GUIDELINES FOR WATER QUALITY PROGRAM DEVELOPMENT IN NATIONAL PARK SERVICE AREAS

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NATIONAL PARK SERVICE
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INTRODUCTION

Background

Pressure placed upon the water resources of national parks, from increasing numbers of visitors and surrounding land use activities, is creating a need for water resource management programs. In particular, the development of effective water quality management programs is necessary to maintain excellent aquatic environments in the parks, to protect the natural systems, and to ensure the safety of visitors. Effective water quality management, however, is often a difficult task which requires a thorough understanding of complex water quality processes within the hydrologic system.

Objectives

The objective of this report is to provide a basis of understanding from which effective water quality management may evolve in the national parks. It is recognized that often water quality expertise is not available among the professional staff of a national park. For this reason, the approach taken in this report emphasizes, in practical terms, the basic concepts of water quality processes and regulatory management. This information will assist the park resource manager in formulating a rational water quality management strategy. The management strategy may include seeking assistance from consultants or other water quality specialists and it is important for the resource manager to have at least a conceptual knowledge of water quality management. To help develop such knowledge this report provides basic information about water quality processes and management and a thought process which will assist in the development of a sound program. Detailed information is not provided but published references and other readily available sources are cited which contain more specific information.

Organization of Report

The beginning of this report contains a series of responses to often misunderstood questions about water quality. The question and answer sections are followed by brief descriptions of monitoring design procedures. Reference citations to published material containing more detailed information are also included. Concluding the report is a questionnaire to stimulate the identification of water quality problems. Responses to questions on this work sheet by the resource manager are intended to assist in the identification of specific water quality issues and provide a rational approach to mitigation.

WATER QUALITY QUESTIONS AND ANSWERS

What is Water Quality?

Simply stated, water quality is a general description of the chemical, physical, and biological characteristics of water. The constituents, often referred to as variables, which comprise water quality include: dissolved chemical constituents, such as nitrate and sodium; physical properties, such as temperature and sediment; and biologic constituents such as streptococci and fecal coliform. A complete list of water quality variables is quite extensive, although every variable will not necessarily be of significant interest in each instance. The magnitudes of these variables change in both time and space in response to many factors acting alone and in complex combinations. In addition, some variables are difficult if not impossible to quantify and are subjective (e.g., taste, odor, color).

<u>What Factors Affect Water Quality?</u>

Resultant water quality is a function of natural and manmade factors. Understanding the water quality process requires a thorough understanding of both the natural hydrology of the water resource and the impacts of man on the watershed as depicted in Figure 1.

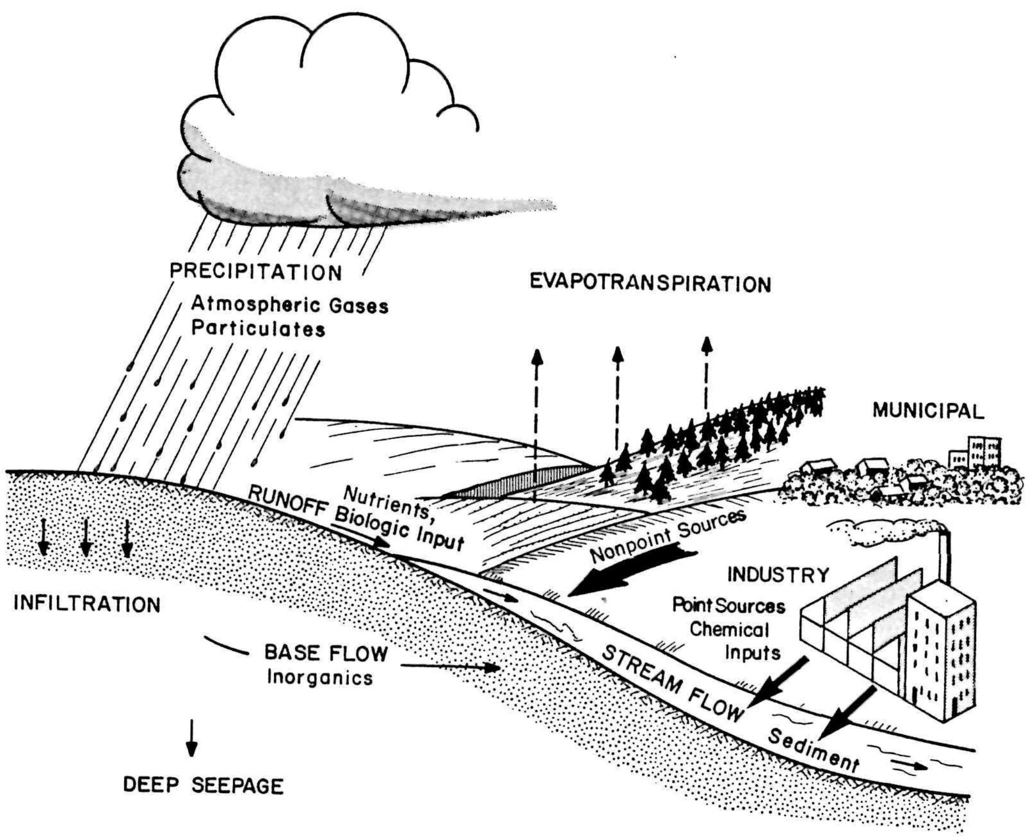

Figure 1. Conceptual Watershed and Hydrologic Cycle

Hydrologic influences include base flow and overland flow components of discharge. Groundwaters entering a stream generally have a large dissolved mineral content due to contact for relatively long periods of time with subsurface material. Runoff entering a stream is often less mineralized but may contain large amounts of biological variables and other constituents washed from the surface and deposited from the atmosphere.

The impacts of man and his livestock include point and nonpoint sources of many water quality variables. Point sources originate from identifiable, single locations such as storm sewer outlets. Nonpoint sources, more common than point sources, are derived from dispersed sources, for example, return flows from agricultural areas.

What is Water Quality Management?

Water quality management may be defined as the effort by society to control the physical, chemical, and biological characteristics of water relative to some identified use. Water quality management efforts have historically been directed at controlling man's impact upon the quality of water. These efforts have been carried out through the establishment of goals and the implementation of plans to achieve the goals. Water quality goals include stream standards and antidegradation policies. Management plans include effluent limitations (e.g., zero discharge) and the use of "best management practices" in land use activities. Often an agency is established which reviews each application to discharge and issues permits as a means of regulating water quality.

How Does Water Quality Management Function?

Water quality management in the United States has evolved around the beneficial use of water. The use of water is important because the acceptability of water quality is necessarily related to the purposes for which the water is used. For example, a water containing high concentrations of nitrates may produce illness in swimmers but may provide an excellent source of irrigation water. Therefore, before an agency can adequately manage the quality of a water body, use of the water must first be established and may include both primary and secondary uses.

Once the use of a water is designated, appropriate goals and plans may be established. Stream standards are selected which are applicable to the designated use. Control measures may be implemented such as effluent limitations to achieve water quality goals. Also, stream and effluent monitoring is conducted to enforce control measures and to evaluate the effectiveness of the overall management program.

What Are Stream Standards?

In simple terms, stream standards may be thought of as water quality goals. These goals may be expressed in a number of ways, but usually they take the form of a numeric criteria or a narrative description. Appropriate stream standards are established at the onset of the management program in accordance with the overall objectives of the program.

Specific numeric criteria have been established for individual water quality variables for each beneficial use of water (U.S. Environmental Protection Agency, 1976). For example, a criteria for zinc concentration in irrigation water may be expressed: "zinc concentration not to exceed 5 mg/ℓ". The value of such a criterion is usually set at the critical concentration of the variable which renders the water unfit for its assigned use. When a numeric criterion is adopted for use it becomes a stream standard.

Narrative standards are often established for variables/conditions which are not well suited for specific numeric criteria. An example of a narrative standard is: "No visible oil or grease floating on surface."

How Is Water Quality Monitored?

Water quality monitoring is used by water quality management agencies to: 1) determine compliance or noncompliance of water quality with stream standards, 2) acquire baseline information, and 3) detect changes in water quality. This water quality information is gathered by two principal techniques, fixed station/fixed frequency sampling and synoptic survey monitoring.

Fixed station/fixed frequency monitoring, the most common type of water quality monitoring, usually consists of the ongoing collection of grab samples at several permanently located sampling stations. The grab samples are analyzed for important water quality constituents and yield data representing a statistical sampling of the water quality process. This type of monitoring program must be carefully designed so that the resulting statistical samples contain information relevant to the objectives of the monitoring effort.

Synoptic surveys, sometimes called intensive surveys or special surveys, differ from fixed station/fixed frequency monitoring in the time and space domain. This type of monitoring generally includes hydrologic analysis, biologic assays, and physical modeling as well as chemical analyses performed over an entire river reach for a specified interval. Synoptic surveys yield information contributing to the overall understanding of the water quality of a specified river reach, but are expensive to conduct and provide information only for the location of the study. For these reasons, synoptic surveys are less frequently used than fixed station/fixed frequency monitoring.

MONITORING NETWORK AND SAMPLING DESIGN

The design of a water quality monitoring network is an intellectual activity which requires careful consideration of many factors. Design decisions such as sampling location and timing must be made while keeping in mind the overall objectives of the monitoring program. One very important point to remember is that monitoring yields sample data from which information regarding overall water quality is extracted. Therefore, it is of paramount importance that water quality monitoring networks be designed to provide data suitable for analytical procedures which will provide inferences meaningful to management objectives. By designing networks with specific objectives and data needs in mind, the resource manager is able to ensure the acquisition of useful information from the monitoring effort. The flowchart on Figure 2 illustrates a logical sequence for the design of a monitoring network.

Preliminary Considerations

The first step in formulating a water quality management program is the consideration of some basic preliminary factors essential to provide a firm basis from which a monitoring network can be developed. First, the underlying question of why and/or if there is a water quality concern must be adequately addressed. Then, from a joint consideration of this initial concern and the established beneficial use of the water, water quality objectives are defined. Water quality objectives spell out what the management agency actually intends to accomplish by the management effort. Possible water quality objectives include the quantification of baseline characteristics, enforcement of stream standards, detection of trends, establishment of seasonal means, etc. Itemizing detailed objectives which include specific stream reaches,

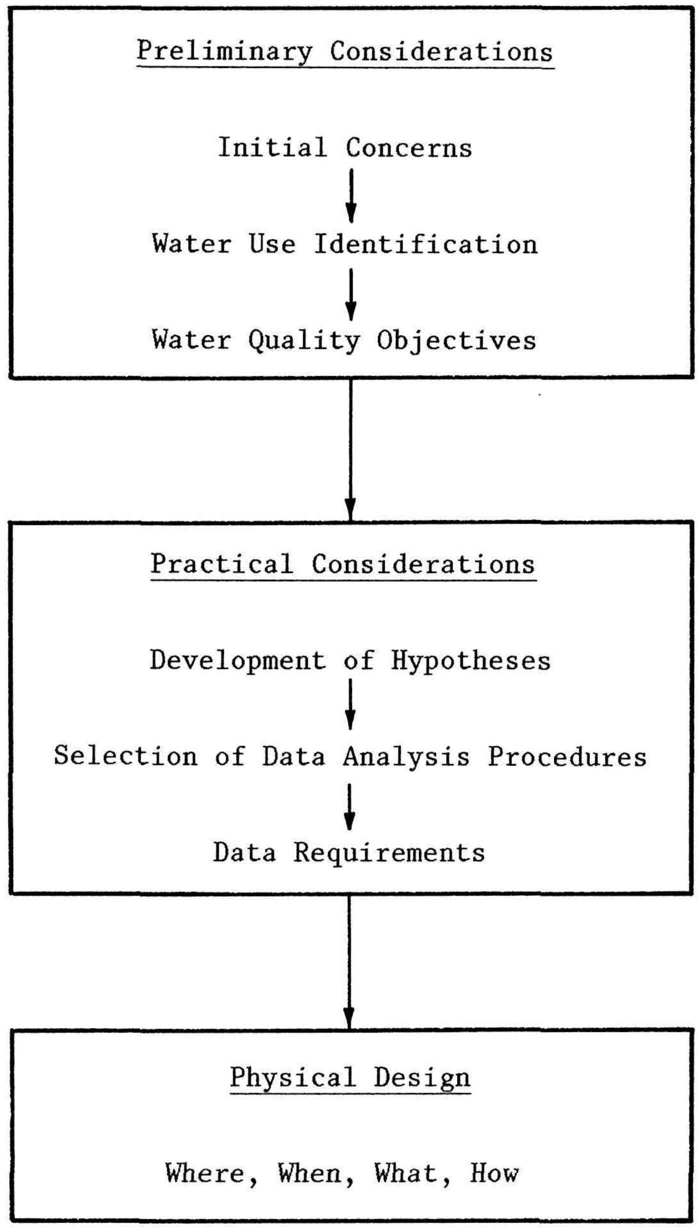

Figure 2. Water Quality Monitoring Design Sequence

water quality constituents, and why they are considered important is absolutely essential to an effective program.

Practical Considerations

Next, the water quality objectives are translated into hypotheses or questions that may be tested by data analysis. For example, the water quality management objective of trend detection may be translated into a practical hypothesis as follows: the mean concentration of mercury at Crossbridge Road for the past five years is equal to the mean concentration calculated over the previous ten year period. A hypothesis such as this may be tested through the use of statistical procedures or other data evaluation methods. Hypotheses must be stated carefully to address objectives while maintaining a practical, useful nature.

At this point it is necessary to select data analysis procedures to use in the interpretation of water quality data. This is accomplished by reviewing both the data requirements and the information provided by the various procedures. Not only must the chosen statistical procedures provide pertinent information, but the data required by the chosen procedures must be practicably obtainable. If the needed data is not practicably obtainable, water quality hypotheses must be restated so that feasible data may provide sufficient information to address the objectives. Such a compromise into more practical goals is more useful than the establishment of hypotheses that may not be realistically evaluated with data collected by monitoring networks constrained by budgetary or other considerations.

Physical Design

Once water quality objectives have been established and data analysis procedures selected, the task of physically designing the monitoring network may begin. There are four principal considerations in the design of a water quality monitoring network: 1) where, 2) what, 3) when, and 4) how. Where to sample, as applied to rivers, includes the macrolocation, microlocation, and representative location. The macrolocation pertains to the selection of a particular river reach to be sampled. The microlocation relates to a specific cross section in the selected reach. The representative location is the location or locations selected in the cross section to provide representative information of the reach being sampled. What to sample includes a rational selection of only those water quality variables which provide information relevant to the purposes at hand. When to sample refers to the selection of an appropriate sampling frequency, time of year and day, and whether or not the samples should be randomly drawn within the time frame. Finally, how to sample pertains to both the sample collection methodology and laboratory analysis procedures.

Sampling Location

The selection of river reaches to sample (macrolocations) depends upon both the objectives of the monitoring program and the total number of sample stations available for use within the network. Often, the total number of sample stations in a monitoring network is less than the optimum number for given monitoring objectives. This results from budgetary and manpower limitations. There are, however, cases where monitoring objectives may be essentially the only factor in selection of macrolocations. For example, if the goal of monitoring is to determine the impact of an effluent discharge, sample stations located on river reaches above and below the effluent source are required. Or, if the monitoring objective is to determine mean concentrations of variables leaving a watershed, a single station located at the bottom of the watershed is warranted.

For most routine monitoring networks, consideration of monitoring objectives with budgetary and/or physical constraints is necessary to establish the best practical network of sampling stations. The network designer, therefore, needs a method to prioritize potential sample station locations. To a large extent this prioritization is necessarily a subjective evaluation based on the characteristics of the river system and monitoring goals. There are, however, a few established methodologies designed for ranking potential sample sites for importance. Sanders (1980) utilizes stream-tributary order ranking as the basis for locating stream reaches to be sampled. Ponce (1980a) presents another methodology for locating sampling stations with direct application to upland areas.

The microlocation or specific cross section to be sampled must be determined next. The sampling cross section should be located with respect to effluent sources so that complete mixing has occurred at the point of sampling. An estimation of the length of stream needed for complete mixing may be obtained from a mixing equation in Sanders (1980). If complete mixing does not occur at a sample location, a composite sample made up of subsamples collected throughout the stream cross section may suffice. Another consideration in selecting the microlocation is accessibility. Obviously, it is important for practical reasons to have sample stations located in easily accessible areas. However, ease of access should not dictate site selection if doing so compromises the quality of data collected.

The representative location is selected from within the microlocation at a point(s) which provides data indicative of the river reach. A physical inspection of the cross section will usually allow the network designer to select appropriate locations. In general, the representative location for physical and chemical constituents should be established away from stream banks, in freely flowing regions of the stream. While, in many cases, biological samples must be collected from stream banks as well as free flowing regions. The depth at which samples are collected is not generally as critical as lateral location because turbulence is enough to mix pollutants uniformly in the vertical profile. The sampler should be careful, however, to avoid sampling right at the surface or bottom because an unrepresentative sample containing floating substances or constituents contributed by benthic decomposition may be collected. Again, biological samples must often be taken from the surface and bottom; more often than not, depth and lateral location are of extreme importance. The representative location should be selected at a location accessible during all stream discharges because it is important for water quality data to be consistent in location of collection.

In the case of a stratified water body, such as a temperature stratified lake, it is usually necessary to identify the individual strata. Identification of stratigraphic layers may be accomplished by a suspended temperature or density probe. In this case, it is important to draw samples at the correct depths and accurately record the associated strata, i.e., hypolimnion, epilimnion, etc. Also, it must be recognized that water bodies such as this tend to be unstratified at certain times of the year, so the analysis of data must be segregated into the stratified and unstratified cases. Often, only those periods when a lake is stratified are critical quality periods and data may not be required from other periods of the year.

Water Quality Constituent Selection

The selection of variables to sample is an important budgetary consideration. Obviously, only those variables which contribute relevant information should be analyzed. All other variables represent avoidable expenses which contribute little to the information obtained by the network. A list of water quality variables typically monitored are given in Table 1. References for more detailed information include: Sanders (1980), Ponce (1980a), American Society for Testing and Materials (1975), McNeely, et al. (1979), Hem (1970), U.S. Environmental Protection Agency (1976), and McKee and Wolf (1978).

Table 1. Some Commonly Measured Water Quality Variables

Physical Constituents		Biological Constituents
Discharge		Total coliform
Water temperature		Fecal coliform
Specific conductance		Fecal streptococci
Suspended sediment		Macroinvertibrates
Turbidity		Algae
	Chemical Constituents	
pH	Chloride	Hardness
Dissolved oxygen	Boron	Salinity
TDS	Iron	Ammonia
Aluminum	Zinc	Nitrate
Calcium	Mercury	Total nitrogen
Magnesium	Cadmium	Orthophosphate
Sodium	Selenium	Total organic carbon
Potassium	Silver	BOD
Bicarbonate	Manganese	Pesticides
Carbonate	Alkalinity	Radionuclides
Sulfate		

Certain variables should be measured in almost any water quality monitoring program. These include discharge, specific conductance, pH, temperature, and dissolved oxygen. These variables are relatively easy to measure and are indicative of general water quality. Discharge should be measured when water quality samples are collected because most other variables are related to flow. Specific conductance is an easily obtainable measurement (estimate) of the total dissolved solids content of a water. Often the natural proportion of important water quality variables is a constant function of conductivity (TDS) and, therefore, specific conductance measurements may provide information regarding many variables even when they are not directly measured. The variables pH and temperature affect the solubility of many variables. Dissolved oxygen is an important indicator of the biological "health" of a water body.

Other variables are selected to answer specific aspects of the objectives previously identified. For example in a water body used for contact recreation, constituents such as total coliform bacteria might be monitored if there is reason to suspect contamination or if a baseline condition is desired.

Sample Timing

The question of when to sample may be answered by consideration of two factors: 1) is statistically random data needed? and 2) how much natural variation occurs in the water quality process? Again, these considerations must be made keeping in mind the overall objectives of the monitoring program.

Random data is needed for many common statistical methods. Biases may be placed in data by collecting water quality information only during certain periods of the year or only on a given day of the week. These biases may cause data interpretation to yield results which are not truly representative of the overall water quality. Sometimes intentionally biased samples may be appropriate, for example, if the primary objective of monitoring is to detect stream standard violations, samples should be collected during periods of high concentrations. In general, however, statistical description of the overall water quality will require random information to be collected by the monitoring program. This requirement for random sampling, however, should never replace common sense or the experience of well trained field personnel.

The number of samples which should be collected in a specified time interval is highly dependent upon the variation found in the water quality process. The more variable a constituent is with time, the greater the number of samples needed. Conversely, if a water quality process is unchanging with time, only one sample is necessary to fully describe the process. Methodologies have been developed to objectively select an appropriate sampling frequency (Sanders, 1980; Ponce, 1980a). Most of these procedures, however, require a good prior estimate of variance and this is not generally available to the network designer. When possible, a preliminary investigation of variable behavior, extrapolation of information from a nearby stream, or evaluation of stream discharge may provide the information needed for determinating sampling frequency.

Sampling and Laboratory Procedures

Perhaps the most important aspect of sampling and laboratory procedures is consistency. Meaningful evaluations of water quality are possible only from data of consistent characteristics. This stipulation applies to sampling locations as well as sampling procedures and laboratory methodology. Approved methods for sampling and laboratory analysis are described in a number of references: U.S. Geological Survey (1977), American Public Health Association, et al. (1976), Velz (1970), Rainwater and Thatcher (1960), and others. Quality control of water quality information, however, encompasses more than simply using acceptable methods. Extreme care must be used in collecting samples, avoiding contamination by the collector and of the sampling apparatus. Laboratories conducting sample analysis must be instructed to use the same analytic procedures throughout the duration of the monitoring program. Also, replicate samples should be supplied to the lab and the results carefully evaluated to ensure that acceptable accuracy and reproducibility is being achieved by the laboratory. Field instrumentation used to measure discharge, conductivity, pH, temperature, etc. should be initially calibrated and checked periodically to ensure accurate readings. Sample preservation techniques (e.g., refrigeration) must be used to achieve representative laboratory results. In certain cases, particularly pH, extra care must be taken to avoid temporal changes in samples. Huibregtse and Moyer (1976) and American Public Health Association, et al. (1976) discuss sample preservation techniques.

SELECTION AND USE OF DATA EVALUATION METHODS

As previously discussed, the choice of which data evaluation procedures to use in the interpretation of water quality data should be made before the monitoring network is designed. The network is then designed to supply information necessary for the selected procedures. The process of selecting appropriate statistical procedures requires a thorough familiarity with the various available techniques. Two references which treat this topic in detail are Ponce (1980b) and Haan (1977). Haan (1977) is a general water resources statistics text without explicit application to water quality, however, the material presented is suitable for this area, also.

Statistics may be used for more than direct interpretation of water quality data. Certain indicator variables, such as discharge and conductivity, may be used to convey information regarding other variables through regression analysis. This process may allow, in certain instances, the measurement of fewer variables than otherwise necessary. Also, if daily records of indicator variables are available, it is possible to generate daily estimates of other variables from regression models and enhance the ability of the management agency to detect critical situations without direct monitoring.

Caution must be exercised in the use of statistics in water quality data interpretation. Often statistics have been incorrectly used in the evaluation of water quality by not accounting for natural inter-relationships between certain variables. An example of inappropriate use of statistics is as follows. Since most water quality variables are inversely proportional to flow, an effect of low runoff may be relatively high concentrations of water quality variables. Such high concentrations are simply the result of low flow and do not necessarily indicate a degradation of water quality. However, a statistical hypothesis test which ignores the effect of flow may indicate that degradation has occurred. Mistaken conclusions such as this are avoidable by having a good understanding of water quality processes and using sound judgments in the selection and use of statistical procedures.

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QUESTIONNAIRE

This questionnaire is intended to guide a thought process to aid in the establishment of an effective water quality management plan. Each question elicits useful information, but to do so requires a commitment of time and careful thought. The answers to these questions will provide much needed input for use by the professional water quality specialist who should ultimately design the water quality program.

1) What prompted concern?
2) Can individual water bodies and any interconnections be identified?
3) Which specific sources are of concern?
4) Possible causes? Can any suspect inflows be identified? Unusual events--hydrologic, anthropogenic?
5) What water quality variables are suspect?
6) Have maps, research, or other previous investigations been compiled and are they available?
7) Does any previous information identify specific problems or sources of inputs?
8) What data are available from special investigations (e.g., research) and what routine data are collected, analyzed and available (e.g., U.S.G.S. data)?
9) After consideration of questions 1-8, is there, in your opinion, sufficient reason to develop a water quality program?
10) If your answer to question 9 was yes; where may professional assistance be obtained to ensure the development of a sound program (e.g., National Park Service Water Resources Laboratory, consultants, etc.)?

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