beach.* This should include an estimation of the area of the beach (length, width), beach material and visitors per day (estimate the peak numbers according to season, whole bathing season, main holiday period, public holidays and weekends). The number of visitors per day should be compared with the visitor capacity of the area.

- *Description of the water environment.* This includes details of the bathing zone (direction and speed of the current, slope, bottom material) and its use (fishing, jetskiing, intensive yachting, swimming, diving, etc.).

- *Counter indications.* Designated sensitive areas (resting place for water fowl, breeding place for rare birds, sanctuary, conservation area and other kinds of protected area such as military sites or other areas where public access is prohibited).

The information listed above should be collected by means of a desk survey of the existing information and during a subsequent field inspection on the beach. The baseline information should be revised annually. Ideally a map should accompany each registration and should show the extension of the beach, the accessibility, the surroundings, etc. The information may then be transferred to a computer system and amended as necessary.

In gathering data for inclusion in a beach registration system it is important to involve the local community. Often local people, local politicians, shopkeepers and, in particular, those charged with the operation of the beach (the local authority, beach operator, lifeguard) will have valuable information. Relevant non-governmental organisations (NGOs) such as nature conservation groups, angling clubs and yacht clubs, water skiing clubs and lifesaving associations, may provide useful information (Chapter 6).

The development of a registration system in the form of a database could aid coastal managers in their decision-making process through highlighting the suitability of beaches for particular uses. For example, it may become apparent that some beaches should not be promoted for recreational use because the area is ecologically sensitive or because bathing might be dangerous due to currents, bottom conditions or particular health hazards.

### 2.3.2 Environmental health assessment

In the past, sanitary inspections or surveys were directed primarily towards microbiological contamination of recreational waters but in recent times they have been broadened to include chemical contamination and other biological and physical hazards. The term environmental health assessment is now used to reflect this broadened scope. An environmental health assessment can be defined as a comprehensive search and evaluation of existing and potential microbiological and chemical pollution and biological and physical hazards that could affect the overall safety of a particular stretch of recreational water or bathing beach. Potential influences on water quality (such as river mouths, sewage outlets, harbour areas, other wastewater outlets) and physical hazards (rocks, open and rough water, rip-tides, shallow water, etc.) should also be considered. A comprehensive environmental health assessment consists of pre-inspection preparations, an on-site visit and the preparation of an assessment report. The environmental health assessment typically relies upon on-site inspection of hazards and mitigating factors for physical and microbiological hazards (Chapters 7 and 8), and on water quality testing, especially for microbiological quality (Chapter 8). When undertaking an assessment the sampling techniques employed are particularly important. Some guidance for obtaining statistically valid measurements is given below. Full details of methods and quality assurance procedures to be followed in sampling programmes are provided in Chapters 3, 4 and 8.

### 2.3.3 Quality monitoring

During routine visits, the site should be surveyed for signs of microbiological and chemical contamination. For example, visible sewage plumes, oil slicks, suspicious odours and fish or bird kills should be considered as immediate indications of unacceptable water quality. Beach monitoring for litter, tar balls, etc. should also be undertaken. The task of deciding the optimum number of samples to take and the most suitable locations in order to characterise quality in a meaningful way, and with the most economic use of resources, can be quite daunting. Statistically-based methods of sampling design can help this task and can also ensure that the data collected are appropriate for later statistical analysis and interpretation (Chapters 3 and 8). Basic sampling design naturally falls into seven aspects:

- Reasons to sample.
- What to sample.
- How to sample.
- When to sample.
- Where to sample.
- How many samples to take.
- Sampling evaluation.

The issues of what, when and how to sample are defined by the assessment programme objectives.

The results of any quality monitoring programme depend on where the pollution comes from, and therefore on where the samples have been taken. The physical factors characterising sampling stations may vary widely between stations, resulting in large differences in analytical values; for example, in bathing water monitoring stations water depth, current speed and direction, existence of haloclines and/or thermoclines, mixing processes, sampling depth and distance to sewage outlets and other pollution sources may all affect water quality. In reservoirs and lakes the phenomenon of thermal stratification is a source of complexity in sampling design because of its potential affect on vertical water quality differences. The most usual basis for design in such circumstances is stratified random sampling.

Sampling sites should be selected on the basis of information gathered during the beach registration and the first on-site inspection. Ideally, the sites chosen should be representative of the water quality or beach area throughout the whole area where users are exposed. The selection of sites should pay particular attention to site-specific conditions that may influence the concentrations and distribution of indicator organisms and pathogens.

Monitoring and surveillance programmes generally rely on observations made on discrete samples obtained within spatial and temporal constraints. An essential component of a monitoring programme is ensuring that the sample obtained is representative of the phenomenon under study. Errors introduced during sample collection and preparation are usually several orders of magnitude higher than errors due to analytical determinations.

The main aspects to be considered for obtaining a representative sample are: the adequate selection of the sampling points, sampling stations, frequency and timing of sampling; the strict adherence to proper sampling and quality assurance procedures; the complete identification of the sample; the adequate preservation of the sample; and the prompt transport of the sample to the laboratory.

The exact location of sampling points in any monitoring programme, including the distance between them, varies with each individual beach. Chapter 9 provides a sampling protocol including sampling and analysis criteria to be followed for microbiological water quality. This should be used in conjunction with the guidance provided in Chapter 3 to adapt the monitoring programme to the resources available. An environmental health assessment in the recreational area provides a good basis for establishing the location and number of sampling stations. The results of an intensive sampling programme, together with a detailed survey of water currents and water discharges, will identify any particular pattern of water quality deterioration that has to be considered when selecting sampling stations representative of the whole recreational area (Chapter 9). The intensive sampling programme should include the analysis of water samples taken at different water depths, at different hours of the day, during different tidal phases, and during any other known source of possible variation. The experience gained during the implementation of the monitoring programme should serve to modify and improve the initial sampling programme. Advanced statistical analysis may be used to identify spatial and temporal patterns amongst sampling results drawn from special surveys. These patterns may then be used as the basis for more general sampling site allocation. This is a particularly important aspect for dealing with the variability associated with reservoirs.

Details of relatively simple types of water sampling equipment are contained in Bartram and Ballance (1996) (see also Chapter 8). For surface and subsurface sampling, the containers used should be bottles of dark-coloured borosilicate glass of 200 to 300 ml capacity, with wide-mouths and ground glass stoppers. The same type of bottle may be used for subsurface sampling with the addition of an extension arm and clamp. Specific sampling procedures are contained in the recommended methods for determination of specific indicator organisms and pathogenic bacteria described in Chapters 8 and 9. For sediments, several types of bottom samplers are available commercially that can be used for collection of samples of sediments for microbiological analysis. The equipment required to monitor aesthetic aspects of recreational water-use areas is generally less than for water quality monitoring and varies depending on the method used (Chapter 12).

Sampling should be performed in a systematic manner to reduce variation between individual results. For this reason, it is necessary to keep constant as many factors as possible. These include the period of sampling (i.e. time of day) and the sampling method, as well as the location and depth (in the case of water sampling) of individual sampling points. Sampling can be considered as completed once the sample is transferred to the sterile container, whether on the beach or aboard a sampling vessel.

When sample transit does not allow the use of a central laboratory, other alternatives must be considered. These may include analysis of samples in an approved laboratory nearby, use of an approved laboratory field kit or use of a mobile laboratory. Such alternatives should undergo thorough testing and comparison before they are adopted.

## 2.4 Elements of good practice

• The objective(s) of a monitoring programme or study should be identified formally before designing the programme and they should be stated prior to data gathering.

• Objectives should be described in a manner that can be related to the scientific validity of the results obtained. The required quality of any data should be derived from the statement of objectives and should be stated at the outset.

• In designing and implementing monitoring programmes, all interested parties (legislators, NGOs, local communities, laboratories, etc.) should be consulted. Every attempt should be made to address all relevant disciplines and to involve relevant expertise.

- The scope of any monitoring programme or study should be defined. This would normally take the form of definition of criteria for inclusion and exclusion of recreational water-use areas and preparation of an inventory of recreational water-use areas.

- A catalogue of basic characteristics of all recreational water-use areas should be prepared and updated periodically (generally annually) (and also in response to specific incidents) in a standardised format. It should include as a minimum the extent and nature of recreational activities that take place at the recreational water-use area and the types of hazards to human health that may be present or encountered. Unless specifically excluded, the list of potential hazards to human health would normally include the microbiological quality of water, cyanobacteria or harmful algae, drowning and physical hazards. Monitoring programmes frequently also address aesthetic aspects and amenity parameters because of their importance to health and well being.

- Programme or study design should take account of information derived from the inventory of recreational water-use areas and catalogue of basic characteristics which, in turn, may require refinement of programme objectives.

## 2.5 References

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