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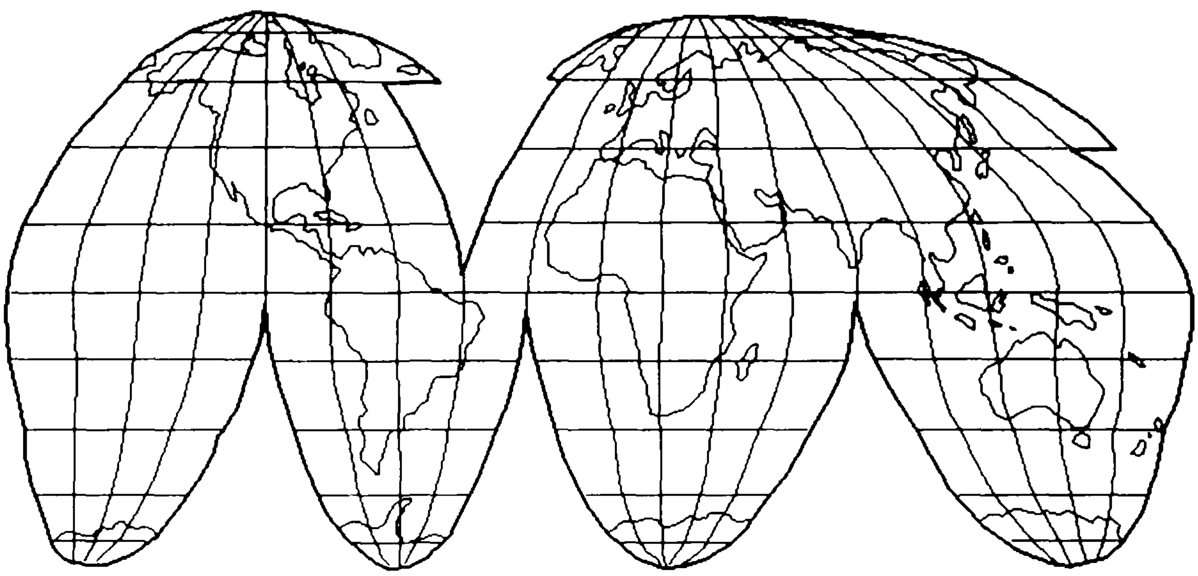
Fourth Annual Ecological Quality Assurance Workshop



EPA/600/R-92/097
February 1992

National Water Research Institute
Burlington, Ontario, Canada

Sponsored by:

U.S. Environmental Protection Agency
Environmental Monitoring Systems Laboratory
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Cincinnati, Ohio, U.S.A.

Environment Canada
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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
ANDREW W. BREIDENBACH ENVIRONMENTAL RESEARCH CENTER
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EXECUTIVE SUMMARY

The first annual Ecological Quality Assurance Workshop sponsored by the Environmental Research Laboratory in Corvallis was held in Denver, Colorado in 1988 for the purpose of providing a forum for exchange of information among scientists from government, academia, and the private sector in the United States and Canada on the use of quality assurance principles and quality control techniques in the design and conduct of ecological studies. Since then, each year the Organizing Committee has endeavored to improve the workshop format and attract a larger and more diverse audience. Consequently, attendance at the workshop has grown from 40 participants in 1988 to nearly 80 at this fourth workshop.

This year, the Ecological Quality Assurance Workshop was held at the U. S. Environmental Protection Agency's Andrew W. Breidenbach Environmental Research Center in Cincinnati, Ohio on February 26-28, 1991. The Workshop provided a forum for scientists to discuss applications of statistical tools, data quality objectives, and other quality assurance concerns in the context of ecological research. The Workshop agenda included plenary sessions, in which invited papers were presented, and workgroup sessions, which provided an opportunity for participants to discuss their experiences with specific quality assurance applications in the areas of aquatic, terrestrial, and atmospheric monitoring programs.

The Organizing Committee for this fourth workshop expected to advance ecological research from a quality assurance standpoint by creating an environment in which scientists would be encouraged to share their experiences and guidance in a format that can be passed on to others. Speaking for the Organizing Committee, USEPA's Dr. James Lazorchak, stated that "the principal goal for this fourth workshop was to develop guidelines for application of statistical tools and data quality objectives in ecological research for use by scientists in the U.S. and Canada." Dr. Lazorchak noted that this goal was an ambitious one largely because the concepts involved are so new. He emphasized that the broad goals for the workshop were secondary in importance to the experience gained by workshop participants as they worked through the processes of statistical study designs and setting data quality objectives.

Plenary Sessions

Ten invited papers were presented during two plenary sessions. Nancy Wentworth, newly appointed Director of USEPA's Quality Assurance Management Staff, provided the keynote address on the principles of total quality management in ecological research. Other papers presented by authors from both the U.S. and Canada addressed specific applications for data quality objectives, statistical tools in ecological monitoring and comprehensive quality assurance programs for environmental monitoring. One noteworthy paper addressed applications of quality assurance concepts developed at the Third Ecological Quality Assurance Workshop to an aquatic monitoring program. Finally, a paper entitled "Ecological Survey of Land and Water in Britain" by John Peters of the United Kingdom Department of the Environment, Rural Affairs Directorate, was presented as a poster display because world events prevented Mr. Peters from attending the workshop. Mr. Peters' paper is included in its entirety in these proceedings.

Workgroup Sessions

Workgroup sessions on applications of statistical tools and the data quality objectives development process were offered in three areas: aquatic monitoring, terrestrial monitoring, and atmospheric monitoring. All workshop participants attended one session each on statistical tools and data quality objectives, for the area of their choice. Each session was led by a scientist with special expertise in the subject area. Although the specific formats for the workgroup sessions varied at the discretion of the individual leaders, each generally provided for examining the topic through specific case studies and allowed the participants to draw from their own experiences in solving problems encountered by others. Ample opportunities were provided for participants to bring problems that they have encountered in their own research before their peers to obtain guidance and assistance. At the conclusion of the workshop, each workgroup leader presented conclusions and recommended guidelines for the topic derived from the discussions.

Although each workgroup session examined different monitoring problems and applications, some common themes were evident in the conclusions and recommended guidelines offered by the workgroup leaders. These included:

> ***The advantages of making a statistician an integral part of the study design team.*** Statistical tools were recognized by the workshop as a fundamental building block of sound monitoring program design. Participants agreed that, irrespective of the type of program or its purpose, ensuring appropriate use of statistical tools by consulting very early with a qualified statistician, experienced in environmental survey design, substantially increases the likelihood that the eventual design will successfully and reliably answer the research question or questions.

The importance of conducting pilot studies to assist in designing full-scale monitoring programs. Pilot studies were cited in all workgroup sessions as a valuable tool for developing stratified sampling schemes, ensuring representative sampling, and refining the investigator's conceptual model for the ecosystem. Although most recognized that historical data can be used for similar purposes, there was general agreement that the reliability of historical databases is generally not known. Only through a well-designed pilot study can a researcher be assured of obtaining initial information regarding temporal and spatial variability needed for full-scale design.

The limitations of existing ecological data. Workshop participants cited a universal lack of quality control information as an important limitation in the existing body of ecological data and recognized that this condition has generally resulted from the fact that ecologists are not usually trained in quality assurance and statistics beyond an introductory level. Moreover, workshop participants recognized that budgetary and schedule constraints have acted to limit the utility of data collected in the past and continue to restrict study designs today. Consequently, the workgroup leaders agreed that, in conducting ecological research, scientists should attempt to collect as much useful information as is practical while in the field.

With regard to use of the data quality objectives process in ecological monitoring, workgroup participants generally agreed that the process provides a framework for negotiating a study design, particularly where many interested parties and perspectives must be satisfied. The workgroup leaders recommended that effective communications and a willingness to accept input from all perspectives on the part of scientists are critical to the success of the data quality objectives process. They also recognized that scientists should not expect to anticipate the full range of concerns and confounding factors that must be accounted for at the start of a study. Consequently, the data quality objectives process should be viewed as a dynamic process that begins in the initial phases of study design and continues throughout the study, as the initial questions to be answered are re-examined and refined based on experience and the investigator's growing understanding of the ecosystem.

The Fifth Annual Ecological Quality Assurance Workshop is planned for the winter of 1992 and will be held in Canada. The organizing committee plans to develop an agenda that builds on the results of this year's workshop and continues to develop practical guidelines for application of quality assurance concepts in ecological research. For information concerning the Fifth Workshop, contact Mr. Robert Graves, U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory - Cincinnati, 26 W. Martin Luther King Drive, Cincinnati, Ohio 45268; or Mr. Robert Bisson, Environment Canada, 867 Lakeshore Road, P.O. Box 5050, Burlington, Ontario L7R 4A6, Canada.

ABSTRACT

The Fourth Annual Ecological Quality Assurance Workshop was held at the U.S. Environmental Protection Agency's Andrew W. Breidenbach Environmental Research Center in Cincinnati, Ohio, February 26 - 28, 1991. Manuscripts of invited papers and reports of workgroup discussions, conclusions and recommendations are presented in this proceedings document.

The purpose of this workshop was to provide a forum for interdisciplinary exchange of ideas and resolution of issues associated with quality assurance (QA) in ecological studies. The workshop served to bring together international representatives from both government, academia and the private sector to discuss ways of improving the quality of ecological studies. The papers and workgroup sessions were designed to meet the following goals:

1. To foster the development of ecological QA concepts.

2. To foster the exchange of ecological quality management concepts and techniques, along with their integration into ecological studies.

3. To assess the effectiveness of these activities in improving the quality of ecological studies.

Workgroup topics centered on (1) the development of guidelines for use of data quality objectives (DQOs) in field monitoring programs, and (2) the development of guidelines for use of statistical tools in field monitoring programs. Participants in the workgroups (workgroups were organized by ecological disciplines: terrestrial, aquatic and atmospheric) were invited by their respective group leader to identify and develop consensus views on important elements in the application of DQOs and statistical tools to environmental field monitoring. Each workgroup presented a brief summary of its discussions in a plenary session held on the last day.

Workgroup presentations covered a broad spectrum of QA topics; ranging from total quality management, DQOs and statistical concepts to particular QA problems encountered by specific programs.

ACKNOWLEDGMENTS

The Organizing Committee for this Fourth Ecological Quality Assurance Workshop included Dr. James Lazorchak and Mr. Robert Graves, of the U.S. Environmental Protection Agency's Environmental Monitoring Systems Laboratory, Mr. Robert Bisson and Mr. John Lawrence of the Canadian National Water Research Institute, Mr. Craig Palmer of the University of Las Vegas, and Ms. Lora Johnson of Technology Applications, Inc. The Committee wishes to acknowledge the efforts of Ms. Johnson, who supervised the workshop logistics, Mr. Dennis M. McMullen of Technology Applications Inc., who assisted with planning the workshop, and Ms. Allison Cook, Mr. John Willauer, Mr. Michael Guill, and Mr. Michael Piehler, all of AScI Corporation, who served as rapporteurs for the workgroup sessions. These proceedings were prepared by Ms. Jan Edwards, of Edwards Associates, Falls Church, Virginia, with assistance from Ms. Johnson and AScI Corporation of McLean, Virginia.

CONTENTS

FOURTH ANNUAL ECOLOGICAL QUALITY ASSURANCE WORKSHOP

PLENARY SESSION A

Wednesday, February 26, 1991

OVERVIEW OF TOTAL QUALITY MANAGEMENT IN ECOLOGICAL MONITORING

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ABSTRACT

The mission of the U. S. Environmental Protection Agency (USEPA) is to make decisions that protect or enhance the quality of the Nation's environment. Most of these decisions are based on environmental data. The USEPA quality program uses the principles of Total Quality Management (TQM) to improve the efficiency and effectiveness of the Agency's environmental data operations.

The essential principles of a Total Quality Management program include:

- **Customer focus**
- **Focus on PROCESS as well as results**
- **Prevention versus inspection**
- **Mobilization of workforce expertise**
- **Senior management commitment and involvement**
- **Feedback**

This presentation will outline the principles of TQM in detail and will show how they can be applied to ecological monitoring.

INTRODUCTION

Over the years, the USEPA has been challenged to quantify the effect of pollution on the environment. These efforts have largely been directed at determining the impact of a single pollution source (or group of sources) on a limited geographical area, or at estimating the net change in discharge resulting from the imposition of regulatory controls across the country. Due to these limitations in scope, the studies have not generated data that could be used to assess the overall condition of the environment, or measure the changes in environmental quality over long periods of time.

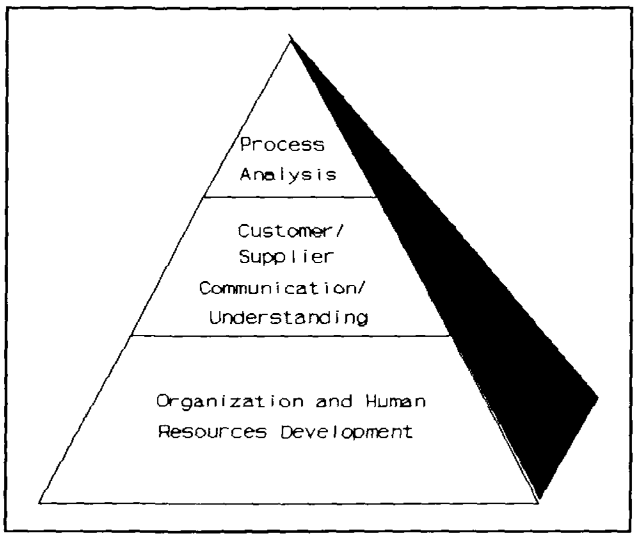
In his speech at the National Press Club in September 1990, USEPA Administrator William Reilly noted that the historical guiding principle for developing environmental policy has been the "ready - fire - aim" approach. That is, with each new environmental concern came a new regulatory program, usually requiring expensive control measures, that were not coordinated with the control measures developed in response to some previous crisis. To quote Administrator Reilly:

> "Rarely did we evaluate the relative importance of individual chemicals or individual environmental media. We didn't assess the combined effects in ecosystems and human health from the total loadings of pollutants deposited in different media, through separate routes of exposure, and at various locations. We have never been directed by law to seek out the best opportunities to reduce environmental risks, in toto, not to employ the most cost efficient, cost effective ways of proceeding." (Aiming Before We Shoot, The Quiet Revolution in Environmental Policy)

The Administrator has recognized that there is a continuum in the environment that cannot be managed piecemeal. Also, without understanding how the environment has been affected by pollutants, the Agency cannot make the most efficient and cost effective decisions. The principles of Total Quality Management (TQM) can assist in improving these decision making processes.

THE EVOLUTION OF TOTAL QUALITY MANAGEMENT

After World War II, the Japanese saw a clear need to improve the quality of their products to gain acceptance in world markets. With help from W. Edwards Deming and others, they recognized that process analysis and understanding were keys to improving product quality. "Made in Japan" in 1950 was a joke; "Made in Japan" in the 1990's has a totally different meaning. The outstanding success enjoyed by the Japanese, beginning in the 1950's, was the first major milestone in the modern quality movement.



Once quality practitioners became adept at integrating process analysis into their operations, the next step in the evolution of quality programs was the focus on customers -- more specifically, the realization that customers had explicit needs, that could be defined, accepted in advance, and then met. This focus on customer-supplier understanding moved away from the historical practice of designing a product and then persuading the market that the product met its need. This new philosophy required the customer and supplier to achieve mutual understanding by collaborating in defining exact specifications for the product (or service), and developing measures designed to assure that the product/service would meet the defined specifications.

More recently, organizations which have achieved success through process analysis and customer-supplier communication have come to realize that there is a third vital dimension to TQM implementation. Cutting-edge practitioners now place great emphasis on human resources and organizational development. Recognizing that all levels of the workforce have much to contribute to the process, they have created tools and techniques to channel that expertise and enthusiasm. The workforce represents a tremendous wealth of knowledge and opportunity to improve the way business is done. Who knows better how a process operates than someone who has ten years experience "on the floor?" Involving the workforce in decision making can remove barriers to implementation of new procedures, because the workforce may well have suggested them!

Associated with workforce empowerment is a clearer focus on the organization itself. By analyzing the organization as a culture undergoing change, TQM practitioners can dramatically increase the likelihood that the TQM philosophy will take hold and bring solid and lasting improvements.

THE PRINCIPLES OF TOTAL QUALITY MANAGEMENT

Each of the Quality masters (Deming, Juran, Crosby, Ishikawa, etc.) has a slightly different approach to defining and achieving quality. There are, however, a number of recurrent principles in the literature. These essential principles of a Total Quality Management program include:

- Customer focus
- Focus on PROCESS as well as results
- Prevention versus inspection
- Mobilization of workforce expertise
- Senior management commitment and involvement
- Fact-based decision making
- Feedback

Customer Focus

The customer for a product, be it a widget or environmental data, must be defined, and queried about the proposed use of the product. Unless there is clear communication and understanding of needs and expectations, there is significant risk that the completed product will not meet the customer's need, and may require rework, at additional expense in dollars, time, and (in the case of environmental data) possible political concern about exposure to potentially dangerous conditions.

Focus on Process as Well as Results

Process understanding is critical to the efficient and effective use of resources. In environmental data collection, a focus only on results may lead to inefficiency in design, superfluous data, data of an inappropriate quality, etc. The focus on process leads to an application that provides the right product, at the right time, for the right price. An example of a process that ensures that the right data are collected will be presented later in this document.

Prevention Versus Inspection

Quality cannot be "inspected in." Quality must be considered from the very beginning of any process design. If the customer and supplier have agreed on the product and the performance measures for the product, then appropriate processes can be created to ensure that those performance measures are achieved. This allows the quality to be designed, not inspected in. Inspection discovers defects and deficiencies after the resources have been expended, and then requires rework, at additional expense in both time and money.

Mobilization of Workforce Expertise

The workforce has an immense knowledge of their areas of responsibility. This knowledge is available "for the asking" by managers who realize that the answers to many of the questions regarding quality and production rest with the workers. The workers appreciate recognition of their knowledge and value to the organization, and can provide very important insights into any process evaluation.

Senior Management Commitment and Involvement

Change cannot occur within a system unless the highest management supports the change. The implementation of TQM is, in many organizations, a significant change that requires funding (for training, etc.), time (to define processes and establish feedback mechanisms), and a continual push to assure that there is not a return to the "old ways" of doing business. Only senior managers can assure that the money, time, and attention are devoted to understanding and improving their organizations.

Fact-Based Decision Making

Having the right information available for decision making is not always easy. It requires understanding the process, understanding the cause of problems, having the skills to obtain the information needed to define and correct the problems (e.g., team-building, communications, etc.), and having the opportunity to use facts, not innuendo, in decision making. This focus on facts, not individuals, moves TQM further from the historical "blame-based" operation to one in which everyone is seeking solutions, not assigning blame.

Feedback

Feedback provides the foundation for TQM -- it is the single TQM principle that allows the others to work. Feedback is the means by which organizations learn whether they have accomplished their goals. It provides information on the success of planning and implementation, whether the client's needs were met in the agreed upon manner, etc.

TQM IN ECOLOGICAL MONITORING

Perhaps the most difficult step in any environmental monitoring program is defining the "customer." Environmental monitoring is not a "production process" in the sense of manufacturing; it is a process whose product is information for use in decision making. Therefore, the "customer" may more correctly be called a data user or decision maker. The decision maker may be an official of the USEPA or another Federal agency, a state program manager, the Congress, etc. For purposes of this presentation, it is assumed that USEPA is the decision maker for the ecological monitoring.

For ecological monitoring, the most urgent quality issue is the establishment of effective communication between the decision maker and the "suppliers" (or data collectors) to define the purpose of the data collection and the measures of its success. In the absence of this dialogue, data collectors are likely to aim for the "best" data that a laboratory analytical procedure can provide within budget, even when non-laboratory sources of error are more important. They are also highly likely to collect data which will not be responsive to the user's true needs, and which are not ultimately suitable for decision making.

Total Quality Management principles point to the solution to this dilemma. A TQM-based approach would lead to a consideration of the following questions during the planning stage of an ecological monitoring program:

- Why do we want to collect data?
- What data do we need?
- To what uses do we expect to put the data/what decisions will be made?
- How much uncertainty are we willing to accept in decisions based upon these data?

While these questions seem straightforward, they are often difficult to answer, especially for a broad monitoring effort which is not directly linked to a specific regulatory program. It is certain that they cannot be addressed intuitively or haphazardly. What is required is a structured TQM planning process which assures effective communication and thorough consideration of the issues before data collection commences.

Initial input must come from the customer/decision maker, who must describe the problem, the specific questions to be answered with data, and anticipated boundaries on the data collection program. It is reasonable to expect that the decision maker will be able to articulate some of these points only in a general sense. In most cases, he/she requires help in specifying the problem, the desired decision, and the data needs. The data collector should work with the decision maker by presenting descriptions of the problem and possible approaches.

Effective communication at the planning stage will assure that the customer states and knows what he/she needs, and that the supplier understands specifically what the customer needs. A false start at this stage will waste valuable time and money. Without this communication, the supplier will likely go off in a direction of limited ultimate value to the customer.

As planning continues, the principal focus now shifts to the supplier. The supplier works with the decision maker's input to establish qualitatively how comfortable the decision maker is with arriving at wrong decisions (these could be called discomfort levels). Next, the supplier develops a formula for decision-making that defines how the different elements of the decision are to be combined. Finally, the supplier converts the decision making formula and the discomfort levels into performance measures that

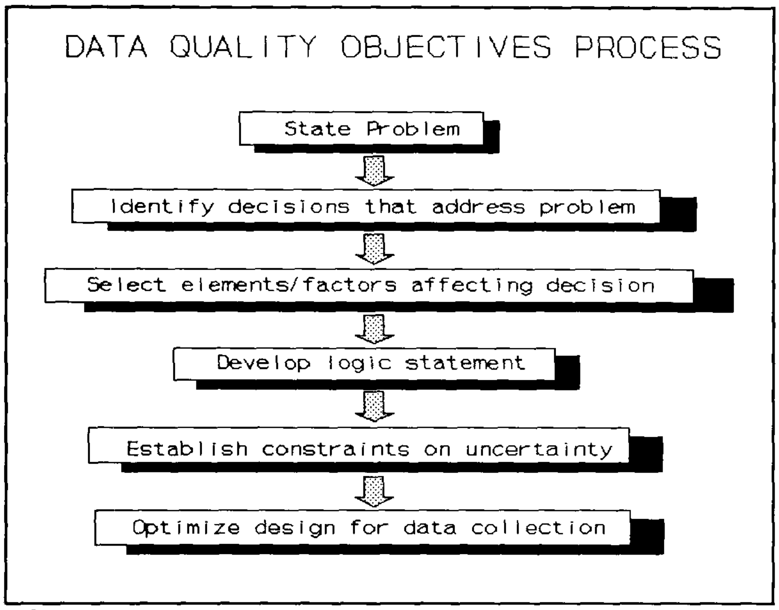


Figure 2. The DQO process includes a comprehensive set of steps in a logical sequence.

establish the constraints on the design for producing the required product.

The preceding discussion is a brief overview of the Data Quality Objectives (DQO) process, a TQM tool devised by the Quality Assurance Management Staff for guiding the planning stage of environmental data operations. The DQO process is a tool for handling complex issues related to ecological monitoring in a structured and effective fashion. It embodies the basic principles of TQM as follows:

CUSTOMER FOCUS - The DQO process brings the customer's needs to the forefront, assures constructive dialogue between customer and supplier, and establishes specific performance measures for gauging whether the customer's needs have been met.

FOCUS ON PROCESS AS WELL AS RESULTS - Too often, the decision maker's message to data collectors amounts to: "Just get me good data!" This is an invitation to confusion, inefficiency, and rework. The DQO tool compels a focus on the planning process, thereby enhancing program effectiveness and credibility.

PREVENTION VERSUS INSPECTION - The aim of the DQO process is to do the right thing, the right way, the first time. Data quality assurance programs which emphasize review over planning simply detect mistakes instead of preventing them.

MOBILIZATION OF WORKFORCE EXPERTISE - The traditional approach to data collection does not take sufficient advantage of the expertise of technical staff. Lacking an adequate understanding of management's perspectives and needs, they are compelled to operate by standard procedure or best professional judgment, not on the basis of specific programmatic needs. The DQO process, by contrast, is designed to create maximum involvement and understanding on the part of technical staff.

SENIOR MANAGEMENT COMMITMENT AND INVOLVEMENT - Often, senior managers do not play a meaningful role in planning data collection programs, because their management and policy perspectives are not readily translated into technical terms. The DQO process does exactly that, leading to refinement and quantification of the manager's qualitative input.

FACT-BASED DECISION MAKING - The Data Quality Objectives process is a highly effective decision management tool. It helps managers to analyze decisions and bring to bear exactly those data needed to address them. Thus it clarifies and enhances the role of environmental data in Agency decision making.

FEEDBACK - One of the strengths of the DQO process is that it facilitates feedback among all those involved in planning -- managers, technical staff, statisticians, etc. The process is designed to be iterative, to incorporate feedback as planning proceeds, thereby producing a much stronger and more thoughtful plan.

CONCLUSION

This paper has provided an overview of the principles of Total Quality Management, and has described how these principles apply to one TQM tool highly relevant to ecological monitoring -- the Data Quality Objectives process. The Quality Assurance Management Staff has also developed other TQM tools which can benefit ecological monitoring program managers. For instance, process flow modelling has proved highly effective in pinpointing opportunities for process improvement.

Total Quality Management is a proven winner which can bring continuous improvement to ecological monitoring programs. We on the Quality Assurance Management Staff will be happy to provide additional information and support to anyone interested in further exploration of these tools.

NATIONAL PESTICIDE SURVEY DATA QUALITY OBJECTIVES: EVALUATION AND RESULTS

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ABSTRACT

EPA's National Survey of Pesticides in Drinking Water Wells (NPS) is the Agency's most extensive monitoring survey for pesticides, pesticide degradates, and nitrate in the United States. Results of the Survey, recently released in the Phase I Report, complete several years of planning and implementation. The Survey specified qualitative and numerical data quality objectives (DQOs) in its design phase. This paper reviews these objectives, explains their development and testing, evaluates the Survey's success in attaining its DQOs, and provides recommendations for future data collection efforts. Specific topics discussed are: (1) explaining the development of numeric precision objectives for survey estimates; (2) identifying data requirements and data elements; (3) analyzing alternative survey designs; (4) comparing objectives and statistical performance of the NPS; and (5) evaluating the role of costs, detection limits, and number of samples in meeting DQOs.

INTRODUCTION

"Did the study answer the question?" "How confident are we in the data?" "Are the data useful for directing policy decisions?" -- all typical questions asked during the final phases of environmental studies. If the answers are unsatisfactory, both scientists and policy makers may find themselves in the unfortunate position of wishing they had designed the study somewhat differently. To prevent this situation from occurring, the U.S. Environmental Protection Agency in 1984 formalized a planning process by which Agency decision makers and scientists interact to reach a consensus on design and implementation issues taking into consideration the limitations of both measurement technology and finite resources (monetary, personnel, physical plant, etc.). As described by Nees, et al. (1988), this process known as the Data Quality Objective (DQO) process, was applied to the National Pesticide Survey (NPS), a complex survey sponsored by the EPA's Office of Water and Office of Pesticides and Toxic Substances to provide statistically valid national estimates for the occurrence of 126 pesticides and pesticide degradates, and nitrate/nitrite in private and community drinking water wells. The purpose of this paper is to review the original DQOs and evaluate the Survey's performance in relation to them.

SURVEY DESIGN AND RESULTS

A detailed description of the Survey can be found in the NPS Phase I Report (EPA, 1990). Only those basic aspects of the design necessary for discussing the Survey DQOs will be presented here. The Survey, which spanned the years 1984-1991, used a three stage stratified design from which more than 1300 wells were selected for sampling using probability based sample selection techniques. First stage stratification variables were ground-water vulnerability measured using a modified DRASTIC scoring method (Alexander, et al, 1986), and pesticide use determined from Doane marketing data and other sources. Exhibit 1 shows the 12 first stage strata which were used to classify all counties in the U.S.

The NPS was conducted as two separate surveys, one for community water system (CWS) wells, and one for rural domestic wells. For the rural domestic well survey only, ninety counties were selected at the first stage and wells were further stratified at the second stage using an index that combined information from subcounty DRASTIC scores and information on cropping intensities. Areas within each county were defined by this index as "cropped and vulnerable".

The goal of a stratified design is to increase sampling efficiency over simple random sampling by grouping sampling units that are expected to have similar characteristics. Sampling rates can then be adjusted to account for differences in variability between the groups, i.e., a group in which more variability is anticipated would require a larger sample size in order to achieve the same level of precision in the data. The NPS chose a stratified design believing that differences in hydrogeologic conditions and pesticide use would affect the number of wells with detectable levels of pesticides and to provide control of sample sizes within strata.

Results of the Survey indicate that about 10 percent of the approximately 95,000 CWS wells in the country can be expected to contain at least one of the 126 pesticides and pesticide degradates included in the NPS. For the approximately 10.5 million rural domestic wells, at least one detectable pesticide can be expected in about 4 percent of the wells. Initial results of the NPS are available in the NPS Phase I Report.

Exhibit 1: FIRST STAGE OR COUNTY-LEVEL STRATIFICATION CELLS

Vulnerability	Pesticide Use			
	High	Moderate	Low	Uncommon
High	1	4	7	10
Moderate	2	5	8	11
Low	3	6	9	12

DISCUSSION OF DQOs

One of the goals of the DQO process is to develop quantitative statements about the level of confidence needed to answer the question(s) prompting the study. The two major goals of the NPS were:

- To determine the frequency and concentration of the presence of pesticides and nitrate in drinking water wells nationally; and

- To examine the relationships of the presence of pesticides and nitrate in drinking water wells to patterns of pesticide use and ground-water vulnerability.

During the Survey development, EPA analyzed numerous alternative designs, sample sizes, and data collection activities to meet these goals. The Agency evaluated acceptable alternative precision estimates for the study domains and estimated costs of the Survey. Survey costs were largely a function of the number of wells to be sampled. Exhibit 2 shows the final DQOs established for the Survey.

For the NPS, DQOs were stated as precision requirements to determine the proportion, or equivalently, the frequency, of the presence of pesticides in drinking water wells nationally. DQOs were not specified for the presence of nitrate, in terms of pesticide or nitrate concentrations, nor in terms of relationships between pesticide or nitrate presence and patterns of pesticide use and ground-water vulnerability. The Survey did not explicitly include final reporting limits for the chemical analysis of the water samples in determining these objectives, but were implicitly included through the assumed detection rates. These topics and their implications will be discussed at greater length in a later paper.

The NPS precision requirements were stated for several different well categories, called domains, as shown in Exhibit 2. For the CWS well survey two domains were defined: all wells nationally, and wells in counties with high ground-water vulnerability. For the rural domestic well survey, five domains were defined: all wells nationally, wells from high pesticide use counties, wells located in counties with high ground-water vulnerability, wells located in "cropped and vulnerable" areas within counties, and wells located in counties with both high pesticide use and high ground-water vulnerability.

Exhibit 2: PRECISION REQUIREMENTS FOR THE NPS

DOMAIN	Detection Rate *p*	Relative Standard Error *RSE(p)*	Detection Probability *DP(p)*
CWS: National	0.005	0.658	0.90
CWS: High Ground-Water Vulnerability	0.005	1.040	0.60
Domestic: National	0.01	1.00	0.63
Domestic: High Pesticide Use	0.01	0.85	0.75
Domestic: High Ground-Water Vulnerability	0.01	0.85	0.75
Domestic: "Cropped & Vulnerable"	0.01	0.525	0.97
Domestic: High Pesticide Use & High Vulnerability	0.01	1.25	0.47

In essence the precision requirements for each domain correspond to the *a priori* expected proportion of contaminated wells (detection rate), together with the associated variance of that proportion. Variances were equivalently stated in terms of relative standard errors, detection probabilities, and confidence intervals. The detection rates and their variances were then used to calculate the necessary minimum sample size that would achieve that level of precision in the NPS estimates. In practice the precision requirements were stated conservatively to provide further assurance of an adequate sample size.

The Survey used disproportionate sampling (i.e., oversampling) in the high vulnerability strata, cells 1, 4, 7, and 10 in Exhibit 1, and the "cropped and vulnerable" strata, to increase the expected number of drinking water wells containing pesticides and to allow separate estimates for the specified domains. Proportionate stratification, with stratum sample sizes made proportionate to stratum population sizes, was expected to yield an insufficient number of detections. EPA was particularly interested in estimating pesticide occurrence in areas of agricultural pesticide use and areas vulnerable to ground-water contamination.

As an example of how to interpret the DQOs or precision requirements, consider the CWS national domain in Exhibit 2. Survey planners assumed that a conservative estimate of the proportion of wells nationally that would have at least one pesticide detection was 0.005, and at least a 90 percent chance of detecting at least one pesticide or pesticide degradate in at least one sampled well was required. In the underlying statistical model the detection rate, 0.005, corresponds to a Binomial proportion, and the detection probability, 90 percent, is a function of the detection rate and its variance. The relative standard error (0.658 in this case) is also a function of the detection rate and its variance and provides an alternative, though equivalent, characterization of the underlying model. Confidence intervals were also calculated as part of the original DQOs but are not presented here[1]. The mathematical relationships between these quantities are presented at the end of this paper.

Three major points of interest concerning the NPS precision requirements are shown in Exhibit 2:

- The constant assumed rate of detection across CWS well domains (0.005) and across rural domestic well domains (0.01);

- The relatively high detection probability (0.97) for the "cropped and vulnerable" domain in the rural domestic well survey; and

[1]Confidence intervals presented as part of the original DQOs were based on a normal distribution approximation to the Binomial distribution. This approximation is not valid for the extremely small proportions (detection rates) assumed for the NPS.

- The higher assumed rate of detection for rural domestic well domains (0.01) than for CWS well domains (0.005).

The first point on its own seems contrary to the need for oversampling, i.e., detection rates in each survey were not specified to be greater in some strata (e.g., counties with high vulnerability) than others. The overriding consideration, however, was that each detection rate was stated conservatively to further ensure adequate sample sizes. The second point translates into a larger sample size requirement for the "cropped and vulnerable" domain which corresponds to oversampling of that domain. This reflects EPA's desire to ensure the most precise estimates for the "cropped and vulnerable" domain.

The third point concerns the quality of the information on which the precision requirements were based. The precision requirements state that the proportion of detections expected in the rural domestic well survey was double the proportion expected in the CWS well survey. The survey results demonstrate the opposite effect. Furthermore, Survey results do not indicate a greater proportion of detections in the subdomains than in the national domains. This brings into question the benefits of the stratification. Effective stratification resulting from high quality information reduces the variance of sample estimates, but ineffective stratification results in loss of performance and possible confounding of results.

The sample allocation procedure used to compute the sample sizes presented in the first column of Exhibit 3 involved a complex optimization procedure that simultaneously calculated sample sizes for the domains. This procedure was performed separately for the two surveys. The optimization procedure accounted for the precision requirements and the cost estimates for each stage of the sampling process. Although the optimization procedure accounted for all domains simultaneously, the sample allocation results were driven mainly by the cost constraints and the domains for which the lowest variance, or highest detection probability, was specified (i.e., the "cropped and vulnerable" domain in the rural domestic well survey and the national domain in the CWS well survey).

Referring to Exhibit 3, the comparison between achieved and specified sample sizes can be made by examining their ratio, termed completeness. With the exception of the "cropped and vulnerable" domain of the domestic well survey, all values for completeness were greater than 95 percent which, considering its complexity, suggests that the Survey was implemented in accord with the design specifications. The low achieved sample size for the "cropped and vulnerable" domain in the rural domestic well survey was largely due to a reduction in the oversampling rate that occurred between the initial sample design and the start of the implementation of the Survey. The initial oversampling rate was reduced to avoid problems associated with wells having high survey weights which could have dominated analysis of the survey data.

EVALUATION OF DQOs

Several approaches can be used to evaluate the DQO requirements. The most transparent measure of the success of the Survey in meeting the requirements of the DQOs is to compare achieved domain variances with the initial variance specifications. As can be seen through the detection probabilities or relative standard errors in Exhibit 4, these indicators of survey performance show that the Survey exceeded the variance specifications in all domains. However, the driving force behind the performance of the Survey, measured in these terms, is the higher than expected detection rates.

Exhibit 3: COMPARISON OF DESIGN AND ACHIEVED SAMPLE SIZES

DOMAIN	SAMPLE ALLOCATION	ACHIEVED SAMPLE SIZE	COMPLETENESS
CWS: National	564	540	96
CWS: High Ground-Water Vulnerability	203	197	97
Domestic: National	734	752	102
Domestic: High Pesticide Use	200	217	108
Domestic: Highly Ground-Water Vulnerability	254	264	104
Domestic: "Cropped & Vulnerable"	463	343	74
Domestic: High Pesticide Use & High Vulnerability	79	83	105

Exhibit 4: COMPARING DESIGN SPECIFICATIONS AND SURVEY RESULTS

DOMAIN	DESIGN SPECIFICATIONS			ACHIEVED RESULTS		
	p	$RSE(p)$	$DP(p)$	p^*	$RSE(p^*)$	$DP(p^*)$[a]
CWS: National	0.005	0.658	0.90	0.104	0.14	1.00
CWS: High Ground-Water Vulnerability	0.005	1.040	0.60	0.093	0.24	1.00
Domestic: National	0.01	1.00	0.63	0.042	0.23	1.00
Domestic: High Pesticide Use	0.01	0.85	0.75	0.036	0.47	0.99
Domestic: High Ground-Water Vulnerability	0.01	0.85	0.75	0.028	0.50	0.98
Domestic: "Cropped & Vulnerable"	0.01	0.525	0.97	0.055	0.32	1.00
Domestic: High Pesticide Use & High Vulnerability	0.01	1.25	0.47	0.014	1.10	0.56

[a] - Detection probabilities are reported to two decimal places. Values reported as 1.00 correspond to values greater than 0.995, but less than 1.00

The *design effect* offers a simple *post hoc* summarization of the complex modeling process. The design effect can be used to calculate an *effective sample size* that corresponds to the sample size that would be required to produce equivalent survey precision under simple random sampling (assuming the same detection rates). For a simple random sample the weights are the same, hence the design effect is equal to one.

Design Effect, *d*:

$$d = \frac{n \sum_{i=1}^{n} W_i^2}{\left(\sum_{i=1}^{n} W_i \right)^2}$$

Effective sample size, n':

$$n' = \frac{n}{d}$$

where n is the sample size achieved by the survey, and the W_i are the survey weights associated with each sampled well. Exhibit 5 provides the design effect, achieved sample size, and the effective sample size for each domain of the Survey.

Another way to evaluate survey performance is to compare the achieved effective sample size to the sample size that would have been allocated to each domain separately under simple random sampling given the precision requirements. A comparison between columns 2 and 3 of Exhibit 6 indicates that for most domains the sample allocation was adequate using this method. The exception is the "cropped and vulnerable" domain in the rural domestic well survey where approximately twice the number of observations would be required under simple random sampling to satisfy the precision requirements. Assuming a design effect of 2.06 (see Exhibit 5) for the "cropped and vulnerable" domain, the number of observations required to satisfy the precision requirements for detection rates and variance is 740. This calculation does not account for cost constraints.

The "cropped and vulnerable" domain is a subset of the national domain. A requirement of 740 observations for the "cropped and vulnerable" domain results in a requirement for substantially more observations for the rural domestic well national domain. In terms of population characteristics the "cropped and vulnerable" areas comprise approximately 35 percent of rural domestic wells nationally (see the NPS Phase I Report). Allowing for the revised rate of oversampling of "cropped and vulnerable" areas

(3:1), this implies a sample size nationally of about 1,200 wells. By this measure the sample allocation procedure underestimated the number of samples required to achieve the precision requirements, but as the observed detection rates were substantially greater than those specified in the precision requirements, the Survey appeared to perform well.

This procedure mixes aspects of the sample allocation procedure and survey results to evaluate survey performance. Using this approach it is clear that all NPS domains fell within precision requirements because the proportion of wells that had a detectable pesticide was much higher than assumed during the design stage, but the specified detection rates were stated conservatively to encourage an adequate sample size.

Exhibit 5: DESIGN EFFECT AND EFFECTIVE SAMPLE SIZE

DOMAIN	Design Effect *(d)*	Sample Size *(n)*	Effective Sample Size *(n')*
CWS: National	1.27	540	425
CWS: High Ground-Water Vulnerability	1.16	197	170
Domestic: National	1.84	752	409
Domestic: High Pesticide Use	1.77	217	123
Domestic: High Ground-Water Vulnerability	1.91	264	138
Domestic: "Cropped & Vulnerable"	2.06	343	167
Domestic: High Pesticide Use & High Vulnerability	1.44	83	58

Exhibit 6: COMPARISON OF ALTERNATIVE SAMPLING METHODS

DOMAIN	Achieved Sample Size	Effective Sample Size	Sample Allocation Under SRS	SRS Sample Allocation Adjusted for Design Effect
CWS: National	540	425	459	583
CWS: High Ground-Water Vulnerability	197	170	183	212
Domestic: National	752	409	99	182
Domestic: High Pesticide Use	217	123	137	242
Domestic: High Ground-Water Vulnerability	264	138	137	262
Domestic: "Cropped & Vulnerable"	343	167	359	740
Domestic: High Pesticide Use & High Vulnerability	83	58	63	91

IN RETROSPECT

The Agency is preparing an extensive analysis of Survey results (NPS Phase II). Final conclusions about the Survey design await release of the study. Preliminary conclusions, however, concerning the final design and the DQO process are appropriate. First, the data quality objectives were satisfied, but largely because the Survey used conservative assumptions (i.e., detection rates). Second, DQOs did not address other analytical and modeling questions that Survey data will be used to answer. Third, the benefits of stratification for the Survey are not obvious. Detection rates among the domains are not very different.

The Survey goals, to provide baseline and modeling data over a broad range of compounds, required satisfying multiple objectives and precluded specifying quantitative data quality objectives for every aspect of the Survey. The NPS reporting limits, while low enough to protect the public health and simultaneously analyze for 126 compounds, were not low enough to generate sufficient data to develop concentration occurrence curves, which would have greatly increased the utility of the study for environmental assessment purposes.

In addition, using less extensive stratification and proportionate sampling, considering the actual detection rates within each domain, would have provided the ability to allocate Survey funds for more samples which could have reduced the variance of the estimates and provided a richer database for analysis. Environmental surveys should critically evaluate the desirability of complex stratified designs using a variety of planning assumptions. Sample costs, stratification data quality, and reporting limits are key areas for intensive scrutiny in the planning and pilot test development stage.

References

Alexander, W.J, S.K Liddle, R.E. Mason, and W. B. Yeager, 1986. Ground Water Vulnerability Assessment in Support of the First Stage of the National Pesticide Survey, Research Triangle Institute, unnumbered report, 168 pp.

EPA, 1990. National Survey of Pesticides in Drinking Water Wells - Phase I Report, PB91-125765

Nees, Monica and Cynthia Salmons, 1987. National Survey of Pesticides in Drinking Water Wells, A Review of the Planning Process and the Data Quality Objectives, RTI/7801/08/01F

STATISTICAL ASSUMPTIONS AND FORMULAS

1. Detections follow a Binomial Distribution denoted *Bin(n,p)* where:

   n represents the sample size; and

   p represents the detection rate or proportion of detections nationally.

2. The variance of *p* is defined as:

$$VAR(p) = \frac{p(1-p)}{n}$$

3. <u>Relative Standard Error (RSE)</u>

$$RSE(p) = \frac{\sqrt{VAR(p)}}{p}$$

4. <u>Detection Probability (DP)</u>

$$DP(p) = 1 - [1-p]^{\theta}$$

   where θ is a surrogate for the sample size:

$$\theta = \frac{p(1-p)}{VAR(p)}$$

5. <u>Binomial Confidence Intervals</u>

   Lower bound is the value p_L that satisfies:

$$\sum_{i=a}^{\theta} \binom{\theta}{i} p_L^i (1-p_L)^{(\theta-i)} \leq \alpha/2$$

   Upper bound is the value p_U that satisfies:

$$\sum_{i=0}^{a} \binom{\theta}{i} p_U^i (1-p_U)^{(\theta-i)} \leq \alpha/2$$

If θ and *p* are large enough, the Normal distribution approximation to the Binomial distribution may be used. This is not the case for the NPS generally (because *p* is most often too small).

PLANNING APPROACHES IN CANADIAN TERRESTRIAL FIELD MONITORING STUDIES

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ABSTRACT

Over the last ten years, many terrestrial field monitoring studies were done in Canada to determine the effects of acidic deposition on the environment. Quality assurance related activities, in the early studies, were incorporated into the work and were done on an individual project basis. Only recently has QA evolved into a formalized, separately identified effort. As a result, it has only been in the last five years that Canadian terrestrial field monitoring studies have adopted a formalized QA approach to planning. This, however, does not preclude the success of the earlier studies. Indeed, early Canadian monitoring efforts were usually well planned and incorporated the necessary QA/QC criteria to provide a valuable data base. Recent terrestrial studies, however, done by the Ontario Ministry of the Environment, have benefited by greater incorporation of QA into the planning stages of the study. A formal QA plan and well documented QC protocols can strengthen a study and ensure the value of a data base for future users.

INTRODUCTION

In the late 1970's, Canada recognized the need to examine the environmental effects of the long range transport of airborne pollutants (LRTAP). Task oriented federal and provincial programmes were established to address this issue. During the next decade, many terrestrial monitoring studies began within these programmes. Most of the studies were done in Ontario, Quebec and the Atlantic provinces, where acidic deposition rates are highest.

Much of the early work was similar in design to earlier phytotoxicological studies. Previously defined and tested field and laboratory procedures were used. Other early monitoring efforts formed the terrestrial part of calibrated watershed studies which also included aquatic and depositional components. As a result, quality assurance was usually addressed on an individual project basis. The QA/QC, which often evolved from earlier studies, was incorporated into the work. The QA/QC needs and practices were reviewed and refined as the project progressed.

Formalized QA planning in environmental studies is a relatively recent phenomenon. This meant that, initially, QA was not a separately organized effort. Instead, QA was addressed as part of "good science", since many of these studies were destined for eventual publication, with associated peer review. Much of the QA/QC is available only in draft form or as internal reports generated during the studies. Most of the analytical support for these programmes was through government laboratories which often also supported several other programmes. Consequently, the laboratory QA/QC is often found in a more formalized form.

Increased emphasis on formalized QA/QC for monitoring studies began in the late 1980's for several reasons.

1. Over the last decade there was an increased awareness that a formal QA plan is helpful in ensuring the integrity of any data collected. This was especially important given the long term nature of most of the studies.

2. As studies progressed, it became clear that data quality objectives should be more accurately defined at the beginning of the study.

3. The political and economic implications of the acid rain-related effects on the environment had gained an international profile. This increased the need for data which were comparable among different agencies, provinces and countries.

4. Small projects carried out internally by two or three people, increased in size and number. As a result, parts of the field measurements, sample collection and data review were contracted to universities and the private sector.

By 1986, QA/QC initiatives began to be put in place before rather than during the study.

OVERVIEW OF TERRESTRIAL PROGRAMS IN CANADA

Table 1 shows the variety of terrestrial studies that were carried out. Many of these studies began without a QA plan or manual. Quality assurance manuals were often produced during the study. Three main types of studies can be identified: biogeochemical monitoring (intensive studies in a small area), baseline monitoring and forest assessment and decline studies.

Biogeochemical studies were located at calibrated catchments located in Kejimkujik, Nova Scotia, Montmorency, Quebec (Lac Laflamme), and in Ontario in Muskoka/Haliburton (Plastic and Harp Lakes), the Algoma area (Turkey Lakes), and the Kenora Experimental Lakes Area (ELA) (Figure 1). Smaller terrestrial monitoring studies were also undertaken near Thunder Bay, Ontario (Hawkeye Lake) and Sudbury, Ontario (High Falls). The early terrestrial work at many of these watersheds consisted of soil and vegetation characterization, and stemflow, throughfall and soil lysimeter leachate monitoring. Only the Turkey Lakes and ELA biogeochemical studies, had formal QA plans and QA manuals were developed during the studies. The Kejimkujik, Plastic, Harp and Hawkeye Lake sites did not have formal QA plans, however, for the latter three sites, QA documentation can be found in internal reports (Lozano et al. 1987, Lozano and Parton 1987, Lozano 1986, Senes Consultants 1986, Senes Consultants 1987a,b,c,d,e) and in Neary (1986). Over the years, terrestrial work at these sites shifted from monitoring to process oriented studies.

In 1980, The Ontario Ministry of the Environment began baseline monitoring. This was designed to benchmark the terrestrial system by providing information on the chemical status of soils, vegetation and lichens in the province. Quality assurance and procedural manuals for soil and vegetation monitoring were developed during the study (Neary 1986). Quality assurance for the lichen monitoring project is briefly addressed in the final report for the project (Case Biomanagement 1990). A soil variability study was also initiated as a separate pilot project to provide an estimate of the variability at specific baseline sites. This provided information on seasonal variability, sampling times and sample representativeness. Forestry Canada also conducted some baseline foliage chemical monitoring. Quality assurance activities related to foliar chemistry variability are given in journal publications (Morrison 1972, 1974, 1985). Soil sensitivity mapping for Canada was conducted by Environment Canada and for Ontario by Environment Canada and the Ontario Ministry of the Environment (Cowell 1986). These mapping efforts cannot be classified as monitoring studies, but the latter study used baseline soils data from the monitoring studies. The mapping criteria and methodology and the conceptual model used for site evaluation are listed in Cowell (1986).

Studies related to forest health in Canada began in the mid to late 1980's. Forest studies undertaken in Quebec, by the Ministère de l'Environnment and the Ministère de l'Energie et des Ressources, as well as the Canadian Forestry Service's Fundy Birch Assessment and Maple Decline study were designed with formal QA plans, use of field methods manuals and attention to error definition in the field and laboratory. (RMCC Quality Assurance Subgroup 1990). Ontario forest assessment and decline studies, including the Acid Rain National Early Warning System (ARNEWS) which began in 1985 on a regional scale, began without formal QA plans. During the study, however, field tested procedures were used, determinations were made of accuracy, comparability and sources of error, measurements and site selection criteria were standardized and pilot studies were used (McLlveen et. al. 1989, McLaughlin et al. 1988, RMCC Quality Assurance Subgroup 1990, Beak Consultants 1990). ARNEWS tested many of the methodologies used during the routine Forest Insect and Disease Surveys (Magasi 1988). The North American Maple Project (NAMP), which began in 1987, is carried out by a number of different agencies in Quebec, Ontario and the USA. Special attention was given to the production of a QA plan, objective setting, testing, detailed documentation of methods and training of field crews (Miller, 1988).

Other studies shown in Table 1 but not covered in this overview are smaller research oriented studies. The absence of a formal QA plan, however, does not preclude the success of a study. This is seen by looking more closely at some of the terrestrial studies done as part of the Ontario Ministry of the Environment's Acidic Precipitation in Ontario Study (APIOS).

Table 1. QA Considerations in Canadian terrestrial LRTAP studies. (Adapted from: RMCC Quality Assurance Subgroup 1990).

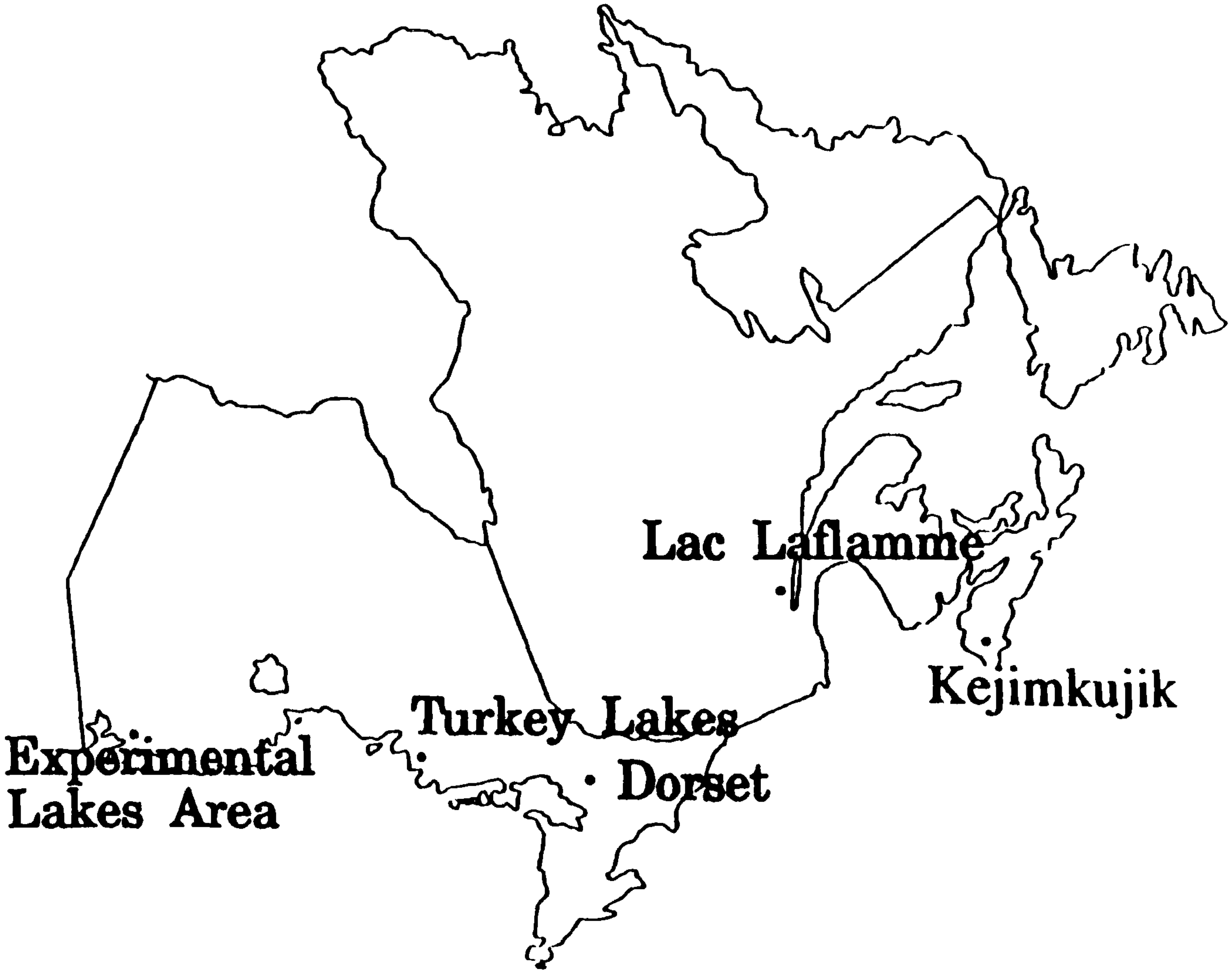
Study Type and Name	Formal QA Plan	QA Manual
BIOGEOCHEMICAL		
Calibrated Watersheds		
E.L.A.	Y	D
Bog Acification	N	B
Turkey Lakes	Y	B
Kejimkujik	N	-
Plastic Lake	N	I
Harp Lake	N	I
Other		
CFS Quebec Balsam Fir	Y	-
CFS Quebec Sugar Maple	Y	-
CFS Maritime Nit. Chem.	Y	B
Halifax Urban Watershed	Lab Only	N
Nashwaak Watershed	N	N
OME Canopy Effects	N	D
OME Forest Soils	N	D
BASELINE MONITORING		
Sensitivity	N	-
OME Soil Baseline	Y	D
Foliage Chemistry	N	D
Ontario Lichens	N	-
TRACE METALS		
New Brunswick (DMAE)	N	B
In Arctic Lichens	N	-
OTHER		
CFS Maritimes - Air Pollution and Plant Reproduction	N	-

Study Type and Name	Formal QA Plan	QA Manual
FOREST ASSESSMENT DECLINE STUDIES		
ARNEWS		
Prairies	N	D
Maritimes	N	B
British Columbia	N	B
North American Maple Project (NAMP)	Y	B
Environment Ontario		
Hardwood Survey	N	B
Dendrochronology	N	B
Maple Decline	N	D
Hardwood Nutrition	N	B
Early Diagnosis	N	N
Insect Defoliation	N	-
Canadian Forestry Service Maritime		
Cuticle Effects	N	-
Pollution Effects	N	B/I
Maple Decline	N	N
Mitigation	Y	B
Birch Assessment	Y	B
Other		
Quebec Forest Health	Y	B
ARA (NS) Maple Product Quality	Y	N

Y = Yes
N = No
B = Before
D = During
I = Informally Considered

Figure 1.

Biogeochemistry Study Sites



ONTARIO MINISTRY OF THE ENVIRONMENT - APIOS PROGRAMME

Organization/Goals and Objective Setting

The APIOS program began in 1979 with a series of defined tasks. Investigations were made into 1) the atmospheric deposition of acidic substances, 2) the effects of acidic deposition on the aquatic systems in Ontario, and 3) the effects on the terrestrial systems of Ontario and 4) the economic effects of acid rain. In 1980, planning of the terrestrial studies began. The organizational and reporting structure of the program was well-defined (Figure 2). A small group of scientists responsible for the project design, implementation and data interpretation were responsible to the Terrestrial Effects Working Group. This group included members from the laboratory supporting the programme (Ontario Ministry of the Environment Laboratory), APIOS Programme Coordination Office, senior management, invited members of the Atmospheric and Aquatic Working Groups, and representatives of other Ministries and industry.

A Technical Subcommittee was formed which included the project scientists, laboratory and APIOS Coordination office representatives, and sometimes members of other work groups. At this level the study planning details were resolved. The specific expectations, goals, objectives and study strategy were defined. Study design, siting criteria, number of sampling locations, field measurements, number of samples, field procedures, sample laboratory analysis requests, data precision and accuracy requirements, completeness, error sources, and data handling all received approval from this group before the project began. The Technical Subcommittee reported, through the Terrestrial Effects Working Group to the Science Committee. The Science Committee provided scientific peer review, and technical and budgetary direction to the proposed projects. The Science Committee reported to the Acid Rain Committee, a group responsible for policy statements for the programme. This structure allowed for considerable input into the project design and required that a certain amount of QA-related activities be built in to the studies themselves.

In 1985, a Quality Management Plan for the APIOS program was written and endorsed by Science Committee. The plan outlined the organizational structure and gave a broad policy statement for all APIOS tasks to carry out in their respective programmes. A QA/QC representative was assigned to help provide direction in formalizing QA/QC activities and identify shortcomings. Types of planning approaches used in the terrestrial studies are discussed in the following case studies.

Case 1 - Biogeochemistry Studies

Field Studies

Biogeochemistry studies were set up in the early 1980's in small subwatersheds within the Plastic, Harp and Hawkeye Lake catchments. The High Falls site near Sudbury was also monitored for a short period in the mid 1980's. Planning of the work was done in stages.

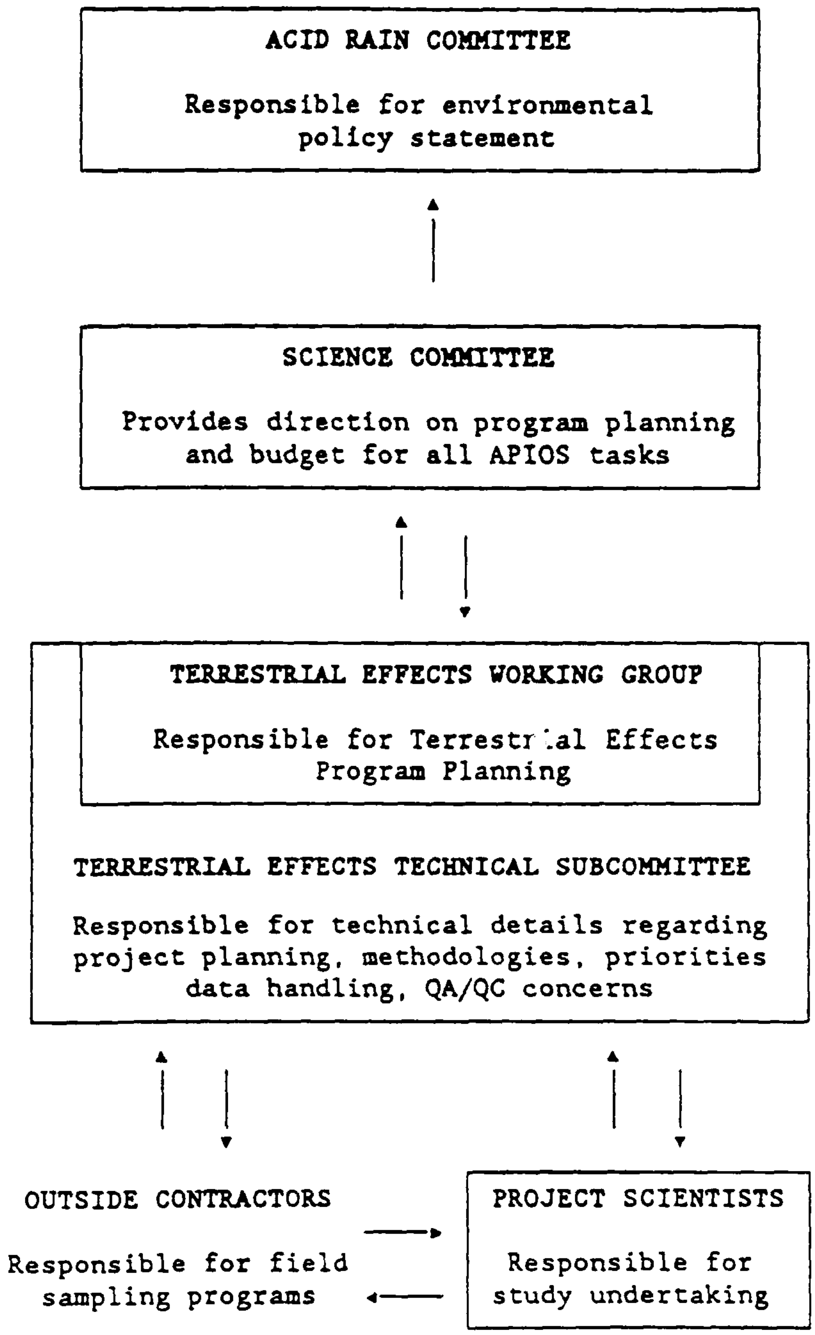
Goals and objectives were first defined. These were presented to the Terrestrial Effects Working Group and then to the Science Committee. Long range goals included measuring the effects of acidic deposition on selected forest ecosystems of Ontario and assessing the role of these ecosystems in regulating lake and stream chemistry. Short term objectives included: 1) documenting element and nutrient distribution and cycling in forested ecosystems receiving similar and different acid loadings; 2) defining interactions between precipitation, vegetation and soil, and their ability to alter the water chemistry of discharge to aquatic systems; and 3) modelling the effects of acidic loading on selected watershed systems (Technical Subcommittee Terrestrial Effects Working Group, 1983).

Once the proposed work was approved, the Technical Subcommittee decided which processes to monitor. A **conceptual model** was defined (Figure 3). Decisions were made on monitoring methods and what type of additional site information was required. Sampling strategies for soil, vegetation, litterfall, biomass estimates, precipitation, throughfall, stemflow and soil water were determined. The data quality objectives were discussed in light of their ability to detect change.

Siting criteria were then chosen. Many criteria were listed which were divided into requirements and desirable attributes. All sites had to meet the requirements, but not all sites had to include all the desirable attributes. Criteria included accessibility, land tenure, subwatershed size, drainage characteristics, soil and vegetation type and fire and harvesting histories. Two of the sites (Plastic and Harp Lake) were also chosen, to coincide with intensive aquatic studies on these lakes and the presence of a meteorological site in the area. The Hawkeye Lake site, located in an area of low acidic deposition, was chosen after a preliminary soils analysis and forest inventory. The High Falls site provided a site in the Sudbury area. This site was later dropped due to the confounding effects of sulphur emissions from Sudbury.

Figure 2. APIOS Program - Terrestrial Effects

ORGANIZATION CHART



In order to help organize the activities and better determine the workload, **sample timing** was examined and the samples were categorized as follows:

Frequency	Measurement
once only	watershed area, forest cover, vegetation biomass, soil characterization and mass event incident precipitation, throughfall, stemflow, lysimeter leachate
fixed interval	precipitation, dry deposition, stream water, litterfall, litter decomposition, groundwater, evaporation rate
continuous	stream flow, SO_2, O_3, NO_x, windspeed

Throughout these planning stages, quality assurance issues were addressed. Much research went into the type of sampling equipment and its construction. Comparisons of collector efficiency were made. For event sampling, quality control protocols were agreed to and documented by the Technical Subcommittee. Equipment cleaning, sample container cleaning and maintenance procedures helped to increase the accuracy of measurements (Gizyn 1983). Standard field forms meant the collection of all necessary field information at each site visit (Gizyn 1983, Senes Consultants 1987e). Field replicates provided **precision** data on the variability of stemflow, throughfall and soil water samples between similar trees and soil types. Sampling (aliquoting) techniques for throughfall and stemflow samples were compared to determine **sample representativeness** and **data comparability** with other studies (Senes Consultants 1986).

Other aspects of **accuracy** were addressed through contamination studies. Sample bags were leached with distilled water and acidified solutions. The solutions were analyzed for signs of contamination. The possibility of metals in the sample adsorbing on the walls of the bag was examined, and an aqueous perishability study for throughfall and stemflow samples was conducted. All results were reported to the Technical Subcommittee and the sampling protocol reviewed. Unfortunately, most of the QC activities were presented as memos to the Subcommittee or informal reports. Lysimeter contamination for the collection of soil waters was addressed in a slightly more formal way and a recommended procedure for washing the lysimeters before use was outlined (Neary 1985).

Detailed **documentation** of sample collector construction, sampling times, sample collection and processing procedures is available for "once only" samples (Neary 1986, Lozano et al. 1986, Lozano and Parton, 1986, Lozano 1986, Senes Consultants 1987a,b,c,d,e). Sample **representativeness** was considered and included checking soil, foliar and litterfall chemical variability. The number of soil pits and litter plots required to estimate the elemental concentration with a 5 percent and 10 percent level of precision was calculated (Tables 2 and 3). Similarly, **estimated error** in the forest inventory was kept to a minimum. The number of sample plots necessary to maintain error below 15 percent was calculated (Table 4). Potential error sources for each input into a biomass model were identified and the size of the error estimated (Senes Consultants 1987e). These inputs included Bitterlich basal area estimates and diameter/height relationships.

Replicate sampling of soil and vegetation was done routinely with every terrestrial project to provide a measure of **precision**. Replicate soil sampling protocols (side by side duplicates, across pit sampling, sample compositing, etc.) were also discussed at length before sample collection. Contamination from mortar and pestle sample grinding was minimized by the use of agate mortar and pestles. Recently, the effects of sample grinding on extractable iron and aluminum in soils was also investigated (Barnes and Neary 1990).

Laboratory Analysis

All of the chemical analysis for precipitation, stemflow, throughfall, lysimeter leachate, biomass, lichens and soil were performed by the main Environment Ontario laboratory. A formal QA plan was in effect in the laboratory long before the inception of the APIOS programme. The key QC elements for all the analyses done for the Terrestrial Effects Program included:

a) Documented, referenced and tested, standard analytical procedures, and proper technician training.

b) QC protocols for instrumental analysis. These included calibration standards (matrix matched, if necessary), sensitivity checks, baseline drift checks, longterm blanks and recovery checks.

c) QC protocols for sample preparation (extraction, digestion, etc.) and instrumental analysis. These included within-run duplicates, method blanks, spiked samples, and between-run duplicates (standard soils/vegetation run with each batch).

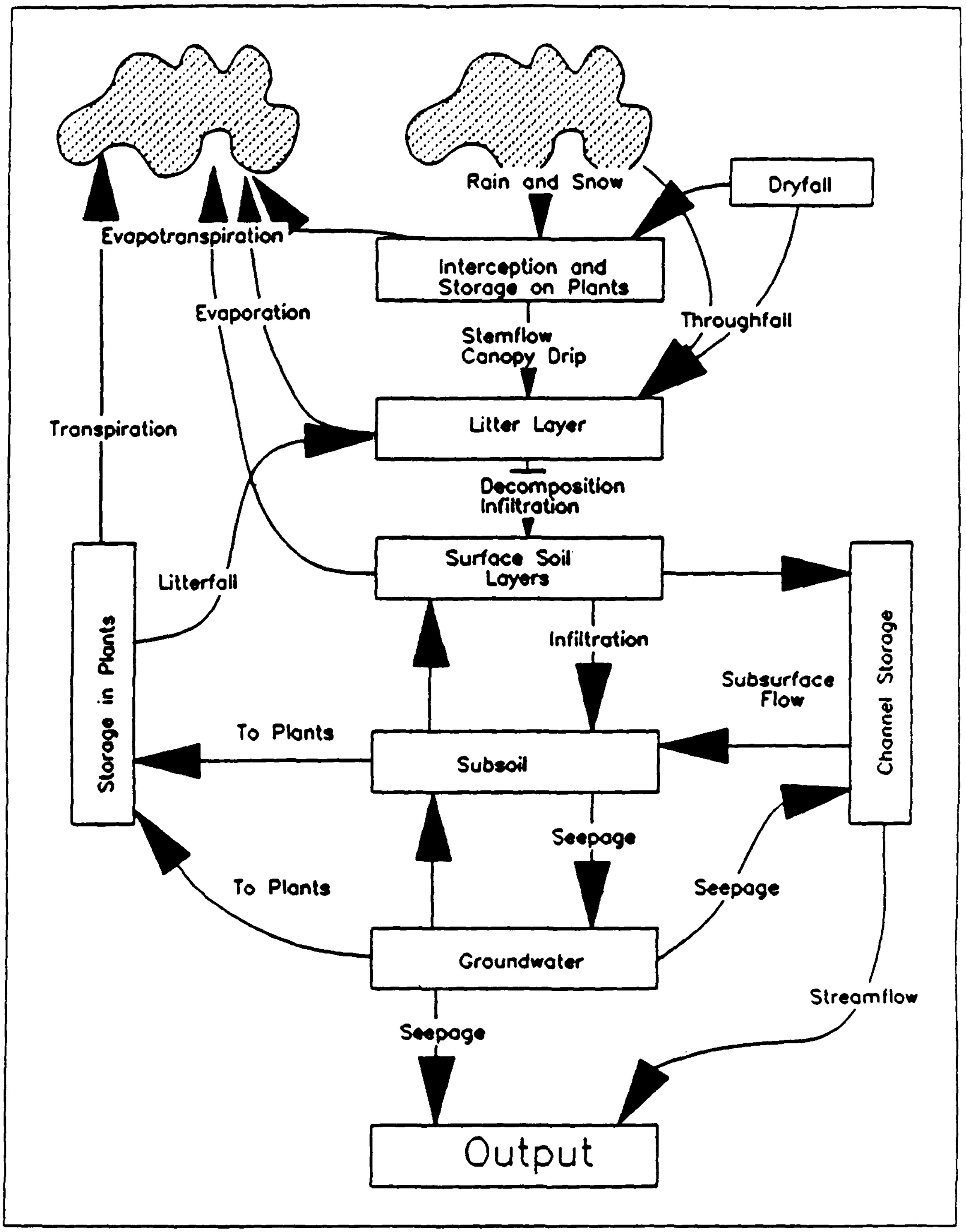


Figure 3: Conceptual Model of Biogeochemistry Study

Table 2. Number of soil pits required to estimate within 10% error at P = 0.05 the mean of a given soil property for Orthic Humo-Ferric Podzols at Plastic 1. (Source: Lozano et al. 1987)

	Actual No. of Pits	pH							Exchangeable				
		H_2O	$CaCl_2$	ORGC	Sand	Silt	Clay	N	Ca	Ng	K	Al	CEC
LFH	6	3	4	11	--	--	--	3	15	9	9	119	8
Ahe	2	5	8	65	17	78	37	44	39	77	32	4	10
Ae	8	2	4	157	18	96	86	66	290	111	35	70	27
Bf1	8	2	1	32	13	61	45	28	501	51	18	194	78
Bf2	5	0	0	95	22	88	44	66	81	108	90	41	41

	Actual No. of Pits		Pyrophosphate[3]		Dithionite[4]			Acid Extractable			
		SO_4^2	Fe	Al	Fe	Al	Al-Ca[3]	Cu	Zn	Pb	Ni
LFH	6	33	758	489	183	401	101	28	15	15	106
Ahe	2	28	17	25	2	12	20	16	3	201	1
Ae	8	38	213	25	124	30	88	122	65	89	161
Bf1	8	39	147	52	44	78	270	46	27	28	35
Bf2	5	41	124	67	33	38	150	12	11	56	25

1 NaCl Extraction
2 Water Extraction
3 Sodium-pyrophosphate Extraction
4 Citrate-bicarbonate-dithionite Extraction
5 $CaCl_2$ Extraction

Table 3. Number of litter plots required to estimate weights of litter fall/nutrients to within ± 5 and 10 percent of mean. P = 0.05 and 0.1 (1985-86). (Source: Lozano 1986)

Plastic Lake

Prob.	Prec.	Leaf	Twig	Seed	Total Litter	N	P	K	Ca	Mg	S	Na	Fe	Al	Mn	Cu	Zn
95	5	23	44	1974	29	61	61	90	44	86	38	82	82	174	447	46	300
95	10	6	11	494	7	15	15	22	11	22	9	20	21	43	112	12	75
90	10	3	7	303	4	9	9	14	7	13	6	13	13	27	69	7	46

Harp Lake

Prob.	Prec.	Leaf	Twig	Seed	Total Litter	N	P	K	Ca	Mg	S	Na	Fe	Al	Mn	Cu	Zn
95	5	113	435	1466	88	101	88	75	44	59	67	80	1597	1534	130	49	138
95	10	28	109	366	22	25	22	19	11	15	17	20	399	384	32	12	35
90	10	17	67	225	14	15	14	11	7	9	10	12	245	236	20	8	21

Table 4. Actual number of sample plots taken during the inventory at Plastic 1 and calculated number of sample plots required to meet 15% allowable error of estimates in a given stand at Plastic 1. (Source: Lozano and Parton 1986)

Forest Stand Types		Number of Sample Plots Actual	Calculated[1]
Pw_5 He_2 Or_1 Ms_1 O_1	- (A)	46	17
Ms_3 Pw_2 Ce_1 Bw_1 Or_1 He_1 O_1	- (B)	49	12
Ce_7 Sb_1 Sw_1 O_1	- (C)	35	94
Pw_3 Ms_2 Or_2 Bw_1 O_2	- (D)	28	16
He_4 Or_1 Pw_1 Ms_1 Po_1 O_1	- (E)	26	20
Rock Outcrops	- (F)	-	-
Brush and Alder Swales	- (G)	-	-
Total		184	159

[1] Number of sampling points required to provide a 15% standard error around the mean stand basal area.

Pw = white pine
He = hemlock
Or = red oak
Ms = sugar maple
O = other
Sb = black spruce
Ce = cedar
Bw = white birch
Po - popular

d) QC protocols involving regular participation in interlaboratory comparison and analysis of standard reference samples.

Case 2 - Forest Assessment Studies

Forest decline was recognized as a serious problem in parts of North America and other parts of the world. In 1984, the decision was made to initiate hardwood decline studies in Ontario. The planning approach used for these studies benefitted from the fact that the decline problem identified had a regional scope. Project leaders, therefore, had to ensure that their work could be compared to work in other parts of North America, or that their methods could be easily mimicked elsewhere and provide comparable data. The subjective nature of decline assessment presented the challenge of good QA planning.

Once again the **goals and objectives** were identified and the **siting criteria** were defined. A total of 110 plots across the province were established. Details on plot selection, size, markings etc. are provided in Beak Consultants 1990. To check the quality of tree assessments by each crew, several plots had assessments done by more than one crew. Seven plots were chosen randomly for overlapping assessments. Each plot overlapped on more than one occasion and the overlaps occurred randomly throughout the province and study duration (Beak Consultants 1990). A statistical evaluation of the results gave a "quality of crew assessment". Several plots were **co-located** with plots for the ARNEWS and NAMP programmes.

For site visits, each crew was trained in the **standard operating procedures** and given a **field procedural manual**. The manual contained the names of contact personnel, detailed descriptions of the field personnels' tasks, contingency plans, "TO DO" and equipment lists, the Tree Assessment Methodology Manual, tree identification package, and a hardwood disease and insect identification package (Beak Consultants 1990). Within 24 hours of visiting a site, all field notes, plot descriptions, location maps and topographic maps were mailed to the head office. A separate file was set up for each plot.

The primary QA effort in the decline project was an improved rating scheme for plot assessment. Tree rating schemes have been very subjective in the past. Assessment parameters are broad, qualitative, non-descriptive and have poor resolution (McLauglin et al. 1988). This makes them of limited value in detecting trends. Instead, a high resolution, quantitative rating system was developed which was reproducible and had a narrow confidence interval within a large gradient.

This decline index was based on the most often noted symptoms in hardwood decline: dieback of the fine branch structure, pale green or chloritic foliage and undersized leaves (McLaughlin et al. 1988). The three crown parameters were individually assessed and then combined in a numerical weighting scheme. The improved objectivity in the assessment resulted in improved data **precision, accuracy and comparability**.

Precision and comparability were also increased by decreasing the variability between technicians. Laminated field assessment templates were prepared which illustrate a series of deciduous tree crown silhouettes in decline gradients of 10 percent (McLaughlin et al. 1988). On the reverse side of the template, three series of colour chips each containing six chips illustrate the range of foliar colour seen in sugar maple in southern Ontario. With the aid of the template, the technician estimates percent decline, chlorosis and undersized leaves. To increase the **accuracy** (or sensitivity) of the rating scheme, the foliar parameters are weighted proportional to the live healthy crown. A low amount of dieback may still give an elevated decline index if a large percentage of the crown is chloritic. This is important because foliar abnormalities usually occur earlier than dieback (McLaughlin et al. 1988).

Finally, **field trials** were performed. Ten people were trained in the use of the decline index and identification. Ten trees were chosen in plots in Ontario and randomly marked. All trees were rated by each person and then all the tree numbers were changed and the trees rated again. This was repeated five times with the tree numbers changed between ratings. The field trial was again repeated using paired evaluators discussing the evaluation and coming up with one rating. Favourable results in the field trial led to the adoption of this rating scheme for all hardwood decline studies in Ontario.

The improved decline index provided reduced subjectivity, faster training of field crews, better precision and comparability and more accurate measurements. These subjective types of studies benefit considerably from a QA/QC conscience approach to planning. The projects can now be carried out over the long term and provide a very valuable data set.

SUMMARY

Canadian LRTAP-related terrestrial field monitoring studies were performed as part of well coordinated large federal and provincial programmes. Planning approaches used over the last decade, however, were neither formalized nor standardized. Nevertheless, with few exceptions, the studies themselves were well planned and QA/QC activities were incorporated into the planning to some degree. Significant work, both in the field and laboratory, was devoted to the production of good quality data, but the draft form and informal presentation of much of this work is unfortunate. Everyone knows the frustration that occurs when the "perfect" historical data base is found to be of limited use because

QA/QC information is unavailable. Without proper documentation, a good data set which is useful today may be of little use twenty years from now when it is most needed. There is little doubt that the earlier studies would probably be done differently today using a more rigorous QA/QC approach to planning.

Over the last decade, there has been an evolution of QA activities into a more structured format. The advantages of a QA approach to planning became apparent in the Ontario Ministry of the Environment's hardwood decline surveys. It is clear that Canadian terrestrial studies started in the last five years, benefitted from an organized QA effort. While formal QA plans help strengthen a study and ensure the integrity of the data, it is important to emphasize that they do not, in themselves, guarantee the success of a study. Similarly, the absence of a formal QA plan does not mean the failure of a study. Efforts of the Federal/Provincial Research Monitoring Coordination Committee, over the last ten years, have resulted in increased documentation of QA-related activities, thereby improving the quality of data produced in Canadian terrestrial monitoring work. These improvements can only help strengthen future monitoring work in Canada.

REFERENCES

Barnes, S. and Neary, A. (1989). The Effect of Sample Grinding on Extractable Iron and Aluminum in Soils. Draft Report, Laboratory Services Branch, Ontario Ministry of the Environment.

Beak Consultants Limited (1990). Results of the 1989 Hardwood Decline Survey for Ontario. A final report for Air Resources Branch, Ontario Ministry of the Environment, Toronto, Ontario.

Case Biomanagement (1990). An Investigation of the Use of Lichens and Mosses as Biomonitors of Acidic Precipitation in Ontario. Report prepared for the Ontario Ministry of the Environment. Report No. ARB-180-89-PHYTO/APIOS 014-89.

Cowell, D.W. (1986). Assessment of Aquatic and Terrestrial Acid Precipitation Sensitivities for Ontario. Environment Canada, Lands Directorate/Ministry of the Environment, Air Resources Branch. APIOS Report 009/86, ISBN 0-7729-2113-x

Gizyn, W. (1983). Acidic Precipitation in Ontario Study, Biogeochemistry Study, Dorset, Ontario: Sample Collection and Processing Procedures. Internal report.

Lozano, F.C. (1986). Total Amount and Elemental Content of Litter Fall on the Harp 4 and Plastic 1 Biogeochemical Sites. Faculty of Forestry, University of Toronto. Presented to the Ontario Ministry of the Environment.

Lozano, F.C. and W.J. Parton (1987). Forest Cover Characteristics of the Harp #4 and Plastic #1 Subcatchments of the Southern Biogeochemical Study. Final report prepared for the Ontario Ministry of the Environment.

Lozano, F.C., W.J. Parton, J.K.H. Lau and L. Vanderstar (1987). Physical and Chemical Properties of the Soils at the Southern Biogeochemical Study Site. Faculty of Forestry, University of Toronto Report. Presented to the Ontario Ministry of the Environment.

Magasi, L.P. (1988). Acid Rain National Early Warning System Manual on Plot Establishment and Monitoring. Canadian Forestry Service, Information Report DPC-X-25, Ottawa, Ontario.

McIlveen, W., D.L. McLaughlin and R.W. Arnup (1989). A Survey to Document the Decline Status of the Sugar Maple Forest of Ontario: 1986. Ontario Ministry of the Environment report, Air Resources Branch.

McLaughlin, D.L., W.I. Gizyn, D.E. Corrigan, W.D. McIlveen and R.G. Pearson (1988). A Numerical Decline Index Rating System to Monitor Changes in Tree Condition of Forest Hardwood Species. Proceedings of the Technology Transfer Conference, Toronto, Ontario, Nov. 28, 29.

Miller, Imants (1988). North American Sugar Maple Decline Project Cooperative Work Plan. Canadian Forestry Service and U.S. Department of Agriculture, Forest Service.

Morrison, I. (1972). Variation with crown position and leaf age in content of seven elements in leaves of *Pinus banksiana Lamb.* **Canadian Journal of Forest Research**. 2:89-94.

Morrison, I. (1974). Within-tree variation in mineral content of leaves of young balsam fir. **Forest Science** 20:276-278.

Morrison, I. (1985). Effect of crown position on foliar concentrations of 11 elements in *Acer saccharum* and *Betula alleghaniensis* trees on a till soil. **Canadian Journal of Forest Research** 15: 179-182.

Neary, A. (1985). Preparation of alundum/ceramic plate tension lysimeters for soil water collection. **Canadian Journal of Soil Science**. 65:169-177.

Neary, A. (ed.) (1986). Procedures Manual Terrestrial Effects APIOS. Ontario Ministry of the Environment. Report ARB-93-86-PHYTO.

RMCC Quality Assurance Subgroup (1990). 1990 Assessment of the Quality Assurance in Studies Monitoring the Effects of Acid Deposition in the Canadian Environment. Draft Report November 24, 1990.

Senes Consultants Limited (1986). Acidic Precipitation in Ontario Study: Terrestrial Effects Programme Northwestern Region. Comparison of Equal and Proportional Volume Sampling Techniques. Report Prepared for the Ontario Ministry of the Environment.

Senes Consultants Limited (1987a). Acidic Precipitation in Ontario Study: Hawkeye Lake Biogeochemical Study Site. Soil Classification and Nutrient/Element Studies. Report Prepared for the Ontario Ministry of the Environment.

Senes Consultants Limited (1987b). Acidic Precipitation in Ontario Study: Hawkeye Lake Biogeochemical Study Site Grove Throughfall and Stemflow Studies July 1983 to March 1986. Report Prepared for the Ontario Ministry of the Environment.

Senes Consultants Limited (1987c). Acidic Precipitation in Ontario Study: Hawkeye Lake Biogeochemical Study Site Litterfall Studies July 1983 to October 1985. Report Prepared for the Ontario Ministry of the Environment.

Senes Consultants Limited (1987d). Acidic Precipitation in Ontario Study: Hawkeye Lake Biogeochemical Study Site Litter Decomposition Studies November 1984 to March 1986. Report Prepared for the Ontario Ministry of the Environment.

Senes Consultants Limited (1987e). Acidic Precipitation in Ontario Study: Hawkeye Lake Biogeochemical Study Site. Status Report and Recommendations, Forest Inventory and Biomass/Bioelement Studies. Report Prepared for the Ontario Ministry of the Environment.

Technical Subcommittee Terrestrial Effects Working Group (1983). Overview Biogeochemical Studies Acidic Precipitation in Ontario Study. Internal Report.

STATISTICAL THINKING AND TOOLS FOR IMPROVING EXCELLENCE IN ECOLOGICAL PROJECTS

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ABSTRACT

The topics of quality assessment, quality control, quality improvement and overall excellence have been with us since the dawn of civilization. Over time, the relative emphasis on these topics has changed, and today the focus in industry is on continual product quality improvement and excellence. Ecological projects and products have definite stages of activity, i.e., a "life-cycle," and quality improvement is possible at all of the life stages. The presentation will review the components for pursuing excellence, the role of statistical thinking, and the methods and tools appropriate for continual quality improvement. Statistical thinking will be seen to be important throughout the stages of an ecological field project. Furthermore, many of the present "Quality Assurance" methods and tools will be seen to be of direct use in the pursuit of excellence within ecological projects. The presentation will conclude with some additional tools and thoughts for pursuing excellence in future ecological field projects.

INTRODUCTION

The attempt to control product quality is a topic that has been with us for centuries, and it presently is receiving expanding attention and effort. However, even a brief review of the history of the pursuit of quality indicates that attention to the quality of products has been rather variable (e.g., Duncan, 1974; Flueck and McKenzie, 1990). It also is interesting to note that during periods of mortal competition (e.g., war) interest in the quality of products used in the conflict typically increases. Examples include the shipbuilding operation of the Arsenal of Venice in the 1500's (e.g., Skrabec,1990), the manufacture of muskets in France in the 1700's (e.g.Durfee, 1984), the extensive training in quality control for ordnance manufacturers during WWII (e.g., Wallis, 1980), and as noted in the newspapers even the present "Desert Storm" action has increased the emphasis on the quality of current military products (Figure 1).

The historical record of the pursuit of quality indicates considerable fluctuation in the methods used to secure quality (Figure 2). During the Eqyptian pyramid building period (ca. 2000 B.C.), the emphasis was on application of uniform methods and procedures through strict adherence to fixed standards. The craft guilds of the middle ages (ca. 1300 A.D.) relied upon strict training and continual oversight by the guild-master to produce products of suitable quality. The industrial revolution of the 1800's brought the implementation of inspection after the production event with the attendant problem of what to do with the nonconforming units.

The 1920's brought a rapidly increasing demand for telephones, and this lead to the idea of inspection of sampled units during the production event; the initiation of statistical quality control (e.g., Shewhart, 1931). The 1950's gave birth to the idea of building-in quality in all activities within a company; total quality control (e.g., Feigenbaum, 1956) and later termed total quality management. The 1960's saw the ideas and methods of continuous quality improvement being shaped (e.g., Deming, 1982). Finally, the 1980's brought forth an emphasis on cost-minimizing "robust" product designs (e.g., Taguchi,1979).

The recent decades (i.e., the 1960's and beyond) have placed the emphasis on methods that plan for quality and build-in quality "up-front". In fact, in many industrial and service companies, quality is now looked upon as an extended process reaching from the quality of Design (i.e., determining the product that really will satisfy the client or customer), through quality of Conformance (i.e., the degree to which the producer and his suppliers are able to surpass the design specifications generated by the customers), to the quality of Performance (i.e., the evaluation of how well the product performs in the marketplace, Gitlow et al., 1989).

FIGURE 1
WAR-TIME EXAMPLES OF THE IMPORTANCE OF PRODUCT QUALITY

Time Period	Event	Action
1500's	The Arsenal of Venice	Built armed galleys to protect maritime trade
1700's	Jefferson's trip	Manufacture of muskets in to France a French factory
1940's	World War II and	A major national program in statistical quality control for military ordnance suppliers
1990's	Desert Storm	Federal investigations of military suppliers for failure to properly test their products

FIGURE 2
A HISTORY OF METHODS USED IN PURSUIT OF QUALITY

Time Period	Event	Method
2000's B.C.	Egyptian Pyramids	Compliance to fixed standards
1300's	Craft Guilds	Training and Monitoring of the complete project
1800's	Industrial Revolution	Inspection after production
1920's	Statistical Control	Process Inspection during production
1950's	Total Quality Control	Build-in quality in all activities
1960's	Continuous Improvement	Expanded Shewhart-Deming Improvement Cycle
1980's	Robust Products	Taguchi "quality by design"

In ecological monitoring and research, we need to investigate the more promising methods and practices of others who already have tread the path of quality improvement. Many successful stories and techniques are available in other disciplines (e.g., Harrington, 1987; Townsend, 1990; Stratton, 1990), and we need to examine them and determine how they might serve us in our quest for excellence. In particular, we need to focus on the opportunities for building in excellence in the planning and implementation stages of an ecological study. We also need to move beyond the viewpoint that a "quality job" will occur just because the "right people" are involved in the planning of the project and a voluminous quality assurance plan is created with many stated check-points. Aside from the question of who are the "right people" and will they fully participate, there remains the point, as Shewhart so aptly remark many years ago, that one cannot inspect quality into a product.

PRINCIPLES FOR EXCELLENCE

There have been numerous discussions in the quality control literature concerning what really constitutes quality and the methodology of Total Quality Control (e.g., Feigenbaum, 196l; Ishikawa, 1985). From a simple dictionary translation, quality can be defined as "degree of excellence", and Total Quality Control can be defined as:

"the complete and unified power to manage the degree of excellence"

Thus Total Quality Control focuses on creating excellence in products and services through teamwork. Needless to say, the above statement immediately raises a number of issues including the questions of how is excellence of a product to be defined, how is it to be measured, and how should it be pursued?

One approach to the question of how is excellence to be defined is to treat the concept of "excellence" of a product as a vector with the elements of the vector representing the various characteristics of the product relevant to its utilization (e.g., the final product is an information one such as a newspaper and the elements of interest are size, topics, depth of coverage, readability, accuracy, and timeliness). To measure the amount or degree of excellence (y), one can form a weighted linear combination of the elements (x_i) using a set of weights (a_i) derived for the particular customer,

$$y = a_1x_1 + a_2x_2 + a_3x_3 + \dots\dots + a_kx_k .$$

Then assuming that the x_i's can be standardized and measured, one is able to compute the excellence score for each competing product in the given market for the particular customer. One also can compare the size of the a_i's to assess the relative importance of each of the k characteristics of excellence.

To create excellence in a product, there are some fundamental principles that must be mastered if a Total Quality or Quality Improvement approach is to be attempted. They are:

1. Understanding that there are Suppliers, Products, and Demanders (customers) in all transactions and that each has an important role to play,

2. Realization that product excellence must be earned by satisfying and/or delighting the customers,

3. Commitment to the concept that management leadership, teamwork, training, and rewards are needed to secure excellence in the jointly produced products, and finally

4. Recognition that "statistical thinking", statistical tools, and computerized technology are the work-horses for improving the excellence of products.

The presentation and implementation of these principles are illustrated in numerous writings (e.g., Deming, 1986; Harrington, 1987; Oakland, 1989; and Townsend, 1990), and it should be noted that a Total Quality approach results in the shifting of the quality improvement task to a broader array of people (e.g., Quality Improvement Teams) than just the quality assurance staff.

STATISTICAL THINKING

The method of statistical thinking has been present in quality control for some time, and Walter Shewhart (1931), W. Edwards Deming (1986), Brian Joiner (1987), and Ron Snee (1990) are examples of people who have advocated and applied it in the quest for quality improvement. In essence, statistical thinking is the view that virtually everything can be seen as a process or a group of processes (i.e., a system) whose inputs and outputs have variability, and the process can be identified, characterized, quantified, sampled, analyzed, and understood such that it's variability can be reduced and the process and products can be improved. A generic diagram of the steps in statistical thinking is presented in Figure 3 (Snee, 1990), and we see that these steps actually are an expansion of the traditional Shewhart-Deming cycle of Plan, Do, Check, and Act (Deming, 1986). Thus statistical thinking encompasses both the art and science of scientific problem solving.

In ecological monitoring and research studies, the idea is to apply statistical thinking to problems in each stage of the life of a project from conception through design, feasibility, implementation, analysis, reporting, and expost studies (Figure 4; Flueck, 1986) to continually improve the final information products. In particular, emphasis should be placed on building in excellence up-front in the design stage, sustaining it throughout the life-cycle of an ecological project, and reducing the need for ex-post checking. In the Environmental Monitoring and Assessment Program (EMAP, an EPA program to assess the conditions of the nation's ecological resources), examples of the use of statistical thinking and building in excellence up-front already have occurred in the design and implementation stages of the program.

In the design stage, the problem of adequate prior information has been resolved by the use of a two-stage sampling design with the first stage focusing on obtaining more general information and the second stage using this information to sharpen the estimates of ecological conditions and trends. The initial problem of providing suitable spatial coverage has been addressed by imposing a regular triangular point grid over the entire conterminous USA, with approximate spacing of 27km, yielding about 12,600 potential sampling points. In addition, the grid was given a random start in order to provide a probability basis for spatial estimates of ecological populations (Overton et al.,1990). These characteristics of the general EMAP design are unique and path-breaking in the design of ecological field studies.

In the implementation stage, examples of statistical thinking include the EMAP-Near Coastal group's use of "bar-coding" for many of the sample types with considerable reported success. Also, the EMAP-Forest group utilized portable data recorders (PDR's) and lap-top computers for some data taking, screening, checking, and transmission to the home-base with a reported 90 percent reduction in data entry errors such as incorrect code, out-of-range values, etc. (C. Liff, internal communication, September, 1990). Clearly, many more opportunities for building in excellence up-front in each of the seven stages of a typical ecological project await their discovery by EMAP participants and EMAP "Improvement Teams".

TOOLS AND TECHNOLOGY

A number of tools and techniques are available for assisting in the task of improvement of quality, and a growing number of them are routinely used in the industrial and service industries both here in the USA and abroad. A list of these tools or methods are presented in Figure 5 and classified by elementary, intermediate, and advanced as presented by Ishikawa (1985). In Japan, the seven elementary or so-called "Seven Indispensable Tools" of quality control (i.e., Pareto charts, Cause-and-Effect diagrams, Stratification, Check Sheets, Histograms, Scatter Diagrams, and Control Charts) are reportedly used by everyone from company directors and presidents on down to research and development staff, foremen, and workers on the production line. The intermediate tools largely are used by engineers and the QA staff, and the advanced tools apparently are utilized by a very limited set of engineers and staff to solve complicated process and quality analysis problems (Ishikawa, 1985). It appears that all of these tools have some use in ecological monitoring and research studies, but one wonders how often they actually get used.

In keeping with the spirit of "continuous quality improvement", four additional tools are presented which have enjoyed considerable use in numerous disciplines including atmospheric, climate, and medical research. These tools (i.e., flowcharts, stem-and-leaf plots, box-and-whisker plots, and median smoothers) are briefly defined in Figure 6.

Flowcharts (Figure 7) already are being used by many quality improvement teams, and a number of quality professionals have made them one of the elementary seven tools (stratification typically is dropped). The remaining three tools have been extensively utilized in exploratory data analysis activities (e.g. Tukey, 1977), and they appear to be very applicable to ecological studies and their quality improvement efforts. It should be noted that both the stem-and-leaf plot (Figure 8) and the box-and-whisker plot (Figure 9) provide greatly enhanced distributional information when compared to the typical summary parameters of mean and variance or a histogram. In fact as shown in Figure 9, the time sequence of yearly box-and-whisker plots for krypton-85 gives both level and variability information within the same diagram. As such, it is a distributional "control chart", and it could become an attractive alternative for displaying grouped ecological time series data.

The median smoother is appropriate when attempting to find the "central path" of a time series, and because it uses a sequence of running medians (e.g., Tukey, 1977) it's pathway is uninfluenced by outlying observations. All four of these graphical tools appear to be suitable for tasks within quality improvement and reporting activities in ecological monitoring and research studies.

With regard to technology, all of the tools presented in Figure 5 have available software for their application. Furthermore, the four additional tools presented in Figure 6 also have computer code available (e.g., Velleman and Hoaglin, 1981), and a number of statistical packages (e.g., Minitab, Stat-Graphics, S-Plus, etc.) already have incorporated these tools into their packages. Clearly, the use of computerized routines has an important place in both on-line and off-line quality improvement studies.

CONCLUDING COMMENTS

Numerous methods and techniques have been successful in improving the quality of products in the industrial and service industries. Many of these methods and techniques appear to have promise for improving the quality of ecological projects at all stages of activity.

Ecological studies produce information as their main product, and these products can take many forms (e.g., data, tables, visual displays, estimation results, reports, etc.). Consequently, the goal of quality improvement activities in ecological projects should be to utilize a Total Quality method to assist in the improvement of the content, form, and delivery of these information products. In this respect, QA should be termed Quality Assistance as suggested by Dan Heggem (Papp et al., 1989).

Finally, assuming that most information in ecology, and in science in general, is fragile and perishable, the early recognition of the need for statistical thinking, appropriate tools, and quality improvement is important. In ecological studies, as in automobile production, it is greatly preferred to build-in excellence in the design stage rather than attempt to retrofit while on the road.

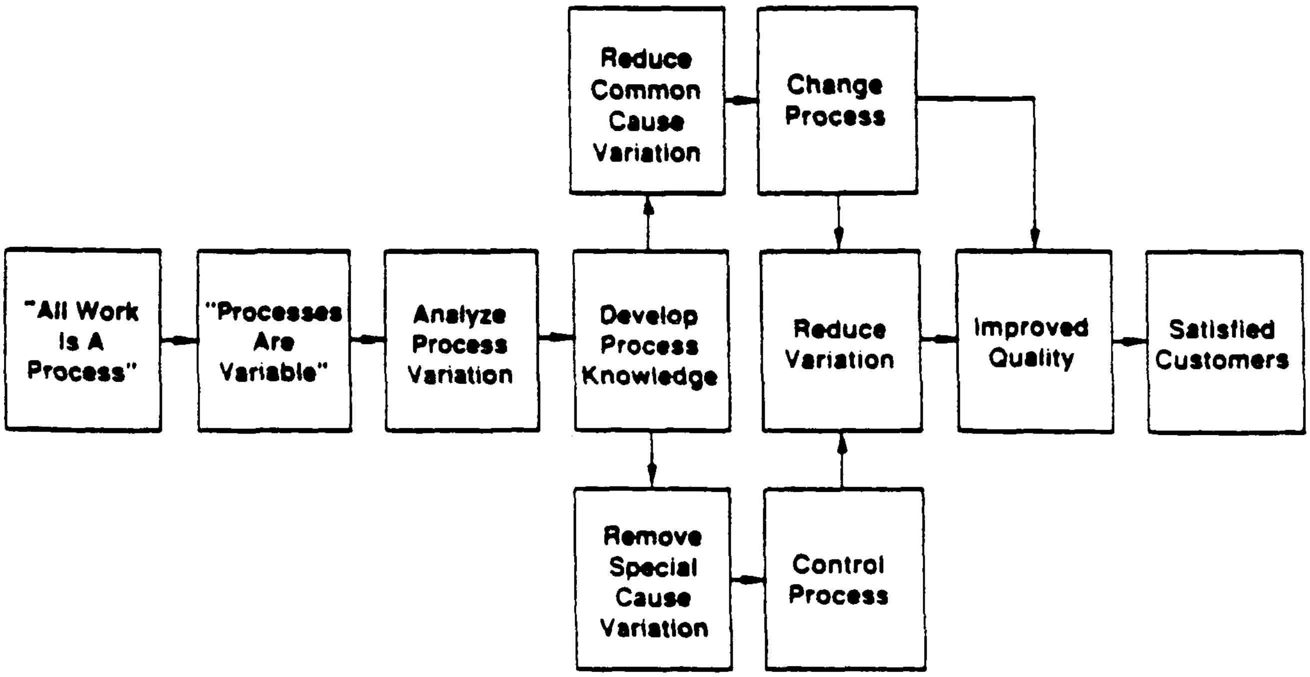


Figure 3. *Statistical Thinking in Quality Improvement.*

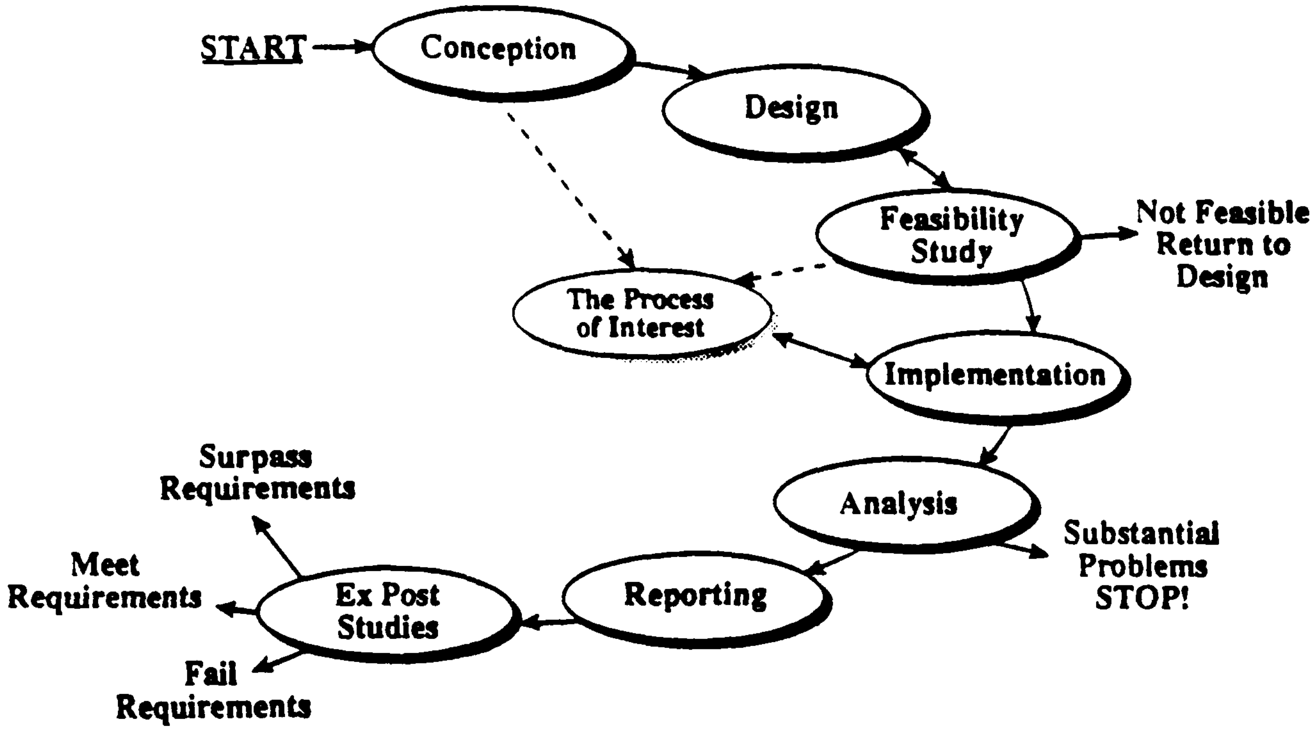


Figure 4. The Typical Stages, or "Life Cycle," of a Research Study.

FIGURE 5

A LIST OF ELEMENTARY, INTERMEDIATE, AND ADVANCED METHODS AND TOOLS USED IN QUALITY IMPROVEMENT

Elementary Methods or Tools

1. Pareto chart
2. Cause and effect diagram
3. Stratification
4. Check sheet
5. Histogram
6. Scatter diagram
7. Shewhart control charts

Intermediate Methods or Tools

1. Sampling surveys
2. Inspection Sampling
3. Statistical testing and estimation
4. Sensory testing
5. Statistical design of experiments

Advanced Methods or Tools

1. Advanced design of experiments
2. Multivariate analysis
3. Operations Research methods

FIGURE 6

A LIST OF ADDITIONAL TOOLS APPLICABLE TO QUALITY IMPROVEMENT

TOOL	DESCRIPTION
1. Flowchart	A formal diagram for depicting the steps and pathways in a process or system
2. Stem-and-Leaf Plot	A display of each observation in a sample organized by leading integers (stems) with the leaves carrying the remaining integers
3. Box-and-Whisker Plot	A summary of the empirical distribution of the sample data using quartiles (i.e. 1,2,3,& 4th) and highlighting outliers
4. Median Smoother	Running (moving) medians of varying lengths and repeats

Figure 7. Flowchart for Software Release

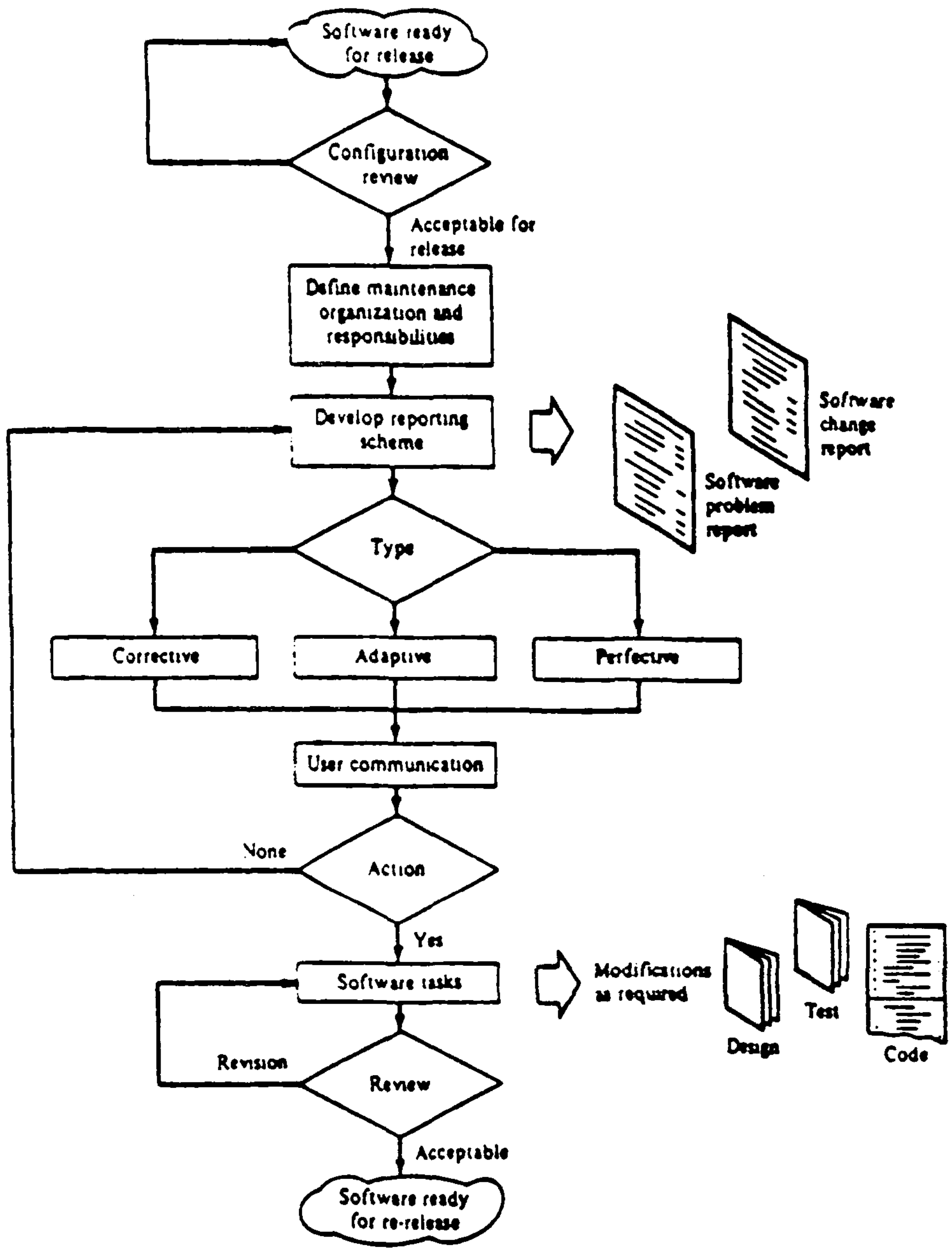
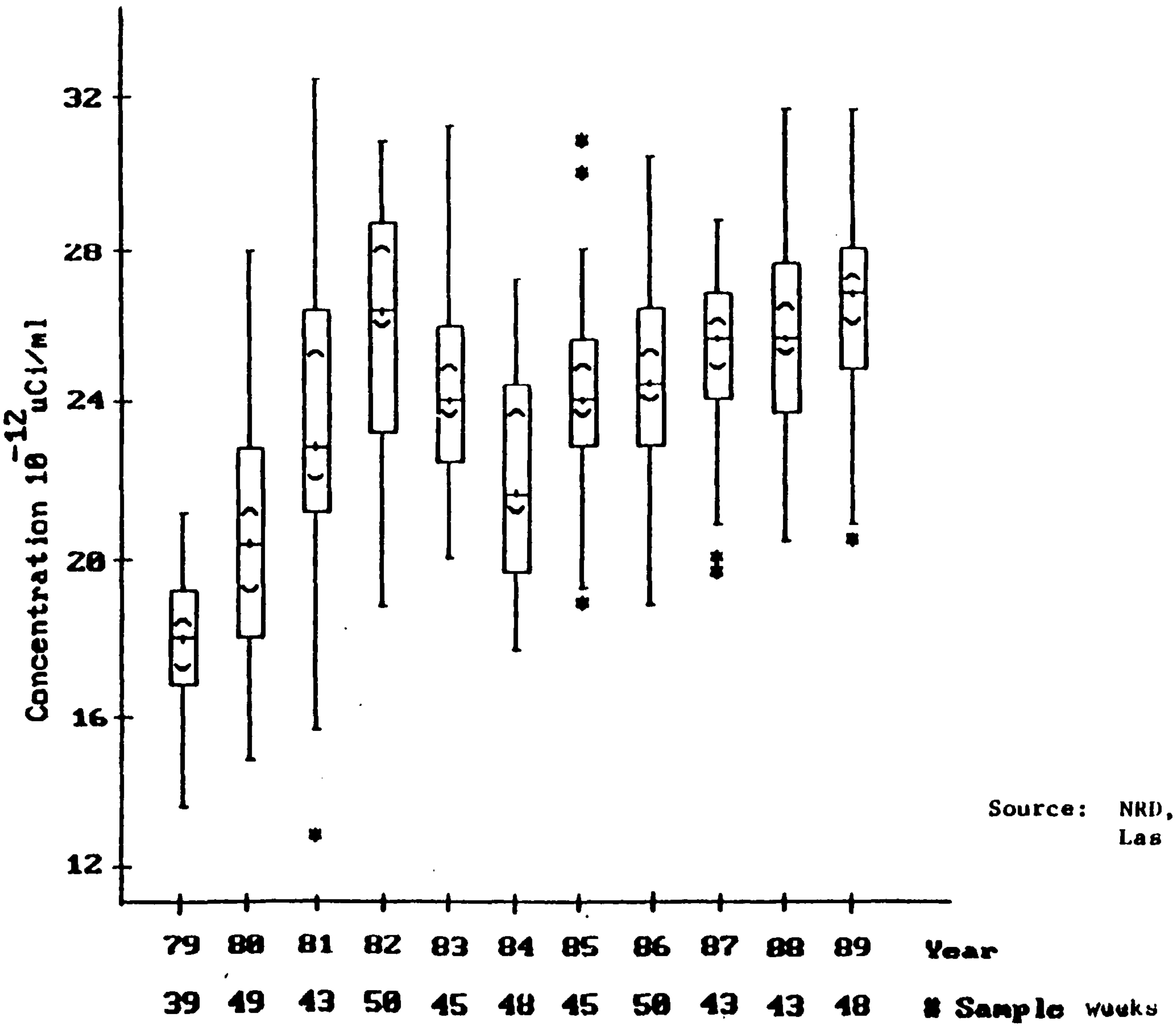


Figure 8. Stem and Leaf Display of Heights of Highest Points in Each State, units are in 100 ft. and rounded to nearest hundred (1 digit leaves)

stem	Leaves		#
0**	3,4,5,8,8	Fla., Del., La., Miss., R.I.	(5)
1,0**	2,3,6,7,8,8		(6)
2	0,0,3,4,4,8		(6)
3	2,4,5,5,6	Penna.	(5)
4	0,1,4,8,9		(5)
5,0**	0,3,3,4,7		(5)
6	3,6,7		(3)
7	2	S. Dak.	(1)
8	8	Texas	(1)
9			
10,0**			
11	2	Oregon	(1)
12	6,7,8		(3)
13	1,2,5,8,8		(5)
14	4,4,5	Col., Wash., Calif.	(3)
15,0**			
16			
17			
18			
19			
20,0**	3	Alaska	(1)
			(50,✓)

Source: Statistical Abstract of the United States, 1970 U.S. Bureau of the Census, Washington, D.C. pp. 169.

Figure 9. **Weekly Kr-85 Data: Rachel,** NV



Source: NRD, EMSL-EPA
Las Vegas, NV

TEST SUBSTANCE

Parameter	S/D*	Location: Laboratory	Location: Field
Receipt	S		
Labelling	S		
Characterization	S	Same controls regardless of location	
Inventory	S		
Custody	S		
Contamination	D	Less change due to controlled environment	Greater chance due to interaction with ambient surroundings
Storage	D	Facilities established	Facilities variable
Environmental Controls	D	Well monitored due to established facility	Less control due to mobile nature
Transport	D	Low chance of accidents due to mainly shorter distances	Greater chance for accidents due to longer distances
Handling	D	Not as complicated due to close mixing	Variable formulating scenarios due to increased distances
Safety issues	D	Usually known and controlled	Accidental releases more likely due to ambient environment

*S = Similar, D = Different

REFERENCES

Deming, W.E., 1986. Out of the Crisis, MIT Press, Cambridge, MA.

Duncan, A.J., 1974. Quality Control and Industrial Statistics, Irwin, Homewood, IL.

Durfee, W.F., 1984. "The History and Modern Development of the Art of Interchangeable Constructions In Mechanisms", J. Franklin Inst., Philadelphia, PA.

Feigenbaum, A.V., 1961, 1983 (3rd ed.). Total Quality Control, McGraw-Hill, New York, NY. 1956. "Total Quality Control", Harvard Bus. Rev., Nov-Dec, 93-102.

Flueck, J.A., 1986. "Principles and Prescriptions for Improved Experimentation in Precipitation Research", Ch. 16 in Precipitation Enhancement - A Scientific Challenge, R.R. Braham, Jr. (Editor), Monograph Vol. 21, No. 43, Amer. Meteor. Soc., Boston, MA.

Flueck, J.A. and D. McKenzie, 1990. "A Total Quality Approach to Environmental Monitoring and Assessment", submitted for publication.

Gitlow, H. and S. Gitlow, A. Oppenheim, and R. Oppenheim, 1989. Tools and Methods for the Improvement of Quality, Irwin, Homewood, IL.

Harrington, H.J., 1987. The Improvement Process, McGraw-Hill, New York, NY.

Ishikawa, K., 1985. What is Total Quality Control? The Japanese Way, Prentice-Hall, Englewood, NJ.

Joiner, B.L., 1985. "The Key Role of Statisticians in the Transformation on North American Industry", Amer. Stat., 39, 224-34.

Oakland, J.S., 1989. Total Quality Management, Heinemann, Oxford, England.

Overton, W.S., D.White,and D.L. Stevens, 1990. Design Report for EMAP, Environmental Monitoring and Assessment Program, Part I. Dept. of Statistics, OSU, Corvallis, OR.

Papp, M.L., D.T. Heggem, R.D. Van Remortel, R.W. Gerlach, J.M. Pollard, and L.D. Stetzenbach, 1989. Alaskan Oil Spill Bioremediation Plan and Standard Operation Procedures. Draft, U.S. EPA, Las Vegas, NV.

Shewhart, W.A., 1931. Economic Control of Quality of Manufactured Product, D. Van Nostrand, New York, NY.

Skrabec, Q.R., 1990. "Ancient Process Control and Its Modern Implications", Quality Progress, 23, no. 11, 49-52.

Snee, R.D., 1990. "Statistical Thinking and Its Contribution to Total Quality", Amer. Stat., 44, 116-121.

Stratton, B., 1990. "Four to Receive 1990 Baldrige Awards", Quality Progress, 23,no.12, 19-21.

Taguchi, G., 1979. Introduction to Off-line Quality Control, Central Japan Quality Control Assoc., Magaya, Japan.

Townsend, P.L. with J.E. Gebhardt, 1990. Commit to Quality, J. Wiley & Sons, New York, NY.

Tukey, J.W., 1977. Exploratory Data Analysis, Addison-Wesley, Reading, MA.

Velleman, P.F. and D.C. Hoaglin, 1981. Applications, Basics, and Computing of Exploratory Data Analysis, Duxbury Press, Boston, MA.

Wallis, W.A., 1980. "The Statistical Research Group, 1942-1945", Amer. Stat. Assoc., 75, 320-333.

STATISTICAL QUALITY CONTROL IN ENVIRONMENTAL IMPACT ASSESSMENT: ROLES AND OBJECTIVES

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ABSTRACT

Decisions and policies for achieving specific environmental objectives are ideally based on measurements and observations, describing the response of the ecosystem to natural and anthropogenic perturbations. Actions based on data of questionable quality are likely to be inappropriate for achieving the intended goals. To avoid this situation, it is necessary to have in place, within any environmental monitoring program, a statistical quality control and quality assurance component which is capable not only of ensuring that the data generated have the required quality but also of communicating the results to decision makers.

Several approaches from the analysis of variability are described in this paper. The aims are to be able to identify, locate, estimate and control the sources of variation. The tools described for doing this include both descriptive graphical methods and statistical models. Some aspects related to the design of data quality studies will also be discussed.

INTRODUCTION

The assessment of the impact of anthropogenic activities on the health of ecosystems is a major issue in environmental research. Besides testing various ecological hypotheses, the detection and estimation of temporal and spatial changes in the structure and the function of the ecosystem community are the basic objectives of much of the research and monitoring activities. By relating observed changes to various levels of intervention such as Load's (nutrients and contaminants) control, it is possible to identify the most effective means of achieving management objectives. For example, the identification of phosphorous and nitrogen as the main factors that stimulate aquatic primary production and lead to accelerated eutrophication of lakes has resulted in the use of phosphorous load reduction as a management tool to control the occurrence of algal blooms in the lower Great Lakes.

Approaches commonly employed in the assessment range from a controlled experiment (eg. bioassays, experimental lakes, etc.) to regular and routine monitoring of the ecosystem. The ability to extrapolate the findings from these approaches to the system of concern is limited by not only the scope and design of the investigation but by also the quality of the generated data. The use of data with questionable quality carries the risk of making wrong decisions with serious consequences. This could be avoided by including a data quality control component as an integral part of the investigation. The objectives of such a component are to locate, estimate and control major sources of variation. Two sources of variations can be distinguished: natural or uncontrolled variation and controlled variation. Large uncontrolled variations are common in the environmental studies due to the natural variability of the material under investigation. Estimating the contributions of natural variation to overall variability should be an essential aim of the quality assurance program. The impact of this variation on the results can be reduced at the stage of study design through the use of replications.

The aim of this paper is to present techniques for assessing data quality. Some of these techniques are informal (mainly graphical) while the others are formal (estimation and hypothesis testing).

INFORMAL TECHNIQUES FOR ASSESSING DATA QUALITY

Graphs are very important informal tools for checking data values for the presence of outliers and for identifying violations of certain assumptions. The following are examples of graphical techniques which are commonly employed to look for small groups of discrepant values.

Frequency distributions, histograms and boxplots

These provide: (1) a data summary (measures of locations and spread), (2) information about possible probability models for representing the data, and (3) identification of illogically inconsistent values.

Control Charts

The ideal for an analytical laboratory is to maintain, at appropriate levels, the reproducibility of all the data produced at the required levels of quality. This means that the main statistical characteristics of data (mean, variance, etc.) remain the same for all the samples analyzed. Control charts are useful instruments for tracing causes of variation especially when the process is not well established and all the conditions that affect the data quality may not be known or may not have been brought under control. A second use of control charts is for the routine control of the quality of the analytical process and for providing evidence that the laboratory is producing results with the required quality.

Cumulative Sum Charts (CUSUM)

The CUSUM charts are more effective than the control charts in detecting whether a change in the mean level has occurred and to estimate the magnitude of the change.

FORMAL ANALYSIS OF VARIATION

This section describes some methods for estimating the magnitude of variations due to various sources. These are usually called the analysis of the components of variance.

Estimation of Two Variance Components

Suppose that n independent water samples were taken from a fixed location in a lake and suppose that each water sample is well mixed prior to dividing it to m equal volume subsamples. Each subsample is then analyzed in the laboratory to determine the concentration of a specific substance. Let x_{ij} be the random variable corresponding to the measured concentration in the jth subsample of the ith sample (j= 1,2,...,m, i= 1,2,....,n). The x_{ij}'s are subject to two types of errors, error due to sampling and error due to subsampling and analytical work. As a model for this setup, we take

$$x_{ij} = \mu + \epsilon_i + \omega_j,$$

Where μ is the mean concentration at the sampling station, ϵ_i is the error due to sampling and ω_j is the error due to subsampling and analytical work. Under the assumption that the errors are mutually independent with zero means. Let σ_ϵ^2 and σ_w^2 be the variances of ϵ and ω respectively. The variance of x_{ij} is then the sum of σ_ϵ^2 and σ_w^2. The object of variance component analysis is to estimate σ_ϵ^2 and σ_w^2 and to test different hypotheses regarding their values. Let x_i and s_i^2 be the mean and the variance for the ith sample, where

$$\bar{x}_i = \frac{(x_{i_1} + x_{i_2} + ... + x_{i_m})}{m}$$

and

$$s_i^2 = \sum_{j=1}^{m} (x_{ij} - \bar{x}_i)^2 \,/\, (m - 1)$$

s_i^2 is an unbiased estimate for the subsampling variance σ_w^2. Hence as a pooled estimate σ_w^2 based on all samples we have

$$\hat{\sigma}_w^2 = \sum_{i=1}^{n} s_i^2 / n$$

Further let s^2 be the between samples variance which is given by

$$s^2 = \sum_{i=1}^{n} (\bar{x}_i - \bar{x})^2 \,/\, (n - 1)$$

and

$$\bar{x} = \sum_{i=1}^{n} \bar{x}_i \,/\, n$$

Then it can be shown that

$$\hat{\sigma}_\epsilon^2 = s^2 - \hat{\sigma}_w^2 \,/\, m$$

is an unbiased estimate for σ_ϵ^2.

The ratio of the between sampling variance σ_ϵ^2 to the within sampling variance σ_w^2 provides an estimate for the impact of two sources of errors on the precision of the results generated by this set up. As an estimate of this ratio we use

$$\hat{\lambda} = \frac{\hat{\sigma}_\epsilon^2}{\hat{\sigma}_w^2}$$

As an example, consider the hypothetical data of Table 1. The rows in the Table correspond to the subsamples while the columns represent the samples. The estimates of the means x_i and the variances s_i^2 are given as the two bottom rows of the Table. The estimates of σ_w^2 and σ_ϵ^2 are respectively. Hence

$$\hat{\lambda} = \frac{\hat{\sigma}_\epsilon^2}{\hat{\sigma}_w^2} = 7.519$$

This shows that the between samples variation is more than seven times of that due to subsampling.

Design Consideration

How can the above information be used to set a routine monitoring program? The answer depends on the objectives of the program. For illustration we consider that the program is designed to either estimate: (1) the mean at the sampling station, or (2) the components of variance. Also the case of estimating both the mean and the components of variance will be discussed. The approach considered here is to minimize the variance of the quantity that we intend to estimate. In all cases the assumption is made that $c = mn$ is fixed (e.g., the number of subsamples to be analyzed is a priori fixed in advance).

Estimation of the Mean

The variance of the overall mean x is

$$\sigma^2 = \frac{\sigma_w^2}{m} + \frac{\sigma_e^2}{n} \qquad (1)$$

$$= \frac{\text{The variance within sample}}{\text{no. of subsamples}} + \frac{\text{Variance between samples}}{\text{no. of samples}}$$

Since c = mn is fixed, then the optimum design determines m or n so that σ^2 is maximized. The optimum value of m is

$$m = \sqrt{\frac{c}{\lambda}}$$

which is estimated by

$$\hat{m} = \sqrt{\frac{c}{\hat{\lambda}}}$$

and

$$\hat{\lambda} = \left(\frac{\hat{\sigma}_e}{\hat{\sigma}_w}\right)^2$$

Since λ is 7.519 and c = 54, then

$$\hat{m} = \sqrt{\frac{54}{7}.519} = 2.68 \approx 3$$

Hence n, the estimate of n, is 18.

Estimation of the Variance Components

To estimate n or m, the variances of σ_w^2 and σ_ϵ^2 as well as the Covariance between them are needed. For simplicity it is assumed the ϵ_i and w_j are normally distributed. It is easy to show that

$$var(\hat{\sigma}_w^2) = \frac{2\sigma_w^4}{n(m-1)},$$

$$var(\hat{\sigma}_\epsilon^2) = \frac{2}{(n-1)}\left(\sigma_\epsilon^2 + \frac{\sigma_w^2}{m}\right)^2 + \frac{2\sigma_w^4}{m^2 n(m-1)}$$

and

$$cov(\hat{\sigma}_w^2, \hat{\sigma}_\epsilon^2) = -\frac{2\sigma_w^4}{mn(m-1)}$$

Minimization of the determinant of the variance-covariance matrix is used to determine the optimum value of m and n subject to the condition c=mn. This determinant is

$$f(m) = \frac{4\sigma_w^8 (m\lambda + 1)^2}{c(c-m)(m-1)} \qquad (2)$$

The value $m=(2\lambda c+c+1)/(\lambda c+\lambda+c)$ maximizes the function f(m). Note that for $\lambda \rightarrow$ INF, the we have $m= 2c/(c+1)$ and when $\lambda=0$, $m= c+1/2$. Also this shows that for $\lambda \rightarrow$ INF and $c \rightarrow$ INF we have $m \rightarrow 2$, which is the minimum possible value of m for the estimation of σ_w^2. Indeed the optimum value of m is a decreasing function of λ. This is expected due to the relative increase in the sampling errors as compared to the subsampling errors.

For the data in Table 1, the value m=2.09 is the estimate of optimum number of subsamples required in future monitoring. The values of the second column of Table 2 are proportional to f(m). These indicate a serious loss of efficiency occurs if m is larger than 4.

Estimation of the Mean and the Components of Variance

Because of the independence of the mean x and the estimates of the variance components, the determinant of the variance-covariance matrix of all parameters is obtained directly by multiplying expressions (1) and (2). so the quantity which we need to minimize for the variation of m is

$$I(m) = f(m)\sigma^2$$

$$= \frac{4\sigma_w^{10}(m\lambda + 1)^2 (c + \lambda m)^2}{c^2 m (m-1)(c-m)} \qquad (3)$$

The value of m that maximizes I(m) is one of the roots of the equation

$$2\lambda (m\lambda + 1)^{-1} + 2\lambda m (c + \lambda m)^{-2} + (c-m)^{-1} - (m-1)^{-1} - m^{-1} = 0$$

This equation has to be solved numerically. In Table 2, Column 3, the values of I(m) $c^2/\Delta\sigma_w^{10}$ are given as a function of m, which show that the minimum value of the determinant occurs between m=2 and m=3.

Estimation of Three Variance Components

The previous analysis can be extended easily to the case of estimating more than two variance components. To show how this is done, the case of three variance components is outlined in this section. Let x_{ijk} be the measured concentration of the kth subsample of the ith sample which was determined in the jth laboratory where i=1,2,...,n; j=1,2,...,l and k=1,2,...,m. Three types of errors are expected to influence the determination of x_{ijk}. These are errors due to sampling, subsampling and the analytical work in the laboratory. Assuming additivity, the model of x_{ijk} can be written as

$$x_{ijk} = \mu + \epsilon_i + \gamma_j + \omega_k$$

The meanings of μ, ϵ_i, ω_k, are given before while γ_j refers to the errors due to the jth lab. It is also assumed that γ_j is independent of ϵ_i and ω_k and has zero mean and variance σ_l^2. The estimates of σ_ω^2, σ_γ^2 and σ_ϵ^2 are respectively

$$\hat{\sigma}^2_\omega = \sum_{i=1}^{n} \sum_{j=1}^{l} \sum_{k=1}^{m} (x_{ijk} - \bar{x}_{ij.})^2 \,/ nl\, (m-1)$$

$$\hat{\sigma}^2_\gamma = \frac{s_1^2 - \hat{\sigma}^2_\omega}{m}$$

and

$$\hat{\sigma}^2_e = s_2^2 - \frac{\hat{\sigma}^2_\gamma}{l} - \frac{\sigma^2_\omega}{ml}$$

where

$$s_1^2 = \sum_{i=1}^{n} \sum_{j=1}^{l} (\bar{x}_{ij} - \bar{x}_i \, ..)^2 \,/\, n(l-1)$$

$$s_2^2 = \sum_{i=1}^{n} (\bar{x}_i \, ... - \bar{x} \, ...)^2 \,/\, (n-1)$$

$$\bar{x}_{ij.} = \sum_{k=1}^{m} xijk \,/\, m$$

$$\bar{x}_i \, .. = \sum_{j=1}^{l} \bar{x}_{ij} \, . \,/\, l$$

and

$$\bar{x}_{\cdots} = \sum_{i=1}^{n} \bar{x}_{i\cdot\cdot} / n$$

In Table 3, the data of Table 1 are modified for the purpose of illustrating the process of estimating three variance components. In Table 3, where three samples were taken from a single sampling location, and each sample is divided into three subsamples with each subsample being given for analysis to one of three different labs at random. Within each lab the subsample is further subdivided to 6 subsamples for the within lab replicate analysis. Applying the formula's given above yields

$$\hat{\sigma}^2_\omega = 0.01896, \qquad \hat{\sigma}^2_\gamma = 0.00816$$

and

$$\hat{\sigma}^2_\epsilon = 0.813$$

These estimates show that most of the variation is caused by sampling.

Design Considerations

Under the condition that the total number N = nml of laboratory determinations is fixed, a sampling design for estimating the mean μ, minimizes the variance of x... which is

$$var\,(\bar{x}\ldots) = \frac{\sigma^2_\epsilon}{n} + \frac{\sigma^2_\gamma}{l} + \frac{\sigma^2_\omega}{m}$$

The minimum occurs when

and

$$l = \left(\frac{N\sigma_\gamma^4}{\sigma_e^2 \sigma_\omega^2} \right)^{\frac{1}{3}}$$

and

$$m = \left(\frac{N\sigma_\omega^4}{\sigma_e^2 \sigma_\gamma^2} \right)^{\frac{1}{3}}$$

Using these formulas for the data on Table 3 yields

$$n = \left(\frac{54(0.813)^2}{(.00816 \times .813)} \right)^{\frac{1}{3}}$$

$$= 1.43 \simeq 2$$

$$l = 0.62 \simeq 1$$

and

$$m \simeq 54 \div 2 = 27$$

In this example it is not realistic to regard l as a variable to be estimated. If this was the case then optimum design will be exactly the same as in the case of estimating two components of variance.

Table 1. Hypothetical Data for the Examples

		SAMPLE								
		1	2	3	4	5	6	7	8	9
Subsamples	1	1.59	1.72	1.59	2.44	2.27	2.46	1.36	1.73	1.53
	2	1.80	1.40	1.50	2.11	2.70	2.21	1.43	1.74	1.41
	3	1.72	2.02	1.50	2.41	2.36	2.50	1.48	1.65	1.64
	4	1.69	1.75	1.49	2.48	2.36	2.37	1.55	1.58	1.51
	5	1.71	1.95	1.47	2.36	2.16	2.24	1.53	1.49	1.52
	6	1.83	1.61	1.63	2.36	2.04	2.24	1.39	1.70	1.36
y		1.723	1.742	1.530	2.36	2.315	2.338	1.457	1.648	1.495
S^2		.00727	.05110	.00412	.01716	.05079	.01518	.00583	.0095	.00971

S_A^2 = .01896

S_B^2 = -.14256

$$\hat{\sigma}_A^2 = S_B^2 - \frac{S_A^2}{n} = 0.14256$$

$$\lambda = \frac{\hat{\sigma}_B^2}{\hat{\sigma}_A^2} = 7.519 \qquad \hat{n} = 2.086$$

Table 2. The dependence of various variances on the number of subsamples
Values are proportional to

No. of	Variance of	f(m)	l(m)	subsamples	the mean
m					
2	0.77	4.95	3.85		
3	0.75	5.44	4.09		
4	0.81	6.44	5.20		
5	0.91	7.60	6.81		
6	1.00	8.86	8.88		
10	1.49	14.66	21.88		
15	2.16	23.71	51.11		
20	2.83	35.47	100.56		
25	3.52	51.31	180.66		
30	4.21	73.76	310.55		
35	4.90	108.02	529.53		
40	5.95	166.77	933.04		
45	6.29	290.81	1828.65		
50	6.98	724.96	5061.67		
53	7.40	3069.34	22708.93		

Table 3. Data for the three variance components

		SAMPLE								
		1			2			3		
		LAB 1	LAB 2	LAB 3	LAB 4	LAB 5	LAB 6	LAB 7	LAB 8	LAB 9
Subsamples	1	1.59	1.72	1.59	2.44	2.27	2.46	1.36	1.73	1.53
	2	1.80	1.40	1.50	2.11	2.70	2.21	1.43	1.74	1.41
	3	1.72	2.02	1.50	2.41	2.36	2.50	1.48	1.65	1.64
	4	1.69	1.75	1.49	2.48	2.36	2.37	1.55	1.58	1.51
	5	1.71	1.95	1.47	2.36	2.16	2.24	1.53	1.49	1.52
	6	1.83	1.61	1.63	2.36	2.04	2.24	1.39	1.70	1.36

Comparison of Alternative Approaches for Establishing Measurement Quality Objectives for Ecological Studies

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ABSTRACT

The planning approach used in the establishment of measurement quality objectives for ecological studies influences not only the allocation of resources but also the overall success of the program. One approach is to assume that natural population variability is the limiting factor to be addressed in statistical sampling designs. A second approach assumes that, in addition, measurement error will be a limiting factor. As a result, significant resources may be allocated in these studies to reduce measurement error. A third approach is to set a goal of making measurement error statistically insignificant relative to population variability. This has the advantage of identifying when resources allocated to continued improvements in reducing measurement error will no longer be needed in studies. A requirement of this approach is the identification of populations of interest and the ability to determine overall measurement error through replicate routine samples and reference samples.

INTRODUCTION

Experimental data all have an overall variance associated with them. The overall variance (σ_o^2) is composed of the population variance (σ_p^2) and the measurement system variance (σ_m^2) or measurement error (Van Ee et al., 1990). The σ_p^2 includes both spatial and temporal variation. The σ_m^2 consists of the sampling method, preparation, and analytical error associated with data collection. It has been proposed that a measured value can be considered as essentially error-less for most uses if the uncertainty in that value is one-third or less of the permissible tolerance for its use (Taylor, 1987).

Measurement quality objectives (MQOs) are defined in terms of precision, accuracy, detectability, representativeness, comparability, and completeness. These characteristics were formerly defined as data quality objectives (DQOs). Usually, however, DQOs are now applied to overall program objectives while MQOs are defined for specific measurement parameters.

When establishing measurement quality objectives for environmental studies, three basic approaches have been identified to balance the acceptable variance, the number of samples, and the cost. These three approaches will be compared. The model used assumes that unbiased samples are collected so that sampling fluctuation is a function of population variance.

THEORY

Approach 1 may be expressed as follows:

For: $\sigma_o^2 = \sigma_p^2 + \sigma_m^2$,

Assume: $\sigma_p^2 >> \sigma_m^2$,

Then: $\sigma_o^2 \approx \sigma_p^2$.

In this approach the population variance is assumed to be much greater than the measurement variance, or the measurement error of currently available methods is assumed to be negligible. Therefore, the overall variance must be approximately equal to the population variance. Since the measurement error is assumed to be negligible, there is no need to improve the measurement system. Project resources are best spent on taking more samples, either at more sites or more often, to address the natural spatial or temporal variability in the population of interest.

The second approach may be expressed as follows:

For: $\sigma_o^2 = \sigma_p^2 + \sigma_m^2$,

Assume: $\sigma_p^2 \not\gg \sigma_m^2$,

Then: $\sigma_p^2 \approx \sigma_m^2$.

In this approach the measurement error is not assumed to be negligible. The population and measurement errors then become approximately equal in importance to the explanation of overall variance. Reducing measurement error is the major focus. Procedures are chosen which will result in the highest precision, lowest detection limit, and least bias. Therefore, significant resources are spent on obtaining the highest quality data.

Approach 3 (Taylor, 1987) may be expressed as follows:

For: $\sigma_o^2 = \sigma_p^2 + \sigma_m^2$,

Set as goal: $10 = 9 + 1$,

or: $10 = 3^2 + 1^2$,

where: $\sigma_p = 3$ and $\sigma_m = 1$.

This approach focuses on the balance between the population and measurement error components. The goal is to make the measurement error statistically insignificant. However, once that goal is achieved, continuing to reduce the measurement error has little benefit in addressing overall variance, as shown in the following example.

Example: $\sigma_o^2 = \sigma_p^2 + \sigma_m^2,$

When: $10 = 9 + 1$

If σ_m^2 is reduced by ½, then

$$9.5 = 9 + 0.5.$$

This approach provides the ability to identify the focus for quality assurance resources. Pilot studies are needed, however, to estimate the values of σ_o^2 and σ_m^2. Table 1 lists some advantages and disadvantages for the three approaches discussed above.

Table 1. Advantages and disadvantages of the three approaches.

	Advantages	Disadvantages
#1	Minimizes effects of σ_p^2	σ_m^2 could be problem
#2	Minimizes effects of σ_m^2	σ_p^2 could be problem
#3	Provides proper balance	Requires estimates of σ_m and σ_p

METHODS

To examine different approaches for establishing MQOs, soils data were examined from the Direct/Delayed Response Project (DDRP). The DDRP was conducted as part of the Environmental Protection Agency's (EPA) Aquatic Effects Research Program (AERP) under the congressionally-mandated National Acid Precipitation Assessment Program (NAPAP) as described in Church et al. (1989). The populations of interest were soil classes across a region. The example data, from one of the 148 sampling class/horizon combinations used in the Mid-Appalachian region (Byers et al., 1990), are from A horizon soil samples collected from deep, well-drained ultisols and alfisols with no fragipan (sampling class TWD).

Two measurement parameters are used in the following example. The first is exchangeable magnesium (MG_CL) determined with an unbuffered 1 mole/liter ammonium chloride solution and soil to solution ratios of approximately 1:13 for mineral soils, such as these, or 1:52 for organic soils. Atomic absorption or inductively-coupled plasma atomic emission spectrometry was specified. The second parameter is extractable silicon (SI_AO) determined by an ammonium oxalate-oxalic acid extraction using a 1:100 soil to solution ration. Inductively-coupled plasma atomic emission spectrometry was specified. The class data values, mean, standard deviation, and variance are listed in Table 2.

Table 2. Data for MG_CL and SI_AO from the DDRP Mid-Appalachian Soil Survey.

MG_CL cmole/kg	SI_AO wt%
0.222	-0.024
0.433	0.033
0.102	0.025
0.104	-0.008
0.105	0.060
0.414	0.056
1.801	0.023
$\bar{x}$ = 0.4544	$\bar{x}$ = 0.0257
s_0 = 0.5655	s_0 = 0.0286
s_0^2 = 0.3198	s_0^2 = 8.185×10^{-4}

Measurement error in the Mid-Appalachian DDRP samples was estimated using the sampling scheme shown in Figure 1. Duplicate samples were taken in the field and at the sample preparation laboratory. Reference samples were also used at the field, preparation laboratory, and analytical laboratory levels to allow the estimation of bias. The overall variance (σ_o^2) was calculated by pooling estimates over all of the 148 sampling class/horizon groups. Since the variance was concentration dependent, the data collection errors were partitioned into concentration intervals to evaluate the data uncertainty associated with the routine data (σ_m^2). The error terms from each interval were pooled and weighted by the proportion of routine samples within the corresponding intervals (Byers et al., 1990). This approach adjusted for differences in the distribution of the routine and QA samples across the observed concentration range. The population coefficients of variance (CV) averaged from 100-150% over a region, which is not unexpected for soils data.

RESULTS

The DDRP data (Table 2) can be used to illustrate the use of approach 3. The MG_CL data are an example of low measurement error. The population is all soil class x horizon combinations in a region,

where: $S_o = 0.474$ meq/100g

$S_m = 0.031$ meq/100g

and: $S_o^2 = S_p^2 + S_m^2$

$(0.474)^2 = S_p^2 + (0.031)^2$

Set: $S_m^2 = 1$,

Then: $234 = 233 + 1$.

Figure 2 (Byers et al., 1990) shows the range and frequency distribution of audit samples and of the routine MG_CL data partitioned into concentration intervals at uniform variability and their relation to pooled precision estimates. It can be seen that the standard deviations are near zero for the audit and duplicate samples, indicating low measurement error. It should be noted that this parameter was measured during all three of the DDRP soil surveys. Since the Mid-Appalachian survey was the third survey, the measurement protocol for MG_CL had been refined during the previous two surveys.

The SI_AO data are an example of high measurement error. The population of interest is again all soil class x horizon combinations in a region,

where: $S_o = 0.029$ wt%

$S_m = 0.013$ wt%

and: $S_o^2 = S_p^2 + S_m^2$

$(0.029)^2 = S_p^2 + (0.013)^2$

Set: $S_m^2 = 1$,

Then: $5 = 4 + 1$.

Figure 3 (Byers et al., 1990) shows the range and frequency distribution of the SI_AO data. The standard deviations of the audit and duplicate samples are all very different from zero, indicating high measurement error. Indeed, the audit and duplicate sample standard deviations are higher than some of the routine sample standard deviations for certain soil sampling class/horizon combinations. The Mid-Appalachian survey was the only DDRP soil survey which included determination of SI_AO. Therefore, the protocol did not have the refinement seen in the MG_CL determination.

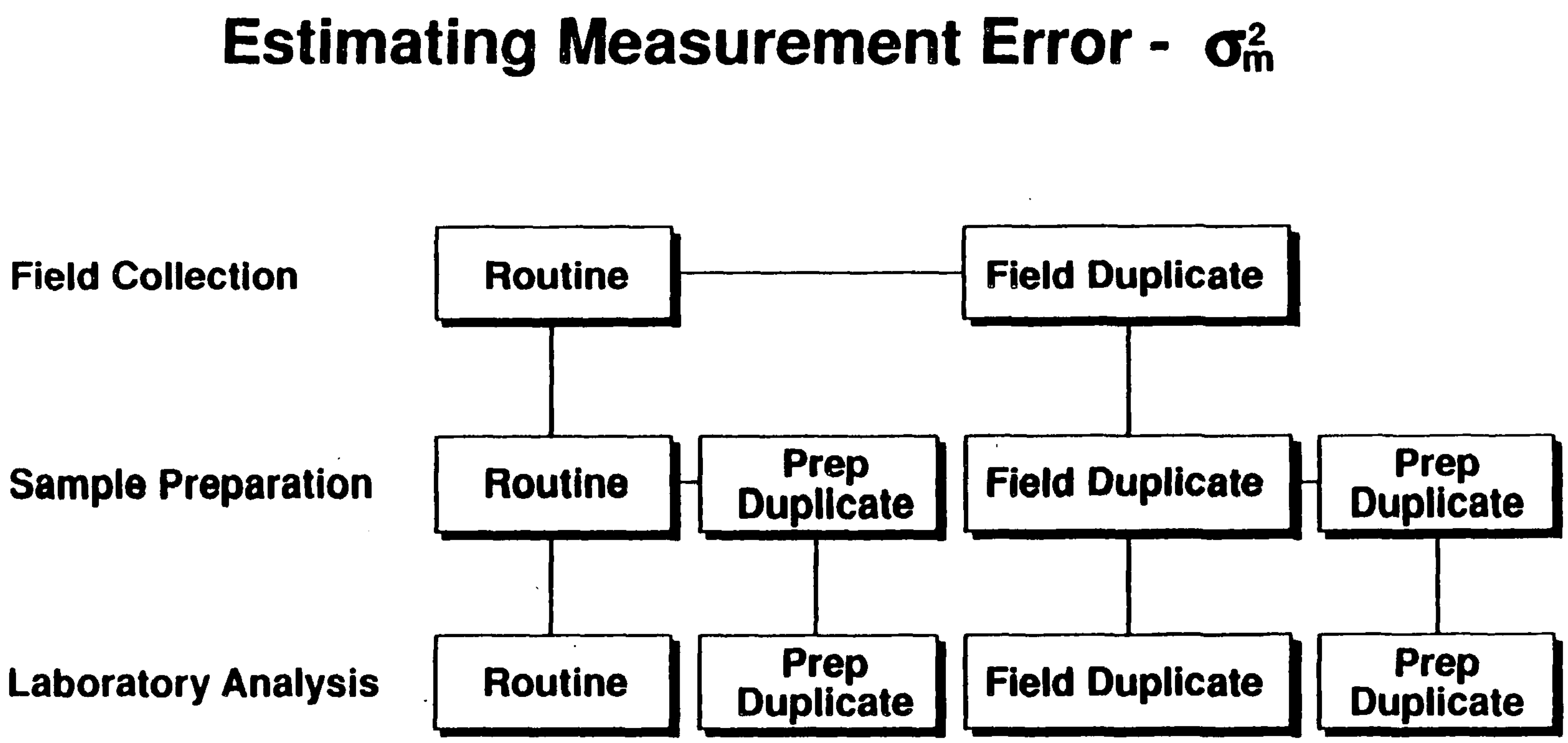

Figure 1. Sampling scheme used for estimation of measurement error.

CONCLUSIONS

A comparison of three approaches for establishing measurement quality objectives reveals the importance of balancing the population and measurement components of the overall variance. Approach 3 allows these components to be balanced using estimates of overall variance and measurement variance. These estimates may be obtained from pilot studies, which are a vital part of environmental studies. Approach 3 also allows a focus on the client; it provides a clear method for defining high quality data.

A key factor in the implementation of the third approach is the proper identification of the population of interest and the overall measurement system. The population of interest is generally the lowest aggregation of data for which estimates are made. In the case of the Mid-Appalachian soil survey, aggregations of data could be made for soil horizons within sampling classes, overall pedons within sampling classes, across different sampling classes with similar characteristics, or for the overall region as a whole. In this case the lowest aggregation is the soil horizon/sampling class combination. In a similar manner, the components of the overall measurement error need to be identified. This needs to include all possible measurement error from the field to the laboratory.

With monitoring programs the population of interest may be the changes at a given site over time. In this case the measurement error needs to include all measurement errors from the field to the laboratory at any point in time plus changes in the measurement system over time. The use of reference materials that span the monitoring intervals is critical to the evaluation of this component of measurement error.

REFERENCES

Byers, G.E., R.D. Van Remortel, M.J. Miah, J.E. Teberg, M.L. Papp, B.A. Schumacher, B.L. Conkling, D.L. Cassell, and P.W. Shaffer. 1990. Direct/Delayed Response Project: Quality assurance report for physical and chemical analysis of soils from the Mid-Appalachian region of the United States. EPA 600/4-90/001, U.S. Environmental Protection Agency, Washington, D.C.

Church, M.R, K.W. Thornton, P.W. Shaffer, D.L. Stevens, B.P. Rochelle, G.R. Holdren, M.G. Johnson, J.J. Lee, R.S. Turner, D.L. Cassell, D.A. Lammers, W.G. Campbell, C.I. Liff, C.C. Brandt, L.H. Liegel, G.D. Bishop, D.C. Mortenson, S.M. Pierson, and D.D. Schmoyer. 1989. Future effects of long-term sulfur deposition on surface water chemistry in the northeast and southern Blue Ridge province: Results of the Direct/Delayed Response Project. EPA/600/3-89/061, U.S. Environmental Protection Agency, Washington, D.C., 887 pp.

Taylor, J.K. 1987. Quality assurance of chemical measurements. Lewis Publishers. Chelsea, Michigan. 328 pp.

Van Ee, J.J., L.J. Blume, and T.H. Starks. 1990. A rationale for the assessment of errors in the sampling of soils. EPA/600/X-90/203, U.S. Environmental Protection Agency, Washington, D.C.

NOTICE

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MG_CL
Exchangeable Magnesium in Ammonium Chloride

Routine Samples

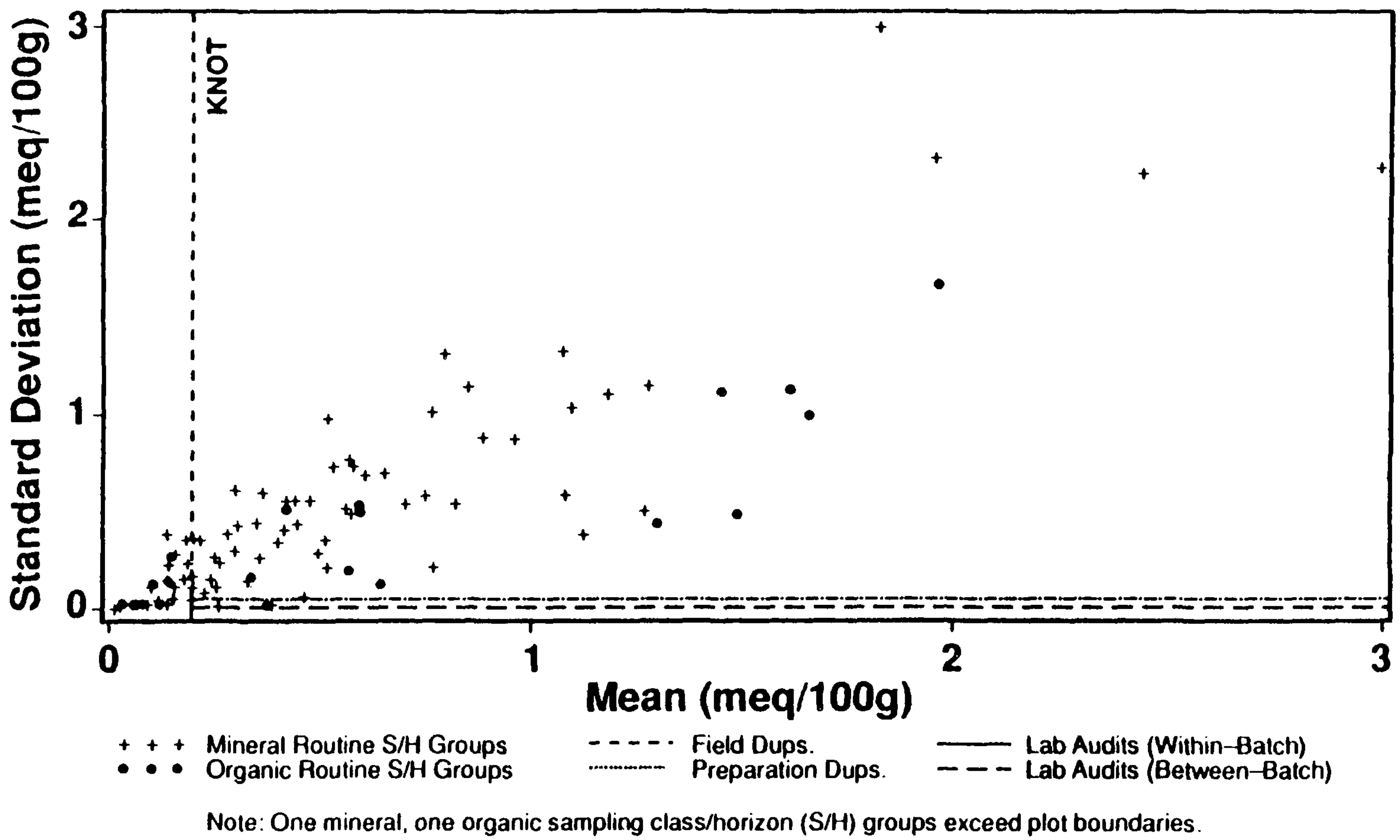

Figure 2. Range and frequency distribution of MG_CL for sampling class/horizon routine sample data partitioned into concentration intervals of uniform variability and their relation to pooled precision estimates. (Byers et al. 1990)

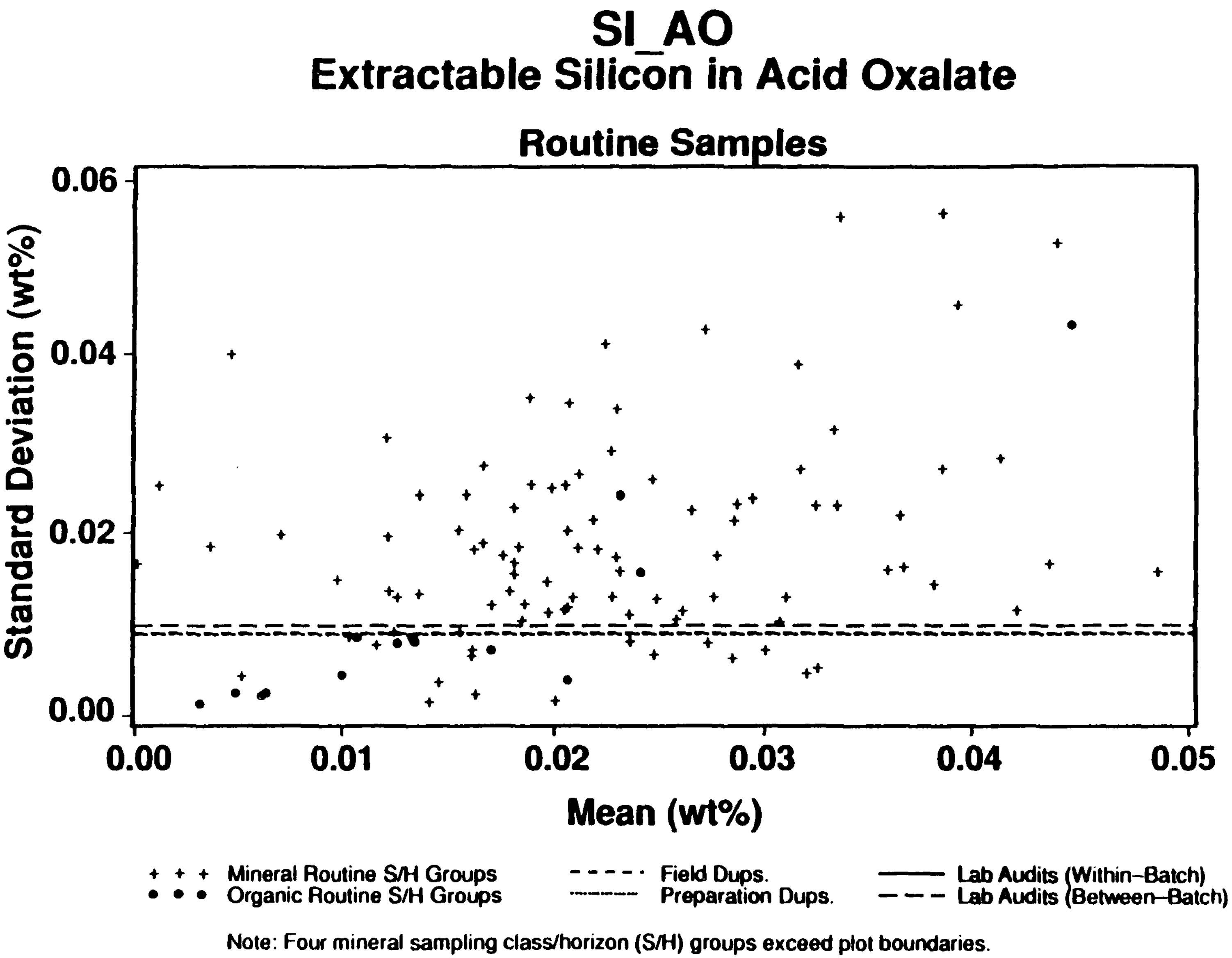

Figure 3. Range and frequency distribution of SI_AO for sampling class/horizon routine sample data partitioned into concentration intervals of uniform variability and their relation to pooled precision estimates (Byers et al., 1990).

FOURTH ANNUAL ECOLOGICAL QUALITY ASSURANCE WORKSHOP

PLENARY SESSION B

Thursday, February 27, 1991

NOAA National Status and Trends Program Quality Assurance Program

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ABSTRACT

NOAA's National Status and Trends (NS&T) Program for Marine Environmental Quality determines the current status of, and any changes over time in the environmental health of the estuarine and coastal waters of the United States. The Quality Assurance (QA) Program is one of NS&T's four major components. The QA Program is designed to document sampling and analysis procedures, and to reduce intralaboratory and interlaboratory variations. To document laboratory expertise, the QA Program requires all NS&T laboratories to participate in a continuing series of intercomparison exercises utilizing a variety of materials. Some non-NS&T laboratories voluntarily participate in the QA Program, and additional monitoring laboratories are welcome. Selected results of the intercomparison exercises will be described.

NOAA'S NATIONAL STATUS AND TRENDS PROGRAM

NOAA's National Status and Trends (NS&T) Program for Marine Environmental Quality determines the current status of, and any changes over time in the environmental health of the estuarine and coastal waters of the United States, including Alaska and Hawaii. The NS&T Program consists of four major components: the Benthic Surveillance Project, the Mussel Watch Project, Bioeffects Surveys, and the Quality Assurance (QA) Program.

The Benthic Surveillance Project determines concentrations of contaminants in sediments and bottom-dwelling fish taken in the same area at sites located around the nation. The frequency of external disease conditions and internal lesions (liver tumors) in the bottomfish are also being documented. Currently, there are about 75 Benthic Surveillance sites in estuaries and coastal waters, including both urban and rural areas. Samples are generally collected biennially at these sites. Sample collection and analysis for the Benthic Surveillance Project is done by the NOAA National Marine Fisheries Service laboratories at Seattle, WA, and Beaufort, NC.

The Mussel Watch Project determines the same contaminants as in the Benthic Surveillance Project in sediments and mussels or oysters, instead of fish. The bivalves are collected on a yearly basis from approximately 220 sites in the United States, while sediments are collected at the same sites on a less-than-yearly basis. Sample collection and analysis for the Mussel Watch Projects is done by the Texas A&M University Geochemical and Environmental Research Group, College Station, TX, and the Battelle laboratories at Duxbury, MA, and Sequim, WA.

Over 77 contaminants are determined by the NS&T Program, including organic chemicals such as DDT and its metabolites, other chlorinated pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons, and butyltins, as well as trace and major elements, such as Pb, Zn, Cd, Ag, As, and Hg (Table 1).

QUALITY ASSURANCE PROGRAM

The quality of the analytical data generated by the NS&T Program is overseen by the QA Program component, which is designed to document sampling protocols and analytical procedures, and to reduce intralaboratory and interlaboratory variation. The QA Program documentation will also allow eventual comparison between different monitoring programs with similar QA activities and thus will extend the temporal and spatial scale of such programs. To document laboratory expertise, the QA Program requires all NS&T laboratories to participate in a continuing series of intercomparison exercises utilizing a variety of materials. The organic analytical intercomparison exercises are coordinated by the National Institute of Standards and Technology (NIST), and the inorganic analytical intercomparison exercises by National Research Council (NRC) of Canada.

Every year, a set of calibration solutions and unknown samples are sent to each laboratory participating in the intercomparison exercises. The type and matrix of the samples changes yearly. Sample types have included freeze-dried sediments, extracted freeze-dried tissues, and frozen tissues. Matrices have included mussel, oyster, fish tissue, and sediments from pristine and contaminated areas. The initial samples of a given exercise are sent to the laboratories early in the spring, with complete handling instructions and data reporting format. Only when a laboratory successfully finishes the analysis of the first set of samples of a given exercise will the next set be sent. If problems are encountered during any of the phases of the intercomparison exercises, the laboratories can contact NIST or NRC for assistance. The results of the intercomparison exercises are discussed among NIST, NRC, and the participating laboratories during the yearly QA Workshop held in late fall or winter. During this meeting, a consensus is reached between NIST, NRC, NOAA, and the laboratories as to the type of materials that will be used for the following year's intercomparison exercise. Some of the materials used for intercomparison exercises have become standard reference materials based on the results of the exercises.

METHODOLOGY

NS&T does not specify analytical methodology. Laboratories can use any analytical procedure as long as the results of the intercomparison exercises are within certain specified limits of the consensus values. This allows the use of new or improved analytical methodology or instrumentation without compromising the quality of the data sets. It also frees the contractor laboratories to use the most cost-effective methodology while generating data of documented quality. The analysis of reference materials, such as the NIST Standard Reference Materials (SRMs) and NRC Certified Reference Materials (CRMs), or of control materials generated for use by NS&T labs as part of the sample stream, is required. All analytical methodology and sampling protocols used are fully documented for future reference. This will provide a record of the continuity of expertise as personnel and instrumentation changes take place. The results of the routine analysis of reference and control materials, and of the intercomparison exercises, are stored electronically as part of the NS&T database.

RESULTS

Intercomparison exercises have been taking place since 1985. Overall, the performance of "core" laboratories, those that have participated since the beginning of the QA Program intercomparisons exercises, has improved with time. It is not possible, however, to document this statistically since different types of materials are used each year and the difficulty of the analyses has increased with time as the level of expertise of the participating laboratories has improved. Thus, possible analytical errors due to matrix interference, analyte level, and other variables change from year to year.

Table 1. Chemicals determined as part of the NOAA National Status and Trends Program

Polyaromatic hydrocarbons

Biphenyl	Fluoanthene
Naphthalene	Pyrene
1-Methylnaphthalene	Benz(a)anthracene
2-Methylnaphthalene	Chrysene
2,6-Dimethylnaphthalene	Benzo[a]pyrene
Acenaphthene	Benzo[e]pyrene
Acenaphthylene	Perylene
2,3,5-Trimethylnaphthalene	Dibenz[a,h]anthracene
Fluorene	Benzo[b]fluoranthene
Phenanthrene	Benzo[k]fluoranthene
1-Methylphenanthrene	Indeno[1,2,3-cd]pyrene
Anthracene	Benzo[g,h,i]perylene

DDT and metabolites

o,p'-DDD	p,p'-DDD
o,p'-DDE	p,p'-DDE
o,p'-DDT	p,p'-DDT

Chlorinated pesticides other than DDT

Aldrin	Dieldrin
a-Chlordane	trans-Nonachlor
Heptachlor	Lindane
Heptachlor epoxide	Mirex
Hexachlorobenzene	

Polychlorinated biphenyls congeners

PCB-8	PCB-18	PCB-28
PCB-44	PCB-52	PCB-66
PCB-101	PCB-105	PCB-118
PCB-128	PCB-138	PCB-153
PCB-179	PCB-180	PCB-187
PCB-195	PCB-206	PCB-209

Elements

Al	Fe	As	Sn	Zn
Cd	Cr	Cu	Pb	Hg
Se				

The results of the fourth round of intercomparison exercises for trace metals in sediments and tissues were made available in the fall 1990 (Berman, 1990). Two samples of sediment and oyster tissue were sent to each of the participating laboratories. The samples were sediment from the Beaufort Sea, a calcareous sediment collected in San Antonio Bay, TX, and a composite oyster tissue of specimens collected over the entire Gulf of Mexico. The oyster tissue was freeze dried and homogenized. The participants were asked to perform five replicate analyses of each sample and of two NRC Certified Reference Materials. The sediments were analyzed for Al, Cr, Fe, Cu, Zn, As, Se, Cd, Sn, Hg, and Pb; analysis of Si, Mn, Sb, and Tl were optional. The oyster tissue was analyzed for the same suite with the addition of Ag. Ten laboratories reported results.

Typical results of the 1990 trace metal intercomparison exercise are shown in Figure 1. The Zn and As analyses results of one of the sediment samples and the oyster tissue sample are shown in Figure 1. In all four examples, results from a "core" lab, a "new" lab, and NRC are shown. The performance of the "core" lab is comparable to that of the NRC, while that of the "new" lab needs improvement. Major advances were noted in the determination of As, Se, Ag, Sn, Sb, Hg, and Pb. No apparent improvement was noted in the 1990 exercise in the determination of Al, Cr, Fe, and Ni which were already being competently determined. There are still problems in the analysis of Se, Sn, Sb, and Hg in sediments. Also improvement in the variance of Al and Fe determinations is needed. The analysis of Al, Si, Cr, Cu, As, Se, Sn, Sb, and Hg in tissues still pose difficulties.

The results of the fifth round of intercomparison exercises for trace organics in sediments and tissues were made available in the fall 1990. Sixteen laboratories participated, although some only reported partial results. An enriched bivalve tissue extract in methylene chloride, and a solution of 6 aromatic hydrocarbons, 6 chlorinated pesticides and 6 PCB congeners in 2,2,4-trimethylpentane, were sent to the participating laboratories. The tissue extract was enriched for the same 18 compounds present in the 2,2,4-trimethylpentane solution. The control materials used were a sediment collected in Baltimore Harbor, a composite Boston Harbor mussel tissue material and NIST SRM 1974. Typical results of the organic intercalibration exercise are shown in Figure 2. The mean absolute percent errors are much better overall for the "core" lab than for the "new" lab, although the performance of the NIST is better than that of the "core" lab. The results of the same "new" and "core" laboratories were used in Figures 1 and 2. Note, however, that different chemists performed the analyses. Further evaluation of the results of the exercise are still underway.

FUTURE DEVELOPMENTS

The intercomparison exercises will continue on a yearly basis, following the established time sequences and final workshop.

The Environmental Protection Agency is implementing a new program, the Environmental Monitoring and Assessment Program (EMAP), to provide the public, scientists and Congress with information that can be used to evaluate the overall health of the Nation's ecological resources. EMAP will focus on indicators of ecosystem health, while NS&T focuses on chemical pollutants. The near coastal component of EMAP, EMAP-NC, is working closely with NS&T in monitoring coastal ecosystems. To assure data compatibility, the EMAP-NC laboratories are participating in NS&T's QA Program and financing part of the work.

Some non-NS&T or non-EMAP laboratories currently participate voluntarily in the QA Program and additional monitoring laboratories are welcome as the QA Program expands during 1991. The 1991 organic intercomparison exercise materials include a fish tissue, an extract of mussel tissue, and calibration solutions. A contaminated sediment, a bivalve tissue, and calibration solutions will be used for the inorganic intercomparison exercises. The expansion effort for the QA Program will continue during 1991. For further information regarding participation in the intercomparison exercises, please contact the author, the NS&T Quality Assurance Coordinator.

REFERENCES

Berman, S. (1990) Fourth round intercomparison for trace metals in marine sediments and biological tissues NOAA/BT4. Unpublished report, NOAA/NOS/OAD, 50pp.

APPLICATION OF QA CONCEPTS FROM THE THIRD ECOLOGICAL WORKSHOP TO A LONG-TERM AQUATIC FIELD ASSESSMENT PILOT STUDY

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ABSTRACT

The U.S. EPA Region III Regional Applied Research Effort (RARE) project was initiated in July 1990 and is intended to aid in addressing questions relating to the effects of coal surface-mining on the biological integrity of stream ecosystems. Results of this joint project between the U.S. EPA and the State of West Virginia will also be used to help assess the effectiveness of pollution abatement requirements. In this paper, QA/QC factors from the Third Annual Ecological QA Workshop are used to evaluate the quality assurance status of the RARE pilot study of 31 July and 1 August 1990. Also, a broad project overview is presented with a focus on the proposed 5-year project duration.

INTRODUCTION

The development of an effective Quality Assurance Plan at the onset of conducting an ecological study is necessary to provide guidance throughout the complex program, delineate lines of responsibility, and to establish accountability. The efficacy and validity of the ecological study and resultant conclusions are dependent upon the quality assurance plan. For ecological studies the major classes of activity of a QA plan are:

- Quality Management
- Sampling Design
- Field Operations

- Laboratory Activities
- Data Analysis
- Reporting

Each have various quality control (QC) elements which control for potential sources of error. Technical interaction of the implemented QC elements with these potential error sources were presented in matrix form in the document produced by Workgroup 2 in the Third Ecological QA Workshop held in Burlington, Ontario in April 1990 (Barbour and Thornley 1990).

The determination of data quality is accomplished through the development of data quality objectives (DQOs). DQOs are qualitative and quantitative statements developed by data users to specify the quality of data needed to support specific decisions (Plafkin et al. 1989). The data quality objective (DQO) logic process resulting from the third workshop consists of several separate but linked thought processes which include (A) statement of the problem to be resolved, (B) identification of potentially pertinent variables and selection of those to be measured, (C) development of a logic statement, (D) specification of an acceptable level of uncertainty, and (E) optimization of research design (Figure 1).

Statement of the problem is the central issue, which relates to the overall objective of the study and the ultimate decision once a judgment is made. Characterization of the problem includes stating the specific question or questions to be addressed which help partition the problem into appropriate components and may pertain to such things as use designation or biocriteria. If historical data exist, they should be acquired and evaluated for utility in designing appropriate questions.

The next step in the DQO logic process is the identification of all variables potentially affecting the problem. These are considered in either abiotic or biotic terms and are related to the central question. From this set, those which will be measured and evaluated in the project are selected. The selection process may be driven by resource limitations and/or available expertise in measuring certain variables. Logic statements are developed for each and include the variable itself, the measured value, the judgment domain or criterion, and guide for the decision-making process.

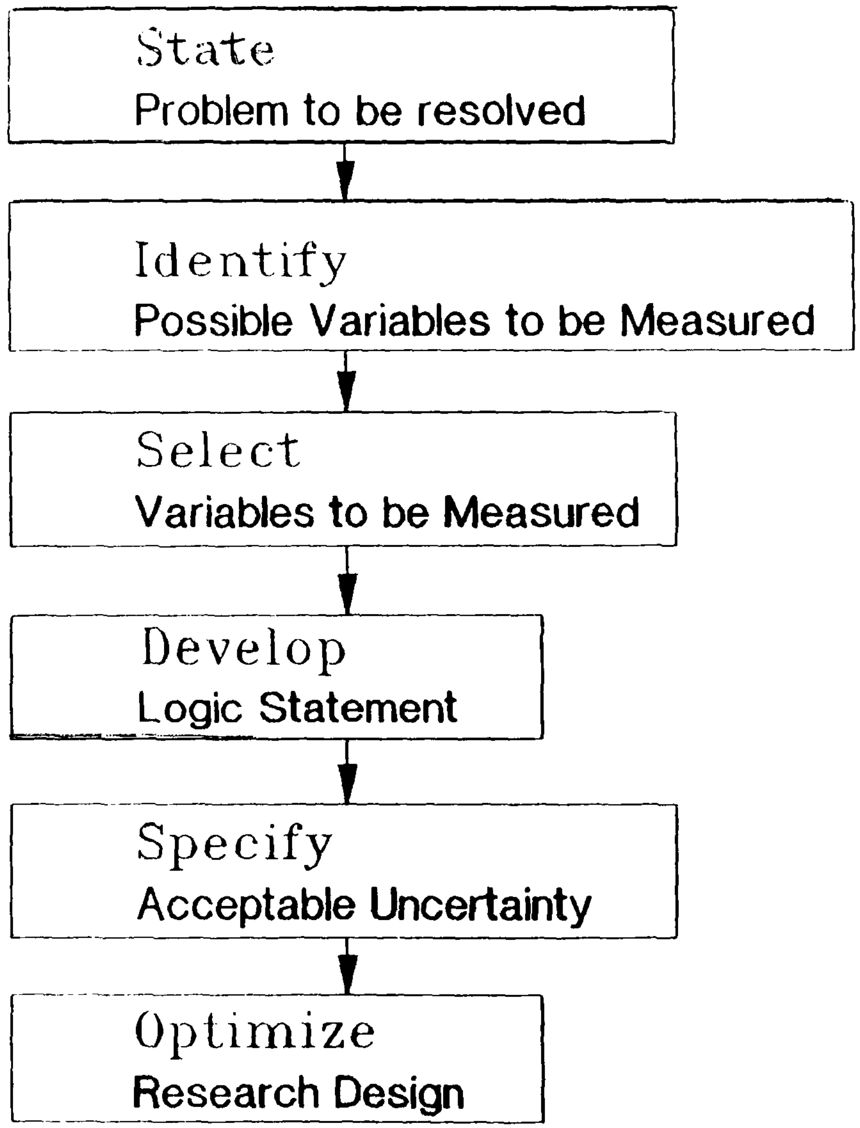

Figure 1. Data Quality Objective logic flow (Barbour and Thornley, 1990).

Given available resources and/or cost investment, the level of acceptable uncertainty must be considered and documented. The level of confidence associated with decisions on all measured variables will ultimately affect the level of confidence in addressing the central question. This level of confidence is related to error analyses and the consequences of that error. Two types of error are recognized--false negatives and false positives. False negatives are when conditions exist and remain undetected. Consequences of this error could be unabated degradation. The latter is the detection of a condition when, in fact, none exists. False positives could lead to the requirement of unnecessary mitigation and the potential loss of credibility for the investigator.

In this paper, an overview is presented of the Quality Assurance plan and the data quality objective logic flow that was incorporated into the initial project work plan developed by U.S. EPA Environmental Monitoring Systems Laboratory (EMSL-Cincinnati) for the West Virginia Regional Applied Research Effort (RARE project) and into the pilot study conducted in 31 July and 1 August 1990. The framework for this analysis resulted from the Third Ecological QA Workshop (Hart 1990) and includes the data quality objective logic process and quality control elements from those proceedings.

THE EPA REGION III RARE PROJECT

Objective

The purpose of this project is to investigate the effects of surface-mining activities on the biological integrity of the aquatic community. Results of this study will be used by EPA (Region III-Wheeling and EMSL-Cincinnati) and the West Virginia Divisions of Energy and Natural Resources (WVDOE, WVDNR) to determine the efficacy of pollution abatement requirements. They will also enable them to address the potential necessity of additional regulations. The data gathered during each sampling event will be of sufficient quality to address the central problem: Is there an effect of the combined surface-mining activities on the biological integrity of streams adjacent to the mining areas? More specific questions relating to the central problem can be developed which may allow evaluation of causative factors. Specific questions to be addressed in this RARE project are:

1. Are the mining activities effecting degradation of stream habitat and/or water quality?

2. If so, is this degradation adversely affecting benthic macroinvertebrate community vigor? and,

3. Likewise, is it adversely affecting fish community vigor?

General Overview

Surface-mining involves several stages including clear-cutting of timber, grubbing (term describing removal of stumps and debris), materials extraction, and reclamation. Logging and blasting of bedrock began on August 01 as field teams were completing samples at the final sites. During the clear-cutting and grubbing portion of this process, much bedrock and all groundcover are removed and nearly all surface soils are mechanically disrupted. This produces a situation ideal for erosive activity during rain events and consequent heavy sediment loading into streams.

The study site is located in Mingo County near Wilsondale in western West Virginia about one hour south of Huntington. The 14 sampling stations (Table 1) are distributed through the east fork subwatershed of the Twelvepole Creek drainage system. Target streams include Alex Branch, Old House Branch, Caney Fork, Pretty Branch, and East Fork Twelvepole Creek; these range in size from first to third or fourth order. In general, the streams are shallow and low gradient. Many of the first and second order streams have a bedrock substrate; the larger streams (third or fourth order) have gravel and cobble substrates. At the time of this pilot study, most of the sites had experienced minimal habitat disruption. East Fork mainstem was an exception in that an asphalt road parallels it on the north side providing runoff through a buffer zone reduction.

Although the majority of this paper deals with the DQOs and QC elements of the pilot study, a brief overview of the 5-year phased project is presented (Table 2). If mining activities proceed as expected, primary sampling events will be annual and will roughly correspond to the stages of mine development. Thus, incremental monitoring of full impact will be achieved throughout continued operations.

Response Variables and Specific Questions

For the identification of more specific questions it becomes necessary to define "biological integrity". Biological integrity is functionally defined as "the condition of the aquatic community inhabiting the unimpaired waterbodies of a specified habitat as measured by community structure and function" (EPA 1990). Karr and Dudley (1981) presented an earlier, more specific definition as "the ability of a habitat to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region".

Variables potentially affecting resolution of the central problem can be divided into abiotic and biotic considerations. Abiotic variables selected for evaluation are the habitat assessment parameters included in the habitat assessment procedure of Rapid Bioassessment Protocols (RBPs; Plafkin et al. 1989) as modified by Barbour and Stribling

(1991, in press). These habitat assessment parameters deal with characteristics of instream structure, canopy cover, channel morphology, riparian vegetative community, and bank structure (Table 3).

Biotic variables are within the communities to be sampled for evaluation of these sites: benthic macroinvertebrates and fish. A multimetric community analysis procedure (RBPs, Plafkin et al. 1989) will be used for evaluation of these components of the biota. Macroinvertebrate community health (as biological condition) is estimated by calculation of metrics dealing with community composition, structure, and function (Table 4); fish communities are evaluated by calculation of the Index of Biotic Integrity (Karr et al. 1986, Plafkin et al. 1989) which also deals with community attributes (Table 5). With this approach, biological condition is integrated with habitat quality for the overall assessment.

TABLE 1 SAMPLING STATIONS FOR THE U.S. EPA REGION III RARE PROJECT. ALL ARE LOCATED IN THE EAST FORK OF TWELVEPOLE CREEK IN MINGO COUNTY, WEST VIRGINIA

Station	Stream	Order
T1	Twelvepole Creek	3-4
T2	Twelvepole Creek	3-4
T3	Twelvepole Creek	3-4
T4	Twelvepole Creek	3-4
T5	Twelvepole Creek	3-4
O6	Old House Branch	1
C7	Caney Fork	2
C8	Caney Fork	2
C9	Caney Fork	1
C10	Caney Fork	1
C11	Caney Fork	1
C12	Caney Fork	1
A13	Alex Branch	1
P14	Pretty Branch	2

TABLE 2 EPA REGION III RARE PROJECT OVERVIEW.

A. Central Question: Effects of surface-mining activities on the aquatic community.

B. Specific Questions:

1. Effects on habitat quality.
2. Effects on biological condition of macroinvertebrate assemblage.
3. Effects on biological condition of fish assemblage.

C.

Phase	Site Condition	Subquestions
Pilot study	Minimal disturbance	1. appropriate response variables 2. appropriate methods / procedures 3. sampling stations / reference sites 4. natural variability of habitat and populations
1	100% deforestation;	1. appropriate analyses to differentiate among stations 2. effects of habitat alteration on aquatic community 3. adequate study design
2	post-grubbing	1. effects on habitat quality 2. effects on macroinvertebrates 3. effects on fish
3	active mining completed	same questions as Phase 2
4	reclamation	same questions as Phase 2
5	2 years post-reclamation	same questions as Phase 2

TABLE 3 HABITAT ASSESSMENT PARAMETERS FOR RIFFLE/RUN PREVALENT SITUATIONS. TAKEN FROM BARBOUR AND STRIBLING (1991, IN PRESS).

Primary -- Substrate, Instream Cover, and Canopy

1. Substrate Variety/Instream Cover
2. Embeddedness
3. Flow or Velocity/Depth
4. Canopy Cover (Shading)

Secondary -- Channel Morphology

5. Channel Alteration
6. Bottom Scouring and Deposition
7. Pool/Riffle, Run/Bend Ratio
8. Lower Bank Channel Capacity

Tertiary -- Riparian and Bank Structure

9. Upper Bank Stability
10. Bank Vegetative Stability (Grazing/Disruptive Pressure)
11. Streamside Cover
12. Riparian Vegetative Zone Width

TABLE 4 BIOLOGICAL CONDITION METRICS TO BE CALCULATED ON MACROINVERTEBRATE SURVEY DATA. FROM RBP III (PLAFKIN ET AL. [1989]).

Community Structure

1. Taxa Richness
2. EPT Index
3. Pinkham and Pearson
4. QSI-Taxa

Community Balance

5. HBI
6. % Dominant Taxon
7. DIC-5
8. Hydropsychidae/Trichoptera

Functional Feeding Group

9. Scrapers/(Scrapers + Filter Collectors)
10. Shredders/Total
11. QSI-Taxa

Logic Statements

A logic statement is a characterization of the expected value or range of values to be obtained for a given variable or composite of variables. Outliers from the established expectations are considered deviations from the norm at which management decisions are made. The entire QA/QC process is dedicated to the ability to make these decisions with some level of confidence. The relationship between habitat quality (as percent of reference) and biological condition (as percent of reference) can be established as illustrated in Figure 2 to provide for an integrated assessment of composited variables. The sigmoid curve represents a conceptual expectation of the relationship between habitat quality and biological condition.

From this relationship, the ability to differentiate between water quality effects and habitat alteration is dependent upon the integrity of the reference data. Essentially, three major outcomes (scenarios) in this integrated assessment approach are possible (Figure 3):

Scenario A - If biological condition is rated as "non-impaired," and habitat quality as "supporting" or "comparable," then biological integrity is indicated;

Scenario B - If biological condition is rated as "slightly impaired" or better, and habitat quality as "supporting" or "comparable," then contaminant effects are present;

Scenario C - If biological condition is rated as "slightly impaired" or lower, and habitat quality as "partially supporting" or lower, then a combination of habitat quality and water quality effects are present.

These scenarios are based on the assumption that acceptable and unacceptable conditions have been ascertained through the establishment of a threshold value. Using the values suggested by Plafkin et al. (1989), separate threshold values can be determined for habitat quality and biological condition.

For habitat - If the habitat assessment score is less than 90 percent of the reference site, then it is less than comparable.

For the benthic macroinvertebrates - If the total of the metric scores is less than 83 percent of reference conditions, then the site is impaired.

The pilot study will be used to evaluate the appropriate threshold values to differentiate between nominal and subnominal conditions. The logic statement for the integrated assessment will be developed to incorporate the composite of variables and ultimately, the judgment of impairment from the mining activities.

Acceptable Uncertainty

The more critical the consequences of ecological analysis for decision-making, the narrower one wants confidence intervals. The capacity to increase confidence in decisions is directly dependent on the available resources and on cost investment.

In this RARE project, the consequences of a false negative would be that stream degradation could continue unabated and there would be no indication of a need for further pollution abatement requirements as mining activities proceed. A false positive might cause unnecessary regulations to be enacted, or, at additional costs for verification, the study to be repeated because of weaknesses in the study design.

Uncertainty in ecological studies arises in several tiers, for purposes of this discussion, roughly corresponding to five of the six major activity classes discussed earlier: sampling design, field operations, laboratory activities, data analysis, and reporting. Hart (1990) and Taylor (1988) point out that components of uncertainty from various sources are additive. It seems that specification of acceptable levels of uncertainty for rapid bioassessment protocols (benthos) must be developed from consideration of specific components to reduce compounding error from an additivity perspective. However, quantifiable confidence limits cannot be developed for some of these activities in the absence of parallel studies. Funding levels usually cannot support simultaneous and complete parallel studies. The level of uncertainty associated with these must be qualitatively related to the implementation of QC elements for control of specific potential error sources. A number of these elements are discussed below.

TABLE 5 BIOLOGICAL CONDITION METRICS TO BE CALCULATED ON FISH SURVEY DATA. FROM THE IBI (RBP V) (PLAFKIN ET AL. [1989]).

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1. Number native species.
2. Number darter or benthic species.
3. Number sunfish or pool species.
4. Number sucker or long-lived species.
5. Number intolerant species.
6. Proportion green sunfish or tolerant individuals.
7. Proportion omnivorous individuals.
8. Proportion insectivores.
9. Proportion top carnivores.
10. Total number individuals.
11. Proportion hybrids or exotics.
12. Proportion disease/anomalies.

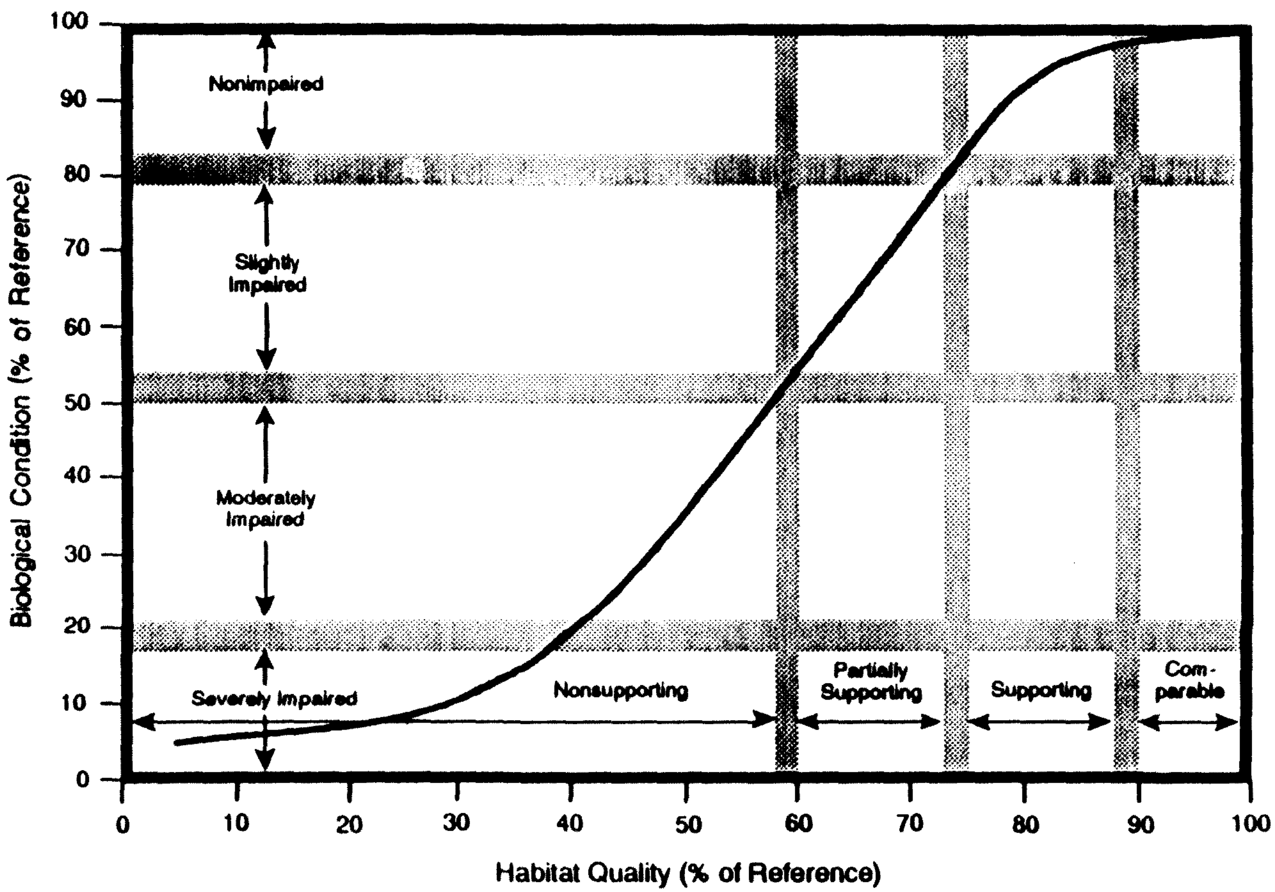

Figure 2. The relationship between habitat and biological condition.

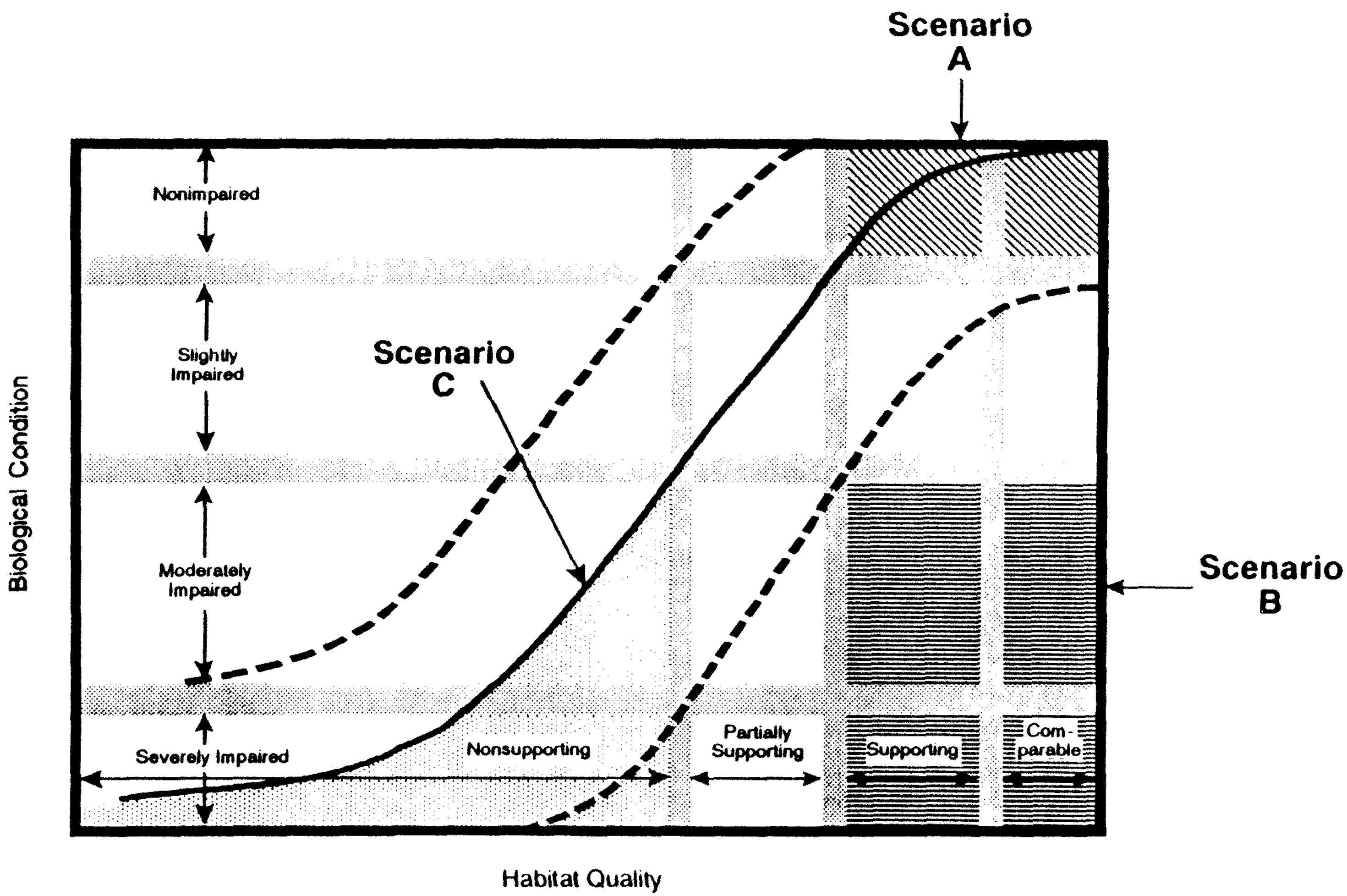

Figure 3. Illustration of three potential results of RBP analyses.

One of those activities for which quantifiable confidence intervals can be calculated is replicate sampling. Duplicate processing of these replicates provides information on sorting efficiency, habitat and biological population/community variability, and suitability of sampling equipment. It also provides for evaluation of the taxonomic treatment. Relative percent difference (RPD), calculated as

$$RPD = \frac{(C1 - C2)\ x100\%}{(C1 + C2)/2}$$

where C1 = number of taxa in the larger sample and C2 = number of taxa in the smaller sample, will be used to evaluate precision between duplicate samples. An RPD of 0.5 (50 percent) or greater will be considered unacceptable and corrective action taken. For three or more replicates, relative standard deviation (RSD) will be used:

$$RPD = \frac{3}{y} x100$$

where s = standard deviation and y = mean of replicate analyses (EPA 1989).

Habitat assessments will be performed by more than one observer; each observer will also perform duplicate assessments. Comparisons using RPD, RSD, and coefficients of variability (CVs) will allow evaluation of both intra- and inter-observer variation.

QUALITY ASSURANCE PROGRAM

Quality Management

Quality management entails a number of activities including delineation of lines of responsibility, outlining of the quality management plan, designation of a quality assurance officer (QAO) and ensuring availability of standard operating procedures (SOPs). Thus far, project organization and lines of responsibility have been illustrated for field operations, laboratory activities, and data analysis (Figures 4-6). The EMSL-Cincinnati Aquatic Biology Branch Chief will serve as QAO. All field and laboratory data sheets from the pilot study have been assembled from various project personnel by EMSL-Cincinnati. The project team consists of the following agencies or groups:

A) U.S. Environmental Protection Agency

1) Environmental Monitoring Systems Laboratory - Cincinnati (EMSL-Cincinnati)
2) Wheeling Region III Support Office

B) West Virginia

1) Division of Natural Resources (WVDNR)
2) Division of Energy (WVDOE)

C) Marshall University, Department of Biology

D) EA Engineering, Science, and Technology, Inc.

There are four components of field operations: benthic macroinvertebrates, fish, habitat assessments, and water quality (Figure 4). Benthic macroinvertebrates (benthos) are sampled by personnel of EMSL-Cincinnati, WVDOE, and EA Engineering, Science, and Technology. Field leaders of the benthos team are from EMSL-Cincinnati. The fish survey crew and leadership is provided by the WVDNR. Habitat assessment is performed by EA and WVDOE. EPA Region III handles all water quality sampling. Field leaders report to the principal investigators who are from EMSL-Cincinnati and EPA Region III.

FIELD OPERATIONS

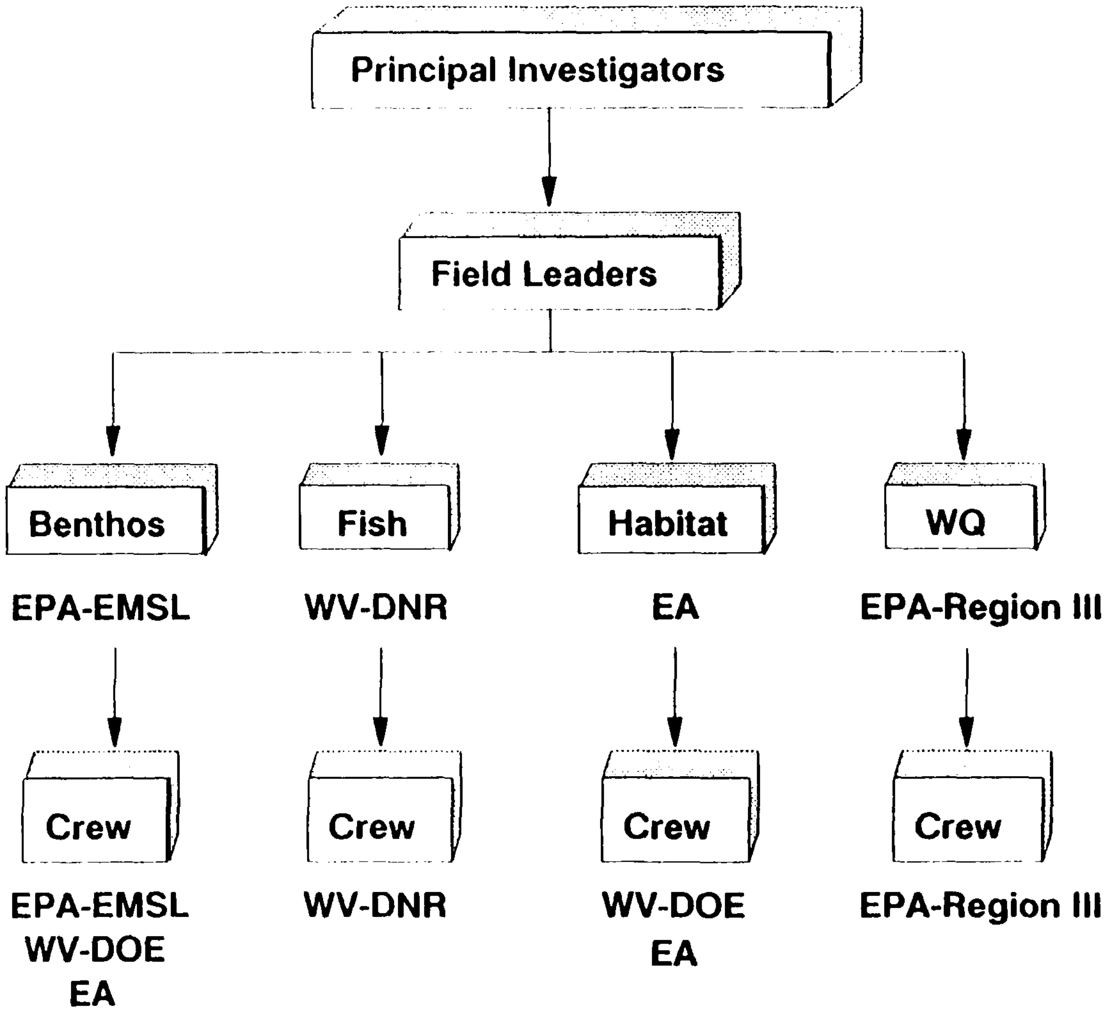

Figure 4. EPA Region III RARE project; field operations organizational chart.

LABORATORY ACTIVITIES

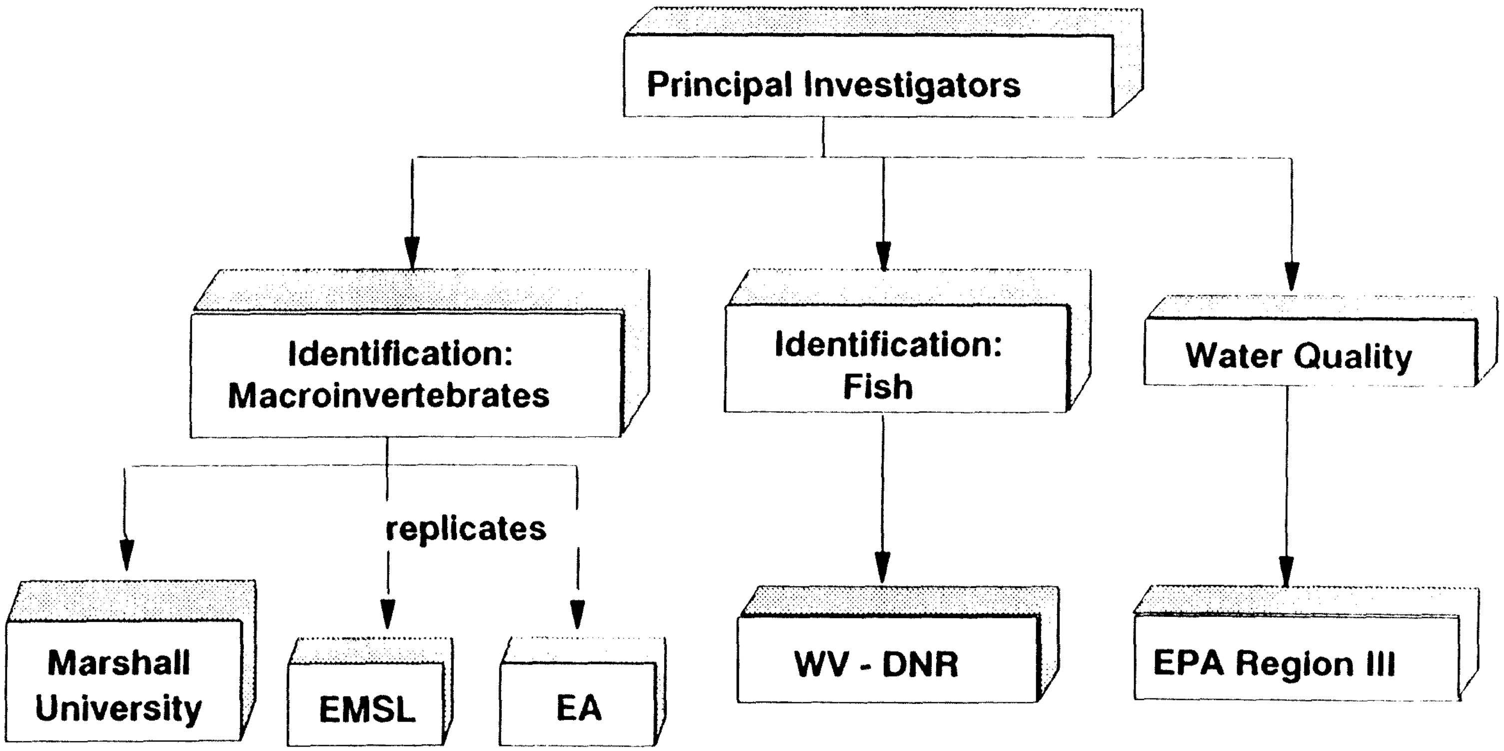

Figure 5. EPA Region III RARE project; laboratory activities organizational chart.

DATA ANALYSIS

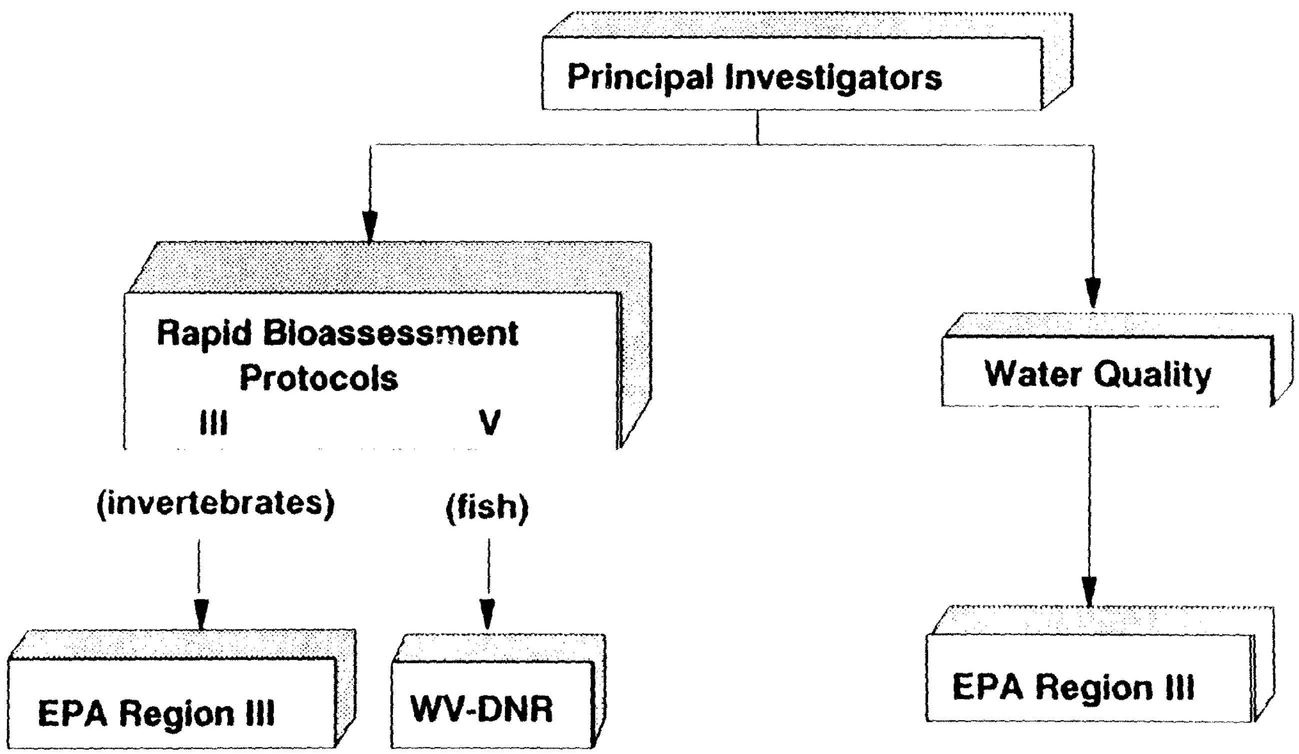

Figure 6. EPA Region III RARE project; data analysis organizational chart.

Laboratory activities essentially are divided into three groups (Figure 5): macroinvertebrate identifications, fish identifications, and water quality. Macroinvertebrate taxonomy is being performed by Marshall University, Huntington, WV, EMSL-Cincinnati, and EA. Fish identifications are being performed by WVDNR. Water samples are being collected and shipped to the laboratory by EPA Region III. All data sheets are submitted to EMSL-Cincinnati.

Data analysis is primarily by EPA Region III with assistance from EA (RBP III metric calculation) and WVDNR (RBP V metric calculation) (Figure 6). Water quality data are being interpreted by EPA Region III. Results are reported to EMSL-Cincinnati principal investigator.

RARE Project Quality Control Elements

For each of the five ecological project activity classes (design, field, laboratory, data analysis, and reporting) there are a number of potential sources of error. Barbour and Thornley (1990) presented a series of matrices illustrating interactions between these potential error sources and various QC elements which might be implemented to minimize error. These matrices are reproduced in this document (Tables 6-10) with accompanying tables indicating QC features specific to this RARE project.

In the left column of the upper part of the table are listed some of the potential error sources; some of which are unique to each activity. The QC elements that will control these potential errors are labelled at the top of the table. The "X" indicates interaction between these two factors. When examining effectiveness of the QC elements, those with the greatest number of interactions (X) are probably most significant. Conversely, those potential sources of error without at least one QC interaction are likely to have adverse influence and thus serious consequences on the performance of this activity. In the lower part of each table are listed specific RARE activities related to these QC elements.

Pilot studies are critical in design of sampling programs for controlling most potential error (Table 6). Environmental strata have been taken into account in the sampling design. The number of sampling sites (14) is manageable for the project personnel, both in terms of fieldwork and data analysis. Sites are distributed among first through third order streams, primarily around two areas designated to become strip mines. Several sites in both areas are located so as to be upstream from mine runoff influences. Historical data for area fisheries surveys in the area have been located and procured for preliminary analysis. Replicate benthic samples are being taken with different collecting gears to examine habitat and population variability as well as equipment efficiency. Sampling equipment was chosen to target riffles, generally recognized as the most productive habitat in freshwater streams. At several sites, duplicate habitat assessments will be completed by different observers. Comparison of site rank-order should provide an estimate of consistency within methods. The pilot study has demonstrated that some of the streams to be sampled have a complete bedrock substrate with no gravel or cobble. For these cases, pools with accumulation of detritus were sampled using a D-frame dip net.

For field operations, the most important QC element is that of training and experience relative to project responsibility (Table 7). In the RARE project, all involved personnel have a number of years of experience along with appropriate professional and academic training. Calibration and maintenance of dissolved oxygen and pH meters follow manufacturer specifications and SOPs. SOPs for benthic sampling are as presented in the workplan prepared by EMSL-Cincinnati and in Plafkin et al. (1989). Sample handling procedures including labelling, logging, and transportation, have been established and are recorded in the EMSL-Cincinnati workplan.

For laboratory operations, training is also the most critical QC element for error control, minimizing human error, and affecting virtually every potential error source (Table 8). Duplicate processing of samples is being performed for the benthos data. Primary samples are sorted and identified by Marshall University; duplicates are processed by EMSL-Cincinnati and/or EA. Taxonomists in these laboratories have from several to many years of training and experience in invertebrate taxonomy. Data sheets from all laboratories have been assembled, duplicated, and distributed to all members of the project team.

In the data analysis phase, personnel training and standardization of the database are the most critical QC elements (Table 9). Data handling and reporting and database standardization are closely tied. All data are being computerized by WVDOE. A professional biostatistician of EMSL-Cincinnati is providing statistical advice and performing analyses. Calculation of rapid bioassessment biological condition metrics is as in Plafkin et al. (1989) and Barbour et al. (1991, in press).

Reporting of the project is primarily supported by training and peer review (Table 10). Several personnel have experience and training in preparing manuscripts for publication in peer reviewed journals. Results and conclusions will be presented at professional meetings and published in peer review journals (such as the Journal of the North American Benthological Society). Technical editing will be performed by in-house personnel and journal editors and reviewers. Standard format will conform to journal and EPA guidelines.

TABLE 6 CONSIDERATIONS FOR DESIGN AND APPLICATION TO THE RARE PILOT STUDY

Design Considerations (Taken from Barbour and Thornley 1990)

	QC ELEMENTS				
Potential Error	Pilot Study	Environmental Strata	Historical Data	Replicates	Equipment Choice
Resources Available	X	X		X	
Logistics	X				X
Response Variables	X		X		
Weather		X	X		
Seasonality	X	X	X		
Site Location	X	X	X		
Habitat Variability	X	X	X	X	
Population Variability	X		X	X	X
Equipment	X				X

Quality Control Elements/RARE Implementation

QC Concepts	Region III RARE
1. Pilot Study	1a. Pilot study.
2. Environmental Strata	2a. Stream-order variability (1st - 3rd).
	2b. Site locations upstream and downstream of mine runoff.
	2c. Annual samples on same date as previous year.
3. Historical Data	3a. Benthic macroinvertebrates, Marshall University.
	3b. Fish, WVDNR.
4. Replicates	4a. Benthic sampling--with available habitat, kicknets (2).
	4b. Habitat assessment--multiple observers; true replicates.
5. Equipment Choice	5a. Square meter kicknet, double composite.

TABLE 7 CONSIDERATIONS FOR FIELD OPERATIONS AND APPLICATION TO THE RARE PILOT STUDY

Considerations for Field Operations (Taken from Barber and Thornley 1990)

	QC ELEMENTS				
Potential Error	Sample Maintenance	Effort Evaluation	Additional Equipment	Calibration & Handling	Instrument Training & Checks
Climate		X	X		
Site Location	X	X	X		
Sampling Equipment Efficiency	X	X	X		
Human (Equipment Use)	X	X			X
Field Notes		X		X	
Sample Processing	X	X	X	X	
Sample Transportation	X	X	X	X	
Sample Tracking	X	X	X	X	

Quality Control Elements/RARE Implementation

	QC Concepts		Region III RARE
1.	Instrument Calibration/ Maintenance	1a.	SOPs, manufacturers specifications.
2.	Crew Training/Evaluation	2a.	All involved personnel have education and number of years' experience relating to project responsibilities.
3.	Field Equipment	3a.	SOPs for kicknet and Surber provided in workplan and Plafkin et al. (1989)
4.	Sample Handling	4a.	SOPs for labelling, preserving, logging, and transportation provided in workplan.
5.	Additional Effort Checks	5a.	Check adherence to SOPs.

TABLE 8 LABORATORY DESIGN CONSIDERATIONS AND APPLICATION TO THE RARE PILOT STUDY

Laboratory Considerations (Taken from Barbour and Thornley 1990)

	QC ELEMENTS					
Potential Error	Sorting & Verification	Taxonomy	Duplicate Process	Archives	Training	Data Handling
Sampling Tracking	X			X	X	X
Improper Storage				X	X	
Sample Preparation	X		X		X	
Reference Error (Taxonomy)		X				
Taxonomic Error (Human)		X	X	X	X	
Counting Error	X		X		X	
Sorting Efficiency	X		X		X	X
Data Records (Labs)	X	X	X		X	X
Data Records (Computer)					X	X

Quality Control Elements/RARE Implementation

QC Concepts	Region III RARE
1. Sorting and Verification	1a. Experience. 1b. Intralaboratory re-checking of sample residue for missed specimens. 1c. Interlaboratory re-checking of sample residue for missed specimens.
2. Taxonomy	2a. Academic training. 2b. Professional experience. 2c. Investigation of unusual erroneous/records.
3. Duplicate Processing	3a. Interlaboratory sample processing; sorting, taxonomy.

TABLE 8 CONTINUED

QC Concepts	Region III RARE
4. Archives	4a. Sample logs--EMSL-C notebooks. 4b. Sample preservation--ethanol. 4c. Taxonomy--investigate unusual/erroneous records.
5. Training	5a. Personnel with academic and/or professional background relating to project responsibilities.
6. Data Handling	6a. SOPs for sample logging, with identification/serial numbers. 6b. Data transcription--checked by trained professionals. Data computerization--entry by trained technicians, output reviewed by trained personnel; check with original datasheets.

TABLE 9 DATA ANALYSIS CONSIDERATIONS AND APPLICATION TO THE RARE PILOT STUDY

Data Analysis Considerations (Taken from Barbour and Thornley 1990)

	QC ELEMENTS					
Potential Error	Handling Training	Standardized & Reporting	Standardized Database	Peer Analysis	Range Review	Control
Inappropriate Statistics	X				X	
Errors in Database	X	X	X			X
Database Management	X	X	X			
Programming Errors	X	X	X	X		
Misinterpret Analysis	X			X	X	

Quality Control Elements/RARE Implementation

QC Concepts		Region III RARE
1. Training	1a.	All involved personnel with academic training and/or professional experience relating to data analysis; RBP workshop participation.
2. Handling & Reporting	2a.	Proofing--compare output with original datasheets, approval of transcription.
	2b.	Documentation--datasheets completed/copied, complete set sent to four different locations.
3. Standardized Database	3a.	Data entry/computerization into WVDOE system.
4. Standardized Analysis	4a.	RBP metric calculation; SOPs, Plafkin et al. (1989) and Barbour et al. (1991; in press).
	4b.	Statistics--Spearman's rank correlation coefficient, t-test; EMSL-C.
5. Peer Review	5a.	Professional biostatisticians, benthic and fisheries biologists.
6. Range Control	6a.	Investigate data variability, outliers.

TABLE 10 REPORTING CONSIDERATIONS AND APPLICATION TO THE RARE PILOT STUDY

Reporting Considerations (Taken from Barbour and Thornley 1990)

	QC ELEMENTS			
Potential Error	Training	Peer Review	Technical Editor	Standard Format
Transcription Error	X			
Poor Presentation	X	X	X	X
Obscure Language	X	X	X	X
Did We Address Question?	X	X		

Quality Control Elements/RARE Implementation

QC Concepts		Region III RARE
1. Training	1a.	All involved personnel with training and/or experience in project reporting.
2. Peer Review	2a.	Address project organization.
	2b.	Address presentation of data and discussion of results; merit (project personnel).
	2c.	Objectives addressed? (project personnel).
	2d.	Publication in peer reviewed journals.
3. Technical Editor	3a.	Document--organization, appropriateness.
	3b.	Basic wording.
	3c.	Journal editors, anonymous reviewers.
4. Standard Format	4a.	U.S. EPA guidelines.
	4b.	Journal format.

Remaining QC Considerations

Several factors remain to be addressed in conception and implementation of appropriate QC elements. For example, contingencies must be developed to handle variability of habitat characteristics. From the pilot study experience, it was determined that a number of factors could potentially influence the effectiveness of sampling gear. Among these are channel width, substrate quality, and flow/depth. At some sites, alternative sampling methods were used. Appropriate statistical treatment of this potential sampling gear variability should be determined. This focus would add to QC elements of the design, field, laboratory, and analysis activity classes. Another consideration will be data differences resulting from duplicate processing, particularly in the areas of taxonomic identification levels and sorting efficiencies among laboratories. Verification of sample processing and laboratory operations will be conducted by the QAO.

Perhaps the most important consideration to be resolved by the pilot study will be selection of reference sites and development of a reference database necessary to assess mining impacts throughout this proposed 5-year project. Historical data will be useful to characterize past conditions and ecological potential of this region of West Virginia. Reference sites corresponding to stream classification types (stream orders 1-4) will be selected for comparisons to the ambient sites receiving mining activity influences.

REFERENCES

Barbour, M.T., and S. Thornley. 1990. Quality Assurance Issues Related to Field Assessment of Aquatic Ecosystems, in Proceedings of the Third Annual Ecological Quality Assurance Workshop, Dan Hart (ed.). Burlington, Ontario. April. pp. 167-183.

Barbour, M.T. and J.B. Stribling. 1991 (in press). Use of Habitat Assessment in Evaluating the Biological Integrity of Stream Communities. Proceedings of U.S. EPA Workshop on Biocriteria, Arlington, Virginia. 12-13 December 1990.

Barbour, M.T., J.L. Plafkin, B.P. Bradley, C.G. Graves, and R.W. Wisseman. 1991 (in press). Evaluation of EPA's Rapid Bioassessment Benthic Metrics: Metric Redundancy and Variability Among Reference Streams Sites. Journal of Environmental Toxicology and Chemistry.

Hart, D. (editor). 1990. Proceedings of the Third Annual Ecological Quality Assurance Workshop. Burlington, Ontario. 214 pp.

Karr, J.R., and D.R. Dudley. 1981. Ecological Perspective On Water Quality Goals. Environmental Management 5:55-68.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. Assessing Biological Integrity In Running Waters: A Method and Its Rationale. Special Publication 5. Illinois Natural History Survey, Champaign, Illinois.

Keith, L.H. (editor). 1988. Principles of Environmental Sampling. ACS Professional Reference Book, American Chemical Society. Washington, D.C. 458 pp.

Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish. EPA/444/4-89-001. U.S. EPA, Office of Water, Washington, D.C.

Smith, F., S. Kulkarni, L.E. Myers, and M.J. Messner. 1988. Evaluating and Presenting Quality Assurance Sampling Data, in Principles of Environmental Sampling, Chapter 10, L.H. Keith (ed.). American Chemical Society, Washington, D.C. Pages 157-168.

Taylor, J.K. 1988. Defining the Accuracy, Precision, and Confidence Limits of Sample Data, in Principles of Environmental Sampling, Chapter 6, L.H. Keith (ed.). American Chemical Society, Washington, D.C. Pages 101-107.

U.S. Environmental Protection Agency. 1989. Preparing Perfect Project Plans. EPA/800/9-89/087. October. Office of Research and Development, Washington, D.C.

U.S. Environmental Protection Agency. 1990. Biological Criteria: National Program Guidance for Surface Waters. EPA/440/5-90-004. April. Office of Water Regulations and Standards, Washington, D.C.

COMPARISONS OF LABORATORY AND FIELD GOOD LABORATORY PRACTICES AND QUALITY CONTROL VIEWPOINTS

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ABSTRACT

As Good Laboratory Practices (GLPs) and Quality Assurance/Quality Control (QA/QC) procedures are applied to field studies, especially large field programs, similarities and differences between field and laboratory environments must be understood. Further, this understanding must be expressed in operational terms. Logistical similarities include the use of written protocols for instrument calibration; sampling; sample shipment and storage; sample analysis; and operation of a QA unit. Logical differences in ambient biological, chemical, and physical endpoints include controlled age-distribution vs. age-variable populations, controlled vs. uncontrolled doses and environmental/substrate variables and easy-to-establish vs. difficult and multiple cause/effect relationships. Such differences create intellectual tensions that influence the acceptable bounds of data accuracy, precision, completeness, comparability, acceptability, and reproducibility. We provide lists of major GLP requirements for field studies. Situations where GLP and QA/QC procedures can be applied as written, require modification and/or are beyond investigative control are also discussed. A case history of a large research program is also provided.

OVERVIEW

- Benefits
- Comparisons
  - 10 parameters
  - laboratory situations
  - field situations
  - differences/similarities
- Rules of thumb from examples
  - parameter by parameter
  - problems and solutions
- Working conclusions

BENEFITS

- Confirmation of common sense field experience
- Logical treatment of laboratory and field environments
- Problem identification with solutions
- Avoidance of some pitfalls

TEN PARAMETERS IN COMPARISON

- Study plan and data quality objectives
- Study personnel and management
- Test substance
- Test system
- Equipment
- Facilities
- Samples and specimens
- Records and data control
- Data analysis
- Operation of QA unit

STUDY PLAN AND DATA QUALITY OBJECTIVES

		Location	
Parameter	**S/D***	**Laboratory**	**Field**
Accuracy	S	Similar because defined a priori, even though values may be different	
Completeness	S		
Measurability	S		
Precision	D	Higher due to better control	Lower due to lesser control
Comparability	D		
Representativenss	D		

*S = Similar, D = Different

STUDY PERSONNEL AND MANAGEMENT

Parameter	S/D*	Location: Laboratory	Location: Field
Protective Clothing	S	Same strictness of measures regardless of location	
Nature of Personnel	D	Use of existing qualified staff	1. Supplemental on-site staff needed 2. Increased attention to training
Study Director Duties	D	Generally, easier exercised when entire study at one location	Fulfillment presents a challenge due to multiple sites
Upper Management Oversight	D	Easier due to location	Harder because of distance

*S = Similar, D = Different

TEST SYSTEM

Parameter	S/D*	Location: Laboratory	Location: Field
Age	D	Known	Not as well known
Origin	D	Known	Not as well known
Population Size	D	Known exactly	Estimated
Habitat	D	Artificial	Natural with multiple interacting variables
Security	D	Standard measures	Additional measures due to site vulnerability
Measurements	D	Direct on all planned specimens	Indirect estimate based on sample
Observations	D	Planned and well controlled	Planned but opportunistic

* S = Similar, D = Different

EQUIPMENT

Parameter	S/D*	Location: Laboratory	Location: Field
Standard Operating Procedures	S	Should exist regardless of location	
Transport	D	Within existing buildings	Better care due to increased distances
Calibration/ Standardization/ Cleaning	D	Normal schedules	More frequent intervals due to moving
Maintenance/ Repair/ Backup	D	Use of available resources	Better planning needed due to lack of resources

*S = Similar, D = Different

FACILITIES

Parameter	S/D*	Location: Laboratory	Location: Field
General Nature	D	Indoor controlled infrastructure	Limitations due to temporary areas
Separate Areas	D	Usually well defined	Not as distinct due to space limitations
Ambient Conditions, e.g., ventilation, water)	D	Dictated and well controlled	Acceptance of natural conditions
Safety Apparatus	D	Hoods, eyewashes, other already established	Needs to be planned for and installed
Maintenance and Repair	D	Resources available	Procuring of resources at site

* S=Similar, D=Different

SAMPLES AND SPECIMENS

Parameter	S/D*	Location: Laboratory	Location: Field
Identification	S	Similar regardless of collection location	
Analytical Lab Storage	S		
Collection	D	Well controlled	Less controlled due to weather conditions
Preservation & Storage When Collected	D	Good control with refrigerators and freezers	Less control due to use of coolers and increased logistics
Shipping	D	Low concern if close to sampling and analysis locations	Stringent controls needed due to distance between collection and analysis

*S = Similar, D = Different

RECORDS AND DATA CONTROL

Parameter	S/D*	Location: Laboratory	Location: Field
Standard Operating Procedures	S		
Protocols	S	Existence and controls similar	
Data	S		
Archival	S		
Protection	D	Easier to control during study	Increased attention due to multiple transfers of records

*S = Similar, D = Different

DATA ANALYSIS

		Location	
Parameter	S/D*	Laboratory	Field
Statistical	S	Similar regardless of data origin	
Extrapolations			
- Tissue	S	All directly calculated from data gathered during study	
- Organ	S		
- Organism	S		
- Population	S		
- Community and Ecosystem	D	Not generally appropriate	Estimated based on data gathered
Interpretations	D	Mechanistic	Holistic

*S = Similar, D = Different

OPERATION OF QA UNIT

Parameter	S/D*	Location: Laboratory	Location: Field
Independence	S	Maintained regardless of location	
Master Schedule	S	Same regardless of location	
Data and Report Audits	S	Same methods regardless of data/report origin	
Inspections	D	1. Coordination easier 2. Adaptable to schedule changes	1. Harder logistics 2. Not easily adaptable to schedule changes
Inspector	D	Input available from QA Unit	Independent individual making quick decisions
Communication With Study Team	D	Better due to closeness	Harder due to dispersed personnel
Cooperator Oversight	D	Minimal; not a problem	Differing levels of compliance

*S = Similar, D = Different

EXAMPLES OF FIELD PROGRAMS

- Large pond study for pesticide client
- Several field sites for decontamination
- Grain field study
- Orchard field study
- Other field programs

FINDINGS

FROM

FIELD PROGRAM EXPERIENCE:

RULES OF THUMB

Parameter	Problem	Solution
STUDY PLAN AND DATA QUALITY OBJECTIVES	• Not an issue once the data quality objectives are set	Not an issue once the data quality objectives are set

RULES OF THUMB

Parameter	Problem	Solution
STUDY PERSONNEL AND MANAGEMENT	• Skill mix, motivation	Careful selection of personnel-- more ingenuity/tolerance required
	• Part-time and new staff	Intensive, on-site training before study starts
	• Safety	1. Protective clothing 2. Qualified hoods 3. Packaging and storage

RULES OF THUMB

Parameter	Problem	Solution
TEST SUBSTANCE	• Geographical distance of mixing and applications	Careful planning and handling
	• Contamination	1. Containment 2. SOPs for decontamination of equipment and people 3. Establishment of clean/dirty areas in field
	• Transportation demands of mixed materials	1. Complete knowledge of degradation properties 2. Careful logistics 3. Portable environmental control
	• Adequate storage of test substance	1. Temperature and light control 2. Ventilation
	• Retention of containers	Written waiver from EPA
	• Accidental releases	1. Safety officer 2. Training

RULES OF THUMB

Parameter	Problem	Solution
TEST SYSTEM	• Lack of security, e.g., poaching, fishing	1. Posting of signs 2. Public announcements about poisoning
	• Untimely weather, e.g., flash storm	Best informed decisions about prevailing conditions, e.g., thresholds of wind speed
	• Irregularity of application, e.g., gullies, winds	Regulation of dose, e.g., wind shields
	• Unexpected nearby events, e.g., aerial spraying, wind drift from roadside spraying	Avoidance of roads

RULES OF THUMB

Parameter	Problem	Solution
EQUIPMENT	• Breakdown, loss, malfunction, theft	Backups are vital!
	• Lack of equipment at needed time	Check lists are essential!
	• Vulnerability of equipment to hot sun and other weather elements	1. Use of shade to reduce overheating 2. Back-ups are vital!
	• Calibration relative to movement of equipment	Calibration plan with on-site verification

RULES OF THUMB

Parameter	Problem	Solution
FACILITIES	• Lack of facilities	Development of same, e.g., trailers, mobiles
	• Safety issues	1. Experienced field foreman 2. Lease/upgrade space, installation of hoods, showers, and eye washes 3. Fire protection
	• Pests, e.g., mice, gnats	Control with care and avoid contaminating chemicals
	• Inadequate space planning	Provision of space for: • Test substance • Samples • Controls • Equipment and supplies
	• Maintenance and repair	Close cooperation with local craftsmen

RULES OF THUMB

Parameter	Problem	Solution
SAMPLES AND SPECIMENS	• Lack of dry and wet ice	Two or more suppliers, including overnight access
	• Time delays to move fresh samples to freezers	Shade and ice
	• Shipping confusion	1. SOP development for shipping 2. Assigned persons
	• Handling of large number of samples in small space	Limiting factors defined and worked out
	• Overall protection	1. Rigorous checklists and follow-ups 2. Care in handling storage containers

RULES OF THUMB

Parameter	Problem	Solution
RECORDS AND DATA CONTROL	• Storage space for records	Regular transfers to central collection in fire proof containers
	• Control of access	Transfer to study director or designate
	• Lack of designated custodian	Specific assignment

RULES OF THUMB

Parameter	Problem	Solution
DATA ANALYSIS	• Generally not an issue	Differences are addressed in study plan

RULES OF THUMB

Parameter	Problem	Solution
OPERATION OF QA UNIT	• Accessibility	1. Timing of field audits to observe most events 2. Cooperation of field operators
	• Varying degree of compliance among cooperators	On-site visit/evaluation/ corrective actions per cooperator's compliance
	• Unqualified inspector	Assignment of experienced field inspectors
	• Nine inspectors and one worker	1. Better planning 2. Simplification of regulations
	• Overanxious auditors, researchers, and other tense situations	Service with a smile

WORKING CONCLUSIONS

1. Complete a good program plan with appropriate SOPs
2. Use well-trained and experienced field staff
3. Assure all back-up equipment is ready for use
4. Use checklists for all activities
5. Respect fully the importance of the specimen/sample
6. Maintain a commitment to GLP from the entire team
7. Solve problems within above context

MANAGEMENT AND RESULTS OF A QUALITY ASSURANCE PROGRAM FOR A CANADA-UNITED STATES ATMOSPHERIC FIELD STUDY

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ABSTRACT

From June 1988 to June 1990, a cooperative Canada-US field study, known as the Eulerian Model Evaluation Field Study (EMEFS), was carried out in eastern North America. Its objective was to collect regional-scale air and precipitation chemistry data for the evaluation of Canadian and US atmospheric long range transport models. Two Canadian and three US monitoring networks operated simultaneously using comparable, but not identical, measurement methods. Considerable effort was expended throughout the study on a quality assurance (QA) program focused on accuracy, precision, comparability, completeness, and representativeness. Work on the study's QA Program began during the design phase by addressing data quality objectives (DQOs) and network comparability. During the study itself, the QA Program was managed by a working group responsible for network operations.

The culmination of the QA Program is to be a document known as the Quality Assurance Synthesis Report, in which quantitative estimates of accuracy, precision, comparability, completeness, and representativeness will be summarized. The results to date indicate good comparability of the air and precipitation chemistry data (somewhat better for precipitation than air), that the accuracy of most measurements can be assured within the DQOs, and that the precision of the measurements is excellent for most chemical species (again, somewhat better for precipitation than for air). These results, and a number of innovative estimators of precision and comparability, are discussed in detail in the paper.

INTRODUCTION

From June 1988 to May 1990, a cooperative Canada-United States field study, known as the Eulerian Model Evaluation Field Study (EMEFS), was carried out across eastern North America. The objective of the study was to collect regional-scale air and precipitation chemistry data for the evaluation of Canadian and U.S. Eulerian long range transport models [Hansen, 1989]. These models were designed to simulate the complicated atmospheric processes of pollutant emission, transport, chemical conversion, and deposition (wet and dry). They focus on the oxides of sulphur and nitrogen with a view to determining the relationships between various pollutant emission sources and receptors in eastern North America. The Eulerian Model Evaluation Field Study was designed to obtain sulphur and nitrogen species concentrations in air and precipitation for comparison against model predictions. It is the quality assurance of these measurements that is discussed in this paper. Complete details of the EMEFS and its field measurement program are given in Hansen [1989].

EMEFS ORGANIZATION AND MANAGEMENT

Data required for the model evaluation exercise were obtained from five air and precipitation monitoring networks operated simultaneously across eastern North America. Of the five networks, two were Canadian and three were American (see Table 1). The networks operated with comparable, but not identical, measurement methods.

Representatives of the five agencies sponsoring the networks formed a Project Management Group (PMG) responsible for coordinating all activities within the study. Direct operational responsibilities were delegated to four teams - one for estimating pollutant source emission rates, one for carrying out special aircraft and ground-based atmospheric studies, one for the model evaluation activities, and the last for making the network measurements. This paper focuses on the QA/QC activities of the network measurement team (known as the Operational Measurements Team or OMT).

MEASUREMENT METHODS

The five monitoring networks operated in eastern North America at the sites shown in Figure 1 (from Hansen, 1989). Note that some of the sites shown did not operate continuously throughout the two year period.

The measurement methods used by the five networks were similar in approach but varied somewhat in detail. Standardization and commonality of the measurement methods was addressed in several workshops held before the study began. Wherever possible, field, laboratory, QA/QC and data management methods were standardized.

TABLE 1 CANADIAN AND US NETWORKS OPERATING DURING EMEFS

NETWORK ACRONYM	NETWORK NAME	SPONSORING AGENCY
US Networks		
OEN	Operational Evaluation Network	Electric Power Research Institute (EPRI)
Acid MODES	Acid Model Operational Diagnostic Evaluation Study	US Environmental Protection Agency
FADMP	Florida Acid Deposition Management Program Network	Florida Electrical Utilities
	The Acid Deposition in Ontario Study Network	Ontario Ministry of the Environment
	The Canadian Air and Precipitation Monitoring Network	Atmospheric Environment Service/ Environment Canada

The five networks all made three types of measurements (certain networks also made other measurements):

1. Precipitation Chemistry - using precipitation chemistry collectors and standard precipitation gauges;
2. Air Chemistry - using multi-stage filter packs;
3. Ozone - using continuous monitors.

The precipitation and air chemistry measurements were made over 24 hour periods, the ozone measurements were made continuously. The emphasis of the precipitation and air chemistry measurements was on species of sulfur and nitrogen, however, other analytes were also measured.

The full suite of precipitation measurements included SO_4, NO_3, Cl^-, pH, NH_4, Na^+, K^+, Ca^{++} and Mg^{++} and air measurements included particulate SO_4, NO_3, NH_4 and gaseous SO_2 and HNO_3 (and, in some networks, NH_3). The methods employed were roughly similar in all networks in that they used commercial precipitation chemistry collectors (of three different types) and, for air, 3 or 4-stage filter packs mounted on 10 m towers (3 different kinds of filter packs and four different kinds of flow systems were used). Four different air and precipitation chemistry laboratories analyzed the air and precipitation samples collected at the field sites. Further details of the measurement methods can be found in Hansen (1989).

THE EMEFS QUALITY ASSURANCE PROGRAM AND ACTIVITIES

To assure the collection of a high quality data base, the OMT designed an extensive quality assurance program for the network measurements. The implementation of the quality assurance program began during the study design phase when a number of workshops were held to determine the types of measurements to be made, the appropriate measurement methods, the degree of commonality between the various networks, and the quality assurance procedures needed to ensure accurate, precise, comparable, representative and complete data. The outcome of the workshops was a common set of within- and between-network QA/QC procedures. A summary of these procedures in the precipitation and air chemistry field monitoring programs is given in Table 2 [McNair and Allan, 1991].

Aside from the within-network procedures of:

- o Measuring field blanks,
- o Carrying out regular site inspections/audits, and
- o Quality controlling the laboratory operating system,

the most notable QA/QC procedures were those addressing within-network precision and between-network comparability. To address the former, four of the five networks operated several sites where duplicate sets of sampling instrumentation were run simultaneously (these sites are referred to hereafter as 'duplicate sites'). The air and precipitation chemistry results from the duplicate instruments were used to determine within-network precision. Between-network comparability was addressed by colocating the instrumentation of several networks at the same sites (these sites are hereafter referred to as 'colocated sites'). Two colocated sites were particularly important. One was located at the Pennsylvania State University, where four of the five networks operated a duplicate set of sampling instruments (the purpose of which was to determine precision and comparability simultaneously). The other site was located at Egbert, Ontario where the same four networks colocated one set of instruments each. At selected other sites, two or more networks also colocated instruments.

QUALITY ASSURANCE PROGRAM RESULTS

The eventual goal of the OMT's quality assurance program is to document the quality of the multi-network data base. To do this, the QA Program results will be synthesized and documented in a report known as the Quality Assurance Synthesis Report. This report will be used by the model evaluators and other data users to understand the uncertainties in the measurement data. Since the report is highly oriented toward data users, it may serve as a useful model for other QA Programs, and, for this reason, the contents are given here in Table 3.

There are several important notes to be made about the QA Synthesis Report:

1. The quality assurance information is to be presented in the context of the five standard data quality attributes, namely, accuracy, precision, comparability, representativeness and completeness.

2. The information on the five data quality attributes will be combined (if possible) into a single measure of data uncertainty - ideally an error bar.

3. An extensive discussion will be presented on the suitability of the measurement methods used by the OMT.

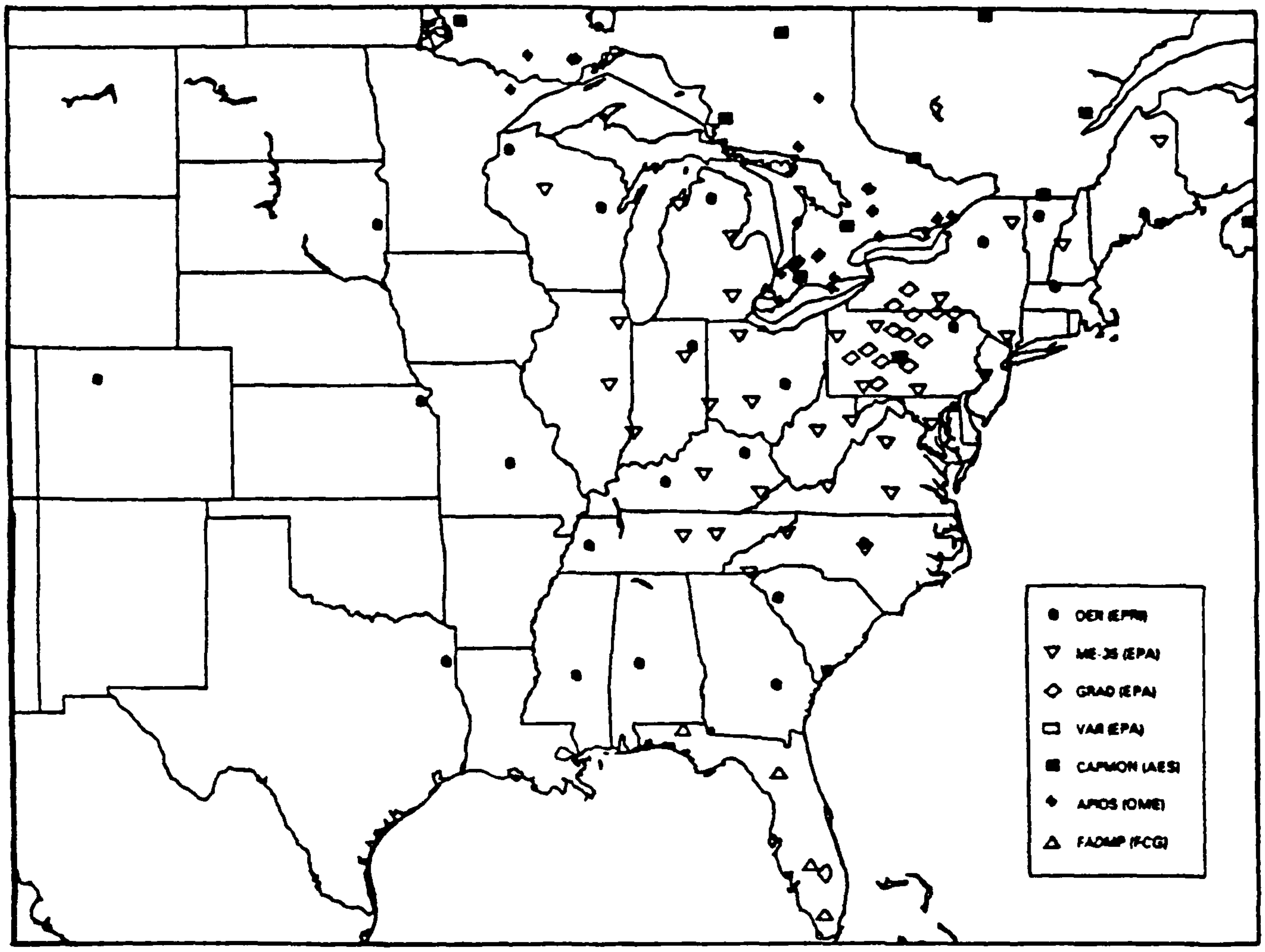

Figure 1. EMEFS monitoring site locations. ME-35, GRAD, and VAR sites constitute the Acid MODES network.

FIELD QA/QC PROGRAMS

PRECIPITATION & FILTER PACK PROGRAMS

	APIOS	CAPMoN	FADMP	ME-35	OEN
			PRECIPITATION CHEMISTRY		
Container Procurement Controls	Bag blanks tested for presence of analytes	Bag blanks tested for presence of analytes	Bucket blanks tested for presence of analytes	Bucket blanks tested for presence of analytes	Bucket blanks tested
Container Inventory Controls	Bag batches shipped to all regional offices simultaneously	Bag batches shipped to all sites simultaneously	Bucket batches shipped to all sites simultaneously	Bucket batches shipped to all sites simultaneously	Bag batches shipped to all sites simultaneously
Container Preparation	-	-	Washed in DW in batches of 25	Field washed, rinsed and tested	Field washed, rinsed and tested
Site Inspection Frequency	Semi-annually	Quarterly	Quarterly	Quarterly	Semi-annually
Field Blanks	Dry bag at least monthly	Dry bag Weekly	Dry bucket Monthly	Bucket rinse Monthly	Bucket rinse Monthly
Duplicate sampling	6 of 18	4 of 17 sites	1 of 4 sites	6 of 58 sites	3 of 25 sites
Inter-network comparison sites	2 of 18	6 of 17 sites	0	5 of 58 sites	4 of 25 sites
			FILTER PACKS		
Filter Procurement Controls	Blanks tested for presence of analytes	Blanks tested for presence of analytes	Blanks tested for presence of analytes	Blanks tested for presence of analytes	Blanks tested for presence of analytes
Filter Inventory Controls	Single supplier Staged shipments Batches tracked	Single supplier Staged shipments Batches tracked	Single supplier Staged shipments Batches tracked	Single supplier Staged shipments Batches tracked	Single supplier Staged shipments Batches tracked
Filter Preparation	Impregnation by ENSR	Impregnation by ENSR	Impregnation by ENSR	Impregnation by ENSR	Impregnation by ENSR
Filter Pack Loading/Unloading	Regional Offices	Central facility	Central facility	Central facility	Central facility
Field Blanks	Passive filter pack Weekly	Passive filter pack Weekly	Passive filter pack Monthly	Passive filter pack * Weekly	Passive filter pack Weekly
Flow Audits	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly
Duplicate sampling	2 of 10 Sites	1 of 12 Sites	1 of 4 sites	6 of 58 sites	3 of 25 sites
Inter-network Comparison sites	2 of 10 Sites	2 of 12 Sites	0	5 of 58 sites	4 of 25 sites

NOTES
* Weekly protocol was discontinued March 1, 1989 except for 2 sites

Table 2. Summary of field QA/QC activities used by the EMEFS networks. ME35 refers to the Acid MODES Network.

TABLE 3. CONTENTS OF THE QA SYNTHESIS REPORT

- o Overview of the Measurement Program
  - Measurement Methods
  - QA/QC Methods
- o Quality Assurance/Quality Control Results
  - Accuracy
  - Precision
  - Comparability
  - Representativeness
  - Completeness
- o Suitability of Measurement Methods
  - Demonstrated Performance Characteristics of Methods During EMEFS
  - Comparison of Methods Against Other Methods
- o Estimation of the 'Overall Uncertainty' from the QA/QC Information.
  - Error Bars

Although the QA Synthesis Report has not yet been written, some preliminary quantitative results are available. A flavour for these results can be obtained from the discussion below.

ACCURACY

Of the measurements made during the study, flow rate and ozone were the only ones for which absolute accuracy could be determined directly. This is because 'transfer standard' flow meters and ozone monitors traceable to primary standards were available for auditing the field instrumentation. An idea of the achievable accuracy of the filter pack flow measurement system is given in Figure 2. Shown are the results of a flow measurement audit carried out on the Acid MODES filter pack sampling system at the Egbert, Ontario site [Bowen and Dowler, 1990]. The results indicate an absolute accuracy of -0.53 L/min (relative accuracy = -2.6% of the audit flow rate). Three such sets of independent audits were done at the colocated sites.

FLOW AUDIT RESULTS
EGBERT, CANADA (AMP)
AUDIT DATE: APRIL 18,1990

AUDITORS: BOWEN, DOWLER

SAMPLERS TYPE ID#	FLOW CONTROLER SETTING	FLOW CONTROLER READING	LEAK CHECK *** CONT. READING AUDIT/SITE	TEMP. DEG. C	BARO. PRESS. MM Hg	AUDIT FLOW L/MIN.	SITE FLOW L/MIN.	FLOW DIFF. L/MIN.	PERCENT DIFF. S-A/A x 100
FILTER PACK	3.33	3.33	0.11/0.11	9.86	748.5	20.53	20.00	-0.53	-2.6

COMMENTS: FLOWS AT STP (0 DEG. C ; 760 MM Hg)

*** LEAK CHECK: AUDIT VALUE IS CONTROLLER READING WITH FLOW LINE PLUGGED (PUMP RUNNING).
SITE VALUE IS CONTROLLER READING OBTAINED FROM OPERATORS LEAK CHECK.
AUDIT VALUE AND SITE VALUE SHOULD BE THE SAME IF THERE ARE NO LEAKS.

Figure 2. US EPA audit results of flow rates on the Acid MODES filter pack sampling system at Egbert, Ontario.

For the other measurements, i.e., filter pack loadings and precipitation composition, no primary standards existed - making it therefore impossible to determine the absolute accuracy of the measurements. As the next best alternative, measurements were made of a number of individual sources of error known to have a potential influence on the overall accuracy. The concept behind these measurements was to determine quantitatively that the sources of error were relatively small, and therefore had little influence on the overall accuracy of the measurements. The measurements included taking field blanks of the filter packs and precipitation collection vessels and analyzing reagent blanks in the laboratory.

PRECISION

The within-network precision of each network's air and precipitation measurement systems was determined by operating duplicate sampling instruments at several sites. The duplicate data made it possible to calculate the precision of each network's measurement systems. Unfortunately, final data are not yet available, but certain insights regarding measurement precision are available. Two of the main points are:

1. The duplicate air and precipitation data are characterized by a highly non-normal frequency distribution. This causes problems with the selection of a representative measure of precision, e.g., the standard deviation of duplicate measurements is not a good measure of precision when the underlying distribution is not normal. Even though only preliminary data are available, we do have some insight into the shape of the underlying distribution and have proposed a suitable measure of precision. To describe this, we begin by defining the 'error' between duplicate measurements at the same site [Vet and Sirois, 1987], i.e.,

$$\text{ERROR} = C_i = [1/\ 2]\ [C_1 - C_2]_i \qquad \text{Eq. 1}$$

where C_1 and C_2 represent the concentrations measured in samplers 1 and 2, respectively at the same site,

1/2 accounts for the variance of both measurements, and

i represents the precipitation event number.

Unfortunately, the distribution of this error term is highly non-normal, a fact easily seen in Figure 3 [Sirois, 1991]. Shown in the solid line is the shape of the error term distribution for duplicate precipitation chemistry measurements. These particular measurements were made in the CAPMoN network over a five- year period - considerably longer than the two-year EMEFS program. However, the distribution is still representative of the EMEFS results.

It is clear from Figure 3 that roughly 90 percent of the errors are near zero. The remaining 10% are relatively large and located at the extreme tails of the distribution. Two sources of variance are responsible for this error distribution - field variance and laboratory variance. While field variance is very difficult to measure, laboratory variance is not, and is shown by the dashed line in Figure 3. It is apparent from this figure that the 'overall precision' and the 'laboratory precision' are quite similar in magnitude except at the extreme tails. There, the large errors appear to be due to field-induced variance alone.

2. As mentioned above, the highly non-Gaussian nature of the error distribution precludes the use of traditional measures of precision. As a result, the OMT has adopted a non-parametric measure of precision called the Modified Median Absolute Difference or M.MAD [Vet and Sirois, 1987]. The M.MAD is simply a non-parametric (i.e., independent of the underlying distribution) estimator of scale adapted from Randles and Wolf [1979]. It is defined as follows:

It is defined as follows:

$$M.MAD=\frac{1}{6745}median[|\Delta C_1-M|,...,|\Delta C_n-M|]\ Eq.2$$

where the 0.6745 term makes the numerator a consistent estimator of the standard deviation of the errors when the underlying distribution is normal,

ΔC term represents the individual errors of the duplicate data from samples 1 to n (as defined in Eq. 1 above)

and M = the median of the ΔC terms.

Since the initial value of ΔC normally equals zero (i.e., no biases exist between duplicate collectors), Eq. 2 reduces to:

$$M.MAD=\frac{1}{6745}median[\frac{1}{\sqrt{2}}|C_1-C_2|]\ Eq.3\ .$$

Note that, in this form, the M.MAD approximately equals the simple Median Absolute Difference (MAD) between collectors.

For the Quality Assurance Synthesis Report, all air and precipitation precision values will be reported in terms of the M.MAD. Also reported will be a non-parametric coefficient of variation equal to the M.MAD divided by the median air or precipitation concentration.

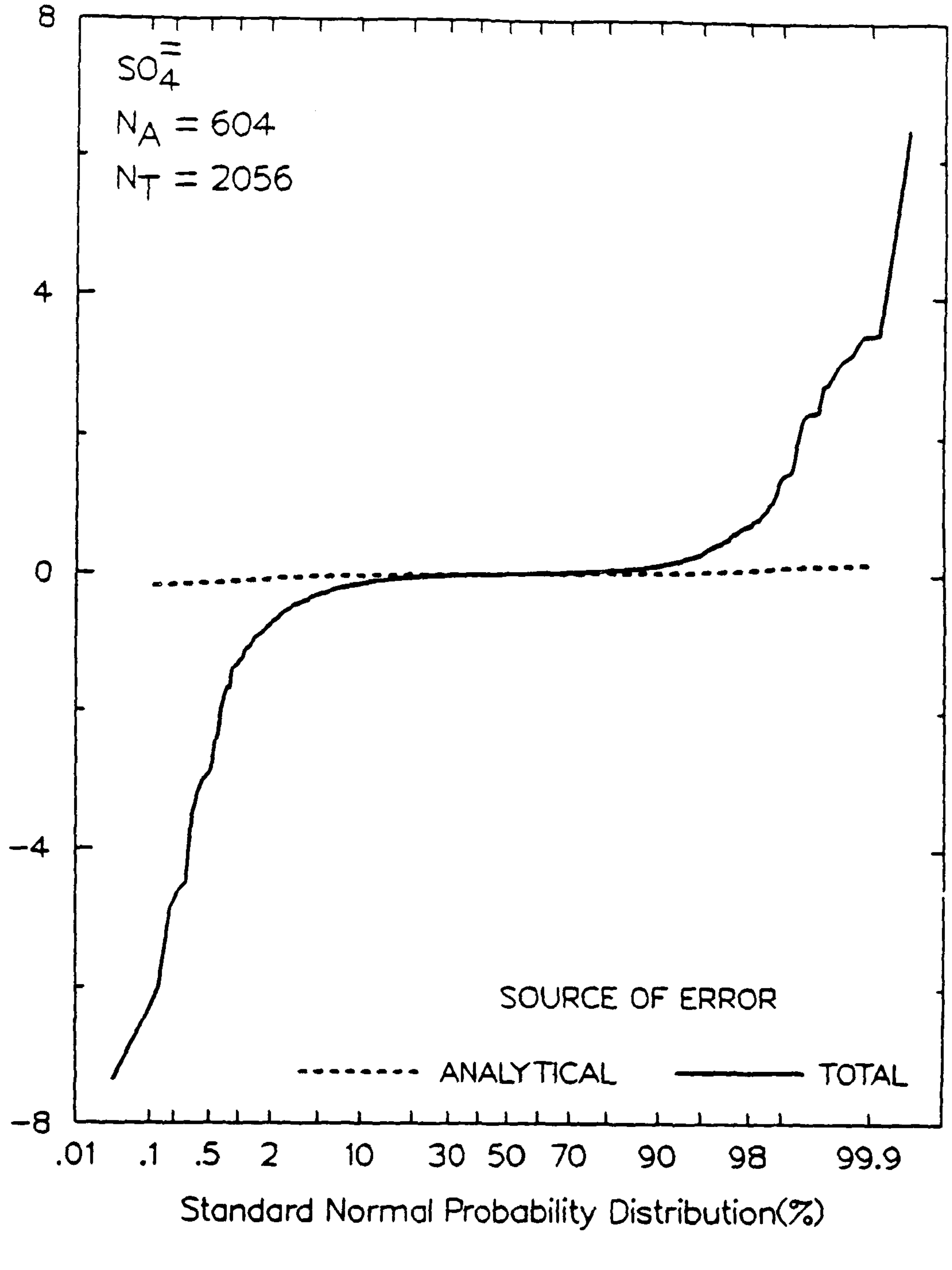

Figure 3. Normal probability distributions of: (a) total error (from Eq. 1) obtained from duplicate site concentrations of sulphate in precipitation (solid line) and (b) analytical error (from Eq. 1) obtained from between-run laboratory duplicate analyses of sulphate (dashed line). Data taken from EMEFS and pre-EMEFS sampling periods.

COMPARABILITY

Comparability was determined through the following activities:

- o Colocation of the networks at specific sites,
- o Precipitation laboratory intercomparison studies,
- o Air filter pack laboratory intercomparison studies,
- o Use of a single filter supplier to all five networks, and
- o Analysis of a single low concentration standard by all laboratories to determine a consistent measure of analytical detection limit.

A brief description of the methods and preliminary results is given below.

Colocation: Multi-network colocation of precipitation and filter pack instrumentation took place at Penn State University, Pennsylvania (in duplicate) and Egbert, Ontario (singularly). To date, the colocated network data have not be analyzed but will eventually be tested to (1) determine whether statistically significant biases occurred between the different networks and (2) quantify the magnitude of such biases. It is expected that these intercomparison results will be very important for ensuring that the various networks were indeed comparable.

Precipitation Chemistry Laboratory Intercomparison Study: The National Water Research Institute of Environment Canada was contracted for the Eulerian Model Evaluation Field Study to operate a precipitation chemistry laboratory intercomparison study. Once per month, ten water samples (covering a concentration range similar to that of real precipitation samples) were sent to each network's precipitation laboratory. The results were analyzed for bias and precision using the non-parametric Youden technique [Aspila, 1989]. Reports were sent to the individual laboratories within two to three months to ensure that corrective action could be taken at any out-of-control laboratories. In fact, none of the laboratories experienced out-of-control situations, although all experienced at least one blunder. Currently, the data from the 27 monthly intercomparison studies are being analyzed to quantify between-laboratory biases. Preliminary results, shown in Figure 4 for SO_4, indicate very small between-network biases (typically <0.1 mg/L) compared to typical sample concentrations [Aspila, 1991]. Note that the magnitude of the biases was determined using the 'median polish technique' [Hoaglin et al., 1983].

Air Filter Laboratory Intercomparison Studies: One of the participating members of the OMT was contracted to carry out a filter pack laboratory intercomparison study for the EMEFS project. This study was considerably more difficult than the aforementioned precipitation laboratory intercomparison study because of major difficulties in producing filters of comparable loadings for each of the pollutant species being measured. Despite the difficulties, the Operational Measurement Team designed a study in which three sets of comparably-loaded filters were distributed to the participating air filter laboratories.

The studies were designed with the following criteria in mind:

- o The intercomparison filters were to be the same as the filters used in the networks;
- o The filter loadings were to be representative of the range of loadings obtained throughout the EMEFS measurement program;
- o The loadings on the filters were to be obtained from ambient air sampling rather than from solution spikes;
- o The pollutant species to be measured in the intercomparison were to be the same as those measured in the routine network operations.

The study design was as follows: of the three intercomparison studies carried out, one was in the middle of the EMEFS project, one at the two thirds point, and one at the end. In each study, 18 sets of filters were distributed to each of the four labs - the 18 being nine sets of duplicate filters. All but one set of filters, which was a set of unused blanks, were collected under ambient sampling conditions by placing eight filter packs on the same sampling manifold at the same time and carefully controlling the flow rate to each. This was done over eight different sampling periods in order to collect the requisite number of ambient samples. Once collected, two filter packs from each sampling period were randomly selected for distribution to individual laboratories. Each lab then received eight sets of duplicate ambient filters and one set of duplicate blank filters. In addition, before each study, a pilot study was undertaken in which all eight filter packs sampled on three different occasions and were analyzed by one laboratory only. The resultant data were used to determine whether the within-network precision (affected by collection and analysis sources of variance) was good enough to allow us to distinguish between-network biases. It was concluded that this was indeed the case and the studies went forward.

The data from the three studies are currently being analyzed and no quantitative results are available to date. The method, however, appeared to work and holds considerable promise for wider applications in the future.

Sole Supplier of Filters: Throughout the two-year sampling period, one supplier of filters was used by all five networks. The supplier obtained the necessary filters from the manufacturers, quality controlled the blank levels, prepared the filters that required chemical impregnation, and distributed them to the five networks. The use of the single supplier of filters assured, at minimum, a comparable starting point for the filter sampling program.

Consistent Measure of Detection Limit: Unfortunately, the various laboratories carrying out air and precipitation analyses used a number of different methods to determine their analytical detection limits. Since most of these laboratories were unwilling or unable to modify these methods, the OMT designed a method of quantifying comparable detection limits across all labs. To do this, the OMT selected the International Union of Pure and Applied Chemistry (IUPAC) definition of detection limit, namely,

> **"the limit of detection expressed as a concentration of C_L, or quantity, Q_L, is derived from the smallest measure, X_L, that can be accepted with confidence as genuine and is not suspected to be only an accidentally high value of the blank measure" [IUPAC, 1978].**

Here, the value for X_L is given by:

$$X_L = \bar{X}_{bl} + kS_{bl}$$

where $\bar{X}_{bl}$ and S_{bl} are the mean and standard deviation, respectively, of the blank measure, and k is numerical factor based on the desired confidence interval - chosen as 3 in this case. The values for $\bar{X}_{bl}$ and S_{bl} are measured experimentally by making 20 or more measurements of a blank solution [Tropp et al., 1991].

For the EMEFS program, the blank measures were determined from surrogate anion and cation samples produced and distributed to all the laboratories by the National Water Research Institute of Environment Canada. These solutions contained less than 0.1 mg/l per analyte and were measured daily (or as frequently as possible). Two sets of the solutions were used over the EMEFS study period. All EMEFS network laboratories were required to analyze the solutions on an ongoing basis and submit the data for independent detection limit determination.

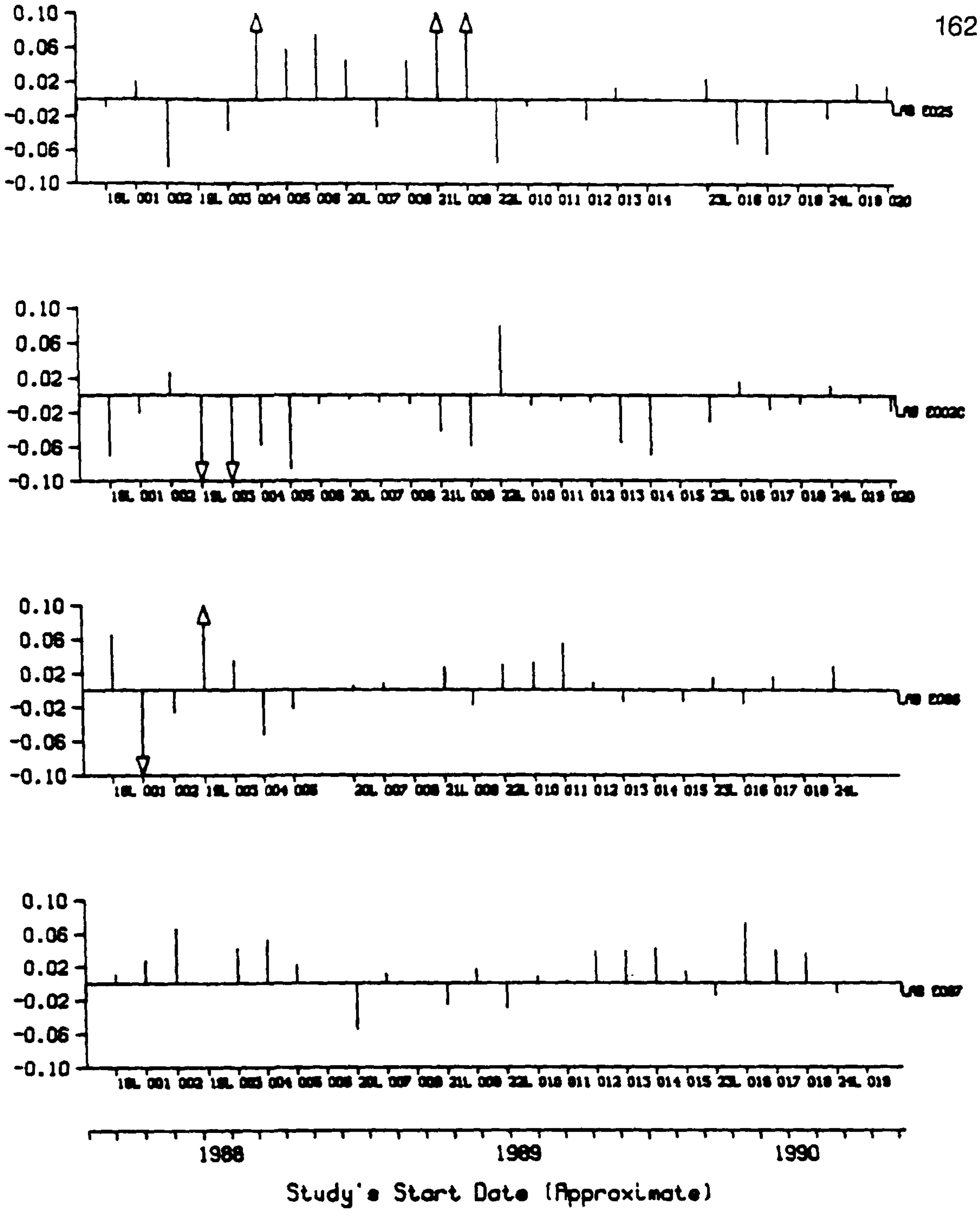

Figure 4. Results of the 27 EMEFS precipitation chemistry laboratory intercomparison studies for $SO_4^{=}$. Shown on the x-axis are the study numbers and approximate dates. Shown on the y-axis is the magnitude of the between-network bias in mg/L. Arrows indicate values exceeding the maximum or miniumum scale. The top 4 graphs represent the participating laboratories, the bottom graph represents the average of the 4 laboratories. All biases were estimated using the median polish technique.

Preliminary results are published in Tropp et al. [1991] and are summarized for SO_4 and NO_3 in Table 4. It is clear from Table 4 that the detection limits of most of the laboratories were comparable, however, two of the laboratories had detection limits roughly an order of magnitude higher than the others. It remains for the OMT to decide how to handle this dichotomy in the multi-network data base. It is worth noting that for SO_4 (the primary analyte of interest to this study), the measured detection limits of two of the six laboratories were lower than the nominal values stated by the laboratories (using their own definitions), two were higher and two were roughly equivalent.

COMPLETENESS

Data completeness was recognized early in the study as a major factor affecting the usefulness and accuracy of the EMEFS air and precipitation chemistry measurements (see, for example, Sirois, 1990). To minimize missing data errors, the five networks agreed to a 90 percent Data Quality Objective for completeness. They then instituted effective and timely corrective action programs to meet this DQO.

For the filter pack measurements in particular, data completeness proved to be an even more important factor because of the 24-hour-integrated nature of the filter pack sampling, i.e., if sampling time was lost during a 24 hour sampling interval, then the integrated filter pack loadings would be unrepresentative of the 24 hour period. To accommodate this, the networks validated only those data from filters that sampled for more than 75 percent of the sampling interval.

REPRESENTATIVENESS

In the context of this study, the representativeness of greatest concern to the model evaluators was the so-called 'regional representativeness' of the monitoring sites. Unfortunately, regional representativeness is not an easily-measured attribute so the networks adopted the following subjective and qualitative methods for handling representativeness:

1. Measurement sites were initially located using accepted siting criteria for regionally-representative sites, and

2. Networks adopted the site rating scheme of Olsen et al. [1990] whereby each site was rated subjectively for its <u>relative</u> regional representativeness. Table 5 summarizes the rating scheme. In the EMEFS data transmittal documents, these site ratings will be published for each site so that model evaluators and other data users will have some opportunity to judge the relative representativeness of the sites they use.

SUMMARY

From its inception, the Eulerian Model Evaluation Field Study was carefully designed to produce a high quality model evaluation data set. To assure such quality, specific procedures were used by the various networks, including: the adoption of standard measurement methods to the extent possible by the five participating networks, the implementation of similar within-network QA/QC procedures, and the operation of an extensive set of between-network colocated site intercomparisons. The results of these QA/QC activities will be documented in a Quality Assurance Synthesis Report that focusses on the accuracy, precision, completeness, comparability and representativeness of the data. Preliminary results suggest that a quality multi-network data base will be available for use by the model evaluators.

TABLE 4. PRELIMINARY RESULTS OF THE STANDARDIZED DETECTION LIMIT STUDY

SO_4 (mOg/L)

	Laboratory					
Set	**1**	**2**	**3**	**4**	**5**	**6**
1	0.124	0.030	0.034	N/A	0.031	0.030
2	0.868	0.058	0.056	1.423	0.022	0.022

NO_3 (mg N/L)

	Laboratory					
Set	**1**	**2**	**3**	**4**	**5**	**6**
1	0.252	0.011	0.045	0.094	0.008	0.017
2	0.104	0.065	0.026	0.052	0.008	0.010

VII. REFERENCES

Aspila K.I. (1989) A Manual for Effective Interlaboratory Quality Assurance. National Water Research Institute Report 89-99, Canada Centre for Inland Waters, 867 Lakeshore Rd., Burlington, Ont.

Aspila K.I. (1991) Personal Communication.

Bowen J.A. and Dowler O.L. (1991) Performance and Systems Audits on EMEFS Field Sites in Egbert, Ontario, Canada and State College, PA. US EPA Internal Report, Quality Assurance Division, Research Triangle Park, NC.

Hansen D.A. (1989) Project Plan for the Acid Deposition Eulerian Model Evaluation and Field Study. Electric Power Research Institute, Palo Alto, CA.

Hoaglin D.C., Mosteller F. and Tukey J.W. [Eds.] (1983) Understanding Robust and Exploratory Data Analysis. John Wiley and Sons, New York.

IUPAC, International Union of Pure and Applied Chemists (1979) Compendium of Analytical Nomenclature, Pergamon Press, New York.

McNair C.S. and Allan M.A. (1991). Personal Communication.

Olsen A.R., Voldner E.C., Bigelow D.S., Chan W.H., Clark T.L., Lusis M.A., Misra P.K., and Vet R.J. (1990) Unified Wet Deposition Data Summaries for North America: Data Summary Procedures and Results for 1980-1986. Atmos. Envir. 24A:3, 661-672.

Randles R.H. and Wolfe D.A. (1979) Introduction to the Theory of Non-Parametric Statistics, John Wiley and Sons, New York.

Sirois A. (1990) The Effects of Missing Data on the Calculation of Precipitation-Weighted-Mean Concentrations in Wet Deposition. Atmos. Envir. 24A:9, 2277-2288.

Sirois A. (1991) Personal Communication.

Tropp R., Tulis D. and Ringler E. (1991) OMT Report on Analytical Detection Limits for EMEFS Laboratories. ABB Environmental Services Inc., Chapel Hill, NC.

Vet R.J. and Sirois A. (1987) The Precision of Precipitation Chemistry Measurements in the Canadian Air and Precipitation Monitoring Network (CAPMoN). Proceedings of the 80th Annual Meeting of the Air Pollution Control Association, June 21-26, 1987, New York, New York.

TABLE 5. REGIONAL SITE REPRESENTATIVENESS RATING SCHEME [Olsen et al, 1990]

LEVEL	RATING	DESCRIPTION
1	Regionally Representative	Site free of non-regional influences or contamination.
2a	Potentially Regionally Representative	Local Sources (i.e., within 40 km) of interference exist but are judged to have little effect.
2b	Potentially Regionally Unrepresentative	Local sources of interference exist with potential loss of regional representativeness.
3	Regionally Unrepresentative	Local sources of interference exist and are known or strongly suspected to have significant effects.

FOURTH ANNUAL ECOLOGICAL QUALITY ASSURANCE WORKSHOP

POSTER SESSION

ECOLOGICAL SURVEY OF LAND AND WATER IN BRITAIN

John C. Peters
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Rural Affairs Directorate
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ABSTRACT

The paper describes the amalgamation of methods, costs and reasons for a survey of the British countryside during 1990.

Changes in agricultural activity fuelled by changes in support mechanisms has resulted in a loss of wildlife habitat and decrease in the varied landscape of Britain. The UK Department of the Environment together with its agencies and the Natural Environment Research Council have embarked upon a survey of land cover features utilising satellite remote sensing, low level air photography and detailed ground survey of a sample of 1 km squares to obtain a database. These data will not only provide a platform for comparison with future surveys but also enable comparisons to be made with past work of a less complete nature but which examined some sectors covered in the 1990 Survey.

The paper refers to important past work indicates the efforts made to ensure quality of survey and lists the features and species recorded.

INTRODUCTION

Until Sir Dudley Stamp set out to obtain a Land Use statement in England and Wales, in the mid-1930's there had been no comprehensive statement of these areas since the Doomsday Book of 1066. Stamp's land use maps and statistics have been augmented by the mapping activities of the UK Ordnance Survey and by a survey in England and Wales in the mid-1960s "The Land Utilisation Survey" of Dr Alice Coleman utilising students as surveyors. None of these surveys covered Scotland, but this is being rectified by the analysis of complete aerial cover obtained in 1989 and 1990. In addition to these country surveys there have been various sectoral surveys of land use such as those by the UK Ministry of Agriculture, Fisheries and Food (MAFF), Forestry Commission (FC) and Nature Conservancy Council (NCC). It is these sectoral surveys which have provided the main basis of national statistics of land use and land use change. Their strength lies in systematic recording, but their limitation in the difficulties of combining data.

In response to economic, social and environmental pressures land cover and the use to which land is put has changed dramatically since the Second World War. Agricultural Statistics reveal complicated shifts in the balance of areas of land under different crops. Forestry statistics show an expansion of conifers in the uplands and changes in the management of broadleave woodlands in the lowlands. Small changes in management, e.g., grazing intensity, time of cropping and fertiliser use are not discernible from generalised land use statistics. Ecological information necessary to identify and quantify the consequences for wildlife of such changes in land use are lacking, however. Three major but unconnected pieces of work took place in the 1970s and early 80s and it is the tying together of these into a major survey of Great Britain (GB) in 1990 that this paper describes.

AMALGAMATION OF THREE SEPARATE STUDIES

The Institute of Terrestrial Ecology Land Classification

In the 1970s the Natural Environment Research Council, Institute of Terrestrial Ecology set out to provide national statistics on vegetation cover and its species composition. The Institute of Terrestrial Ecology, National Ecological Survey, which took place in 1978 used an approach developed by Dr R Bunce of that Institute.

The Survey required detail that could only be provided by surveyors working on the ground. The three distinct levels of information were:

i) A land classification based on multi-variate analysis of physical variables (geology, climate, topography) designed to provide a framework for stratified sampling. The resulting hierarchy of 32 land classes defining the environmental variation of Britain was based on measurement of map data for each 1 km square from the national grid. (220,000 in all).

ii) Within each of the 32 environmental strata, random 1 km squares were used for field sampling of the vegetation and features of land cover. (8 from each in 1978 in 1978, 12 from each in 1984 (384 squares) and now increased to 528 proportionalised to each land class).

iii) Within each square random quadrats of both open vegetation and linear features (hedge, roadside, stream banks) were surveyed to give details of the species composition and cover.

The national extent and distribution of each type of land cover, vegetation type of species is then calculated from the detailed field survey by summating data for each class according to the area and distribution of each land class throughout the country. The land class therefore provides descriptions of the environmental conditions to which particular land use or ecological features are related through the data generated from ground surveyed 1 km squares.

Monitoring Landscape Change

At the time that the Institute of Terrestrial Ecology were embarking on their national vegetation survey, the Department of Environment together with its agencies the Countryside Commission and Nature Conservancy Council wanted to assess the rate of change that was taking place both nationally and regionally in the main countryside features so that some assessment could be made of the implications for both landscape and wildlife. It was soon recognised by the participants that the only retrospective datasets available to enable change assessment to be made was by utilising the national archive of aerial photographs.

The study was mounted to:

i) Examine major landscape features and their distribution from three periods of historic air photography.

ii) From the aerial photography available the dates chosen were the 1950s to 60 around 1970 (within two or three years) and around 1980 (within about two years).

The Department of Environment only has jurisdiction in England and Wales and not Scotland or Northern Ireland. The study was therefore embarked upon jointly with the Countryside Commission for these two countries.

The survey consisted of:

i) A sample of 707 sites of approximately 5 sq kms.

ii) At 140 of these sites a 1 km sq was ground surveyed.

iii) The rest of the sites were surveyed from 1:50,000 scale air photography.

iv) The sample of 2.3 percent of the land area of England and Wales collected data on a number of similar features for each of the three dates of air photography. (See Table 1).

v) The sample was stratified according to one of 16 generalised soil types within each county of England and Wales. This combination was chosen because county boundaries would enable grossing up to DOE regions.

vi) The size of sample sites was considered to be the smallest area for which the results would reach the specification of +/-5 percent error where features had a coverage of at least 15 percent of the area.

vii) Landsat Thematic Mapper census survey for England and Wales using a reduced number of amalgamated broad land cover features.

This "Monitoring Landscape Change" (MLC) study, produced a mass of net change statistics indicating the magnitude of change from one landscape feature to another as well as an estimate of the stock of these features at each of the three time periods. Because the survey sample was limited in both numbers of samples and the total area surveyed it was not possible to provide better than regional scale data on change. This went some way to answering the problem of how much change was occurring in countryside features, but it was not possible to answer the question as to the implications in terms of significance to landscape or wildlife because such data resolution was such that assessment could not measure feature quality and/or what mixture of features make up landscape value (Table 1).

In order to overcome some of the shortcomings of a limited sample in assessing the stock of features a parallel investigation using Thematic Mapper (TM) satellite images took place. Investigation of the accuracy of area prediction by confusion matrices indicated the importance of technique in expressing the pattern of features in the landscape but showed that accuracy even at 85 percent was insufficient in monitoring change. Change requires high mapping accuracy, particularly when the amount of change is small.

The MLC contract was carried out by Hunting Surveys and Consultants, part of the Hunting Group of companies. They completed the study in two years of intensive air photographic interpretation at a cost of some £400,000

In order to conduct the MLC survey a joint steering committee had been set up between the Countryside Commission, Department of Environment and the Nature Conservancy Council. Although funds were provided by both the Countryside Commission and Department of Environment, the Nature Conservancy Council was unconvinced that the scales of air photography used and the sampling intensity were sufficient to describe features accurately enough to assess wildlife habitat.

The Nature Conservancy Council therefore decided to go its own way and set up a National Countryside Monitoring Scheme (NCMS) using low level air photography (1:25,000) which attempted to determine ground features in greater detail. Although NCC managed to complete a study for Scotland using this approach, it was for only two periods: 1945 (approx) and 1976. In spite of increasing the sample to 10% of the land area, they also found that the results were poorly translatable in terms of habitat and landscape.

Ecological Classification of Running Waters

In parallel with these efforts to obtain statistics on change in the landscape and its implications DOE started a study in 1975 with the objective of determining the effect of regulating the flow of river water by headwater storage reservoirs on the ecology of rivers. Terms of reference were:

i) To examine ways of improving prediction of after effects of river flow control.

ii) To obtain some advance warning of expected effects.

iii) To explain the observations made from monitoring of river systems.

The UK Department of Environment contracted the Natural Environment Research Council/Institute of Freshwater Ecology (IFE) - then known as the Freshwater Biological Association (FBA) - to:

a) Sample a wide variety of British rivers in areas known to be as free of pollution as possible.

b) To describe the fauna in terms of its distribution according to physical and chemical data sampled for the same stretches of rivers.

c) Analyse this dataset by multi-variate analysis to develop a river classification capable of describing any reach of river on the basis of the faunal community associated with chemical and physical status.

This system has now been developed for the UK. Measurements of variables can be input into a computer model (RIVPACS) in order to enable a description of the expected fauna to be output. Departures from this prediction are indicative of the effect of changes in river regime outside normal limits of variation.

Research over the past 15 years has enabled improved predictions to be made and then to place in the context of observed changes produced by such changes as pollution as well as river regulation.

The Countryside Survey 1990

During the period 1987-1990 research was conducted into the opportunities for co-ordinating the types of approach used in the three surveys described above. This research programme was entitled "Ecological Consequences of Land Use Change" (ECOLUC).

Only the ITE survey provides a general classification to which all land use and cover types can be related as well as details of the ecology. The field survey information has been repeated in 1990 for comparison with 1978 and 1984 and provides quantitative data on land cover, vegetation type, and plant species composition. This database includes information on the distribution of plant species in open land, at its margins and in linear features, such as roadsides and can be summarised to include their spatial relationships or purely as summaries by 1 km square or land class. (See Annex B).

TABLE 1 MONITORING LANDSCAPE CHANGE PROJECT
Area features: summarised results for the whole of England and Wales, 1947-1980

Feature	1947 Cover per cent	1947 Relative standard error* %	1969 Cover per cent	1969 Relative standard error* %	1980 Cover per cent	1980 Relative standard error* %
Broadleaf	5.6	5.7	4.7	5.7	4.2	5.5
Coniferous	0.7	24.0	2.2	19.8	2.7	16.5
Mixed	0.7	14.6	1.0	12.0	0.9	11.7
Woodland	7.0+	5.3	7.9+	6.8	7.9+	6.8
Upland heath	3.0	20.3	2.4	26.2	2.4	25.5
Upland grass (smooth)	1.2	20.8	0.9	24.8	0.6	28.0
Upland grass (coarse)	4.6	14.6	4.3	17.5	3.9	18.8
Blanket bog	0.7	27.7	0.7	27.4	0.7	28.5
Bracken	1.1	20.4	1.0	23.4	1.0	25.2
Lowland grass heath	1.5	16.0	0.4	24.3	0.3	29.5
Lowland heather	0.4	22.8	0.2	34.5	0.2	31.6
Semi-natural vegetation	12.6+	7.4	10.1+	9.6	9.2+	10.2
Cultivated land	28.1	2.7	31.7	2.5	35.4	2.6
Improved grassland	38.1	2.8	34.5	3.1	31.0	2.9
Rough grassland	2.9	9.0	2.2	8.7	2.2	9.2
Neglected grassland	3.7	8.8	3.6	8.1	3.1	9.7
Farmed land	72.7+	1.4	72.1+	1.4	71.8+	1.4
Water/Wetland	1.3+	18.3	1.1+	17.2	1.1+	16.7
Built-up land	4.5	5.8	6.5	5.2	7.3	5.1
Urban open space	0.7	13.5	1.1	10.2	1.3	9.6
Transport routes	0.5	19.1	0.5	14.3	0.5	11.7
Other land	6.4+	5.5	8.8+	5.0	10.0+	4.9
Total	100.0+		100.0+		100.0+	100.0+

*Relative standard error is equal to coefficient of variation.
+Figures for sub-totals include rare features for which percentages are not presented in this summary table. Full tables are presented in Volumes 3, 4 and 5 of the Final Report.

Definitions

In Table 2, a number of British land assessment studies are compared. Although they measure the same broad categories of land cover, close examination indicates that features such as permanent grassland have a different definition because they have been measured from aerial photographs, satellite scenes or ground survey. In the latter instance, species composition has been used to define the feature.

It is vital in any survey that undertakes to link past datasets that data are collected that can be manipulated in the same way as the previous surveys. In the Countryside 1990 Survey the 1 km squares data are recorded by ground survey, low level air photography as well as satellite remote sensing. Study of the ground survey information has demonstrated the importance of linear features such as hedgerows and stream sides in maintaining diverse ecological communities. The importance of surveying these landscape features in order to provide data on implications for species content arose from the three-year period of research leading to the present survey (ECOLUC).

The MLC project identified the scale of changes recorded in major features. The scale of these changes has been applied to ecological data from a number of other studies derived from many sources in order to see whether the resolution at which MLC worked and at which changes were observed, was meaningful in ecological terms. It is apparent that measures of fragmentation and isolation of habitats such as woodlands and the frequency of occurrence of these fragments in the landscape have important implications for the make up and variety of bird species that may be associated with woods and hedgerows. A number of algorithms were derived to measure both buffer zones and distances from different landscape features to analyze these associations.

Freshwater Studies

The analyses to link these into the land classification have evaluated the extent to which topographical, meteorological, geographical and cartographic variables (landscape variables within the ITE Classification) can be used independently or in conjunction with physico-chemical descriptors of river type used in RIVPACS.

Linkage between change in the land cover and land use in river catchments has been associated with change in the datasets on invertebrate communities utilised in RIVPACS. Analysis of these data show a correlation coefficient of 0.946 between land class mean on the first access of the multi-variate analysis and the macro-invertebrate assemblages used to place GB rivers in one of 32 river classes. Studies took place on eight river catchments - a total of 34 sub-catchments. Each was sampled in 1980 and again in 1989 and comparisons made with land use changes in that period.

The success of this approach is so promising that the UK National Rivers Authority (NRA) has included as part of their quinquennial series of river surveys, RIVPACS

The success of this approach is so promising that the UK National Rivers Authority (NRA) has included as part of their quinquennial series of river surveys, RIVPACS compatible samples from 4000 sites totalling 9000 samples. This dataset will allow examination of the relationship between water quality and land use. As a result it should now be possible to upgrade the RIVPACS system hitherto based on the relationship between macro-invertebrate assemblages and physical and chemical characteristics of the river, to include landscape and land use variables. This is particularly important in assessing the true significance of point source pollution incidents against diffuse effects. It will improve environmental options set according to measures of "best practicable environmental option", i.e., balancing the possible effects of pollutant disposal to water as opposed incineration, dumping at sea or disposal to land.

One-Kilometer Square Land Classification - Ground Survey of 528 Squares

Through the stratification system provided by the land classification and the sample survey of a proportion of individual 1 km square on the ground, it is possible to determine sample means and their variance within each land class. For example this variance can be represented in terms of numbers and lengths of hedgerows, areas of different crops, quantity of woodland, transport routes etc. Hitherto survey results are applied as class means for each class to the 1 km squares that make up a particular area. An area of interest can be described in terms of the proportion of the 32 land classes that may be present.

It is also possible to describe each land class in terms of features in the form of a landscape sketch. This shows the numbers of a particular feature distributed as an "ideal" landscape. As the quantity of each feature can also be described in terms of its 95 percent confidence limits it can also be presented in the form of the highest and lowest numbers of features superimposed on the same landscape. By this method policy makers can have a visual representation of the possible variation in a landscape that may come about in response to different economic support strategies for land management. Subjective measures of like/dislike of a particular landscape change can be translated into objective terms. Summation of the total proportion of squares that may be affected by changes can then be used to measure the implications regionally, nationally or by area of interest eg, National Park or water catchment, of altered land management practices (see Table 2).

TABLE 2 FEATURES IN EACH SURVEY

CS 1990	LANDSAT CLASS	MLC	LANDCOV SCOTLAND	NCMS
-	sea/estuary	coast/estuarine	-	-
water	inland water	open water	water	open water
beach	tidal flats/beach	-	beach	-
saltmarsh	saltmarsh	saltmarsh	saltmarsh	-
maritime grass	sand dune/grass heath	sand/shingle	marram dune	-
amenity ley permanent pasture	managed grass	pasture amenity	improved grass airfield	semi-improved & improved grass, recreational
herb rich grass	rough grass	rough pasture, neglected pasture	smooth grass, golf links	unimproved grass
fen marsh	fen/marsh/rough grass herbaceous	freshwater marsh	wetlands	lowland mire wet ground
upland & moorland grass	montane grass	upland grass moor	Nardus/Molinia	-
bog	upland bog	peat bog	bogs	blanket mire
moor shrub heath/burnt	heather moor	upland heath	wet heather undefined	heather moor, montane heather
Pteridium	bracken	bracken	bracken	bracken

TABLE 2, CONTINUED

CS 1990	LANDSAT CLASS	MLC	LANDCOV SCOTLAND	NCMS
lowland heath	heather heath	lowland heath gorse	dry heather	maritime heath
scrub	scrub/orchards	scrub	scrub	scrub
trees/deciduous species	decisuous/mixed	broadleaved	broadleaved	b'leavedwood/plantation
trees/evergreen species	evergreen	coniferous	coniferous	conifer wood/plantation
mixed wood	-	mixed wood	undifferentiated mix	mixed wood
-	-	orchard/hops	-	orchard
arable	arable	arable/market garden	arable	arable
vacant land, abandoned and fallow	rudiral weed	-	-	-
built	suburban,urban	housing transport derelict	developed rural, built-up road, rail	built
bare	bare	rock, mineral	bare	bare rock/soil
felled wood	felled	-	felled	recent felled
linear/points aquatic, flush, burnt arable, misc. spp/uses	CLASSES EXCLUDED FROM LANDSAT CLASSIFICATION	A-linear/small features B-isolated features	cloud, snow, mixed mosiac, lines/points, recent plough, wood, open canopy, plantation	young plantation marginal inundated parkland

For each ground surveyed 1 km square, maps are produced Annex A shows the areal extent of habitats and cover features as well as the extent of linear features (hedges, walls, fences, ditches, roads - see Annex B). These data are being digitised for entry into the ARCINFO geographic information system (GIS) and can be output in both vector and raster format. This flexibility enables the areal data to be used to correct feature estimates obtained from the satellite remote sensing programme.

Satellite Remote Sensing

This part of the survey has the following aims:

i) To compile a digital map of land cover in Great Britain based on a hierarchical classification of land cover types (Annex B).

ii) To make quantitative assessments of accuracy of end products.

iii) To integrate this map with 1 km square topographic and thematic data obtained from the land classification and ground survey.

Landsat Thematic Mapper (TM) data will be geometrically corrected to OS national grid using 25m output pixels. Summer/winter composites will be made by co-registering scenes or part of scenes. The baseline will be 1990 +/- two years.

Images will be classified using maximum likelihood supervised classification. Training of the classifier will use sub-division of target classes to ensure low within-class variance and the number of training areas per sub-class has been adjusted to adequately define sub-class-statistics. Consistency at the national scale will only be obtainable for the aggregated 20- class product. Accuracy levels are likely to vary according to the detail of level of sub-division, but the expectation from initial tests is to classify target classes with 80 to 85 percent accuracy measured pixel by pixel or of 90 percent if measured per land parcel using a "majority verdict" of component pixels. Checks will be made against the ITE 528 1 km square ground data to enable correction factors to be applied using the 528 squares as control points. By extracting 1 km sub-images from the TM class maps and co-registering these with the 1 km field data a confusion matrix and correspondence statistics will be derived to enable tabulations of accuracy by land cover type and derive coefficients to correct the maximum likelihood classification.

Financial Investment

Some indication of the total cost of Countryside Survey 1990 and the lead in research programmes is necessary in understanding the attention paid to stringent data collection.

i) The ground survey of 525 one-km squares has amounted to £700K approx. out of a total for all aspects, including data analysis and remote sensing of £1.8 million.

ii) The lead-in research within the ECOLUC project cost £350,000 over three years and the research to develop the RIVPACS system amounted to £1.6 million over 10 years. In addition experience gained from MLC of £400K should be added to make the total direct investment just over £4 million.

iii) Added to this there has been basic scientific research undertaken by the Natural Environment Research Council for some 15 years in developing and testing the land classification and the river classification. It is likely that the scientific investment required to attract applied customer funding from the Government has not been far short of another £0.5 million.

Discussion

Research that brings methodologies into applied use and requires investment over periods of time and is of this magnitude tend only to be linked to policy needs in the later stages of development at a time when their outputs can be identified as being able to derive information within short timescales. This means that identification of resources in the early stages can only be made if sufficient professional individuals working in the particular field of inquiry, can be motivated and convinced of the likely eventual promise of the method. This means that the science involved must receive adequate peer review.

Throughout the development of the method used for this 1990 Countryside Survey there has been a peeling off of sections of the work which could be demonstrated as being useful to a variety of users prepared to invest in the project and support continued development. The river classification was linked to feasibility studies of engineering proposals for regulating reservoirs which have themselves a long lead-in period and therefore able to support a low level research initiative for some years. The land classification approach proved to be useful at surveying a single county in England (Cumbria, where the research station initiating the work was situated).

Development of the satellite remote sensing study has perhaps been less reliant upon a customer identifying interest and more on a methodology chasing a use. But even here it has been the UK Forestry Commission wishing to find ways of rapidly updating stock maps that has provided long term funding and stimulus to link the three levels of survey, ground, air photography and satellite data as is now being done in the 1990 Survey.

Stimulus for the survey to take place at this point in time has arisen from public pressure on politicians to preserve the landscape and wildlife of the British countryside, seen to be threatened by the rapid development of farm intensification and associated amalgamation of farms into larger and more efficient food production units. This has been fuelled by a post-war Government policy to make the UK self-supporting in food production. Since our entry into the Common Market supports in the European Commission for the agricultural sector have further stimulated the process and confirmed the perceptions of the general public that they do not like to see the changes taking place in the countryside.

Emphasis on the use of survey is changing from a wish to know where changes and their magnitude take place toward using these results as an objective description of different areas so that perceptions of what is wanted can be turned into objective to measures and used in a process of habitat restoration. A policy is beginning to develop towards setting "Environment Quality Objectives" for land. This may possibly be an ambitious use of the data which in consequence may be criticised as being inadequate in hindsight. Quality control must therefore include a strong element of understanding present objectives. Otherwise the very best of data can be devalued as being irrelevant to new objectives.

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BIBLIOGRAPHY

Armitage, P. D., Moss, D. Wright, J. F. and Furze, M. T. (1983)
The Performance of a New Biological Water Quality Score System Based on Macro-invertebrates Over A Wide Range of Unpolluted Running Water Sites. Water Research Volume 17, Number 3.

Barr, C. J., Bunce, R. G. H., Riddsdale, H. and Whittaker, H. A. (1986).
Landscape Changes in Britain. Institute of Terrestrial Ecology, Monks Wood, Huntington.

Bunce, R. G. H. and Heal, O. W. (1984)
Landscape Evaluation and the Impact of Changing Land-Use of the Rural Environment: The Problem and an Approach.
In: Planning and Ecology. Ed. R. D. Roberts, T. M. Roberts, Chapman Hall: London.

Bunce, R. G. H. and Smith, R. S. (1978)
An Ecological Survey of Cumbria. Cumbria C C and Lake District Special Planning Board: Kendal.

Coleman, A. and Maggs, K. R. A. (1968).
Land Use Survey Handbook (5th edn). Isle of Thanet Geographical Association.

Furze, M. T., Wright, J. F., Gunn, R. J. M., Clarke, R. T., Johnson, H. A., Blackburn, J. H., Armitage, P. D., and Moss, D. (1991 in press)
The Impact of Land Use Change on Aquatic Communities Department of the Environment Report.

Griffiths, G. H. and Williams, Ceri. (1990)
The Impact of Land Use Change on Aquatic Communities - Mapping Land Cover Change in Water Catchments from Satellite Imagery. National Remote Sensing Centre, Farnborough, Hants. GU14 6TD.

Griffiths, G. H., Wooding, M. G., Jewell, N. and Batts, H. A. (1988)
Use of Satellite Data for the Preparation of Land Cover Maps and Statistics. Report to the DOE. National Remote Sensing Centre: Farnborough.

Harvey, D. R., Barr, C. J., Bell, M., Bunce, R. G. H., Edwards, D., Errington A. J., Jollans, J. L., McLintock, J. H., Thompson, A. M. M. and Tranter R. B. (1986).
Countryside Implications for England and Wales of Possible Changes in the CAP. Centre for Agricultural Strategy: Reading.

Hill, M. O. (1989)
Computerised Matching of Releves and Association Tables, with an Application to the British National Vegetation Classification. Vegetatio 83, 187-194.

Hooper, A. J. (1988)
Monitoring of Landscape and Wildlife Habitats EC. Environmental Management in Agriculture - European Perspectives edit J. R. Park.

Nature Conservancy Council. (1987).
Changes in the Cumbrian Countryside. NCC, Peterborough.

Natural Environment Research Council. (1991 in press)
The Land of Britain. Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU.

Stamp, L. D. 1962.
The Land of Britain: Its Use and Misuse, 3rd edn. Longman, London.

ANNEX A

COUNTRYSIDE SURVEY 1990

FIELD SURVEY QUALITY ASSURANCE by Dr. C. Barr and Dr. R. Bunce (ITE)

1. Countryside Survey 1990 is ITE's third major national field survey of the rural environment. As part of a continuous process of improvement in methods and standards of field survey, greater emphasis than before has been focused on quality assurance. In planning the survey, time has been set aside to consult widely and to analyse the collective experience of ITE staff and those in other institutions and agencies with responsibility for the planning and execution of relevant field surveys.

2. This paper summarises the main ways in which quality control has been exercised, before, during and after the field survey.

Pre-survey

3. **1984 surveyors' recommendations on mapping:** At the conclusion of ITE's 1984 survey, a meeting was held at ITE Merlewood during which more than 30 major and minor recommendations were made for future surveys of land cover and landscape features. These were accepted and included in the planning of Countryside Survey 1990.

4. **Consultants' recommendations on vegetation recording:** As part of the 3 year period of research "Ecological Consequences of Land Use Change" (ECOLUC) project, ITE commissioned independent consultants to evaluate ITE's methods and to make recommendations for vegetation recording in further survey work. A sub-sample of 64 ITE sites was re-visited by Consultants in 1988, and vegetation quadrats were recorded. Data were compared with those from the 1977/8 ITE survey and the accuracy of change was assessed. These results, together with a further exercise, involving an examination of observer variability, led to a series of recommendations (eg the need to permanently mark quadrats, and to employ experienced botanists). The consultants' major recommendations were incorporated into the methods employed in the current survey.

5. **Internal appraisal document:** In February 1990, also resulting from ECOLUC, ITE produced a publication titled "ITE Land Classification and its application to survey: an internal appraisal". This review, which accommodated the comments of international referees, included recommendations in field survey methods, especially relating to sampling strategies (eg the need to move towards proportional sampling) and statistical aspects (eg development of suitable statistical procedures for dealing with data sets containing a high proportion of zeros). These recommendations were implemented in plans for the current survey.

6. **Qualified survey staff:** To mount the survey it was necessary for ITE to recruit 24 temporary field staff. These staff were selected from a total of over 200 applicants, most of whom had considerable experience of botanical surveys. The 18 survey teams, each of two persons, included at least one member or an experienced consultant, especially in the early part of the field season.

7. **Field handbook:** A comprehensive handbook was prepared, based on the lessons learned from previous surveys and recommendations, and incorporating the ideas and advice of staff in government agencies and other interested organisations. The handbook included both details of the standard methods to be used, and definitions of categories to be recorded. (Plans are in hand to make this available for general information and use).

8. **Field training course:** A two-week training course was held immediately prior to the field season (in late May). The main objectives of the course were to teach and standardise procedures, and to assess the botanical expertise of the surveyors. More than 50% of the course was spent in the field, learning methods through practical demonstrations and experience. The course was intensive but held in comfortable surroundings with time available for a wide range of activities relating to field work (eg seminars, botanical identification, first aid courses). Staff from a range of Government agencies, academic institutions and others (eg Department of the Environment, NCC, FC, IFE, Newcastle University and consultancies) were invited to instruct surveyors in particular areas of expertise and to provide policy background to the survey. The course was particularly valuable in bringing together a large group of taxonomists who were able to work and learn together.

9. **Aerial photographic interpretation:** As an aid to field survey, aerial photographs (taken post-1984) were obtained for each sample square and comparisons made with the Ordnance Survey (OS) base maps. All physical boundary changes were marked on the based map, as were isolated features such as individual trees. Recognisable differences in ground vegetation types, especially in the uplands, were marked as an aid to field mapping. All extraneous information (eg house names) was deleted to give a clearer revised base map.

<u>During survey</u>

10. **Mixing of survey teams:** Although different regions of GB were allocated to the six ITE Research Stations which are scattered throughout GB observer bias was reduced by mixing the members of survey teams within a region, at intervals. As well as reducing the chances of bias, this strategy ensured that surveyors were frequently reassessing their performance against new partners.

11. **Permanent plot marking:** To meet the overall objective concerning relocation of vegetation plots, metal marker plates were placed in field boundaries, or at the plot location in open land. Sketches were made showing the location of each plot and its marker plate, and lengths and bearings to nearby landmarks were measured and mapped. Finally, a photograph was taken showing the relationship of the quadrat to its surroundings.

12. **Supervision and expertise at each ITE Station:** To guide the field surveyors with administrative, logistical and procedural aspects, a Survey Coordinator was appointed at each ITE Station. Additional botanical expertise was also made available to allow surveyors to cross-check and confirm taxonomic identifications.

13. **Field supervision:** Apart from day-to-day supervision by Station Coordinators, each field team was visited independently by the Project leader on five occasions throughout the season, and checks were carried out on general procedures and mapping. In addition, checks on vegetation recording and botanical identification were carried out at least four times by independent external consultants.

14. **Desk-checks of recording sheets:** Data recording booklets were returned to ITE Merlewood Research Station on completion, throughout the season. Checks were carried out to ensure that 100% mapping has been completed in each site, and that all quadrats were recorded and samples taken. Any problems were notified immediately to Station Coordinators who ensured that omissions and errors were corrected. In the event, less than 10% of recording booklets were affected and re-visits were necessary in only two recorded cases.

15. **Newsletter:** During the survey, staff were circulated with six editions of a newsletter which were useful in updating and clarifying points in the Field Handbook, as well as providing a focal point for communication between staff.

Post-survey

16. **Coordinators' feedback meeting:** Having canvassed the views of field surveyors based at their ITE Station, the Coordinators reported back to the Project Management team in early December. Points to be discussed included the use and interpretation of codes (and the identification of any limitations in their use), and recommendations for future surveys.

17. **Repeat survey:** A sample of 30 sites (6%) was revisited to collect a second set of data from each. The exercise was being carried out by project management staff and consultants and allows an assessment of the quality of data-recording during the season. Because the repeat survey was carried out at the end of the normal field season, there will be an opportunity to examine the effects of temporal variation and, in some areas, the effects in drought on vegetation. It is intended that an

independent panel of expert field botanists should carry out a quantified assessment of the two sets of field records and should carry out a quantified assessment of the two sets of field records to identify the causes of any differences between them.

18. **External checking of data recording forms:** It is intended that an independent consultant will check and comment on all data recording forms, especially as a means of validating the botanical components of the land cover mapping, and the vegetation quadrats. In addition, cross-checks will be made between the location of species recorded in the Countryside Survey 1990 and information held at the UK Biological Records Centre (part of the Environmental Information Centre at ITE Monks Wood) which holds records and publishes maps of 10 km square scale of the distribution of over 7000 UK species.

19. **Checking of machine-readable data:** All information collected during the field survey is being entered into computers. Typing and coding errors will be reduced by double punching by two separate firms entering data. There is partial repeat digitising of cartographic data. Checks for legitimate code combinations will be carried out.

20. **Advisory Committee:** General progress of the project is steered by a 15 strong committee which includes sponsors, academics, government and international observers from Europe.

ANNEX B

ITE LAND CLASSIFICATION

Descriptions of main classes

1. Undulating country, varied agriculture, mainly grassland
2. Open, gentle slopes, often lowland, varied agriculture
3. Flat arable land, mainly cereals, little native vegetation
4. Flat, intensive agriculture, otherwise mainly built-up
5. Lowland, somewhat enclosed land, varied agriculture and vegetation
6. Gently rolling enclosed country, mainly fertile pastures
7. Coastal with variable morphology and vegetation
8. Coastal, often estuarine, mainly pasture, otherwise built-up
9. Fairly flat, open intensive agriculture, often built-up
10. Flat plains with intensive farming, often arable/grass mixtures
11. Rich alluvial plains, mainly open with arable or pasture
12. Very fertile coastal plains with very productive crops
13. Somewhat variable land forms, mainly flat, heterogeneous land use
14. Level coastal plains with arable, otherwise often urbanised
15. Valley bottoms with mixed agriculture, predominantly pastural
16. Undulating lowlands, variable agriculture and native vegetation
17. Rounded intermediate slopes, mainly improvable permanent pasture
18. Rounded hills, some steep slopes, varied moorlands
19. Smooth hills, mainly heather moors, often afforested
20. Midvalley slopes, wide range of vegetation types
21. Upper valley slopes, mainly covered with bogs
22. Margins of high mountains, moorlands, often afforested
23. High mountain summits, with well drained moorlands
24. Upper, steep, mountain slopes, usually bog covered
25. Lowlands with variable land use, mainly arable
26. Fertile lowlands with intensive agriculture
27. Fertile lowland margins with mixed agriculture
28. Varied lowland margins with heterogeneous land use
29. Sheltered coasts with varied land use, often crofting
30. Open coasts with low hills dominated by bogs
31. Cold exposed coasts with variable land use and crofting
32. Bleak undulating surfaces mainly covered with bogs

SUMMARY OF LAND COVER DATA
Recorded for 528 1 km squares

LEYS

Lolium perenne
Lolium/Dactylis glomerata
Dactylis glomerata
Mixture/unspecified
Hay/silage

PERMANENT PASTURE

Lolium perenne dominant
Lolium perenne present but also Holcus lanatus or Poa trivialis or Agrostis spp. in various mixtures.
Unspecified/mixtures or generally improved pasture.
Cynosurus cristatus/Agrostis spp. or Holcus pasture that is not in good condition being somewhat neglected.

ROUGH PASTURE

Agrostis/Fescue
Mixture/unspecified
Rush infested but not entirely rushes
Bracken infested but not entirely bracken
Mixtures of Deschampsia flaxuosa and Nardus stricta

OTHER DOMINANT SPECIES

Calluna vulgaris
Vaccinium myrtillis
Pteridium aquilinum
Juncus effusus/Juncus atriculatus and mixtures or marshland.
Molinia caerulea
Eriophorum vaginatum
Tall herb vegetation
Herb-rich grazed grassland
Ploughed land or fallow
Derelict
Wheat
Barley
Oats

Sugar Beet
Kale/fodder species
Turnips/roots/swedes/rape
Potatoes
Beans/peas
General horticultural crops
Orchards
Roads
Built up land
Footpaths
Railways
Cliffs, sand and mud
Canal/Stream
Lake

PHYSIOGRAPHY/INLAND WATER/COASTAL

INLAND PHYSIOGRAPHIC FEATURES

Cliff>30m high
Cliff 5-30m high
Pebble/gravel shore
Rock outcrop & cliff >5m high
Scree
Surface boulders
Isolated boulder
Eroding raw peat
100% rock
>50% rock
10-50% rock
Stable raw peat
Current domestic peat workings
Current commercial peat workings
Old peat workings
Soil erosion
Ground levelling

COASTAL FEATURES

Rocky shore

Sandy shore
Sandy dune
Bare mud

INLAND WATER FEATURES

Lake natural
Lake artificial
Pond natural
Pond artificial
River

Signs of drainage
Rock
Sand/Gravel
Mud
Peat

Canalised river
Canal
Stream
Roadside ditch
Other ditch
Spring
Well
Levee

Lake shore
River bank
River substrate
Stream substrate
Waterfall
Rapids
Gorge

AGRICULTURE/NATURAL VEG ETC.

COVER TYPES

Amenity grass > 1ha
Ley
Permanent pasture
Upland grassland
Moorland grass
Moorland - shrub heath
Herb-rich grassland
Maritime grass
Lowland heath
Aquatic macrophytes
Aquatic marginal veg
Bog
Fen
Marsh
Flush - calcareous
Flush - non calcareous
Garden Centre/Nursery
Saltmarsh
Wheat
Barley
Oats
Mixed grain

Sugar beet
Turnips/Swedes/Roots
Kale
Potatoes
Field beans
Peas
Lucerne
Maize
Rye
Oilseed rape
Other crop
Flowers
Commercial horticulture
Commercial glasshouse
Soft fruit

Ploughed
Vacant
Abandoned/neglected
Burnt
Fallow

SPECIES (IF > 25%)

Corsican pine
Scots pine
Lodgepole pine
Norway spruce

PROPORTIONS

25-50%
50-75%
75-95%
95-100%

Sikta spruce
Douglas fir
Larch
Western hemlock
Western red cedar
Other conifer
Elm
Oak
Beech
Ash
Sycamore
Birch
Poplar
Alder
Lime
Willow
Hawthorn
Gorse
Bramble
Other broadleaf
Mixed softwoods
Mixed hardwoods
Game/Sporting

DESCRIPTIONS/FEATURES

Undamaged
Cutting/Brashing
Felling/Stumps
Natural regeneration
Underplanting
Plantation
Planted
Ploughed land
Staked trees
Tuley tubes
Fenced single trees
Windblow
Dead standing trees
Re-growth - cut stump

USE

Commercial
Domestic
Timber production
Fuelwood production
Conservation
Amenity
Recreation
Grazing-Agricultural
Shelter
Game/Sporting

COVER TYPES

Scattered trees
Woodland/forest
Coppice
Scrub
Line of trees
Belt
Individual trees
Hedgerow tree

AGE

1-4 years
5-20 years
21-100 years
>100 years

BOUNDARIES

WALL

Dry stone
Mortared
Other

FENCE

Wood only
Iron only
Wire
Other

HEDGE

>50% Hawthorn
>50% Willow
>50% Beech
>50% Gorse
>50% Other
Mixed hedge
Hedge trimmed
Hedge uncut
Hedge derelict
Line of relict hedge
Laying
Flailing

BANK

Stone
Earth

DESCRIPTIONS

>2m High
>2m High
>1m High
Stockproof
Not stockproof

Filled gaps <10%
Filled gaps >10%
Signs of replacement
Signs of removal
No longer present
Derelict
Burnt

RECREATION

FORMAL

School playing fields
Other playing fields
Race track
Tennis courts
Boating area
Static informal caravans
Golf courses
Static formal caravans
Information point

INFORMAL

Horse jumps
Other horse accessories
Angling notice
Angling platform
Boat-house
Boat-inland water
Nature trail

Touring caravan park
Camp site

BUILDING/STRUCTURES/COMMUNICATIONS

BUILT COVER TYPES

Building
Garden/grounds with trees
Garden/grounds without trees
Public open space

Allotments
Car park
Other land

USE

Residential
Commercial
Industrial
Public Service and facilities
Institutional
Educational/cultural
Religious

Forestry
Sporting/recreational
Waste domestic
Waste industrial
Quarry/mine

DESCRIPTION

New
Vacant
Derelict

STRUCTURES

Bridge
Tunnel
Dam
Pipeline
Pylon
Other pole
Silo
Silage pit/clamp
Other Agri store
Snow fence
Speed restriction
Quarry/pit
Recreation areas
Sea
Rock

COMMUNICATIONS

Road (tarmac)
Verge <1m
Verge <5m
Verge <5m
Constructed track
Unconstructed track
Footpath (exclusive)
Footpath (other)
Railway track
Other railway land
Embankment
Airport/aerodrome
Informal barrier

WOODLAND

Broadleaved copse
Mixed copse
Conifer copse
Broadleaved shelterbelt
Mixed shelterbelt
Conifer shelterbelt
Gillside woodland
Scrub
Broadleaved woodland
Conifer woodland
Mixed woodland

OTHER CATEGORIES

Phleum pratense
Lucerne
Maize
Nardus stricta
Molinia/Trichophorum/Eriphorum recorded as mixtures
subartic type vegetation
Vaccinium myrtillus
Erica tetralix
Rye
Juncus squarrosus
Unspecified mixed mountain grassland
Unspecified mixed mountain moorland always with some *Calluna*
Trichophorum - always with a proportion of *Calluna*
Calluna recorded as co-dominant with *Eriophorum*
Calluna recorded as co-dominant with *Vaccinium*
Burnt
Parkland
Maritime grassland recorded on sea cliffs
Mustard and oilseed rape
Mixed grain oats and barley
Saltmarsh
New built-up land

Aggregation of classes for accurate map outputs from satellite remote sensing

		water	sea/estuary
			inland water
wetland	wetland		
		intertidal	intertidal flats/
			beach
			saltmarsh
			sand dune/grass
			heath
		lowland	managed grass
			fur/marsh/rough herb
			montane grass
		upland	upland bog
		herbaceous	bracken
vegetation			rudiral weed
			heather moor
		shrub	scrub/orchards
			heather heath
	'woody'		
			deciduous/mixed
		woodland/	evergreen
		trees	
		arable	arable land
man-made	man-made		
suburban			
		non-vegetated	urban/industrial
			felled
bare	bare		bare rock

FOURTH ANNUAL ECOLOGICAL QUALITY ASSURANCE WORKSHOP

WORKGROUP SESSION REPORTS

THE DEVELOPMENT OF GUIDELINES for use of DATA QUALITY OBJECTIVES in AQUATIC MONITORING PROGRAMS

Leader:
Dennis M. McMullen
Technology Applications, Inc.

Rapporteur:
Michael Guill
ASci Corporation

I. Introduction

To open each work group session,the workgroup leader, Mr. Dennis McMullen, provided an overview of the Data Quality Objectives (DQO) process. He described the process as consisting of seven stages: (1) statement of the problem to be resolved, (2) identification of the research question, (3) statement of the inputs, (4) narrowing of the boundaries of the study, (5) development of a logic statement, (6) development of uncertainty constraints, and (7) optimization of design for obtaining data.

To assist the groups in understanding and applying the DQO process, he presented ten questions categorized into three Stages. Stage one questions address the problem of concern: *What is the purpose of the environmental data? What are the resources and time constraints? What are the consequences of Type I and Type II errors?* Stage two questions address information needs: *What is the population of interest? What level of confidence must attend results? Do pertinent, usable data currently exist? What new data are needed?* Stage three questions address the scientific approach: *What approaches to data collection are available? Which approaches provide data quality commensurate with Stage two requirements? What research and development activities are needed to meet Stage two requirements?*

The workgroups were then given a brief overview of EPA's Environmental Monitoring and Assessment Program (EMAP) objectives, namely: (1) to estimate current status, extent, changes and trends in indicators of the nation's ecological resources on a regional basis with known confidence, (2) to monitor indicators of pollutant exposure and habitat condition, and to seek correlative relationships between human-induced stresses and ecological condition that identify possible causes of adverse effects, and (3) to provide periodic statistical summaries and interpretive reports on ecological status and trends to the EPA Administrator and the public. Three basic types of indicators to be estimated were identified: Response Indicators (*e.g.*, indices of biotic diversity), Exposure Indicators (*e.g.,* toxicity tests and habitat assessments), and Stressor Indicators (*e.g.,* population density and land use).

Mr. McMullen introduced the concept of the DQO Hierarchy, with **Measurement Quality Objectives** as the first tier, addressing baseline data; **Indicator Quality Objectives** as the second, addressing the indicators of ecological interest; **Ecosystem Quality Objectives** as the third, addressing the consideration of multiple indicators together; and **Societal/Environmental Endpoints** as the fourth and final tier, addressing cross-ecosystem assessments.

Mr. McMullen's presentation then focused on the EMAP Surface Waters objectives, which involves investigation of three specific endpoints: **Trophic State** (in particular, the occurrence of eutrophication due to anthropogenic nutrient loading), **Fishability** ("Are there fish in these systems, can I catch these fish, and if I catch them, can I eat them?"), and **Biological Integrity** (defined as the ability to support and maintain a balanced, integrated, adaptive community of organisms with a species composition, diversity, and functional organization comparable to that of natural habitat of the region).

Mr. McMullen then reviewed the development of the logic statement for the EMAP Surface Waters sediment toxicity indicator. The DQO process forces the investigator to remain focused on the central questions and the information required to answer these questions, as can be seen in the following DQO-based question/answer pairs:

1. Q: What is the problem or environmental concern that this indicator will address?

   A: Whether the bottom sediments of lakes in the U.S. are toxic to aquatic life.

2. Q: How does this problem relate to societal interests or concerns?

   A: Sediments may be hazardous to humans. They may be critical habitat for ecologically important species, or loss of critical species resulting from sediment toxicity may lead to loss of fisheries and lower aesthetic value.

3. Q: What information is needed to address the problem?

   A: A method of measuring sediment toxicity is needed; a definition for "indicator species" is needed; and a method for assuring that the laboratory test design reflects in-vivo toxicity is needed.

4. Q: What data will be collected in the field and by what method?

   A: A field investigation plan is needed that will provide data to describe, at a minimum, the types and levels of contaminants in sediment; fish community structures, including species identification, abundance, and diversity; and the physical/chemical environment, including water chemistry and the physical characteristics of water bodies studied. This plan must include a sampling plan that identifies specific methods to be used and describes the rationale for selecting sampling stations and sample collection frequencies.

5. Q: What laboratory analyses will be performed and by what methods?

   A: Workgroup participants suggested the following investigations to determine sediment toxicity: (1) a 10-day acute, solid-phase test with amphipods using survival as the endpoint to be measured; (2) a 7-day chronic, solid-phase test with fish using survival and growth as endpoints; and (3) a 7-day chronic, solid-phase test with Daphnia, using survival and reproduction as endpoints.

6. Q: How will the data provided be used to address the problem?

   A: The laboratory data will demonstrate the relative toxicity of sediment to a single or multiple indicator species. From this information, population and community level effects can be extrapolated.

After working through the process of answering each question, workgroup participants concluded that the original question to be addressed should be further refined and restated as: *What number/percentage of lakes in a given region of the U.S. have sediments that are toxic to aquatic life, as demonstrated by effects observed relative to controls in laboratory bioassays?* The work group also identified the sources of variability in the data. They included: (1) measurement variability (including analytical measurement variability and other measurement variability, such as from sample collection, and handling); and (2) sampling variability (including spatial and temporal representativeness of the sample, and the representativeness of test method (*i.e.*, laboratory test vs. field effects).

II. Summary of Discussions

Following the introduction to DQOs, each work group session applied the suggested process to development of DQOs for a program designed to select a fish tissue contaminant indicator to be used by the Surface Water component of EMAP. Available time was not sufficient for either session to complete all seven steps of the DQO process. Following is a summary of discussions regarding the first four steps.

State the Problem to be Resolved. Since the goal of the case study was selection of appropriate indicators of fish tissue contaminants for the Surface Water component of EMAP, workgroup participants focused on problems inherent to making scientific generalizations over a wide range of species, contaminants, and environmental settings. The workgroup leader suggested that the general underlying problem to be resolved in the case study is the lack of information and understanding of fish tissue contaminants and contaminant levels in the U.S.

Identify the Research Question. The two sessions arrived at fairly similar preliminary research questions:

- Is the consumption of fish from a particular reach of river hazardous to human health?

- Are the fish in a given area safe to eat? Is it necessary to issue a fish consumption advisories for specific areas?

State the Inputs. In order to characterize the information needed to answer the research questions, participants in both sessions developed extensive lists of issues to be addressed. The issues fell into several general categories, as follows:

- Definition of terms: Participants in both sessions identified numerous terms that must be clearly defined and understood at the outset of the project. These included terms such as "contaminant", "area", "fish", "safe", and "hazardous".

- Identify contaminants of concern: Participants agreed that the contaminants of concern must be determined early in the planning process. Questions were raised concerning how a contaminant list could most effectively be generated; whether it should include all compounds for which toxicological data exists, or whether it should be limited to contaminants that have been identified by a field reconnaissance program. It was suggested that the investigator should identify: (1) potential sources of contaminants (conspicuous point sources, industry in the region, effluents, contaminated runoff); (2) information available from data generated in past epidemiological and toxicological studies; and (3) contaminants of regional concern historically. It was further suggested that the investigator use this information to plan and conduct a pilot study in order to refine the study and assure that results of future data collection and analysis will be of sufficient quality to answer the research question.

- Method detection limits: Both sessions addressed the problem of interpreting "Not Detected" results and acknowledged the problems that arise when currently available measurement techniques are not sufficiently sensitive to detect concentrations of concern.

Participants identified specific information that would be necessary to answer the research questions, including: (1) the trophic status of the body of water in question; (2) the natural history of the fish in question (including the location of feeding, whether they are resident or migratory, and size and age distributions); and (3) data on the bioconcentration factors of the contaminants.

Each session discussed the topic of variability and the consequences of error. Two possible undesirable effects of error in this instance were identified: (1) the closing of fisheries which are not dangerously contaminated, and (2) the failure to regulate unsafe fisheries.

Narrow the Boundaries of the Study. Four general topics of concern were identified as points where the scope of the investigation could be narrowed: (1) What are the water bodies of concern? (2) Which contaminants are to be investigated? (3) What fish (or other) species are of concern? and (4) What human populations are placed at risk by the contaminants?

III. Conclusions and Recommendations

Participants in both sessions agreed that the DQO process provides a good tool for identifying potential sources of error in a research study design and for determining acceptable levels of uncertainty in decisions based on environmental data. Participants further agreed that, in order to be successful, the DQO process must be supported by strong management endorsement, in terms of both philosophical commitment and commitment of resources needed to implement the process. Other general conclusions reached by the sessions and offered as guidelines for using the DQO process in aquatic ecological applications include the following:

- Collection and review of historical data is a critical first step in study design. Investigators should examine all relevant studies and literature in detail prior to designing the investigation. Federal and state agencies should also be consulted to obtain unpublished information.

- The use of pilot studies is an essential element in meeting the objectives of the DQO process.

- *Investigators should be careful to determine* that *all data to be* collected will provide information useful in addressing the research question.

THE DEVELOPMENT OF GUIDELINES for use of STATISTICAL TOOLS in AQUATIC MONITORING PROGRAMS

Leader:
Dr. Peter MacDonald
McMaster University

Rapporteur:
Jan Edwards
Edwards Associates

I. INTRODUCTION

Workgroup sessions on the use of statistical tools in aquatic monitoring involved two discussion periods. In the first, each session discussed aquatic monitoring programs and problems that were of interest to individual participants. Each participant described a case or problem of interest and identified key concerns or objectives related to the use of statistical tools and monitoring program design. In the second discussion period of each session, the workgroup reviewed some important statistical concepts and their potential applications in aquatic monitoring.

II. SUMMARY OF DISCUSSIONS

As each workgroup participant described a study or monitoring program of interest to them, the group identified the potential applications for statistical tools. The following types of problems were discussed:

> Questions of data comparability: Several participants described situations where, because of budget constraints or changes in programs made over time, data collected over periods of many years that varies in terms of sample numbers and locations and/or analytical technique must be used to characterize trends or draw conclusions. Problems inherent to making comparisons of data sets from different sources (e.g., two different laboratories) were also discussed. One challenging example involved evaluating the quality of macroinvertebrate species identification and enumeration data from numerous laboratories. The workgroup agreed that a simple contingency table is a useful tool for comparing data sets from two sources.

Using small data sets: Workgroup participants identified cases where conclusions must be drawn on the basis of relatively small data sets. Participants noted that often, budget constraints or the limitations of historical data require aquatic biologists to rely on relatively small data sets to draw significant conclusions or make decisions. In such cases, it becomes necessary to make an explicit evaluation of sample representativeness.

Interpreting data outliers: Several participants described situations that required techniques for explaining or interpreting data outliers. The workgroup agreed that data interpreters should rely on all possible sources of information, including notebooks kept by field personnel, which can sometimes provide the key to otherwise inexplicable results.

Establishing baseline conditions or identifying "reference" lakes and rivers: One participant described a case that required identification of a reference river and noted that the wide range of variables to be considered makes identification of an appropriate reference very difficult in aquatic environments. Nonetheless, participants agreed that establishing baseline conditions or a reference from which to evaluate change or trends is a critical element of study design.

Data useability issues: Several participants described situations that required application of data known to be flawed or of limited applicability. They cited a need for tools that assist in determining when bias or error is sufficient to render data unusable.

Developing sample stratification regimes: One participant described a study that involved developing techniques for delineating regions within a wetland or estuary environment. Participants noted that environmental regions or strata often are not distinguishable in obvious ways. The workgroup discussed use of multivariate analysis to examine numerous variables and their relationship to each other in order to define regions. Participants agreed that pilot studies should be used to identify and understand strata so that effective sampling regimes can be developed.

At the close of each session, the workgroup reviewed some statistical principles and tools that are generally helpful in designing environmental studies. The workgroup participants concluded that application of statistical tools is helpful in data interpretation in cases where there is evidence of data correlation, where effects are masked, where there are missing data, where the wrong variable has been measured, or where other confounding factors or variables are at work.

Participants discussed the advantages of consulting statisticians early in the development of a study design and agreed that statistics should be viewed by scientists as an integral component of study design rather than as a "widget" or enhancement added after the data are collected. Participants concluded that there are several basic considerations that should be taken into account when designing an aquatic monitoring program: balance, control, replication, reproducibility, and checks for correlation and dependence. Balance or weighing considerations ensure that the correct suite of variables are chosen for measurement. In general, participants in both sessions agreed that it is advisable to collect as much data as possible while in the field, taking into account budget considerations. Once the data are collected, they need not all be evaluated at once. Establishing a control or reference for a study ensures that change or trends over time can be reliably detected. The concept of replication allows for distinguishing between measurement error and natural variability. Replication should be achieved by repeating measurements at the most elementary level. Checks for correlation allow the scientist to evaluate data in time and space to determine whether any patterns of variability can be ascertained.

The workgroup addressed two different types of sampling regimes: stratification and cluster sampling. Stratified sampling techniques are applicable when strata can be defined within which there is relatively low variability for the parameters of interest. The numbers of samples needed within strata increase as variability within strata increases. Pilot studies are needed to define and understand strata within a population. In general, stratified sampling regimes are more cost-effective because they allow collection of fewer samples.

Cluster sampling techniques are applicable in cases where a cluster of sample locations is representative of a whole population. Cluster sampling techniques simplify the logistics (and potentially the cost) of sample collection. Their effectiveness however, depends on the extent to which the cluster is representative of the whole population. Again, pilot studies are needed to determine whether a cluster sampling technique will be effective.

III. Conclusions and Recommendation

Based on the two sessions, the workgroup proposed the following guidelines for the use of statistical tools in aquatic monitoring programs.

1. Statisticians should be involved in study design from the beginning, but only if the statistician is experienced and interested in environmental survey design.

2. Optimal statistical design requires information. Pilot studies should be used to provide specific information needed for sampling design. Pilot studies should be used to:

   - Understand the performance characteristics of the measurement technique;

   - Investigate the scale of population variation sufficient to determine whether stratified or cluster sampling is appropriate; and

   - Select appropriate sampling intervals in space and/or time.

3. Pure measurement error expresses the limitations of the methodology and should be measured at the most elementary level. Variation between laboratories will not be less than variations within one laboratory.

4. Measure as many variables as practical. They need not all be analyzed at once. In studying ecosystems, multivariate analysis is useful to an extent, but in examining multiple variables, the scientist runs the risk of confusing the issue with statistics. On the other hand, if measurement of additional variables can be accomplished for relatively little extra cost, more information increases the chances of measuring the "best" variable.

5. The role of control or comparison groups may differ from study to study, however, in all cases, a baseline or standard for comparison should be established. New studies can be used as a baseline for future study.

6. In cases where more than one measurement method is applicable, selecting the best method should involve balancing decreasing cost with increasing variance.

7. Methods for combining results from different studies, called meta analysis, may be borrowed from clinical studies for use in ecological studies. Such combining depends on an ability to measure the reliability of each data-generating study.

8. In studies conducted over very long periods of time that experience a change in measurement technology, new and old technologies should be run in parallel until sufficient calibration is achieved.

9. Aggregating data in space or time reduces variability but may introduce bias.

10. Managers should make their own evaluations of monitoring data. Numerous statistical support and graphical software packages are available to assist managers with data evaluation.

11. Graphical displays of data should be carefully designed to take into account the concerns, needs, and perspective of the intended audience.

DEVELOPMENT OF GUIDELINES for use of DATA QUALITY OBJECTIVES in TERRESTRIAL MONITORING PROGRAMS

Leader:
Elizabeth Leovey
USEPA

Rapporteur:
Allison Cook
ASci Corporation

I. Introduction

The leader of this workgroup, Elizabeth Leovey of EPA's Office of Pesticide Programs, provided a case study as the context for application of the Data Quality Objectives (DQO) process. The case involved EPA review of the registration for a fictitious herbicide, "Power Wilt", under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Workgroup participants acted the roles of interested parties in applying the DQO process and designing a monitoring study (or series of studies) needed to determine the potential environmental consequences caused by application of Power Wilt.

This case was a relatively complex one because the hypothetical pesticide affects several different components in the environment (i.e. plants, soil, water, and air), and because its impact varies between sites due to factors such as climate and geography. Also, the fact that the case involved an applied research study mandated under an EPA regulation introduced policy concerns into the DQO process. By taking on different public and private sector roles, the workgroup participants obtained first-hand experience in solving an inherently adversarial problem.

Consequently, this workgroup examined the following types of questions:

> How realistic is the DQO process in planning field research for a perceived environmental problem?

- Since the DQO process is intended for research planning, does the process in fact perform well in a situation that involves both scientific, policy, and economic concerns in an inherently adversarial setting?

- And finally, what are the strengths and weaknesses of the DQO process? What improves the likelihood of success, and what can make the DQO process work better in complex situations?

At the outset of the sessions, Ms. Leovey reviewed the five main steps in the DQO process:

1. State the problem to be addressed,

2. Identify variables and select those to be measured,

3. Develop a logic statement for each variable to be measured,

4. Specify an acceptable level of uncertainty, and

5. Optimize the study design.

In the case study, the Environmental Protection Agency is requesting that the manufacturer of "Power Wilt", Herbicides Inc., conduct studies to respond to public concerns and resolve data gaps. Since the compound was originally registered in 1975, additional adverse impacts have been discovered which have generated significant public concern. Power Wilt was described as a highly toxic herbicide that kills broadleaf plants with virtually no effects on mammals. Levels toxic to plants can be measured by present analytical methods.

The specifics of the field study required may vary depending on the negotiation format chosen. Different types of public participation are encouraged by the Agency. In this example, participants could refine the required study through a public hearing, at which all interested parties present their positions and specify the questions they would like to see answered, and the problem-solving strategy they recommend. Or they could choose to negotiate directly with the registrant instead. In this instance, representatives from various interest groups may provide input into the study design process through their state representatives, by attending some negotiation sessions, or by writing to EPA staff directly.

The following perspectives were identified for role-playing purposes:

The Environmental Protection Agency

EPA is responsible for registration of pesticides, including specification of label instructions. Although the use of Power Wilt, as registered in 1975, was judged not to cause unreasonable adverse effects on man and the environment, EPA is now concerned about some of the new findings mentioned below. The Agency would like the registrant to perform a new study, due to increased public interest in the material. EPA is interested in discussing these issues with the registrant, particularly the fate of the chemical under actual use conditions. The Agency's objective is to arrive at a reasonable solution that can resolve most concerns.

The Registrant

"Power Wilt" is manufactured and formulated by Herbicides, Inc., a subsidiary of a Fortune 500 Company. The registrant is motivated to maintain sales of the material because it is a very remunerative product. Herbicides, Inc. attempts to maintain a positive public image and claims that when used properly, the chemical is environmentally safe. The registrant argues that if this product is banned, users will increase application of materials that are more toxic to fish and wildlife.

Agricultural Interests

Agricultural interest groups have a range of concerns. Growers of crops that are sensitive to Power Wilt claim that applications of the herbicide on grains and evergreens have caused yield reductions on adjacent plantings of broadleaved crops. The material is highly soluble in water and can be transported by spray drift, runoff of irrigation water, and occasionally by fog. Some agriculturalists are also concerned about contamination of surface water and groundwater supplies. The chemical is known to persist in the soil, especially at higher latitudes, and in soils with high organic content. This characteristic impairs farmers' ability to use crop rotations: for example, use of Power Wilt on a grain crop will reduce yields on a crop of soybeans or sugar beets planted at the same site the following season.

Environmental Interests

Environmental advocacy groups share some of the concerns of the agriculturalists. They are also concerned with the movement of Power Wilt into surface water and groundwater. In addition, they contend that airborne droplets of the herbicide, carried into forests and other protected areas by low-lying fog, can threaten populations of rare broadleaved plants.

Other Interested Parties

Several less vocal parties are also stakeholders in the negotiation process. Members of the State Highway Departments Association use this material in management of roadside weeds. Consequently, the Association is concerned about liability from growers affected by drift. Pesticide applicators are also sensitive to claims that they are responsible for misuse of the material. Range farmers are in favor of continued use of the compound, because the herbicide effectively removes weeds, improving rangeland yields while not endangering grazing cattle. Forest managers like to apply Power Wilt to prepare fir plantation lands before planting. Finally, U.S. Department of Agriculture is interested in obtaining more information on the chemical before publicly advocating a course of action.

II. Summary of Discussions

The process used to address this case varied considerably between the two sessions, due primarily to different group dynamics and the different negotiation formats selected. In the first session, participants chose to have EPA negotiate with the registrant and representatives from different interested parties provided indirect input to the negotiations. The workgroup member who played the role of the registrant was familiar with the chemical company's perspective. His forceful negotiation style and argument about the type of study that was affordable strongly influenced the DQO process. In the second session, a public hearing format was selected. This allowed for more equitable participation by all members. In this session, less time was spent discussing the problem of interest, and more time was spent optimizing the research design.

Participants in the first session initially attempted to summarize the problem to be addressed (Step 1 of the DQO Process). There was some controversy surrounding the fundamental question posed.

Variants of the key question included:

- Can losses to nontarget crop plants actually be attributed to "Power Wilt"? Are they due to misuse of the material?
- Are label requirements adequate to protect non-target plants?
- What are the fate and transport of this material in the environment?

The participant taking the role of the EPA representative opened the workgroup session and stated her position: that the registrant should conduct some additional testing in order to determine whether or not losses of nontarget crops are in fact due to misuse of "Power Wilt". The position taken by the environmental advocacy group was that in addition to the type of study envisioned by EPA, one or more field studies were necessary to measure the detrimental impacts of the materials on surface water, groundwater, and endangered species. Environmentalists also asked how the stated acute toxicity measure of 40 parts per trillion (ppt) had been obtained, due to the fact that this concentration is much lower than the amount measurable by gas chromatography technology. This session then asked the registrant to conduct a fate and effects study for a worst-case scenario. Late in the session, they discussed Step two of the DQO Process, "Selection of Variables to be Measured in the Study". Variables of interest were determined to be:

- Fate and effects over time (persistence of the material)
- Fate in different parts of the environment (such as water, soil, and plants)
- Fate under varying climate conditions (such as winter temperatures and foggy conditions)
- Effects on different nontarget crops of interest
- Effects under different geographic conditions
- Effects with different application techniques

The workgroup finally discussed the worst-case scenario (or set of scenarios) to be chosen to optimize the study so that results could be obtained which pertained to the majority of questions raised during the session. Conditions that were considered to contribute to a worst-case scenario were:

- Sensitive soil composition, high soil organic matter;
- Timing in life cycle when broadleaf plants are most sensitive (i.e., early stages);
- Application to different crop types:
    - forests
    - roadside weed control
    - grain crops
    - rangeland
- Time of year when herbicide is normally applied; and

Significant wind speed conditions, and possible foggy conditions.

It thus became apparent that several field studies would be needed in order to test all variables of interest under worst-case conditions. In conclusion, the first session pursued a fate and effects study, in part because this research option was familiar to the registrant. It was decided that conducting such a study under worst-case conditions for all pertinent variables would require setting up field plots at several sites.

During the second workgroup session, which involved a public hearing format, there were three main players: 1) Environment and Agriculture as a coalition; 2) the registrant; and 3) the Environmental Protection Agency. In this session, the Environment/Agriculture coalition was vocal and well-prepared with data to strengthen their argument.

The environmental and agricultural interest groups echoed concerns voiced during the previous session: growers near roadside spray programs cited a significant decrease in yield; these yield losses apparently had not responded to improved applicator training; crop rotation systems were at risk; and rare forest species appeared to be vulnerable to the herbicide. Canadian growers also requested that "Power Wilt" be tested under northern conditions where it is apparently more persistent, as well as in the southeastern U.S., which was the study site that the registrant proposed.

The Environment/Agriculture coalition thus helped identify variables that needed to be considered in any studies. They were effective in holding this position because they requested that the herbicide be otherwise substantially restricted in use or suspended.

This second workgroup session focused on the following research questions: 1) is "Power Wilt" toxic?; and 2) At what concentrations? They questioned the 1975 data. In order to obtain up-to-date phytotoxicity data, initial laboratory studies -- bioassays of plants such as potatoes, tomatoes, and soybeans at known dilutions of the chemical -- were eventually proposed. In addition to these laboratory studies, the registrant was also asked to monitor sensitive crops in the field under different herbicide application regimes and review the half-life of the compound in the soil under various climate conditions.

An important point that was raised during both sessions was that it was unclear how the cited toxic dose to plants of 40 ppt had been obtained. Participants requested that the registrant perform new toxicity measurements using state-of-the-art techniques.

During both workgroup sessions, the different interests of the main stakeholders in the problem assured that certain concerns would be consistently raised. However, each session approached the same problem in a different way. This was primarily due to differences in group dynamics and the format in which participants chose to negotiate.

III. Conclusions and Recommendations

Because of the differences in format used to address the case study, the two workgroup sessions reached differing conclusions with regard to the utility of the DQO process. The first session concluded that the DQO process is more appropriate for simple monitoring studies, and less appropriate for basic research or complex problems. Participants believed that in basic research, investigators must be free to modify the fundamental question and the study design as the problem becomes better understood. They concluded that the structure imposed by the DQO process would limit investigators and does not encourage such mid-course correction during an investigation. Participants in the second workgroup session concluded that the DQO process was generally useful as a checklist, but need not necessarily be followed in the prescribed sequence of steps. For example, participants found that Step 5: "Optimization of Study Design" could be addressed before Step 4: "Specification of an Acceptable Level of Uncertainty". The steps in the process were continually repeated as questions arose later in the process that required going back to Step 1.

Workgroup members concluded that several common factors drove the DQO process during both sessions. Time was considered to be one such factor. The fact that the problem negotiation and study design needed to be completed during the finite workgroup period put pressure on the participants to arrive at a workable solution.

In both sessions, it was evident that genuine participation by all interested parties -- listening with a desire to cooperate and arrive at an agreeable solution contributed to the success of the data quality objectives process. The fact that this case study was regulatory in nature made the process adversarial. However, somewhat counterintuitively, the adversarial nature of the situation helped speed the DQO process along and forced all participants to arrive at a consensus solution. The fact that EPA might take regulatory action provided further motivation for compromise.

Participants concluded that the process was also driven by the need to preserve good science, as an end in itself, and also to maximize program effectiveness. Research results that lack credibility can be interpreted as wasted program resources and leave EPA (or any research organization) vulnerable to criticism by the public and during peer review. Also, realistically speaking, other nonscientific factors drove the process, such as cost and social concerns.

At the conclusion of the two sessions, the workgroup offered the following recommendations as general guidelines for application of the DQO process to terrestrial monitoring programs conducted in a regulatory setting such as that characterized by the case study:

- The success of the DQO process will depend on the individual participants and group dynamics. Although the DQO process lays out a series of steps that can aid problem-solving, each outcome depends on the players' willingness to participate, their individual communications and negotiations skills, and other such factors, in addition to scientific considerations.

- All participants should provide input into the initial problem definition stage. Such initial communication is vital to arriving at the best research design that is also agreeable to all parties involved.

- A facilitator is key, particularly at the problem definition stage, to improve participation by all parties, and enhance process flow according to a structured format. A skilled facilitator helps ensure that the views of all parties are expressed, and thus ultimately factored into the DQO process.

The most difficult parts of the DQO process, in both sessions, appeared to be:

- Specifying the acceptable level of statistical uncertainty needed in study results (this step requires that participants have some background in statistics and a detailed understanding of the biological system under study); and

- Identifying the single study or series of studies that will answer the questions posed.

In conclusion, the DQO process was considered to provide a helpful checklist in the design of appropriate and scientifically valid field studies for the terrestrial monitoring case examined. However, the sessions showed that in the case of "real world" situations in which scientific considerations must be balanced with economic, social, and other non-scientific factors, multiple valid solutions to the same problem can be possible, the non-scientific factors may drive the process, and good communication and equitable group participation are important in applying the DQO process successfully.

THE DEVELOPMENT OF GUIDELINES for use of STATISTICAL TOOLS in TERRESTRIAL MONITORING PROGRAMS

Leader:
Dr. James Gore
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Rapporteur:
Michael Piehler
ASci Corporation

I. Introduction

Both sessions of this work group were conducted as informal open discussions that addressed the difficulty of applying appropriate statistical tools to data acquired from terrestrial monitoring programs. Dr. James Gore, the work group leader, led the discussion by posing questions to the participants pertaining to specific phases of a scientific investigation and allowing the participants to discuss how procedures at each stage of investigation affect the use of statistical tools. The objective of the discussions was to recommend general guidelines for designing a terrestrial monitoring study that lends itself to the use of effective statistics. Participants in both sessions agreed to focus on monitoring studies designed for observational purposes (i.e., research-oriented monitoring) rather than for purposes of investigating specific sources of pollution.

II. Summary of Discussions

Participants in both sessions agreed that there is a need for increased communication between scientists and statisticians during all phases of the investigation. Scientists should inform statisticians about specific factors in their studies that may influence the statistical analysis of their data. Participants further agreed that, in general, statisticians should understand certain aspects inherent to biological investigations at the outset. These include:

1. That dependent and independent variables in a natural system are often arbitrarily determined and sometimes influence each other. There is often mutual causation (e.g., the level of moisture in a forest influences the growth of trees and the growth of the trees increases the level of moisture).

2. That "statistical" significance is not always biologically meaningful. Statisticians need to have some information about the system that is being studied in order to effectively determine the appropriate increment of analysis.

3. That biological measuring systems have inherent limitations in precision and accuracy. This affects the level of detected change which can be considered biologically significant. Furthermore, it indicates that significant digits should be determined appropriate to the measuring system's limitations.

4. That the full range of sampled phenomena must be considered in order to detect a trend.

In addition, participants identified those considerations that statisticians expect from scientists during a study. The statistician expects to be consulted before the scientist begins sampling. The statistician also expects to have some preliminary data to predict the required sample size and statistical design. Such data are often provided through a pilot study.

The groups agreed that the first requirement for a statistically sound study is the ability to state the question that is being investigated. Each work group session encountered some difficulty in identifying the question typically asked in terrestrial monitoring studies, but eventually participants agreed that the question most often asked is: "Is there change over time?"

In the first session, it was established that a general framework for terrestrial monitoring studies is needed. Participants suggested that the framework should include a reference to the successional state of the area in question. Incorporating consideration of successional change allows for separation of spatial and temporal variability by providing a baseline of natural variability. The goals for detecting change can then be defined as either deviation from a trend or deviation from a characteristic variance.

Both sessions identified many logistical problems that occur in large scale terrestrial monitoring programs. A baseline measurement is often difficult to make in the environment. Few historical data sets available are supported with full QA/QC documentation and consequently often must be considered unreliable. Another logistical concern in a large scale terrestrial monitoring project is the frequency of sampling. Both groups agreed that because of constraints on time and money, extensive sampling at high frequency is often prohibitive. Consequently, accurate characterization of temporal variability can be difficult to achieve. A final problem with large monitoring programs identified by participants was the assessment of the extent and focus of the sampling. Participants agreed that terrestrial monitoring programs should have as one of their goals providing data that will be useful for future studies. The difficulty is in creating a study design that is sufficiently robust to capture enough important information, while avoiding unnecessary measurements.

Given these inherent dilemmas in terrestrial monitoring, the participants concurred that a pilot study is generally necessary to focus monitoring on the relevant issues. Several requirements were recommended for designing an effective pilot study, as follows:

1. Separate spatial and successional variation.

2. Sample at a frequency sufficient to assess annual variation so that the investigator can determine the appropriate time of year to sample and steps can be taken to avoid sampling rare conditions (i.e., those existing less than 5 percent of the time).

3. Develop specific protocols for sampling, with different protocols for discrete regions. Determine plot size and shape based on the composition of the discrete areas.

5. Study plots should include ecotonal areas to provide an early indication of change.

6. Always include QA and QC procedures.

7. When possible, pilot studies should not occur simultaneous with the parent study, but should be a precursor to the main study. This prevents the use of "ready-shoot-aim" strategies of data collection.

In each session, the participants agreed that large scale terrestrial monitoring programs should not be based on arbitrary or political boundaries. By determining natural boundaries and designing monitoring programs accordingly, available statistical options are maximized. Finally, the workgroup sessions concluded that when designing terrestrial (or any other) monitoring programs, regulators should not set goals for the program without determining whether they are realistically attainable.

III. Conclusions and Recommendations

Based on the two sessions, the work group leader summarized conclusions and recommendations concerning guidelines for the use of statistical tools in terrestrial monitoring as follows:

1. Scientists should consult with statisticians before beginning sampling. Communications should continue throughout the study.

2. Before beginning a terrestrial monitoring program, there must be a concise statement of the question to be addressed.

3. Incorporating an understanding of successional change is useful in that it allows for the separation of spatial and temporal variability.

4. In designing a terrestrial monitoring program, the goal should be to create a design sufficiently robust to capture information for future use, while avoiding unnecessary sampling.

5. A pilot study is necessary before sampling begins to accurately assess the scope and direction of sampling efforts and allow for the use of effective statistics.

6. Large scale monitoring studies should be stratified using ecological boundaries and not arbitrary or political boundaries.

7. Before setting goals for a terrestrial monitoring study, their attainability should be assessed.

DEVELOPMENTS OF GUIDELINES for use of DATA QUALITY OBJECTIVES and STATISTICAL TOOLS in ATMOSPHERIC MONITORING PROGRAMS

Leader:
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Rapporteur:
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I. Introduction

Led by Dr. Neville Reid, the atmospheric workgroup addressed a single case study from both the perspectives of the Data Quality Objectives (DQO) process and the use of statistical tools in atmospheric monitoring. At Dr. Reid's suggestion, the group designed an atmospheric monitoring network intended to provide data needed to support development of broadly applicable emissions standards and other regulatory controls. The group first applied the DQO process to develop a reasonable, cost-effective network design. Then, in the second session, the group considered application of statistical tools to enhance the utility of the monitoring data.

To develop DQOs for the case study, the workgroup structured its discussions according to the following topics:

- The Problem
- The Issue
- The Sources
- The Customers/Users
- Statement of Intent
- What to Measure
- How to Measure
- When to Measure
- Where to Measure
- Possible Monitoring Networks

II. Summary of Discussions

The Problem

The workgroup began by examining the case study presented by Dr. Reid, an atmospheric monitoring network for toxic chemicals in the Great Lakes region. The objectives of the study were to (1) monitor for ambient concentrations of toxic chemicals, (2) follow time-trends in the atmosphere, (3) identify the sources, and (4) feed data back to the development of regulations. Participants agreed that the scope of the case study should be narrowed somewhat to make the task practical within the time allowed. Consequently, the focus was narrowed to one chemical at a specific location. The specific problem which the group decided to address was to develop DQOs and statistical tools for a regional scale monitoring network designed to determine the input of PCBs to Lake Ontario by wet and dry deposition from the atmosphere.

The Issue

The PCB concentration in Lake Ontario has declined and stabilized in the past, but new evidence shows a recent increase. The major issue is the accumulation of PCB in biota. Bioaccumulation of PCBs in fish tissue, especially Coho Salmon (*Oncorhynchus kisutch*), has raised concern about the edibility of Great Lakes' fish. This increase could also be of ecological concern to the region as well. The workgroup agreed that this matter may pose a health risk and may endanger the economies of the communities along the lake which depend on the lake for their livelihood.

The next step involved examining preliminary studies of PCBs in Lake Ontario. Preliminary studies suggest that atmospheric input accounts for approximately 50 percent of the total PCB loading in the Lake. Isolated studies indicate that spatial variability may be small. These studies also show that the temporal variability is small from a seasonal stand point, but daily variability may be greater, and may need to be examined closely.

The Customers/Users

The workgroup identified possible customers/users for monitoring data. These included provincial, state, and federal government organizations, the tourism industry, and the sports and recreation industry in both Canada and the U.S. Participants agreed that the customer's/user's questions should be understood and clearly stated. Questions regarding measurement precision, accuracy, and species tolerance to PCBs at various concentrations must be identified and addressed. The process should be designed to understand the principal concerns of different user groups and the degree of clean-up or reductions in PCB concentrations that each group believes would be acceptable. To accomplish this goal, workgroup participants agreed that the DQO process should incorporate everyone involved in the study: the researchers, the statisticians, customers/users, and managers.

At this stage in the process, participants agreed that the researcher should consult a statistician to determine what data are needed to address the question, and then determine what statistical tools are available to best illustrate how the data will answer the customer's/user's questions. This information should be furnished to the customers/users to show precisely the information that the study will produce and its utility in solving the problem. Participants also stated that, when communicating with the user community, it is not only important to state the objectives of the study clearly and concisely, but also, to state the non-objectives — specifically what the study will not address — as well.

The workgroup participants agreed that there should be an attempt to maximize the utility of the data. In other words, as the DQO process proceeds, researchers should recognize that not all of the customers/users can be determined from the outset. Other customers/users might become apparent as the study progresses. Consequently, the workgroup agreed that field studies should be planned to acquire as much data as is reasonably feasible recognizing, however, that collecting too much collateral data can be wasteful.

The Sources

There was considerable discussion and some disagreement about the sources of the PCB input to Lake Ontario. The principal disagreement concerned whether the sources of the PCB input could be located. The PCB concentration in Lake Ontario had declined and stabilized in the past, but new evidence shows an increase in the PCB concentration. This increase has been attributed to a shift in the ecological equilibrium. The workgroup concluded that, since commercial production and use of PCBs have been banned both in Canada and the United States, the increase in PCBs is likely to be attributable to other sources and possibly the surrounding environment. Participants believed that ascertaining what these sources are would be difficult and possibly not feasible.

Initially, the workgroup agreed that locating specific sources of PCBs would be unrealistic owing to the fact that the PCB input was coming from non-point sources. Two known sources of PCBs are electric transformers and toxic waste sites, but these sources do not account for the quantity of PCBs found in the Lake. It was suggested that the increase may be occurring through terrestrial soil disturbance and through re-suspension of the PCBs in lake sediment, caused by wave action.

Statement of Intent

The workgroup agreed that the intent of the case study was to monitor concentrations of total PCB in air and precipitation, and derive wet and dry deposition rates for PCBs.

What to Measure

The workgroup agreed that the following data should be gathered by the monitoring network:

- PCB concentration in air and precipitation (congener specific)
- Precipitation quantities
- Precipitation type (rain, snow, etc.)
- Water content in air
- Total particulate matter and particle size distribution
- Meteorological parameters

How to Measure

The workgroup recognized that atmospheric monitoring has inherent limitations in precision and accuracy, and that these limitations should be clearly stated for the DQOs. Participants identified the following measurement techniques:

- Sorbent equipped high volume samplers with denuder for air
- Wet-only collectors with sorbent for precipitation
- Standard rain-gauge and meteorological instruments

Wind directional sampling was also mentioned, but it was pointed out that this type of sampling may contribute bias to the study.

When and Where

Determining when and where to sample was difficult for the workgroup. In the time allowed, recommendations for actual sampling locations and frequencies could not be developed. However, the workgroup identified several important issues that would affect the final location of monitoring stations. These included:

- The location of known or potential PCB sources to the Lake;
- The degree of mapping in the atmosphere surrounding the Lake basin; and
- The importance of temporal variation in PCB loading rates.

Possible Monitoring Networks

The workgroup then developed some possible monitoring network schemes, considering best-case scenarios first, and then examining the network taking budgetary constraints into consideration. The first iteration utilized 30 sampling sites in a tesselated pattern around lake Ontario, with two samples collected per week. The estimated cost was $300,000 for the start-up and $3,000,000 per year for operation and analysis.

The second iteration sacrificed spatial resolution. This was done with a radial distribution of the sampling sites, resulting in a decrease in the number of sites from 30 to 12, with two samples collected per week. The estimated cost of this scheme was $150,000 for start-up and $1,500,000 per year for operation and analysis. The third iteration sacrificed temporal resolution by cutting back sampling to one sample per week.

The workgroup concluded that a combination of the second and third iterations, a compromise in both spatial and temporal resolution, should be developed for the final version. Participants agreed that it would be important to sample at as many sites as possible, but composite the samples for purposes of analysis, and integrate over longer times.

III. Conclusions and Recommendations

The workgroup developed the following conclusions and recommendations regarding the use of DQOs and statistical tools in atmospheric monitoring:.

1. DQOs should be set by a project team that includes the scientists, statisticians, managers, and data users.

2. In atmospheric monitoring programs, as well as other studies, the question to be addressed must be properly and completely posed, and especially with monitoring programs, there should be emphasis on determining the importance and relative magnitude of temporal variations in the parameters to be measured.

3. The customer/user should be identified and involved in the DQO process. Their input will be required, to establish the question and to set the quantitative expectations for data quality.

4. An attempt should be made to anticipate future data requirements and to maximize the utility of the data but, there should also be an awareness of the risks of becoming too diffuse and of producing data of little or no utility.

5. Full specification of required data quality is needed, including specifying the level of precision required or requested, how precision will be calculated, and what the acceptable detection limits are.

6. Once the question is identified and defined and the types of data needed are determined, combine this information with budgetary constraints to obtain a practical study design.

7. In preparing alternative study scenarios, document what is lost or changed between scenarios. This information will allow the researcher to illustrate how all reasonable scenarios were investigated in the DQO process.

8. One of the principal benefits of the DQO process is that it documents the study design and the process by which it is developed.

APPENDIX A

LIST OF PARTICIPANTS

APPENDIX A
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February 26-28, 1991
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