

PROCEEDINGS

WORKSHOP ON WATER QUALITY MONITORING
IN COLORADO

Edited by

Robert C. Ward and William L. Raley

July 1985

COLORADO WATER RESOURCES



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Norman A. Evans, Director

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INTRODUCTION TO PROCEEDINGS

These proceedings record the presentations made during a one-day workshop on Water Quality Monitoring in Colorado held at Colorado State University (CSU) on May 16, 1985. The workshop was supported by the Colorado Water Resources Research Institute and the Cooperative Extension Service.

The workshop discussed the evolving role of monitoring in water quality management by reviewing existing monitoring efforts and current research on monitoring system design. The workshop consisted of three sessions. The first session was a review of current monitoring efforts by three government agencies: (1) the U.S. Environmental Protection Agency, Region VIII; (2) the Colorado Department of Health; and (3) the Larimer-Weld Council of Governments. The second session was a review of current research efforts underway at CSU on the design of water quality monitoring systems. During the luncheon Tad Foster, a member of the Colorado Water Quality Control Commission, in asking the question, "What is the quality of our water?" provided the transition from the review of current efforts discussed in the morning sessions to what can we do in the future to improve monitoring in Colorado.

The third session was a panel discussion which was initiated by a presentation on our ability to get information from monitoring. The panel discussion focused on summarizing our current ability to get water quality information (i.e., an accurate understanding of the behavior of water quality in the environment); the existing knowledge that could be readily utilized to improve our ability to acquire information; and the type of research needed to further enhance our ability to obtain information in the future. It was noted that for monitoring systems supporting a particular mission (i.e., resources management or regulatory control), the ability to obtain information is tied closely to our ability to define what information is sought. Only in this way can the design of monitoring systems be focused around clearly defined and understood information goals.

WELCOME

Norman A. Evans
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I was fortunate to be appointed by Governor Love as a charter member of the Colorado Water Quality Control Commission in 1966 and served for 14 years. In that time the commission really paid little attention to groundwater as you well know, I'm sure. Groundwater was a subject to us then that seemed way off in the far distant future, if at all, under quality control regulation. As a matter of fact, when it was even mentioned it was in the spirit of something quite mysterious and even unmanageable. I know those of us on the Commission through those earlier years felt like groundwater quality control was low priority.

But now the time has come when groundwater quality is high in priority, and so this workshop today is very timely. Groundwater has come to be recognized as a critical resource nationwide. The amount of water supplied by groundwater is surprising a lot of people. It is a large proportion of the total supply for domestic use.

And deterioration in quality is more than imagination. The facts are emerging rapidly and we have to pay serious attention.

Fortunately the Water Quality Control Commission and the Division of Water Quality Control in the State Health Department are working now--and have been for several years--on the framework for regulatory action in groundwater. The most recent draft has just been circulated by an ad hoc committee of which I am a member. I hope most of you will look it over and comment on it.

I just wanted to point out to you that the topic of the workshop today is extremely timely, and as you know better than I, extremely challenging--challenging in the sense of getting the framework for regulation put together and then finding the tools to monitor and ultimately enforce regulation.

Best wishes on a very fruitful conference.

EPA'S ROLE AND FUNCTION IN WATER QUALITY MONITORING

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Introduction

"Water quality monitoring" is defined as the set of activities which provides chemical, physical, geological, biological, and other environmental data required by environmental managers. For the purpose of this paper, water quality monitoring is limited to those activities involved in the EPA and state implementation of the Clean Water Act in inland waters. Water quality monitoring has been an active program of EPA and its predecessors even before the passage of the Federal Water Pollution Control Act (now known as the Clean Water Act). Section 106 in the act refers specifically to water quality monitoring and allows grants to states to assist them in administering programs for the prevention, reduction and elimination of pollution. To carry out this program a state must establish and operate appropriate devices, methods, systems and procedures necessary to monitor, and to compile and analyze data (including classification according to eutrophic conditions) on the quality of navigable waters and to the extent practicable, groundwater including biological monitoring.

There are other sections in the act in which water quality monitoring plays an important role, such as 305(b) in which states are required to report biennially to the Region as to the quality of their waters.

EPA's role in all of this is to assist the states in accomplishing the water quality monitoring requirements of the act and to assure that monies granted to the states are used to obtain sound scientific data.

EPA Assistance

One of EPA's first efforts in helping states was to develop a document entitled "The Basic Water Monitoring Program." This document was issued as guidance to the states to provide a framework for addressing national water quality monitoring needs. It stressed intensive surveys and called for EPA and the states to operate a national network of fixed monitoring stations, develop and operate a pilot biological monitoring program, and

report on water quality in accordance with section 305(b) of the act. We have revised this document and now call it "**Guidance for State Water Monitoring and Wasteload Allocation Programs.**"

It covers the following topics:

1. overview of water quality programs;
2. monitoring for water-quality based controls;
3. monitoring for compliance and enforcement;
4. water quality assessments;
5. quality assurance;
6. data reporting; and
7. total maximum daily loads and wasteload allocations.

EPA and the states will use this document in developing annual work plans for the water quality monitoring program. I've attached a table that summarizes the monitoring activities that we are concerned about.

Another area in which we give assistance to the states is in bioassays/biomonitoring. In the fixed laboratory facility at the Denver Federal Center and through the use of a self-contained mobile laboratory unit, the EPA, Environmental Services Division, is able to provide biomonitoring support to the states and regional programs.

This is accomplished through conducting static and flow-thru bioassays either at the central laboratory or on-site using such test organisms as:

- fathead minnows
- rainbow trout
- channel catfish
- daphnia
- ceriodaphnia

The studies are developed to:

1. monitor existing permits or stream conditions; and/or
2. Develop site-specific toxicity standards in support of existing water-quality based permits or receiving water standards.

Specifically, in Colorado numerous static tests have been conducted to monitor selected discharges. Additionally, two on-site studies were conducted, one at the Littleton/Englewood Wastewater Treatment Plant and one at the Longmont Wastewater Treatment Plant, to study the ammonia toxicity problem.

We assist Colorado in the monitoring of municipalities and industries through the National Pollution Discharge Elimination System (NPDES) Program. Each year, as stated previously, we sit down with the state and come up with an annual work plan on how many facilities we will sample and how many the state will sample. Besides sampling the effluents, we occasionally will take upstream and downstream samples.

We have (over the years) completed intensive surveys in the state. The last one was on the South Platte and was done for the purpose of determining any toxics in the river. The report is titled, "**Toxic Hot Spot Study: South Platte River Along the Front Range.**" The report is available in our office.

Another area of monitoring in which we have been involved in Colorado is acid rain. Last year we began a program to assess acidification potential of two high elevation lakes within the Mt. Zirkel Wilderness area. Both lakes were sampled every other week over a period of ten weeks. Samples were taken from the water column and sediment and were analyzed for metals, common ions, nutrients, conductivity, pH, acid neutralizing capacity, dissolved organic carbon and dissolved inorganic carbon. Biology parameters such as phytoplankton, macroinvertebrates, diatoms and fish were also sampled for. This project will continue this year with a few lakes in the San Juan's added.

We also help the states in providing a data bank for water quality data. This program is called STORET (Storage and Retrieval). The Data Analysis Branch (DAB) of our Environmental Services Division (ESD) has responsibility for overseeing that the ambient surface and groundwater quality data collected by various federal, state and local agencies for the six states in our Region are entered into STORET. Because the Branch has the capability of quickly accessing large volumes of data from STORET, it is called upon to perform various mathematics and statistical calculations or to produce graphics for the various EPA or state program offices.

From time to time, the Branch will select and retrieve data for a particular year or timed period and will prepare a report on the status of quality and comment on any discernible changes or trends of pollutant concentrations. Unlike the typical type of water quality oxidation analysis

or stream quality simulation modeling that evaluates a microsystem, the EPA must also address the macrosystem to evaluate the effectiveness of its programs and report the results to Congress. Hence, the DAB has developed analytical procedures to scan the vast array of data. The present procedure that has gained nationwide acceptance basically evolved from a "water quality index" proposed by the National Sanitation Foundation some years ago. The Foundation's principal concern was measuring and evaluating the effectiveness of wastewater treatment facilities and the impact on the receiving streams. From this concept a global evaluation was attempted to describe stream qualities by index number. Water quality parameters were divided into physical, bacterial, toxics, and nutrient groups and the index represented a product of the relationships. The apparent weakness of this analysis was that stream use classification was not considered. Under the Clean Water Act the states were required to establish water quality standards and classify their stream segments.

Thus, the current analytical procedure addresses this issue by driving the program with a criteria matrix that contains seven use categories, namely: cold water fisheries; warm water fisheries; drinking water; primary contact recreation; secondary contact recreation; irrigation; and stock watering. The program compares concentrations of 50 parameters of the retrieved data to the criteria matrix and reports the number of exceedences of criteria and the magnitude of exceedence. A severity value is calculated based on the product of the two. The program further summarizes and tabulates the data and ranks the severity values by use categories. This program, known as the "Use Impairment Analysis," has already proved invaluable as an initial screening tool and has enabled program managers to prioritize problem areas for funding and has assisted in the preparation of the national reporting requirements.

EPA Overview

As stated in the introduction we also have an overview role in the water quality monitoring program of the State of Colorado. Some of the areas we will be assessing and questions we will be asking of the state are as follows:

Did the state develop enough data to evaluate changes or trends in

all of the waters they identified as "partially supporting" or "not supporting designated uses?"

Did the state make progress in reducing the amount of "unassessed" waters (number of stream miles, shore miles, acres, etc.) reported in their biennial Section 305(b) reports? If so, did the reduction represent the results of actual monitoring, or use of a technically valid method of projecting water quality.

Did the state undertake any monitoring and/or screening programs to identify new or emerging problems (e.g., previously unknown toxic pollutant contamination)? For instance, did the state conduct monitoring/screening to evaluate "unassessed waters"? Did the state monitor/screen waters identified as "fully supporting designated uses" to determine whether toxic pollutants may be present in the water column, sediments, or biota?

Did the state conduct chemical and/or biological monitoring to confirm and/or characterize pollution problems in all the waters it identified as "partially supporting" or "not supporting designated uses"?

Did the monitoring program provide adequate support to making important water quality based regulatory decisions? For instance, in looking at all the water quality standards revisions, TMDLs/WLAs, water-quality based permit issuances, and nonpoint source control decisions performed by the state, did the state have available the water quality data and analysis it needed at the time those regulatory decisions were made? For those decisions where the data were not adequate, were the data gaps the result of applying rational priorities to the use of resources?

Did the state allocate resources to operate acceptable monitoring? For instance, did the state devote needed resources for developing water quality-based controls, assessing water quality conditions and trends, ensuring compliance with NPDES permits, and other activities?

Other areas we will be coordinating with the states are the mix of fixed stations, their location and parameter coverage versus intensive surveys.

Hopefully, my discussions will give you some idea of EPA's involvement in water quality monitoring. Thank you for your time.

OVERVIEW OF GUIDANCE FOR STATE MONITORING AND WASTELOAD ALLOCATION PROGRAMS

PURPOSE	ACTIVITY*	TYPE OF DATA NEEDED	WHO COLLECTS	METHOD	REQUIRED DATA REPORTING	PARAMETER COVERAGE	DATA USES							COMMENTS
							NATIONAL WATER QUALITY ASSESSMENT	STATEWIDE WATER QUALITY ASSESSMENT, 305(b)	REGIONAL OVERSIGHT	SITE-SPECIFIC CONTROLS	PROGRAM MANAGEMENT, WASTELOAD ALLOCATIONS	PROGRAM MANAGEMENT, CONSTRUCTION GRANTS	CHECK WATER QUALITY STANDARDS	
Conduct Water Quality Assessments (Chapter 4)	Assess conditions and determine trends	Physical/chemical	States	Fixed stations and monitoring surveys. Include toxics in fish flesh and sediments.	Enter appropriate data into STORET or "hard copies" to EPA. Report findings through 305(b) reports.	As needed to assess attainment of use	X	X	X	X	X	X	X	Source of "before" data for program management
			States	Biosurveys and bioassays at fixed stations and in surveys. Include measurement of kinds and numbers of fish.	Send abstract of findings to EPA, if requested by EPA and report findings through 305(b) reports.	Site specific	X	X	X	X	X	X	X	
Develop Water Quality-based Controls (Chapter 2)	Identify water quality limited segments and set control priorities.	Physical/chemical	States	Fixed stations and surveys. Also math modeling.	Enter all data into STORET or "hard copies" of data to EPA	As needed	X	X	X	X	X	X	X	Source of "before" data for program management
		Biological	States	Biosurveys and bioassays. Also math modeling.	Send abstract of findings to EPA, if requested by EPA	As needed	X	X	X	X	X	X	X	Source of "before" data for program management
Review and revise (or reaffirm) water quality standards	Develop water quality-based controls (TMDLs/MLAs)	Physical/chemical	States	Use attainability studies, site-specific criteria, etc.	Enter data from representative stations into STORET or "hard copies" of data to EPA.	As needed	X	X	X	X	X	X	X	Source of "before" data for program management
		Physical, chemical, & biological	States	Intensive surveys (including biological sampling) and math models.	Send abstract of findings to EPA, if requested by EPA.	As needed	X	X	X	X	X	X	X	
			States	Effluent	Non point source loadings	Background	Enter data from representative stations into STORET or "hard copies" of data to EPA.	As needed	X	X	X	X	X	X
Issue water quality-based permits, make construction grant decisions, implement non point source controls														

* Technical guidance is available from EPA for each of these activities. For copies, contact the Regional Monitoring or Wasteload Allocation coordinator.

Overview of Guidance for State Monitoring and Wasteload Allocation Programs, con't.

PURPOSE	ACTIVITY*	TYPE OF DATA NEEDED	WHO COLLECTS	METHOD	REQUIRED DATA REPORTING	PARAMETER COVERAGE	DATA USES							COMMENTS
Assess compliance with and effectiveness of controls (technology & water quality-based for point sources) and non point sources (Chapter 3)	Monitor municipal and industrial sources & BMP sites for compliance.	Effluent &/or non point source discharge	Dischargers States (if delegated authority)	Effluent monitoring as specified in permit. Bioassay if specified in permit	Enter appropriate data into RCS	As specified in the permit	NATIONAL WATER QUALITY ASSESSMENT	STATEWIDE WATER QUALITY ASSESSMENT, 305(B)	REGIONAL OVERSIGHT	SITE-SPECIFIC CONTROLS	PROGRAM MANAGEMENT, WASTELOAD ALLOCATIONS	PROGRAM MANAGEMENT, CONSTRUCTION GRANTS	CHECK WATER QUALITY STANDARDS	
	Document protection of desiq. use.	Ambient physical, chemical, & biological	Dischargers with possible assistance from States	Intensive survey (including biological assessments and effluent sampling) to document results of controls and impact on water quality after controls are in place. If problems are noted, re-examine controls. Fixed stations as needed to document results of controls and impact on water quality.	Abstract of findings to EPA Enter data from representative stations into STORET or "hard copies" of data to EPA. Send abstract of findings to EPA, if requested by EPA	As specified in the permit Same as "before" survey		X	X	X	X	X	X	Source of "after" data for program management Use water quality standards guidance. Follow-up monitoring to assess attainment of designated uses.
			Dischargers with possible assistance from States		Enter all data into STORET or "hard copies" to EPA	Same as measured at downstream stations for "before" and "after" intensive surveys. Include parameters limited on permits.	X	X	X	X	X	X	X	Use water quality standards guidance. Follow-up monitoring to assess attainment of designated uses.

* Technical guidance is available from EPA for each of these activities. For copies, contact the Regional Monitoring or Wasteload Allocation Coordinator.

**WATER QUALITY MONITORING BY THE
COLORADO DEPARTMENT OF HEALTH**

**R. Dennis Anderson
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Colorado Department of Health**

Introduction

The Colorado Water Quality Control Division has various water quality data needs which while related in terms of the overall water quality goal of the Division, i.e., "To protect, maintain and improve the quality of the State's surface and groundwaters and to assure safe drinking water for the citizens of Colorado," are primarily program-dependent and not necessarily interrelated. The data collection can be divided into three categories: drinking water; NPDES effluent monitoring; and ambient. The ambient can further be subdivided into routine monitoring, special studies, and biological monitoring. There is no program at present for groundwater monitoring.

Drinking Water Monitoring

Drinking water monitoring in Colorado is conducted by all publicly owned treatment works (POTWs) and the state is only involved in monitoring for giardiasis and for special studies. The frequency of sampling and parameters sampled are dictated by regulations (Colorado Department of Health, 1981) which delineate the sampling by community or non-community (trailer parks, campgrounds, etc.) supplies. The basic requirements are outlined in Table 1.

NPDES Effluent Monitoring

The point source or compliance monitoring program needs are primarily related to the enforcement of NPDES permits. In this regard, the routine monitoring is geared toward the designated state and EPA major permittees or significant minor permittees because of the probability that their impact on the water uses of the state will be greatest. (Significant minors are those dischargers whom the state considers to have a probable impact on the receiving stream.) In addition, the Division samples ski areas at least once per ski season. State monitoring of the minor permittees is conducted only for specific enforcement of NPDES permit development due to the lesser impact of these dischargers on the uses.

Table 1

Sampling Requirements for
Drinking Water Supplies

<u>Parameter</u>	<u>Community</u>		<u>Non-Community</u>	
	<u>Groundwater</u>	<u>Surface Water</u>	<u>Groundwater</u>	<u>Surface Water</u>
Tot. Coliforms	1 or more/month	1 or more/month	1/3 months	1/3 months
Turbidity	N/A	daily	N/A	case-by-case
Prim. Inorganics	1/3 years	1/year	NO ₃ once	NO ₃ once
Organics	N/A	1/3 years	N/A	N/A
Radiological	1/4 years	1/4 years	N/A	N/A

Compliance tracking for the minors is almost entirely accomplished throughout the review of self-monitoring submittals. Frequency of sampling by the Department of Health is primarily determined by the funding available that year for laboratory analyses but is generally two times per year for majors and significant minors at least once per year. Parameter coverage is specific to each permit. Frequency of monitoring required of permit holders is dependent on the size and type of treatment plant.

Ambient Monitoring

Ambient monitoring includes the fixed station monitoring network, special studies, and bioassays. The fixed station monitoring network was developed for several purposes. These include development of baseline data for setting water quality standards and classifications, determining NPDES permit requirements, detecting long-term trends or changes in water quality and effects of both point and non-point sources on water quality. The special studies purposes are generally the same with the addition of collection of data for enforcement actions and variance requests. The major emphasis, however, has been placed on stream standards and classifications and NPDES permit development needs.

In the fixed station network the following criteria are considered in siting a station:

- (1) importance of stream in both size and beneficial uses;
- (2) existing or proposed development on stream and the possible impacts on beneficial uses;
- (3) representative of upstream land use areas or geological conditions;
- (4) availability of data from other sources (USGS, 208 Agencies, EPA, etc.); and
- (5) accessibility.

The water quality constituents to be monitored in the fixed station network are selected for several reasons. In general the more important are:

- (1) probability of or existing impact on designated uses of a stream;
- (2) importance in detecting trends;
- (3) cost of analysis and collection; and
- (4) relationship to land uses in drainage and natural geologic conditions.

Determination of the frequency of sampling at each station is determined by allocating samples to the station in proportion to a water quality parameter's variation at the station (Ward and Nielsen, 1978). Because of time and costs involved not all parameters are evaluated. To determine which parameters are considered most important at any station, a variety of information is used. This may include comparison of existing data with stream standards, input from district engineers, 208 Agencies, Division of Wildlife or others familiar with local problems, and information obtained from stream standards and classification hearings, NPDES permit development, and 305(b) reports. A decision is then made by the Division as to which parameters will be statistically analyzed at each station.

The needed sampling frequency for each parameter per year is determined and the number of samples at each station needed per year is determined by the parameters showing the highest frequency. A limit on frequency of sampling at any station, however, is limited to 24 per year due to budget and time limitations. The frequency may be lowered further by constraints on accessibility of station and total costs of analyses for the monitoring network as a whole. This frequency analysis has resulted in a three-tiered sampling frequency in Colorado's routine monitoring network; that is, stations with scheduled frequencies of 6, 12, or 24 samples per year. New stations with no data are generally sampled 12 times per year to begin with and are then modified according to analysis of the data collected. The various constituents are analyzed at each station at a frequency according to their importance and ease or cost of analysis.

Biological (fish) sampling is conducted at 12 of the routine stations each fall. Fish are collected and tissue analyses performed for toxics which are for the most part not sampled as part of the routine program. If toxics are present, follow-up sampling of sediment and waters is to be conducted. The selection of the stations is an attempt to represent a cross-section of Colorado geographical regions and water quality.

At present, there are 102 active stations in the network, of which 8 are sampled bi-weekly, 20 monthly, and 74 every other month. Fifty-one stations are inactive. The data record available on the stations ranges from 3 to 17 years.

Frequency of sampling as mentioned previously is 24, 12, or 6 times

annually. Frequency of analyses for any parameter also varies by stations depending on the parameter's importance to the needs of the program, ease of analysis (i.e., field analyses), probability of occurrence of an unusual parameter based on past data or its suspected occurrence. A detailed list of the parameters being sampled since July, 1983 is given in Table 2.

Special Studies

Intensive or special studies are conducted for a myriad of purposes with the emphasis being shifted as Division priorities are changed. Studies have been conducted in the past for wasteload allocations, water quality assessments, enforcement, variance requests, stream classifications and standards setting, clean lakes grants, and use attainability analyses.

The studies may consist of as little as one day chemical and biological sampling of a stream for classification purposes or as much as a year or more of sampling a lake and tributaries for purposes of setting phosphorus standards. A list of studies conducted over approximately the last year is given below.

<u>Study Area</u>	<u>Purpose and Parameter of Concern</u>
Boulder Creek	Wasteload Allocation; Ammonia
Clear Creek	Wasteload Allocation; Ammonia
San Miguel River	Wasteload Allocation; Ammonia
South Platte River	Wasteload Allocation; Ammonia, Dissolved Oxygen, Chlorine
Cherry Creek/Chatfield Reservoirs	Follow-up sampling to verify reservoir model and phosphorus standard; Phosphorus
Cache la Poudre	Bioassay to determine appropriate nitrite standard
Eagle River	Water quality assessment including zinc bioassay; metals
Plum Creek	Stream classification and standards; Ammonia
Electra Lake	Baseline data prior to intensive development in basin; nutrients

Table 2
Parameter Coverage in Colorado
Ambient Monitoring Network

Parameters, Analyzed each visit at all stations	Parameters analyzed six times annually at primary stations and secondary stations*	Special Parameters analyzed six times annually at selected stations	Parameters analyzed in bio- logical (fish) samples
Temperature	Specific conduct- ivity	Total Arsenic	Priority Pollutants
pH	Total Kjeldahl-N	Boron	Organic Scan
Dissolved Oxygen	NO ₂ +NO ₃ -N	Total Cyanide	Cadmium
Suspended Solids	Sulfate	Acid Recoverable	Chromium
Dissolved Solids	5 day BOD	Chromium	Copper
Ammonia - N		Acid Recoverable	Iron
Total Phosphorus-P		Molybdenum	Lead
Total Alkalinity		Acid Recoverable	Manganese
Total Hardness		Nickel	Mercury
Acid Recoverable		Acid Recoverable	Nickel
Cadmium		Silver	Zinc
Acid Recoverable		Mercury	
Copper		Uranium	
Acid Recoverable		Total Alpha and	
Iron		Beta	
Acid Recoverable			
Lead			
Acid Recoverable			
Manganese			
Acid Recoverable			
Zinc			
Fecal Coliforms			

* Primary stations are those sampled 12 or 24 times per year; secondary stations are those sampled 6 times per year.

Data Management

All ambient data is input into the U.S. Environmental Protection Agency (EPA) STORET system and the laboratory data sheets bound and filed in the Water Quality Control Division office. In addition, typed reports are prepared on most special studies. NPDES self-monitoring data has just recently begun to be input into EPA's Permit Compliance System (PCS) and is also filed in the Division office. Drinking water data is stored on EPA's Model States Inventory System (MSIS).

Future Monitoring

It is anticipated that the Division will continue the present program at its present level during the next fiscal year provided the funding is maintained. In addition, an attempt will be made to expand the biological monitoring program to include routine macroinvertebrate monitoring. This would be implemented at several of the existing biological stations by the use of artificial substrates. A pilot program for toxic biomonitoring as part of the NPDES permits program will also be implemented at selected sites. Funding for groundwater monitoring will again be requested of the legislature.

References

- Colorado Department of Health, "Colorado Primary Drinking Water Regulations." Denver, Colorado (1981).
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REVIEW OF WATER QUALITY MONITORING PROGRAMS IN THE LARIMER-WELD REGION

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History

In 1978 the initial Areawide Water Quality Management Plan was adopted by the Larimer-Weld Regional Council of Governments (LWRCOG). That plan recognized the need for developing a coordinated water quality monitoring program in the region to ensure protection of the beneficial uses of the area's waters and to provide necessary information to guide cost-effective decision making in investments for water pollution control. The plan identified the principles of monitoring program design, regional goals, program objectives, general recommendations, and criteria for program design. A sixteen-member advisory committee was established to assist in designing a regional water quality monitoring program through review of the then existing programs and identification of program needs. The committee developed priorities for monitoring in the region and identified program design criteria. The culmination of these efforts was the production of a report in 1980 entitled **"Water Quality Monitoring Implementation Plan."**

The priorities identified in the 1980 Implementation Plan included the following:

1. A. bioassays to determine toxicity of pollutants in specific streams;
- B. instream biosurveys to define the species, number, and extent of aquatic life;
- C. sampling of EPA-proposed priority pollutants in streams;
2. instream monitoring above and below municipal and industrial discharges to define the actual water quality impact of these sources;
3. collection of flow data to determine actual seven-day/ten-year low flows to be used in establishing permit conditions;
4. definition of water quality trends in the region;
5. definition of non-point and point source relationships;
6. identification of non-point source impacts.

Until 1980 data had been collected from various sources but there had been no regionally coordinated program. The USGS had done cooperative monitoring for various entities at 18 stations in the region and the Colorado Department of Health had 13 stations. Local governments and industries had done some individual sampling, and there had been some special studies done such as bioassays. Biosurvey data was collected for Kodak at several stations on the Cache la Poudre four times a year from 1969 to 1975, and it was reinstated in 1979 along with a one-time survey on the Big Thompson sponsored by Loveland.

Current Status

The result of implementation of the regional monitoring plan after 1980 has been to achieve monitoring goals in a coordinated and more efficient manner. Agreements and cooperation between the various federal, state, and local monitoring entities has provided more data that is available for use by all concerned parties and at a cost which is less than what it would be for individual programs. An example of these joint efforts is the cooperative agreement between the USGS and LWRCOG for monitoring on the Poudre and Big Thompson and the contracts between LWRCOG and the Cities of Fort Collins and Loveland to provide the funding for the USGS work. Other agreements include those between Fort Collins and Kodak and between Loveland and Hewlett-Packard to share the expense of monitoring where it is of mutual concern. Recent efforts have also included the cooperative funding of special studies by a group of Larimer-Weld area discharge permittees.

The major regional monitoring programs include those by the USGS, Fort Collins, Kodak, Greeley, Loveland, and Longmont. The State Department of Health also continues to operate their own program. Data has been collected since approximately 1981 on the stations indicated and listed on the attached figures and tables excerpted from the 1985 Update of the LWRCOG Water Quality Management Plan. In 1984 a complete review and assessment of the Loveland program was conducted to improve the usefulness and consistency of data developed.

Also in 1984 the LWRCOG conducted a Water Quality Assessment on the Cache la Poudre, Big Thompson, St. Vrain and South Platte Rivers. This was the first time data was accessed since initiation of the regional

monitoring program in 1980. The assessment focused mainly on determining if standards were being met. Some deficiencies in the monitoring program were noticed during this assessment as follows:

1. Although the data collection effort was intensive, data acquisition was difficult for the LWRCOG since there was no centralized data bank. Consequently, local monitoring efforts can be overlooked in data analysis.
2. In the regional priorities for water quality monitoring nothing was said about reporting. Currently there is no entity responsible for reporting regional results besides the LWRCOG. There is no funding on the local level for reporting other than of localized results for purposes such as permit compliance.
3. Information goals are not clearly defined. What a report should contain is determined after monitoring and is not used in the program design.
4. There are no statistical criteria imposed at any point in the data analysis except for the mean plus standard deviation criteria for determining a standard as used by the State of Colorado.
5. The cost effectiveness of the monitoring program has not been addressed. Are the funding entities getting the best information for the money spent?

The information provided to the LWRCOG by the water quality assessment has influenced management decisions in three areas:

1. It was determined that the water quality standards set forth by the State of Colorado were generally met on all segments in the region. Since no statistics were previously defined concerning the frequency of exceedence to determine meeting a standard, standards are considered met if the data did not exceed the standard greater than 15 percent of the time. This is the criteria the State of Colorado uses to determine if a segment is impaired.
2. The biological data coupled with the chemical data were used to illustrate protected use in all segments in the Larimer Weld Region. There do not appear to be any adverse effects on the aquatic biological community due to water quality problems.
3. Since the standards were met and uses protected in the region, it

was determined that the secondary treatment provided is adequate to protect the integrity of the streams. There is no need for advanced waste treatment in the region. By the same token, it appears that existing treatment being provided at the secondary level for point source discharges is the appropriate level to protect beneficial uses and meet standards.

Future Efforts

At this point in the program with the thorough analyses of available data just completed for the 208 Plan Update, consideration is being given to a reevaluation of the area's monitoring needs. A redefinition or refinement of the regional program objectives will be completed. To be included would be overall review of constituents being sampled, locations and frequency of sampling, and adjustment of the overall design of individual monitoring programs where objectives dictate the need. The different entities' programs and procedures for sampling, laboratory analysis and reporting would also be evaluated for efficiency, consistency, and thoroughness. To provide data that can be used interchangeably, it must be assured that all persons monitoring in the region are using comparable sampling and analytical methods. Quality assurance and quality control programs may need to be implemented or improved. Finally, a review needs to be done of the methods and the timeliness of data analysis and of data reporting, and uniform procedures need to be agreed upon.

The future goals of the LWRCOG monitoring program focus mainly on remedying the problems identified in the 1984 Water Quality Assessment. Those recommended are:

1. Data gathered by the municipalities, industries, USGS and CDH should all be on a single data management system.
2. Information goals of both the dischargers and the LWRCOG need to be defined. This would determine the types of reports produced.
3. The statistics that are to be used in the decision-making process need to be defined, even if only in a broad sense.
4. The data must be looked at more closely to determine if the monitoring program can be optimized. There may be room to cut back on data collection and be able to budget for data management and reporting.

ATTACHMENTS

Table V.3-1

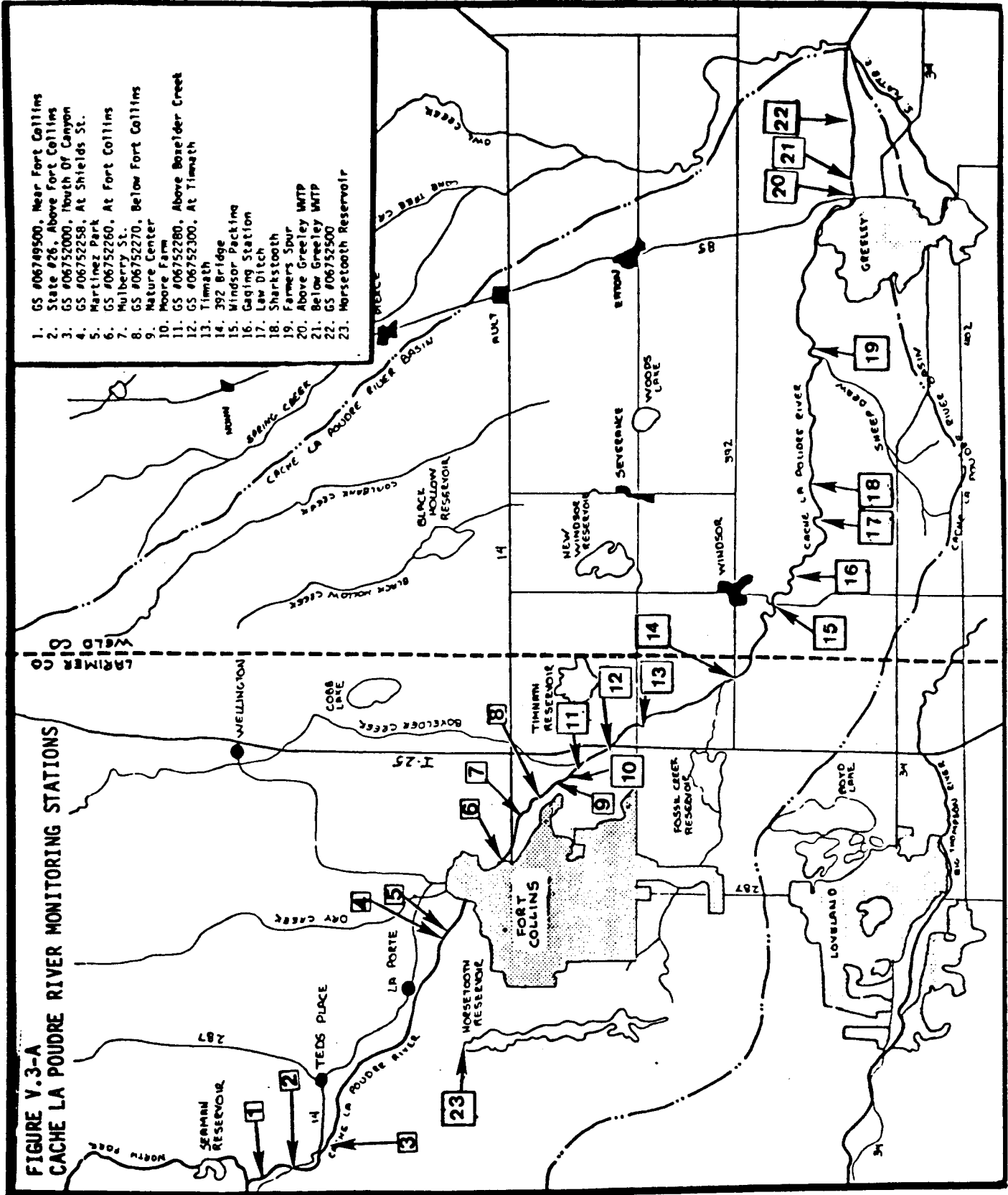
Water Quality Monitoring Stations on the Cache la Poudre River

Station Name	Station Number	Monitoring Entity	Type of Monitoring	River Mile
Near Ft. Collins	06749500	USGS, FC	Chemical	60.1
Above Ft. Collins	26	State	Chemical	59.0
Mouth of Canyon near Ft. Collins	06752000	USGS, FC	Chemical	56.2
At Shields St.	06752258	USGS, FC	Chemical	46.6
Martinez Park		KCD,CSU,FC	Chemical & Biological	46.2
At Ft. Collins (Lincoln St.)	06752260	USGS, FC	Chemical	44.6
Mulberry St.		FC, CSU	Chemical & Biological	42.1
Below Ft. Collins (Prospect St.)	06752270	USGS, FC, CSU	Chemical & Biological	41.0
Nature Center		FC	Chemical	39.9
Moore Farm		CSU, FC	Biological	39.3
Above Boxelder Creek	06752280	USGS, FC	Chemical	38.7
At Timnath (I-25)	06752300	USGS	Chemical	37.0
Below Ft. Collins (I-25)	126	State	Chemical	37.0
Timnath		KCD, CSU	Chemical & Biological	35.0
392 Bridge		KCD, CSU	Chemical & Biological	30.0
Windsor Packing		KCD, CSU	Chemical & Biological	25.5
Gaging Station		KCD,CSU	Chemical & Biological	22.5
Law Ditch		KCD, CSU	Chemical & Biological	21.5
Sharkstooth		KCD, CSU	Chemical & Biological	20.0
Farmers Spur		KCD, CSU	Chemical & Biological	14.5
Above Greeley WWTP (85 Bridge)		G	Chemical	4.85
Below Greeley WWTP (Ash Av.)		G	Chemical	4.3
Near Greeley	06752500	USGS	Chemical	3.00
At Greeley	27	State	Chemical	3.00
Horsetooth Reservoir	06737500	USGS, FC	Chemical	

Key: USGS - U.S. Geological Survey
 FC - City of Ft. Collins
 KCD - Kodak Colorado Division

G - City of Greeley
 CSU - Colorado State University

**FIGURE V.3-A
CACHE LA POUDE RIVER MONITORING STATIONS**



1. GS #06749500, Near Fort Collins
2. State #26, Above Fort Collins
3. GS #06752000, Mouth Of Canyon
4. GS #06752258, At Shields St.
5. Martinez Park
6. GS #06752260, At Fort Collins
7. Mulberry St.
8. GS #06752270, Below Fort Collins
9. Nature Center
10. Moore Farm
11. GS #06752280, Above Base/der Creek
12. GS #06752300, At Timmath
13. Timmath
14. 392 Bridge
15. Windsor Packing
16. Gaging Station
17. Law Ditch
18. Sharkstooth
19. Farmers Spur
20. Above Greeley WMP
21. Below Greeley WMP
22. GS #06752500
23. Horsetooth Reservoir

FIGURE V.3-B MAJOR HYDROLOGIC FEATURES -
CACHE LA POUDBRE RIVER

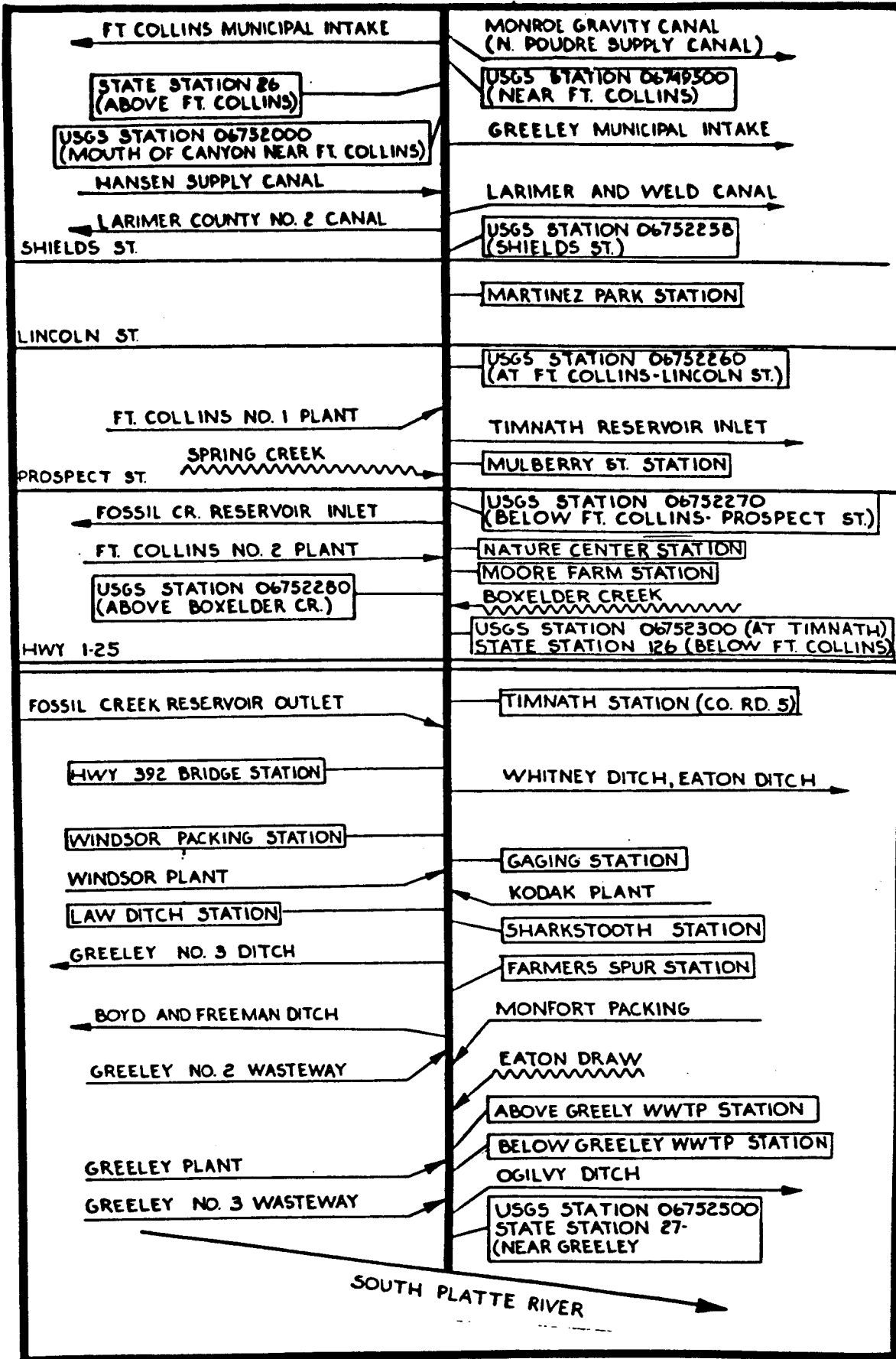


Table V.3-2

Constituents of Chemical Monitoring -
USGS on the Cache la Poudre River

<u>Frequency</u>	<u>Constituent(s)</u>	<u>Frequency</u>	<u>Constituent(s)</u>
12/yr.	Flow	12/yr.	Ammonia - NH ₄
	Water Temperature		Nitrate - NO ₃
	Specific Conductance		Nitrite - NO ₂
	Dissolved Oxygen		Specific Conductance - Lab
	pH		Total Alkalinity as CaCO ₃
	Organic - N		Hardness - Noncarbonate
	Ammonia - N		Total Dissolved Solids
	Nitrite - N		Total Suspended Solids
	Total Kjeldahl Nitrogen		
	NO ₂ + NO ₃	4/yr.	Arsenic
	Ortho-Phosphate		Barium
	Phosphorous		Cobalt
	Total Hardness as CaCO ₃		Iron, Suspended
	Calcium		Total Iron
	Magnesium		Manganese, Suspended
	Sodium		Total Manganese
	Sodium Adsorption Ratio		Molybdenum
	% Sodium		Nickel
	Potassium		Selenium
	Chloride		Mercury
	Sulfate		
	Flouride		
	Silica		
	Cadmium		
	Chromium, Total		
	Copper		
	Iron, Dissolved		
	Lead		
	Manganese, Dissolved		
	Silver		
	Zinc		
	Aluminum		

Table V.3-3

Frequency of Physical/Chemical Monitoring by the
City of Fort Collins on the Cache la Poudre River

Analysis	LOCATION					
	1*	2*	3*	5*	6*	8*
Flow		8Y	1W	8Y		1W
BOD ₅		8Y	8Y	8Y	8Y	8Y
COD		8Y	8Y	8Y	8Y	8Y
Total Chlorine						
Water Temperature	1W	8Y	1W	8Y	1W	1W
Total Coliform	1W	8Y		8Y		8Y
Fecal Coliform	1M	8Y		8Y		8Y
Fecal Strep	1M					
Total Count	1M					
pH	1W	8Y	1W	8Y	1W	1W
Dissolved Oxygen		8Y	1W	8Y	1W	1W
Color	1W					
Turbidity	1W					
Specific Conductance	1W	8Y	1W	8Y	1W	1W
Total Solids	1M					
Total Suspended Solids						
Total Alkalinity as CaCO ₃	1W	8Y		8Y		8Y
Total Hardness as CaCO ₃	1W	8Y		8Y		8Y
Chloride	1M	8Y		8Y		8Y
Silica	1M					
Sulfate	1M	8Y		8Y		8Y
Ortho-Phosphate		8Y		8Y		8Y
Phosphate as p	1M	8Y		8Y		8Y
Fluoride	1W					
Aluminum	1M					
Chromium	1M	8Y		8Y		8Y
Iron	1M	8Y		8Y		8Y
Manganese	1M					
Nickel	1M	8Y		8Y		8Y
Copper	1M	8Y		8Y		8Y
Lead	1M	8Y		8Y		8Y
Zinc	1M	8Y		8Y		8Y
Calcium	1W					
Magnesium	1M					
Cadmium	1M	8Y		8Y		8Y
Borium	1M					
Sodium	1M					
Boron						
Mercury	1M	8Y		8Y		8Y

(1) Frequencies listed are:

- 1M = 1 per month
- 1W = 1 per week
- 1D = 1 per day
- 8Y = 8 per year
- 2M = 2 per month

Table V.3-3 (cont.)

Analysis	LOCATION					
	1*	2*	3*	5*	6*	8*
Silver	1M	8Y		8Y		8Y
Arsenic	1M	8Y		8Y		8Y
Selenium	1M	8Y		8Y		8Y
Ammonia - NH ₄		8Y	1W	8Y	1W	1W
Nitrate - N	1M	8Y	1W	8Y	1W	1W
Nitrite - N		8Y	1W	8Y	1W	1W
Total Kjeldahl Nitrogen		8Y		8Y		8Y

1* - Raw Water Plant 1 (USGS 06749500)

2* - Martinez Park

3* - Lincoln Street (USGS 06752260)

5* - Near Prospect

6* - Nature Center Above WWTP #2

8* - Above Boxelder Creek (USGS 06752280)

Table V.3-4

Constituents of Chemical Monitoring -
City of Fort Collins on the Cache la Poudre River

<u>Frequency</u>	<u>Constituent (s)</u>
(See Table V.3-3)	BOD ₅
	COD
	Chlorine
	Water Temperature
	Total Coliform
	Fecal Coliform
	Fecal Strep
	Total Count
	pH
	Dissolved Oxygen
	Color
	Turbidity
	Specific Conductance
	Total Solids
	Total Suspended Solids
	Total Alkalinity as CaCO ₃
	Total Hardness as CaCO ₃
	Chloride
	Silica
	Sulfate
	Ortho-Phosphate
	Phosphate - P
	Fluoride
	Aluminum
	Chromium
	Iron
	Manganese
	Nickel
	Copper
	Lead
	Zinc
	Calcium
	Magnesium
	Cadmium
	Barium
	Sodium
	Mercury
	Silver
	Arsenic
	Selenium
	Ammonia - NH ₄
	Nitrate - N
	Nitrite - N
	Total Kjeldahl Nitrogen

Table V.3-5

Biological Monitoring by Colorado State
University-KCD on the Cache la Poudre River

<u>Location</u>	<u>Type of Biosurvey</u>	<u>Monitoring Frequency</u>
Martinez Park	Benthic Fish	5/yr 3/yr
Prospect Street	Benthic Fish	5/yr 3/yr
Moore Farm	Benthic Fish	5/yr 3/yr
Timnath	Benthic Fish	5/yr 3/yr
392 Bridge	Benthic Fish	5/yr 3/yr
Windsor Packing	Benthic Fish	5/yr 3/yr
Gauging Station	Benthic Fish	5/yr 3/yr
Law Ditch	Benthic Fish	5/yr 3/yr
Sharkstooth	Benthic Fish	5/yr 3/yr
Farmer's Spur	Benthic Fish	5/yr 3/yr

Table V.3-6

Constituents of Chemical Monitoring -
Kodak/Colorado on the Cache la Poudre River

<u>Frequency</u>	<u>Constituent(s)</u>
8/yr	Flow pH Dissolved Oxygen Air Temperature Water Temperature Specific Conductance Total Hardness as CaCO ₃ Total Alkalinity as CaCO ₃ Total Solids Total Suspended Solids Turbidity Ammonia - NH ₄ Nitrite - N Nitrate - N Total Kjeldahl Nitrogen Ortho Phosphate Total Phosphate - P Total Cadmium Total Copper Total Zinc Fecal Coliform Total Coliform Chloride Fluoride Sulfate Free Cyanide Total Silver Ionic Silver
4/yr	Total Aluminum Total Manganese Total Cyanide Total Iron Total Barium BOD ₅ COD Soluble TOD TOC TOX Boron Total Arsenic Total Selenium Total Potassium Total Sodium Total Nickel Total Lead Extracted Silver Total Chromium Dissolved Aluminum

Table V.3-7

Constituents of Chemical Monitoring -
City of Greeley on the Cache la Poudre River

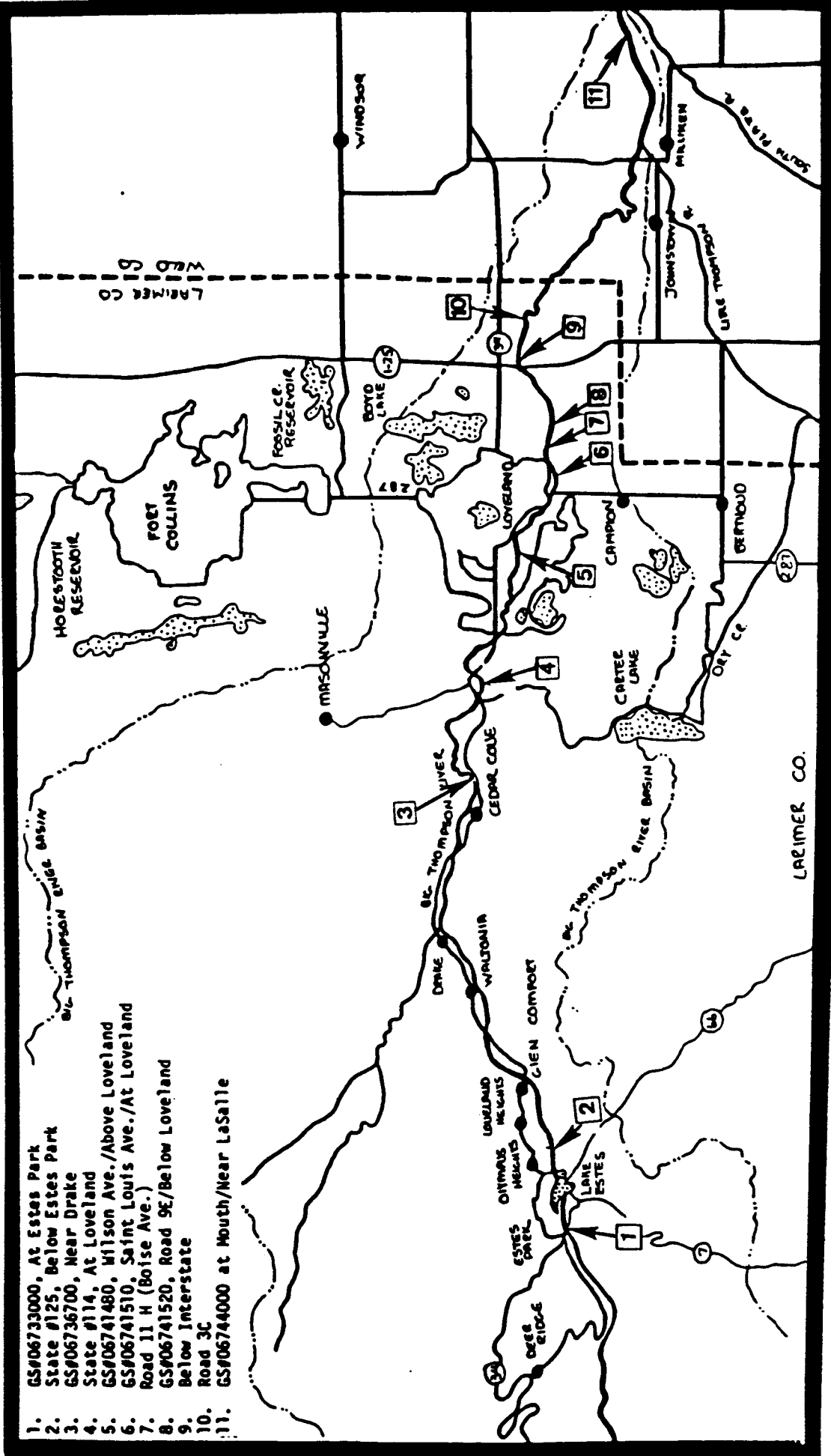
<u>Frequency</u>	<u>Constituent(s)</u>
12/yr	Flow Water Temperature Dissolved Oxygen PH Specific Conductance Residual Chlorine Sulfate Nitrate - N Nitrite - N Ortho-phosphate Total Iron Ammonia - NH ₄ Total Alkalinity as CaCO ₃ Total Solids Total Hardness as CaCO ₃ Total Suspended Solids Total Dissolved Solids BOD ₅ Fecal Coliform Total Phosphate
2/yr	Aluminum Copper Manganese Lead Boron Cadmium Total Chromium
4/yr	Mercury Nickel Zinc

Table V.3-9

Big Thompson River Basin Monitoring Stations

<u>Station Name</u>	<u>Station Number</u>	<u>Monitoring Entity</u>	<u>Type of Monitoring</u>	<u>River Mile</u>
At Estes Park	06733000	USGS	Chemical	59.2
Below Estes Park	125	State	Chemical	55.0
Near Drake	06736700	USGS	Chemical	37.6
At Loveland	114	State	Chemical	34.0
Above Loveland (Wilson Ave.)	06741480	USGS, LV, HP, CSU	Chemical & Biological	28.7
At Loveland (St. Louis Ave.)	06741510	USGS, LV, HP	Chemical	25.3
County Rd. 11H (Boise Ave.)		LV, HP, CSU	Chemical & Biological	24.4
Below Loveland (County Rd 9E)	06741520	USGS, LV, HP, CSU	Chemical & Biological	22.8
I-25		LV, HP	Chemical	20.3
County Rd 3S		LV, HP, CSU	Chemical & Biological	18.3
At Mouth near LaSalle	06744000	USGS	Chemical	1.60
At Mouth	28	State	Chemical	.9
Carter Lake	06742500	USGS	Chemical	

Key: USGS - United States Geological Survey
 LV - Loveland
 HP - Hewlett-Packard
 CSU - Colorado State University



- 1. GS#06733000, At Estes Park
- 2. State #125, Below Estes Park
- 3. GS#06736700, Near Drake
- 4. State #114, At Loveland
- 5. GS#06741480, Wilson Ave./Above Loveland
- 6. GS#06741510, Saint Louis Ave./At Loveland
- 7. Road 11 H (Boise Ave.)
- 8. GS#06741520, Road 9E/Below Loveland
- 9. Below Interstate
- 10. Road 3C
- 11. GS#06744000 at Mouth/Near LaSalle

FIGURE V.3-C
BIG THOMPSON RIVER MONITORING STATIONS

FIGURE V.3-D MAJOR HYDROLOGIC FEATURES -
BIG THOMPSON RIVER

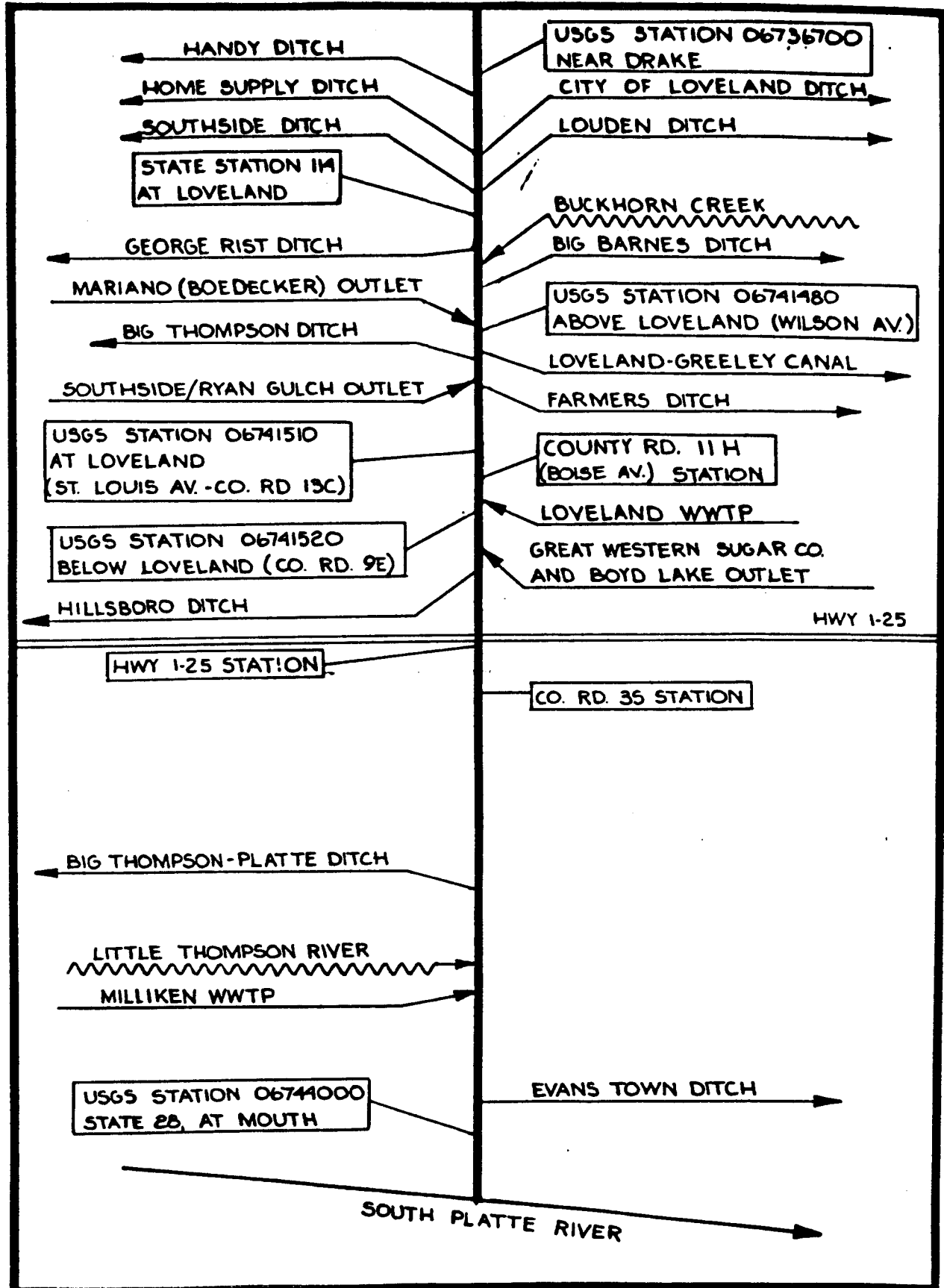
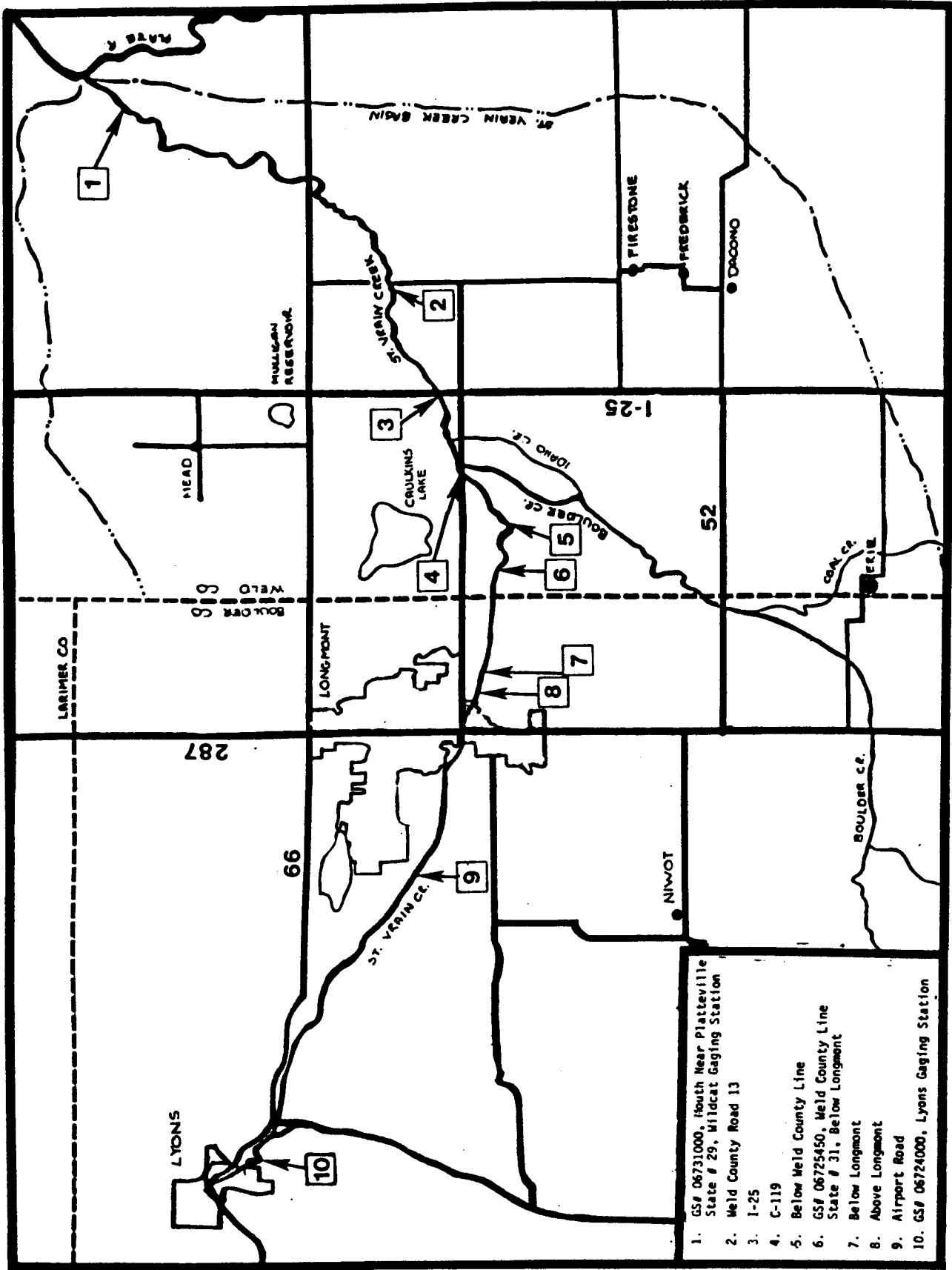


Table V.3-15

Water Quality Monitoring Stations on St. Vrain Creek

<u>Station Name</u>	<u>Station Number</u>	<u>Monitoring Entity</u>	<u>Type of Monitoring</u>	<u>River Mile</u>
Lyons Gaging Station	06729000	USGS	Chemical	33
Airport Rd.		CSU, LM	Chemical & Biological	25.9
Above Longmont WWTP		CSU, LM	Chemical & Biological	22.0
Below Longmont WWTP		LM	Chemical	21.7
Weld County Line		LM	Chemical	20.1
Below Weld County Line		CSU, LM	Chemical & Biological	18.7
Below Longmont	06725420 31	USGS State	Chemical	17.3
C-119		LM	Chemical	16.9
I-25		LM	Chemical	14.4
Weld County Rd. 13		CSU, LM	Chemical & Biological	11.3
Wildcat Gaging Station		State	Chemical	1.1
Mouth Near Platteville		USGS, LM	Chemical	1.1

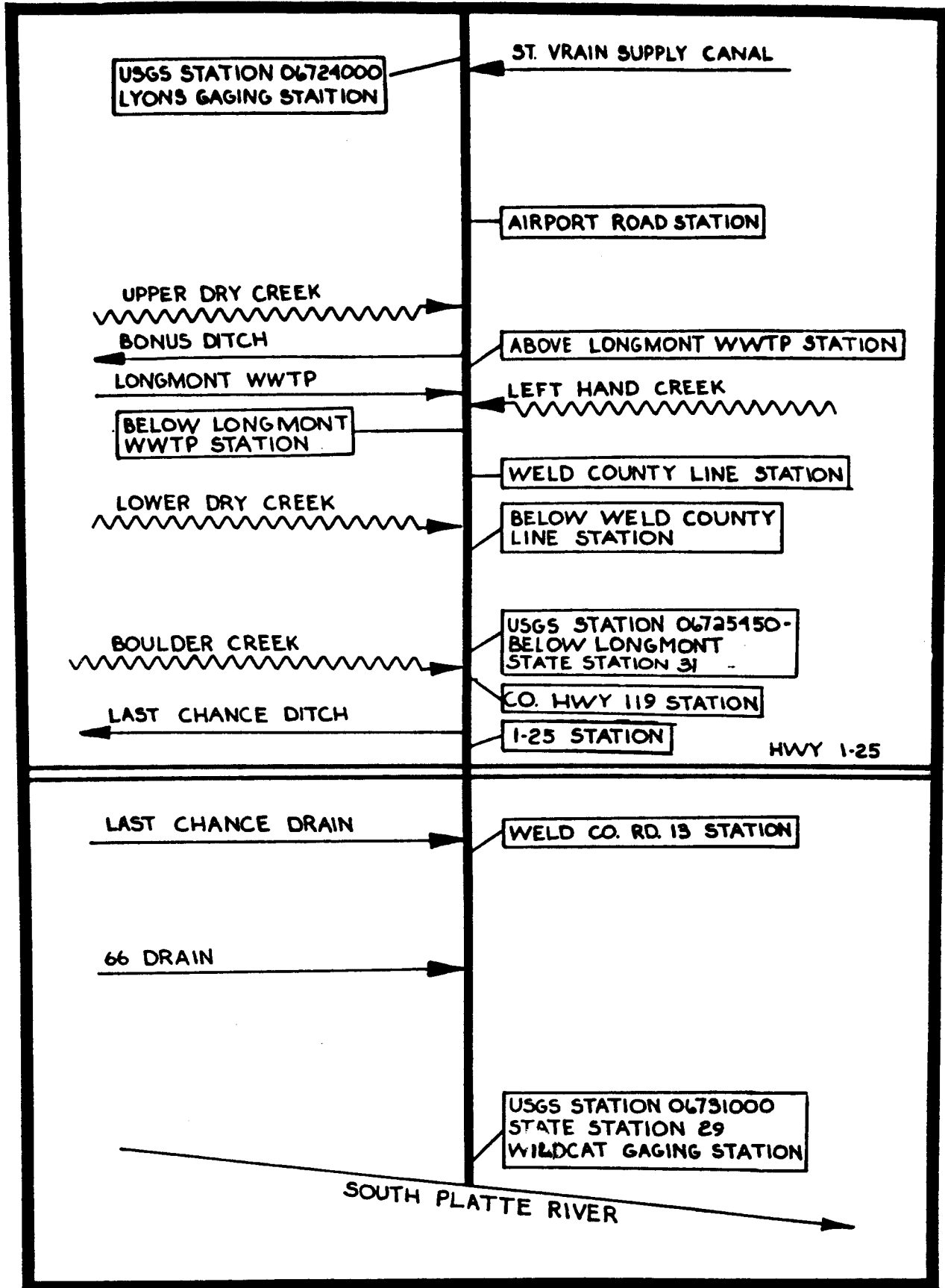
Key: USGS - U.S. Geological Survey
LM - City of Longmont
CSU - Colorado State University



1. GSF 06731000, Mouth Near Platteville State # 29, Wildcat Gaging Station
2. Weld County Road 13
3. I-25
4. C-119
5. Below Weld County Line
6. GSF 06725450, Weld County Line State # 31, Below Longmont
7. Below Longmont
8. Above Longmont
9. Airport Road
10. GSF 06724000, Lyons Gaging Station

FIGURE V.3-F
SAINT VRAIN CREEK MONITORING STATIONS

FIGURE V.3-G MAJOR HYDROLOGIC FEATURES -
SAINT VRAIN CREEK



FRAMEWORK FOR THE DESIGN OF WATER QUALITY INFORMATION SYSTEMS

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Water quality monitoring, like the management it supports, is evolving. With passage of the Federal Water Quality Act of 1965, monitoring for regulatory water quality management purposes, especially at the state level, took a huge step in its evolution. The federal act required states to initiate monitoring programs, but the exact form and reasons for such monitoring efforts were vaguely defined.

Since 1965, there have been numerous legal refinements to the focus and strategies used to manage water quality (e.g., The Water Pollution Control Act Amendments of 1972, The Resource Conservation and Recovery Act of 1976 and numerous changes in state laws). While management was undergoing rather frequent changes in its evolution, monitoring was remaining much as it had been for years.

This mismatch in evolution was beginning to be recognized in the late seventies and early eighties when it became time to justify the past expenditure of large sums of public money on water quality management with documented general improvement in water quality conditions as measured by a monitoring program. The documented results simply did not seem to be available. As a result monitoring became the subject of two federal government reviews (Council on Environmental Quality, 1980 and General Accounting Office, 1981) and of Congressional hearings (Committee on Science and Technology, 1983). These studies and hearings, and the dialogue they created (e.g., Loftis and Ward, 1982, and van Belle and Huges, 1983), have generated concern for monitoring and have emphasized the need to improve the way monitoring systems are designed and integrated into our efforts to manage water quality.

The problem is not the fact that funds are not available for monitoring, but rather the lack of a systematic approach to quantitatively defining the goals of monitoring (i.e., the information sought) and designing the total water quality information system to meet these goals.

Langbein (1979) notes that we have not examined the effects of management principles upon the need for data. Ward and McBride (1985) examined the objectives of water quality management in New Zealand trying to define the water quality information needed to ensure and document that the objectives are met. They found Langbein's (1979) observation true: that while it is often noted that the free market minimizes the need for data, the regulated schemes dependent on regulatory tools, such as permits and charges, tend to multiply the need for data. This is especially true when the laws require, or as Langbein (1979) states, legally codify, monitoring in such a way that questions of efficiency of data collection, or information development, are irrelevant.

Thus, money is being spent on monitoring, but the information gained has no way of routinely being judged or evaluated as to its efficiency relative to the objectives of the management effort. Designers of water quality monitoring systems have for too long justified their designs on their own interpretation of the legal requirements without really examining why, practically, information is sought (National Academy of Sciences, 1977). No longer will it be acceptable for a designer to call his/her design complete with specification of the where, what and when of sampling--the design must also define why and relate all facets of the design to the answer. This will require a new approach to monitoring system design.

Objectives

The purpose of this paper is to propose a systematic approach to design of a total water quality information system by: (1) defining the monitoring system; and (2) presenting a framework to monitoring system design that offers an opportunity to avoid some of the pitfalls of the past. The monitoring system addressed in this paper is that often referred to as fixed-station, routine monitoring. While many of the concepts could be applied to special, short-term surveys or to effluent monitoring, others could not. The major emphasis of the paper is on approaching monitoring system design from a total systems viewpoint rather than on the ad hoc basis used so often in the past.

Monitoring System

A monitoring system can be viewed as having six major components

which follow the flow of information (Ward, 1979). Figure 1 lists the components, in the order of information flow, with a few of the aspects of each component listed as a means of further definition. The system as viewed in Figure 1 is independent of monitoring type and water environment.

The first three components in Figure 1 (sample collection, laboratory analysis, and data handling) are more "operational" in the sense that these activities are necessary to obtain the numbers in a form ready for abstracting the information. The latter three components (data analysis, reporting and information utilization) are more "informational" in that these components are converting the numbers into information that can be readily understood by those requiring knowledge of water quality conditions.

To be effective in meeting the information goals of the monitoring effort, the total monitoring system must be properly balanced. Many monitoring systems in the past have, in effect, ended after data handling. Such systems tend to let the operation of collecting data become an end in itself. As the system viewpoint in Figure 1 implies, however, the latter half of the system is just as critical in developing accurate knowledge of water quality conditions as the first half. Thus, whenever a monitoring system is designed to acquire information about water quality, all six of the components listed in Figure 1 must be addressed and defined in a quantitative manner. There must be no opportunity for the data to lose direction as it flows along the system. Each step in the data's path must clearly be identified so that it moves quickly and effectively toward the information goals. The budgeting for monitoring must allow for effective functioning of the informational end of the monitoring system. Even a well designed system, if not funded in its entirety, will fail to meet its information goals. In other words, a balanced monitoring program is balanced in its design as well as in its funding.

Design Procedures

The design of water quality monitoring systems has historically focused on the concept of "network design" - determining where to sample, what to measure, and how frequently to sample. Such network design was necessary before the activities outlined in Figure 1 could begin. The

WATER QUALITY

Sample Collection

- Sampling Technique
- Field Measurements
- Sample Preservation
- Sample Transport

Laboratory Analysis

- Scheduling and Operational Procedures
- Analysis Techniques
- Quality Control
- Data Recording

Data Handling

- Computer Hardware
- Data Base Management System
- Screening and Verification of Data
- Storage and Retrieval

Data Analysis

- Statistics
- Model
- Indices

Reporting

- Types of Reports (Formats)
- Frequency of Reporting
- Distribution of Reports

Information Utilization

- Technical
- Program Management
- Public (News Media)

Accurate Understanding of
Water Quality Conditions

Figure 1. The water quality monitoring system following the flow of information.

activities listed in Figure 1 often would not be specified prior to initiation of sampling, especially the data handling, data analysis and reporting efforts. Even the network design efforts were rarely documented, thus any change in personnel often meant a gross change in sampling procedures with a resultant loss of information. It is no wonder that many water quality monitoring efforts today are heavily criticized for their inability to supply water quality information.

Monitoring system design in the past has generally consisted of a few informal discussions regarding where samples are to be taken, what is to be measured, and how frequently. The rationale for these decisions (network design) was not documented. The sampling routes were planned and laboratory methods were selected, again without documentation as to why. Over time, as the numbers began to pile up, pressure developed to "analyze" the data. The numbers (data) were often on laboratory sheets in a file cabinet. The effort to simply pull the numbers together was great and staff had difficulty in finding the time to compile the numbers in a form ready for analysis.

Since the data analysis procedures had not been identified before sampling began, they were selected after the data were in hand - most often by someone other than the person who set up the monitoring systems in the first place. In selecting the data analysis procedures, the person doing the analysis had to "guess" at which statistical procedures were most appropriate. Too often the statistics were manipulated to show desired results, but since the system was designed without specifying the statistics, why not? A very difficult situation, to say the least.

The report was written in a manner deemed most appropriate by the staff at that time. If the information finally obtained had any bearing to what was initially expected (but not quantified or documented) it was more a matter of chance than by design.

To place water quality monitoring system design on a more systematic basis, a five-step process presented in Figure 2 is proposed. This design approach has been developed and tested over the past three years, primarily during several consulting jobs of the author's where the task was to design a total water quality information system to support a company's or agency's information needs. The design framework presented

STEP 1 Evaluate Information Expectations

- Water Quality Problems
- Water Quality Goals
- Management Goals and Strategy
- Monitoring's Role in Management
- Monitoring Goals (as statistical hypotheses)

STEP 2 Establish Statistical Design Criteria

- Statistically Characterize "Population" to be sampled
 - * plot concentration and flow versus time
 - * normality testing
 - * variance homogeneity testing
 - * independence testing
- from many statistical methods, select most appropriate (match assumptions of statistical method to statistical characteristics of water quality population).

STEP 3 Design Monitoring Network

- Where to Sample (from monitoring's role in management)
- What to Measure (from water quality goals and problems)
- How Frequently to Sample (from needs of statistical method selected)

STEP 4 Develop Operating Plans and Procedures

- Sampling Routes
- Field Sampling and Analysis Procedures
- Sample Preservation and Transportation
- Laboratory Analysis Procedures
- Quality Control Procedures
- Data Storage and Retrieval Hardware and Data Base Management Systems
- Data Analysis Software

STEP 5 Develop Information Reporting Procedures

- Type of Format of Reports
- Frequency of Report Publication
- Distribution of Reports (information)
- Evaluation of Report's Ability to Meet Initial Information Expectations

Figure 2. Steps in the design of a water quality monitoring system

in Figure 2 helps to ensure that water quality monitoring systems are designed in a systematic and scientifically sound manner and that they are capable of producing the information initially agreed upon.

As part of initiating any design, there must be a clear purpose in mind. Step 1 of the monitoring system design process, as outlined in Figure 2, involves determining what information is sought--why is the monitoring being undertaken? A major task under Step 1 is to evaluate management's need for the type of information the monitoring system is to acquire. Such an evaluation should be designed to stimulate a discussion among information users and monitoring system designers regarding not only what the user wants, but what the monitoring system is capable of producing. This discussion will, invariably, cover the water quality goals, management strategies and monitoring's role in management if an acceptable compromise between information "demand and supply" is to be reached. Specifics on water quality problems and goals and monitoring's role in management become input for later aspects of "network design." Likewise, a formulation of information expectations into statistical hypotheses plays a large role in future sampling frequency determinations. Figure 3 contains an example of the type of objective quantification that can serve to guide design of the entire system. Output of Step 1 is a mutually agreed upon (by information user and system designer) and carefully documented statement about the information the monitoring system is expected to produce.

Step 2 involves two major elements: (1) evaluating the statistical characteristics (e.g., underlying frequency distributions and dependence structure) of the water quality population to be sampled; and (2) using the above information to select the most appropriate statistical tests with which to ultimately, as part of the ongoing monitoring effort, obtain the desired information from the collected data. Knowledge of which statistical tests are most appropriate plays a role in determining the sampling frequency in Step 3. Thus, in Step 2, the statistics of the monitoring program are being dealt with in a quantitative manner, before sampling begins.

Step 3 is where the monitoring network (i.e., the where, what and when of sampling) is designed. Representative sampling sites are identified

Example 1

Management Goal:	Maintain or improve water quality.
Monitoring Goal:	Detect trends in water quality.
Definition of Water Quality:	Variables to be measured are DO, BOD, nitrates, TDS, etc.
Statistical Methodology:	Linear regression fit of water quality data versus time.
Statistical Hypothesis:	Slope (B) of linear regression line is zero at 95 percent confidence level. $H_0: \beta = 0$ $H_1: \beta \neq 0$
Monitoring System Product:	Conclusions regarding slope of regression line being significantly different from zero for variables being considered (trends are found to exist when $\beta \neq 0$)
Reporting:	Management goal is met when all slopes are zero or positive.

Example 2

Management Goal:	Promote beneficial uses of water (uses to be considered must be defined along with criteria-levels of water quality--which must be satisfied if each use is to be met. Use and criteria--i.e., standards--are then assigned to specific water bodies).
Monitoring Goal:	Measure compliance with standards.
Definition of Water Quality:	From standards.
Statistical Methodology:	Fit water quality data to a normal or log normal probability distribution.
Statistical Hypothesis:	Standard is met if 15 percent or less of the distribution is above standard.
Monitoring System Product:	Conclusions regarding probability of violation at each sampling site (violation is defined as at least 85 percent probability of standard being met).
Reporting:	Management goal is met when all sampling sites report ≥ 85 percent probability of compliance.

Figure 3. Examples of objective quantification required to support design of a total water quality monitoring system.

and precisely documented as to the exact spot where the sample will be taken. "Representative," in the above sentence, is defined according to the role the particular monitoring effort plays in management as defined in Step 1. The variables to be measured are derived from the water quality problems and goals of the management effort and the correlation structure between variables. It may not be necessary to measure two variables that are highly correlated--measuring one provides information on the other. The frequency of sampling and measurement frequency of different variables (which may be different from the sampling frequency) are computed using the requirements of the statistical tests chosen for future data analysis as part of Step 2 as the basis for the calculations. The mechanics involved in "network design" are described in detail by Sanders et al. (1983).

Step 4 involves defining the means by which samples will be collected, analyzed, verified and the data stored and retrieved. Quality control is a major concern at this point. Computer hardware and software are specified. The monitoring system operations, as defined in Figure 1, are spelled out in detail during this step. To achieve this definition of detail, literature and standard methods are utilized heavily. The key point is that in Step 4 the operations of the entire system will be defined in sufficient detail that different people working in the monitoring effort will generate identical results. Nothing, operationally, should be left open to interpretation. To do so is to generate data that may not be comparable.

Step 5 takes the evaluation to the point of having the monitoring system produce a final product (written reports) which is designed to convey the information expected in Step 1. To communicate the expected information effectively, the reports must be prepared in a format, at a frequency and distributed in a manner that matches the needs of the user of the information and the ability of the monitoring system to generate information. The most appropriate reporting methods and procedures should be identified as part of the monitoring system design, but they should not be beyond future fine tuning. In fact, a procedure to continuously evaluate the reporting methods and the entire monitoring system should be designed into the reporting procedure.

Summary and Conclusions

The need to view water quality monitoring as a total information system, and design accordingly, has been presented. To guide design of the total system, a framework of steps which follow from initial objective definition to specification of reporting formats is proposed.

Experience with the framework has shown that it works well where the objectives of monitoring are clearly focused on a narrow problem and/or site. Where a broad (e.g., region or state) regulatory monitoring effort is concerned, the inability to clearly define, much less agree upon, objectives prevents ready implementation of the framework. This points out the need to further refine the state-of-the-art in objective definition for large-scale monitoring programs supporting regulatory missions.

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~~DATA-STATISTICS-INFORMATION~~

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I want to tell everybody that we'll have a set of proceedings that is being transcribed and will be made available, and the kind of material that Robert covered was pretty in-depth; however, instead of trying to take notes, maybe you could just sit back and listen and try to find an error in our arguments or something so we can have some time to talk about it this afternoon.

As for lies, damned lies and statistics, that's the thing we've got to overcome constantly; and we can thank Benjamin Disraeli for saying that. It was related to the Boer War.

What I want to do, or the goal of this particular presentation, is to maybe bring statistics down from the theoretical and point out to you what it is--a tool. It's just something that we use. It's a data transformation technique. It extracts, weeds out and develops information.

I've got an overhead here following the chain of events of what we do in monitoring and in water quality management. We start off with some type of monitoring network, and then from that monitoring network we generate data. And we are very good at generating data; we are very good at storing it and retrieving it--unbelievably good--and we have found people who can generate data any time you want. We are trying to move beyond just collecting data, and I think in the last ten years with maybe a little bit of help from us and other people in the area that we are beginning now to do what Robert Ward was talking about. Let's go beyond fulfilling the minimum requirements of collecting data and let's start trying to make some sense out of it.

Now, following the data collection, there is some type of analysis technique and Robert Ward pointed out one. You can get a list of your data and hand it to the decision-maker--there's the data, you make the decision. That's one analysis technique that some of you probably use more times than not. You might even look at a statistic in that data. For example, the minimum, that's a statistic, and use that minimum for

analysis--or the maximum, or maybe they might even come across and say, "Look, give me the mean of that data and we'll say that's what the average water quality of that river is and we'll base our decision-making on that." These people say, "Heck, I never use statistics; I don't even know what they are." And yet they use them on a day-to-day basis anyway.

Robert also talked about graphics. If nothing else, take your water quality variables and develop a graphical representation of what you've got, and if you see a line vertically increasing, as time progresses, you can make a basic statement about water quality trends. This information is from a graph. Now, what we do with statistics is determine how significant is the slope. And when Robert said 95 percent confidence, this means that there is a 95 percent chance that the true slope is greater than zero. How bad is that slope or how realistic is that slope? Is it truly a slope associated with a change in the water quality data, an intervention, more pollution, or is it just random fluctuation of water quality data? And that's what we use statistics for. You can take out the randomness of the data.

There is a natural variation in the data, and no matter what EPA or the State wants to do, you can't change that.

Earlier this morning Dennis Anderson mentioned that if 15 percent of the samples exceed the standard, then a violation has occurred. Ten years ago that would not have been said. The standards say never. Exceeding the standard constitutes a violation. Saying its 15 percent starts telling you there is a natural variation we've got to take into account. We have not done this in the past, but we're beginning to now. The legislation is taking the randomness of the water quality variable into account.

I think the statistical analysis of data is the way to go. We have to understand statistics--we have to know when we get into assumptions, how close are the assumptions to reality. Remember, statistics is a tool for extracting information and can be misused as well, as Disraeli pointed out. That doesn't mean you throw it out. We still hammer nails into the wall with screwdrivers. It works--crudely--but it gets the job done. In some cases, the concept of independence of data is not so good, the concept of identical distribution is not so good; however, that does not

mean that we cannot use, for example, the Student's t-statistics to determine whether the means are different. Well, it looks like they're different using this test; we know the assumptions are not exactly close; but they're reasonably close. It's a tool that we use. We don't use it absolutely but just as another input to the decision-making. Once we get this information and we distill it down, decision-makers do not like to go through all the ramifications of the data analysis. They do not want a book-load of data. They might like a graph because they can look at that and make a pretty quick decision. They want that information so that they can understand it, and then make the decision. For many years we just collected the data and put it on the shelf. And you got paid for how much data you collected, not how many decisions you made. So the whole system was kind of mixed up. Decision-making is the appropriate end result of data collection.

You can get very definitive on how to set up your decision-making mode--how you're going to analyze the information and come up with a decision. Then once you get the decision you get the action, whatever the action is. For example, you could be put in jail if you're polluting and fined \$5,000 per day. Another action. Go after Martin-Marietta because they are polluting the groundwater with TCE and Denver may have to close the water treatment plant. The State might finally get into the groundwater monitoring when the problem is already there.

The interesting thing about groundwater monitoring and the lack of it in this State is this: first thing they're going to say is they'll go and start monitoring and find all this TCE and the question the lawyer on the other side asks is, "Well how much was in there before naturally?" The State doesn't know. It won't have any ambient background data. "Well then, how can you say we made it worse?" When the State starts ambient monitoring after they have polluted everything, it's kind of tough to determine baseline quality. We've already done that to stream standards in major rivers in the United States. How do you develop stream standards when you never know what the ambient quality is? There are a couple of sampling stations north of Ted's Place where we could probably get a good idea of ambient quality. That's about it. All the way downstream the water quality is the result of man's activities.

Water quality variables--which variables are you going to use? What's your decision-making mode? One we at the University use is: WHICH EQUIPMENT DO WE HAVE IN OUR LABS THAT IS WORKING? You collect the data that you can measure easily--data that doesn't vary randomly a great deal. You don't want to use BOD or coliform bacteria to measure trends. The variance, which is a statistical term representing the spread of data, is so great you can probably never discern a trend or change. But maybe you can because it doesn't have that much inherent variance with a sampling technique. So you use statistics to pick out the water quality variables.

Let's kind of go over the analysis technique I mentioned before a little more and throw out some of these strange words. You're probably familiar with a lot of them. Certainly when you do data analysis it is not always statistical. It doesn't have to be. We're not promoting this. We do have a book on statistics, by the way. Schaum's Outline on Statistics is the best one I've ever seen. Even better than our book!

The tabulated data--just look at the data. Look for the maximum; look for the minimum; look for the range of data. You might even look for the spread of the data. You might plot it. If that's all you have to do you've begun to extract information. Graphs and models are very nice. You can get your water quality data to be some kind of mathematical model--that's what we do in universities. That's what we get paid for in research--developing mathematical models which more or less define the processes in easily definable mathematical terms. If you've got that kind of situation you're really in good shape as far as extracting information is concerned, because if you can model it you've extracted a heck of a lot of information from that data.

Statistics. Now some of the statistics you're quite familiar with. The mean, the mode, the median, the minimum, the maximum. These are all statistics. What is a statistic? It is a random variable or a function of random variables. And what is a random variable? Every bit of water quality data you've ever collected is a random variable. Every bit of it. It is generated from a random process that is so complicated that we look at the statistics of the system in defining it versus trying to model it and look at the input variables in trying to model it. It is a

random variable and statistics are the result of a random variable or a sequence of random variables, something that is a function of random variables. That's all it is.

Variance. Variance is another statistical moment--the second moment if you want to get really precise. What is variance? It's a measure of the spread of the data. The BOD varies from 2,000 mg/l to 10,000 mg/l. The MPNs from 1 million counts per hundred ml to 2 counts per hundred ml--and back and forth. And that kind of erratic spread is variance.

Skew. Skew is very important for water quality data. What do we mean by skew? There are one or two values very high; the rest of them are very low. That would be a skewed random phenomenon associated with that particular variable. If you have skew data, you want to get a measure of central tendencies; you don't estimate the mean, you estimate the median since it won't be affected much by the outliers. This is where the data--knowledge and statistics--can work hand in hand in writing quantitative criteria. Now the whole thing you find out with statistics is to define exactly what you are doing and how you did it. To throw numbers up without the background on what you do essentially can be fraud, and we're still fighting this problem that Disraeli mentioned a long time ago.

Distribution. Now that's something you've probably not heard of and we have to work on it. How is the data naturally distributed? Not distributed whether it's here or over here, but what the distribution is if we collected a hundred pieces of data--would it be normally distributed? Would it be symmetrical or would it have a skew? If it has a skew is it log normal? And we've found from our research most water quality data is log-normally distributed.

Once you have the distribution data, you can specify the standards exactly. And you can define what concentration 15 percent of the data should exceed randomly, and then if you collect more than 15 percent of the data exceeding that standard, my gosh, you've got a violator, you've got an intervention.

You've actually got a change of the population. That's another term we use in statistics, the population of the particular variable. What we're asking is, has the population changed due to man? Has the mean, or

the variance, the kurtosis, the skew, changed due to polluting by man? If it has, that's a measure of nonhomogeneity. In our terms that's intervention; in laymen's terms, it's a violation.

Correlation and regression of variables are statistical analyses of data. Basically, correlation amongst variables is a reasonable way to decide which variables to monitor. Conductivity can be correlated with dissolved solids, with sulfates, with chlorides, and with other water quality variables. When we correlate it, that means we can measure conductivity and we know some things about the others. And we might measure conductivity daily, and measure sulfates only once a month, because conductivity more or less tells what sulfates are doing--if there is a strong correlation. The regression of conductivity and sulfates is usually linear. Total dissolved solids (TDS) are linearly related to conductivity as well. You multiply the conductivity in micromoles per centimeter times 0.65--if its 700 you multiply it by 0.65 and times TDS is about 420. That's how much dissolved solids you've got in the water. Conductivity you measure like this (snap of a finger); total dissolved solids takes 24 hours. So we can use statistics and regression in particular to separate what variables we're going to measure and what variables not to measure on a regular basis.

Baseline quality. We don't have baseline quality for Martin-Marietta, and I can't wait to see the court case on this one. The lawyer's answer to that will be, "How can you tell us there's been a leak? You don't know what the concentration or TCE was before the leak."

Fine polluters. That's what we've tried to do for a long time. EPA has spent its life doing this. How many polluters they've caught polluting and fined and put in jail or anything else, you could probably count on one hand. Mainly because the data they were supposed to use couldn't go into a court of law. There was no chain of evidence, there was no quality assurance, etc.

Wasteload allocation. Periodically, you go collect data in the stream, and if you want to raise the standard you decide the ambient data for only the last two or three years. This is an area that a lot of people misuse a great deal.

Decision-making. This is the fun part. Send them to jail. Fine them. Make them pay for the cleanup.

Ignore. This is what we've been doing a long time, ignoring. The State doesn't even monitor groundwater. I don't think we'll be able to do this much more; that is, not developing an ambient groundwater monitoring program. Get extended variance; that's the thing of the future for the compliance program. Fifteen years is what the Army wants for the Arsenal. I think they could knock it down to ten. Most of the senators that make the decisions will be dead anyway. It doesn't matter.

Water quality variables. There are several ways to select the water quality variable to be monitored. One way is you are told by EPA. TCE, trichloroethylene is a popular one. You can be told. But sometimes when you're trying to develop a monitoring program for only your use you get that choice. The most important thing in water quality now is precision.

Reproducible data. We all have the same method. We go out and take the same sample, we come up with the same concentrations, and we check this by statistical analysis of the data. Accuracy is somewhat important, but we're not so worried about accuracy. We really aren't. What we're worried about is precision because we're comparing this year's data to last year's. The absolute amount we don't care about that much. Accuracy is associated with truth and absolutes. We don't know what the real number is. We do know about precision.

Sampling locations. These are the whats, whens, wheres, and whys and all of that. We spend a week teaching you how to do this at all different levels and models; the more sophisticated you want to be we can teach you in the summertime. Representativeness of the data is the most important aspect of sampling locations on a river. How many of you who have sampled on a river have ever checked to see if the middle concentration is the same as that concentration you got on the other side? Did you know it can change thousands of a percent depending on distance across the river? If you're a regulatory agency you get on the side of discharges. If you're the discharger, you get on the other side of the stream. And you collect the data even though it's not representative--you're paid for samples, so you collect anyway. We've been doing this since 1956. Most of the data was not representative of bigger rivers. You need to take

multiple samples in a cross section--maybe 6 samples minimum, if you want to get reasonably representative samples. Instead of taking 10 minutes, it takes you 2 hours. It's unbelievable how many nonrepresentative samples that we have in this country and nobody has ever really looked into it. And you can look into it by the statistics of the data in cross sections, no problem. Then you get an area of complete mixing and that's nice. Then one sample is representative spatially. Spatial correlation analysis can be used to measure representativeness.

Sampling frequency. This was mentioned this morning by Mr. Anderson, I believe, and using statistics that Robert and one of his graduate students did years ago. The sampling frequency concept can be developed very simply, and it was not developed before 1970--Tim Steele did work on it. Tim was the first one that I saw doing work on any aspect of getting sampling frequency associated with water quality variation.

Data analysis is the final thing and this is the part where the precision, the reproducibility, is important. If I give everybody in our class the same data, and I tell them to use the Student's t-test to determine whether there's been a change or a significant difference between last year's data and this year's data, they'll all come up with the same answer. And maybe uniformity or data analysis is the most important thing we can do as far as water quality monitoring is concerned.

Allowable error. An interesting thing is that allowable error is associated with significance levels, and this is where industry changed the RCRA requirements--they changed allowable error which allowed them to really get away with more pollution. However, you have to know something about statistics. Changing the level or significance from 5 percent to 1 percent for testing procedures allowed a much bigger change than before. The test would say they were making a definitive change in water quality. Difference in means, significant trends--all these are methods that can be analyzed utilizing general, run-of-the-mill textbook methodology. Okay, I went very fast. Are there any questions?

MONITORING FOR PERMIT COMPLIANCE

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Introduction

Most types of waste discharges to the environment are currently regulated through some form of permit system. A discharge or disposal permit, issued by either Federal or State governments, usually requires some degree of monitoring--normally self-monitoring--to measure compliance with permit conditions. The obvious objective of this type of monitoring is, therefore, to detect permit violations. When no violations occur, the permittee is said to be in compliance. If any violations occur, the permittee is said to be out of compliance, must take corrective action, and may be subject to fines.

All this sounds logical and simple on the surface. However, a multitude of problems have arisen in practice, largely because of the difficulty associated with defining the term violation (Schaeffer et al., 1980b). This paper will briefly examine two types of permit monitoring in an attempt to review and summarize means by which permittees can partially overcome these problems through employing statistical methods of network design and monitoring data analysis. First industrial wastewater discharge monitoring under the NPDES system will be examined. Then monitoring of hazardous waste sites under RCRA will be discussed.

NPDES Monitoring

Most municipal and industrial waste discharges into receiving waters are regulated by the Clean Water Act as currently amended and by the associated NPDES permit system. Since states have largely assumed this regulatory function from the USEPA, the term SPDES is sometimes used. Discharge permits generally require self-monitoring at the final effluent for a stated list of pertinent water quality variables at specified frequencies. Usually either grab or 24-hour composite samples are specified. Typically the results of sample analyses are compared against fixed-limit standards. If any sample violates the standard, the discharger is out of compliance.

Unfortunately, however, waste treatment loading, wastewater treatment processes, and laboratory analyses are all characterized by some degree of random variability. Thus it is inevitable that any worthwhile fixed-limit standard will occasionally be violated. Most state agencies, aware of this fact, are fairly reasonable in their dealings with permittees. In some cases, standards expressed in statistical rather than fixed-limit terms have been tried.

Dischargers are, however, still often saddled with a compliance monitoring scheme which is not well matched to the nature of the process it is supposed to track. Some have added additional monitoring--extra locations, extra variables, and higher frequencies--to that required by the permit. In this way they hope to obtain additional information on the current and future ability of their treatment processes to meet current and future permit conditions.

However, the collection of additional data, in and of itself, may not provide the needed information. Unless the data collection strategy is carefully designed to meet stated objectives, and unless data are analyzed and reported in understandable formats, they may tend to pile up without being used for their intended purpose.

The general approach to network design described in Sanders et al. (1983) may be used for designing industrial monitoring programs to provide needed information for measuring current permit compliance and assuring compliance in the future. This approach may be divided into five steps as follows.

Monitoring Goals and Objectives: The first step is logically to agree upon and write down the goals and objectives of monitoring. This exercise should include much discussion among the data users. A typical set of goals and objectives might look like the following (Schaeffer et al., 1980b, Foess and St. John, 1980, and Berthouex and Hunter, 1975).

- I. Overall goals of monitoring
 - A. Assuring day-to-day compliance with discharge permit conditions;
 - B. Providing supervisory-level control of treatment activities; and
 - C. Planning for new facilities, etc.
- II. Supporting objectives
 - A. Detection of upset conditions in wastewater loadings or treatment

- process performance to prevent permit violations;
- B. Providing a data base for management decisions regarding treatment activities; and
 - C. Detecting long-term changes in operation conditions which could lead to future problems.

Background Data Analysis: The second step is the analysis of available background data to determine important statistical characteristics of the water quality random variables being monitored. These characteristics include seasonal or periodic behavior, serial correlation, and form of the probability distribution. All three are important in network design and in data analysis.

Many if not most water quality variables exhibit predictable cyclic behavior on an annual, weekly, or other basis. Such cycles may be the result of seasonal temperature variation or regular patterns in human activities. The simplest way to detect cyclic behavior in a water quality random variable is to examine plots of previous observations against time. This can easily be accomplished using a microcomputer and commercially available software; for example, the IBM PC and Lotus 1-2-3. A more advanced approach, based on time series analysis, is described in Loftis and Ward (1980).

If cyclic behavior is present, then future monitoring programs should be designed to avoid obtaining aliased data. Aliasing would occur if only "high spots" or only "low spots" in the cycle were sampled. Cyclic behavior should be accounted for in data analysis, either by time averaging to remove it or by using statistical tests which are appropriate for seasonal data.

The second characteristic of concern is serial correlation or redundancy of information in successive observations. Serial correlation is usually present when water quality observations are spaced closer than one month apart.

The presence or absence of such correlation in a water quality time series is difficult to infer from a time series plot, and more quantitative methods (Loftis and Ward, 1980) must be employed. Serial correlation can be avoided by designing sampling programs with sufficiently large time intervals between samples. Alternatively, serial correlation can be

removed in data analysis by time averaging. In any case, it is crucial that the presence of serial correlation be identified and dealt with prior to the use of any statistical test for trend. The outcomes of such tests are greatly affected by serial correlation.

Third and finally, one is interested in the form of the probability distributions which describe the random behavior of the water quality variables of concern. The overriding issue here is which variables may be treated as normally or log-normally distributed and which may not. A variety of quantitative tests (for example, Chi-squared tests and Kolmogorov-Smirnov tests) and semiquantitative tests (for example histograms or normal probability plots) may be employed. Sanders et al (1983) present details. For those variables which are found to violate an assumption of normality, the use of statistical procedures based on the normal distribution would be inappropriate. One must, therefore, rely on nonparametric methods for these variables.

Statistical Design Criteria: The third step in network design is to translate the overall goals and objectives of monitoring into design criteria which are quantitative and stated in statistical terms when possible. Examples of such objectives would be the following:

- (1) to determine the mean monthly sulfate mass flux at the final effluent within 10 percent at a 90-percent level of confidence;
- (2) to detect a 20-percent change in annual mean COD loading to biological treatment at an 80-percent level of confidence;
- (3) to detect a trend in mercury concentration within a waste stream of magnitude 5 percent per year with a probability of 60 percent;
- (4) to detect excursions of benzene concentration at a particular point in treatment with near 100-percent certainty.

It is usually difficult to be this precise in stating statistical design criteria initially. It is, however, essential to begin to view information expectations in statistical terms in order to make the network design process a quantitative rather than a qualitative exercise.

Network Specifications: After network design criteria have been stated as concretely as possible the monitoring locations, variables, methods, and frequencies can be specified. Where specific statistical criteria have been stated, the necessary sample size (sampling frequency)

to satisfy these criteria can be found directly. Often only a limited number of sampling frequencies would be convenient to implement. For example daily, weekly, or monthly sampling might be practical. In such cases one simply chooses the least frequent sampling which will satisfy all stated criteria.

In industrial wastewater monitoring a common criterion is the detection of upsets of key variables with a high degree of certainty. The safest means of accomplishing this task is through the use of continuous monitors. Composite samplers may also be used, but one must be wary of problems with sample dilution prior to analysis. On the other extreme, grab samples are largely ineffective as a means of detecting upsets. A comparison of grab and composite sampling is given by Schaeffer et al. (1980a).

Another common criterion is the determination of mass loads of certain variables entering and leaving a treatment process in order to determine process efficiency. A seemingly obvious point which is sometimes neglected in both industrial and surface stream monitoring is that accurate flow measurements are as important as accurate concentration measurements for mass load determinations. For accuracy, both flow and concentration measurements should be taken at the same points in time.

Data Management Scheme: The final and perhaps most crucial step in planning any water quality monitoring program is to design a data management system as an integral part of the program from the start. Data management should include checking all water quality observations for obvious errors before entry into a permanent data base. (This step does not, of course, substitute for a separate program of quality control over laboratory and automated methods of analysis.)

A computerized data base can be used to store and retrieve all types of water quality data. Both mainframes and microcomputers can be used. Through microcomputers, however, the user groups can have more direct access to the data and can exert more direct control over data management than is usually possible with mainframes. Thus both the extent and effectiveness of data utilization should be increased. A large number of powerful data base packages--for example dBase II, dBase III and KnowledgeMan--are now available for the IBM PC and other micros.

The next step in data management is routine, computerized statistical analysis of data. The procedures utilized must provide the information specified in the statistical design criteria and must be compatible with the characteristics of the data as identified earlier.

Fortunately, more and more powerful statistical packages are becoming available for microcomputers. Most include nonparametric methods; many add graphics or at least limited plotting capabilities; and some include sophisticated time series analysis techniques. Among entries with promising potential are Statgraphics, SPSS, and Minitab. The latter two are downsized versions of popular mainframe packages.

All is not roses, however. A problem which has nagged the author, and others no doubt, is the frequent lack of compatibility between statistical and data management software packages. Such packages may be user friendly, but they are often very unfriendly toward each other.

Data management is, of course, not complete without information dissemination. It is, therefore, important to include routine preparation of reports, including graphical presentations and statistical summary results, as part of the system. Here again the computer plays a key role. Finally, feedback from the data users provides for continual updating of the entire monitoring program in light of changing conditions and information needs.

RCRA Monitoring

Unlike those associated with older pieces of environmental legislation, the regulations associated with the Resource Conservation and Recovery Act spell out the details of required monitoring activities and prescribe specific statistical procedures for data analysis. This is regarded by the author as a significant step forward. Equally significant, however, is the degree of confusion and consternation which has arisen from the statistical and logical flaws in the regulations. The purpose of this section is, therefore, to note both the promise and peril associated with RCRA monitoring regulations in the hope that increased understanding will lead to realization of the former rather than the latter.

The regulations associated with RCRA currently require a detection monitoring program in which groundwater quality data are to be collected at least quarterly from upgradient wells for one year for four indicator

variables (pH, total organic carbon, specific conductance, and total organic halogens) in order to establish background conditions. After the first year, both upgradient and downgradient wells are sampled at least semiannually and statistically compared with background data to detect significant changes. Statistically significant degradation of downgradient water quality results in the implementation of a more involved compliance monitoring program which could lead to an expensive cleanup effort.

The standard being used here is simply that no significant degradation of groundwater quality may occur due to the regulated site. What is unique and promising is that the writers of the regulations have recognized the importance of natural (statistical) variability in groundwater quality and have acted accordingly, expressing the meaning of compliance or noncompliance in statistical rather than fixed-value terms.

The required sampling frequency and statistical analysis procedures for detection monitoring are spelled out in the regulations. Since RCRA has gone beyond other legislative efforts to standardize monitoring and data analysis procedures, it has received much attention and criticism regarding the appropriateness of the specified approach. In particular, serious questions have been raised regarding the choice of the hypothesis test which is specified in the regulations and the specification of sample size based on replicate analyses.

The specified test for comparison of means in groundwater quality is Cochran's Approximation to the Behrens-Fisher Student t-test. This test was developed for the comparison of means from two populations in which the variances are not necessarily equal. (The usual t-test assumes that the two variances are equal.) The assumptions of the specified test are that the two populations are normally distributed and that the samples are independent.

The problem of testing for equality of means when the variances are unequal is referred to as the "Behrens-Fisher Problem." The associated hypothesis test requires the use of special tables. However, for Cochran's Approximation, which is employed in practice, regular t-tables may be used. Although there is some error involved in the approximation, other limitations of this approach, as described below, are probably more significant.

The first limitation is the normality assumption. Many water quality random variables are clearly not normal, particularly if there is a significant fraction of nondetects in the data record. EPA has recognized the problem of non-normality in the past and at one time recommended a nonparametric approach, the Mann-Whitney test. Currently, EPA suggests that if the coefficient of variation of sample data is less than 1.0, the data may be regarded as normal for purposes of the test. This assumption is questionable. In the absence of normality, other "equivalent" tests may be utilized if approved by EPA.

The second limitation is the assumption of independence. As long as samples are taken quarterly or less frequently, an assumption of serial independence is probably justified. However, the presence of predictable seasonal variation is still likely. Quarterly sampling to establish background concentration values is purported to account for seasonal variation, but the statistical test as written into the regulations is inappropriate for the analysis of seasonal data.

Supposedly the use of a test which does not require equal population variances addresses this issue since the background data would include seasonal variation and subsequent data sets might not. This is not a very sound argument statistically, however, and brings up the third limitation, which is the question of whether the assumption of unequal variances is appropriate. In most cases it would seem that such an assumption is not appropriate since under the null hypothesis, that the two means are equal, one infers that no change has occurred. One would, therefore, expect that variances be equal as well as means.

The fourth limitation is the question of how the sample size should be specified for the test. EPA states that if four quarterly samples are taken and four replicate analyses are performed on each, the sample size is 16. This is a rather serious error since one does not have 16 independent samples. The correct approach is to average the replicates and use a sample size of four. The effect of using a sample size of 16 is to greatly increase the probability of a Type I error, false detection of a change.

This brings us to the fifth limitation, which is the specification of the Type I error or significance level for the test. EPA originally

specified a significance level of 0.05 and has since retreated to 0.01. If the test were properly constructed and all assumptions satisfied, this would probably be too low and would provide inadequate power or ability to detect degradation of water quality. Because of the questions regarding normality, seasonality, and sample size discussed above, however, the actual significance level of the test may be much different from 0.01 (probably larger). In fact, there is no way to tell what it really is.

Although these limitations are serious, a number of researchers are beginning to address them in such a manner as to find practical solutions for the near term. EPA has expressed a willingness to implement such solutions. A really satisfactory approach to groundwater quality monitoring network design will, however, require a unified understanding of pollutant transport through porous media as a physical process and of groundwater quality observations as random variables. This level of understanding probably lies several years in the future.

Conclusion

Water quality monitoring for permit compliance can be viewed advantageously as a statistical sampling process. In some cases, notably RCRA, the permit system explicitly recognizes this fact. In others, for example fixed-limit discharge standards, it does not.

In either case, however, the permittee can benefit from a statistical approach to defining information expectations, to monitoring network design, and to data analysis. Through a statistical approach, more information on current or emerging water quality conditions can be obtained from a given level of monitoring, thereby placing the permittee in a better position to maintain permit compliance for both the present and the future.

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Luncheon Address

WHAT IS THE QUALITY OF OUR WATER?

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As a member of the Colorado Water Quality Control Commission, I appreciate the opportunity to evaluate with you the scientific efforts which so significantly impact our regulatory decisions. I am not going to speak at length on monitoring but I'll try to put monitoring into the legal, political, and regulatory context, and show how important a role you the scientist and technician are going to have and prepare you for the lawyers who likely will be questioning you.

Let me start with a question: How good is our water quality?

As a member of the Colorado Water Quality Control Commission (WQCC), my data tells me it is very good throughout the State. Ninety-four percent of the classified streams have water quality which meets and protects the classified aquatic, drinking water, recreational and agricultural uses.

But you as scientists may tell me my data is not any good for reaching the conclusion I just made. You may be right! If STORET data is used, can I use total metals averages to really conclude that dissolved metal concentrations are sufficiently low throughout the year to protect aquatic life? Indeed, are my classifications realistic recognizing the lack of instream data throughout the state?

As a public policy and decision maker I need data for a variety of purposes, so I ask you as scientists to give me the data and the analytical approaches to evaluate that data so that I can create alternative policy choices, weigh the consequences of my choices and properly reach a supportable and hopefully widely acceptable decision.

You, the scientists, will have to find the opportunities for flexibility in decision making, since it is so difficult to find regulatory flexibility in the general law of water quality.

The central point I hope to develop with you is that the Federal Clean Water Act (CWA) and EPA's regulations do not on their face provide for clear flexibility in administering the water quality program, but

they do subtly provide for potentially significant regulatory flexibility in the scientific judgments which must be made.

I'll develop this point by first examining our present water quality--our near term water quality issues, the conflict between EPA and the state over regulatory flexibility, and the future search for regulatory flexibility while seeking to achieve the goals of the federal CWA.

Present water quality conditions are very good. The 305b CWA Report for 1984 showed:

1. Colorado has 14,000 miles of streams.
2. Of these, 10,000 miles are classified.
3. Of the 10,000, 94 percent fully support the classified uses.
4. But 4 percent do not have sufficient water quality.
5. Out of the 10,000 miles only 130 miles are not classified for aquatic life. Thus, the goal of the CWA, to achieve fishable/swimmable streams is largely achieved.
6. Of the 4 percent which do not have water quality to protect a classified use:
 - 53 percent are due to inactive mine drainage;
 - 26 percent because of municipal discharge;
 - 5 percent due to industry; and
 - 16 percent due to non-point sources.

In addition, the 305b report identified 33 stream segments which are now or in the near future will be unable to meet necessary stream standards. These "threatened" streams are primarily threatened by discharges of unionized ammonia.

Last Fall the Water Quality Control Division estimated 72 communities would need Advance Waste Treatment (AWT). AWT is most often needed to remove unionized ammonia to protect fish classified streams. Now the WQCD believes that the figure may be less than 72 communities. But, it may become more than 72 if the unionized ammonia standard is revised to more restrictive or lower numbers. The present unionized ammonia standard for most Front Range streams is subject to some attack. A potential standard of .03 mg/L may be necessary to protect catfish. A .03 mg/L standard would require AWT where the present .1 mg/L standard does not. Thus, the number of threatened streams would increase.

This brings me to our future near term issue: How can the State reevaluate existing classifications and standards and amend them so as to achieve the goals of the CWA while avoiding undue or unjustified financial burdens on dischargers.

A special Task Force sponsored by the WQCC is seeking to reevaluate our classification system, the related unionized ammonia standards, and heavy metals standards. Hopefully the Task Force effort and necessary revisions to the WQCC Basic Standards Regulation which guides the water quality classification and standards setting process will be done before mandatory hearings now required by a new Colorado water quality law are held. S.B. 83 is nearly out of the Colorado legislature. It authorizes reviews of all aquatic classified streams. Those revisions will have to be thorough and hopefully final.

S.B. 83 is the result of the conflict with EPA over the lack of consistency between the Colorado water quality program and the federal water quality program requirements.

In essence, by passing S.B. 83 Colorado is giving up its rulemaking flexibility based on considerations of economic reasonableness for assurances from EPA that rulemaking flexibility can be found in the application of science to site-specific problems.

The question is whether some flexibility can really be found. "Flexibility" is an overworked word with no precise meaning. It depends on your perspective:

- (1) To a discharger it means not having to pay additional costs to protect instream uses.
- (2) To environmentalists it means having the opportunity to improve present water quality to potential maximum quality and use.
- (3) The CWA provides a touchstone through its goals and objectives:
 - (a) to achieve fishable and swimmable streams where attainable;
 - (b) to eventually eliminate the discharge of all pollutants;
and
 - (c) to restore and maintain the biological integrity of the nation's waters.

Such goals do not allow for much flexibility. But we must recognize that achieving these goals to the greatest extent possible must be within

the real limitations of technical capability, economic capability, and political reality. These limitations necessitate some flexibility.

"Technological push", economical push and even political push may have been appropriate philosophies for removal of the first 85 percent of pollution, but the imposition of high capital costs and O&M costs to remove the last percentage of pollutants must be justified as being the minimum and necessary costs and that such costs are not wasteful or excessive.

"Flexibility" in my perspective is having a process that seeks to achieve the goals while assuring that the means of achieving the goals are fully justified.

The "process" consists of both the rulemaking and the permit writing forums.

"Flexibility" comes out of this process based upon the scientific data provided and analysis at several steps in the process. More specifically, three clear steps can occur.

First, the adopted stream classifications may need to be reevaluated and refined through rulemaking hearings into subclassifications. In public hearings to reconsider classifications, we need to identify what we are protecting or trying to achieve, and give the decision makers and the public some choices:

- (a) What aquatic life is in the stream now?
- (b) What is the potential aquatic life?
- (c) What are the sensitive species?
- (d) What species are residents, visitors, stockers?
- (e) What constitutes a "balanced" population?
- (f) What subclassifications would allow little pollution loading and what will allow the greatest pollution loading?
- (g) What physical factors justify a downgrading to one of the alternative subclassifications?

Second, once a classification is established, we must carefully identify what numeric limits for the various pollutants are appropriate. Again, what are the alternatives?

- (a) Red Book numbers (are they too gross?).
- (b) EPA recalculation procedure numbers (how reliable is this

new procedure?).

- (c) Site-specific bio surveys (how accurate is instream monitoring for defining actual ambient conditions under which present fish populations are apparently living? How accurate is a data base which mixes acid recoverable and total digestion laboratory techniques, or is used with little attention paid to time of day, time of year, or frequency of sampling?)
- (d) site-specific bioassays (how accurate are the methods in reflecting actual instream conditions recognizing variations in many elements affecting pollutant toxicity?)

Clearly, the WQCC is seeking a higher level of refinement in establishing site-specific numbers. We need to learn more about elements that bind toxic pollutants as well as cause synergistic and additive reactions. We need to establish numbers which are for acute and chronic concentrations and related to sensitive portions of fish life cycles. We may need to have water quality monitoring stations related to instream aquatic life transects and hydrologic gauging points, so as to collect water quality data specifically defined for aquatic life concerns.

The third step in the public process is translating the adopted water quality standards into specific permits, and flexibility at this step also heavily depends upon the scientists and your data.

- (a) Flexibility in avoiding unnecessarily expensive wastewater treatment may be best achieved by writing permits not on the very low instream flow defined by the Q7/10 but on some higher and more frequently observed flow level. Is Q7/10 too great a margin of safety? There is a study going on now at CSU to assess alternatives to the Q7/10.
- (b) Further flexibility may be found by translating water quality standards into wasteload allocations while also recognizing the aging or persistence, degradability or volatile nature of the pollutant or its changing toxicity with changes in pH or temperature or other conditions.

Hopefully, good, refined scientific methods will give the decision makers choices so that a sound decision is made which is achievable

technically, economically and politically.

But once an effluent limit is in place, determination of compliance and the true effectiveness of compliance must be assured. We need enforcement monitoring techniques which are reliable, quick, relatively inexpensive and reproducible. I expect monitoring of compliance will tend to expand in terms of the number of effluent limits. Periodic screening will be necessary to determine the presence of pesticides, toxic solvents, and solvents, but standards and effluent limits set below measurable detection levels will continue to be a monitoring problem. Perhaps biomonitoring may become useful as a screening tool and confirmation of compliance.

I think it is obvious that our future calls for continued refinement of monitoring techniques and use of monitoring data.

Whether instream monitoring data is used for setting standards, establishing waste load allocations and effluent limits or confirming compliance, greater scrutiny will be paid to monitoring methods and the accuracy of what it is supposed to be telling us.

I foresee lawyers cross-examining expert witnesses concerning:

- (1) Specific locations of monitoring stations.
- (2) Evidence showing the propriety of that location and how much it represents, or to what extent it represents a stream segment.
- (3) Evidence showing the time of day of instream sampling for ammonia and related pH and temperature.
- (4) Evidence that specific samples taken have been properly taken, processed, analyzed and recorded.
- (5) Perhaps, whether a chain of custody is available, to show that field processing and delivery have been timely, or that lab procedures are appropriate for the purpose the data is being used.
- (6) For example, in the Hecla Mine hearing before the WQCC, total digestion-based laboratory data was not acceptable, so two years of additional collection is necessary before a sound decision can be made.

Why will greater scrutiny during public hearings be placed on monitoring? Because the cost of removal of the last increments of pollution

are so high that the dischargers must fully explore and determine that the costs are justified.

"Flexibility", then, is the avoidance of effluent limitations which are not justified, and compliance with effluent limitations which have been fully evaluated and justified in a legal, scientific, and public process.

I look forward to your participation in this jousting arena of science and the law.

Not a student

MANAGEMENT INFORMATION FROM WATER-QUALITY MONITORING PROGRAMS

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Introduction

We use the term monitoring in reference to all types of water-related data collection including, in part, water quality studies of a research nature. The original meaning of monitoring, "to watch over," or to determine compliance with the law, has been lost (Sanders and others, 1983). Regardless of its connotation, any program that obtains data about our waters ultimately should provide information. While this process may seem redundant, it is not in the field of water quality monitoring. A number of reports are published annually that contain water quality data; however, little information can be derived directly from the data because relations between the data do not exist. I was pleased to see that Dr. Sanders placed the word "statistics" between the words "data" and "information" in the title of his paper in this symposium. Clearly, his connotation is that data must be transformed to information if they are to be useful.

A water quality monitoring program should be designed for specific purposes and specific goals, much like a research project. Monitoring programs that endeavor to be broad-based to measure all possible water quality changes usually result in little information. The investigator becomes inundated with large quantities of data, usually at the expense of specific high-quality analysis. In the past two decades the Nation has faced two major water quality crises--eutrophication and acidic precipitation. One of the reasons that these water quality crises were undetected by many water quality monitoring programs was that the programs were broad in scope, lacked a specific purpose, and sample-analysis quantity was favored instead of quality.

In a review of some successful water quality monitoring programs, I found each to have three phases. The first phase is planning and design; the second phase is program operation; and the third phase is data collection shutdown, data analysis, data interpretation, and report issuance. Some programs never reach the end of data collection; however,

the data are analyzed and interpreted on a regular basis so the important requirements of the third phase are met. Those programs in which the first phase is ignored result in obvious consequences: data, but no information. In addition, if the analysis and interpretation part of Phase III is ignored, the result also is simply a tabulation of data. Unfortunately, too many monitoring programs end this way.

In the paragraphs that follow, I discuss the primary criteria for successful water quality monitoring programs using these three phases. No attempt will be made to provide step-by-step planning, design criteria or mathematical treatment. The reader is referred to Moss (1976), Moss and others (1978), Moss (1979), Sanders and others (1983), and Kwiatkowski (1984) for detailed mathematical treatment of water networks. My purpose is to emphasize primary considerations that are paramount to the design and operation of successful water quality monitoring programs, but are ignored in most papers dealing with rigorous mathematical treatment. The scope of the paper will be limited to surface-water systems and primarily will be concerned with water chemistry. For information on groundwater systems, the reader is referred to Claassen (1982) for sampling design and procedures, and Maddock (1972) for data-collection networks. An excellent book on biological monitoring is that by Pascoe and Edwards (1984).

Phase I--Planning and design of a Monitoring Program

The single most important criterion is to ask the correct questions in the planning stage, such as: (1) is a monitoring program needed; that is, are there other less costly ways to determine the same information such as a short-term reconnaissance study; (2) what are the goals of the monitoring program and what is the purpose; and (3) what is the problem to be solved with the program? Question 3 refers to addressing the need of the program, and unless it can be answered clearly and concisely, the program has little chance of success.

In the planning and design of the program, it is imperative that the investigator have some knowledge of the system being studied. Usually this is no problem today, because water quality data exist for many rivers and lakes. Minimal water quality information needed is measurements of specific conductance (or dissolved solids), pH, and water temperature.

If additional information is available, especially on constituents related to the purpose of the program, obviously these need to be used. The investigator, however, needs to be cautious in the use of data collected for another purpose unless such factors as detection limits, analytical procedures, and sampling methods are known. Effective monitoring programs are designed for specific purposes, and commonly data are not transferable to other specific program needs.

Instream constituents are only one part of a modern, comprehensive water quality monitoring program. The characteristics of the surrounding watershed also need to be understood (Likens, 1984) before constituent selection is made. This information commonly can be extracted from topographic maps. Characteristics such as drainage area, location of tributary streams, streambed elevation and slope, access and land use may affect decisions concerning the location of sampling stations, the frequency of sampling, and the selection of constituents to be sampled. A knowledge of climate is also important. The investigator needs to be fully aware of the location of areas of groundwater discharge to the earth's surface. Where such discharge is sufficient to alter water quantity of the stream system, that area may need to be included as a sampling station. The point to be made here is that the watershed or drainage area needs to be well understood in the planning of a water quality monitoring program (Hynes, 1975 and Likens, 1984). Urban or metropolitan drainage areas generally are complex and defy accurate planning, as well as complicating constituent selection. It is no mystery that for decades the best we could do with urban or metropolitan systems was to measure the biochemical oxygen demand of the water.

Sample station selection, frequency of sampling, selection of constituents, and data analysis procedures are partners in any monitoring program. Each has a bearing on the cost of the program, as well as on personnel and laboratory needs. Several statistical tests provide insight to cost and frequency balance (Snedecor and Cochran, 1967; Greeson and others, 1977; and Sanders and others, 1983). As a general rule, the number of sampling stations needs to be kept to a minimum. A large number of samples collected at a few stations always is more useful than a few samples collected at numerous stations. As Green (1979) states,

"Differences among (sampling stations) can only be demonstrated by a comparison to differences within (sampling stations)." Sampling stations need to be located at areas of maximum information content rather than at areas with ease of access. Access, however, obviously is important and needs to be possible at high flows. The use of secondary sampling stations at which a decreased number of constituents are collected provides a means of adding stations for short periods for the sampling of particular constituents.

It is important to determine that the sampled water transports or contains the constituents in question. LaBaugh and Winter (1984) found that the major tributary to Williams Fork Reservoir in Colorado transported less than 50 percent of the phosphorus entering the reservoir. This tributary had been gaged since 1904. Two lesser ungaged drainages contributed more than 50 percent of the phosphorus, and thus transported the constituent of concern to the reservoir.

Selection of the constituents to be sampled depends wholly upon the purpose of the monitoring program. The investigator always is wiser to measure a small number of critical constituents specific to the purpose of the program that probably will have expected effects (increased or decreased concentrations) than to measure a large number of constituents, many of which will indicate little change or effect of water quality. Specific conductance usually is sufficient to determine changes in major dissolved ions, and an occasional water sample for ion analysis usually is sufficient for verification of specific-conductance values. Trace-element selection is more difficult, in that their concentrations are not as predictable and their contributions to specific conductance are minor. Organic constituents also are unpredictable, and need special sampling and transport requirements. If sampling is for suspended materials sorbed to sediments, then non-filtered samples, collected with the use of routine sediment-sampling equipment, are needed.

It is imperative to decide at the onset if total (unfiltered) or dissolved (filtered) samples are to be used for analysis. Any decision to change after the monitoring program is underway will result in noncomparable, and hence useless, data. Concentration variability of dissolved constituents usually is less than concentration variability of

total constituents; thus, the results for dissolved constituents are much easier to interpret. If dissolved constituents are to be used for analysis filtering generally needs to take place streamside, an activity that needs to be factored into the cost and time of sample collection.

Sampling equipment and sample containers need to be compatible with the type of samples to be collected. For example, samples for trace elements need to be collected in nonmetal samplers and stored in nonmetal containers. Samples for organic analysis need to be collected in nonorganic containers and stored in nonorganic containers. Methods vary on the types of preservatives for each type of constituent, except that chilling to 4°C. will decrease bacterial and phytoplankton activity in sample containers. The analyzing laboratory needs to be consulted on preservation techniques. The investigator, however, should be satisfied by experimental findings that sample concentrations are not altered by shipping containers or by storage prior to analysis.

In shallow streams a hand-held container generally will suffice for collecting a representative sample of water. In large rivers a weighted sampler using the equal-transit-rate (ETR) technique (Guy and Norman, 1970) is necessary. In lakes a pumping sampler or a messenger-activated point sampler is necessary. The samplers, including hoses and pumps, may need to be treated or otherwise modified so they will not contaminate the sample. Water quality sampling is discussed in a number of publications such as Hem (1970), Greeson and others (1977), Green (1979), Claassen (1982), and Sanders and others (1983). The classic paper by Rainwater and Thatcher (1960) still is useful.

Selection of a laboratory analytical technique usually is left to the servicing laboratory; most on-site field investigators do not bother with this part of their water quality monitoring program. Although the investigator does not have to understand the details of every analytical method, he or she needs to understand detection limits, precision, and interferences of the analytical method, as well as degradation rates and properties of the material being analyzed. A full description of the analytical method always needs to be recorded as a part of the monitoring program. Changes in analytical methods, preservation, and sampling result in changes in constituent concentrations. Such changes too often are

mistaken for environmental alterations in the system being monitored, and these mistakes usually lead to erroneous conclusions. One rule to follow in monitoring program data analysis always is to suspect sample handling or analytical techniques for concentration changes. Thus, in stating that concentration changes are the result of changes in the system, the investigator needs to determine beyond doubt that sample handling and analytical techniques were not the cause of the change.

Sample frequency needs to be related to the temporal concentrations of the constituents under consideration. Usually sampling more frequently during increasing or decreasing discharge is more useful. During low flow or stable flow sampling frequency often can be decreased. Seasonal changes just before and just after leaf fall also need to be included if organic chemical constituents are involved. Samples need to be analyzed to determine if synoptic sampling is necessary.

The investigator needs to be mindful of the time lapse between the collection of samples and how this will later affect the analysis and interpretation of the data. The largest part of total loads of some materials occur in very short times, often associated with highest flows; sampling at those times is essential. With industrial or municipal discharges to river and lake systems an ill-defined or erratic pattern of discharge often occurs. Sampling these systems is essential when the largest concentrations are present, which may mean a rather frequent sampling program in the absence of information on waste discharge.

Some constituents such as dissolved oxygen (DO) do not lend themselves to periodic sampling, although they generally are included in water quality monitoring programs. A periodic DO concentration has a minimal or nonexistent information value. However, near-continuous DO measurements generally will yield a great deal of information. If continuous DO concentrations cannot be obtained, then hourly measurements over a 24-hour period during the low-flow and warmest part of the year will provide useful information, and usually is sufficient to understand the oxygen resources of most waters.

Before using continuous monitoring equipment the investigator needs to realize that this equipment is not carefree. Frequent cleaning and calibration of probes is necessary for accurate results in the field,

just as in the laboratory. When automatic water samplers are used the investigator needs to satisfy the condition that the samplers are as useful as real-time samples, and that sample storage in the automatic sampler has not altered the constituent concentration.

One final Phase I consideration before the program begins is to decide how the data will be analyzed. If stochastic statistical techniques are to be used in data analysis, then the data need to be collected in a random manner. If anthropogenic effects on the system are expected, a stratified, random system using weekends and holidays as one stratum and week days as another stratum generally will suffice. The number of weekend days and week days to sample depends in part on the budget of the monitoring program. However, a sufficient number of samples for each period (season, weekend, weekdays) is necessary for adequate statistical testing. Also, it is helpful to have equal numbers of samples for each period and station, although this is not a rigid requirement. The type of test to be used will dictate the sample size. In this regard, the investigator should refer to Elliott (1974) and Green (1979).

A water quality monitoring report needs to have a carefully written methods section that details the techniques used. Fortunately, the methods section of the final report can be written (as can the introduction, purpose and scope) before the program is activated.

Phase II--Program Operation

Once underway, a water quality monitoring program requires continuous attention and evaluation. Too often the samples are collected, analyzed, and the data stored until the program has ended. This procedure usually leads to forgetfulness and an unawareness of changes in the system being monitored. Together with the collection of data, detailed field notes are needed that will explain anomalies and later be useful in data interpretation. The laboratory analyst also needs to keep detailed notes. Filing of data for future analysis and interpretation is inappropriate unless thoroughly reviewed by the investigator soon after they are received from the servicing laboratory. On a periodic basis (no longer than 3 months) the investigator needs to review all data collected and make simplified comparisons to ensure that the purpose of the monitoring program is being accomplished. Periodically, the results need to be thoroughly

reviewed for the following: (1) redundancy of concentrations between time periods; (2) redundancy of concentrations between stations; and (3) information value of the constituents. Where such redundancy occurs, consideration needs to be given to decreasing the frequency of constituent analysis, discontinuing or decreasing the number of selected sampling stations, or deleting or decreasing the number of particular constituents to be analyzed. For some constituents lower detection limits may be necessary.

Data, like lunches, are not free. Even if data come with a bargain laboratory "analytical package," they require an effort on someone's part before they find their final resting place. Because of the cost of data collection, data type and sample station evaluation need to be a continuing part of Phase II. When the data or stations "stop telling a story," it is time for careful review and possible elimination. For an excellent review on station consolidation see Lettenmaier and others (1984).

Any changes in sampling stations need to be thoroughly documented as the program progresses, and such documentation needs to be attached to the laboratory sample analysis for future reference. Also, changes observed in the system being monitored need to be carefully documented, such as diversions, construction activities (bridges), agricultural return water, and so forth. (Photographs are useful to document changes.) The use of secondary sampling stations, those at which a decreased number or constituents are collected, commonly is useful in defining the impact of changes.

Phase III--Shutdown, Data Analyses, Interpretation and Report Issuance

Water quality monitoring programs often continue too long and are difficult to stop. If designed correctly and conducted as a project study, they will yield useful information in a relatively short time. This does not mean they should all be of short duration; indeed there are good reasons for long-term programs (Likens, 1983). However, too often monitoring programs continue for long periods because they are poorly designed; the data fail to "tell a story," and the investigator has no way of knowing (aside from dollar constraints) when to stop the program. A well-designed and conducted water quality monitoring program will produce useful results, just as a research project that follows a well-designed

experimental plan.

The investigator needs to be mindful of the intended use of the report. Many reports using complex mathematical models are neglected by water managers (regardless of how well the program was directed), because they cannot understand the findings. Complexity of analysis usually does not equate to understanding. "Seek simplicity and mistrust it" is an old saying in science, but it has a ring of truth to it. The investigator needs to use the simplest techniques in analyzing data, but the techniques should provide maximum information. Generally, water managers will be far more interested in concise conclusions than complex models.

Below are some questions that a water management board or commission might have at the completion of a monitoring program. These questions are listed in Phase III which considers the final report, but they need to be considered under Phase I by those designing water quality monitoring programs. Some general questions might be:

- (1) What is the present status of the quality of the water (based on the constituents measured)?
- (2) What is the variation among and between constituent concentrations at the sampling stations? Is the variability natural or anthropogenic?
- (3) How do the concentrations of the various constituents compare to harmful or hazardous concentrations recorded in contemporary literature, or to local, state or federal water quality standards?
- (4) How do the constituent concentrations relate to stream discharge, seasons, and other events?
- (5) What are the consequences of the constituent concentrations on the stream or lake? Can the stream or lake receive larger concentrations of these constituents without harmful effects; that is, what is the assimilative capacity of the stream or lake for the constituents measured?
- (6) Where are the weak points in the program--what other constituents, stations, or sample frequency should have been included in the program?

These questions may provide much needed considerations for future

water quality monitoring programs. Design of water quality monitoring programs is still in its infancy. The point made is that designers of water quality monitoring programs will do well to discuss expected results with managers, board members or commissioners ultimately responsible for water management.

Conclusions

Water quality monitoring programs will become more commonplace in the near future, and will help in the assessment of the quality of the Nation's water. Because of their long-term nature and relatively inexpensive personnel costs, they may be the most helpful source of available data. Well-designed monitoring programs are imperative to obtaining a thorough understanding of our water resources. In this regard, the design and implementation of a water quality monitoring program need to be given the same careful planning as a research project. This means careful planning of experimental design, of program operation, of sample collection and analysis, of data collection and analysis and of the issuance of a final interpretive report.

Research Needs

If the field of water quality monitoring is to advance on a cost-effective basis, the development of in-situ probes and samplers that provide real-time data will be needed. Probes that continuously measure specific conductance, temperature, pH and dissolved oxygen have been available for about two decades. It is interesting that additional probes have not since been developed. Biological in-situ measuring devices for phytoplankton numbers and chlorophyll also are needed. The problem of sample preservation and storage so as to reduce changes in chemical or biological composition is yet to be solved for many constituents, and will become a more important problem with increased organic-compound sampling and analysis. Indeed, it would be very useful if we had reliable preservatives so these samples could be stored for longer periods, or even archived awaiting development of better analytical instrumentation. We would have a much better understanding of the Nation's waters today had we been able to "save" samples collected several decades ago for analysis on today's modern instruments.

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