



DHV CONSULTANTS &
DELFT HYDRAULICS with
HALCROW, TAHAL, CES,
ORG & JPS

VOLUME 6
WATER QUALITY SAMPLING

DESIGN MANUAL

Table of Contents

1	INTRODUCTION	1
	1.1 GENERAL	1
	1.2 THE MONITORING CYCLE	2
2	MANAGEMENT ISSUES FOR WATER QUALITY MONITORING	3
	2.1 INTRODUCTION	3
	2.2 RIVERS	4
	2.3 LAKES AND RESERVOIRS	6
3	MONITORING OBJECTIVES	7
	3.1 INFORMATION NEEDS	7
	3.2 WATER QUALITY MONITORING IN INDIA	9
	3.2.1 CENTRAL POLLUTION CONTROL BOARD	9
	3.2.2 NATIONAL RIVER CONSERVATION DIRECTORATE	11
	3.2.3 CENTRAL WATER COMMISSION	12
	3.2.4 OTHER ORGANISATIONS	13
4	NETWORK DESIGN	14
	4.1 INTRODUCTION	14
	4.2 NETWORK DENSITY, SAMPLING FREQUENCY AND PARAMETER SELECTION	16
	4.2.1 INTRODUCTION	16
	4.2.2 MONITORING CATEGORY	21
	4.2.3 SURVEILLANCE CATEGORY	23
	4.2.4 SURVEY CATEGORY	25
	4.2.5 INTEGRATED AND AGGREGATED WATER QUALITY SAMPLES	26
	4.2.6 RECOMMENDATIONS ON FREQUENCY AND PARAMETERS	27
	4.3 EXAMPLE APPLICATION: NETWORK DESIGN IN MAHANADI BASIN	28
5	NETWORK RATIONALISATION	38
	5.1 INTRODUCTION	38
	5.2 MONITORING OBJECTIVES OF DIFFERENT WATER QUALITY ORGANISATIONS	39
	5.3 RATIONALISING NETWORKS OF MULTIPLE ORGANISATIONS	39
	5.4 PRINCIPLES FOR NETWORK RATIONALISATION	44
	5.5 EXAMPLE OF NETWORK RATIONALISATION, CAUVERY RIVER	44
	5.5.1 BACKGROUND	45
	5.5.2 EXISTING MONITORING PROGRAMME	45
	5.5.3 METHODOLOGY ADOPTED	46
	5.5.4 RECOMMENDATIONS AND CONCLUSION	47
	5.6 HOW TO PROCEED WITH NETWORK RATIONALISATION	48
	5.6.1 CWC REGIONS	48
	5.6.2 STATE LEVEL REVIEW COMMITTEES	49
6	SITE SELECTION	50
	6.1 GENERAL	50
	6.2 SELECTING A WELL – MIXED SITE IN A RIVER	50
	6.3 SELECTING NON-RIVER SITES	51
	6.4 SAMPLING ACCESS	51
	6.5 SAFETY CONSIDERATIONS	51
7	FIELD TECHNIQUES	52
	7.1 SAMPLE COLLECTION	52
	7.2 FILED MEASUREMENTS	55

7.2.1	MEASUREMENT OF TEMPERATURE	55
7.2.2	MEASUREMENT OF pH	55
7.2.3	MEASUREMENT OF CONDUCTIVITY	55
7.3	SAMPLE HANDLING	55
7.3.1	SAMPLE PRESERVATION	56
7.3.2	SAMPLE TRANSPORTATION	56
7.3.3	SAMPLE STORAGE	57
8	EQUIPMENT	57
8.1	SAMPLERS	57
8.2	FIELD ANALYSES AND SAMPLE HANDLING	60
8.3	SAMPLE CONTAINERS	60
8.4	PREPARATION AND STERILISATION OF EQUIPMENT	61
8.5	TRANSPORTATION BOXES	61
8.6	OTHER ITEMS	62

1 INTRODUCTION

1.1 GENERAL

The term ‘water quality’ is generally used to express the physical, chemical or biological state of water. This, in turn, may be related to the suitability of water for a particular use or purpose.

The quality of water is characterised by a range of physical, chemical and biological parameters, which arise from a variety of natural and human influences. Normally field or laboratory analysis, or in-situ measurement, of the water for one or more parameters of interest determines its quality.

Monitoring is defined by the International Standards Organisation (ISO) as:

‘The programmed process of sampling, measurement and subsequent recording or signalling, or both, of various water characteristics, often with the aim of assessing conformity to specified objectives.’

A systematic plan for conducting water quality monitoring is called a ‘monitoring programme’. This manual supplies the technical aspects of the design of a monitoring programme that aims at generating water quality data that is justified, complete and accurate. Figure 1.1 shows all relevant components of a water quality monitoring programme and also shows the division into sampling related and analysis related topics (see dotted horizontal line).

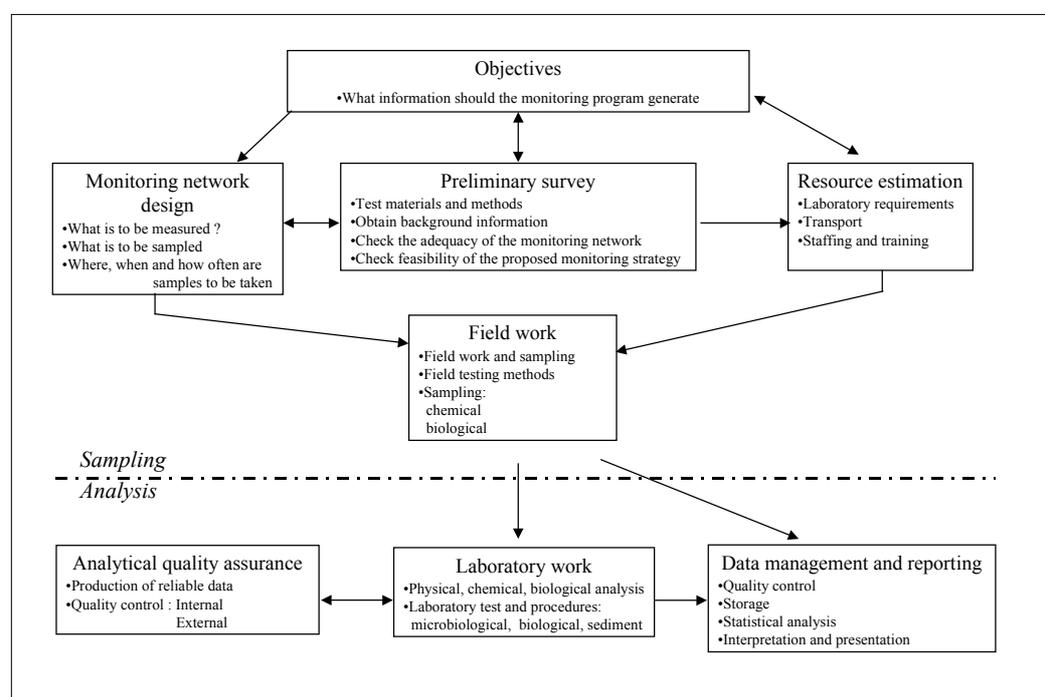


Figure 1.1: Elements of a water quality monitoring program

This volume deals with the topics above the horizontal line, described in chapters 1 through 8. The manual does not include biological or eco-toxicological monitoring. No specific criteria with respect to organisational or cost aspects are included in this manual.

1.2 THE MONITORING CYCLE

The process of water quality monitoring should principally be seen as a sequence of related activities that starts with the definition of information needs, and ends with the use of the information product. This sequence of activities is linked in a cycle, which is called the 'monitoring cycle', as shown in Figure 1.2.

Successive activities in this monitoring cycle should be specified and designed based on the required information needs as well as the preceding part of the chain. In developing water quality monitoring programmes, all stages of the monitoring process should be considered (i.e. all steps in the cycle). Each step is briefly described below.

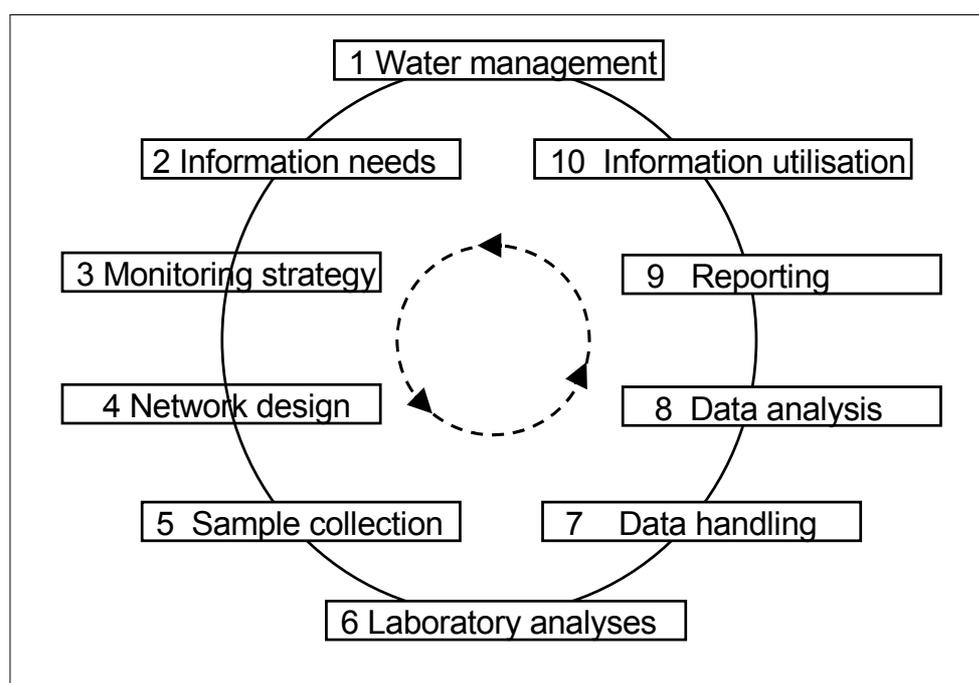


Figure 1.2: The Monitoring Cycle⁴

1. **Water management:** The need for information should be based on the main issues or problems in management of water, and the active use of information in the decision-making process. Water management should consider the functions/use of a water system, the problems and threats to the water system and the possible measures that can be taken to manage the water system.
2. **Information needs:** *The most critical step* in having a successful water quality monitoring programme is to have a clear definition and specification of the monitoring objectives and information needs for water management. Information needs and monitoring objectives need to be specified so that the following steps in the monitoring cycle can logically follow.
3. **Monitoring strategy:** After the specification of the information needs, a monitoring strategy is required to design and operate the monitoring programme in such a way that the desired information is obtained. The strategy defines the approach and the criteria needed for a proper design of the monitoring programme.

⁴ from UN/ECE Task Force on Monitoring and Assessment: Guidelines on Water-Quality Monitoring and Assessment of Transboundary Rivers

4. **Network Design:** The design of the monitoring network includes the selection of sampling locations, parameters, and sampling frequency. These aspects of the design can and should be specified in a short document.
5. **Sample Collection:** Sample collection refers to going to the field and collecting the water samples to be analysed for water quality parameters. Samples are collected at the sampling locations and with the sampling frequency as specified in the network design. Some simple 'field analyses' are conducted at the time of sample collection.
6. **Laboratory Analysis:** The majority of samples collected in the field are brought to a chemical laboratory for analysis of various water quality parameters. The parameters to be analysed are according to the specifications in the network design.
7. **Data Handling:** The results of the field and laboratory analyses are entered into a data handling system. In the Hydrology Project, this is the computerised SWDES (Surface Water Data Entry System). The data handling with SWDES also includes the data validation.
8. **Data Analysis:** In this step, the collected data have to be analysed, keeping in mind the information needs and objectives of the monitoring programme (as defined in step 2). Data analysis should provide information (i.e. transform data to information) which is relevant to the water managers who need the information. In the Hydrology Project, data analysis will take place with the computer software HYMOS.
9. **Reporting:** In this step, the results of the data analysis are reported to the water managers and other who want and need the water quality information. Reporting is typically done via a written report, but can also presented by a newsletter, or electronically (with internet), or as a presentation.
10. **Information Utilisation:** The water managers who receive the information from the monitoring programme via the report(s) can then act upon this information. For example, measures could be taken to address identified problems.

This volume discusses steps 1-5 of the monitoring cycle in more detail.

2 MANAGEMENT ISSUES FOR WATER QUALITY MONITORING

2.1 INTRODUCTION

Using the monitoring cycle as the basis for water quality monitoring, the first step is the identification of the water quality management issues (Figure 2.1).

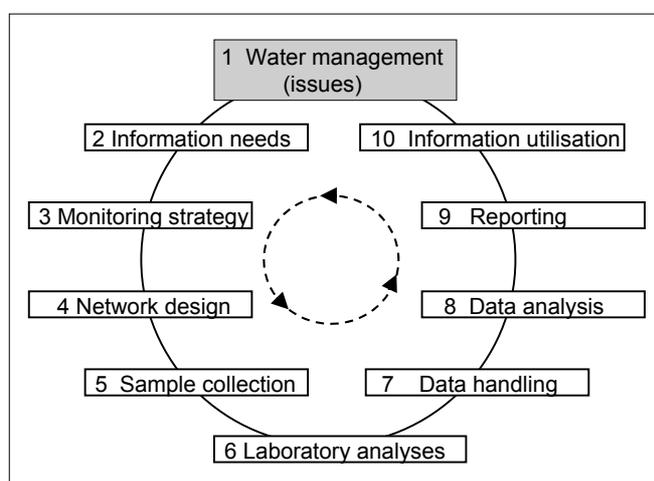


Figure 2.1:
Water Management Issues: Step 1 in
monitoring cycle

Contamination of water is certainly one of the key issues, as it can prevent water from being used for its intended purpose. Contamination can enter the water bodies through one or more of the following ways:

- Direct point sources: Transfer of pollutants from municipal - industrial liquid waste disposal sites and from municipal and household hazardous waste and refuse disposal sites.
- Diffuse agricultural sources: Wash off and soil erosion from agricultural lands carrying materials applied during agricultural use, mainly fertilisers, herbicides and pesticides.
- Diffuse urban sources: Run off from city streets, from horticultural, gardening and commercial activities in the urban environment and from industrial sites and storage areas.

An overview of water quality issues relevant to rivers, lakes and reservoirs is presented below.

2.2 RIVERS

Change in Physical Characteristics

Temperature, turbidity and total suspended solids (TSS) in rivers can be greatly affected by human activities such as agriculture, deforestation and the use of water for cooling. For example, the upward trend in soil erosion and the related increase in TSS in rivers can be seen in most of the mountainous regions in India.

Contamination by Faecal and Organic Matter

In India, faecal contamination is still the primary water quality issue in rivers, especially where human and animal wastes are not adequately collected and treated. Although this applies to both rural and urban areas, the situation is probably more critical in fast-growing cities.

The release of untreated domestic or industrial wastes high in organic matter into rivers results in a marked decline in oxygen concentration (sometimes resulting in anaerobic conditions) and a rise in ammonia and nitrogen concentrations downstream of the effluent input. The most obvious effect of the release of organic matter along the length of the river is the depletion of oxygen downstream of the discharge as shown by the so-called 'oxygen-sag curve' which plots dissolved oxygen concentration against distance. Industrial activities which discharge large organic loads include, pulp and paper production and food processing. Faecal matter affects the use of water for drinking water source or bathing water, as well as ecological health of river.

Toxic Pollutants: Organics and Heavy Metals

Organic pollutants (mostly chemicals manufactured artificially by man) are also becoming an important water quality issue. They enter rivers as:

- point sources directly from sewers and effluent discharges (domestic, urban and industrial sources)
- diffuse sources from the leaching of solid and liquid waste dumps or agricultural land run-off
- indirectly through long-range atmospheric transport and deposition

Uncontrolled discharge of industrial wastewaters often causes pollution due to toxic metals. Other sources of metal pollution are leachates from urban solid wastes landfills and mining waste dumps.

Rivers such as the Yamuna, which pass through large towns and cities are often badly affected with organic pollutants. Another example is that of Damodar River which is polluted with heavy metals arising mostly from electroplating, tanning and metal based industries.

River Eutrophication

During the 1950s and 1960s, eutrophication (nutrient enrichment leading to increased plant and algal growth) was observed mostly in lakes and reservoirs. Since the 1970s the increasing levels of phosphates and nitrates entering rivers, particularly in developed countries, were largely responsible for eutrophication occurring in running waters. In India, isolated reports have appeared for some river reaches especially in plains around agriculture tracts of land.

In small rivers eutrophication is said to promote macrophyte (large plants) development, whereas in large rivers phytoplankton (algae) are usually more dominant than macrophytes. In such situations the chlorophyll concentration of the water may reach extremely high values due to the fact that this pigment is present in all plants.

Eutrophication can result in marked variations in dissolved oxygen and pH throughout the day. The changes in water quality caused by eutrophication can be a major cause of stress to fish due to the release, at high pH, of highly toxic gaseous ammonia and depletion of oxygen after sunshine hours.

Salinisation

Increased mineral salts in rivers may arise from several sources:

- pollution by mining waste waters
- pollution by certain industrial waste waters
- increased evaporation in the river basin (mainly in arid and semi-arid regions)
- surface/irrigation run-off

Industrial and mining waste pollution results in increase in specific ions. Evaporation, however, increases the concentration of all ions.

Changes in River Hydrology

Many human activities, directly or indirectly, lead to modifications of river channels, which can, in turn, induce changes to the aquatic environment. Major modifications to river systems include the following:

- changes to depth and width for navigation
- creation of flood control ponds
- creation of reservoirs for drinking water supply
- damming for hydroelectric power generation
- diversion for irrigation purposes

All of the above affect the hydrology and related uses of the river system and so have a great potential to affect water quality. It must be remembered, however, that not all such water quality changes are necessarily deleterious.

Contamination from Agrochemicals

Agricultural land use and cultivation practices have been shown to exert major influences on both surface water and groundwater quality. Of particular concern, in India, is the leaching of fertiliser chemicals (e.g., nitrate) and pesticides from regular, intensive cultivation of crops. These cultivation practices affect surface waters and relatively shallow unconfined aquifers, both of which are used for potable supply.

Little attention has been given in this country to the leaching of pesticides from agricultural land in spite of the dramatic increase in the use of pesticide formulations over the last years. There are currently few laboratories with the capability of analysing pesticides.

Mining Activities

A range of surface water groundwater pollution problems can be associated with mining activities. The nature of the pollution depends on the materials being excavated and extracted. Both surface and underground mines usually extend below the water table and often dewatering is required to allow mining to proceed. The water pumped, either directly from the mine or from specially constructed boreholes, may be highly mineralised and its usual characteristics include low pH (down to pH 3) and high levels of iron, aluminium and sulphate. Disposal of this mine drainage effluent to surface water or groundwater can cause serious impacts on water quality for all uses. Pollution of surface and groundwater can also result from the leaching of mine tailings and from settling ponds and can, therefore, be associated with both present and past mining activity.

2.3 LAKES AND RESERVOIRS

Pollution Pathways

The following pathways, in addition to the ones mentioned above, assume special significance in the case of lakes and reservoir pollution:

- Riverine sources: pollutants in solution in the inflow or adsorbed onto particulate matter, or both. The cumulative input is the sum of contaminants from all of the rivers draining the watershed into a lake.
- Groundwater sources: groundwater systems polluted from point and diffuse sources (noted above) flowing into rivers, and directly into lake beds.
- Atmospheric sources: direct wet and dry atmospheric deposition of contaminants to the lake surface and wash off of similar pollutants from the land. This latter process is defined as secondary cycling.

In addition to the above, lakes serve as traps for pollutants carried by rivers and groundwater draining the watershed. The pollutant concentration in the lake usually builds up due to evaporation of water from the lake's surface unless there is a natural flushing with good quality water.

Eutrophication

Simply speaking, eutrophication is the biological response to excess nutrient input to a lake. The production of biomass and its death and decay results in a number of effects, which individually and collectively result in impaired water use. The most important of these effects are decreased dissolved oxygen levels, release of odorous compounds (e.g. H₂S) and siltation.

Many important lakes in India (e.g., Hussainsagar (Hyderabad), Nainital (Uttar Pradesh) and Dal (Jammu and Kashmir) have reportedly progressed to advanced eutrophication levels.

Lake Acidification

One of the major issues related to lakes in particular, and to freshwaters in general, is the progressive acidification associated with deposition of rain and particulates (wet and dry deposition) enriched in mineral acids. The problem is characteristic of lakes in specific regions of the world, which satisfy two major critical conditions: the lakes must have soft water (i.e. low hardness, conductivity and dissolved salts) and be subjected to 'acid rain'.

To date, lake acidification has not been reported as a problem in India.

Bioaccumulation and Biomagnification

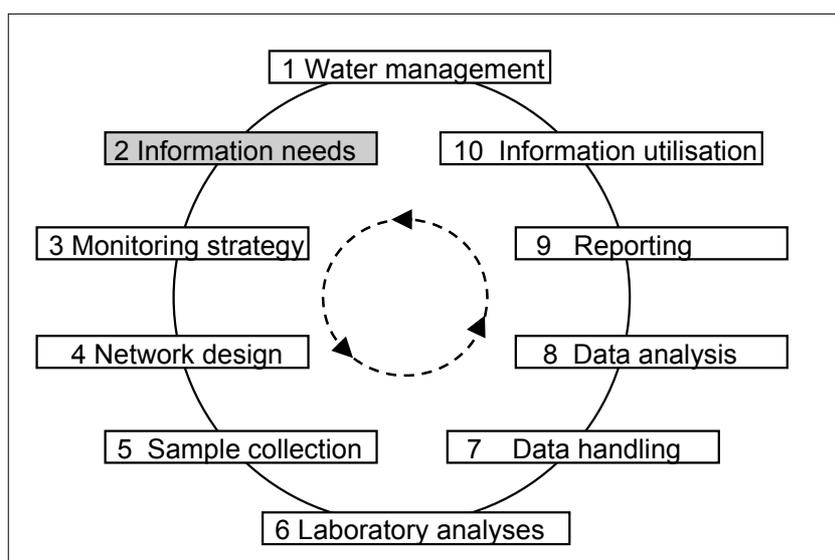
The processes of bioaccumulation and biomagnification are extremely important in the distribution of toxic substances (discharged in waste effluents) in fresh water ecosystems. The concentration of pollutants within the organism due to bioaccumulation and biomagnification depends on the duration of exposure of the organism to the contaminated environment and its trophic level in the food chain. Several fold increases in trace contaminant concentrations have been commonly observed in lakes and estuarine environments.

3 MONITORING OBJECTIVES

3.1 INFORMATION NEEDS

Using the monitoring cycle as the basis for water quality monitoring, the next and *critical* step after identification of the water quality management issues is the definition of monitoring objectives and specific of information needs:

- what is the purpose or objective of the water quality monitoring programme?
- what water quality information do the water managers want and need to have?



*Figure 3.1:
Identification of Information Needs : Step 2 in monitoring cycle*

These above questions are fundamental - there is no point in 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. Definition of the programme's objectives, and providing answers to the above questions, prior to planning the sampling exercises will ensure that the correct conclusions regarding

sampling locations, number of samples, selection 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

These global objectives can also be considered under three separate categories of sampling, i.e.:

- **Monitoring** - long-term standardised measurements in order to define status or trends (i.e.: 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 categories, types and their associated objectives are described in Table 3.1. Naming of objectives as routine monitoring, multipurpose monitoring, etc. should be replaced by well defined terms as noted above.

As far as this manual 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.

Category	Type	Objective
Monitoring	Baseline	Natural Background Concentrations
	Trend	Detection of changes over time due to anthropogenic influences
	Flux	Calculation of load Calculation of mass flux
Surveillance	Water Use	Check that water is fit for use
	Pollution Control	Check effects of discharges Check water quality standards
Survey	Classification	Classification of reach
	Management and Research	Investigation of pollution and need for corrective measures Special Interest Filling in knowledge gaps

Table 3.1: Water Quality Monitoring Objectives for different monitoring categories

3.2 WATER QUALITY MONITORING IN INDIA

In India, water quality monitoring has been carried out historically for a number of reasons. Different organisations have been and are currently operating networks to satisfy their own particular objectives:

- Central & State Pollution Control Boards
- Central Water Commission & State Irrigation Departments
- Central Ground Water Board & State Ground Water Departments
- National River Conservation Directorate (NRCD)
- Research Institutions (e.g., NEERI)
- Others (Academic Institutions, State Public Health and Environmental Departments (PHED), Water Supply and Sewerage Boards (WSSB), etc.

Activities of these organisations are detailed below. Tables 3.4 and 3.5 summarise information regarding objectives mandates of water quality monitoring for the four important players in the field of surface water quality monitoring in India.

Prior to the Hydrology Project, State Surface Water (Irrigation) Departments were not involved in routine water quality monitoring. Under the Hydrology Project, these state departments have started water quality monitoring activities.

3.2.1 CENTRAL POLLUTION CONTROL BOARD⁵

The Water (Prevention and Control of Pollution) Act, 1974, was passed for restoration and maintenance of wholesomeness and cleanliness of national aquatic resources. The Central Pollution Control Board (CPCB) was constituted in September 1974 as part of the Ministry of Environment and Forests. Since the parliament has no powers to make laws for the states, all the Houses of Legislature of 25 states of the Union of India adopted the Act and respective State Pollution Control Boards (SPCBs) were formed. For Union Territories, the Central Board initially exercised the powers and performed the functions of pollution control. Later, for each Union Territory pollution control committees under the local administration were formed and the functions and powers of the Central Board were delegated to the respective committee. The Air (Prevention and Control of Pollution) Act was passed in 1981 for the control of air quality.

In order to adopt stronger environmental policies and new laws, the Environment (Protection) Act, 1986, was enacted. The act empowered the Central Government to take all necessary measures to protect and improve the environment.

Under the Environment Act the 'environment' includes air, water and land and the inter- relationship which exists among and between the biotic and abiotic components.

Its functions in relation to objective of prevention and control of pollution of water environment and to maintain and restore wholesomeness of water can be summarised as:

- Advise Central and State governments with respect to location of any industry, which is likely to pollute a stream or ground water.

⁵ Extracted from 'Water Quality Monitoring, the Indian Experience' Assessment and Development Studies of River Basins Series: ADSORBS/12/1984-85, CPCB and 'Pollution Control Acts, Rules and Notifications Issued Thereunder', September 1997, CPCB

- Advise Central Government on restriction of areas in which certain types of activity shall not be carried out or shall be carried out subject to prescribed safeguards.
- Lay down standards for treatment of municipal and industrial wastewaters and the treated effluents.
- Co-ordinate activities of State Pollution Control Boards and provide technical assistance where necessary.
- Sponsor investigation and research.
- Organise training and awareness programmes.
- Plan and cause to be executed national programmes on pollution control.

Water Quality Monitoring Network

Water quality monitoring is one of the important activities of CPCB. It helps in the identification of waterbodies, which are in need of quality improvement. It also helps in formulation of national pollution control programmes.

National water quality monitoring programme was initiated by CPCB in 1977, when under 'Global Environmental Monitoring System (GEMS)', 24 surface water and 11 groundwater stations were selected for monitoring.

Parallel to GEMS, a national programme of Monitoring of Indian National Aquatic Resources (MINARS), was started in 1984, with a total of 113 stations spread over 10 river basins.

Presently the inland water quality monitoring network is operated under a three tier programme:

GEMS:	50 stations
MINARS:	430 stations
YAP	27 stations
Total	507

Out of these 507 stations, 444 are on rivers and canals, 38 on lakes and creeks and 25 are groundwater stations.

The stations operated by SPCBs are mostly to monitor the effect of specific waste discharges and to evaluate the impact of water pollution control programmes.

The water quality data are reported in Water Quality Statistics yearbooks.

Approach to Pollution Control

The basic objective of Environment Protection Act is to maintain and restore the wholesomeness of water by prevention and control of water pollution. The act does not define 'wholesomeness'. Taking a pragmatic approach, the Board has identified predominant uses, calling them designated best use, of different water bodies or stretches of river and also defined water quality criteria for different uses of water. These criteria are given in Table 3.2.

Based on the monitoring data, the existing water quality is compared with the water quality objective defined by criteria for the designated-best-uses. Where the designated-best-use requires better quality water than what is existing, an action plan is prepared for maintenance of the use.

Ganga action plan was the first such plan. Now the National River Conservation Directorate, Ministry of Environment & Forests (see chapter 3.3.2) has prepared other action plans also.

Designated best use	Class	Criteria
Drinking water source without conventional treatment but after disinfection	A	Total coliform organisms MPN/100mL shall be 50 or less. pH between 6.5 and 8.5 Dissolved oxygen 6 mg/L or more Biochemical oxygen demand 2 mg/L or less
Outdoor bathing (organised)	B	Total coliform organisms MPN/100mL shall be 500 or less pH between 6.5 and 8.5 Dissolved oxygen 5 mg/L or more 4. Biochemical oxygen demand 3 mg/L or less
Drinking water source with conventional treatment followed by disinfection	C	Total coliform organisms MPN/ 100mL shall be 5000 or less pH between 6 and 9 Dissolved oxygen 4 mg/L or more Biochemical oxygen demand 3 mg/L or less
Propagation of wild life, fisheries	D	pH between 6.5 and 8.5 Dissolved oxygen 4 mg/L or more Free ammonia (as N) 1.2 mg/L or less
Irrigation, industrial cooling, controlled waste disposal	E	pH between 6.0 and 8.5 Electrical conductivity less than 2250 micro mhos/cm Sodium absorption ratio less than 26 Boron less than 2mg/L

Table 3.2: Primary water quality criteria for various uses of fresh water

3.2.2 NATIONAL RIVER CONSERVATION DIRECTORATE⁶

Surveys carried out by the Central Pollution Control Board indicated that large stretches of many of the Indian rivers were grossly polluted, particularly from municipal wastewaters. While the rules and regulations under the Environment (Protection) Act could be applied to industrial establishments, their enforcement for the municipal discharges was not feasible, as the municipalities do not have sufficient resources to undertake large scale sewerage and sewage treatment works.

The Ganga Action Plan (GAP) was started in 1985 as a 100% centrally funded scheme to restore the water quality of River Ganga to the bathing class. To accomplish this task, pollution abatement works related to 25 class I towns in Uttar Pradesh, Bihar and West Bengal located on the river banks were undertaken. Later in 1991, important tributaries of River Ganga were also included in the action plan. In 1994 the GAP model with suitable modifications was extended to the national level through a National River Conservation Plan (NRCP) and the Ganga Project Directorate was renamed National River Conservation Directorate (NRCD).

NRCD Programmes

At present, 10 states are covered under NRCD programmes. This includes all eight Hydrology Project states except Kerala. For each river action plan, a number of schemes are undertaken, such as:

- Sewage interception and diversion
- Sewage treatment
- Low cost sanitation
- Electric crematoria
- River front development
- Other schemes

⁶Extracted from 'National River Action Plan' 1994 and 'Status Paper on River Action Plans' 1998 Ministry of Environment & Forests, GOI, New Delhi

Formulation and execution of schemes has started in 12 major river basins of the country. The schemes were identified on the basis of water quality surveys carried out by CPCB under its water quality monitoring programme.

Water quality monitoring

NRCD is contracting with various organisations in the country such as CPCB, SPCBs (see chapter 2.2.1) and academic institutions to measure water quality of river stretches where it has taken up pollution abatement schemes. So far the major monitoring thrust has been in the Gangetic basin. With schemes being taken up on other rivers, the monitoring programme of the Directorate is also extending.

The objective of the monitoring programme is to establish the water quality in the rivers before the schemes are taken up and then compare it with the quality as the implementation of scheme progresses in order to check the efficacy of the actions taken. The stations are usually closely spaced downstream of cities and wastewater out falls. The stations may be classified as surveillance type for pollution monitoring. The water is analysed mainly for pollution related parameters, BOD, DO and coliforms. At some places analysis for heavy metals is also included.

Due to a number of organisations participating in the analysis programme it has become necessary to conduct AQC exercises for the laboratories. CPCB laboratory is acting as reference laboratory for inter-laboratory exercises.

3.2.3 CENTRAL WATER COMMISSION

The Central Water Commission has a national network of hydrological observations in all the major river basins of the country. It is operating 570 gauge discharge observation stations in the 12 basins or zones. Table 3.3 lists numbers of the stations on the peninsular rivers. It is seen that out of 295 stations, water quality measurements are carried out at 146 stations.

S. No.	State	GD	GDS	Total	WQ
1	Andhra Pradesh	26	14	40	19
2	Bihar	1	3	4	3
3	Daman	1	-	1	1
4	Gujarat	12	10	22	11
5	Goa	2	-	2	2
6	Karnataka	22	15	37	19
7	Kerala	6	13	19	13
8	Maharashtra	45	22	67	24
9	Madhya Pradesh	27	24	51	24
10	Orissa	8	12	20	12
11	Rajasthan	9	2	11	2
12	Tamilnadu	13	8	21	16
	Total	172	123	295	146

GD – gauge discharge

GDS – gauge discharge & silt

WQ – water quality (including gauge discharge)

Table 3.3: CWC operated hydrological observation stations⁷

⁷ source: GOI, Central Water Commission, River Data Directorate, New Delhi, April 1992

Mandates and objectives of water quality monitoring

Being the apex national body for development of water resources in the country, its mandate is assessment of water resources in general. This would include the following objectives in regard to water quality monitoring:

- Establishment of baseline water quality
- Assessment of suitability of water for various uses, particularly for irrigation
- Detection of trends in water quality changes.
- Dissemination of water quality information upon request

CWC has no mandate with respect to managerial measures like informing the public, checking discharges for compliance with regulations or corrective measures. quality data collected are not used for data analysis and presentation other than tabular listings in the yearbooks.

Water Quality Monitoring Network

The CWC has been involved in surface water quality monitoring since 1972. It operates several level I and level II laboratories in the Peninsular Area. The analyses are generally limited to a standard list of 20 classical parameters. A few irrigation related water quality indices are calculated from the measurements of chemical quality of the water. The samples are collected from rivers and adjacent groundwater wells through the level I site laboratories (located at a limited number of gauging sites) where in situ parameters (T, pH, EC and DO) are determined. Remaining parameters are determined in some 11 level II laboratories in the Peninsula. At some locations pollution related parameters, BOD and coliforms are also measured.

Sampling frequency ranges from every 10 days (thrice monthly) to every fortnight (twice monthly). So far surface water pollution with toxic metals and organic micro pollutants has not received attention.

The results of the monitoring programme are computerised in the regional offices in different packages (spreadsheet or word processor). Annual reports (in tabular form only) are produced and contain monthly averaged data, not the original measurements

3.2.4 OTHER ORGANISATIONS

Other organisations, which are interested in water quality measurements, include

- Academic Institutions
- National and State Research Organisations
- Central Public Health and Environmental Engineering Organisation (CPHEEO)
- State Health Departments
- State Public Health Engineering Departments
- Municipalities
- Water Supply and Sewerage Boards (WSSB)

The first two named organisations usually do not conduct long term monitoring. They take up surveys for research studies or investigation of water quality management problems. The remaining organisations carry out water quality surveillance on a regular basis usually for use related objectives. Monitoring of raw and treated water for drinking water supply was identified as the major reason.

Mandates	CWC	NRCD	sSW	sGW	sPCB	WSSB
Monitoring (directly or through sponsored studies) of water quality and subsequent assessment	✓ assessment of water re-sources, implying quality	✓	✓	✓	✓	✓
Storage and processing of water quality data	✓	✓	✓	✓	✓	✓
Management / control of pollution		✓			✓	
Dissemination of water quality information /mass awareness	✓ upon request , official use	✓ restricted	✓ upon request, official use	✓ upon request, official use	✓	✓
Imparting training in water quality management to target groups.					✓	✓

Table 3.4: Mandates of Indian organisations involved in water quality monitoring

a – Central Ground Water Authority, formed recently.

Objectives	CWC	NRCD	CPCB	sSW	sGW	sPCB	WSSB
Estimation of natural background or baseline concentrations	✓	✓	✓	✓	✓	✓	✓
Estimation of trends in quality changes due to anthropogenic or other influences	✓	✓	✓	✓	✓	✓	✓
Routine evaluation of fitness of water for its designated use (specify the uses addressed)	✓ irrigation	✓ various	✓ various	✓ irrigation	✓ irrigation drinking	✓ various	✓ drinking
Provide warnings of potentially deleterious changes for specific use			✓		✓	✓	✓
Calculation of mass loads / flux			✓			✓	
Check effects of effluent discharges for compliance or charging			✓			✓	
Characterisation/ Classification of water bodies			✓		✓	✓	
Specific investigations and corrective measures		✓	✓		✓	✓	✓

Table 3.5: Monitoring Objectives of Indian organisations involved in water quality monitoring

4 NETWORK DESIGN

4.1 INTRODUCTION

The network design for water quality monitoring networks as described in this chapter is especially important for State government organisations entering into the field of water quality monitoring, such as state irrigation departments. Other organisations, such as the Central Water Commission will also find a good review of network design here. In addition, CWC and other organisations that have a substantial record of water quality data will find additional guidance in chapter 5 on rationalisation of existing networks.

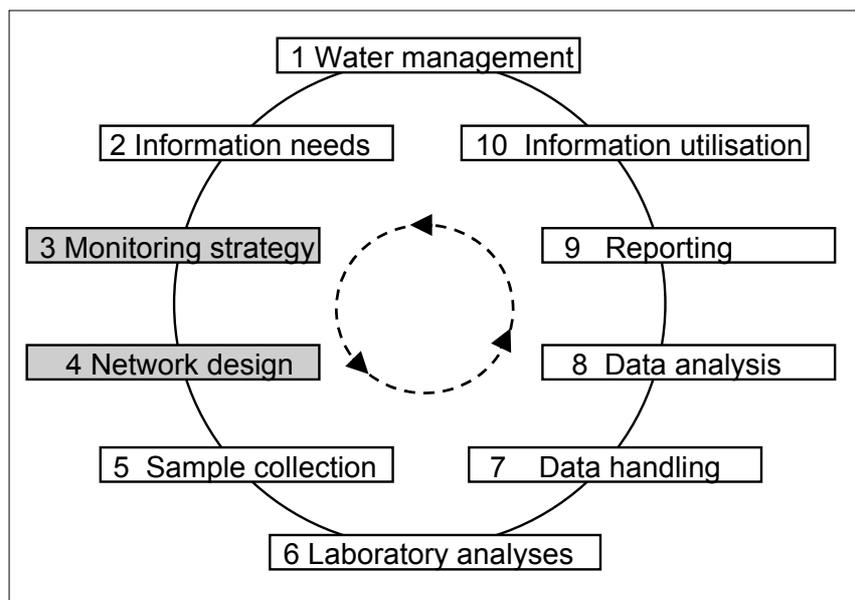


Figure 4.1:
Monitoring Strategy and
Network Design: Steps 3 &
4 in the monitoring cycle

This chapter discusses the aspects of monitoring strategy and network design as they are applicable to water quality monitoring under Hydrology Project.

Monitoring Strategy

After the specification of monitoring objectives and information needs, a general strategy is required to design and operate the monitoring programme in such a way that the desired information is obtained. A strategy gives the general approach which is to be followed, while the network design specifies the details.

The following points summarise the general strategy of water quality monitoring under Hydrology Project.

- Water quality monitoring is focused on *ambient* water so as to indicate the actual status and trends that are relevant for the functions and uses of the river/reservoir. Early warning is not a monitoring objective, nor is quality analysis of effluents, suspended matter, bottom sediment or biological organisms. These activities are not part of the monitoring effort unless specified otherwise, for a specific reason.
- Water quality monitoring is to be a structured activity, with defined and documented procedures for all activities such as sampling, field and laboratory analysis and data analysis. This will create consistency between different organisations and allow comparison of data collected by them.
- Water quality sampling is to be conducted at an established network, with defined stations that get sampled at a regular frequency. The defined stations are of a specific category, such as monitoring, survey and surveillance (as given in Table 3.1). Within these categories, there are also certain types, e.g. baseline, trend and flux types under the category 'monitoring'.
- Water quality sampling is based on 'grab' samples of the ambient water, unless specified otherwise for a specific reason.
- Water quality analysis is focused on physico-chemical analyses to provide information about the status of the water quality (this includes BOD and coliform analyses). Biological surveys, bio-assays or ecotoxicological analyses are not part of the water quality monitoring.
- Each organisation is responsible for its own water quality monitoring (defining monitoring network, maintaining laboratory and equipment, managing staff, .etc.) Wherever possible, CWC and State surface water departments will coordinate activities, also taking into consideration PCB activities.

Network Design

The design of a monitoring network consists of three 'dimensions', which together form the 'Network Design':

- the density (how many locations in a particular area or on a certain river-stretch are investigated, and what are the locations)
- the frequency of sampling (how many samples per year are collected from each location)
- the list of parameters that are analysed in each sample collected.

Chapter 4.2 discusses these 3 dimensions, organised per monitoring type. Network design is illustrated with a worked out example in Chapter 4.2.

Note that ideally a sampling location should be located at a river gauging site, but this is not necessarily always so. Also note that sampling location or stations in this chapter indicate the approximate vicinity where a sample is to be collected, the exact position is referred to as 'site' and is further discussed in chapter 5.

4.2 NETWORK DENSITY, SAMPLING FREQUENCY AND PARAMETER SELECTION

4.2.1 INTRODUCTION

The categories of water quality monitoring and types of water quality monitoring stations and their objectives have been presented in Table 3.1. For each particular monitoring type referred to, it is necessary to define:

- Network density:
- Sampling frequency: How often should samples be collected
- Parameters

This complete information is now presented in Table 4.1 and discussed below.

The 'network density' of the monitoring programme refers to where monitoring will be carried out and how many monitoring stations there should be. (i.e., approximately the number of sampling points per unit area). With reference to Table 4.1, it is possible to list each sample type and discuss the network density, which may be appropriate as below.

Sampling frequency is defined as the number of samples 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. Sampling frequency can also be discussed in terms of the each of the sample types listed in Table 4.1 as below.

Category	Type	Objective	Network Density	Sampling Frequency (per year)	Parameters
Monitoring ⁵	Baseline	Natural Background Concentrations	One for each mainstream stem and one for each major tributary (>20% of flow at confluence)	Initially 3 - 4 then repeat every 2 - 3 years	see Table 4.2
	Trend	Detection of changes over time due to anthropogenic influences	Mainstream: - after each 1½ 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	Simultaneously with flow measurement (ie, 24 X)	
Surveillance ⁶	Water Use	Check that water is fit for use	At all points of use or intake	see chapter 4.2.4, 'Water Use' Surveillance	see Table 4.3
	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 ⁷	Classification	Classification of reach	Within each reach	Annually (less frequently if reach unchanged, more frequently if considerable changes)	see Table 4.4
	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	

⁵ Monitoring: Long-term, standardised measurement in order to define status and trends

⁶ Surveillance: Continuous, specific measurement for the purpose of water quality management and operational activities

⁷ Survey: A finite duration, intensive programme to measure for a specific purpose

Suggested water quality parameters for each sample type are given in Table 4.2 (Monitoring Category), Table 4.3 (Surveillance Category) and Table 4.4 (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.

It is important to remember that the parameters suggested in Tables 4.2. to 4.3 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 (e.g., 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 (e.g., 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 the concerned pollutant(s) 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.

Parameter Group	Parameter	Baseline	Trend	Flux
General	Temperature	✓	✓	
	Suspended Solids	✓	✓	✓
	Conductivity	✓	✓	
	pH	✓	✓	
	Dissolved Oxygen	✓	✓	
	Total Dissolved Solids	✓	✓	
Nutrients	Ammoniacal Nitrogen	✓	✓	✓
	Total Oxidised Nitrogen	✓	✓	✓
	Total Phosphorus	✓	✓	✓
Organic Matter	Chemical Oxygen Demand		✓	
	Biochemical Oxygen Demand		✓	✓
Major Ions	Sodium	✓		
	Potassium	✓		
	Calcium	✓		
	Magnesium	✓		
	Carbonates and Bicarbonates	✓		
	Chloride	✓	✓	✓
	Sulphate	✓		
Other Inorganics	Silica	✓		
	Fluoride			
	Boron			
Metals	Cadmium		✓	✓
	Mercury		✓	✓
	Zinc		✓	✓
Organics	Pesticide (Indicator)	✓	✓	✓
	Surfactants		✓	
	Mineral oil & petroleum products			
	Phenols			
Microbiological	Total coliforms	✓	✓	
Biological	Chlorophyll 'a'	✓	✓	

Table 4.2: Water Quality Parameters (Monitoring Category)

Parameter Group	Parameter	Water Use ⁸					Pollution Control ⁹
		D	I	B	L	F	
General	Temperature	✓	✓			✓	✓
	Suspended Solids	✓				✓	✓
	Conductivity	✓	✓		✓	✓	✓
	pH	✓	✓	✓	✓	✓	✓
	Dissolved Oxygen			✓		✓	✓
	Total Dissolved Solids		✓				
Nutrients	Ammoniacal Nitrogen	✓				✓	✓
	Total Oxidised Nitrogen				✓		
	Total Phosphorus						
Organic Matter	Chemical Oxygen Demand						✓
	Biochemical Oxygen Demand	✓		✓		✓	✓
Major Ions	Sodium		✓				
	Potassium						
	Calcium		✓				
	Magnesium		✓				
	Carbonates and Bicarbonates						
	Chloride	✓	✓				✓
	Sulphate						
Other Inorganics	Silica						
	Fluoride	✓					
	Boron		✓				
Metals	Cadmium					✓	
	Mercury					✓	
	Zinc						
Organics	Pesticide (Indicator)	✓				✓	
	Surfactants						
	Mineral oil & petroleum products	✓					
	Phenols	✓					
Microbiological	Total coliforms	✓	✓ ¹⁰	✓	✓	✓	✓
Biological	Chlorophyll 'a'	✓				✓	

Table 4.3: Water Quality Parameters (Surveillance Category)

⁸ 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

⁹ Suggested suite of parameters to test for organic pollution. For guidance only, specific parameters sampled will depend upon the discharge being monitored.

¹⁰ 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

Parameter Group	Parameter	Water quality criteria requirements
General	Temperature	
	Suspended Solids	
	Conductivity	✓
	pH	✓
	Dissolved Oxygen	✓
	Total Dissolved Solids	
Nutrients	Ammoniacal Nitrogen	✓
	Total Oxidised Nitrogen	
	Total Phosphorus	
Organic Matter	Chemical Oxygen Demand	
	Biochemical Oxygen Demand	✓
Major Ions	Sodium	✓
	Potassium	
	Calcium	✓
	Magnesium	✓
	Carbonates and Bicarbonates	
	Chloride	
	Sulphate	
Other Inorganics	Silica	
	Fluoride	
	Boron	✓
Metals	Cadmium	
	Mercury	
	Zinc	
Organics	Pesticide (Indicator)	
	Surfactants	
	Mineral oil & petroleum products	
	Phenols	
Microbiological	Total coliforms	✓
Biological	Chlorophyll 'a'	

Table 4.4: Water Quality Parameters (Survey Category)

4.2.2 MONITORING CATEGORY

The 'Monitoring' Category comprises the following types:

- Baseline
- Trend
- Flux

Baseline

This type, 'baseline' monitoring, is designed to build up a picture of the 'natural' (i.e., 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 (e.g., 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.

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

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 (e.g., 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). The exception to this rule would be if a major tributary joined the main river before the next '120% flow' point. In this case 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 (i.e., 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 km²) twelve 'Trend' samples should be obtained per year at each station. On smaller river catchments (<100,000 km²) twenty-four samples should be obtained at each station annually.

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

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.

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.

4.2.3 SURVEILLANCE CATEGORY

The 'Surveillance' Category comprises the following types:

- Water use
- Pollution control

Water Use

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 (e.g., 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

As it is impossible to generate a generic list of parameters for this type of monitoring, Table 3.3 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

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 (i.e., one upstream and one downstream) for each discharge that is having, or thought to be having, a detectable effect on river water quality (Note: analytical data for the discharge itself should be available from 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.

As noted in Table 4.3, 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 4.3 represent the type of analysis which might be undertaken to check a river or a discharge for organic pollution (e.g., to monitor effluent derived from a sewage treatment works).

4.2.4 SURVEY CATEGORY

The 'Survey' Category comprises the following types:

- Classification
- Management and research

Classification

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.

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.

The parameters for this sampling type are taken from the CPCB classification scheme for Indian river water quality standards (Table 4.4) as this is the classification which should be applied nationally.

Management and research

Samples 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 of sampling points as each survey must be planned individually.

As discussed above samples will normally form part of a special survey aimed at gathering information to address a particular problem. As with sample point location, therefore, no guidance is possible on the number of samples which should be taken at each monitoring point as each survey of this type should be planned individually.

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.

4.2.5 INTEGRATED AND AGGREGATED WATER QUALITY SAMPLES

The objective of water quality sample collection is to obtain a small portion of water which accurately represents the characteristics of the water body being sampled. This is sometimes referred to as taking a 'representative sample' and is vitally important if the analysis which follows sampling and the conclusions which are ultimately drawn from the data are to have any validity.

Normally, for water quality sampling so-called 'grab sampling' is used. That is, an individual sample is collected from a particular place at a particular time normally by means of a sampling device. Grab samples (also called 'spot' and 'snap' samples) are normally taken where the watercourse is known to be well mixed and representative of the water quality in the surrounding reach or area. In addition to grab samples, there are a few types of composite sample which are called 'integrated water quality samples'. These would only be collected under certain circumstances as described below. Preferably, samples should be collected at a well-mixed region of a river and thus a grab sample is adequate.

Time integrated sampling

These integrated or 'composite' samples are normally taken if a description of the watercourse over a particular time period is required. A time integrated sample consists of grab samples collected at the same sampling point at different times and mixed. Time integrated samples can also be 'flow-proportional bulked' where the final sample is made up by mixing portions of the individual samples in proportional to the flow in the river at the time the sample was obtained. This type of sample gives a good indication of the load of pollutant in a river where the flow is known to vary considerably with time.

Space integrated sampling

These integrated samples are normally taken where the watercourse is known to be not well mixed. By obtaining samples at different depths or widths (or both) in a watercourse and mixing them, a well integrated sample which simulates a more thoroughly mixed water body can be achieved.

The particular type of sample required at each sampling station must be judged according to the prevailing conditions in the watercourse and the type of information required from the sample. Integrated water quality information is potentially more cost effective compared to differentiated information. Integrated sampling does not reduce the number of samples to be collected but does reduce the number of samples to be analysed. This is done by clubbing samples in space or time

Aggregate parameters

In addition to integrated samples, it should be recognised that some water quality parameters are integrated or 'aggregate' parameters. These parameters do not represent the concentration of a single chemical compound, but give an aggregated measurement that is indicative of the presence of one or more compounds. Aggregate parameters give a result that relates to a broad characteristic of the sample. Examples of common aggregate parameters are Electrical Conductivity and Total Dissolved Solids.

Aggregate parameters can be especially useful for monitoring of pollution related parameters. Examples of such aggregate variables are:

- Organic Carbon: Total (TOC), Dissolved (DOC)
- Kjeldahl Nitrogen: (organic nitrogen and ammonia)
- Chemical Oxygen Demand (COD)
- Biochemical Oxygen Demand (BOD)
- Organic Halogen: Adsorbable (AOX), Extractable (EOX), Volatile (VOX)

4.2.6 RECOMMENDATIONS ON FREQUENCY AND PARAMETERS

Based on the above information related to categories and types of stations, recommendations have been made regarding assigning different *types* of monitoring stations in a monitoring network and the sampling frequency. Parameters for each of the types of stations are listed in Table 4.5. These recommendations are especially relevant for the State surface water (irrigation) departments who are just recently beginning with water quality monitoring:

- Since not much is known about the present water quality status at various stations, to start with, all stations will be a combination of *baseline* and *trend* stations.
- Samples will be collected every two months: May/June, August, October, December, February, and April. This will generate six samples from perennial rivers and 3-4 samples from seasonal rivers, every year.
- After data are collected for three years, the stations will be classified either as *baseline*, *trend* or *flux* station.
- Those stations, where there is no influence of human activity on water quality, will be reclassified as *baseline* stations. Others will remain as *trend* stations.
- If a station is classified as a *baseline* station, it will be monitored, after every three years, for one year every two months.
- If a station is classified as *trend* station, it will continue to be monitored but with an increased frequency of once every month.
- Stations will be classified as *flux* stations where it is considered necessary to measure the mass of any substance carried by the flow. The frequency of sampling at such stations and analyses of constituents of interest may be increased to 12 or 24 times per year. Measurement of discharge at such stations is necessary.
- The recommended parameters for analysis are given in Table 4.5.
- Other inorganics, metals, organics and biological parameters will be determined as part of special *survey* programmes.
- The *survey* programmes may include some of the trend stations where there is a need for determination of any of these groups of parameters.

- The *survey* programmes will ordinarily be of one year duration. The sampling frequency may be the same as that for trend stations.
- Special arrangements for sampling and transport of the samples would be necessary for the *survey* programmes and microbiological samples.

Parameter Group	Initially	Baseline	Trend
General	Temp, EC, pH, DO, TDS	Temp, EC, pH, DO, TDS	Temp, EC, pH, DO
Nutrients	NH ₃ -N, NO ₂ + NO ₃ , total P	NH ₃ -N, NO ₂ + NO ₃ , total P	NH ₃ -N, NO ₂ + NO ₃ , total P
Organic matter	BOD, COD	None	BOD, COD
Major ions	Ca ⁺⁺ , Mg ⁺⁺ , K ⁺ , Na ⁺ , CO ₃ ⁻⁻ , HCO ₃ ⁻ , Cl ⁻ , SO ₄ ⁻⁻	Ca ⁺⁺ , Mg ⁺⁺ , K ⁺ , Na ⁺ , CO ₃ ⁻⁻ , HCO ₃ ⁻ , Cl ⁻ , SO ₄ ⁻⁻	Cl ⁻
Other inorganics	None	None	None
Metals	None	None	None
Organics	None	None	None
Microbiological	Total coliforms	None	Total and faecal coliforms
Biological	None	None	None

Table adapted from HP report: 'Surface Water Quality Network Design, Guidelines and an Example', June 1997

Table 4.5: Parameters of analysis for surface water samples

4.3 EXAMPLE APPLICATION: NETWORK DESIGN IN MAHANADI BASIN

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:

1. river basin boundaries
2. sea or ocean boundaries
3. state boundaries
4. national boundaries
5. 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 4.2 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 4.3.

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 4.4 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 (fertilisers, 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.

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 centres. Use the overlay created in step 3 to find the best position for the baseline stations. Figure 4.5 shows the baseline stations for Mahanadi.

Note that areas upstream of visible sources of pollution may be polluted to some extent (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 section 3.2.3. 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 4.6) 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 therefore 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 4.6) 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 3.6 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 4.6). 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 5.2. 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, to the same map that contains the newly designed network, see Figure 5.3. 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 5.4, a duplication of effort can be observed at several locations. This observation should be used to start a dialogue between both organisations. Mandates and availability of data (are the data public?) should be the main topics for such a dialogue.

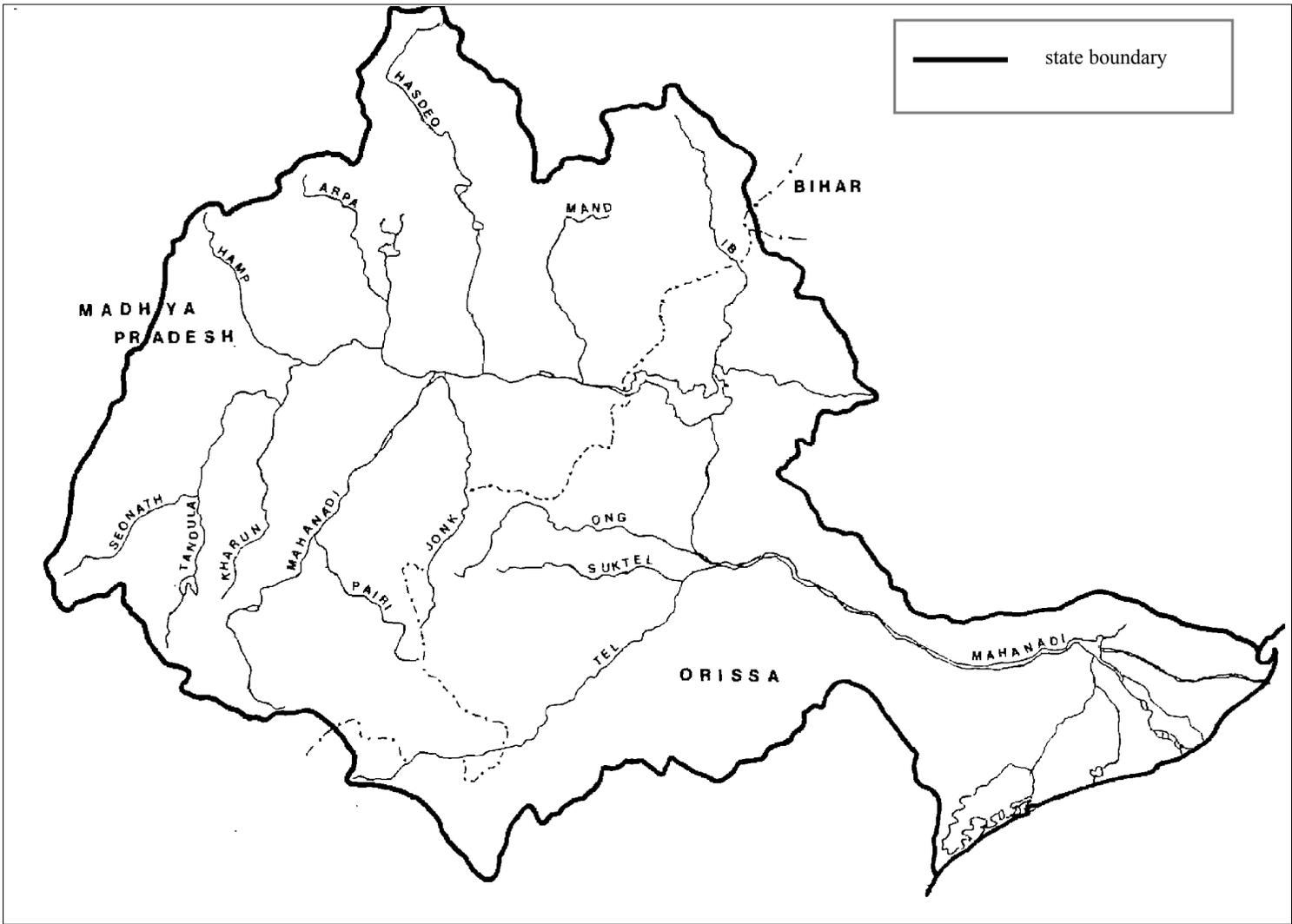
Likewise you should review the mandate of your organisation. The network proposed so far only addresses objectives (a), (b) and (c) listed in chapter 3.1.

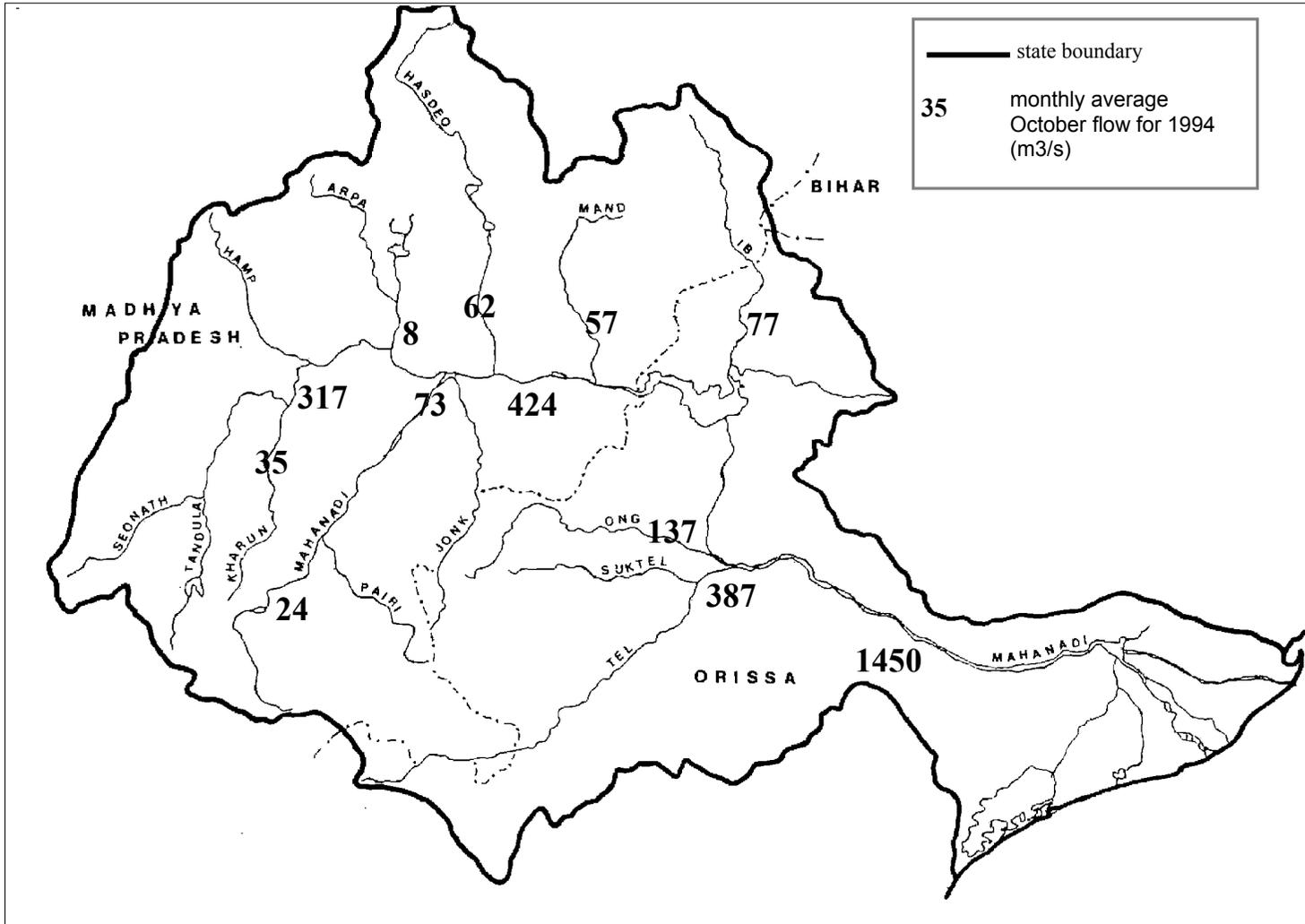
Step 11: adding Surveillance and Survey type stations

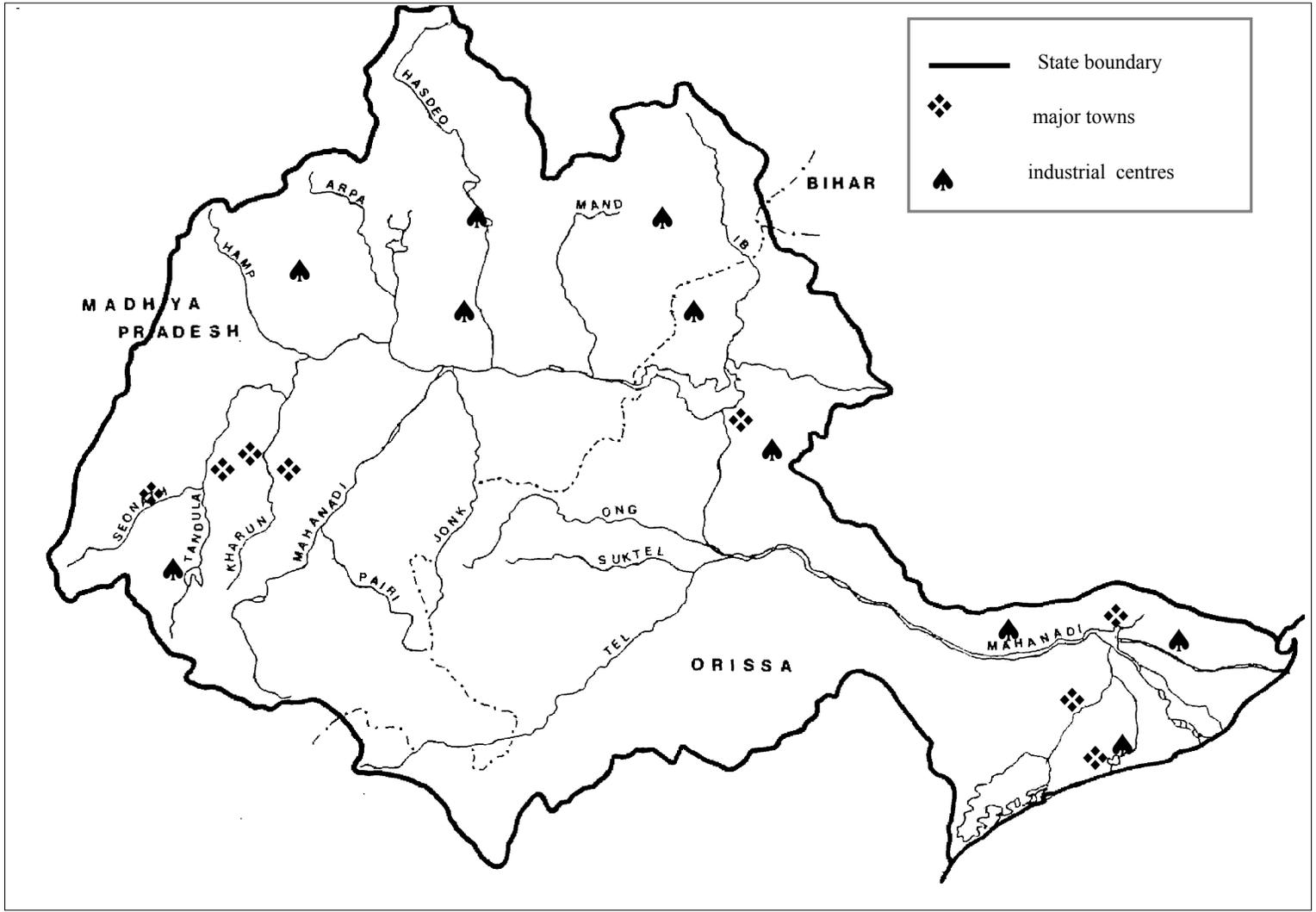
To be done by the agencies after step 10 and only if the mandate so requires.

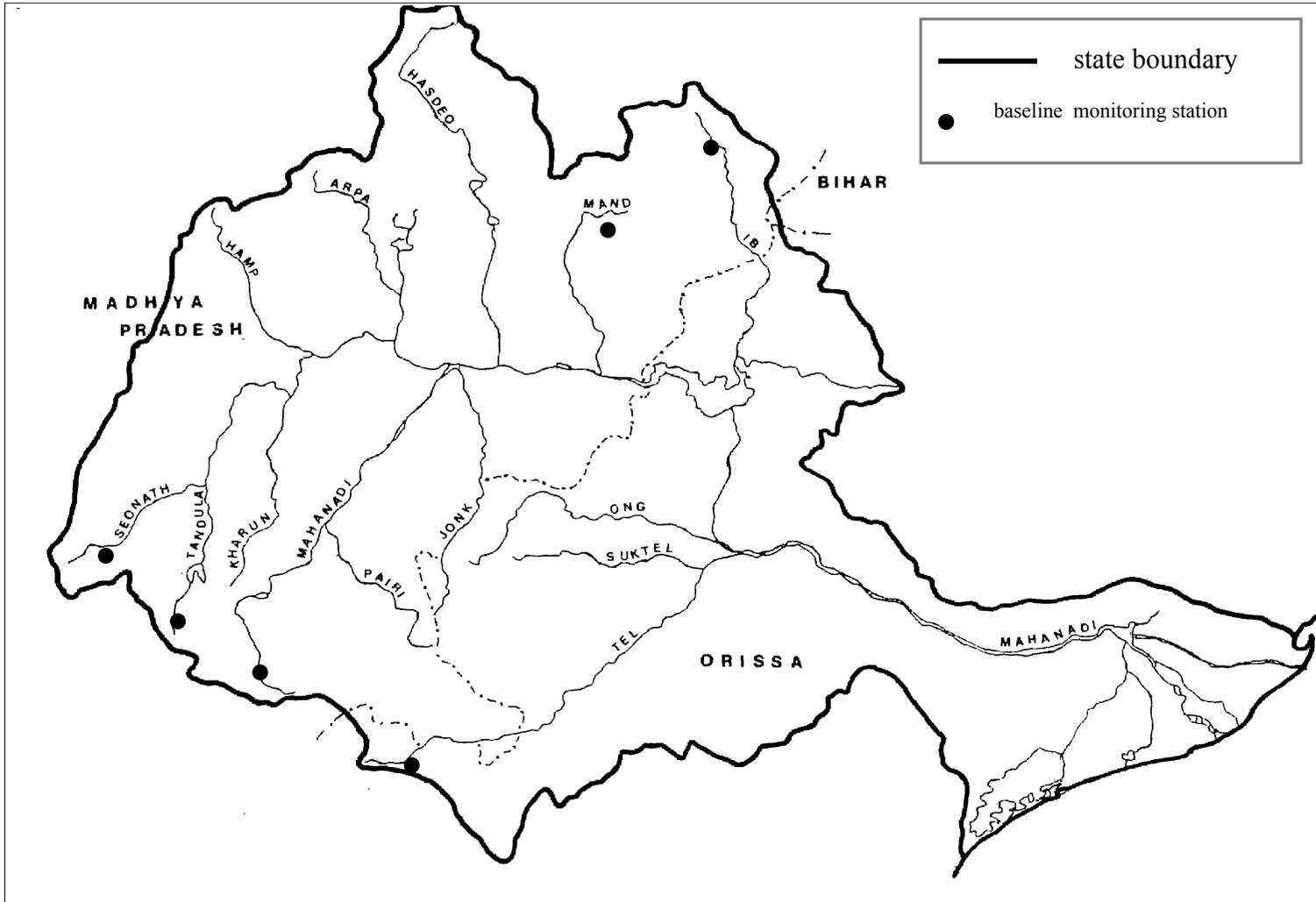
Step 12: sampling frequency and analysis parameters

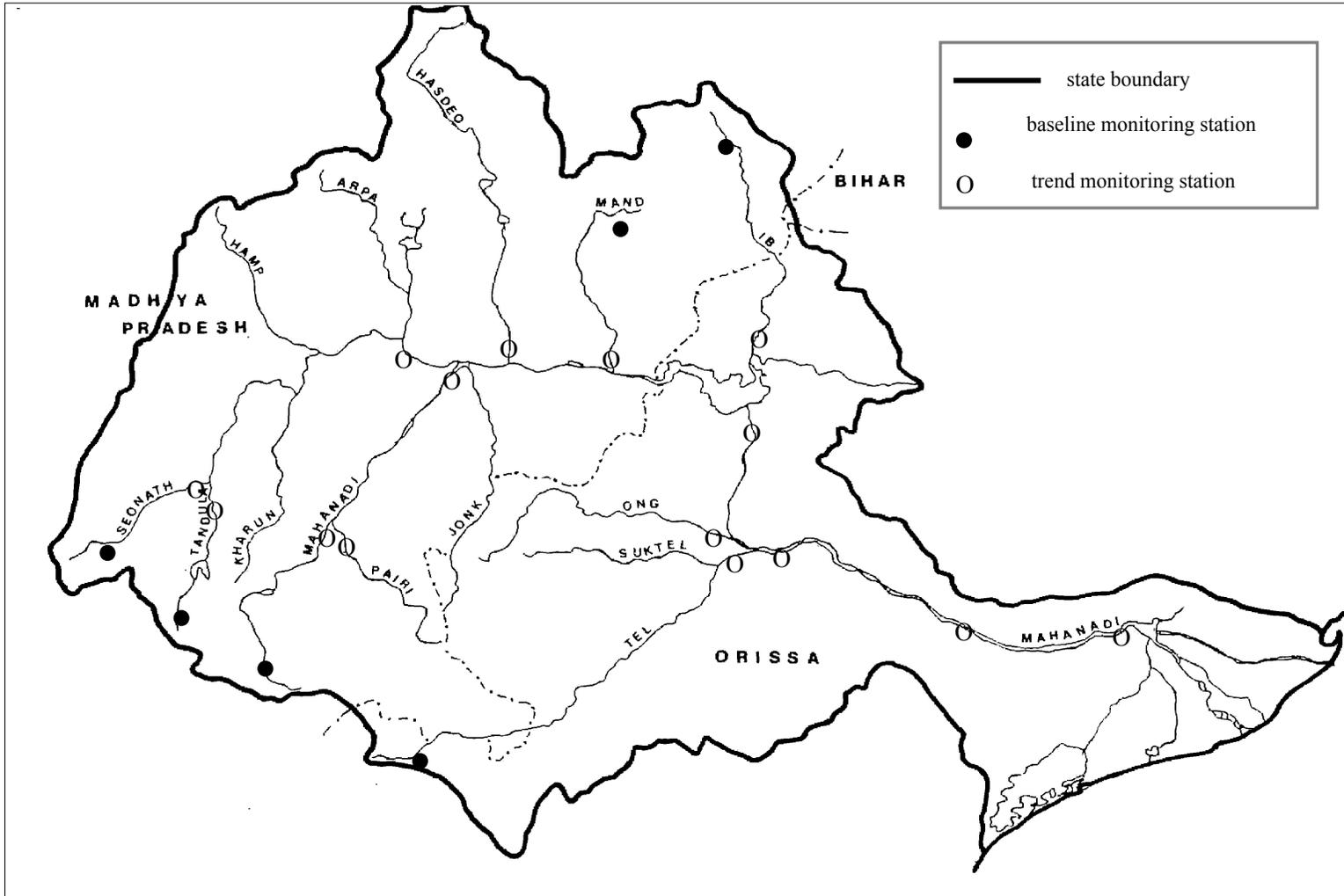
Use the information given in chapter 4.2 and Tables 4.1 to 4.4 keeping in mind the objectives, feasibility of sampling, costs and above all capacity of your field staff and your laboratory(s).

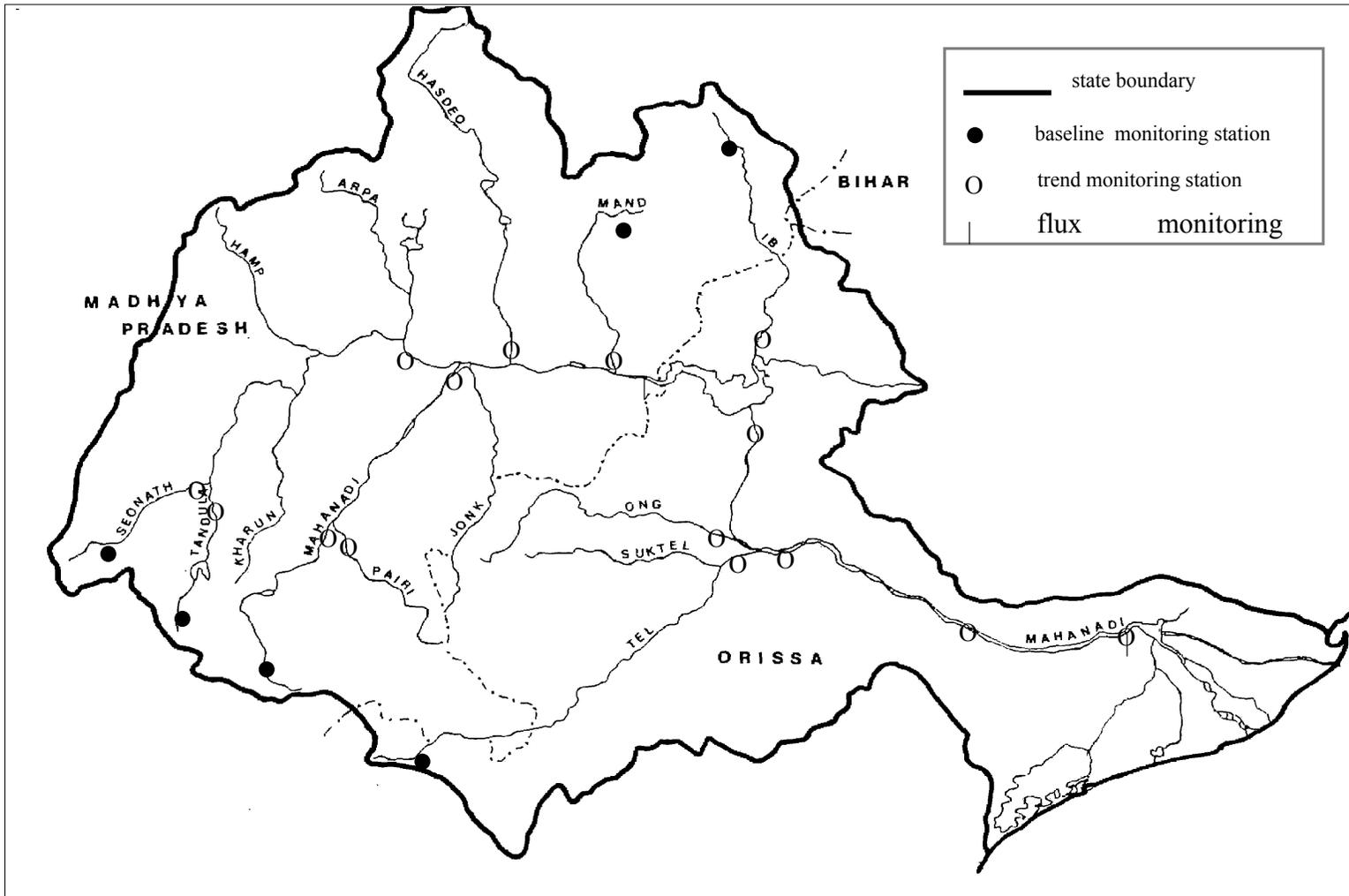












5 NETWORK RATIONALISATION

5.1 INTRODUCTION

Network rationalisation refers to the review and 'optimisation' of existing water quality networks. Periodic analysis and review of data is essential in any water quality monitoring programme. It may lead to new or redefined information needs, which may then be translated into a different monitoring network design: sampling locations, sampling frequency and parameters. An analysis and review of data will ensure that the monitoring programme is producing the information needed as defined by the monitoring objectives.

Within a single organisation, network rationalisation refers to an objective analysis of previously collected data. This analysis may lead to 'pruning' of the network stations if correlation can be established between stations or between parameters. This saving of effort can be directed towards an increase in frequency of measurement for greater reliability and/or introduction of new water quality parameters for characterisation.

Network rationalisation is also very important when multiple organisation are conducting water quality monitoring within a single state or river basin. In this case, network rationalisation refers to a cooperative analysis of the monitoring networks by all the involved organisations. This analysis includes a review of the monitoring objectives and information needs of the different organisations as well as their network design: sampling locations, sampling frequency and parameters. Such an analysis may eventually lead to optimisation of effort and costs if it is identified that more than one organisation is monitoring the same location for the same purpose. In this manner, rationalisation can spare monitoring capacity which can be used for new monitoring activities.

Steps in rationalisation are shown below.

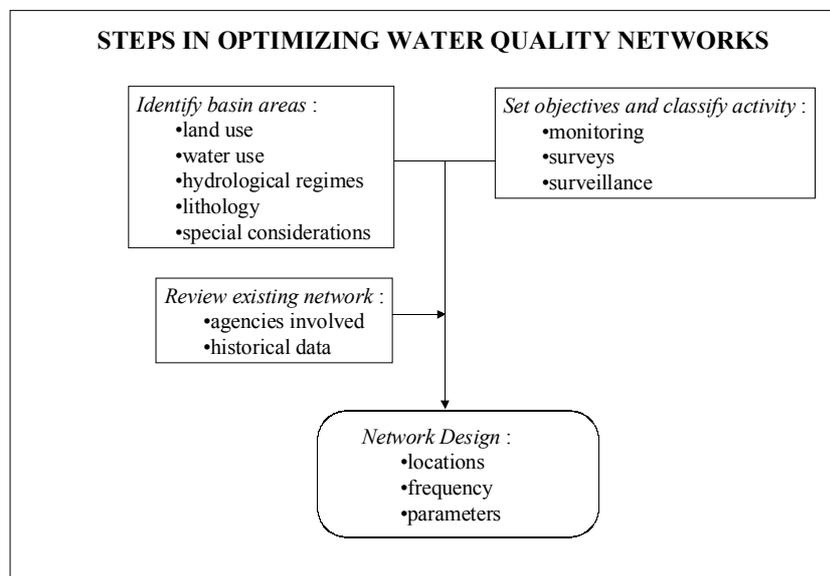


Figure 5.1:
Steps in Rationalising Water
Quality Networks

The releasing of spare monitoring capacity through regular data review, is particularly important in the context of the Hydrology Project. The problem of water pollution due to trace contaminants has not yet been quantified, as India's monitoring programmes are not, to any large extent, set up to detect this type of pollution. Now, however, with laboratories being established and upgraded with advanced level equipment under HP, there is a major opportunity to monitor trace contaminants and it is therefore essential that maximum use is made of this opportunity.

5.2 MONITORING OBJECTIVES OF DIFFERENT WATER QUALITY ORGANISATIONS

As a first step to network rationalisation for the multiple Hydrology Project agencies, the mandates and objectives of various Indian organisations conducting water quality monitoring were discussed at a series of technical meetings, and were formalised at the Workshop on Surface Water Quality Monitoring, Delhi March 7-8, 2000. The following mandates related to water quality monitoring were identified for organisations mentioned in Chapter 3.2:

1. assessment of water resources
2. control and management of water pollution
3. preservation of ambient water quality
4. supplying water of acceptable quality for different uses, particularly for domestic consumption and irrigation
5. training in water quality management
6. dissemination of water quality information

The HP surface water agencies identified (1), (4) and (6) above as their prime mandates.

At the Delhi Workshop on Surface Water Quality Monitoring it was recommended that water quality monitoring networks should be designed with objectives in consonance with these mandates. Thus the objectives for HP agencies would be:

- monitoring for establishing baseline water quality, observing trend in water quality changes and calculation of flux of water constituents and
- surveillance for drinking water and irrigation use (in comparison with standards).
- dissemination of water quality information

5.3 RATIONALISING NETWORKS OF MULTIPLE ORGANISATIONS

In general there is no need for more than one organisation to measure at a particular location. Potential needless duplication of measuring effort should be recognised in the design phase of a network (chapter 4). In some cases there may however be good arguments for some overlap in the monitoring programmes of different organisations, examples are:

- in case of a very important location, e.g. at the boundary of a state
- in case data collected by an organisation are not available to others
- in case of doubt on the reliability of the measurements
- in case the information needs of the organisations (frequency, parameters) do not match

If two or more organisations want to rationalise the overlap in their networks, it should delegate one or more knowledgeable persons to take a seat in a working group. The working group's assignment is to report on the on outcome of the following steps:

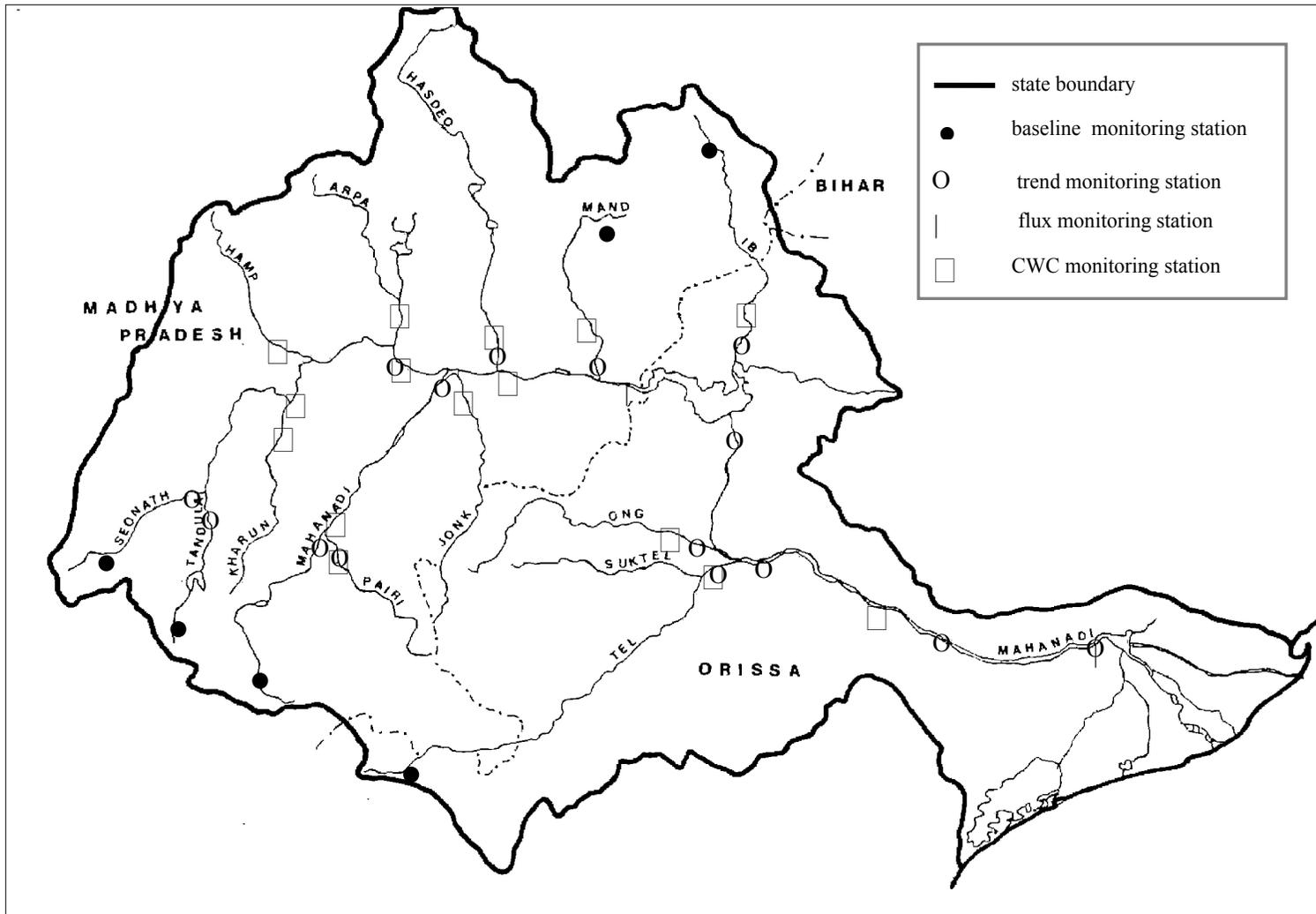
1. **Comparing information needs.** If information needs are too different, e.g. pollution monitoring at a paper mill outlet compared to biomonitoring of river sediments there is not much overlap in the monitoring programmes and the need for integration is small
2. **Comparing networks.** Actual networks should be compared in detail, that is site wise and parameter wise keeping in view the mutual measuring frequencies.
3. **Investigate if the data are public domain.** If an organisation publishes its data in a yearbook, available to the public, there seems to be no reason not to provide the same to other organisations.

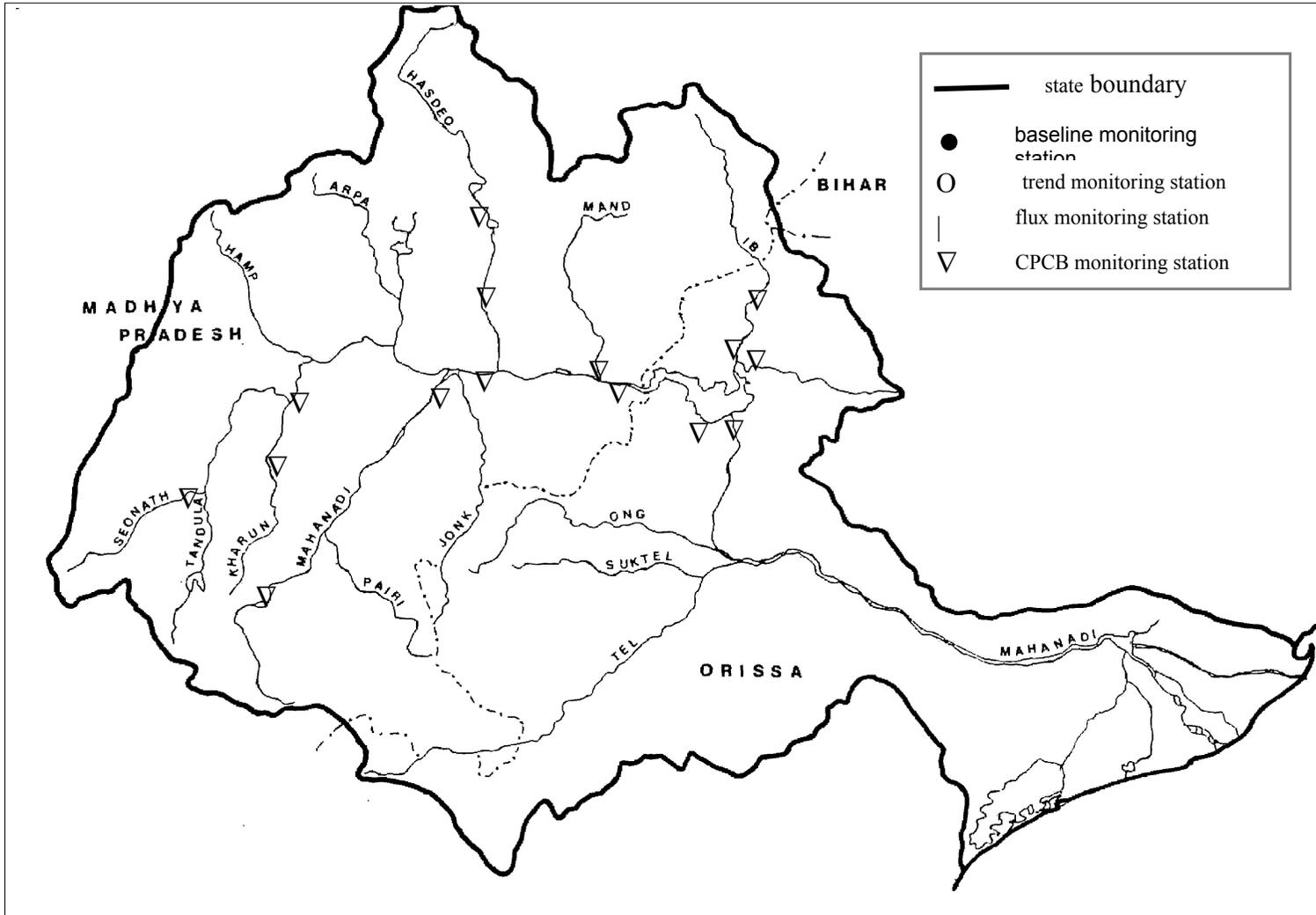
4. **Comparing historical data.** If historical data for the same location are available from both organisations they should be compared in order to find out if the required similarity between the data is present. Are the data reproducible.
5. **Demonstration of the validity of data.** The organisations should inform each other on the validation checks performed on the data.
6. **Demonstration of AQC programmes.** The organisations should inform each other on the analytical quality control programmes they employ to ensure the needed quality of the data.
7. **Summarise the findings and recommend on integration of the networks.**

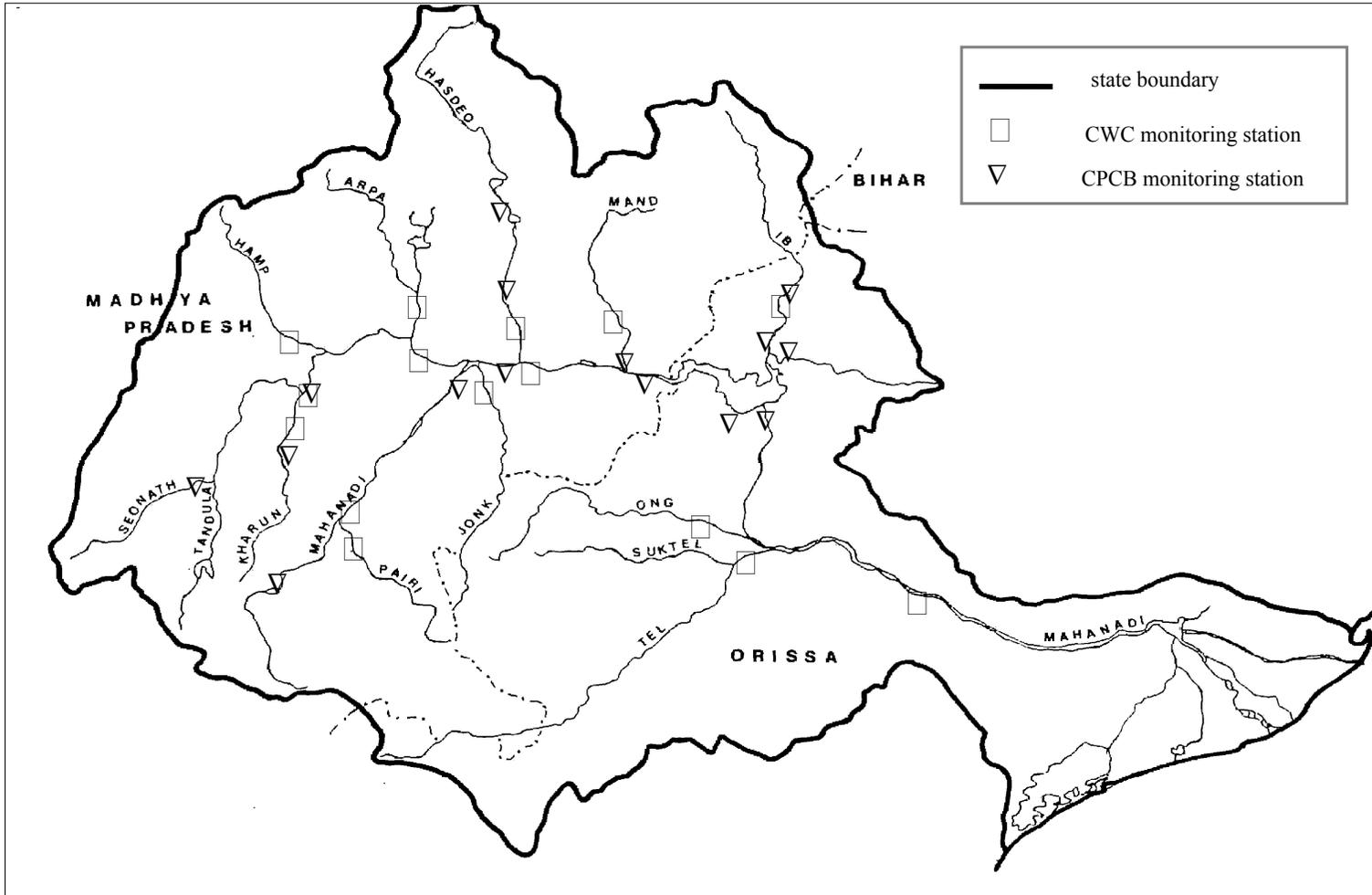
Examples of comparing networks (step 2) can be given for the Mahanadi river basin in the states of Madhya Pradesh and Orissa. The Mahanadi river has been historically monitored by CWC and State Pollution Control Boards. Under the Hydrology Project, State surface water departments also started monitoring the river.

Comparison of the monitoring networks is given in a series of figures:

- Comparison of CWC and State monitoring locations (Figure 5.2)
- Comparison of CPCB (MINARS) and State monitoring locations (Figure 5.3)
- Comparison of CWC and CPCB (MINARS) monitoring locations (Figure 5.4)







5.4 PRINCIPLES FOR NETWORK RATIONALISATION

This section discusses the issues relevant to rationalising an existing network, and the principles that should be followed in doing so. The examples given below are specifically relevant to network rationalisation within one organisation, however, they can also be applied for several organisations who are conducting water quality monitoring within the same state or river basin. In both cases, rationalisation must be seen as a type of optimisation, to gain the most water quality information with the available resources of the organisation(s) doing the monitoring.

Within a single organisation the following types of data analyses should be made:

1. Is there a correlation between different parameters at one station? If there is a good correlation between two or more parameters, then possibly one or more parameters could be dropped from the parameter list, saving analysis effort. The values for the dropped parameter(s) should then be estimated from the remaining, measured parameter. Examples of possible parameter correlation are BOD-COD, EC-major cations/anions, etc.
2. Is there a correlation between water quality parameter(s) and river discharge at a station? If there is a good correlation then water quality information could be approximated at all times that discharge information is available. This can supply additional water quality information at times between sampling events, without additional sampling effort.
3. Is there a correlation in parameters between 2 (or more) stations? If such a correlation exists, then one of the stations could be dropped, thus saving on sampling and analysis effort. The water quality information for the dropped station should then be estimated from the parameters at the measured station. Alternatively, the redundant sampling station could be moved to a new location where unique water quality information will be gained.
4. Is the sampling frequency sufficient to meet the monitoring objectives (e.g. if an objective is trend detection, is the frequency high enough to be able to detect trends?). Analysis of the data with respect to the monitoring objectives may result in a raising or lowering of sampling frequency.
5. Does monitoring of 'survey' or 'surveillance' category monitoring indicate any new water quality issues which should be taken up in 'monitoring' category (i.e. flux or trend type)? If so, new locations and/or parameters may be added for monitoring, that is to say, the network design can be adapted.

Since the analyses for rationalisation (optimisation) involves statistical techniques, sufficient historical data should be available. Thus, rationalisation of a network may usually be done only after say 3 to 5 years of data collection.

5.5 EXAMPLE OF NETWORK RATIONALISATION, CAUVERY RIVER¹¹

An example of network rationalisation within one monitoring agency is given for the Cauvery River. The CPCB has been monitoring water quality in the Cauvery river since 1980. In 1995, the CPBC decided to review the monitoring programme they had for the river and see how the monitoring programme conducted within their own organisation could be improved. The objectives of the exercise were to rationalise and optimise the monitoring programme in terms of the following:

- to suggest deletion/addition of parameters to the existing parametric list;
- to suggest deletion/relocation of certain sampling sites, if necessary;
- to suggest minimum frequency at which the monitoring should be conducted.

¹¹ Extracted from 'Optimisation of Monitoring Programme for River Cauvery', Monitoring of Indian National Aquatic Resources Series, MINARS/11/1995-96, CPCB, Delhi

5.5.1 BACKGROUND

The Cauvery River is one of the 14 major rivers of India and ranks number 8 among the Indian Rivers. The catchment area of the river is 87,900 sq. km. spread over Karnataka (41.2%) Kerala (3.3 %) and Tamil Nadu (55.5%). The river travels a distance of 354 km. through Karnataka and 416 km. through Tamil Nadu, totalling 770 km. to discharge into Bay of Bengal.

The CPCB started monitoring of river Cauvery in 1980 at two locations in Karnataka. Since 1990, the monitoring is being conducted at 20 locations. The growth of the monitoring network is presented in Figure 5.5.

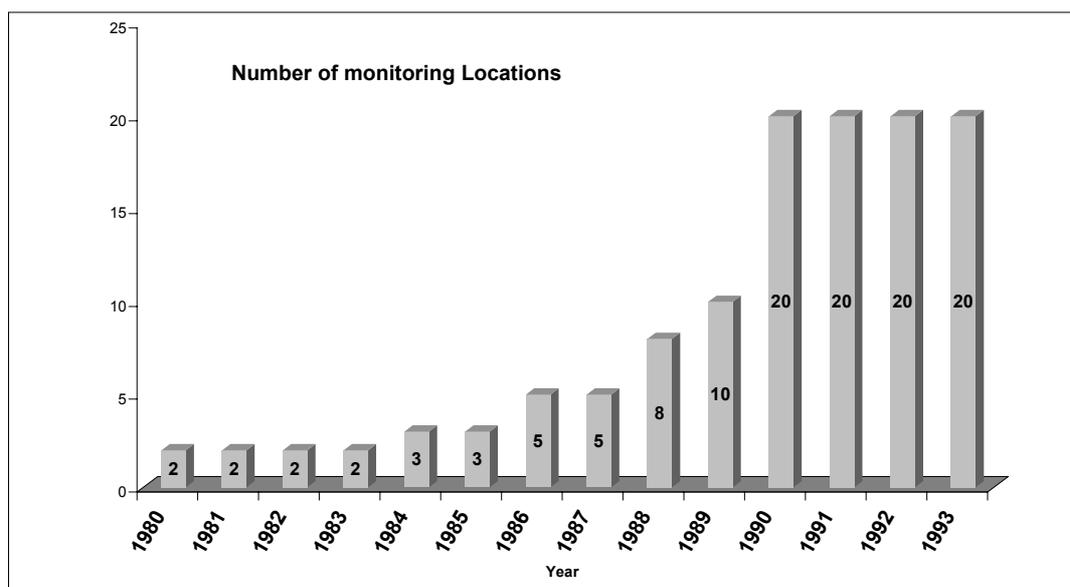


Figure 5.5: Growth of Monitoring Locations on Cauvery River

Monitoring is not only an expensive exercise but is time consuming and tedious. The monitoring programme needs to be drawn very carefully to get the optimum results. Based on the data collected on the Cauvery River, it was attempted to rationalise and optimise the monitoring programme.

5.5.2 EXISTING MONITORING PROGRAMME

Monitoring Sites

The monitoring on Cauvery River is conducted at 20 sites from Napokulu in Karnataka to Pitchavaram in Tamil Nadu over a distance of 766 km.

At present the monitoring is conducted once a month at all the monitoring sites.

Parameters Monitored

Presently 24 parameters are analysed to study the water quality of river Cauvery at 20 monitoring stations. A list of the parameters is presented in Table 5.1.

1.	Temperature	13.	Hardness
2.	pH	14.	Calcium
3.	TSS	15.	Magnesium
4.	Velocity of flow	16.	Alkalinity
5.	Dissolved Oxygen	17.	Sulphate
6.	Biochemical Oxygen Demand	18.	Sodium
7.	Total Kjeldahl Nitrogen	19.	Chemical Oxygen Demand
8.	Nitrogen, nitrate + nitrite	20.	Total Dissolved Solids
9.	Total Coliform (MPN)	21.	Fixed Dissolved Solids
10.	Fecal Coliform (MPN)	22.	Phosphate
11.	Conductivity	23.	Boron
12.	Chloride	24.	Free Ammonia

Table 5.1: Parameters monitored in Cauvery river basin

5.5.3 METHODOLOGY ADOPTED

The logistic approach backed by statistical analyses of data has been adopted to rationalise/optimize the monitoring programme of river Cauvery. The statistical techniques used are Correlation Analysis, Analyses of Variance, and Least Significance Difference test. A brief description of the methodology adopted to undertake different tasks is given below.

Rationalisation of parameters list

Firstly the existing parametric list has been reviewed, keeping in mind the primary criteria requirement of the different classes of water and major agricultural and industrial polluting sources. For the remaining conventional parameters, correlation analyses have been used to decide whether or not to continue analysing these parameters.

Optimisation of monitoring locations

The existing monitoring sites have been scrutinised to identify the stations existing in close proximity to each other without having a significant polluting source between them. Subsequently correlation analyses for the major parameters have been performed to decide whether to continue or discontinue monitoring at one of the neighbouring sites.

Optimisation of monitoring frequency

In this case, the year has been divided into different seasons and analysis of variance has been conducted for different seasons at different stations for the major parameters. The objective of the analyses was to test whether variations among different months of the same season were significant. If the monthly variations for the major parameters at most of the sites for a particular season were significant, the frequency of monitoring for the particular season could be reduced. For other cases, least significance difference (LSD) test was conducted to identify the sub-groups having similar values. This analysis has two fold objectives firstly to decide about the frequency depending upon the number of subgroups and second to select the months for monitoring.

All the statistical analyses were conducted by using the software package "SPSS for windows".

5.5.4 RECOMMENDATIONS AND CONCLUSION

The determinations of the following parameters have been recommended for water quality monitoring of river Cauvery at all the locations.

1.	Temperature		Hardness
2.	pH	10.	Calcium
3.	TSS	11.	Magnesium
	Velocity of flow	12.	Alkalinity
4.	Dissolved Oxygen		Sulphate
5.	Biochemical Oxygen Demand 3 days, 27°C	13.	Sodium
6.	Total Kjeldahl Nitrogen	14.	Chemical Oxygen Demand
7.	Nitrogen (nitrate + nitrite)	15.	Fixed Dissolved Solids
8.	Total Coliform (MPN)	16.	Phosphate
	Fecal Coliform (MPN)	17.	Boron
9.	Conductivity	18.	Free Ammonia
	Chloride		
19.	Indicator of Toxicity		
20.	Indicator of Total Pesticides		
21.	Boron		
22-24	3 Optional Location Specific Parameters		

Table 5.2: Revised parameter list recommended for monitoring in Cauvery river basin at all stations (showing changes from original parameter list)

- As the parameters defining primary water quality criteria for the different Designated-Best-Use classes have been included in the recommended list of parameters as such, the parametric list need to be modified whenever the water quality criteria will be modified.
- To have baseline data the monitoring site located at D/S Napakula Bridge may be shifted to U/S of Bhagmandala.
- The monitoring at the 5 sites viz., 1386 at Karekuara village, 1322 at 1 km D/S R. Bhavani confluence, 1324 at Mohanur, 1325 at D/S Tiruchirappali, and 1326 at Coleroon may be discontinued because the values of most of the parameters could be estimated from the nearby sites. Thus it is recommended to monitor 15 sites in place of 20 monitored at present.
- The recommended 15 monitoring sites are shown in Figure 5.2.
- It is recommended to conduct the monitoring at a frequency of twice per season i.e., eight times per year against monthly i.e., twelve per year.
- The Months recommended for monitoring in various seasons are given below.

Season	Months recommended for monitoring
Winter (December, January, February)	January, February
Summer (March, April, May)	April, May
SW Monsoon (June, July, August, September)	June, August
N E Monsoon (October, November)	October, November

Conclusion

With the recommended programme, the total number of samples will be reduced from 240 per year to 120 per year. Accordingly the expenditure on monitoring of river Cauvery will be reduced by 50 percent, while the information gained from monitoring will remain essentially the same.

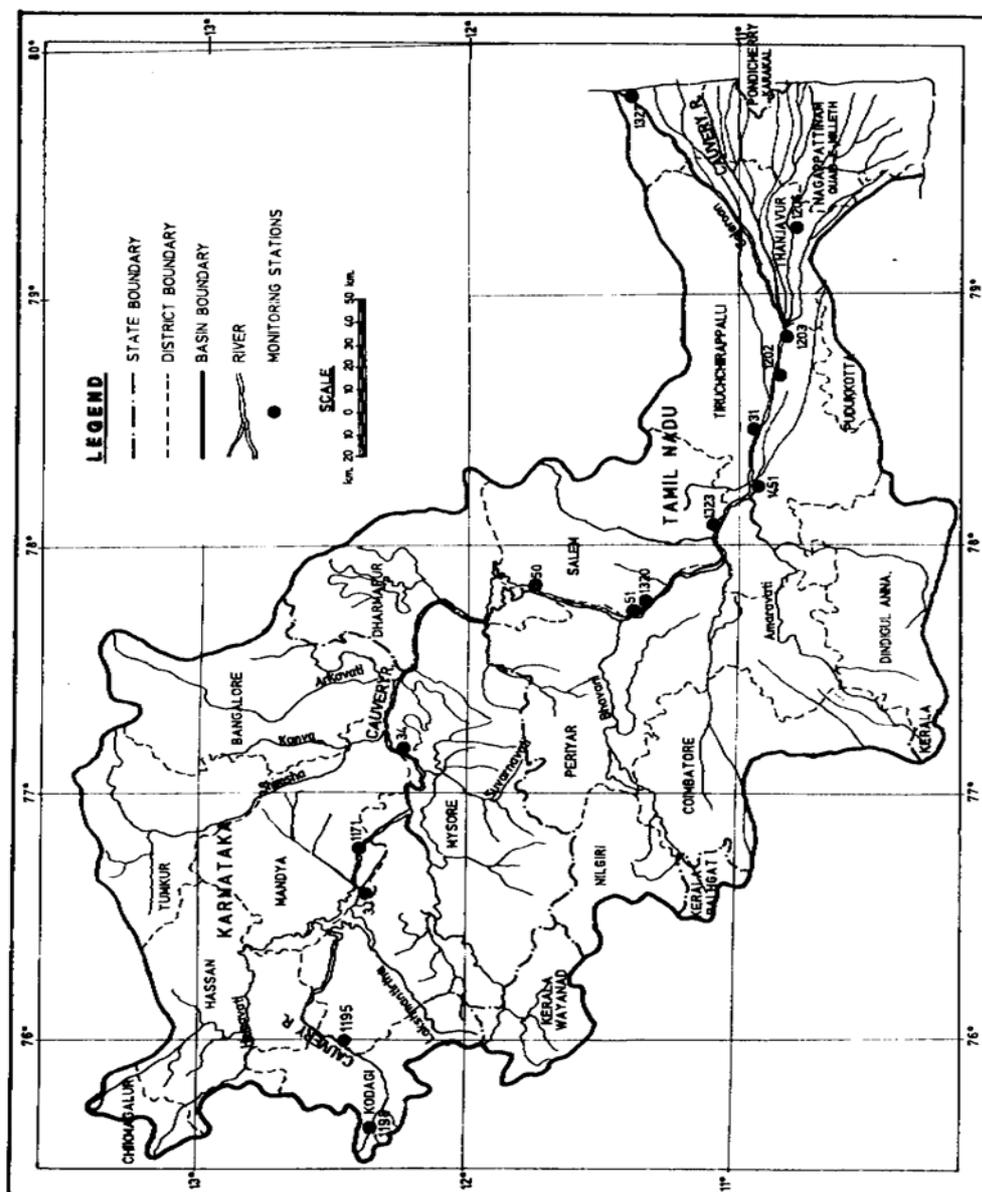


Fig 5.6: Recommended monitoring locations for Cauvery River after network rationalisation

5.6 HOW TO PROCEED WITH NETWORK RATIONALISATION

5.6.1 CWC REGIONS

- At the National Workshop on Surface Water Quality Monitoring, Delhi March 7-8, 2000, it was agreed that there is a strong need for review of water quality networks. CWC has historical water quality data collected over the past several years. These data may be used to classify stations in

their networks, keeping in view the monitoring objectives. This will lead to rationalisation of the existing networks and may result in modifications in regard to location of stations, frequency of sampling and choice of water quality parameters.

It was recommended that in CWC, the Chief Engineer of each region should mobilise a working group with the goals of :

- classifying monitoring stations as baseline, trend or flux
- coordinating between different agencies to avoid overlap and duplication of efforts
- rationalising parameters and frequencies for monitoring

The recommendations of the group would be implemented by the concerned Chief Engineer.

5.6.2 STATE LEVEL REVIEW COMMITTEES

At the National Workshop on Surface Water Quality Monitoring, Delhi March 7-8, 2000, it was agreed that for regular assessment of monitoring needs and optimisation of monitoring efforts, review of monitoring networks and data should be carried out periodically.

It was recommended that review of water quality networks should be done at regular intervals of three years by a State Level Review Committee to advise on:

- location of stations, frequency of monitoring and choice of parameters, including need-based and location-specific parameters
- coordination among agencies involved in water quality monitoring in the state to avoid duplication of efforts
- data analysis, interpretation and dissemination

The membership of the committee could comprise representatives from the following agencies:

- Central Water Commission (CWC)
- State level surface water agencies
- Central Pollution Control Board (CPCB)
- State Pollution Control Board (SPCB)
- Regional Data Centres of the State and CWC
- National Rivers Conservation Directorate (NRCD) representative in the State, if any
- Public Health Engineering Departments (PHED) and Water Supply and Sewerage Boards (WSSB)
- User agencies from educational and research institutes

The Committee may meet at least two times a year for discussing the progress of monitoring work. However, detailed review shall be carried out after 3 years, as recommended above.

- It was agreed that CWC would request CPCB to take the initiative in formulating the State Level Review Committees.

6 SITE SELECTION

6.1 GENERAL

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

- Wherever possible, the water quality sampling site should be located at an existing stream gauging site. This provides several important advantages:
 1. Discharge data is available which will provide important information for data analysis, for example allowing fluxes to be calculated;
 2. The site will in general be easily accessible and well maintained, especially if full time staff is present for stream gauging measurement;
 3. Any important changes at or near the site will be noted by the stream gauging staff.
- 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

6.2 SELECTING A WELL – MIXED SITE IN A RIVER

As a guide to where a river is likely to be well-mixed following a major discharge or tributary input, Table 6.1 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 (e.g., if an upstream discharge is a heated effluent, temperature could be used to check that the water body is completely 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.

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

Table 6.1: *Estimated distance for complete mixing in streams and rivers (retrieved from Chapman, 1992).*

6.3 SELECTING NON-RIVER SITES

Samples from reservoir sites will be collected from the outgoing canal, power channel or water intake structure, in case water is pumped. When there is no discharge in the canal, sample will be collected from the upstream side of the regulator structure, directly from the reservoir.

6.4 SAMPLING ACCESS

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 - e.g., 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)

6.5 SAFETY CONSIDERATIONS

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.

When sampling from a 'structure' the sampling personnel should pay attention to keep one's balance to avoid an unwanted fall off. When sampling is undertaken from a bridge the sampling personnel should be aware of the danger of traffic passing by. Drivers of vehicles may not take the required care because of the distraction caused by the sampling operation.

Another potential danger originates from the use of chemicals in the field. The only potentially dangerous chemicals carried are nitric and sulphuric acids. They come under the chemical hazard category 'inorganic acids and bases' which require gloves (made of butyl-rubber) to protect hands and glasses for eye protection. In case of skin or eye contact rinse thoroughly with abundant water and consult a doctor afterwards.

7 FIELD TECHNIQUES

This chapter describes the need for field measurements and furthermore describes how a sample is collected, handled and preserved until it gets to a laboratory. These aspects are all part of Step 5 of the monitoring cycle: 'Sample Collection'.

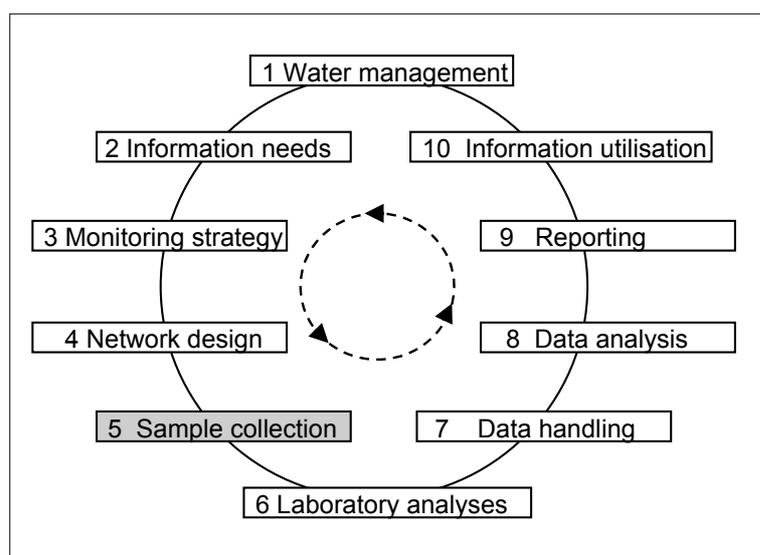


Figure 7.1:
Sample Collection: Step 5 of the
monitoring cycle

7.1 SAMPLE COLLECTION

Samples will be collected from the selected at the intended date and time of sampling. At that time the collector should collect the required volumes of water in the allocated container(s). Usually, the samples to be collected are grab-samples. If the sampling strategy prescribes other than grab-sampling than samples must be mixed (integrated over time and space) according to the instruction in chapter 3.4.

The sample should be collected from approximately 20cm below the water surface (see Figure 7.2). Care must be taken not to catch any floating material or bed material into the container. If the water is less than 40cm, the sample should be collected at half the actual water depth. If possible, sampling from shallow waters (less than 40cm) should be prevented by moving, within the site, to a deeper part of the river or stream.

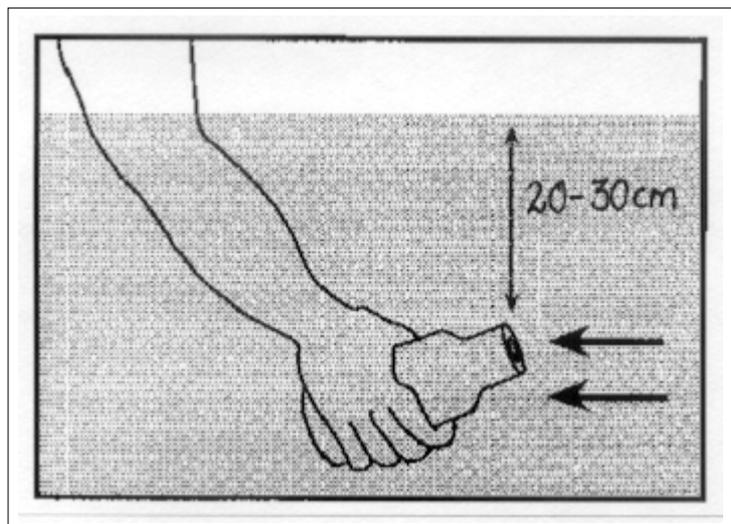


Figure 7.2:
Collecting a sample from surface water

Sample containers

Note that the type of container and the number of containers needed depend on the parameters selected for monitoring. Table 7.1 gives the required type of container, the suggested volume of sample and the recommended sample-pre-treatment for most common parameters.

In the design-phase of the monitoring programme, a list of containers should be prepared for each monitoring site. Starting from Table 4.2 the list of parameters to be analysed for a 'trend' station is known, in combination with the container specifications listed in Table 7.1 one can deduce the different number of containers needed. This example is worked out in Table 7.2. Note that the number of containers is surprisingly high. This is caused by a large number of combinations of container material (PE, Glass, Teflon), container specifics (special containers for DO, Pesticides, Coliforms) and pre-treatments (different acids to be added). From Table 7.2 one may conclude that some containers may be combined, this is however not recommended, for the following reasons:

- combining container 3 (Phosphorus) with container 6 (Coliforms) is theoretically possible but bears the risk contamination when the container is opened in the lab for P-analysis. It is safer to collect separate samples;
- combining container 3 (Phosphorus) with container 9 (Pesticides) is also theoretically valid but here the risk of volatilisation of pesticides from the container is a risk that should be avoided by collecting separate samples. Separate containers are a must when samples are to be sent to different laboratories;
- combining container 1 (general) and 5 (BOD) is valid if the total volume of the sample (2000mL) fits in one container. If a standardised set of (1L)containers is available in the laboratory it may after all be more practical to collect two separate bottles. Smaller sample containers also reduce the remaining head-space after aliquots have been removed from the container in the laboratory, which is preferable.

Parameter Group	Parameter	Sample Container	Sample Pre-treatment
General	Temperature	On-site analysis	On-site analysis
	Suspended Solids	1	None*
	Conductivity	On-site analysis	On-site analysis
	pH	On-site analysis	On-site analysis
	Dissolved Oxygen	2	7
Nutrients	Dissolved Solids	1	None*
	Ammoniacal Nitrogen	3	8
	Total Oxidised Nitrogen	3	8
Organic Matter	Total Phosphorus	4	None*
	Chemical Oxygen Demand	3	8
Organic Matter	Biochemical Oxygen Demand	2	4°C, Dark
	Major Ions	Sodium	3
Potassium		3	None*
Calcium		3	None*
Magnesium		3	None*
Carbonates and Bicarbonates		1	None*
Chloride		1	None*
Sulphate		1	None*
Other Inorganics	Silica	1	None*
	Fluoride	1	None*
	Boron	1	None*
Metals	Cadmium	3	9
	Mercury	4	9
	Zinc	3	9
Organics	Pesticide (Indicator)	5	4°C, Dark
	Synthetic Detergents	1	None*
	Organic Solvents	1	4°C, Dark
	Phenols	5	8
Microbiological	Total coliforms	6	4°C, Dark
Biological	Chlorophyll 'a'	1	4°C, Dark
<p>NOTES:</p> <p>Containers:</p> <ol style="list-style-type: none"> 1000 millilitre polyethylene bottle Special BOD bottle (normally 300 millilitre) 500 millilitre polyethylene bottle 100 millilitre glass bottle 1000 millilitre glass (or Teflon) bottle with Teflon lined caps Strong thick-walled, screw-capped glass bottle (300 millilitre capacity). Only good quality will maintain a good seal after multiple sterilisations in an autoclave <p>Preservation:</p> <ol style="list-style-type: none"> Samples for dissolved oxygen analysis are fixed by adding 1 ml of manganous sulphate solution, 1 ml of alkaline iodide-azide solution and 1 ml of concentrated sulphuric acid to the sample and mixing. Care should be taken to ensure that no air is added to the sample during this process. Samples should be acidified with 2 ml of concentrated sulphuric acid Samples should be acidified with 2 ml of concentrated nitric acid. <p>*None: Ideally, <i>all</i> samples should be kept cool and in the dark after collection. If this is not possible, then at least samples for BOD, coliforms, chlorophyll, pesticides and other organics that are likely to volatilize MUST be kept at 4°C, and dark. Remaining samples can have no preservation.</p>			

Table 7.1: Water Quality Parameters - Sampling Containers and Pre-treatments Required

	Analysis	Container	Volume (mL)	Preservation
0	on site analysis	PE bowl or container	±200	-
1	General (SS, TDS, major ions, chlorophyll-a)	Glass, PE	1000	-
2	COD, NH ₃ , NO ₂ + NO ₃ -	Glass, PE	500	H ₂ SO ₄ , pH <2
3	P	Glass	100	-
4	DO	special BOD bottle	300	DO fixing
5	BOD	Glass, PE	1000	4°C, Dark
6	Coliforms	Glass, PE, Sterilised	300	4°C, Dark
7	Heavy metals (Cd, Zn)	Glass, PE	500	HNO ₃ , pH <2
8	Mercury	Glass	1000	HNO ₃ , pH <2
9	Pesticides	Glass, Teflon	1000	4°C, Dark

Table 7.2: Example of different container types needed for a sampling location of the 'trend' type (deduced from Tables 4.2 and 7.1)

7.2 FILED MEASUREMENTS

It is often necessary to measure a number of water quality parameters in the field rather than in the laboratory. Normally, this is because these parameters are likely to change their value before they can be analysed in a laboratory.

In the context of the present programme, there are four physico-chemical parameters which normally need to be measured in the field. These parameters are dissolved oxygen, temperature, pH and conductivity. There follows below, therefore, a description of the field techniques which can be adopted for these determinands.

On-site analysis should be carried out from the 1000mL PE container used for sampling the general parameters group. Contamination with suspended solids or chemicals (calibration standards) must be avoided by pouring a part into a separate bowl or container.

7.2.1 MEASUREMENT OF TEMPERATURE

Water temperature is usually measured in degrees Celsius, using a thermometer or a thermistor. Normally, if temperature is measured electronically using a thermistor this device is built into an instrument which is capable of making other water quality measurements (e.g., pH or EC).

7.2.2 MEASUREMENT OF pH

Measurement of pH is carried out to determine the acid balance of the water on a scale of 1 (strongly acidic) to 14 (strongly alkaline).

Ideally, pH will be measured in the field at the time of sampling using either indicator paper (which changes colour depending upon the pH of the water) or a purpose-built meter. As portable pH meters are now relatively inexpensive this is now the preferred method of measuring pH as these instruments are much more accurate than indicator papers.

7.2.3 MEASUREMENT OF CONDUCTIVITY

Conductivity is a measure of the ability of water to conduct electricity. This, in turn, is directly related to the concentration of dissolved ions in solution. The conductivity of water gives a reasonable indication of the concentration of dissolved solids in the water, therefore.

Like pH, conductivity is ideally measured on site at the time of sampling. Measurement is effected with a purpose-built conductivity meter.

NOTE: Rather than use separate meters for temperature, pH and conductivity it is possible to purchase a single instrument which will measure all three parameters. However, such an instrument *may* be more expensive than single parameter meters.

7.3 SAMPLE HANDLING

The preservation, transportation and storage of samples is another vital link in the sampling chain as failure to carry out these operations with sufficient care can change the characteristics of the sample and lead to incorrect analytical results. There follows below, therefore, some guidelines on how these procedures should be undertaken.

7.3.1 SAMPLE PRESERVATION

As a general rule, all water quality samples should be stored at a temperature below 4°C and in the dark as soon after sampling as possible. However, this might not be practical for a large sampling campaign. If it is not possible to keep all samples cooled and dark, then at least samples for BOD, coliforms, chlorophyll, pesticides and other organics that are likely to volatilize MUST be kept at 4°C, and dark (see Table 7.2). In the field, this usually means placing them in an insulated cool box together with ice or cold packs. Once in the laboratory, samples should be transferred as soon as possible to a refrigerator. Cooling serves the purpose of reducing the reaction rate of all bio-chemical reactions taking place in the sample and thus slowing down undesired changes in the quality of the sample.

When a sample is being collected for dissolved oxygen analysis by the 'Winkler' method, it is important that, because the dissolved oxygen concentration in the sampling bottle can change rapidly from its original value, the sample is chemically 'fixed'. This ensures that the dissolved oxygen concentration determined is as near as possible to that which prevailed in the water body. Chemical fixing of dissolved oxygen is carried out by adding 1 ml of manganous sulphate solution, 1 ml of alkaline iodide-azide solution and 1 ml of concentrated sulphuric acid to a 300 ml water sample and mixing. The analytical determination may then be carried out up to 8 hours later with no loss of accuracy.

If samples collected for chemical oxygen demand (COD) analysis cannot be determined the same day they are collected they should be preserved below pH = 2 by addition of concentrated sulphuric acid. This procedure should also be followed for samples for ammoniacal nitrogen and total oxidised nitrogen analysis.

Samples which are to be analysed for the presence of metals should be acidified to below pH = 2 with concentrated nitric acid. Such samples can then be kept up to six months before they need to be analysed. Mercury determinations should be carried out within five weeks, however.

7.3.2 SAMPLE TRANSPORTATION

Normally, a motor vehicle with a reasonable weight carrying capacity, such as a light van or car, should be used for water quality sampling. This is because a one (or more) day sampling campaign encompassing a number of sampling points can mean that many bottles of water are collected. This is particularly the case where a range of parameters are to be determined each of which requires a different type of sample bottle.

Transporting samples by public transport like bus or train is possible but the weight of the cool-box containing several filled sample bottles and ice will easily exceed a weight of 10 kg and may not be easy to handle.

For economic reasons and the necessity of analysing the collected samples as soon as possible (some preferably within a day) it is best to plan a sampling campaign such that it can be completed in one day. Ideally, this will entail visiting a number of sampling points in a logical order and ending the day's journey at the laboratory where the samples can be analysed or at least refrigerated until the following day. If samples cannot be analysed until the following day, such sampling campaign should not be carried out the day before a laboratory staff holiday.

Initially all sample containers are sent to the laboratory that is involved in organising the monitoring campaign. If needed samples, may be forwarded from there only for advanced analyses in a higher level laboratory.

7.3.3 SAMPLE STORAGE

Sample storage, by definition begins immediately after the sample is collected, therefore some discussion about storage is given here.

As discussed above in Chapter 6.1, ideally all samples need to be stored in the dark and below 4°C so that the determinand values do not change. In practice, this treatment may not be possible for all parameters. However, samples for BOD, coliforms, chlorophyll, pesticides and other organics that are likely to volatilise should always be kept cool and dark. For this reason it is good practice to store these water samples during transportation in a cool box. After arrival in the laboratory the samples should be transferred to a refrigerator until they can be analysed. Sample storage usually takes place at the same location where the samples eventually will be analysed.

8 EQUIPMENT

8.1 SAMPLERS

For many water quality sampling applications all that is required is a weighted sampling can with a rope attached to its handle. The can is then placed into the river such that it submerges and fills with water. Once filled, the sampling can is pulled from the water using the rope. Although virtually any style of sampling can will do for this application, there are a number of features which are preferable as follows:

- small volume - it is preferable that the sampling can has a relatively small volume (e.g. a few liters). This makes it easier to haul in the can when it is full of water, particularly if sampling is being carried out from a high platform such as a river bridge
- plastic - this makes the sampling can lighter, easier to clean and less likely to chemically react with the parameters to be determined in the water sample. For the same reasons the rope attached to the bucket should also be made of a synthetic fibre
- lipped - the provision of a lip to the sampling can makes pouring the water into a sample bottle much easier

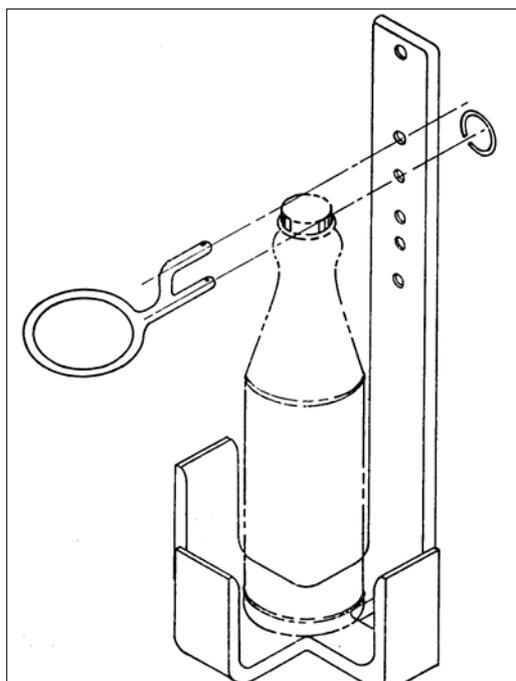


Figure 8.1:
Sample bottle holder for water sampling

The simplest form of a water sampling device is a bottle attached to a string. To lower a plastic or glass bottle in a body of water it is necessary to use a bracket or holder of sufficient weight to overcome the buoyancy of the bottle and allow it to sink as rapidly as desired to the required depth. Such a holder designed to contain a one or two litre bottle is shown in Figure 8.1. Where feasible a sample may be collected by holding the sample bottle in hand and submerging it to a depth of about 20 cm. Holding the mouth slightly downwards and then turning the bottle upright to fill it (see Figure 7.1).

For faster flowing streams and rivers, or where samples from different depths in the watercourse are desired, a 'multi-purpose' sampler (or 'sampling iron') may be more appropriate. This consists of a bottle in a weighted frame which sometimes has a rudder attached so that the sampler's position is maintained in the flowing water. This sampler will, depending upon its exact type, have one or two ropes attached to it and can also be used for sampling at depth (see Figure 8.2).

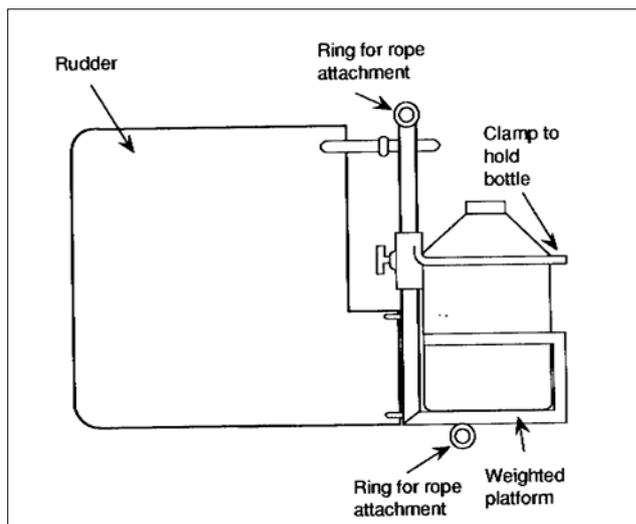


Figure 8.2:
Multi-purpose sampler (adapted from WMO)

A so called depth-sampler is designed in such a way that it can retrieve a sample from any predetermined depth. A typical depth sampler is shown in figures 8.3 and 8.4. The design in Figure 8.3 (Meyer's bottle) is simple, cheap and recommended in most cases. Its functioning is supposed to be mainly self-explanatory (the stopper is removed at the desired depth by a short pull at the suspension cord). The design in Figure 8.4 is more advanced, expensive and will operate at greater depth (>30m). The key to its functioning is closing the flaps at the desired depth. This is done by sending down a weight (called messenger) along the rope. The small pressure applied on the latch is enough to open the spring-loaded flaps.

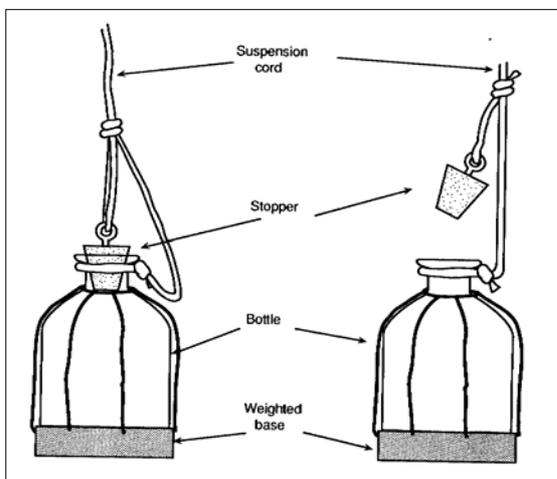


Figure 8.3:
Simple depth sampler suitable for moderate depths
(Meyer's bottle).

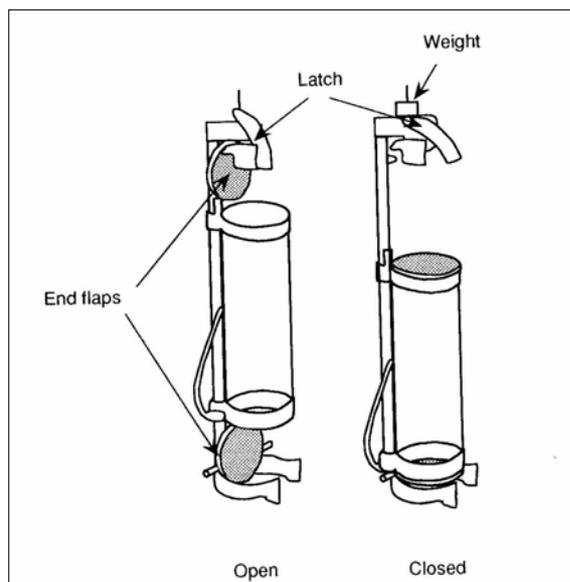


Figure 8.4:
Depth sampler

Samplers for Dissolved Oxygen

Sampling water to determine its dissolved oxygen content can be difficult because no air bubbles should be allowed into the sample as they can change the dissolved oxygen concentration of the sample. A purpose-built dissolved oxygen sampler should be used, therefore.

This type of sampler is essentially a metal tube (30cm long x 10cm diameter) into which a special ground glass-stoppered bottle (a 'BOD bottle') can be inserted. The sampler is designed such that when submerged, the water enters the BOD bottle directly by means of a dip-pipe thus displacing all air from the bottle. The volume of the sampler is at least five times as big as the volume of the BOD-bottle placed into it, which results in the required flushing of

the bottle before the final sample volume is contained. Once the sampler is full it is retrieved and the full bottle is then immediately sealed with a ground glass stopper. (see Figure 8.5).

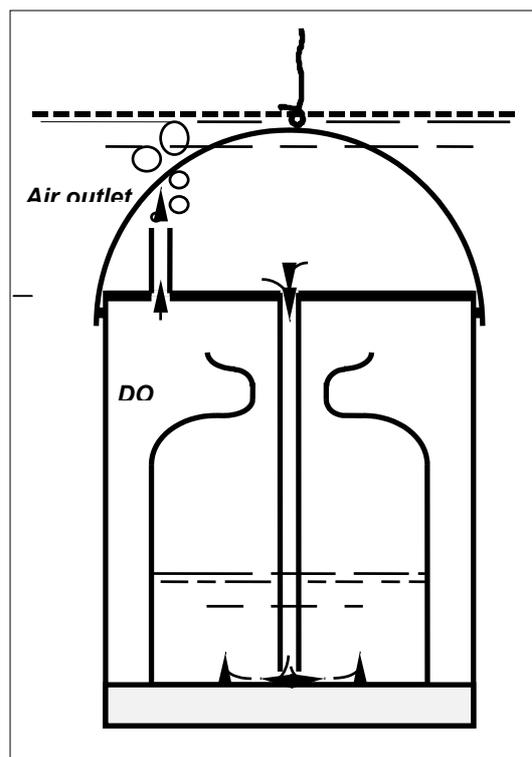


Figure 8.5:
Dissolved oxygen sampler (with one BOD-bottle).

8.2 FIELD ANALYSES AND SAMPLE HANDLING

In addition to sampling, field operatives also need to be able to take measurements and chemically 'fix' certain samples so that their parameter values do not change prior to laboratory analysis.

The measurements which need to be taken on site are those of temperature, pH and conductivity. These can most usefully be determined in the field by means of a small portable instrument capable of measuring all these parameters. As meters of this type require at least daily calibration and regular maintenance a supply of distilled water, pH buffers, standard solutions, batteries and basic spare parts should also be carried with the meter.

Samples for metals analysis should be acidified with concentrated nitric acid as soon as they are obtained. The sampler also needs to carry a bottle of concentrated nitric acid in a bottle carrier, therefore.

Samples for dissolved oxygen concentration of water can change rapidly due to chemical and biological activity in the sample bottle. To prevent this change, the sample must be chemically 'fixed' as soon as it is obtained. This fixing is carried out by adding 1 millilitre of manganous sulphate solution, 1 millilitre of alkaline iodide-azide solution and 1 millilitre of sulphuric acid to the sample in the bottle as soon as it has been taken. Thus it is necessary to equip every field operative with these solutions.

8.3 SAMPLE CONTAINERS

In order to cover the range of parameters which need to be sampled and analysed, a variety of sample containers are used (as discussed in Chapter 6.1). The different types are reviewed here again and briefly discussed:

- 1000 millilitre glass (or teflon) bottles with teflon lined caps - for pesticides and phenols

- 500 millilitre polyethylene bottles - for metals (except mercury)
- 100 millilitre glass bottles - for mercury and phosphorus
- 1000 millilitre polyethylene bottles for all other chemical parameters
- BOD bottles, with ground glass stoppers, of a volume consistent with the dissolved oxygen samplers (possibly 300 millilitre)
- strong thick-walled glass bottles of at least 300 millilitre capacity for microbiological analysis. These should be fitted with screw caps capable of maintaining a good seal even after multiple sterilisations in an autoclave

8.4 PREPARATION AND STERILISATION OF EQUIPMENT

Preparation of equipment is extensively discussed in the Field Manual Volume 6 (Section 3.6). It is usually carried out in the laboratory to which the samples, at least part of them, are sent to and analysed.

This section summarises the equipment requirements for the purpose of field sampling preparation.

In general, bottles which are to be used for collecting samples must be thoroughly washed and rinsed before use. Washing can be done by hand but, if there are many bottles to wash, it is often best undertaken by machine.

Bottles which are to be used for collecting microbiological samples must be thoroughly washed and sterilised before use. Sterilising can be carried out by placing the bottles in an autoclave at 121°C for fifteen minutes or, if the caps of the bottles do not contain plastic or rubber materials, in an oven at 170°C for at least two hours. Thus, any laboratory that needs to prepare bottles for microbiological samples requires either an autoclave capable of comfortably sterilising at least twenty bottles at one time or an equivalent size sterilising oven.

Bottles to be used for the collection of pesticides are to be rinsed with organic solvent (e.g. hexane) prior to use. This should be done in the laboratory.

Some samples need to be preserved or fixed in the field. For dissolved oxygen fixing, every field operative should bring three pipetted glass or plastic stoppered 500 millilitre bottles containing the DO fixing solutions. As these solutions can be corrosive the three bottles should be carried in an appropriately sized bottle carrier to ensure they do not tip over and spill their contents.

For other parameters, (e.g. COD, NH₃, NO₂⁻, NO₃⁻) addition of concentrated sulfuric acid should be done in the field after sampling. For heavy metals, addition of nitric acid needs to be done in the field after sampling. Therefore, the field operative should be equipped with two pipetted glass or plastic stoppered 100 millilitre bottles containing the two acids.

8.5 TRANSPORTATION BOXES

After labelling and preservation, the samples have to be packed for transport, preferably in an insulated cool box. After sampling, many water quality parameters undergo chemical or biochemical reactions in the sample bottle causing the concentration to change from that which was present in the watercourse. To prevent this alteration of parameter values, ideally all samples should be kept at a temperature below 4°C and in the dark until they are analysed. If this is not possible, then at least samples for BOD, coliforms, pesticides and other organics that are likely to volatilise MUST be kept at 4°C, and dark. Remaining samples can have no preservation. In the field, the best way to ensure that samples are kept cold is to pack them into insulated cool boxes containing either an ice/water mixture

or a large number of ice packs. Thus sufficient cool boxes to contain a full day's sampling campaign should be available to each field operative that is required to take water quality samples.

Samples should be transported to concerned laboratory (level II or II+) as soon as possible, preferably within 48 hours. If samples are being brought to a Level I laboratory for the 'field determinations', they should be transported in less than 24 hours.

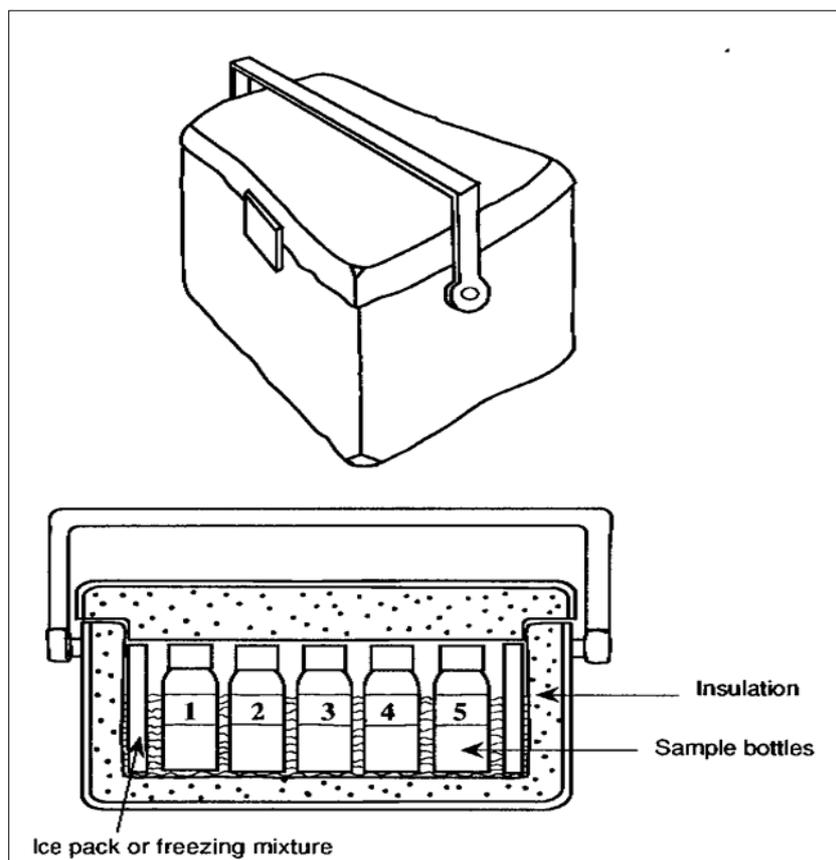


Figure 8.6: Insulated bottle carrier for water quality samples

8.6 OTHER ITEMS

In addition to that specified above a field operative taking water quality samples will need certain other items of equipment as specified below:

- maps (preferably marked with all relevant sampling points)
- a supply of labels, pencils and marker pens
- report forms and a field notebook
- first aid kit
- rubber boots or waders (if conditions require)
- personal protectives (gloves and eye protection)

• Itinerary for the trip (route, stations to be covered, start and return time)	• Personnel and sample transport arrangement
• Area map	• Sampling site location map
• Icebox filled with ice or icepacks	• Weighted bottle sampler
• DO sampler	• Rope
• BOD bottles	• Sample containers
• Special sample containers: bacteriological, heavy metals, etc.	• DO fixing and titration chemicals and glassware
• Sample preservatives (e.g. acid solutions)	• Thermometer
• Tissue paper	• Other field measurement kit, as required
• Sample identification forms	• Labels for sample containers
• Field notebook	• Pen / pencil / marker
• Soap and towel	• Match box
• Spirit lamp	• Torch
• Drinking water	• Knife
• Waste container	• Gloves and eye protection

Table 8.1: Checklist for water quality sampling field visit

Note that depending on the local conditions, water body, analysis requirements, etc., not all items on the check list may be necessary. Other items, not listed, may be required. The field operative may make his or her own personal checklist based on Table 8.1.