ASPECTS OF MONITORING IN RIVER BASIN MANAGEMENT

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INTRODUCTION

A brief review of monitoring techniques being used in river basin management suggests that monitoring approaches are as varied as the basins being managed. Even though monitoring techniques may vary, a substantial core of common practices exist. Although common practices exist, implementation of monitoring programs may not always result in data which improves the probability of management success. Because monitoring program design reflects natural variation within the basin and is often limited by fiscal constraints, monitoring approaches vary, often more a function of the training and experience of the scientist or engineer directing the monitoring effort than a result of application of standard practices. A common result is river basin management dependent on monitoring programs which are narrowly focused (many emphasize only chemical water quality). Inappropriate or non-correlative data is often produced by different agencies in a single basin limiting basin wide management initiatives. The design, implementation and maintenance of monitoring programs to meet agency requirements must be tempered with an understanding of the importance of generating data which provides the opportunity for the development of comprehensive, basin wide, management programs.

My responsibility in this paper is to provide an overview of the theme "Monitoring" for this Third River Basin Conference. The following discussion provides a general review of physical, chemical, and biological monitoring. Several monitoring approaches particularly relevant to river basin management are highlighted. Some of these approaches are proven, some have been applied but remain unproven, and some are speculative.

At the outset, I will consider that monitoring is conducted as a part of a management program. A river basin management program requires an organized approach to data collection. Management decisions should be based on an understanding of the complex physical, chemical, and biological interactions occurring in a river and its watershed. To implement any management decisions an organization must exist which provides the basis for collective and coordinated action. The structure of this action forcing organization must include a system for deciding the merits of actions and the development or enforcement of regulations, or other control measures. The technical support required for river
basin management includes description of general watershed conditions and quantitative measures of physical, chemical, and biological parameters. Monitoring provides this technical support allowing selection of management programs with the highest probability of success. River basin management is subject to the limitations of society where the complexity of social, behavioral, or political issues often create barriers to action. Where barriers to action are encountered, scientific or technical information (such as that provided by monitoring) introduces a quantitative and generally invariable information resource which provides a common language for discussion and review of complex issues, overcoming barriers to decisionmaking, and encouraging sound management.

The role of monitoring in river basin management is illustrated in Figure 1. The objective of management is making decisions which will achieve desired results. A decision made without a clear understanding of its consequences often results in an outcome which will not meet management objectives. To assure that objectives are met, some feedback is required which reports on outcome. Monitoring provides this feedback. In examining the management and decision making framework more closely it can be seen that monitoring also plays an important role in modifying other mechanisms of decision making. A management decision (if it involves technical issues) is typically based on some model or protocol (termed a prediction algorithm) which is based on experience or developed through application of technical information (noted in Figure 1 as data/information input). A management decision is thus made on some prediction of outcome, illustrated in Figure 1 as a prediction loop. If the decision option has an acceptable predicted outcome, that option will be the basis of management. If the predicted outcome of a management option is unacceptable (as judged by some set of management objectives or societal values), it is possible using the
prediction algorithm to test alternate approaches. The prediction loop allows iterative testing of alternatives until the best management approach is identified. Monitoring not only provides direct feedback to management, but can also contribute to the prediction loop by providing information to modify the prediction algorithm. Monitoring is designed to acquire data from which management information is extracted. If monitoring indicates that the management strategy is meeting established objectives, no change is made in the management approach. Even though management objectives are met, it is essential that monitoring continue to provide early warning of any change in management results. If monitoring indicates objectives are not being met, the management strategy must be changed, modified to achieve the desired objectives.

The integration of prediction and monitoring loops occurs when both prediction and monitoring are connected in the management approach. The prediction loop provides flexibility in evaluating numerous decision options. When a management strategy is selected, monitoring assesses if the results meet management objectives. Used together, prediction and monitoring become a powerful management tool. A second interaction between the prediction and monitoring loops occurs when monitoring data are used to provide the data or information input to the prediction algorithm. The result of this interaction is the enhancement of the effectiveness of management. A continuing improvement in prediction algorithm accuracy is possible, improving the certainty that the management approach will meet expected or required objectives. A third interaction occurs when the prediction algorithm identifies new or important relationships between parameters monitored. Monitoring programs can then be modified to incorporate additional analyses. In summary, monitoring can be used in a sensitivity analysis of prediction algorithms and provide the foundation for prediction algorithm development. Prediction algorithms can also be used to identify parameters which should be monitored to assess management strategy success.

In developing monitoring programs, the emphasis is usually placed on data collection and initial data analysis. The importance of monitoring in river basin management is based on the information content of the data collected and the utility of monitoring results in decision making (predictive model application).

The distinction between data and information should be clarified. Data, in the form of concentrations of substances or numbers of organisms only provide the opportunity for developing information. Information is generated as data analysis is performed and data, particularly time sequenced or series collections, are synthesized, correlated, and evaluated. Critical to this view of the data/information dichotomy is the understanding that information content is dependent on data quality and once data are collected it is a resource which should be optimized for maximum information extraction. The challenge in river basin management is the collection of data within the constraints imposed by time and limited fiscal resources which will provide the maximum information for sound decision making. Any data collection program must be designed to meet existing as well as future information requirements. In addition, monitoring must not be viewed simply as the source of data or information; the results of monitoring must be integrated into the management program, particularly in decision models or management protocols through both monitoring and prediction algorithms.
The major questions which arise concerning the design of a monitoring program are simply stated as what, where, and when to monitor. This paper will address these questions in each of the following sections discussing physical, chemical, and biological monitoring approaches.

River Basin Analysis

The river basin, or watershed (the terms will be used interchangeably) is the fundamental unit of evaluation in many monitoring efforts and is the focus of this conference. The literature justifying basin wide monitoring is extensive and is supported by a recognition that the stream is an integral part of its valley (Hynes, 1975). It is impossible to depend on cause/effect determinations based on isolated observations in limited areas of a watershed because of the influence of upstream areas as well as the downstream impact of any upstream change (Vannote, et al. 1981). The wisdom of basin management is well accepted, but caution must be exercised in a blanket application of watershed approaches. Hughes and Omernik (1981) note that in the United States only about 60% of the streams have topographically well defined watersheds. The remaining 40% of the streams occur in areas where topography or surficial geology produce conditions which defy precise delineation of watershed boundaries. If viewed from a management perspective, the absolute reliance on watershed boundaries may be inappropriate, particularly if contaminant sources and sinks occur outside traditional topographically defined boundaries.

Monitoring Approaches

Different techniques of monitoring are often used if the objective is analysis of physical, chemical, or biological condition. The selection of parameters to be monitored and the monitoring technique to be used is an important part of the overall monitoring effort. Reviewing the history of water quality control provides some insight into why specific techniques are selected for analysis of certain parameters. In general, monitoring methods reflect the changing concerns for public health, safety, and environmental protection. The selection of parameters monitored parallels advancement in analytical techniques. An index of this development might be derived from the number of rules or regulations directed to water quality or environmental protection, modified by a value which reflects enforcement activity. In the United States, this index of concern has moved generally upward since the late 1800's (initiated with passage of the Rivers and Harbors Act of 1899) with the sharpest rise occurring in the decade following 1965. International concern also follows the same trend with leadership provided by countries which seem to have the luxury of worrying about the environment, rather than development.

The trend in analytical improvement shows sharp increases with the advent of new technologies. Initial analysis procedures were primitive. Hinman (1920) identified a test of drinking water used in 1784 assessing quality if the water would "...dissolve soap without forming lumps...and deposit nothing or very little by tests." The establishment of water quality criteria is based on analytical capability. In the United States, earliest criteria were for residues, ammonia, and bacteria per volume of water (McKee and Wolf, 1963); recommended criteria published in 1968 (Federal Water Pollution Control Administration, 1968) listed approximately 50 criteria for drinking water in five categories (physical, microbiological, inorganic chemicals, organic chemicals, and radioactivity); the 1976 criteria (U. S. Environmental Protection Agency, 1976) included 53
parameters. The most recent listing of criteria includes 65 toxic substances (both inorganic and organic chemicals) many of these substances are added to the existing criteria. In addition, analytical improvements such as gas chromatography/mass spectrometry have expanded the list of parameters of concern into the hundreds, if not thousands. Presently, sophisticated analytical tools provide the opportunity to monitor more environmental parameters than can be appropriately used in either regulatory, environmental control, or management activities. A tremendous amount of data is being generated in ongoing monitoring programs, but little information is being obtained from this effort.

The following discussions are directed to physical, chemical, and biological parameter monitoring. The intent of the discussions is to identify the parameters typically selected for monitoring and discuss how physical, chemical, or biological monitoring results can be synthesized or made internally consistent to allow integration with other data. The production of correlative, high quality data and information from physical, chemical, and biological monitoring is the basis for sound management.

PHYSICAL SYSTEM MONITORING

The parameters typically selected physical system monitoring include standard hydrologic parameters (discharge, velocity, width, depth, slope), substrate characteristics, temperature, and a number of water quality related parameters involving sediment analysis (size distributions, specific weight, and density as a function of time).

The primary emphasis of physical monitoring is flow or discharge. In the United States a network of gaging stations has been created to provide long term records of stream flow conditions. Flow information, particularly return frequency (such as the seven day low flow with a frequency of once in ten years) has been used in the regulation of wastewater discharges (providing a basis for calculating dilution factors). The design of the flow monitoring network in the United States is based on the division of river drainage basins into regions and subregions identifying hydrologic accounting units. The gaging stations are usually located in downstream areas where flow from each unit can be monitored and integrated with all river basin measurements.

The importance of temperature and sediment analysis in water quality determination is well recognized. Temperature affects saturation values for dissolved gasses, alters the metabolic rate of aquatic organisms, and may affect the nature of water (viscosity and specific gravity) producing substantially altered mixing characteristics as temperatures change. Sediment may carry adsorbed substances, alter light and temperature regimes, and directly affect aquatic organisms. The integration of measures such as temperature and sediment with chemical parameters often provides insight into mechanisms of transfer or alteration which affect the fate or environmental concentration of toxic substances. This information is essential to river basin management utilizing stream assimilative capacity.

Recently a renewed interest in physical monitoring parameters has developed as monitoring emphasis has been placed on biological systems. The interest is generally not placed on the measurement of single parameters, rather an emphasis is placed on the integration of all physical measures into a comprehensive habitat.
description for aquatic organisms. This habitat description includes depth, width, and velocity as well as substrate characteristics and measures of hydraulic variability both within a specified reach (such as pool and riffle measurement) and for the hydrologic accounting unit (flow frequency analysis). Physical habitat requirements are now weighted equally with chemical water quality conditions in management approaches (Karr and Schlosser, 1978). Maintenance of habitat quality should be a primary objective of river basin management.

The location of physical monitoring stations is dependent on the objective of the physical monitoring effort. For example, measurement of suspended solids reach substrate or habitat characteristics, or water quality related physical parameters can be performed at any convenient location. The continuous monitoring of flow or discharge requires establishment of a gaging station and rating the station with discharge measurements. The optimum location for a gaging station is upstream from a hydraulic control (a natural or man-made feature which limits flow) in a reach of stream which will not change significantly through time. The specific location requirements and high maintenance costs for gaging stations have limited the number of stations. With a limited number of fixed stations, the hydrologic accounting unit has been used to define flow originating in subregions of a watershed providing a basis for reach or watershed specific hydrologic analysis.

Although it is possible to sample physical parameters at any location in the watershed, and at any time, the most valuable information is provided by long term records at one location where changes in physical conditions can be compared. Because the number of gaging stations is limited, gaging station data reach specific special studies can be employed to improve management success. Determination of flow frequency related changes in width, depth, and velocity at any location within a watershed is possible using relationships defined by stream hydraulic geometry (Horton, 1945; Strahler, 1957; Stall and Fok, 1968). Because a consistent relationship exists between drainage area, width, depth, and discharge for most watersheds, it is possible to use hydraulic geometry relationships to extrapolate data from a fixed point gaging station to the upstream hydrologic accounting unit (Stall and Fok, 1968). A second management technique requires a short term data collection effort on a "representative reach" of stream (Bovee, 1981). From a detailed watershed evaluation, one or more reaches are selected which are representative of a larger river reach. Measurements of depth, velocity, and substrate are made at several cross sections in this reach. This data is used to calibrate a hydraulic model which is used to predict flow related parameters throughout the representative reach. The use of hydrologic information from the model can be expanded if gaging station data is available for the reach providing the opportunity for flow frequency analysis (Sale, et al., in press).

A strong case can be made for continuous measurement of flow in physical monitoring. With rating curve data for each gaging station, it is possible to calculate depth, velocity, and average reach width for any discharge. Applying hydraulic models provides the opportunity to extract useful information from a limited data resource. When continuous monitoring is not possible, the next alternative should be event sequenced monitoring. Since most physical parameters are subject to flow variability, using flow as a basis for event sampling is particularly useful. At many U.S. Geological Survey gaging stations, sampling devices which will only collect samples during high flow are often used. Although
Monitoring in river basin management

anticipating storm events is extremely difficult, it is possible to design a monitoring program to support measurement of one or more hydrologic events (either high or low flow). Thus sampling frequency of physical parameters, if not continuous, should be selected to provide sampling of both average and low frequency events.

The integration of physical habitat measurements and monitoring in river basin management has required the development of a number of methodologies which synthesize physical measurements prior to integration. The utility of flow return frequencies in management/regulation has already been identified. The synthesis of physical measurements to meet management objectives in the United States is exemplified in instream flow needs analysis methodologies. Since flow occurring in the stream is critical to the maintenance of several uses (such as navigation, recreation, and aquatic life) instream flow needs analysis is an important component of river basin management. If flow is withdrawn or diverted aquatic habitats are modified. A computer based analysis system PHABSIM (Physical Habitat Simulation) has been developed by the U. S. Fish and Wildlife Service to assist with instream flow needs analysis (Stalnaker and Arnett, 1976 and Milhous, et al., 1981). PHABSIM uses hydraulic simulations and species specific habitat requirements (for velocity, depth, and substrate) to provide a measure of physical habitat available at different flows. The importance of PHABSIM in river basin management is that it provides a basis for quantification of habitat as well as integration of this physical information with water quality or other management objectives. An example of the utility of PHABSIM in river basin management is provided by Sale, et al. (1982).

CHEMICAL MONITORING

The parameters measured in chemical monitoring programs are as varied as the goal of the management and limited mainly by cost considerations. With advances in analytical instrumentation, the number of substances (this term used to identify elements or compounds) analyzed has increased and detection limits have improved. Although a chemical monitoring program will typically be designed to meet specific management requirements, several chemical parameters are regularly analyzed. Conductivity, pH, transparency, dissolved solids, major nutrients, trace elements, organic and inorganic carbon, and oxygen-related measurements are routinely monitored in the United States, Table 1.

The design of specialized monitoring programs depend on wastewater characteristics and management objectives. Although attempts have been made to categorize wastewater by developing profiles for industrial categories, a significant variability in the presence and combination of substances of interest requires careful selection of parameters to be monitored. The management objectives of a monitoring program play a significant role in the parameters selected for analysis. Unfortunately, management emphasis may lead to poor monitoring design. A common fault of wastewater treatment is the emphasis on treatment of a limited number of substances. Even when effluents are known to contain complex mixtures of substances, treatment is often focused on one or two parameters. For example, the emphasis in domestic wastewater treatment is generally on BOD and suspended solids removal with wastewater polishing achieved by disinfection. Limited emphasis has been placed on toxic substances and only
Table #1 Water Quality Characteristics Measured at EPA National Water Quality Surveillance System Stations.

Characteristics measured a/

Field determinations
- Streamflow
- Water temperature
- Conductivity
- pH
- Transparency or turbidity

Common constituents
- Bicarbonate, carbonate, residue (total filterable), residue (total nonfilterable),
  calcium (total), magnesium (total),
  sodium (total), potassium (total),
  chloride (total), sulfate (total)

Major nutrients
- Total phosphorus
- Total nitrite plus nitrate
- Total Kjeldahl nitrogen
- Total ammonia nitrogen

Trace elements
- Total iron

Organic and biological
- Total organic carbon

Oxygen-related measurements
- Dissolved oxygen
- Chemical oxygen demand

a/Frequency varies, with about half of the stations sampling bi-weekly and the rest sampling monthly.

Source: EPA National Water Quality Surveillance System parameter list, Mar. 9, 1977

recently has concern about disinfection byproducts modified treatment processes. Management approaches which limit the parameters analyzed and support a continuation of that limited analysis are very common. Once parameters are selected a tendency exists to standardize monitoring. The data generated may not reflect process modifications or watershed changes which may significantly affect management outcome.

The primary issues raised in chemical monitoring program design are not what to analyze but where and when monitoring should take place. In the United States the water quality monitoring program has been evolving for the past ten or more years (dating from passage of the Clean Water Act (33 U.S.C. 1251 et seq.). The existing monitoring network relies on approximately 1,000 primary network stations maintained by the Environmental Protection Agency (EPA) with the cooperation of the states. A second network of approximately 500 stations in the National Stream Quality Accounting Network (NASQUAN) and an additional 7000 water quality sampling stations are maintained by the U. S. Geological Survey (USGS). The parameters monitored and the frequency of analysis vary between EPA and NASQUAN stations, the primary difference is the continuous monitoring of flow (due to location at gaging stations) in the NASQUAN network, Tables 2 and 3.

The water quality monitoring approach used in the United States has been severely criticized (U. S. General Accounting Office, 1981). The general accounting office concluded that water quality is too complex to be monitored by networks which depend on fixed stations and infrequent sampling. The inadequacies of fixed stations stem from the same factors cited above in discussions of parameter selection. A fixed station may or may not be placed to provide the best
monitoring data (and associated information). Stations are often located as a matter of convenience (at bridges or sites where the river is readily accessible) rather than following a sampling design specific to wastewater and stream characteristics. Because streams are dynamic systems with variability in flow changing mixing zones and zones of impact, a fixed station may not provide an accurate picture of actual water quality.

Another problem cited by the General Accounting Office (GAO) in sampling location is the provision for integrated sampling across the width of the stream. Poor mixing of wastewaters and inappropriate selection of sampling location can lead to monitoring results which poorly describe actual environmental conditions. Collecting integrated samples across the width or throughout the depth of the stream is essential to adequate chemical monitoring, but can significantly increase monitoring costs.

Sampling frequency is the second area of concern in designing water quality monitoring programs. It is axiomatic that as the frequency of sampling increases, costs rise (but at a generally decreasing unit cost). Although continuous monitoring is desirable, instrumentation exists for only a limited number of parameters. If samples are collected infrequently, major events are often missed and a false picture of water quality condition can be developed. The end result of most chemical monitoring is abundant data, but extremely poor information.
Table #3  Parameters Measured at U. S. Geological Survey NASQUAN Network Stations

<table>
<thead>
<tr>
<th>Characteristics measured</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field determinations</td>
<td></td>
</tr>
<tr>
<td>Discharge (flow)</td>
<td>continuous, daily or monthly a/</td>
</tr>
<tr>
<td>Water temperature</td>
<td>continuous, daily or monthly a/</td>
</tr>
<tr>
<td>Specific conductance</td>
<td>monthly</td>
</tr>
<tr>
<td>pH</td>
<td>monthly</td>
</tr>
<tr>
<td>Fecal coliform bacteria</td>
<td>monthly</td>
</tr>
<tr>
<td>Fecal streptococcus bacteria</td>
<td>monthly</td>
</tr>
<tr>
<td>Common constituents (dissolved)</td>
<td></td>
</tr>
<tr>
<td>Bicarbonate, carbonate, total hardness, non-carbonate hardness, calcium, magnesium, fluoride, sodium, potassium, dissolved solids, silica, turbidity, chloride, and sulfate</td>
<td>monthly or quarterly b/</td>
</tr>
<tr>
<td>Major nutrients</td>
<td></td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>monthly</td>
</tr>
<tr>
<td>Total nitrite plus nitrate</td>
<td>monthly</td>
</tr>
<tr>
<td>Total Kjeldahl nitrogen</td>
<td>monthly</td>
</tr>
<tr>
<td>Trace elements (total and dissolved)</td>
<td></td>
</tr>
<tr>
<td>Arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, selenium, and zinc</td>
<td>monthly or quarterly</td>
</tr>
<tr>
<td>Organic and biological</td>
<td></td>
</tr>
<tr>
<td>Total organic carbon</td>
<td>quarterly</td>
</tr>
<tr>
<td>Total phytoplankton</td>
<td>monthly</td>
</tr>
<tr>
<td>Three co-dominants of phytoplankton</td>
<td>monthly</td>
</tr>
<tr>
<td>Periphyton, biomass dry and ash weight</td>
<td>quarterly</td>
</tr>
<tr>
<td>Periphyton, chlorophyll a and b</td>
<td>quarterly</td>
</tr>
<tr>
<td>Suspended sediment</td>
<td>monthly</td>
</tr>
</tbody>
</table>

a/Continuous or daily depending on whether the station is equipped with a monitor or whether daily observations are made. Monthly measurements made at stations where a long-term record is available.

b/Quarterly or monthly, depending on whether relationships have been established between conductance and concentrations of various common constituents.


The GAO suggested an alternative to fixed station monitoring. The major recommendation was that special studies of individual rivers or river segments be made. With proper design, a water quality analysis would produce scientifically sound, useful information. This approach certainly has its merits, but special studies may produce little information on long term trends in water quality.

The design of chemical monitoring programs must meet three critical objectives. The first is an accurate appraisal of existing water quality. The second is sound information for the assessment of trends. The third objective is the maintenance of information quality to provide a basis for integration with physical and biological information. Unfortunately, one or more of these objectives may be viewed as mutually exclusive if the typical constraints placed on water quality monitoring programs are identified. It is beyond the scope of this paper to suggest detailed approaches to meet all of the objectives. It is also difficult to identify a case study where all objectives have been met simultaneously. It is possible, though, to suggest an approach to water quality monitoring which will meet all objectives.
First, the water quality monitoring program should be flexible. The addition or deletion of parameters analyzed should follow regular review. The monitoring program should include both fixed stations and special studies. Fixed station monitoring should be conducted following rigorous sampling and analysis quality assurance guidelines. The implementation of special studies should include not only more detailed sampling at fixed stations, but also periodic analysis throughout the reach being managed to assess overall water quality condition.

The periodic reviews of the water quality monitoring program should take into account changes in watershed condition, addition or deletion of wastewater sources and changes in management objectives. The integration of the chemical monitoring program with physical and biological monitoring information can be facilitated by both fixed station and special study design. As in the USGS monitoring network, continuous flow monitoring should be maintained at all fixed stations to facilitate calculation of substance loading and provide a record of flow variability (useful for identifying trends and integrating chemical and biological monitoring). Special water quality studies can be integrated with instream biological monitoring. The presence or absence of aquatic organisms can provide some indication of water quality history, and residue analyses can provide information to alter the list of substances analyzed. Of critical importance is the collection of correlative, high quality data.

In summary, chemical monitoring presents complex problems in river basin management. It is often the core of an overall monitoring program. Although it is the core or foundation of the monitoring program, it is inappropriate to consider chemical monitoring a sufficient basis for river basin management. Water quality information should be of sufficient quality to provide an indication of trends (both through time and distance) and provide a basis for the integration of physical and biological information.

BIOLOGICAL MONITORING

Biological monitoring (biomonitoring) has been the subject of a recent series of reviews (Cairns, et al., 1982) which cover in detail topics from early warning systems, through toxicity testing and community monitoring, to future needs. Although this coverage is comprehensive, it may be useful to review some topics which are important in river basin management.

The parameters measured in biomonitoring are species or communities of aquatic or semiaquatic organisms. The basic unit of measurement is the species, but limited systematic understanding of all groups of aquatic organisms has often forced applied ecologists to use communities as identifiable entities in biomonitoring. Although strong arguments are made by Resh and Unzicker (1975) for species identification, the realities of sampling difficulties, taxonomic differentiation, and ecological understanding limit most biomonitoring (Herricks and Cairns, 1982). The approach used in the face of these difficulties has been the selection of an indicator or target species in biomonitoring. The indicator species is typically well described taxonomically, and sufficient data exists to define its ecological characteristics (tolerance to pollution, etc) leading to its utility in identifying water quality types. Target species are selected to provide a management objective. It is assumed that if the target species is maintained, the community or ecosystem will meet a desired management objective. Similarly, it is assumed that if water quality is suitable for the maintenance of the target species, the remainder of the community will be maintained.
As might be expected, the general assumptions made when indicator or target species are identified, may be called into question. The major limiting factor is the complexity of aquatic ecosystems. The dynamic nature of streams and rivers, and the major differences which exist between upstream and downstream reaches produce a range of environmental conditions which preclude presumptive application of the results from one area to another. Where an extensive biomonitoring record exists, the use of indicator or target species can be the basis of management decisions. Management based on sound information will have a high probability for success. Where only a limited record exists, management options will not be limited, but the probability of success will be much reduced.

Since most river basin management programs will be based on limited data, methods must be applied which will maximize information extraction and increase the probability for management success. The improvements suggested for biomonitoring include technological innovations which provide early warning of pollution effects (Cairns and Van Der Schalie, 1980) more comprehensive watershed analysis (Karr and Schlosser, 1978), integration of stream habitat conditions (Karr, et al., in press), and better measures of aquatic community condition (Matthews, et al., 1982; Herricks and Cairns, 1982).

The major advances in biomonitoring will occur as a more complete understanding is gained of factors which control aquatic ecosystems. The National Research Council in a recent report (National Research Council, 1981) identified relevant aquatic ecosystem properties and processes which are important in assessing the effects of chemicals. Population properties such as mortality, fecundity, rate of growth, phenotypic and genotypic variability, behavior and migration will play an important role in determining chemical effects. System properties such as diversity, productivity and biomass, nutrient and mineral cycling, functional composition connectivity, population interaction, genetic and taxonomic variability, and geographic specificity may also alter chemical effects. Biomonitoring must take into account the full range of of population and system properties. The complexity of the task is overwhelming.

Although the task of developing a comprehensive biomonitoring program may be overwhelming, opportunities exist for the formulation of sound biomonitoring programs through careful selection of population or system measures and building on existing data and information resources. As an example, a good place to start would be modification of procedures used to select indicator or target species. Recent experimental studies (Paine, 1966; Paine, 1980) suggest the presence of "keystone" species or species groups termed "modules" which play an inordinately important role (in relation to their numbers) in the maintenance of the community. The identification of keystone species or species modules which play an important role in aquatic community maintenance would allow management based on defined ecological relationships rather than assumptions of indicator or target species importance. The basis of selection of species for biomonitoring would be experimental ecological analysis rather than descriptive interpretation of species importance.

A second improvement in the formulation of biomonitoring programs is possible if the system property of connectivity is analyzed. Levins (1981) illustrates the number of possibilities which exist for the connection between organisms and trophic levels in the typical community. The National Research Council (1981)
discusses the implications of connectivity in assessing chemical effects on ecosystems. The organization of the system (this term can mean either a community or ecosystem) will control the point of impact and based on the point of entry will define the expected movement and potential effects throughout a complex food web. Although the prospects of exact definition of all connections existing in an aquatic community are limited, developing an understanding of the fundamental connections existing in an aquatic community provides a basis for selection of what should be monitored and affords an opportunity for prediction which is essential to sound river basin management.

In summary, as in chemical parameter selection, the selection of what to monitor in biomonitoring depends not only on the capability for measurement but the utility of the data when integrated with other measurements. Most biomonitoring will depend on community level analysis with selected species used for detailed analysis (as in toxicity testing). The selection of indicator or target species can be improved through experimental analysis of species relationships in the community. An understanding of connections between species and trophic levels can be especially valuable in prediction models, a valuable tool in any management structure.

**Biomonitoring Design**

The selection of where and when to sample is typically made after biomonitoring objectives are established. The indicator species (keystone species or species module), or the aquatic community selected for biomonitoring will partially define sampling location and schedule. The final definition of biomonitoring design will be a compromise between ecological definition and practical limitation.

One method of differentiating biomonitoring design activities has been proposed by Cairns, et al. (1976) as in plant and in stream biomonitoring. In plant systems hold organisms in the effluent stream, providing an early warning of effluent effect. Regular, short term effluent toxicity testing can also be considered an in plant biomonitor although the benefits of continuous biological assessment are lost by periodic testing.

In stream testing is extensively used in biomonitoring. Samples are obtained from stream habitats, analyzed, and interpreted to assess effluent impacts and assist in management decisions. When the objective of biomonitoring is assessment of a single effluent, a minimum of three sampling locations are normally established. The first is an upstream reference location which will provide samples unaffected by the effluent. A second sampling location lies in the area of maximum impact, used to assess effluent effect. The third sampling point is usually located some distance downstream, allowing mixing, dilution, and assimilation of the effluent, delimiting the zone of effect (or recovery). When more than one effluent exists, or tributaries enter the reach being managed, sampling locations should bracket possible sources to assist in interpretation of any change observed in biomonitoring. In most biomonitoring designs, sampling locations are fixed. Fixed biomonitoring locations suffer from the same limitations of fixed station chemical monitoring. Modifying sampling procedures may resolve some of the limitations of fixed location sampling. At a fixed location it is possible, even necessary, to change sampling methods to accommodate changes in physical or chemical conditions. For example, artificial substrates may be used where habitat is limited or drift sampling may be selectively used to
identify a component of macroinvertebrate community dynamics. The use of
different nets and traps may be required to adequately sample transient fisheries
or assess spawning potential. Although organisms may be displaced from the fixed
location, modification of procedures to sample transient populations (comparing
transient with resident populations) may provide extremely valuable information
for management.

Sampling frequency is possibly more critical than location in biomonitoring
design. The typical biomonitoring program is based on a seasonal sampling
frequency, a minimum of three or four sampling periods are usually specified.
Although the life history of aquatic organisms do follow seasonal patterns,
adjustment in sampling frequency is often required to assess community dynamics.
A well designed biomonitoring program should be based on a sampling frequency
keyed to the life history of keystone species or species modules. This design,
will of necessity, be flexible requiring constant modification of sampling
frequency based on prevailing stream conditions. By careful modification of
sampling frequency, some of the limitations of fixed location sampling can be
overcome. Changes in community composition can be identified and assessments made
of natural or effluent causes of observed change.

SUMMARY

The role of monitoring in river basin management is to provide the information
required to make sound management decisions. The challenge in designing an
effective monitoring program design is the collection of data within the
constraints imposed by time and fiscal resources which will provide the maximum
information for management. Presently, sophisticated analytical tools are
available for use in monitoring programs. These tools provide the opportunity to
monitor more environmental parameters than can be appropriately used in management
activities. A continuing problem faces managers. The advancement of analytical
capabilities constantly creates the opportunity for more extensive monitoring.
With limited fiscal resources, choices often have to be made between maintenance
of existing monitoring programs and implementation of new programs which include
analysis of new parameters and the development of sophisticated analytical
capabilities. If existing programs are abandoned, the ability to determine trends
may be lost. If implementation of new monitoring programs represent a knee-jerk
response to political or social pressure, the actual information gained from the
new analyses may be limited in relation to the cost of data acquisition.

Recognizing the difficulties associated with selection of a monitoring program
in river basin management suggests that the role of monitoring information in
river basin management be reviewed, and carefully defined to meet the specific
needs of each basin. Even though monitoring programs must be designed to meet
specific basin needs, monitoring must provide a standardized data and information
resource. A standardized data resource allows comparison between basins, and
supports selection of a core of parameters which should be monitored in any
management program.

The selection of a general core of parameters for river basin monitoring is
possible if general monitoring objectives are similar. The objectives of
monitoring should be: 1) develop information resources which accurately describe
existing environmental conditions and identify short term and long term trends, 2)
provide correlative data from physical, chemical, and biological analyses and, 3)
support a flexible management approach which takes into account the dynamic nature
of streams and rivers and reflects changes in use or development of the watershed.
To meet these objectives, narrowly focused monitoring programs must be abandoned. For example, it is not possible to meet these objectives if only chemical parameters are monitored. An emphasis must be placed on information quality. Management strategies should be developed through use of predictive algorithms constantly improved by monitoring. Finally, all monitoring activity in a river basin should be integrated to provide correlative high quality data.

It is possible that we will be able to agree at the end of this conference on the specific parameters which should be monitored to meet the above objectives. I will suggest that at a minimum, flow and some measure of stream habitat be monitored. To these physical parameters should be added selected chemical parameters which include common constituents and critical toxic substances. Finally, monitoring should provide an assessment of biological condition through measures of keystone species or species module abundance as well as community functional capability. Properly integrated, these parameters will provide sufficient information to adequately support river basin management.

REFERENCES


