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Hydrology Project

Technical Assistance

Surface Water Quality Network Design
Guidelines and an Example

June 1997

DHV Consultants BV & DELFT HYDRAULICS
in association with
HALCROW - TAHAL - CES - ORG - JPS

Technical Assistance for
HYDROLOGY PROJECT

Dear Colleague,

You may be aware that guidelines on the design of water quality monitoring networks were presented during the technical meeting on “Review of Standards for Collection, Storage and Processing of Surface Water Data”, at Chennai, April 30-May 2, 1997. At that time we also presented a worked out example for Mahanadi basin, showing the application of these guidelines. On the request of participants this example material is compiled in the present report for distribution.

For your convenience we also included the guidelines as an annex in the present report. We suggest that you review these guidelines before going through the example.

Kindly use the guidelines to design your newly network(s) or review the existing ones. In the near future we plan to vistit your agency for a discussion on the design of water quality monitoring networks in your state. Prior to this meeting we request you to prepare maps, for each river basin under your responsibility, similar to those given in the example. This will help to streamline the discussion.

In case you have any difficulty or want some additional information do not hesitate to contact us directly on through your State Management Consultant.

We look forward to your participation and a fruitful interaction.

With regards,

Yours sincerely,

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Consultants/Water Quality

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Guidelines for Water Quality Monitoring Network Design: an example application for Mahanadi basin

Guidelines for Surface Water Quality Monitoring Network Design are included in the “Manual of Hydrological Field Measurement and Data Processing Practices”. Application of these guidelines to the design and evaluation of an existing network in Mahanadi basin was presented at the “Technical Meeting on Review of Standards for Collection, Storage and Processing of Surface Water Data”, Chennai, April 30-May 2, 1997. The present report is a compilation of this material. It is suggested that the reader should review the guidelines given as an annex to this example before going through the example.

The design of a new network and evaluation of any existing network(s) in comparison to the designed network, may be carried out as described in the following steps. Steps 1 to 6 concern the design and 7 to 10 deal with evaluation of existing water quality monitoring networks.

Step 1: construction of a base map

A good start for the design of a water quality monitoring network is to obtain a map of the right scale. The map should cover the whole river basin and its size should be manageable. In this example an A4 size (21x29.7cm) is used. In an office a larger map should be used. The scale of the maps presented here is approximately 1:2,500,000, however, a 10 time larger scale (1:250,000) should be used. It can easily be obtained from Survey of India publications. For a more detailed planning of the actual locations of sampling sites a map of 1:50,000 scale is recommended. A base map can be constructed from existing maps with the help of ‘transparent’ drawing paper.

Draw the following items on this map:

- river basin boundaries
- sea or ocean boundaries
- state boundaries
- national boundaries
- rivers, dams and lakes

Note that existing stations, for discharge or water quality measurements, are not plotted on this map at this stage. Once the base map is ready make several copies, these will be helpful when preparing other layers (overlays) as described in the next steps. Figure 1 shows the base map of Mahanadi basin.

Step 2: classification of the main stem and major tributaries

The guidelines require identification of major tributaries that contribute more than 20% of the flow in the main stem at the point of confluence. For this hydrological data should be used. Since this classification is somewhat arbitrary high accuracy is not required. Flows occurring in the post monsoon season (two to three month after the end of the monsoon) may be taken for such analysis.
In this example the monthly averaged October flow values for 1994, taken from CWC yearbook, are given in Figure 2.

Missing flows, as is the case for Tandula, Pairi, Kharun, Arpa, Suktel may be filled in by hydrologists who are familiar with the area, or obtained from other sources.

In the example the following tributaries are classified as minor: Kharun, Pairi, Hamp, Arpa, Jonk and Suktel.

Step 3: construction of overlays with pollution sources

All known major sources of surface water pollution should be drawn on one or more overlays. In the present example one overlay with the locations of major towns and industrial centers shown in Figure 3 was prepared. These represent direct sources of pollution (discharging directly or via small creeks and rivers to the main river).

Non-point pollution sources such as agriculture (fertilizers, pesticides) cause indirect or diffuse pollution and can be taken into account by creating separate overlays for land use indicated by shaded areas.
An additional overlay with geological information such as rock types, exchange of ground water by the stream, etc., may also be created.

Overlays can be created on one of the clean copies of the base map as created in step 1 or transparencies. The latter is preferred since it is more flexible and allows combinations of more layers in a convenient way.

Step 4: positioning of baseline stations

The first stations to be located in the network to be designed are the so called baseline stations (see annex section 2.1).
Each major tributary should have a baseline station to get a good overall picture of the (natural) background concentration of various constituents of water in rivers in the basin. Major tributaries were identified in step 2. Baseline stations should be positioned in relatively unpolluted areas such as upstream of major towns and industrial centers. Use the overlay created in step 3 to find the best position for the baseline stations. Figure 4 shows the baseline stations for Mahanadi.

Note that areas upstream of visible sources of pollution may be polluted to some extend (villages, agriculture). If such pollution is expected, moving the baseline station farther upstream should be considered. However, if no unpolluted reach exists, the baseline stations will serve as reference stations and will still be needed in the review of the effect of major anthropogenic sources on downstream water quality.

Step 5: positioning of trend stations

Trend monitoring stations show how water quality varies over time. The procedure of positioning trend stations is described in annex section 2.1. Briefly, trend stations are located on the main stem when the river flow increases by 20% of the flow at the previous station. In the case of confluence with a major tributary, trend stations are located both on the tributary and on the main stem of the river, just above the confluence point.

After putting the trend stations (see Figure 5) it should be checked whether the distance between two successive trend stations on the main stem or the distance between a baseline station and the next downstream trend station is no longer than say 100 km. This distance should be more or less equal to the distance traveled by the river water in 2 days and must therefor be adjusted if local flow velocity deviates significantly from 0.58 $m.s^{-1}$. The reason for putting an additional trend station if the water is not monitored for 2 days originates from the fact that natural processes may cause significant changes in water quality in this period of time.

Note that in the example (Figure 5) trend stations on the main stem before the confluence with Hasdeo and Mand are missing. This is explained in step 7.

Step 6: positioning of flux stations

Flux stations aim at gauging the load of anthropogenic pollutants passing a sampling point. Figure 6 shows two flux stations. The first one is situated on the main stem at the state boundary between Orissa and Madhya Pradesh. This station not only serves as a ‘state boundary’ station but also monitors the load of pollutants into Hirakud reservoir. The second flux station is positioned on the main stem of Mahanadi just before the delta.

Step 7: review of the monitoring network so far

After putting the baseline, trend and flux stations one should critically review the network. It should, for example, be checked if the distance between successive trend stations on the main stem is not too short. This can happen if major tributaries join the main stem in a short reach. If trend stations occur within a distance of 2 days of river travel time from each other, leaving out an intermediate trend station can be considered. If the distance between a trend and a flux station is too short combination of the two should be considered.

Initially two trend stations were located on the main stem of Mahanadi before the confluence with Hasdeo and Mand (not shown in Figure 5). Since the distance between the trend stations at Arpa and Mand is less than 100km the trend station before the confluence with Hasdeo was considered superfluous. After positioning the flux station on the main stem before Hirakud (at the state boundary) it was decided to combine the trend station before the confluence with Mand with this flux station.

Finally, the actual locations of the stations should be decided keeping in mind approachability and convenience in collection of samples. For this a larger scale map would be required.

In case other agencies are also operating water quality monitoring networks in the same basin, their network should be compared with the proposed network to avoid duplication. In this example networks of CWC and CPCB are compared in steps 8 and 9.

Step 8: review of existing networks of CWC and state agencies

Prepare a separate overlay with the locations of water quality monitoring stations of CWC and, if existing, monitoring stations of state agencies, like for example the irrigation department. After overlaying these locations on the newly prepared network positions of stations should be looked at critically.

In the current example CWC stations were added, for your convenience, to the same map that contains the newly designed network, see Figure 7. From this map we draw the following conclusions:

- there are no CWC baseline stations except for Hasdeo;
- Seonath river is not addressed by CWC, though it is a major tributary for Mahanadi;
- the minor tributaries Hamp and Kharun were not addressed in the example design (unlike CWC);
- the trend stations are closer to confluence than the CWC stations
- the delta is unattended by CWC
- there is no flux station upstream of Hirakud dam
- the rest of the stations are overlapping to a great extent

Step 9: review of existing network of CPCB

Prepare a separate overlay with the locations of monitoring stations of Central Pollution Control Board. In our example we added the CPCB stations operated under MINARS (Monitoring Indian National Water Resources) stations, for your convenience, to the same map that contains the newly designed network, see Figure 8. From this map we draw the following conclusions:

- there are no baseline stations
- there are no CPCB (MINARS) stations located downstream of Hirakud (a relatively unpolluted area)
- only the polluted areas (towns and industrial areas) are addressed

This is in accordance with the objective of CPCB (MINARS) which is monitoring of pollution. This objective is not addressed so far in the baseline, trend and flux stations.

Step 10: review of mandates

When combining the overlays of the monitoring stations of CWC with CPCB (MINARS), as done in Figure 9, a duplication of effort can be observed at several locations. This observation should be used to start a dialogue between both organizations. Mandates and availability of data (are the data public?) should be the main topics for such a dialogue.
Likewise you should review the mandate of your organization. The network proposed so far only addresses objectives (a), (b) and (c) listed in the annex section 1.

Step 11: adding Surveillance and Survey type stations

To be done by the agencies after step 10 and only if the mandate so requires.

Step 12: sampling frequency and analysis parameters

Use the information given in annex section 2 and Tables 2.1 to 2.4 keeping in mind the objectives, feasibility of sampling, costs and above all capacity of your field staff and your laboratory(s).

Annex: Guidelines for Water Quality Monitoring Network Design

1 Surface Water Quality Monitoring Objectives

When planning any surface water quality monitoring programme, there are certain key questions which need to be answered. Amongst the most important of these questions are the following:

- what is the purpose or objective of the monitoring programme?
- what is the nature of the variability of the watercourses or effluents which will be monitored?
- what are the consequences of arriving at a wrong conclusion?
- what is the cost of sampling and the associated analytical effort?

Of the above questions, the first is the most fundamental. There is no point monitoring surface water or effluent quality unless the objectives of the programme and, hence, what will be done with the resulting data, are clearly defined prior to commencement. Definition of the programme's objectives, and providing answers to other relevant questions such as those given above, prior to planning the sampling exercises will ensure that the correct conclusions regarding sampling points, number of samples, spread of analytical parameters and sampling frequency are reached.

Normally samples of effluents and water bodies are taken with one or more of the following 'global objectives' in mind:

a) to build up an overall picture of the aquatic environment thus enabling pollution cause and effect to be judged
b) to provide long-term background data against which future changes can be assessed
c) to detect trends
d) to provide warnings of potentially deleterious changes
e) to check for compliance or for charging purposes
f) to precisely characterise an effluent or water body (possibly to enable classification to be carried out)
g) to investigate pollution
h) to collect sufficient data to perform in-depth analysis (eg, mathematical modelling) or to allow research to be carried out

In the context of the present study, these global objectives can also be considered under three separate categories of sampling, ie:

- **Monitoring** - long-term standardised measurements in order to define status or trends (ie: a, b and c above)
- **Surveillance** - continuous specific measurements for the purpose of water quality management and operational activities (ie: d and e above)
- **Survey** - a finite duration, intensive programme to measure for a specific purpose (ie: f, g and h above)

These three basic sampling categories can be further split into a number of sample types, each of which have a specific objective. These sample types and their associated objectives are described in the first two columns of Table 2.1.

As far as the present study is concerned, it is important to realise that water quality monitoring is a sub-set of the overall hydrological monitoring programme. For this reason the 'Monitoring' category identified above is the most important of the sampling categories as it will enable a complete flow and concentration (and therefore load) profile to be built up for all analytical parameters of interest in all of the catchments within the study area.

2. Surface Water Quality Network

2.1 Network Density and Sampling Frequency

For each particular sample type referred to in Table 2.1 it is necessary to determine where monitoring will be carried out and how many of these monitoring stations there should be. Together these parameters can be thought of as the 'network density' of the monitoring programme (ie, approximately the number of sampling points per unit area).

Sampling frequency, on the other hand, is how many samples are taken per unit time at each sampling point. As with network density, frequency of sampling is closely linked to the monitoring objective and other factors such as the known or suspected variability of the samples and the cost of the sampling and analytical effort.

With reference to Table 2.1 it is possible to list each sample type and discuss the network density and sampling frequency which may be appropriate as below:

Baseline (Monitoring Category)

This type of 'baseline' monitoring is designed to build up a picture of the 'natural'(ie, before the influence of pollution by man) background conditions of a particular watercourse or river basin.

To adequately cover a river catchment whilst limiting cost, it is proposed that only the major tributaries within a basin are sampled. This could be achieved by sampling on the main river stem and on any tributaries which contribute more than 20% of the volume of the main river as measured at the confluence point.

In order to ensure that the data obtained reflect the natural condition of each tributary it will be necessary to site each baseline sampling station at a convenient point upstream of any man made pollution. Practically, this may prove difficult but if this is the case the best possible point should be chosen with, if necessary, some notes describing how this point may deviate from the 'ideal' baseline monitoring station.

A further important consideration when planning sites for baseline monitoring stations is the geology of each river catchment and how this might vary over the basin area. The underlying rocks in a river basin influence the chemical quality of the water and so, if the geology of the catchment is known to vary, it is worth considering obtaining a baseline sample from each distinct geological area. This will aid understanding of the basic water chemistry of the river system and how this varies over the catchment area.

Sufficient samples need to be taken to characterise the water including, if applicable, describing the influence of natural changes in the system (eg, seasonal effects). Initially, therefore, it is sensible to take three to four samples at each point spread throughout the year to account for seasonal effects.

Trend (Monitoring Category)

Trend monitoring stations are designed to show how a particular point on a watercourse varies over time due, normally, to the influence of man's activities. By regularly sampling such stations it is possible to build up a picture of how the point is changing either gradually or as a result of a particular upstream event (eg, a new source of pollution being discharged to the river).

Ideally, this type of sample needs to be obtained at regularly spaced points throughout the river basin in order to completely characterise the catchment. However, in order to limit the number of samples to a reasonable level, it is suggested that this sampling is initially carried out only along the main river stem and on ‘major’ tributaries (> 20% of the mainstream flow at the confluence point).

Similarly, main river samples should be taken at sites where the river flow has increased by approximately 20% from the flow which existed at the previous station. Thus, the first such sampling station would be at a site where the flow is 20% greater than that which applied at the baseline station (see above). In the case of confluence of a major tributary, a sample station should be sited on both the main river and the tributary at points just upstream of the confluence. Sampling station sites would then continue to be distributed downstream on the main river as before (ie, a new sampling station to be located whenever the main river flow increased by 20% as compared to the flow at the previous station). It should be noted that in this scheme the only ‘Trend’ sampling stations not located on the main river stem are those sited on major tributaries and then only at points just upstream of the confluence with the main river.

This type of sample needs to be taken between 12 and 24 times per year. This ensures that these important points are sampled regularly enough to provide sufficient data for trend analysis to be carried out and to ensure that seasonal effects within the data can be identified. In order to limit sample numbers whilst retaining data quality it is suggested that on large river catchments (>100,000 km^2) twelve ‘Trend’ samples should be obtained per year at each station. On smaller river catchments (<100,000 km^2) twenty-four samples should be obtained at each station annually.

Flux (Monitoring Category)

Flux samples are taken so that the mass of particular pollutants can be calculated at important points on the river system. Measurement of the flow of the river is also normally carried out at the same time so that the mass flux (load per unit time) of pollutants can be calculated.

Samples are normally taken at points in the river system where it is deemed necessary or useful to know the flux of one or more pollutants. Such points are immediately upstream of where a major river crosses a state or national border (often for political reasons) or before a river discharges into a lake, sea or ocean (to enable the pollutant load being discharged by the river to be judged).

Within this programme, therefore, flux sampling stations should be located on all main river stems and major tributaries at sites immediately upstream of the points where these watercourses discharge into lakes, seas or oceans or cross state or national borders. It should be noted that when flux samples need to be obtained upstream of lakes, seas or oceans, care must be taken to choose the sampling station site such that the influence of the receiving water body is excluded from the samples obtained.

Flux samples should be collected at the same time as water flow measurement is carried out at these points. Flux samples should be obtained at least twenty-four times per year.

Water Use (Surveillance Category)

As the name implies, these samples are taken to ensure that the water is fit for its intended use. Possible uses of river water for which such sampling may be undertaken are: drinking water, irrigation, cooling, industrial processes, human bathing, livestock watering, support of fish life and support of other aquatic life.

If the water to be used is abstracted from the river the sample is taken at the abstraction point. If the water is to be sampled for an in-river use (eg, bathing), sampling is carried out at or very near to the point of use.

Sampling stations should be positioned at all points of use, wherever practical and without unnecessary duplication. That is to say, if there is an 'irrigation' sampling station on a particular river reach there is no need for another one at a nearby abstraction point unless significant changes are thought to have taken place in the river between these two points.

Sampling frequency will depend on the use to which the water is being put. The following is a rough guide to the frequency of sampling which would be appropriate for each designated use:

- drinking water - one sample per day (minimum)
- irrigation - one sample per week when irrigation is being carried out. More frequently during times of change in the river regime or if pollution is suspected
- bathing - depends upon number of bathers but daily in the bathing season if numbers bathing are high, weekly if less people bathing
- livestock watering - monthly (minimum) but more frequently during times of change in the river regime or if pollution is suspected
- waters supporting fish and other aquatic life - monthly minimum but more frequently if pollution is present or suspected or if the river flow is particularly low

Pollution Control (Surveillance Category)

This sampling is undertaken for particular pollutants to check the effect that discharges are having on the receiving watercourse or to ensure that watercourses are within their designated quality standard limits.

Samples to measure the effects of discharges are normally taken upstream and downstream of the outfall whilst river samples are taken from one or more points within the reach where the water quality standards apply.

Within the programme, there should be two sampling stations (ie, one upstream and one downstream) for each discharge that is having, or thought to be having, a detectable effect on river water quality (NB: analytical data for the discharge itself should be available form the State Pollution Control Board). In each river reach that has designated water quality standards, a sampling station should be located in the most polluted part of the reach. This will ensure that the quality of the reach is not overestimated.

With regard to discharges, the number of samples taken per year should reflect the importance of the discharge in terms of the effect it has on the receiving water and its pollution load. If the discharge is having a significant effect on the river, upstream and downstream sampling of the watercourse should be undertaken at least monthly (possibly even weekly if the discharge has a considerable effect on river water quality); if the discharge has little or no noticeable effect on the quality of the river then annual sampling of the watercourse is adequate. River water samples for checking water quality standards should be taken monthly within each designated reach.

Classification (Survey Category)

These samples are taken to classify a river reach in accordance with Indian River Water Quality Standards.

Samples should be taken from each river reach which has a distinct designated use.

Within the programme, a sampling station should be located within each designated reach at the point where the river is most polluted. Only by obtaining a sample at this point can the reach be properly classified according to its true pollution characteristics.

Samples taken for classification purposes should be obtained over one or two year period covering all seasons . Further sampling should then only be carried out if the regular trend monitoring indicates that the classification of the river may have changed.

Management and Research (Survey Category)

Samples may be taken for special purposes such as investigating and tracing pollution, instigating anti-pollution measures or gathering information for research purposes.

Samples will normally form part of a discrete survey which has been dedicated to gathering the information required to address a particular problem. As such, no guidance is possible on the location or number of samples which should be gathered as each survey must be planned individually.

2.2 Parameter Selection

Suggested parameters for each sample type are given in Table 2.2 (Monitoring Category), Table 2.3 (Surveillance Category) and Table 2.4 (Survey Category). For convenience, the parameters have been split into the following groups:

- general (basic parameters many of which can be measured instrumentally either in the field or in the laboratory)
- nutrients (nitrogen and phosphorus parameters which will measure the nutrients available for plant growth and eutrophication)
- organic matter (parameters capable of estimating the likely effect on watercourses of the discharge of organic matter)
- major ions (the inorganic anions and cations which can describe the chemical composition of the water and help to assess pollution)
- other inorganics (miscellaneous inorganic species which are important for certain water uses or for classification purposes)
- metals (three metal species which are important because of their toxicity or because they are useful indicators of the presence of other metals)
- organics (particular species which are important due to their toxicity, effect on potability of water or effect on the natural river processes)
- microbiological (one indicator species for the presence of faecal pollution of water)
- biological (one chemical which is present in plants, is a good indicator of algal growth and, therefore, eutrophication of waters)

The choice of parameters for each sampling type is carried out in a similar fashion to network density and sampling frequency selection, on the basis of the stated sampling objectives. This can be seen in the discussion of each sampling type as below.

Baseline (Monitoring)

As baseline monitoring is concerned with the natural and unpolluted state of the river basin it would seem that a reasonably wide range of parameters should be chosen so that the catchment can be adequately characterised. However, the range can be narrowed down somewhat because, as these samples should be unpolluted, there is little point looking for parameters which do not occur naturally in the area. Thus, many anthropogenic chemical species can be excluded including man-made organic materials, heavy metals and other organic polluting matter. The analysis of major ions is important, however, as these species help to show the natural chemical make-up of the river basin.

It is important to note that some chemical species which would normally be derived from man's activities are present in the list of baseline monitoring parameters. Such species include ammoniacal nitrogen, total oxidised nitrogen, total phosphorus and an indicator pesticide. These parameters have been included as they can reach otherwise unpolluted watercourses through diffuse inputs such as run-off from land - for example excess fertiliser, which often contains nitrogen and phosphorus compounds, can pollute rivers after it has been applied to agricultural land. Total coliforms have also been included in the baseline list as these species can be present in water following contamination by animal faeces.

Trend (Monitoring)

Trend monitoring is chiefly concerned with cataloguing the variation in pollution concentration at a sampling point. As such, traditional anthropogenic pollutants such as organic matter, metals, nutrients and microbiological need to be determined. In addition, a number of general parameters are also important as they are also good pollution indicators.

Flux (Monitoring)

With flux monitoring the aim is to gauge the quantity (load) of anthropogenic pollutants passing a sampling point. Thus the parameters measured are similar to those measured in trend monitoring except that it is not necessary to measure most general parameters as it is not possible to calculate a load of many of these species.

Water Use (Surveillance)

As it is impossible to generate a generic list of parameters for this type of monitoring, Table 2.3 splits water use into five distinct categories. Parameter selection has then been carried out so that pollutants particularly important to each use are screened. For example, certain crops are sensitive to high boron concentrations so this chemical is included in samples to be taken from water used for irrigation.

It should be noted that no attempt has been made to sample river water which is to be abstracted for industrial process and cooling water use. This is because the water quality required for this type of use is very variable, depending on the particular process employed by the abstracting organisation. As this is the case, and considering that those abstracting water for industrial process or cooling use will always, if they are concerned about water quality, analyse the water themselves, it was considered that no official sampling of such abstractions was necessary.

Pollution Control (Surveillance)

As noted in Table 2.3, analytical parameters in samples taken to check discharge permits or river water quality standards will generally reflect the permit or set of standards against which the sample is being compared. Thus, if a particular discharge only has a permit to discharge zinc and cadmium, the sample will just be analysed for these parameters and no others. The parameters in Table 2.3 represent the type of analysis which might be undertaken to check a river or a discharge for organic pollution (eg, to monitor effluent derived from a sewage treatment works).

Classification (Survey)

The parameters for this sampling type are taken from the CPCB classification scheme for Indian river water quality standards (Table 2.4) as this is the classification which should be applied nationally.

Management and Research (Survey)

As each particular survey undertaken within this sample type will have its own objectives no general guidance can be given on the parameters which should be determined.

It is important to remember that the parameters suggested in Tables 2.2 to 2.4 represent a minimum suite of parameters for each sample type. This is to maintain a sensible balance between the desire for more information and analytical costs. It should be noted, however, that some potentially important parameters have not been included in the programme (eg, certain heavy metals). It may be, therefore, that for each river catchment, some research effort should be directed towards ascertaining whether or not certain pollutants, which are not routinely covered by the programme, are present in unacceptable concentrations. Pollutants which could usefully be subjected to this type of investigation are:

- heavy metals such as lead, copper, nickel, arsenic, chromium
- organic pollutants such as polychlorinated biphenyls (PCBs) and certain types of pesticide (eg, DDT)
- certain organic solvents
- oils and hydrocarbons

If any of the above, or other, parameters are discovered in unacceptable concentrations at a sampling location then this pollutant should be added to the parameter list for that sampling point. Frequency of the parameters analytical determination will then depend on the polluting nature of the substance and its concentration in the river.

3. Site Selection

When selecting sites for surface water quality sampling the following considerations are important:

- that the site can be precisely described (as it is likely that more than one person will need to do the sampling)
- that the water body is well mixed both horizontally and vertically at the sampling point
- that the water body at the sampling point is representative of that particular reach or area of water
- that the site is within easy reach of a road (if the sampler is using a vehicle to get to the site)
- that the water is easily accessible at the sampling point
- that sampling can be carried out away from the bank (on a river, mid-stream or near to it is usually preferred, on a lake it is best to sample away from the bank as near-shore points are rarely representative of the bulk of water)
- that the site is inherently safe for sampling

As a guide to where a river is likely to be well mixed following a major discharge or tributary input, Table 3.1 gives estimated downstream distances from the confluence point for watercourses of various widths and depths. It must be remembered, however, that these distances are for guidance only and should be not be used without careful consideration of the situation obtaining at each site.

If there is any doubt that the water body is sufficiently well mixed at the sampling point (for example, if the site is on a river just downstream of a major discharge), it is wise to test the site by sampling it at various depths and widths for a parameter that is thought to vary (eg, if an upstream discharge is a heated effluent, temperature could be used to check that the water body is completed mixed). If no, or little, variation is detected the sampling point can be used. However, if the water body varies substantially a new sampling site should be selected and, if considered necessary, tested as before.

Normally it will be obvious if a particular site on a river or lake is representative of the surrounding water. On a river, for example, it would be no use sampling the water for dissolved oxygen analysis downstream of rapids which will quickly aerate the water and may give a false impression of its pollution status. Similarly, if water at the sampling point appears to be much slower or faster flowing than the bulk of the liquid in the reach, the point should be rejected as is unlikely to be representative.

There are a number of ways to gain access to the water for sampling as follows:

- from a bridge (normally a good choice of site as it is accessible, convenient, can be easily located and usually allows sampling from the stream mid-point)
- from a boat (a good choice on a lake as it allows sampling away from the bank, but can be inconvenient)
- from the bank (acceptable if access is good and sampling can be carried out away from the bank - eg, by the use of a pole or other device)
- by wading into the water (acceptable if this can be carried out safely and without any disturbance to the water or sediment which may contaminate the sample)
- from a jetty or other similar structure (normally a good choice if sampling can be carried out away from any flow effects which the jetty induces in the water)

An important point to be considered in the selection of sampling points is the safety of the sampling personnel. If there is any doubt that a sample can be obtained without undue risk a different point should be selected. Points to be wary of in this regard are places with steep-sided or slippery banks; areas where the current is particularly strong and the water deep and, when wading, river beds with deep holes.

Table 2.1
Water Quality Monitoring Objectives, Network Densities and Sampling Frequencies

Category	Type	Objective	Network Density	Sampling Frequency (per year)	Parameters
Monitoring[1]	Baseline	Natural background concentrations	One for each mainstream stem and one for each major tributary (>20% of flow at confluence)	Initially 3 - 4 X then repeat every 2 - 3 years	see Table 2.2
	Trend	Detection of changes over time due to anthropogenic influences	*Mainstream:* - after each 1½ -2 days travel time or after each major infiltration (whichever is sooner) *Tributary*: Before confluence if >20% of mainstream flow	12 X (if river catchment area > 100,000 km^2) 24 X (if river catchment area < 100,000 km^2)	
	Flux	Calculation of load Calculation of mass flux	State or border crossings Outflows into lakes and seas and oceans	Simultaneously with flow measurement (ie, 24 X)	
Surveillance[2]	Water Use	Check that water is fit for use	At all points of use or intake	see Section 2.1, 'Water Use'	see Table 2.3
	Pollution Control	Check effects of discharges Check water quality standards	Upstream and downstream of discharge point In river after mixing	For discharges with significant effects: 12 X (or 52 X for high significance). Annually for others. For river waters: 12 X	
Survey[3]	Classification	Classification of reach	Within each reach	Annually (less frequently if reach unchanged, more frequently if considerable changes)	see Table 2.4
	Management and Research	Investigation of pollution and need for corrective measures Special Interest Filling in knowledge gaps	Dependent upon scale of survey required	Sufficient to characterise problem and likely solution	

[1] Monitoring: Long-term, standardised measurement in order to define status and trends
[2] Surveillance: Continuous, specific measurement for the purpose of water quality management and operational activities
[3] Survey: A finite duration, intensive programme to measure for a specific purpose

Table 2.2
Water Quality Parameters (Monitoring)

Parameter Group	Parameter	Baseline	Trend	Flux
General	Temperature	X	X	
	Suspended Solids	X	X	X
	Conductivity	X	X	
	pH	X	X	
	Dissolved Oxygen	X	X	
	Total Dissolved Solids	X		
Nutrients	Ammoniacal Nitrogen	X	X	X
	Total Oxidised Nitrogen	X	X	X
	Total Phosphorus	X	X	X
Organic Matter	Chemical Oxygen Demand		X	
	Biochemical Oxygen Demand		X	X
Major Ions	Sodium	X		
	Potassium	X		
	Calcium	X		
	Magnesium	X		
	Carbonates and Bicarbonates	X		
	Chloride	X	X	X
	Sulphate	X		
Other Inorganics	Silica	X		
	Fluoride			
	Boron			
Metals	Cadmium		X	X
	Mercury		X	X
	Zinc		X	X
Organics	Pesticide (Indicator)	X	X	X
	Synthetic Detergents		X	
	Organic Solvents			
	Phenols			
Microbiological	Total coliforms	X	X	
Biological	Chlorophyll ‘a’	X	X	

Table 2.3
Water Quality Parameters (Surveillance)

Parameter Group	Parameter	Water Use[1]					Pollution Control[2]
		D	I	B	L	F	
General	Temperature	X	X			X	X
	Suspended Solids	X				X	X
	Conductivity	X	X		X	X	X
	pH	X	X	X	X	X	X
	Dissolved Oxygen			X		X	X
	Total Dissolved Solids		X				
Nutrients	Ammoniacal Nitrogen	X				X	X
	Total Oxidised Nitrogen				X		
	Total Phosphorus						
Organic Matter	Chemical Oxygen Demand						X
	Biochemical Oxygen Demand	X		X		X	X
Major Ions	Sodium		X				
	Potassium						
	Calcium		X				
	Magnesium		X				
	Carbonates and Bicarbonates						
	Chloride	X	X				X
	Sulphate						
Other Inorganics	Silica						
	Fluoride	X					
	Boron		X				
Metals	Cadmium					X	
	Mercury					X	
	Zinc						
Organics	Pesticide (Indicator)	X				X	
	Synthetic Detergents						
	Organic Solvents	X					
	Phenols	X					
Microbiological	Total coliforms	X	X[3]	X	X[3]		X
Biological	Chlorophyll 'a'	X				X	

[1] D = Water Abstracted for Treatment as Drinking Water, I = Water for Irrigation, B = Waters Used for Human Bathing, L = Water for Livestock Watering, F = Waters Capable of Supporting Fish and Other Aquatic Life
[2] Suggested suite of parameters to test for organic pollution. For guidance only, specific parameters sampled will depend upon the discharge being monitored.
[3] It is recognised that practically, even though high concentrations of coliforms may exist in irrigation and livestock watering waters, it may not be possible to discontinue the use of a particular water source

Table 2.4
Water Quality Parameters (Survey)[1]

Parameter Group	Parameter	CPCB Classification
General	Temperature	
	Suspended Solids	
	Conductivity	X
	pH	X
	Dissolved Oxygen	X
	Total Dissolved Solids	
Nutrients	Ammoniacal Nitrogen	X
	Total Oxidised Nitrogen	
	Total Phosphorus	
Organic Matter	Chemical Oxygen Demand	
	Biochemical Oxygen Demand	X
Major Ions	Sodium	X
	Potassium	
	Calcium	X
	Magnesium	X
	Carbonates and Bicarbonates	
	Chloride	
	Sulphate	
Other Inorganics	Silica	
	Fluoride	
	Boron	X
Metals	Cadmium	
	Mercury	
	Zinc	
Organics	Pesticide (Indicator)	
	Synthetic Detergents	
	Organic Solvents	
	Phenols	
Microbiological	Total coliforms	X
Biological	Chlorophyll 'a'	

[1] Table does not include any parameters for the 'Management and Research' sampling type as these will be survey specific.

Table 3.1
Estimated Distance for Complete Mixing in Streams And Rivers
(after Bartram and Ballance, Water Quality Monitoring, E & FN Spon, London, 1996)

Average River Width (m)	Mean River Depth (m)	Estimated Distance for Complete Mixing (km)
5	1	0.08 - 0.7
	2	0.05 - 0.3
	3	0.03 - 0.2
10	1	0.3 - 2.7
	2	0.2 - 1.4
	3	0.1 - 0.9
	4	0.08 - 0.7
	5	0.07 - 0.5
20	1	1.3 - 11.0
	3	0.4 - 4.0
	5	0.3 - 2.0
	7	0.2 - 1.5
50	1	8.0 - 70.0
	3	3.0 - 20.0
	5	2.0 - 14.0
	10	0.8 - 7.0
	20	0.4 - 3.0

List of figures

state boundary

state boundary

state boundary
major towns
industrial centres

state boundary
baseline stations

state boundary
baseline stations
trend stations

state boundary
baseline stations
trend stations
flux stations

state boundary
baseline stations
trend stations
flux stations
CWC stations

state boundary
baseline stations
trend stations
flux stations
CPCB stations

state boundary
CWC stations
CPCB stations