



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

VOLUME 6
WATER QUALITY SAMPLING

DESIGN MANUAL

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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).

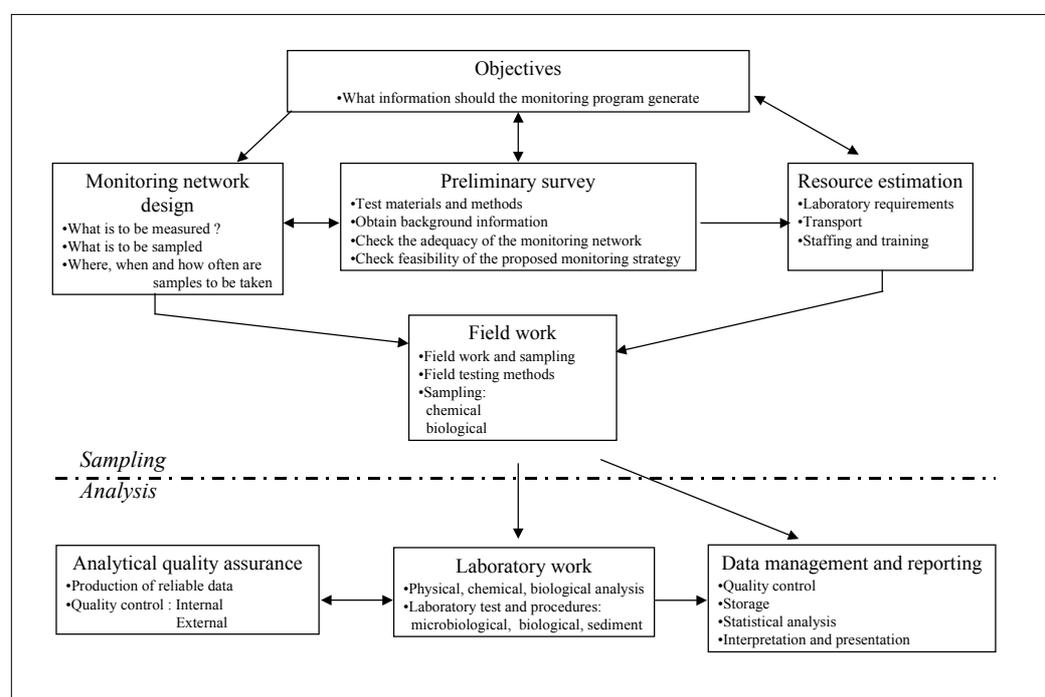


Figure 1.1: Elements of a water quality monitoring program

This volume deals with the topics above the horizontal line, described in chapters 1 through 7. 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.

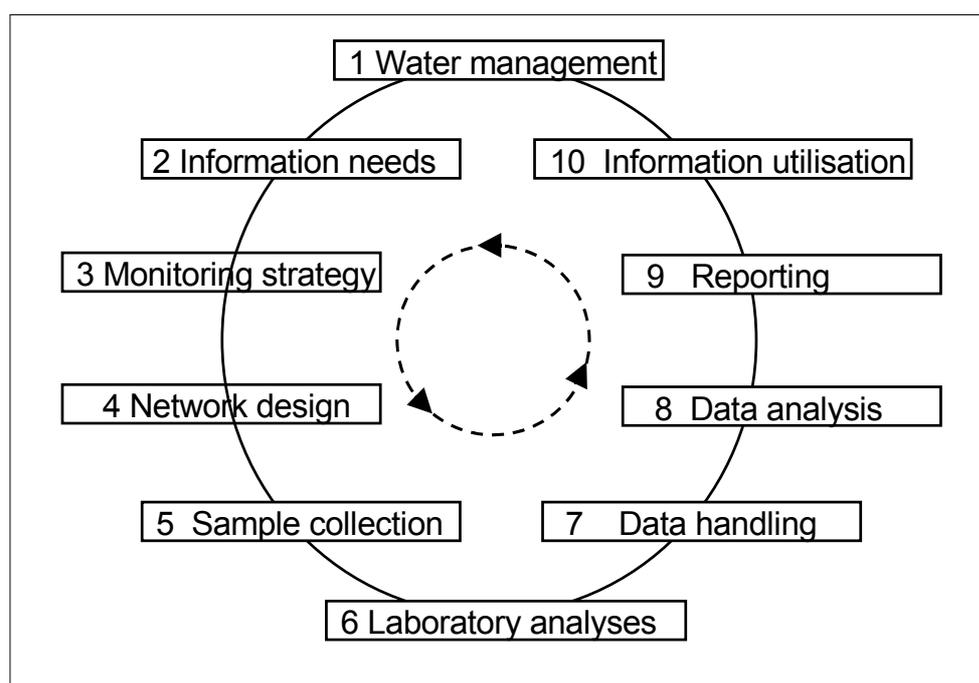


Figure 1.2: The Monitoring Cycle¹

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.

¹ 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 GWDES (Ground Water Data Entry System). The data handling with GWDES 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).

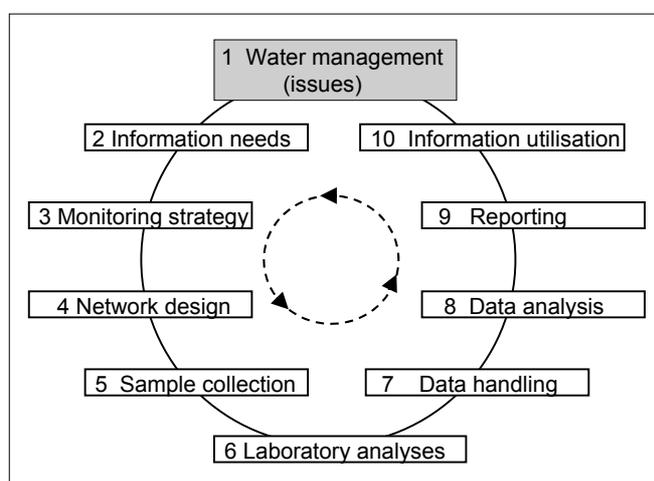


Figure 2.1:
Water Management Issues: Step 1 in
monitoring cycle

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: Percolation from agricultural lands carrying materials applied during agricultural use, mainly fertilisers, herbicides and pesticides.
- Diffuse urban sources: Percolation 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 groundwaters is presented below.

2.2 WATER QUALITY ISSUES

Contamination by Faecal and Organic Matter

In India, faecal contamination is one of the primary water quality issues, 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 drains, which do not have adequate carrying capacity results in ponding of the wastes. This ultimately results in percolation and contamination of groundwaters. Contamination may also occur when such wastes are discharged in river channels through infiltration. Unusually high levels of nitrate has been recorded at a number of places in the country. Intentional use of municipal sewage for 'sewage farming' is another reason for such wide scale contamination.

Toxic Pollutants: Organics and Heavy Metals

Toxic organic pollutants (mostly chemicals manufactured artificially by man) and inorganic contaminants are also becoming an important water quality issue. They enter groundwater from the leaching of solid and liquid waste dumps. Nearly all of the municipal and industrial solid waste disposal sites are unsecured landfills. Uncontrolled discharge of industrial wastewaters often causes pollution due to toxic metals. Other sources of metal pollution are leachates from mining waste dumps.

Over-abstraction

In most situations, groundwater in comparison to surface water is the preferred source for agriculture, municipal and industrial use due to various considerations, such as, availability, quality, cost etc. Consequently, due to over-abstraction, i.e. withdrawal being more than recharge, the water levels have gone down. This in turn has resulted in changes in the geo-chemical regime of groundwater reservoirs deteriorating the water quality. Some changes which have become obvious are:

- appearance of arsenic
- increase in concentration of fluorides
- sea water intrusion

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

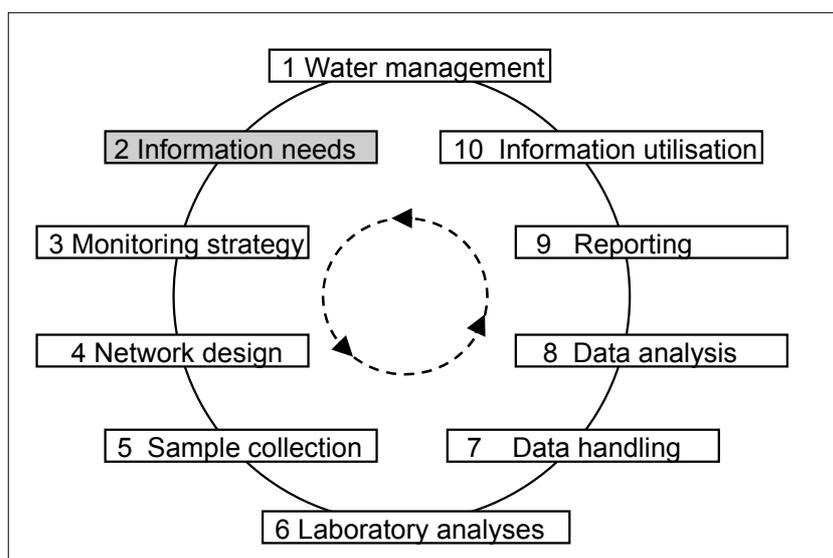
A range of surface water groundwater pollution problems can be associated with mining activities. The nature of the pollution depends on the materials being excavated and extracted. Both surface and underground mines usually extend below the water table and often dewatering is required to allow mining 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.

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 groundwater 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 groundwater sources are taken with one or more of the following 'global objectives' in mind:

- a) to build up an overall picture of the aquifer water quality thus enabling contamination 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
- f) to precisely characterise aquifer water quality (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:

- **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 (i.e., d and e above)
- **Survey** - a finite duration, intensive programme to measure for a specific purpose (i.e., 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.

Category	Type	Objective
Monitoring	Baseline	Natural Background Concentrations
	Trend	Detection of changes over time due to anthropogenic influences
Surveillance	Water Use	Check that water is fit for use
	Pollution Control	Check effects of discharges Check water quality standards
Survey	Classification	Classification of aquifer water quality
	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, groundwater 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 Ground Water Board & State Ground Water Departments
- Central & State Pollution Control Boards
- Central Water Commission & State Irrigation Departments
- National River Conservation Directorate (NRCD)
- Research Institutions (e.g., NGRI, 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 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 GROUND WATER BOARD

The Central Ground Water Board was created in 1972 by the amalgamation of Exploratory Tubewells Organisation, which was established in 1954, with a cadre from Geological Survey of India. It is the national apex body concerned with planning the development of groundwater resources throughout India. The main activities of the Board are hydrogeological surveys, exploration, monitoring of water table and water quality and assessment of development of groundwater resources.

Out of the total of about 16000 observation points in the country, nearly 9000 points are located in the nine HP States. The water level in these wells is measured four times a year during fixed 10 day periods. Water quality measurements are carried out once a year in the pre-monsoon period.

Mandate

The mandate of the board, briefly stated, is to 'Develop and disseminate technologies and monitor and implement national policies for the scientific and sustainable development and management of India's groundwater resources, including their exploration, assessment, conservation, augmentation, protection from pollution and distribution, based on principles of economic and ecological efficiency and equity'.

The CGWB was also constituted as an authority for the purpose of Regulation and Control of Groundwater Management and Development under official gazette notification in Part II – Section no. 30 on 14th January, 1997, to perform the following functions:

- exercise powers under Environment Protection Act, 1986 for issuing directions
- resort to penal provisions under the act
- regulate indiscriminate boring and withdrawal of groundwater.

Water Quality Monitoring Network

Most of the monitoring network of the Board comprises open dug wells tapping the phreatic aquifer. Only about 5% wells are tubewells, which are in the phreatic or deeper aquifers.

As noted above, the water quality of all the network wells is measured once a year during pre-monsoon period. It was reported that in some cases where there was localised pollution of the open well, water quality measurements were not representative of aquifer water. Further, purging of small bore, non-production, tubewells was not done before collecting samples for water quality analysis. Purging of such wells was considered to be necessary specially when contaminants present in low concentration are monitored.

Except at few locations the laboratories in the HP States, do not have the capability to monitor micro-level organic and inorganic pollutants. Water samples are routinely analysed for the major anions and cations. In some cases special studies were conducted to monitor for the presence of nitrates and phosphates as a result of urban and agricultural pollution and naturally occurring fluorides.

The water quality data are used to prepare water quality maps of EC and in some cases specific ions. The data are also used for classification of waters according to various diagrams and water quality indices.

3.2.2 NATIONAL RIVER CONSERVATION DIRECTORATE²

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

²Extracted 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 stations³

³ 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 CENTRAL POLLUTION CONTROL BOARD⁴

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.

⁴ 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

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.
- 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. In recent years the number of groundwater stations has increased.

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

3.2.5 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 Groundwater Departments
- 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	CGWB	NRCD	CPCB	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		✓ through CGWA ^a	✓	✓			✓	
Dissemination of water quality information /mass awareness	✓ upon request , official use	✓ upon request , official use	✓ restrictive	✓ regular publications	✓ 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	CGWB	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	✓ irrigation drinking	✓ 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 groundwater and irrigation departments.

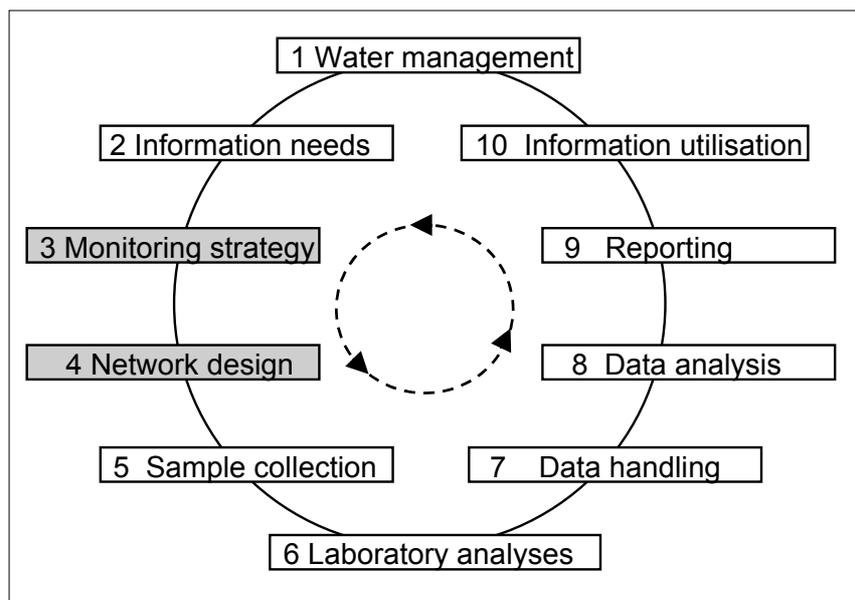


Figure 4.1:
Monitoring Strategy and
Network Design: Steps 3 &
4 in the monitoring cycle

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 *in-situ* water so as to indicate the actual status and trends that are relevant for the functions and uses of the groundwater 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 and trend types under the category 'monitoring'.
- Water quality sampling is based on 'in-situ sampling, 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, CGWB and State groundwater 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 the different aquifers to be monitored, 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.

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 later.

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 information except density is presented in Table 4.1.

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).

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.

Type of Station	Frequency	Parameter
Baseline	<p>New Stations: Once every year (pre-monsoon, April-May) for 3 years, thereafter every alternate year if there is no perceptible deterioration in quality. Otherwise, re-categories as trend/surveillance station</p> <p>Existing Stations If no perceptible change is observed in previous 5 years data indicating no deterioration in quality, sample once every alternate year (pre-monsoon, April-May)</p>	<p>Analyse 20 parameters as listed below:</p> <p>General: Colour, odour, temp, pH, BC, TDS</p> <p>Nutrients: NO₂⁻, NO₃⁻, ortho-phosphate</p> <p>Organic matter: COD</p> <p>Major ions: K⁺, Na⁺, Ca⁺⁺, Mg⁺⁺, CO₃⁻, HCO₃⁻, Cl⁻, SO₄⁻</p> <p>Other inorganics: SiO₂, F⁻, B and other location specific parameters, if any</p>
Trend	Four times every year (once in a pre-monsoon, April-May, and thereafter at intervals of three months)	<p>April – May: Analyse 20 parameters as listed for baseline monitoring</p> <p>Other times: Analyse 14 parameters as listed below:</p> <p>General: Colour, odour, temp, pH, BC, TDS</p> <p>Nutrients: NO₂⁻, NO₃⁻, ortho-phosphate</p> <p>Organic matter: COD</p> <p>Major ions: Cl⁻</p> <p>Other inorganics: F⁻, B₃⁺</p> <p>Microbiological: Total & faecal coliforms</p>
<p>Trend-cum-surveillance/impact</p> <p>For other areas having problem of the following nature due to geologic features or human interference</p> <ul style="list-style-type: none"> - Fluoride - Iron - Industrial/mining/geological features - Agricultural - Salinity due to irrigation, natural contribution or seawater intrusion - Urban pollution 	Minimum four times a year (as in trend stations), higher frequency, if dictated by importance of water user	<p>April – May: Analyse 20 parameters as listed for baseline monitoring</p> <p>Other times: Analyse 14 parameters as mentioned for Trend Stations and additional parameters as follows according to the problem under surveillance (e.g. Heavy metals in mining areas)</p> <p>F</p> <p>Fe</p> <p>As, Cd, Hg, Zn, Cr, Pb, Ni, Fe, phenols, cyanide, sulphide, etc. (according to local situations)</p> <p>Pesticides in most prevalent use in the area: BHC (total), DDT (total), endosulphan, aldrin, dieldrin, carbamate, 2-4-D, monocrotophos, malathion, methyl parathion, etc.</p> <p>Na⁺, K⁺, Ca⁺⁺, Mg⁺⁺, CO₃⁻, HCO₃⁻, Cl⁻, SO₄</p> <p>Total and faecal coliforms (already included under 16 parameters for trend monitoring)</p>

Note: The parameters to be analysed as mentioned above are the minimal requirement. This does not, however, restrict analysis of more parameters depending upon specific requirements of the analysing agency and its manpower availability.

* If COD value exceeds 20 mg/L, the sample is to be analysed for BOD also.

Table 4.1: Water Quality Monitoring Objectives, Frequencies and Parameters

Suggested water quality parameters for each sample type are also given in Table 4.1. 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 indicating pollution of groundwater)
- major ions (the inorganic anions and cations which can describe the chemical composition of the water and help to assess pollution, potability, seawater intrusion etc.)
- other inorganics (miscellaneous inorganic species which are important for certain water uses or for classification purposes)
- metals (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)
- microbiological (one indicator species for the presence of faecal pollution of water)

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 Table 4.1 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 may have not been included in the programme. It may be, therefore, that 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:

- organic toxic 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.

4.2.2 GROUNDWATER MONITORING NETWORK DESIGN

A groundwater quality monitoring network should take into account the features of the area or region, which are likely to have an impact on the water quality. Some of these features are:

- Aquifer geology
- Type of aquifer
- Land use pattern
- Geological set
- Geomorphological set up
- Drainage basin

A simple approach to locating the monitoring stations would be to mark the boundaries of the relevant features on a map and locating at least one station in each intersection. For example, if in an area there are two aquifer geological formations, shale (G) and limestone (L), Figure 4.2 (a), and two types of land uses agricultural (A) and fallow (F), Figure 4.2 (b), then their intersection would yield three

unique possibilities as shown in Figure 4.2 (c). The network should have at least three stations, one in each of the intersections. Depending on the extent of each intersection and resources, the number of stations in each of the intersections may be increased. The density of the network may also be increased by including more influencing features or sub-features, as in the case of agriculture, canal command area and non-command area could also be considered as different features.

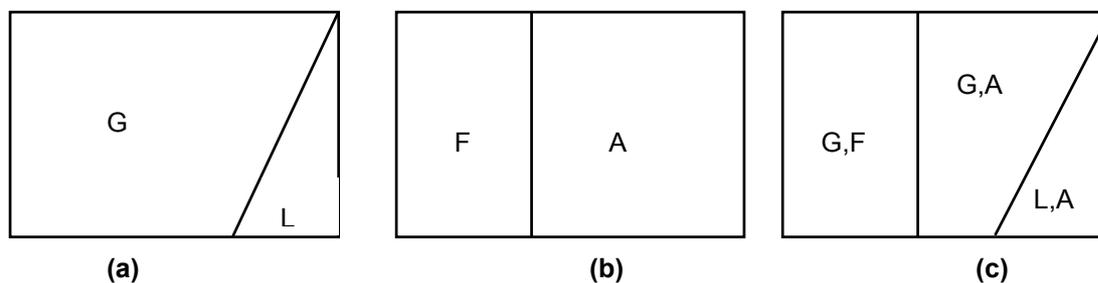


Figure 4.2: Intersections of features influencing groundwater quality

Often the water quality monitoring network is clubbed with the groundwater level monitoring network, which comprises of open dug wells and piezometers. Some of these wells may not be in use as a source of water. For water quality monitoring stations, it is essential that the water is pumped, so that the water in the well represents the aquifer water and not storage water. Where purpose-built piezometers are installed for water level measurements, arrangement should be made for purging the storage water before sampling for water quality measurement, if such wells are included in the network.

The classification of the groundwater monitoring stations should be on similar lines as that for surface water stations. Stations, where there is no or little possibility of anthropogenic influence on aquifer water quality, should be classified as *baseline* stations. A few of these baseline stations may also be called trend stations. The baseline stations may be monitored only once a year, where the groundwater quality does not change rapidly. The sampling may be done during the pre-monsoon season, when the water quality is most critical. The *trend* stations on the other hand may be monitored four times a year to facilitate drawing statistically reliable conclusions in 2 to 3 years.

Stations, where there is a threat to water quality, may be classified as *Surveillance* or *trend-cum-surveillance* stations. These stations should also be monitored four times a year or more frequently, if the water use involves greater risks.

Surveys may also be taken up in the groundwater quality monitoring programme, with specific objectives, such as to find if the groundwater in an area contains naturally occurring fluoride, or pesticides as a result of contamination from agricultural applications. Such surveys may be carried out for at least two years. The frequency of sampling may be 3 to 4 times a year. At the end of the survey, depending upon the results, a few survey stations may be retained in the network as baseline, trend or trend-cum-surveillance stations

The water quality parameters for which the water samples should be analysed are similar to those discussed for surface waters, except dissolved oxygen, which has no relevance in routine monitoring of groundwater. Further, samples may not be analysed for BOD (Biochemical oxygen demand) unless recent contamination is suspected.

5 NETWORK RATIONALISATION

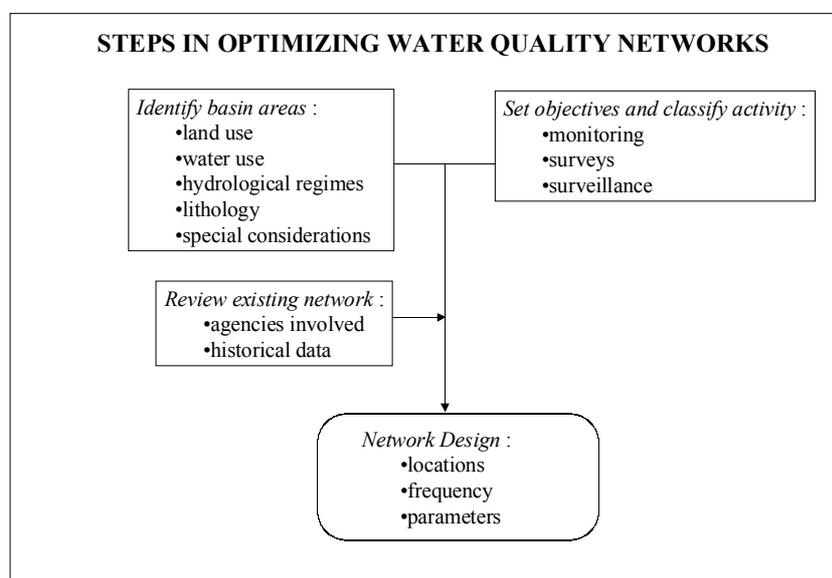
5.1 INTRODUCTION

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 Groundwater Quality Monitoring, Bangalore, June 26-27, 2000. The following water quality monitoring objectives were identified for organisations mentioned in chapter 3.2:

- monitoring for establishing baseline water quality, observing trend in water quality changes
- surveillance of water quality for resource management
- 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. groundwater pollution monitoring at a paper mill outlet compared to operation of baseline stations 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.**

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 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.
3. 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.
4. 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 GROUNDWATER GHATAPRABHA BASIN, KARNATAKA

Groundwater quality in Ghataprabha basin has been measured for the last several years by CGWB. A preliminary analysis of the data was made to find out if the monitoring network could be optimised with respect to number of parameters and stations. A few conclusions, which need to be tested statistically, are presented here.

Figures 5.3 and 5.4 show the isopleths for chloride concentration in the groundwater and its EC value, respectively, over an area of approximately 10,000 km². These lines were drawn for measurements taken during the period 1970 to 1993.

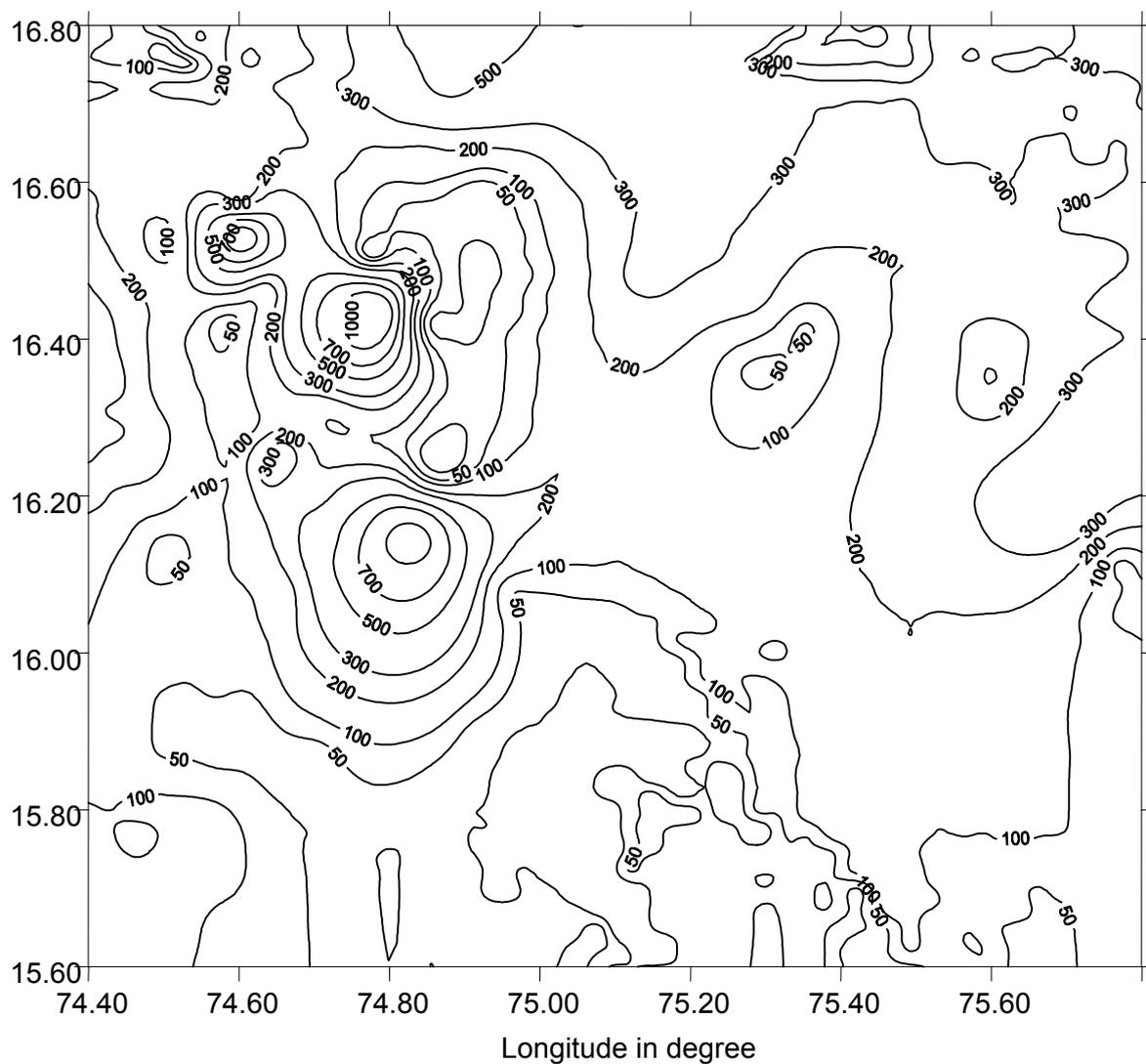
In order to find out if there is any change in the water quality over time, the contours could be plotted for two periods of shorter span, say 1974 to 1983 and 1984 to 1993, and compared. In case no change is noted, only a few key stations may be continued and other stations could be discontinued for a few years. After a gap, once again the whole basin could be covered. Resources saved in this manner can be used to include intensive monitoring of areas where water quality problems are known to exist or are perceived or include new parameters of relevance.

Figures 5.5 and 5.6 show relationships between EC and bicarbonate and EC and chlorides, respectively, for some wells in the basin between 1970 and 1993. It may be noted that EC could be used to estimate the concentration of the two constituents fairly accurately. Similar plots for other parameters could also be obtained.

The decision whether to discontinue the measurement of any parameter would ultimately depend on the accuracy with which the parameter need to be determined and the confidence level with which it

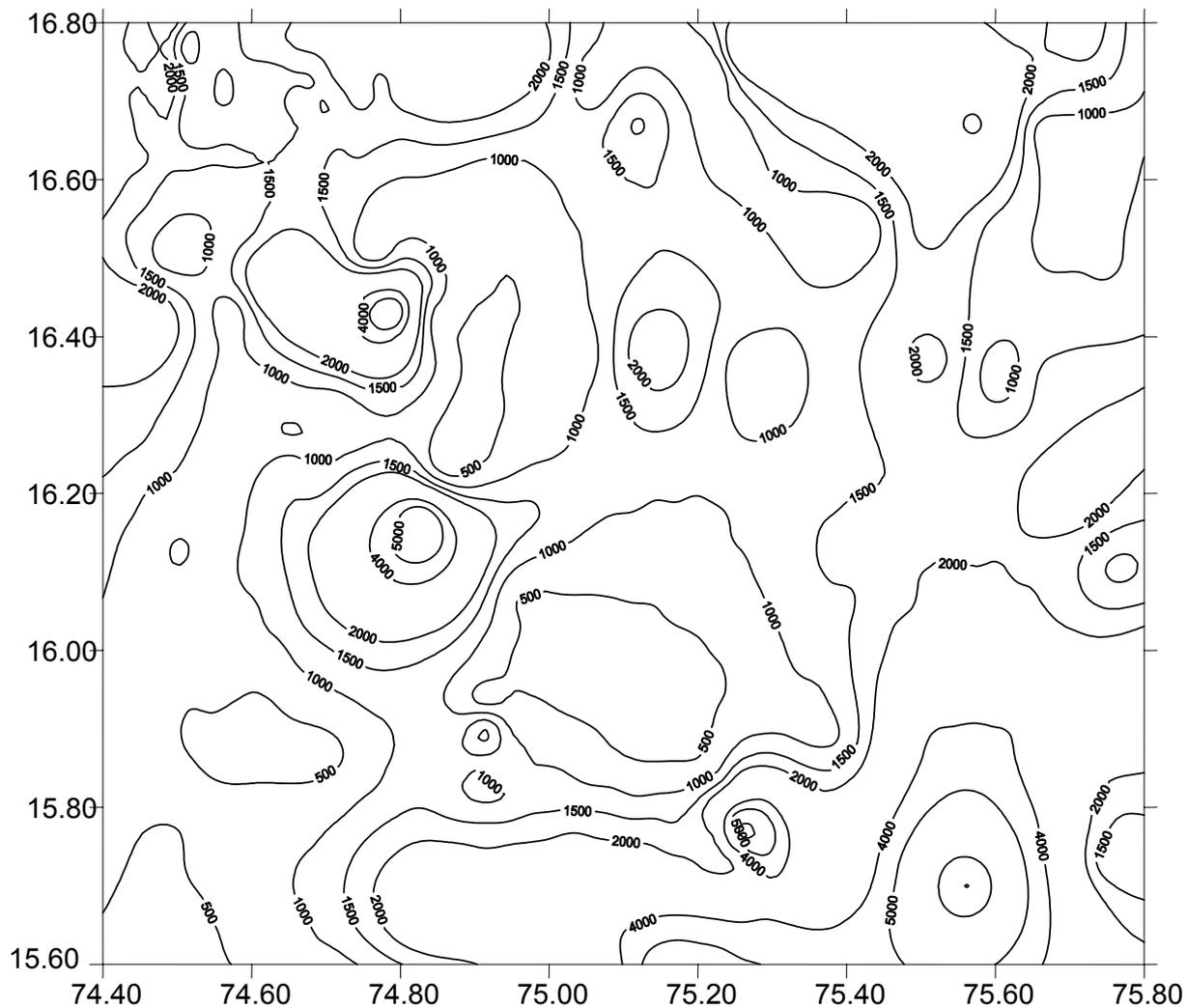
can be predicted from the available relationship. In the present case, it may be noted that the data points for bicarbonate have a greater scatter compared to the chloride data. The bicarbonates in a water sample are in equilibrium with the partial pressure of carbon dioxide in the atmosphere. Its concentration therefore may change on storage of samples, while there would not be any such change in chloride concentration.

In summary, the above remarks show that there is a need to examine the available data in greater depth and draw conclusions regarding optimisation of the network.



Period: 1970-1993

Figure 5.2: Chloride (mg/l) map of Ghatprabha Basin, Karnataka



Period: 1970-1993

Figure 5.3: Conductivity (micro-mhos/cm) map of Ghatprabha Basin, Karnataka

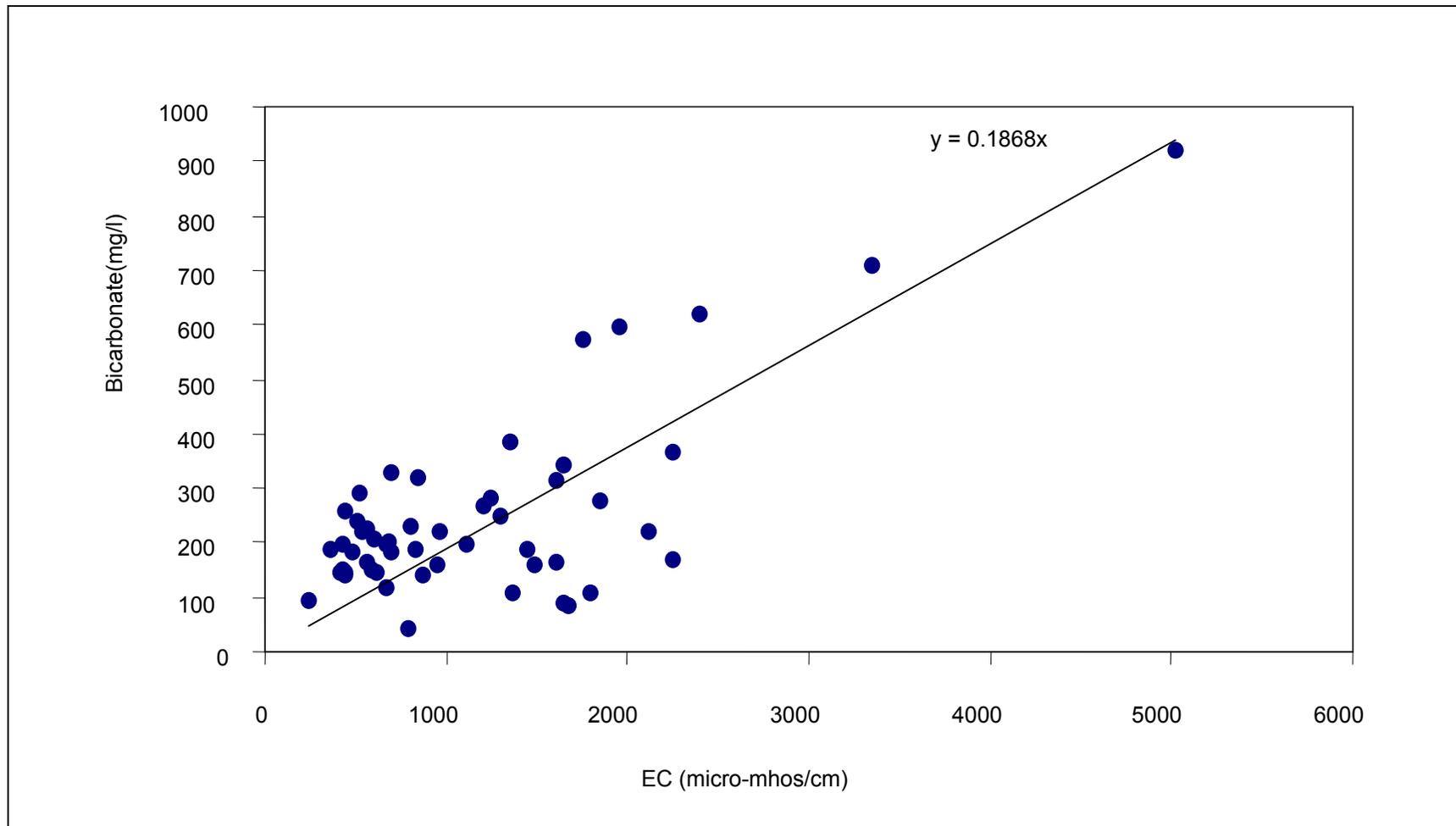


Figure 5.4: EC-Bicarbonate, Data: CGWB, Karnataka, Ghataprabha Basin, Period 1970-97

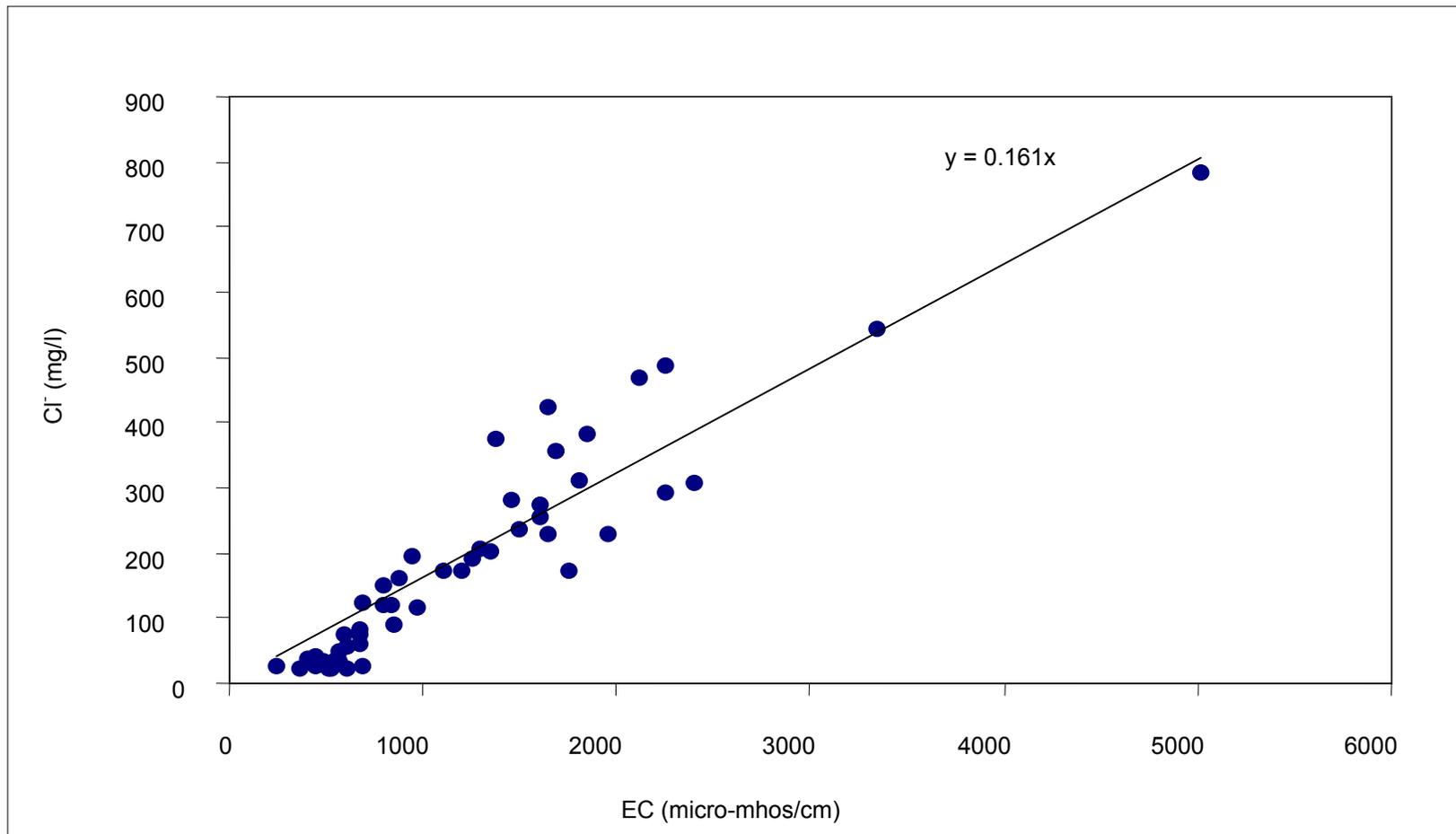


Figure 5.5: EC-Chloride, Ghataprabha Basin, Data: CGWB, Karnataka, Period 1970-93

5.6 HOW TO PROCEED WITH NETWORK RATIONALISATION

5.6.1 CGWB REGIONS

- At the National Workshop on Groundwater Quality Monitoring, Bangalore, June 26-27, 2000, it was agreed that there is a strong need for review of water quality networks. CGWB 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 each region should mobilise a working group with the goals of:

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

5.6.2 STATE LEVEL REVIEW COMMITTEES

At the National Workshop, 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 Ground Water Board (CGWB)
- State level groundwater agencies
- Central Pollution Control Board (CPCB)
- State Pollution Control Board (SPCB)
- Regional Data Centres of the State and CGWB
- 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 CGWB would request CPCB to take the initiative in formulating the State Level Review Committees.

6 SITE SELECTION

Samples for groundwater quality monitoring would be collected from one of the following three types of wells:

- *Open dug wells* in use for domestic or irrigation water supply,
- *Tube wells* fitted with a hand pump or a power-driven pump for domestic water supply or irrigation
- *Piezometers*, purpose-built for recording of water level, only if the arrangement is provided for purging.

Traditionally in most of the groundwater agencies in the country, recording of water levels was taken up first. With time, as the importance of water quality measurements became obvious, sample collection for water quality measurements became obvious, sample collection for water quality measurements was taken up as an additional activity and the same wells, which were used for water level measurements, were also used as water quality measurement stations. Many of these wells are open dug wells, which are not in use and therefore, do not represent the water quality of the aquifer, as the water in these wells is mostly stagnant. It is emphasised that open dug wells, which are not in use or have been abandoned, will not be considered as water quality monitoring station. However, such wells could be considered for water level monitoring.

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'.

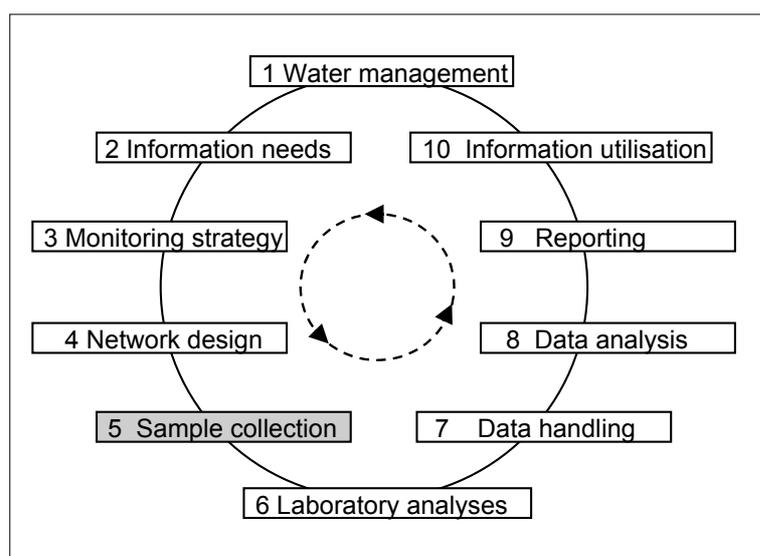


Figure 7.1:
Sample Collection: Step 5 of the
monitoring cycle

7.1 SAMPLE COLLECTION

Samples will be collected from the selected stations 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.

Samples for groundwater quality monitoring would be collected from one of the following three types of wells:

- *Open dug wells* in use for domestic or irrigation water supply,
- *Tube wells* fitted with a hand pump or a power-driven pump for domestic water supply or irrigation
- *Piezometers*, purpose-built for recording of water level and water quality monitoring.

Different procedures are to be followed for the different types of wells:

- *Open dug wells* : Use a weighted sample bottle to collect sample from an open well about 30 cm below the surface of the water. Do not use a plastic bucket which is likely to skim the surface layer only.
- *Tube well*: Samples from the production tube wells will be collected after running the well for about 5 minutes. Kindly ensure that the suction pipe and delivery pipe is not corroded or rusted.
- *Piezometer*: Non-production piezometers should be purged using a submersible pump. If the well is equipped with a dwlr, the instrument should carefully be removed conforming to the instructions provided with the instrument. Before starting purging, the technical condition of the well needs to be checked and its suitability for the insertion of a submersible pump needs to be verified. This is usually performed by inserting a metal body, similar in shape to the submersible pump, into the well. Once smooth insertion of the metal body to the required depth and its subsequent removal is performed, the submersible pump can be safely inserted and the purging operation may start. The purged water volume should equal 4 to 5 times the standing water volume, before the sample is collected. Information on the basis for purging volume and selection of pump is given in Appendix A.

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 and type of samples. Starting from Table 4.1 the list of parameters to be analysed say for a 'trend-cum-surveillance' 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 4 (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 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.

Sample identification forms

The sample identification form provides a record of all important information concerning the sample collected. Complete the sample identification form at each monitoring site, detailing the samples that are collected at that site. Note that if more than one bottle is filled at a site, for different types of analyses, this is to be registered on the same form.

Local conditions, such garbage in a well or visible pollution around a well as at the sampling site should be recorded on the form, at the time of sampling. Such information may be useful in analysis of data.

The form for identifying the sample and recording the field measurements and site conditions is given in Table 7.3.

Duly filled-in sample identification forms should be given to the laboratory analyst together with the samples. The forms should all be kept in a master file at the level II or II⁺ laboratory where the samples are analysed.

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
	Dissolved Solids	1	None*
Nutrients	Ammoniacal Nitrogen	3	8
	Total Oxidised Nitrogen	3	8
	Total Phosphorus	4	None*
Organic Matter	Chemical Oxygen Demand	3	8
	Biochemical Oxygen Demand	2	4°C, Dark
Major Ions	Sodium	3	None*
	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

NOTES:
Containers:
1. 1000 millilitre polyethylene bottle
2. Special BOD bottle (normally 300 millilitre)
3. 500 millilitre polyethylene bottle
4. 100 millilitre glass bottle
5. 1000 millilitre glass (or Teflon) bottle with Teflon lined caps
6. Strong thick-walled, screw-capped glass bottle (300 millilitre capacity). Only good quality will maintain a good seal after multiple sterilisations in an autoclave

Preservation:
7. 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.
8. Samples should be acidified with 2 ml of concentrated sulphuric acid
9. Samples should be acidified with 2 ml of concentrated nitric acid.

*None: Ideally, *all* 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.

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	Coliforms	Glass, PE, Sterilised	300	4°C, Dark
5	Heavy metals (Cd, Zn)	Glass, PE	500	HNO ₃ , pH <2
6	Mercury	Glass	1000	HNO ₃ , pH <2
7	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 4.1 and 7.1)

Sample code												
Observer				Agency				Project				
Date			Time			Well code						
Source of sample: <input type="checkbox"/> Open dug well <input type="checkbox"/> Hand pump <input type="checkbox"/> Tube well <input type="checkbox"/> Piezometer												
Parameter code	Container				Preservation				Treatment			
	Glass	PVC	PE	Teflon	None	Cool	Acid	Other	None	Decant	Filter	
(1) General												
(2) Bacteriological												
(3) BOD												
(4) COD, NH ₃ , TON												
(5) H Metals												
(6) Tr Organics												
Field determinations												
Temp	°C	pH		EC								µmho/cm
Odour code	(1) Odour free	(6) Septic		Colour code								
	(2) Rotten eggs	(7) Aromatic										
	(3) Burnt sugar	(8) Chlorinous										
	(4) Soapy	(9) Alcoholic										
	(5) Fishy	(10) Unpleasant										

IF WELL IS PURGED, COMPLETE BELOW:

Office Well Data			
Diameter	φ		cm
Depth	D		m
Static water level (avg)	SWL		m
Water column (D-SWL)	H		m
Initial volume well	V		L
Projected pump discharge	PQ		L/s
Projected time of purging (V/PQ)	PT		min
Field Flow Measurements			
Static water level on arrival	SWL		m
Actual pump setting			m
Purging duration			min
PUMP DISCHARGE BEFORE	Q		L/min
PUMP DISCHARGE AFTER	Q		L/min
Volume purged	V		L
Dynamic water level	DWL		m
Field Chemical measurement			
TIME AT START OF SAMPLING STARTED	T (°C)	EC(µmho/cm)	pH
+10 min			
+20 min			
+30 min			
+40 min			

Table 7.3: Sample Identification Form for Groundwater Samples

7.2 FIELD 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 temperature, pH, conductivity and oxidation reduction potential (ORP). 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.

7.2.4 MEASUREMENT OF OXIDATION-REDUCTION POTENTIAL (ORP)

ORP can be measured in the field with a purpose-designed platinum (Pt) electrode and meter in mV. Before measuring the ORP it is necessary to calibrate the meter. This should be carried out at least once per day, before the first measurement is taken. Calibration is achieved by the determining the ORP (Zobell's solution. For correct interpretation, simultaneous recording of the temperature of the water sample is necessary.

Once calibrated, the ORP of the water can be measured by immersing the electrode in a sample of water as soon as it is taken. Contact with air should be prevented as much as possible. It is important to remember that an ORP electrode often takes some minutes to stabilise, the reading must, therefore, be taken after this stabilisation has occurred.

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, 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.

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

The preferred type of sampler in the field for groundwater sampling is the submersible pump. The sampler should be cleaned and rinsed. Sampler should also be briefly checked for functioning, closing of caps, if applicable, and condition of the cable by which the submersible pump will be lowered inside the well.

To take a representative sample, the sampling procedure should meet the following requirements:

- allows removal of stagnant water from the well (called purging) by means of a submersible pump so that the sampled water represents the water in the aquifer;
- avoids degassing of the sample and volatilisation of components in it;
- prevents oxidation caused by contact with the atmosphere, and
- avoids contamination of the sample and the well.

Three conventional methods and one sophisticated technique are reviewed briefly with respect to their capability of providing representative samples as follows:

Conventional Techniques (not recommended under HP)

1. **Bailers** or **depth samplers** are the grab samplers that operate by lowering the device to a known depth in the water column, closing the valve at the bottom and raising it to the ground surface. Major limitation is the high atmospheric contact during sampling. Furthermore, bailers are difficult to clean (dead-volumes) and the risk of cross-contamination from one well to another (cross-contamination) is high. In addition, contamination of the well water during sampling can be foreseen when a large bailer scrapes the casing of small diameter wells. Purging of the well before sampling by the use of bailers is very time-consuming.
2. **Suction devices** lift the water sample by applying suction directly to the water or via a collection bottle. Suction can either be generated manually or by a pump (e.g. peristaltic or centrifugal type) but the sampling depth is limited to 8 or 10m. The major limitation is degassing and aeration that cannot be controlled. As with bailers, effective purging is very time-consuming using suction devices.
3. **Gas-driven devices** apply gas (air) creating positive pressure directly on the water that drives it from the borehole - back flow being prevented by check valves. Usually compressed air is pumped down the borehole through a delivery tube. The air then forces water up through a second tube (acting as an airlift pump) and the air water mixture emerges at the head of the well. The intense contact between high-pressure air and the water causes oxidation and disturbance in the dissolved gas balance of the waste water, namely, degassing and volatilisation, which in turn

can cause precipitation of contaminants. This will mean that the sampled water is no longer representative of the groundwater from which it is taken.

Sophisticated Technique (recommended under HP):

4. **Submersible pumps** are lowered into the borehole and water is driven out continuously at the surface. The following three principles are used to drive out the water: gears or rotor assembly (electric centrifugal pump), gas-operated plunger (piston pump) or a gas operated diaphragm (bladder pump). Submersible pumps of these three types are rated acceptable for sampling groundwater for all parameters, including volatile organic carbon, trace metals and dissolved gasses and is therefore recommended as the lifting device for the current water quality programme under HP.

If a submersible pump is used to obtain water samples from boreholes, it should ideally have the following characteristics (See Appendix A):

- **Variable pumping rate:** The capacity assessment has been calculated in Appendix A. A variable pumping rate is also necessary to allow high speed for rapid purging and slower speeds for sampling (less than or equal to 0.1L/min).
- **Size:** The outer diameter of the pump should be considerably less than the smallest inner diameter of the boreholes or piezometers in the monitoring programme. A gap of at least 3cm is needed all around to guarantee that the pump does not scrape/damage the sides of the wells during lowering and lifting. The smaller the pump compared to the inner diameter of the well, the easier the lowering and lifting will be. If the well is equipped with a digital water level recorder (DWLR), it is recommended that the DWLR is removed before insertion of the submersible pump to avoid physical damage to the equipment, tubes or cables.
- **Material:** The material of the pump, tubing and fittings (all parts that make contact with the well water) should be inert and resistant to corrosion. The most common material used is stainless steel.
- **Power supply:** A portable power generator set together with an adjustable frequency converter (to regulate the pumping speed) is required.
- **Portability:** The weight and size of the complete set of generator and accessories should be such that it could be easily transported even through off-road terrain. A lighter set is easier to handle and will increase the ease and speed of transportation and positioning.
- **Noise:** The noise level of the sets should be acceptable and for this purpose an exhaust silencer with muffler is advised.
- **Cleaning:** The pump and the tubes must be easy to clean (no 'dead-volumes') in order to avoid cross-contamination of wells.
- **Maintenance and repair:** The pump must be easy to repair in the field and all tools and spare parts must be included with the portable set.
- **Accessories:** A water level indicator and a field kit mounted with probes for analysing/monitoring parameters, like temperature, pH, conductivity and ORP are worth considering.

For manual sampling of hand-dug wells (which cannot be purged) all that is required is a weighted sampling can with a rope attached to its handle (Figure 8.1). The can is then carefully lowered down the well until it fills with water and is then brought out of the wall. Although virtually any style of sampling can is acceptable for this application, there are a number of features that are preferable as follows:

- **Small volume and diameter:** It is preferable that the sampling can has a relatively small volume and diameter. This makes it easier to haul the can up the well when it is full of water and helps to ensure that the can does not touch the sides of the well.
- **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.

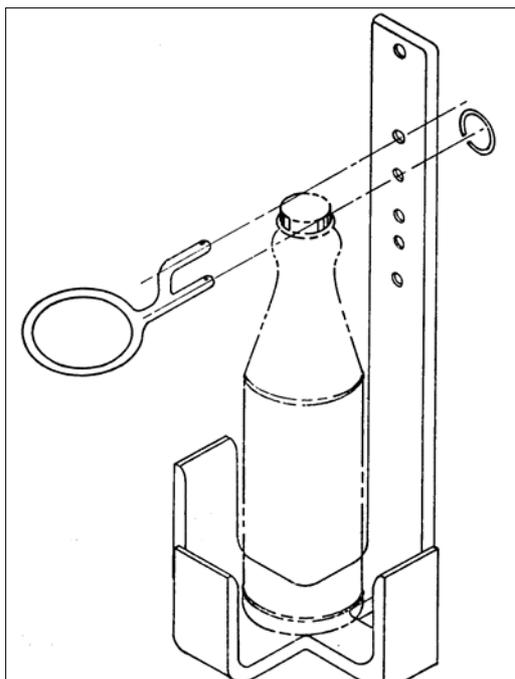


Figure 8.1:
Sample bottle holder for water sampling

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.

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, conductivity and oxidation reduction potential (ORP). 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.

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 7.1). 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 (III-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, NH_3 , NO_2^- , NO_3^-) 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.

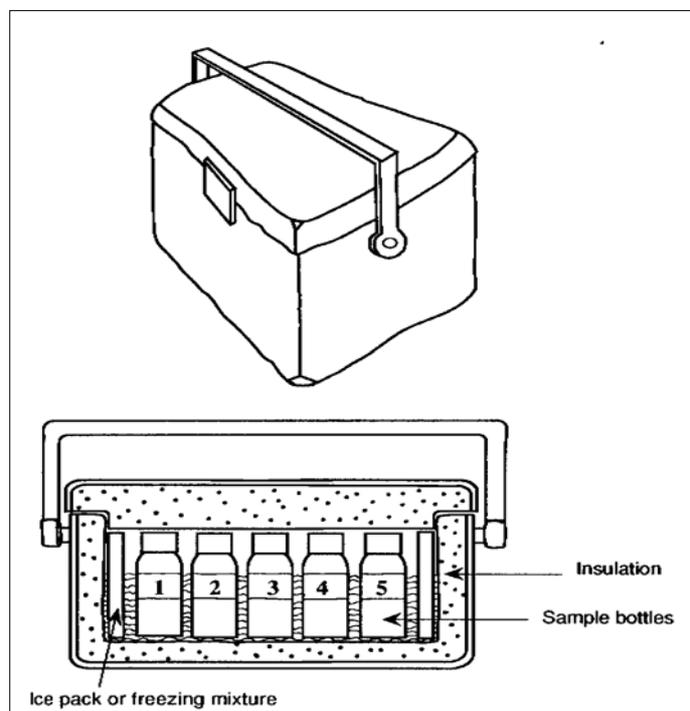


Figure 8.2:
Insulated bottle carrier for water quality samples

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:

• 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
• BOD bottles	• Rope
• Special sample containers: bacteriological, heavy metals, etc.	• Sample containers
• 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.

Appendix A

Specifications for Submersible Pumps

The specifications for capacity and discharge of submersible pumps depend largely on the situation in the field (depth of the water table, hydraulic characteristics of the aquifer, diameter of the well, initial thickness of the water column, time available for the sampling procedure, etc.). The effect of varying field conditions on the required pump capacity has been calculated and is presented in Table A-1. In these calculations the following assumptions made:

- pump heat loss is 20% (efficiency = 80%)
- specific yield is 2%
- Darcy-Weisbach coefficient is 0.04 (for both casing and delivery tube)
- transition losses add up to 1 m
- height of delivery point above ground is 2 m
- diameter of the delivery tube is 3.81cm (1.5 inch)
- depth of pump below the dynamic water level is 2 m

The set-up of the well under purging is presented in Figure A-1. In the calculations it is assumed that mixing of well water and aquifer water is complete and instantaneous. Equation A-1 gives the mass concentration balance for the well under purging (change in mass equals inflow minus outflow). This equation can be re-arranged into A-2. Assuming the factor Q_i/V to be constant, the solution to A-2 is given in equation A-3. The reciprocal of the Q_i/V is the relaxation time T_C ; the smaller T_C the faster the well assumes the aquifer concentration. The fraction of aquifer water in the well at time t is given by equation A-4.

$$\frac{d}{dt} (Vc) = Q_i c_i - Q_o c \quad (A-1)$$

$$\frac{d}{dt} (c - c_i) + (c - c_i) \frac{Q_i}{V} = 0 \quad (A-2)$$

$$\frac{c - c_i}{c_o - c_i} = \exp\left(-\frac{Q_i}{V} \cdot t\right) = \exp\left(-\frac{t}{T_C}\right) \quad (A-3)$$

$$C = 1 - \exp\left(-\frac{t}{T_C}\right) \quad (A-4)$$

In the solution of the differential equation it has been assumed that $T_C = V/Q_i$ is constant. This is not entirely correct. The actual value of T_C at time t is given by equation A-5, where the effect of draw-down has been estimated with the help of the Cooper-Jacob, equation A-6. From A-5 it is observed that the actual value of T_C is slightly smaller than V_o/Q_o . Hence, by estimating T_C from V_o/Q_o , the required pumping time to obtain a certain purging efficiency is on the conservative side.

$$T_C = \frac{V}{Q_i} = \frac{V_o}{Q_o} \cdot \frac{\left(1 - \frac{s}{H}\right)}{\left(1 - \frac{r^2}{4T} \cdot \frac{1}{t}\right)} \quad (A-5)$$

$$s = \frac{2.3Q_0}{4\pi T} 10 \log \frac{2.25Tt}{r^2 S} \quad (A-6)$$

where:

V	=	volume of water in well during purging	[m ³]
V ₀	=	volume of water in well when purging starts	[m ³]
C	=	actual concentration in well	[g/m ³]
C ₀	=	initial concentration in well	[g/m ³]
C _i	=	concentration in aquifer water	[g/m ³]
Q ₀	=	pump discharge	[m ³ /s]
Q _i	=	flow of aquifer water into the well	[m ³ /s]
t	=	time of purging	[s]
T _C	=	relaxation time	[s]
s	=	draw-down	[m]
H	=	initial height of water column	[m]
r	=	internal radius of well	[m]
T	=	aquifer transmissivity	[m ² /s]
S	=	specific yield	[-]

These equations are dimensionally homogenous, so any consistent system of units may be used.

The required capacity of the pump is calculated by A-7. It computes the product of discharge (Q) and the total dynamic head consisting of total head (h_d + d + s), friction head in tubes (h_{ft}), casing (h_{fc}), bends (h_t) and the velocity head (v_t²/2g).

$$C_p = \left(\rho \cdot g \cdot Q \left(h_d + d + s + h_{ft} + h_{fc} + h_t + \frac{V_t^2}{2g} \right) \right) / \eta \quad (A-7)$$

with:

$$h_{ft} = f_c \cdot \frac{d_p + s + d + h_d}{2r_t} \cdot \frac{V_t^2}{g}; \quad V_t = \frac{Q}{\pi r_t^2}$$

$$h_{fc} = f_c \cdot \frac{H - s - d_p}{2r} \cdot \frac{v^2}{g}; \quad v = \frac{Q}{\pi r^2}$$

where:

C_p	=	Pump capacity	[W]
Q	=	discharge	[m ³ /s]
h_d	=	above - ground lift	[m]
d	=	depth to static water level	[m]
s	=	draw-down	[m]
d_p	=	depth of pump below dynamic water level	[m]
h_t	=	height loss in transitions (bends etc.)	[m]
v_t	=	stream velocity in delivery tube	[m/s]
v	=	stream velocity in well	[m/s]
h_{ft}	=	friction loss in tubes	[m]
h_{fc}	=	friction loss in casing	[m]
f_c	=	Darcy-Weisbach coefficient of well casing	[-]
f_t	=	Darcy-Weisbach coefficient of delivery tube	[-]
r	=	internal radius of well	[m]
r_t	=	radius of delivery tube	[m]
g	=	acceleration due to gravity (9.81 m/s ²)	[m/s ²]
η	=	pump efficiency	[-]
ρ	=	density of water	[kg/m ³]

These equations are applicable in metric system only.

A.1 Pump discharge

Figure A-2 shows the effect of pumping time on purging efficiency for different pump discharges. As expected, purging efficiency increases with pumping time and pump discharge applied. This figure can be used to select the appropriate pump discharge for a required purging time.

A.2 Pump capacity

The required pump capacity (in terms of power consumption) is a function of the dynamic lift head of the water in the well, the discharge rate needed to obtain the desired purging efficiency within the time available and the heat loss of the pump. Table A-1 presents the conditions used in the calculations. The dynamic head is a function of the depth to the static water, the draw-down caused by pumping and a few other factors, like friction in tubing, as listed in equation A-7. Figure A-6 shows the build up of the dynamic head for various depths to static water level (SWL). As shown, all factors except friction loss in casing and the velocity head have practical importance at small depths to SWL. For greater depths to SWL, only the depth to SWL itself is contributing significantly to the dynamic head (all other factors become relatively unimportant also caused by the decline in Q).

Figure A-3 shows the pump capacity as a function of static water level depth. The curve shows a maximum pump capacity at moderate depths to SWL. At lower depths to SWL the pump capacity requirement is relatively low because of limited lift head. At higher depths to SWL the pump capacity requirement is also relatively low because of a low discharge needed to purge the small initial well volume. This figure also shows the effect of purging time. In order to decrease the purging time by 25% (say from 20 to 15 minutes) a 45% more powerful pump is needed (1.6 instead of 1.1 hp). This disproportionate increase is caused by the additional draw-down resulting in increased lift head. This effect will be larger in aquifers with lower transmissivity.

Figure A-4 shows that at higher transmissivities the required discharge and capacity of the pump decreases.

Figure A-5 shows that a larger well diameter requires a larger capacity pump. The required capacity increases almost quadratic with the diameter. The purpose build piezometers under Hydrology Project are relatively large in diameter. Approximately 30% of the wells has or will have a diameter of 11.4 cm (4.5 inch) whereas 70% has or will have a diameter of 15.2 cm (6 inch). In many countries in Europe and the USA a diameter of 2 to 2.5 inch is common for this type of monitoring piezometers. From a monitoring point of view one can state that the smaller the diameter the better. For practical reasons (drilling, availability of material and experience of contractors etc.) however, a larger diameter may be preferred.

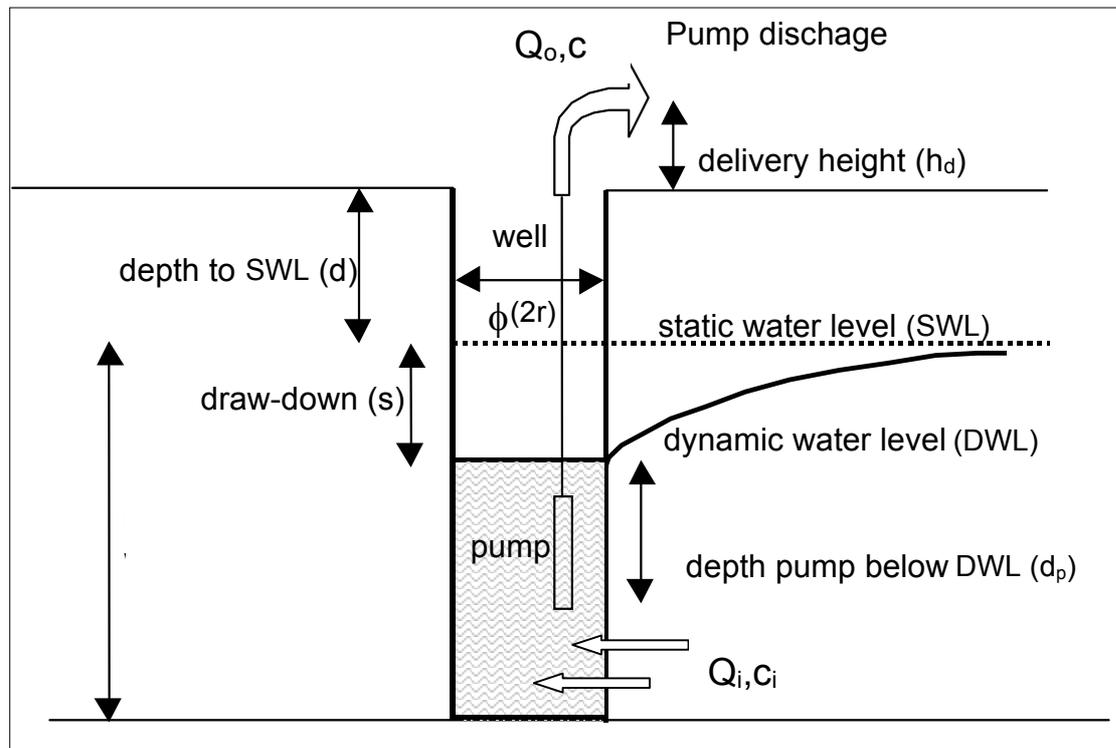


Figure A-1: Schematic Presentation of Well Under Purging (pumping) Operation

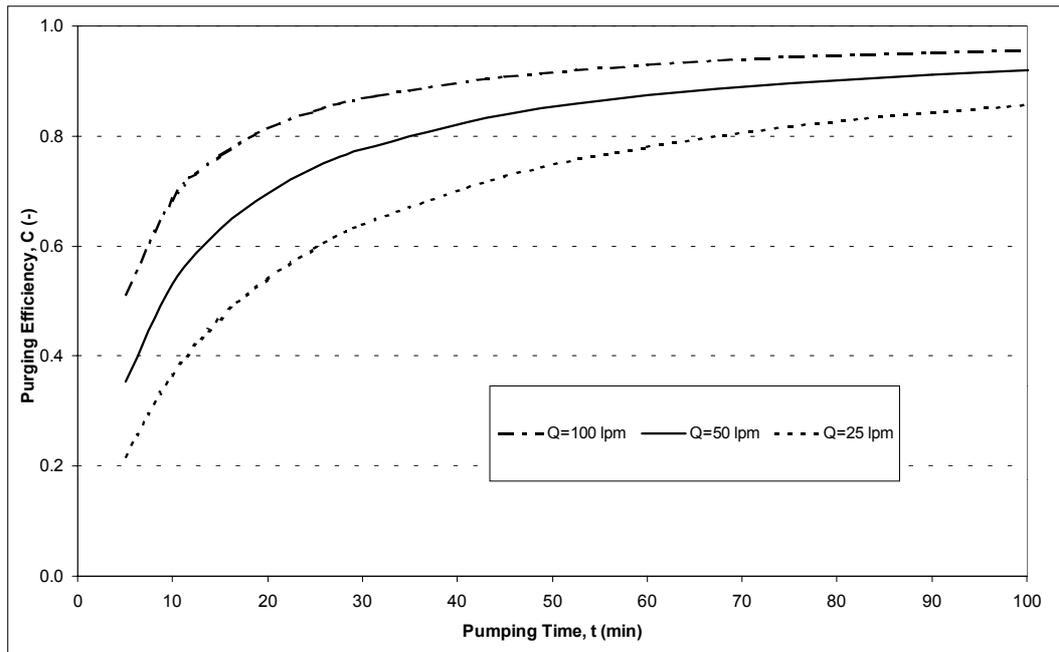


Figure A-2: Purging Efficiency as a Function of Pumping Time for Different Pump Discharges. Conditions: Depth to SWL=40 m, Well Depth=90 m, $T=20 \text{ m}^2/\text{day}$, $S=2\%$, Pump Efficiency=0.8, $\phi=10 \text{ cm}(4\text{'})$, $f_c=f_t=0.04$

Conditions	Field	Initial water column (H)	(m)	85	80	70	60	50	40	30	20	10	5	3	
		Equipment	Depth to static water level (d)	(m)	5	10	20	30	40	50	60	70	80	85	87
	Transmissivity (T)	(m ² /d)	20	20	20	20	20	20	20	20	20	20	20	20	
	Specific yield (S)	(-)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
	Well Diameter (ϕ)	(inch)	4	4	4	4	4	4	4	4	4	4	4	4	
Calculations	Chols	Depth of pump below dynamic water level (dp)	(m)	2	2	2	2	2	2	2	2	2	2	2	
		Height of delivery above ground level (hd)	(m)	2	2	2	2	2	2	2	2	2	2	2	2
		Head loss in transitions and bends (ht)	(m)	1	1	1	1	1	1	1	1	1	1	1	1
		Tube Diameter	(inch)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
		Darcy-Weisbach coef. for casing (fc)	(-)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	Darcy-Weisbach coef. for delivery tube (ft)	(-)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	
	Pumping Time (t)	(min)	30	30	30	30	30	30	30	30	30	30	30	30	
	Pump Discharge (Q)	(lpm)	143.7	136.1	119.0	102.0	85.0	67.9	50.9	34.0	17.0	8.5	5.1		
	Initial Well Volume	(l)	689	648	567	486	405	324	243	162	81	41	24		
	No. of Initial Volumes Purged	(-)	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3		
	Draw-down (s)	(m)	8.1	7.6	6.7	5.7	4.8	3.8	2.9	1.9	1.0	0.5	0.3		
	Dynamic Head	(m)	20.1	24.2	32.2	40.5	48.9	57.5	66.2	75.1	84.0	88.5	90.3		
	Purging efficiency (C)	(-)	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85		
	Velocity in casing (v)	(m/s)	0.098	0.093	0.082	0.070	0.058	0.047	0.035	0.023	0.012	0.006	0.003		
	Velocity in delivery tube (Vt)	(m/s)	2.101	1.991	1.741	1.491	1.243	0.993	0.745	0.497	0.248	0.124	0.074		
	Friction head in casing (hfc)	(m)	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
	Friction head in delivery tube (hft)	(m)	3.80	3.32	2.38	1.63	1.06	0.62	0.32	0.13	0.03	0.01	0.00		
	Height of delivery above ground level (hd)	(m)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00		
	Head loss in transitions and bends (ht)	(m)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
	Pump Capacity (efficiency 80% assumed)	(HP)	0.80	0.91	1.07	1.15	1.15	1.08	0.94	0.71	0.40	0.21	0.13		
	Pump Capacity (efficiency 80% assumed)	(W)	599	682	795	855	861	809	699	528	295	155	95		

After 30 minutes of pumping, 85% of the water pumped originates from the aquifer and 15% from stagnant well water.

Table A-1: Pump Capacity in a 90 m-deep, 100mm Diameter Well with Varying Depths to Static Water Level

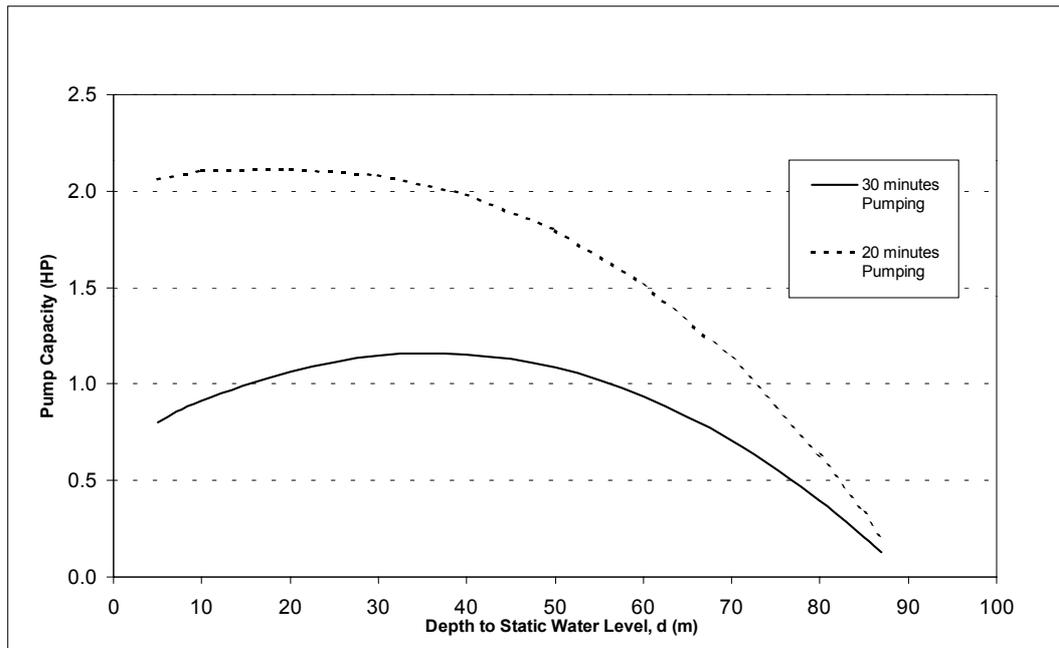


Figure A-3: Pump Capacity (in hp) required to obtain a 99% Purging Efficiency as a Function of Depth to the Static Water Level and Purging time. Conditions: Well Depth=90 m, $T=20 \text{ m}^2/\text{day}$, $S=2\%$, Pump Efficiency=0.80, $\phi=10 \text{ cm (4")}$, $f_c=f_R=0.04$

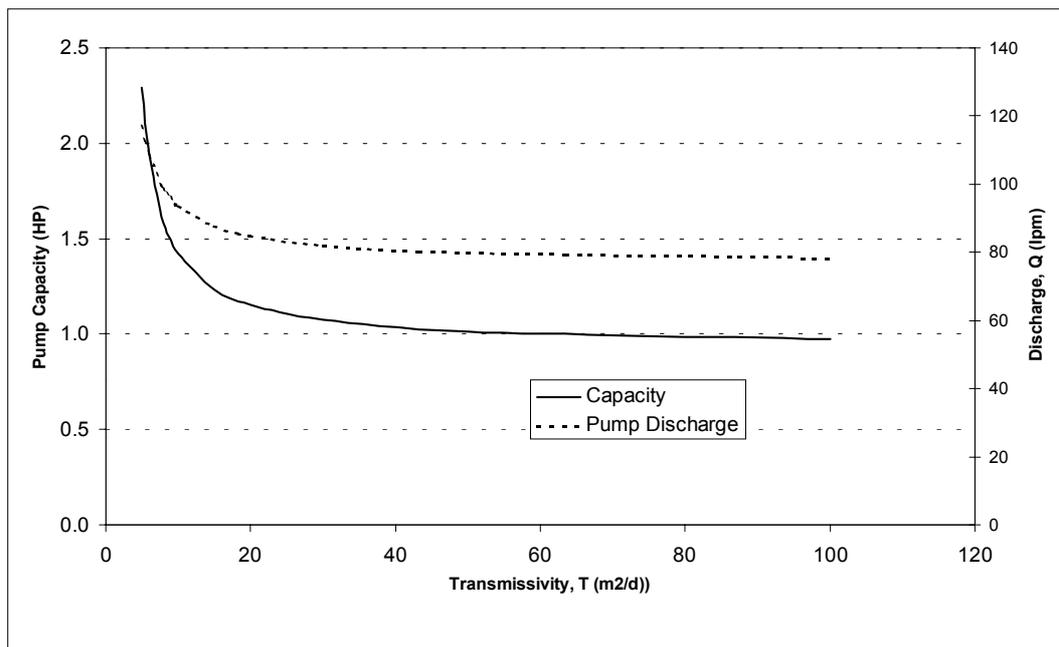


Figure A-4: Pump Capacity, Discharge and related Number of initial Well Volumes Required to Obtain 99% Purging Efficiency after 20 minutes as a Function of Aquifer Transmissivity. Conditions: Depth to SWL=40 m, Well Depth=90 m, $\phi=10 \text{ cm (4")}$, Pump Efficiency=0.80, $S=2\%$, $f_c=f_t=0.04$

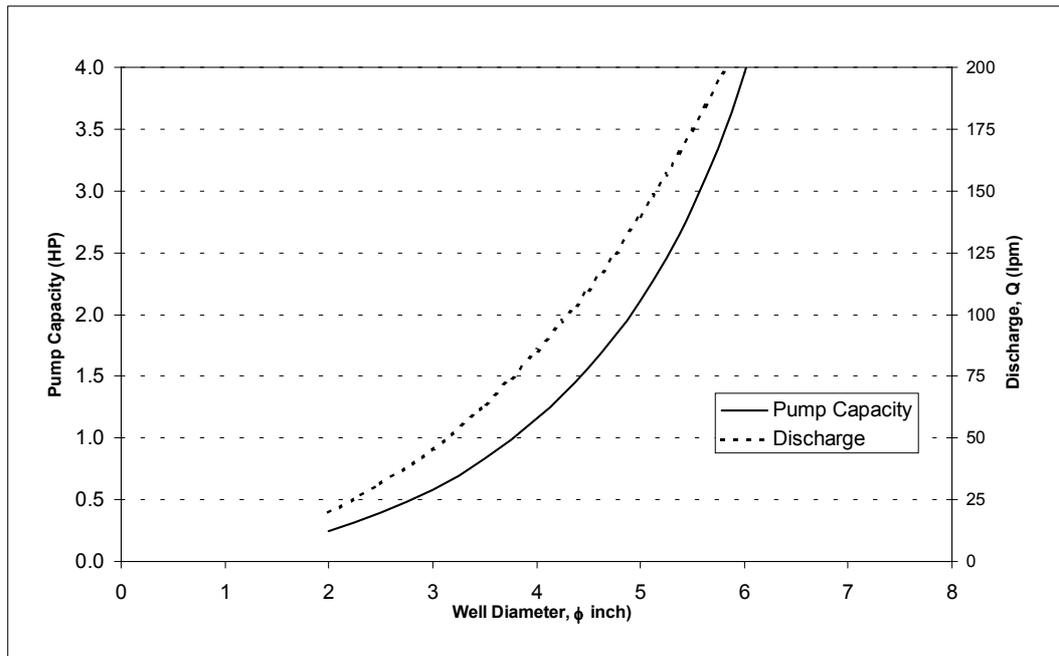


Figure A-5: Pump capacity (in hp) and discharge required to obtain 99% purging efficiency after 20 minutes as a function of well diameter. Conditions: Depth to SWL=40 m, Well Depth=90 m, $T=20 \text{ m}^2/\text{day}$, $S=2\%$, Pump Efficiency = 0.80, $f_c=f_t=0.04$

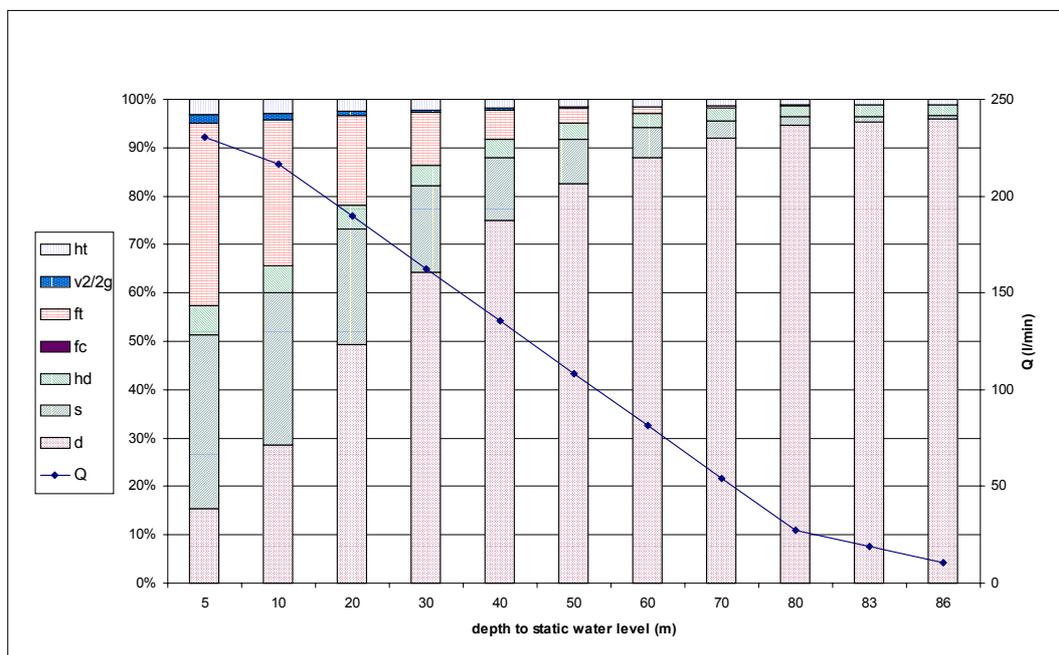


Figure A-6: Relative Importance of various Components contributing to the Dynamic Head of a 90 m Deep Well for various SWL Equipment Specification for Submersible Pump