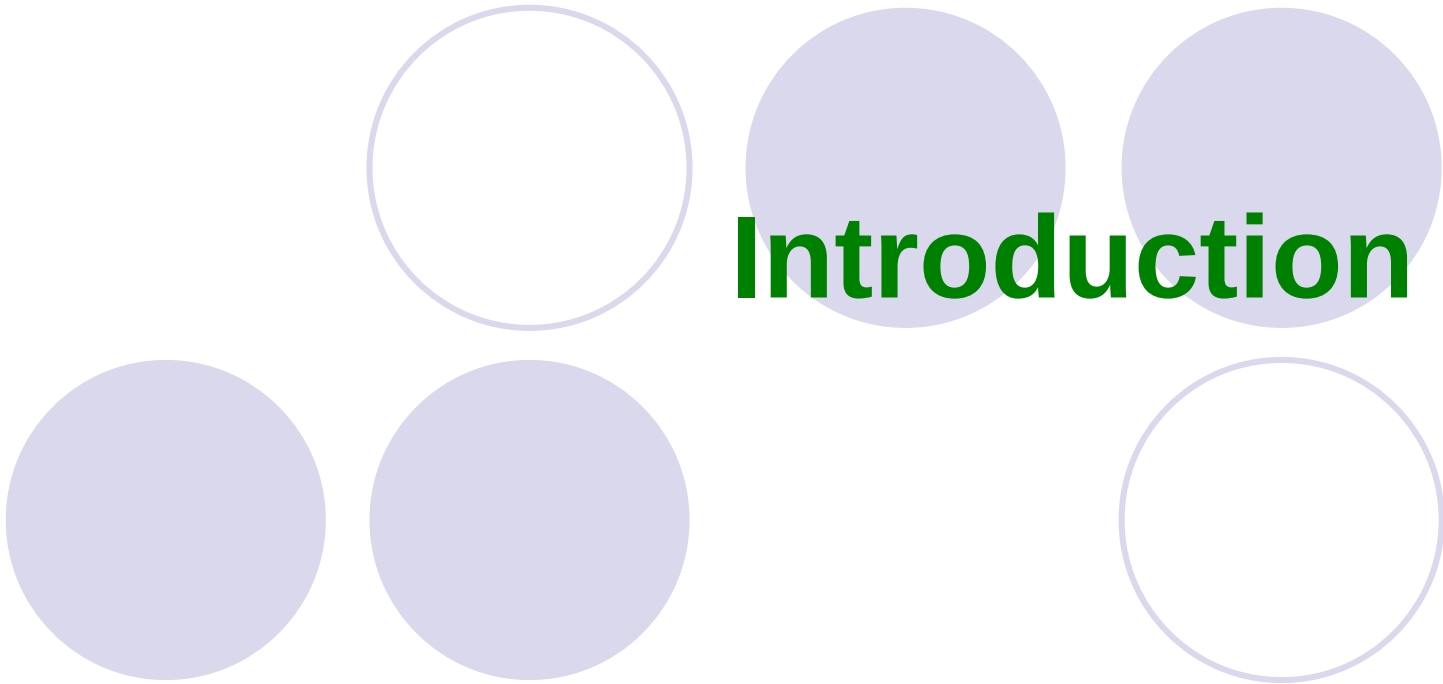
Design of Water Quality Monitoring Programs


Introduction

- **When designing a monitoring program, what is the essential works to do before field work?**
- **----to have clear objectives and documented methods that will be used to analyze data**
- **Give out three classification of the ordinary parameters when carrying out surface water monitoring.**
- **----physical, chemical, and biologic parameters**

Framework for Designing Monitoring Programs

- Setting Monitoring Program Objectives
- Study Design, Data Analysis Techniques, and Specific Data Requirements
- Sampling
- Laboratory Analysis
- Data Management and Analysis
- Reporting

Setting Monitoring Program Objectives

- **A number of questions need be considered when designing monitoring programs. These can be thought as “how” questions: how to collect, what to collect, when to collect, where to collect, and how to store and analyze samples.**
- **These are unanswerable without a clear specification of the information required. Without knowing the answer to the why question, it hardly matters how we answer the “how” questions.**

Defining the Issue

- A preferred approach initially will consist of identifying and articulating the issue.
- Defining the issue is an interactive process between the designer of the monitoring program and the user of the information.

Categories of Issues

- **Establishment of environmental (ecosystem/use) values and long-term management, protection, and restoration of aquatic ecosystems**
- **Identification of contaminant sources and cycling in aquatic ecosystems and assessment of the magnitude of problems and measures that need to be taken to protect ecosystem values**
- **Evaluation of the performance of management strategies**
- **Compliance with legislative or administrative standards**

- What's the meaning of "issue" here?
- ----basic objectives of the monitoring
- How an issue is defined depends on what?
- ----values, previous knowledge, and experience
- The initial statement of the issue may be the most crucial single step, why?
- ----determine the information required from a monitoring program

The need for a Conceptual Process Model

- What's the requirement to conceptual process models?
- ----be made explicit to illustrate the components and linkages in the system to be monitored. (Fig. 2.2)

- Conceptual process models assist in defining the "why" questions.

What the conceptual process models can be used to help define?

- What the important components of the system are and what the important linkages are likely to be
- The important questions to be assessed
- The key processes and cause-effect relationships
- The spatial boundaries
- The temporal and seasonal considerations
- The scales at which measurements are to be made
- Site selection
- What the valid measurement parameters are for the processes of concern

- **All process models are simplifications of reality and involve personal judgments.**
- **They do not need to be so comprehensive as to embrace all components of the system, but they do need to be sufficient for the issue being investigated.**
- **It is important to be aware that the conceptual process model being used might be wrong. As information is collected and reviewed, the assumptions underlying the model should be validated and changed to reflect any changed perspectives.**

Identifying the Water Quality Information Required

- What kind of data should be measured and collected? How about the data source?
- ----water quality measurements; stream-flow, tidal, or current records; and any biologic data that might be available.
- ----published studies; in the departmental records of various agencies; in local university departments.

Articulating Specific Program Objectives

- **The setting of specific monitoring program objectives commonly will go beyond scientific issues to address management issues.**
- **Clear objectives make it possible to design a sampling program to obtain the information required. Developing useful objectives requires practice and experience.**
- **Table 2.2 presents a list of some criteria that may be used as a checklist for writing objectives so as to get beyond data to information. (P2.7)**

Study Design, Data Analysis Techniques, and Specific Data Requirements

The study design stage is fundamental for ensuring a cost-effective sampling and analysis program. Based on the monitoring program objectives and the agree-on conceptual process model, general decisions must be made on

- **Spatial boundaries**
- **Measurement scales**
- **Study duration**
- **Study type**
- **Measurement parameters**
- **Presentation and interpretation of data**

Defining Spatial Boundaries, Measurement Scales, and Study Duration

- What the “scale” means?
- ----Scale refers to the units of space or time at which the system is observed.
- What factors should be considered when making measurement scale decisions?
- ----cost of data collection, the uniformity over space of the parameters of interest

Study Type

- **What is descriptive studies?**
- **----Descriptive studies are concerned with gathering data and conducting analyses to describe the state of a system or predict its state at a future time or under different circumstances. We can make informed predictions on unmeasured variables within the bounds of the data we have collected.**

- **What is understanding system processes studies?**
- **----Studies designed to increase our understanding of processes by establishing causality, through which we could make informed predictions about the behavior of the system outside the bounds of our data and experience.**

Selection of Measurement Parameters

- There are decisions to be made as to whether driving or causal factors should be measured or whether consequential or resulting factors are more appropriate to address the issue of concern. Or do you need to measure both? If so, why?
- When selecting parameters to be measured, what considerations should be borne in mind?
- ----relevance; validity; diagnostic value; reliability

Presentation and Interpretation of Data

- **What's the common methods for data presentation?**
- **---- presented in tables and graphs**

- **Please name the two main categories of inferential statistics.**
- **----Estimation, is where a value or a range of values is given that approximates the true value (e.g., confidence limits).**
- **----Hypothesis testing, is making a judgment about a spatial or temporal difference or cause and effect (e. g., null-hypothesis tests).**

Articulating Specific Data Requirements

- **What's the specific data requirements include and serve as?**
- **---- The specific data requirements include location, spatial boundaries, measurement scales, study duration, type of study, parameters to be measured, and techniques to be used for data presentation and interpretation. They serve as the concrete instructions for decisions to be made as to the appropriate sampling and analysis program.**

Sampling

- **Sampling can involve the physical collection and removal of a subset of the system for later analysis or the taking an in situ measurement at a selected place and time. The major problem of sampling is**
- **----representativeness**
- **Errors in accurately representing a water body or population by a subsample can far exceed errors in analyses.**
- **Data are not information, so if the samples cannot provide the information required, they are not worth the time and expense of collection and analysis.**

Sampling-Site Selection

- **Preliminary selection of Sites may be undertaken from maps and aerial photographs.**
- **It is important to undertake a field reconnaissance to check each proposed site.**
- **Safe access under all weather and flow conditions should be verified.**

Characterization of Spatial and Temporal Variability

- **High environmental variability and logistical and financial constraints on sample collection and analysis often result in data that are too variable to detect a disturbance or trend. Types of variability include**
- **----Spatial variability of parameters because of environmental heterogeneity; Time dependency and temporal and seasonal effects; Disruptive processes; Dispersal of pollutants**
- **Normally, the design of an ongoing monitoring program will require a short period of intensive monitoring as a reconnaissance study to determine the spatial and temporal variability characteristics of the system.**

- **Three types of sampling regimes are used to account for spatial and temporal variability:**

- **----Systematic sampling. Samples are collected at regular intervals in space or time. Sampling sites are selected by personal judgment to best cover the area and may be biased.**
- **----Random sampling. Samples within a site are collected randomly, such that each sample has an equal chance of representing the whole. It is based on valid statistical conclusions instead of casual or haphazard way.**
- **----Stratified random sampling. The system to be sampled is divided into parts (strata), each as uniform in the parameter of interest as possible. (equal size? Geographic location?)**

Frequency and Timing of Sampling

- Timing of sampling might range from intermittent to continuous. The consideration of timing depends on the process under investigation. (Table 2.3, P2.8)
- The decisions on time scale need to consider
- ----The purpose of the data collection.
- ----The characteristics of the response of interest.
- ----The statistical or other tools that will be used to interpret the data.
- ----Anything that takes longer to happen than the period over which measurements are made cannot be detected.
- Event-based sampling
- Biological sampling

Precision and Replication

- **The smallest differences or changes that must be detected is a decision depends on what?**
- **---- statistical significance? ecological importance? socioeconomic importance?**
- **How to get the number of replicates?**
- **----Once the size of the differences or magnitude of the trends have been answered, then the number of replicates can be got by performing the appropriate calculations.**
- **Pseudoreplication and True replication**
- **---- True replication require sampling from the same site at a number of times, not from different sites at the same time.**

Field Measurements

- Some measurements need to be taken directly in the field, such as pH and temperature, because they may alter during transport and storage. Field measurements of parameters allow cost-effective, real-time investigation of spatial distribution of contaminants.
- Field measurements consist of
- ----Data measured by field sensors; Remote sensing; Field observations; Real-time measurement by automatic means
- The precision of field measurements is usually poor because of the low detection limits required for most contaminants, so they are best used as screening tools.

Sample Collection

- **Device-related sampling errors cannot be accounted for by statistical methods or replication, and in many cases, they will be undetectable unless specific tests have been undertaken. Checks should be made that sampling devices are not made of materials that will contaminate samples.**
- **The sampling device should not significantly disturb the environment being sampled or alter the samples taken. Different devices will need to be used to ensure quantitative sampling of all the required parameters.**

Sample Preservation and Storage

- Why samples should be preserved reasonably?
- ----to retard physical, chemical and biological changes.
- Considerations for preservation and storage include
- ----Selection and decontamination of sample containers, selection of a preservation technique, and the acceptable time interval between sample collection and analysis
- How to make preservation choices?
- ----depending on the analyte to be measured
- All biologic activity is eliminated effectively only at -40 ℃.
- Acid Is often added to prevent adsorption of metals to containers and precipitation of insoluble salts.
- Why chemical preservatives should be avoided if possible?
- ----They may contaminate samples or interfere in chemical or biologic analysis.

Quality Assurance (complementary material)

- **Quality assurance (QA)** is a set of operating principles that, if strictly followed during sample collection and analysis, will produce data of known and defensible quality. That is, the accuracy of the analytical result can be stated with a high level of confidence. Included in quality assurance are quality control (QC) and quality assessment.
- **Prepare a QA plan including the following:** cover sheet with plan approval signatures, staff organization and responsibilities, sample control and documentation procedures, standard operating procedure for each analytical method, analyst training requirements, equipment preventive maintenance procedures, calibration procedures, corrective actions, internal quality control activities, performance audits, data assessment procedures for bias and precision, and data reduction, validation, and reporting.

- **The cover sheet with approval signatures indicates that the plan has been reviewed and judged suitable, and that the organization and responsibilities section outlines the chain-of-command and assigns specific functions to each person involved.**

- **Sample control and documentation procedures permit tracing a sample and its derivatives through all steps from collection to analysis and display of results. Documentation always is important but is especially so when chain-of-custody requirements are imposed.**

Quality Assurance in Sampling

- **The sampling locations must be specified accurately.**
- **Taking note of the time when samples were taken.**
- **Transfer of results to a database should be automated where possible, with checking of the printout against the field and analysis register.**
- **Chain-of-custody documentation is mandatory in legal cases.**
- **A field-sampling sheet is mandatory if parameters are to be measured in the field.**
- **All equipment and field instruments should be kept clean and in good working order, with records kept of calibrations and preventative maintenance.**

Quality Control in Sampling

- **The objective of a field quality control program is to control sampling errors to acceptable levels. Thus procedures are designed to prevent, detect, and correct problems in the sampling process and to statistically characterize errors through quality control samples.**
- **Major errors to be avoided are faulty sampling device operation, incorrect sample collection and labeling, and sample changes before measurement.**

Sampling Protocols

- **Sampling protocols include procedures to be followed in the collection, labeling, transport, and storage of samples and ancillary field data required.**
- **Protocols will be matrix- and constituent-specific and will determine the sample collection device, type of storage container used, and preservation procedures.**
- **The protocol also will specify the types and numbers of quality control samples to be taken.**
- **Training of the sampler within the protocol (to use sampling equipment, sampling, and taking field measurements).**

Prevention of Sample Contamination (P2.19-2.20)

- Types of blanks
- ----Container blanks.
- ----Equipment blanks.
- ----Trip blanks.
- ----Field blanks.
- ----Field filter blanks.

- What's the difference between container blanks and field blanks?
- ----in the lab vs. in the field

Reproducibility and Accuracy

- **Three procedures are commonly used to ensure reproducible and accurate sampling:**
- ***Duplicate samples (splits).*** **By dividing one sample into two or more subsamples, allows the magnitude of errors occurring from sampling to sample analysis to be determined.**
- ***Replicate samples.*** **Two or more samples are collected simultaneously to establish the reproducibility of sampling.**
- ***Recovery of known additions.*** **Spiking of subsamples in the field with a known amount of the analyte of interest and subsequent measurement will allow the detection of change.**

Field Occupational Health and Safety

- **Hazards and risks involved in field sampling need to be identified and documented on a preliminary site visit. The major issues could include: Access? Toxic and hazardous substances? Pathogens? Dangerous fauna? Weather?**
- **Personnel who are to conduct sampling should be physically and mentally able to carry out field work. All staff must be appropriately trained as part of the formal risk-minimization strategy. Training will include: Familiarization with environmental hazards that may be encountered, safety procedures, sampling protocols, and use of sampling equipment; Qualification to drive appropriate vehicles and in advanced first aid.**
- **Actions to reduce risks include: Choose safe sites with safe access; Wear appropriate clothing; Take appropriate safety gear and a first aid kit; Maintain contact with help, and never sample alone; Never go into deep water; Avoid contact with contaminated water.**

Cost-Effectiveness of the Sampling Program

- **It is desirable that the cost of sampling programs be as low as possible to meet the stated monitoring objectives.**
- **Cost-Effectiveness considerations involve trade-offs between the data required for statistical analyses and the cost of data acquisition.**
- **Cost of data acquisition are determined by**
- **----the number of sampling sties, the number of sampling occasions, replication, cost of sampling collection, cost of analyses, and the cost of data handling and interpretation.**

Laboratory Analysis

Choosing an Analytical Technique

- **The choice of an appropriate analytical method is based on three considerations:**
- **----The range of concentrations of the analyte that need to be determined. (the lowest concentration of interest?)**
- **----The accuracy and precision required. (cost)**
- **----The maximum period between sampling and analysis. (real-time analysis needed?)**

Quality Assurance in Analysis

- **The objective of a laboratory quality assurance program is to control subsampling and analytical measurement errors and produce data for the user that are acceptable.**
- **Procedures are designed to prevent, detect, and correct problems in the measurement process and to statistically characterize errors through quality control samples.**

Traceability of Results

- **The record system needs to provide a traceable pathway covering all activities from receipt of samples to disposal and allow retrieval of all original test data within the terms of registration. The following are required for all analyses:**

- **unique sample identification**
- **Identification of analyst**
- **Identification of equipment used**
- **Original data and calculations**
- **Identification of manual data transfers**
- **Documentation of standards preparation**
- **Calibration solutions used**
- **Certified reference materials used**

Laboratory Facilities, Human Resources, and Protocols

- **The laboratory environment must be clean and checked regularly for airborne contamination that can enter through air-conditioning systems or be generated by users of the laboratory. (deionized water)**

- **All equipment should be kept clean and in good working order, with records of calibrations, preventative maintenance, all repairs, and any incidents that may affect equipment reliability.**

- **All staff undertaking analyses must be technically competent and skilled in the particular techniques being used and should have a professional attitude toward their work.**

- **Fully document the methods used. The methods must be described in sufficient detail that an experienced analyst, unfamiliar with a particular method, can follow the procedure and obtain acceptable results.**

Quality Control in Analysis

- **Quality control (QC) may be either internal or external. External QC is also known as ”quality assessment”.**
- **A good internal quality control program consists of at least seven elements: certification of operator competence, recovery of known additions, analysis of externally supplied standards, analysis of reagent blanks, calibration with standards, analysis of duplicates, and maintenance of control charts.**
- **External quality control includes performance evaluation samples, laboratory intercomparison samples, and performance audits. Quality assessment is the process of using external and internal quality control measures to determine the quality of the data produced by the laboratory.**

Terms

- ***Bias*** **is a measurement of systematic error and can be attributed to either the method or the laboratory's use of the method.**
- ***Precision*** **is the nearness with which measurements of a given sample agree with each other.**
- **When combined, bias and precision are expressed as *accuracy*.**

- ***Certified reference materials*** **are materials of a known concentration with a similar matrix to the sample being analyzed that have been analyzed comprehensively such that their composition can be certified reliably. The accuracy of laboratory methods and procedures can be established by comparison of results with the certified values. Results within the confidence limits specified for the certified reference material are deemed acceptable.**

- ***Independent methods comparison*****: Analytical inaccuracies can be determined by the analysis of samples by two or more independent methods.**

- ***Recovery of known additions*: By spiking a sample with a known amount of analyte, it's possible to estimate the recovery and hence the accuracy of the method used. It is assumed that any interference or other effects biasing the method will affect the spike in a similar way to the analyte in the unspiked sample.**

- ***Calibration check standards*: The linearity of calibration plots must be verified initially by the use of multiple standards. Standard curves can then be verified daily by analyzing at least one standard within the linear range, ensuring the instrument is giving the correct response.**

- ***Blanks* should be incorporated at every step of sample processing and analysis (field blanks, laboratory procedural blanks). Blanks cannot be used to detect analyte loss. They are useful only to detect contamination. (particularly in minor contamination)**

- ***Replicate analyses* are used for assessing precision.**

- ***Quality assessment of analyses*** **is the process using internal and external measures to determine the accuracy and precision of the analytical data being produced. Techniques used include internal evaluation samples, proficiency testing programs (interlaboratory comparisons), and performance audits.**

- ***Internal evaluation samples*****: Samples with a known analyte concentration prepared in the laboratory but independent of the analyst or obtained from an outside source.**
- ***proficiency testing programs (interlaboratory comparisons):*** **unknown samples; testing instrument calibration, performance, and operator skills; modest degree of sample preparation; consensus values; accreditation authorities sponsor.**
- ***Performance audits*** **are unscheduled checks in which deviations from standard operating procedures and protocols are identified and corrective action taken.**

Laboratory Occupational Health and Safety

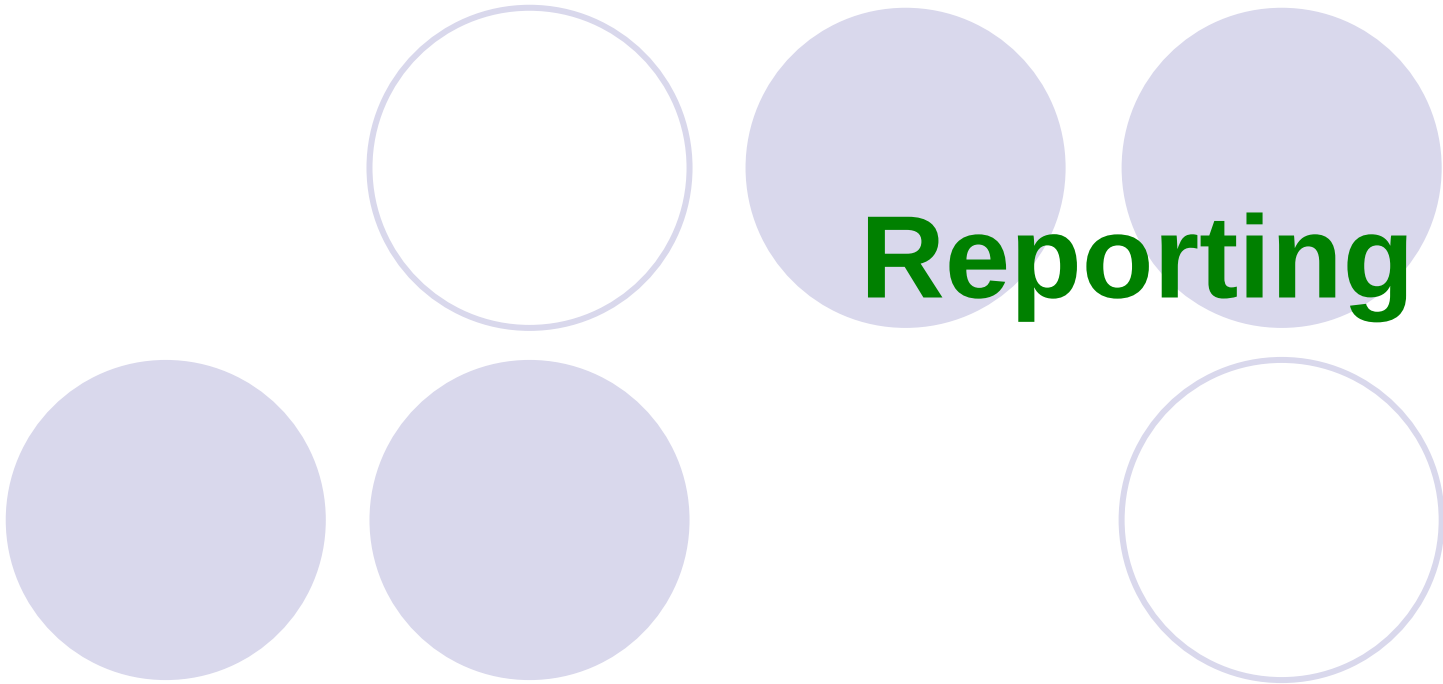
- **The hazards and risks associated with laboratory work need to be identified and documented.**
- **All staff must be appropriately trained as part of the formal risk-minimization strategy. Training will include familiarization with protocols (analysis, safe handling, disposal procedures, chain-of-custody), safety procedures, use of laboratory equipment, and qualifications in advanced first aid.**
- **Actions to reduce risks include: wearing appropriate clothing; appropriate first aid kit; training of laboratory staff in first aid procedures; maintaining contacts with help and never working alone.**

Data Analysis and Management

- **Decisions about specific data requirements and data presentation and interpretation are made as part of the general study design. It is essential that appropriate statistical tools are available and that the person undertaking the analysis of data has sufficient training to do so.**
- **There are many pitfalls in data analysis, and an awareness of the assumptions underlying statistical procedures and the limitations of the statistical package being used is required.**

Data Management

- ***Need for a Data Management and Reporting System:*** **Substantial investment in data collection; sheer magnitude of data accumulated; computer-based data management systems**
- ***Types of Data Management Systems:*** **updating the databases to use new computer technologies; difficulties of transferring data; commercial databases**
- ***System Design Considerations:*** **The needs of the user are the most important feature in the design of a water quality database. The record system needs to provide a traceable pathway covering all activities from receipt of samples to disposal to ensure the integrity of the sample from collection to final analysis with respect to the variables of interest.**


Reporting

Reporting and Information Dissemination

- **Monitoring programs should clearly identify the end users' needs and their information requirements. A reporting system is required that efficiently and accurately transmits this information.**
- **Different clients may want data in different forms and on different time scales. It is important to identify the various users and work with them to articulate their data needs.**
- **Users will request information over different time frames depending on the use and application of the information. In both short- and long-term monitoring programs, a realistic time frame in which to report the information must be developed.**
- **Types of reports include scientific journals, conference papers, technical reports, guidelines, and manuals.**
- **Avenues for dissemination include the Internet, compact discs, videos, industry and professional association seminars and workshops, abstracting services, community group presentations, and media articles.**