QUALITY ASSURANCE FOR FORESTRY RESEARCH

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INTRODUCTION

This paper was designed to provide participants of the California Forest Response Program planning conference with a broad introduction to Quality Assurance (QA) for forestry research. QA for forestry research is becoming increasingly complex and is beyond the scope of a single presentation. However, this review can lay a framework for future refinement.

The need for integrating QA into forestry research projects is expanding due to three inter-related concepts: 1) increasing use of research results for environmental policy decisions, 2) increasing pressure from private industry and the public for accountability of environmental policy decisions, and 3) the government's increasing role in supporting applied research. Reduced funding levels for research are also focusing attention on the quality of data produced and the value of thorough documentation.

WHAT IS QUALITY ASSURANCE?

Quality assurance is a system of planned quality control activities designed to produce data of known and sufficient quality, as defined below:

quality control (QC): a set of routine activities during a research effort designed to monitor performance or quality in sample collection, analysis, and recording. QA integrates the development, coordination, documentation, and evaluation of QC activities into a planned program.

known quality data: data for which information on precision, accuracy, completeness, representativeness, and comparability is documented. Where immeasurable, estimates and qualitative descriptions would suffice.

sufficient quality data: data for which the above quality attributes meet pre-set criteria (called "Data Quality Objectives" or "DQOs"). The criteria are developed independently for each unique research situation. For example, two data users (decision makers) examining growth effects over a 5 and 20 year periods, respectively, may require different measurement precision to detect the same effects.

Quality assurance programs are based on the research objectives, information to be collected, and identification of desired data quality (DQOs). Ideally, data users could specify exactly the quality needed to make a decision; however, decision makers have not reached that stage in forestry research and scientists are left with a broader interpretation of "sufficient". Therefore, the scientist's role in establishing DQOs and corresponding QA for large integrated research programs such as the California Forest Response Program is crucial.

QUALITY ASSURANCE PROGRAMS

Quality assurance programs are founded on four basic concepts: planning, comparability, quality control, and documentation. Planning for a QA program requires that scientists describe projected QC and research protocols/ procedures in more detail than may normally be found in proposals and workplans. Additional information might include sample transport, personnel training, or other specific requirements. Advanced planning, as with basic planning activities, minimizes future problems and confusions over inappropriate designs or analyses and facilitates auditing. QA planning is expedited through interactions between scientists and QA personnel.

QA programs also ensure comparability among similar research projects through standardized procedures and protocols. This becomes particularly important with large integrated programs such as the EPA and USDA Forest Service Forest Response Program or the California Forest Response Program. It is important to note that QA programs do not establish standardized procedures, they monitor the use of standardized procedures selected by researchers within integrated programs.

Quality control activities, the third concept of a QA program, allow scientists to monitor their research as it progresses and to adjust the research to optimize performance and meet data quality requirements. The early detection of sub-optimal performance or insufficient quality saves scientists valuable resources and time. The evaluation of performance is accomplished through efforts by the scientist, with internal QC, and QA personnel, through auditing.

Finally, a QA program requires thorough documentation of research, providing an in-depth record of research activities and data quality. This becomes particularly important for communication within cooperative research programs, with multiple investigators and integrated results. Documentation also aids in backtracking problems within a project, minimizing effects of personnel changes, substantiating individual conclusions, and establishing and preserving quality data sets.

Quality assurance programs are relatively new to forestry research though the underlying concepts of planning, comparability, quality control (precision and accuracy), and documentation are common to researchers. The scientific community is now compiling these concepts into integrated forestry QA programs following the lead of early QA programs. Such programs were developed for air and water quality monitoring/survey projects involving large numbers of systematic, repeated measurements and laboratory analyses. For these projects, comparability and consistency were crucial to the effort, and estimates of the data quality required to support the effort was fairly well defined. Forestry research, including projects within the California Forest Response Program, will have some monitoring or survey aspects which can be adapted directly from early QA programs.

However, many forestry projects are aggregations of other scientific areas in various combinations, including: intensive field site research, experimentation or manipulation, the collection and use of existing information, and methodology development. It is in these four areas of forestry research that QA has been initially developed in the US EPA/ USDA Forest Service Forest Response Program. They are the focus of the remainder of this paper.

Intensive Field Site Research

Intensive field site research is common in forestry research and represents one of the most challenging areas for establishing quality assurance. In this area of research, scientists and managers are most concerned with:

- measurement consistency (precision) over space,
- measurement consistency (precision) over time, and
- the accuracy of the measurements.

Within a large research program, there may not be "standardized" procedures for taking consistent measurements at intensive field sites due to diversity in research objectives and research sites. There are "standard" or "common" forest measurements, for example tree diameter breast height (DBH) is measured universally at 1.4 meters, from which we can base standardized intensive site measurements, but consistency in complete plot characterization is rare. Even with common and easily repeatable measures, there are no "true values" by which to test accuracy at field sites; the scientific community lacks standard trees, sites, soils, and environments. Therefore, QA programs attempt to increase consistency and accuracy in field measurements through time and space by:

1) establishing standardized procedures and protocols for integrated research projects with common objectives and similar sites, such as the California Forest Response Program.

2) comparing new procedures and protocols (as they are developed) with established procedures and protocols to document old and new biases.

3) providing personnel training and periodic evaluations of performance.

4) providing routine equipment calibration, maintenance, and performance checks.

5) developing accuracy checks (standards) for field measurements wherever possible. For example, standard height poles, artificial slopes, and single-variable standards (e.g., soil texture) can be used to check the accuracy of individual segments of an overall effort.

Experimentation

Experimentation and manipulation are also basic to forestry research, where materials are manipulated under greenhouse, laboratory, or field conditions. Scientists and managers in large research programs are typically interested in comparability between paired or integrated experimentation studies, where experimental conditions are duplicated in different locations (e.g., duplicate exposures are various sites examining different species or genotypes). For unique or unpaired projects, comparability and standardization are less important.

Scientists and managers are also interested in duplicating "real-world" conditions when dictated by an experimental design. This allows for appropriate examination of a specific treatment. Finally, scientists and managers are typically concerned with:

- appropriateness of experimental material (experimental inferences),
- consistent application of treatments over time and space,
- measurement precision, and
- measurement accuracy.

Quality assurance for experimentation is especially difficult due to diversity in research objectives and activities involved. As with intensive site characterization, there may be few standardized procedures/protocols for projects within a large integrated research program, though there exist common research techniques. Again, this inconsistency is due to the variety of objectives and experimental material. There are few quality control standards for forest soil, seedling, or mature foliage manipulations, except for laboratory chemicals. QA programs for forestry experimentation therefore concentrate on:

1) monitoring experimental conditions over time and space to document the consistent and appropriate generation of experimental conditions.

2) documenting the use of appropriate experimental material, which usually applies to the genetic make-up of plant material or, possibly, mineralogy of soil material.

3) establishing consistent procedures and protocols within groups of integrated projects, and comparing old and new procedures and protocols (as with field measurements).

4) providing personnel training and performance evaluation for consistency over time and space.

5) providing equipment calibration, maintenance, and performance checks for consistency over time and space.

6) developing and implementing routine measurements of precision and accuracy, wherever possible.

Equipment performance evaluations are crucial to QA for experimentation/manipulation projects since measurements of precision and accuracy may not exist, particularly for physiological measurements (e.g., photosynthesis). Assessing performance documents that equipment is functioning at its inherent level of precision and accuracy.

Collection and Use of Existing Information

Projects which collect and use existing information for summary or reanalyses are the first of two types of research projects which do not directly collect environmental data but require QA all the same. The other, methodology development, is addressed in the next section. Projects which collect and use existing information are common to large forestry research programs as an attempt to avoid "re-inventing the wheel". Scientists and managers are typically concerned with:

- documenting exactly what information is collected;
- evaluating the representativeness/completeness of the collection process;
- evaluating the quality of the information (precision/ accuracy of data, representativeness/completeness of information); and
- ensuring the security of the information against unauthorized manipulation.

There are no established procedures for meeting the objectives of completeness and representativeness; however, there are common procedures for documenting the information. QA programs emphasize the use of this information in evaluating completeness, representativeness, and quality. A QA program also provides for:

1) thorough documentation of design and implementation of collection activities, and manipulations to the data base;

2) security against unauthorized entry into the data base; and

3) documentation of all entries and manipulations.

Methodology Development

Methods development projects compose the second category of research projects which do not directly collect environmental data which is entered into an assessment data base. QA is required for methods development projects because of their importance in supporting forest surveys, intensive site research, and experimentation. These projects require very thorough documentation of processes and results. With these projects, scientists and managers are concerned with:

- the design and appropriateness of the tests,
- the evaluation criteria, and
- the interpretation of specific test results.

There are few established QA procedures for these projects though the requirements are relatively straight-forward. Quality assurance programs concentrate on:

1) ensuring appropriate review of test designs and decision criteria through a peer panel;

2) ensuring advanced planning of evaluation criteria to avoid biases once data are collected; and

3) documenting the testing procedures, results, and the conditions surrounding the test.

CONCLUSION

Quality assurance programs are required as an integral part of coordinated, policy-driven research programs such as the California Forest Response Program. Following the concepts of planning, comparability, quality control, and documentation as outlined in this paper, scientists will meet most QA requirements regardless of the client. The QA information generated must be used, however, and used in a timely manner. For scientists, the information allows: 1) performance monitoring, keeping an experiment performing within data quality limits through feedback into the experimental system; 2) comparison of study results with similar projects and facilities, specifically in context to performance records; and 3) the review of detailed experimental records long after the research is completed.

For program managers, QA documentation provides: 1) evidence of advanced planning and prescribed decision criteria; 2) evidence that activities planned were actually implemented according to predetermined requirements; and 3) evidence of data quality or information produced to be evaluated against the needs of the overall research program. Obviously, the advantages of QA may be common to both managers and scientists. For example, scientists can benefit from independent evaluations of their work, and managers can assure themselves that the research they manage is meeting its quality objectives.

Finally, the importance of documentation, or "evidence", is prevalent throughout this paper. Evidence of the scientist's quality control activities within a project and evidence of quality assurance activities within a program of integrated projects is the backbone of quality assurance as dictated by the changing nature of forestry research. Since the first attempts to implement QA in forestry research in the EPA/Forest Service Forest Response Program, managers and scientist alike have realized the benefits of QA at minor expense relative to overall research budgets. QA works when applied with a little common sense and its basic objective in mind: to produce data of known and sufficient quality.

IMPACTS OF ATMOSPHERIC DEPOSITION ON FOREST SOILS AND ECOSYSTEMS, SYNTHESIS AND INTEGRATION

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ABSTRACT

Understanding the effects of acid rain and air pollution on forest ecosystems requires understanding the entire soil-plant-atmosphere system; the ecosystem. Decline of trees is a natural phenomenon involving normal processes. Forest decline associated with air pollution is an extension of that phenomenon. It is clear that where forest declines have been reported, multiple factors or stresses are affecting tree health. Studies cannot limit themselves to one part of the ecosystem, or measure only one of the components of the system. Innovative experimental designs, multiple sites with pre-existing stresses, and simultaneous measurements of key response variables are all necessary prerequisites to adequate understanding of important processes. With that understanding, we can begin to understand the aggregate of the processes and thus understand decline. Integration of approaches before studies begin and of results after studies are complete are both necessary for understanding and for formulation of policy. Tools of integration can include conceptual models, expert systems based on artificial intelligence, and mathematical models. Mechanistically-driven mathematical models provide the best hope of achieving synthesis, integration, and ultimately understanding.

INTRODUCTION

Individual Perspective

I am flattered to be invited to interact with this distinguished group in the development of plans to conduct and coordinate research on the effects of acid deposition and air pollution on the forests of California. My background is that of a forest ecologist with an emphasis on soils, and I carry that bias on the issue of air pollution and forests. In this discussion, I will use the term "air pollution" to refer to both gaseous air pollutants and acid precipitation (Abrahamsen and Tveite 1983). Although I have conducted research and reported on the effects of acidic deposition on soils, I have not directly studied impacts of air pollution on forests. I might therefore be considered a knowledgeable virgin on the subject. That is, I lack that final and important intimacy with the problem that simultaneously leads to increased knowledge but loss of innocence. I hope that my innocence gives me a fresh perspective, and that I can add something to the conference.

Ecosystem Perspective

Although my emphasis will be on the soil, such a singular view is impossible. Air pollution affects the tree, the tree in turn affects the soil, the soil then affects the tree, and around and around it goes. It is obviously as impossible to divorce soil from the remainder of the system as it is to separate the trees from the forest. They are all parts of the inextricably-linked ecosystem. The potential problem of the effects of air pollution on forests demands a truly ecosystem perspective. I stress that point because too often ecosystem research is given lip service but is not really accomplished. It will not be sufficient to understand soil processes, or processes in the foliar organs of the tree, or in the roots, or in any single component of the system to fully understand the problem.

We must study or understand everything: effects of long-term climate and its periodic shifts; shorter-term weather and its variability; hydrology; genetics (why do some trees in a stand appear to suffer and others do not?); soil science in all its areas of physics, chemistry, and biology; tree physiology; phytopathology; and so on. We must also have a perspective on the types of data that we can gather in natural systems. We must understand the principles of significant differences in measurements, of white noise and of bias, of pure randomness and of the random path down which many ecosystems have traveled to reach their present state. Unfortunately, Renaissance men or women went out with the Renaissance. Only a limited number of scientists can even discuss the majority of the above topics.

Is that cause for dismay? I hope not. We must solve the puzzle of the ecosystem in the same way that we solve other puzzles - by considering each piece and how it joins adjacent pieces. To deal with the effects of air pollution on forests, we need a mechanistic understanding of ecosystem processes followed by an integration of that understanding. I believe that we now understand the interaction between acidic deposition and lake acidification, including the role of the terrestrial system in that interaction. In part, this understanding was achieved because the relevant physical and chemical processes involved were almost wholly understood before the applied research began; it was only necessary to link those processes into a coherent whole. We do not have full knowledge of all the processes involved in the interaction between air pollution and forest growth; elucidation of the processes and their linking are both necessary.

I would like to outline the direction that I plan to take in this presentation. First, I will discuss some of the major hypotheses relating air pollution and forests, next I will suggest some experimental approaches and some caveats to be used in the design of experiments to help understand the relevant processes, and finally I will present some ideas for integration of data.

FOREST DECLINE

We have met to discuss the potential interaction of air pollution and forest health, and to map a strategy for accumulating meaningful information to understand that interaction. I will use the term "forest decline" to refer to the situation in which trees in a population gradually deteriorate over time (Manion 1981); decline of conifers has recently been linked to air pollution both in Europe and in North America. The term Waldsterben has been used to describe this decline in Europe (Schutt and Cowling 1985). A distinction of these recent declines is that they are abnormal; that is, rates of tree deterioration exceed those normally observed in forest ecosystems.

I do not plan to explore in detail the important information about the relationship between air pollution and forest decline. That material has been covered elsewhere. Some of the most relevant and recent references that come to my mind are the reviews by Morrison (1984), by Kozlowski and Constantinidou (1986a, 1986b), by McLaughlin (1985) and the associated responses (Anon. 1985), by Burgess (1984), by Johnson and McLaughlin (1986), and a conference held in Minnesota in 1985 (Acid Rain Foundation 1985). Before I discuss experimental design and data synthesis and integration, however, I will provide a minimal reiteration of forest decline from my perspective.

Hypotheses

The hypotheses that have been offered to explain forest decline in both Europe and the eastern United States provide a partially mechanistic explanation for it (Hakkarinen et al. 1986). They do so by either explicitly or implicitly stating mechanisms or changes in mechanisms associated with stresses that impinge upon trees. The hypotheses include:

1. Acidic deposition causing soil acidification leading to toxic levels of Al or protons in soil solution.

2. Air pollution leading to nutrient levels that are deficient for plant growth either by leaching of nutrients (bases) from the soil, by leaching of nutrients from leaves, by immobilization of nutrients in organic matter, or by inhibition of mycorrhizal activity.

3. Direct injury to foliage by gaseous pollutants such as ozone, H_2O_2, SO_2 and unidentified organics.

4. Excess nitrogen deposition leading to disrupted growth patterns, such as lack of winter hardening and nutrient imbalances.

5. Natural phenomena such as drought, pathogens, and insects creating injury.

This list demonstrates that there is a place for most subject-matter areas of forest biology/ecology in the study of decline; forest tree nutrition, leaf physiology, forest pathology, climatic monitoring, soil chemistry, and many other areas are relevant. I do not want to give the impression that any of the above hypotheses wholly explains forest decline as it has been reported. Careful review of the literature seems to indicate that just as in any good multiple-choice test, the correct answer is "some or all of the above". In other words, any given case of forest decline is likely to involve the interaction of more than one of the kinds of stress described above, or is due to multiple stresses (Manion 1985). The problem is not simple enough to be related to a single causal agent, although at any given location a single stress may be primal. A comprehensive understanding of forest decline, however, must deal with all permutations and combinations of stresses (Fig. 1).

Although Fig. 1 may imply a chaotic system, there are some threads of rationality that can serve as a basis for consideration of either that figure or the larger question of forest decline. There are at least two characteristics that indicate that we are dealing with normal processes in understanding decline; that we have not been confronted with a whole new suite of biological or biochemical changes. First, trees in natural environments are continually under stresses such as those shown in Fig. 1. Some stresses are chronic, such as a site that is low in nutrients, while other stresses are acute, such as an early autumn frost. Anthropogenic effects either add an additional stress(es), or increase the intensity of normally-occurring stresses.

Second, tree decline is normal. The natural process of forest stand development involves the continuous decline in vigor and ultimately the death of many trees. The causes of the decline of an individual tree are many, such as suppression in the understory, injury by wind or animals, or infection by a pathogen. When we speak of forest decline we are speaking of a situation in which a greater proportion than normal of the trees in the stand are involved, and in which the normal processes may be proceeding at an accelerated rate.

RESEARCH DIRECTIONS/QUESTIONS

Introduction

As we contemplate a research plan to deal with the effects of air pollution on California's forests, it seems to me that progress must involve a consideration of the full range of normal plant-related processes, a winnowing to those that are most closely related to the hypothesized causes of decline, and a further winnowing to those about which our knowledge is insufficient. We must also be cognizant of those processes whose elucidation is intractable within any reasonable time-frame. A mechanistic

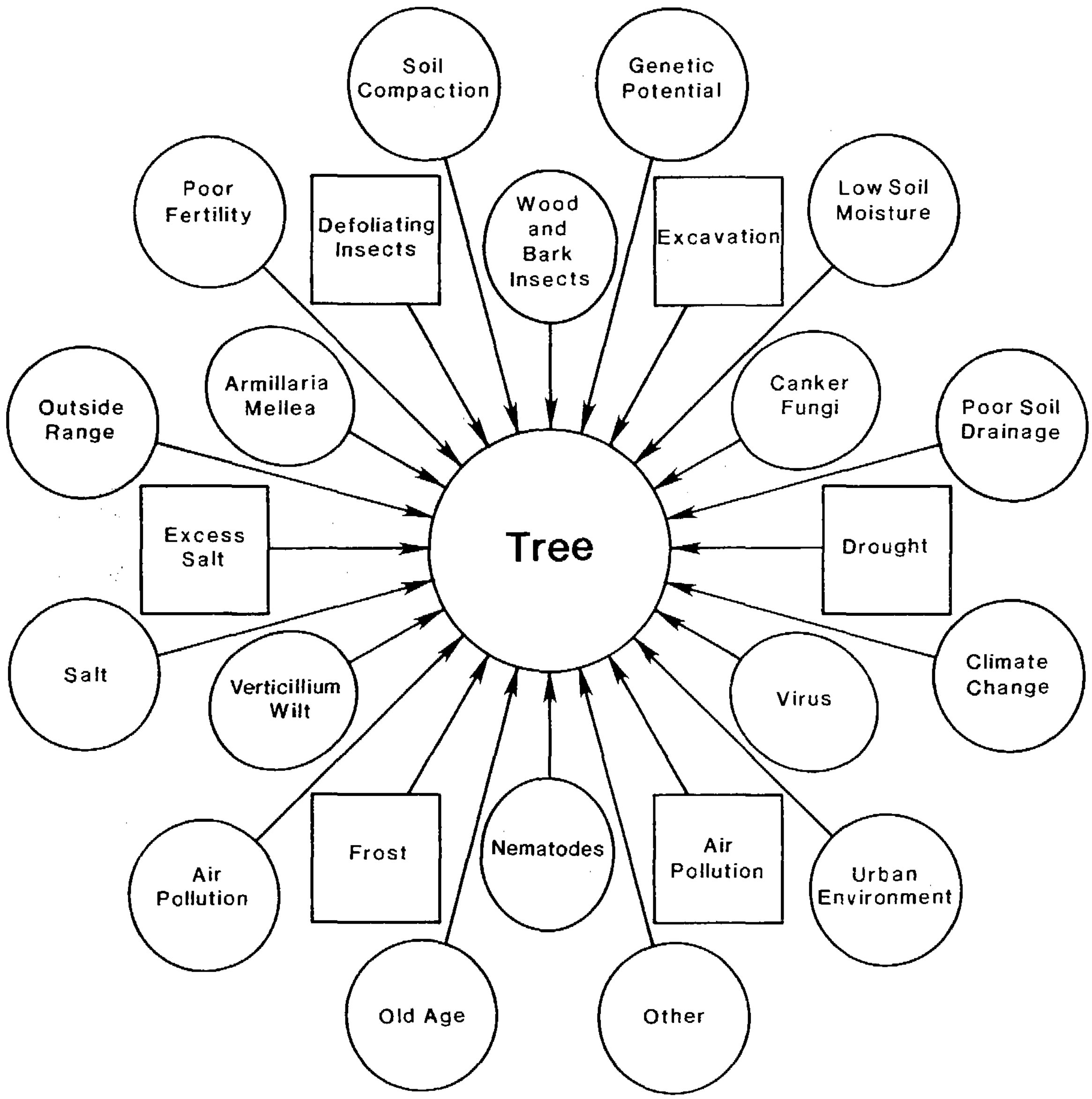

Fig. 1. A subset of the stresses that can impinge upon a forest tree, and that have been postulated to lead to forest decline. Factors in the outer ring have been termed predisposing, those in squares in the inner ring inciting, and those in circles in the inner ring contributing factors (modified from Manion 1981). Stresses can occur simultaneously or sequentially, and their duration and intensity may vary, so that the specific terms only represent fuzzy zones along a continuum of multiple stresses.

understanding of each relevant and measurable process is necessary for integration. In fact, the winnowing process that I have just outlined is one step in integration.

I would like to present some caveats, questions, and a few answers dealing with the design of experiments concerning the interaction of air pollution and forests. I will do so by considering various aspects of the experimental design, including duration of the experiments, location, treatments, and response. In my view, experimental manipulations are necessary in order to achieve a mechanistic understanding of forest response to air pollution.

Experimental Design

Duration

The first problem that must be confronted is that of dealing with effects of experimental treatments on large, long-lived organisms such as forest trees. Although a change in the organism may occur due to a stress or treatment, the result of that change may not manifest itself for one or more years. "Because of the exponential and modular nature of plant growth, ...changes will have ramifications throughout the life of an individual plant" (Lechowicz 1987). The plant/soil system has sufficient buffering so that any change may not be immediately obvious. For example, Abrahamsen (1984) and others conducted an experiment in which artificial acid rain was applied to young Scots pine trees over the period 1974 to 1981. Even in the most acidic treatments (pH 2.0 and 2.5), growth of the trees was stimulated for the first few years of the study. Not until 1979, the fifth year of application, was growth of trees depressed on the most acidic treatments. This was a site with a poorly-buffered soil, and with an extremely acid treatment. What are the implications of this result for long-term answers to short-term questions, and for funding of such research?

One solution to this problem, to be discussed again below, is to select measures of response that are sufficiently sensitive to detect changes within the short-term. For example, rather than waiting for the occurrence of necrosis due to increased SO_2, can changes in response of guard cells provide an early-warning sign? Such a measure would require simultaneous measure of leaf water potential, thus leading to consideration of more than one aspect of the ecosystem.

Location

When the location for experiments is considered in its broadest context, we must confront the eternal question of the advantages of laboratory versus field experiments. The answer is obviously that both have their place in any integrated study. Laboratory experiments may sacrifice reality for control, while in the field we gain reality but as a consequence we lose control.

One of the most fruitful approaches to understanding multiple stresses is to study at multiple sites. In these cases, although control is sacrificed the range of realities helps to better understand treatment effects. I have seen evidence of the value of multiple sites in the Integrated Forest Study (IFS) and the Study of Aluminum Biogeochemistry (ALBIOS), both sponsored by the Electric Power Research Institute. Multiple sites provide a wide range of ecosystems, with unique combinations of environments and of responses to those environments. As such, they have important heuristic value.

Multiple sites should be selected where both natural and/or anthropogenic stresses exist, and where manipulations can be performed. By manipulations, I mean such things as differential fertilization, soil leaching, fumigation, or periodic removal of either above- or below-ground plant tissue. Examples of naturally-stressed ecosystems include those near the lower and upper elevational limits or near the dry end of the range of a species or forest type. In each of those cases, we can assume that some combination of stresses is contributing to that limit. Transplant experiments with known genetic material, in combination with such multiple pre-stressed sites, would be powerful tools for deciphering the interacting effects of natural and experimentally-induced stresses.

Treatment

Experiments must be designed to yield data that will show relatively large differences in response among treatments, and do so in the short term. But if such experimental treatments drift far from levels found in real ecosystems, are they of any value? If rainfall pH never falls below 3.7, of what value is a study using artificial rain of pH 2.0? Is fertilization with supraoptimal amounts of nutrients a meaningful treatment?

Another related question that is appropriately treated in this section is the acceleration of response by short-term high doses versus long-term low doses. No one has suggested that forest decline occurs rapidly. Experimental acceleration of responses may be wholly unrealistic.

The effects of synergism in treatments must be considered. It is not adequate to subject organisms to only one kind of stress, when in nature they are subjected to multiple stresses. For example, air pollutants rarely exist singly. It is unlikely that the effects of stresses are additive (see Fig. 1). For example, SO_2 and O_3 interact synergistically on some clones of white pine (Houston 1974). Work has shown that Al may affect stomatal functions (Horton and Edwards 1976). Levels of Ca and Al in soil solution are both important in affecting root mortality (Huttermann and Ulrich 1984).

Response

We need to consider how we measure responses of trees or forests to treatment. We must consider the entire organism, but at the same time find its "pulse", the measure both in terms of organ and characteristic of the organ that most effectively reflects the health of the tree. One of the most common measures of response is biomass. Why? Is a "successful" tree one with large biomass? Similarly, diameter at breast height may not be the most valid response variable. Simply because it is convenient doesn't mean that it is valid. These measures are traditional and have some biological definition, but are they the best measures? Instead, should we measure concentrations of elements in cell sap, or leaf nutrient content at budbreak? Or should we measure production of propagules? Or leaf area? The list is limitless. Waring and Schlesinger (1985) have tabulated some indicators of stress in forest ecosystems.

To further complicate things, we must go one step further. We must consider the forest as the sum or really as more than the sum of the responses of individual trees. How do measurements on individual trees translate into indices of forest health? Does competition or other interactions among trees enter the relationship of multiple stresses? Here in California, differential responses to ozone among tree species are likely to affect forest succession (McBride et al. 1985).

Because of the insensitivity of many measures of response of trees to treatments, some workers have used physiological or even biochemical measures of vigor when dealing with forest trees. Unfortunately, ease of access and knowledge (both highly correlated) have led to primary consideration of foliage by such measures. In the words of one of my colleagues, most tree physiologists are "phyllocentric" (R. Goldstein, personal communication, 1986). According to the hypotheses listed earlier, many of the effects of air pollution on trees are hypothesized to operate to or through the root system. It is clear that we need more "rhizocentric" work. We aren't certain about the mass of roots that are directly involved in uptake of water and/or nutrients, or their horizontal and vertical distribution; we don't know how much redundancy exists in the root system or how many roots a tree really needs; we don't know the rate of turnover, and so on. In short, we know very little.

For example, what is the effect of complete decimation of the population of current-year roots for two or more consecutive years due to natural stresses such as drought, or to anthropogenic stresses such as an input of strong acids? Does such a decimation echo over time as it does in animal populations, leading to a population crash of the fine-root system? Does such a crash then lead to decline of the organism? We need studies of the demography of the root system.

Another question that must be addressed is where stresses affect trees. We know that the general rule calls for a response to stress at the point at which the stress is applied. In other words, carbon will be allocated to roots if they are stressed, and to foliage if it is stressed (Lechowicz 1987). Alternatively, supra-optimal resources may reduce carbon allocation to certain organs. Pertinent hypotheses suggest that continued stress to foliage leads to allocation of carbon to those organs, with less allocation to roots, or a general decline in the root:shoot ratio (Lechowicz 1987). As a result, roots are less able to function if they are subjected to a natural stress such a drought. Conversely, foliar uptake of supraoptimal amounts of nitrogen leads to atrophy of root systems, and similar susceptibility to stresses such as drought. We need some understanding of the process of allocation.

Minirhizotrons are gaining increasing attention in agronomy as a method of quantifying root behavior without major disruption of the root system (Upchurch and Ritchie 1984). Minirhizotrons can be installed relatively quickly in established forests. Such a technique deserves consideration in studies of forest decline. Another aspect of root physiology that is finally beginning to elicit attention is the complex biochemistry in the rhizosphere. Interactions among plants, symbiotic and free-living microorganisms, and the soil may lead to conditions in the rhizosphere that are quite different than those found in the bulk soil (Huttermann and Ulrich 1984). How does that affect trees? How can we predict rhizosphere chemistry from bulk soil chemistry? Does it make any difference to the trees?

There is a final point in consideration of responses. Almost all dose-response work with which I am familiar, whether dealing with effects of radiation on fruit fly reproduction or with damage of foliage due to defoliation by insects, first shows a stimulation and then a depression in growth. In Germany, they recorded exceedingly good growth of spruce in the decade or two before Waldsterben. A review of recent studies of effects of gaseous pollutants indicated that in 14% of the studies growth was increased in the treatments relative to the controls (Lechowicz 1987). I have already mentioned the increased growth of pine trees under very acid treatments observed by Abrahamsen (1984) and his coworkers. Should we view stimulation as the first signs of depression?

I further believe that measures should be both sensitive and spatially and temporally simultaneous. For example, elements frequently mentioned in hypotheses concerning decline include Al, Ca, Mg, and N. Simultaneous measurement of all four in a variety of components of the ecosystem would provide valuable integration of a number of processes. Some of the components that I am referring to are the soil solution, soil exchange sites, plant foliar and root tissues, solutions in the xylem and phloem, and throughfall. A mechanistic understanding of normal or abnormal processes in forests must link levels of all these elements in all these components. Such processes include ion uptake, transport, and leaching.

I have already mentioned the water status of the plant. It must be linked with the water status of the soil and also with levels of those elements that have been shown experimentally to interfere with water uptake or transmission (i.e., Al). Simple experiments on stress induced by damage or removal of either or both root and shoot tissue may provide clues to redundancy and allocation, especially if the plants are also under other stresses. I have mentioned the normal decline of trees within forest stands. Measurements such as those that I have previously described of declining understory trees in healthy forests, and their further stress by treatment, may also provide clues to the phenomenon of multiple stresses.

INTEGRATION

There are two problems that face us. First, I have discussed measurement of the response of trees or other organisms to anthropogenically-induced stresses. Second, even if relevant studies were carried out, using the best techniques and the most innovative experimental designs, how can we integrate or synthesize all the data?

It is obvious that we must integrate, and that keyword was included in the title of this talk. Unfortunately, I have no solution or magic potion. No software or hardware. No short-course in personnel interactions. In fact, I must confess some pessimism concerning the ability of scientists from diverse disciplines to interact in an integrated manner. Part of the problem is differences in vocabulary, part is differences in scientific perspective, part is individual idiosyncrasies.

I believe that the first step in integration is creation of an object of focus. We need something around which we can rally the troops, their data, and their expertise. We need a vehicle through which scientists in diverse disciplines can communicate, interact, and educate one another. I see three paths that can be followed, either simultaneously or separately, in attempting this integration.

Conceptual Model

First, a conceptual model can be developed. This model would be a "word" or concept model, patterned somewhat after Fig. 1, but with mechanisms associated with each of the arrows in Fig. 1. It would include the invisible compartments and arrows that are not shown in the figure. It should also include mechanisms associated with the hypothesized causes of decline that I listed earlier. It would both identify the processes that are presumed to be relevant and those that are extricable. Although this is a necessary first step, especially in experimental design, I don't believe that it provides the rigor of thought or logic necessary to really integrate the diversity that faces us.

Artificial Intelligence

Another approach in the search for integration may be the use of expert systems, a type of artificial intelligence (AI). I know very little about the topic, but its potential usefulness in many fields has been receiving increasing attention. I bring to your attention its possible use in our problem of integration. I am not an advocate, nor do I have enough information to be a doubter. Such systems are designed to reproduce the expertise of human specialists, and are especially valuable for problems that are primarily heuristic as opposed to algorithmic. Algorithmic problems can be better dealt with using mathematical models as described above; if the problems require experiential and judgmental knowledge and rules of thumb, they are more readily handled by expert systems. Such systems have been used in financial planning, factory scheduling, medical diagnosis, and soil classification (McCracken and Cate 1986).

Most expert systems consist of a development facility that codifies the expertise of human specialists, usually with the aid of a knowledge engineer; a knowledge base that contains that information; and an inference engine that combines case-specific user input with the knowledge base to solve the problem or answer the question (Tucker 1986). The potential to integrate the expertise of scientists from diverse disciplines, and to introduce case-specific information for any given situation, intrigues me. The logical rigor demanded of those systems may help focus both thought and work. Such systems are, after all, nothing more than the excruciating restatement of what is known and how judgments are reached. They may be capable of summing the separate bodies of information that are both existent and are to be developed by each of the many scientific disciplines interacting to understand forest decline.

I will close this section with two quotes from the literature dealing with expert systems. "The unique strength of expert systems is their ability to effectively integrate numeric, judgmental or preferential, and uncertain information in rational ways" (Huggins et al. 1986). Alternatively, "It is now up to the user to become aware of what AI can do. If they expect more of AI than it can deliver, they will surely be disappointed" (Rauch-Hindin 1986). Enough said?

Mathematical Model

A final and I believe powerful approach to integration is the development of a mathematical model. A set of mechanistically-based algorithms that link the components of the tree/soil/atmosphere provides an ideal vehicle for scientists from multiple disciplines to focus their attention and to integrate their knowledge. If development is successful, the model also provides a means of extrapolation, either spatially or temporally. I know that there are many whose opinions of mathematical models is low. I will agree that many models that I have seen represent the best of science fiction; invalid musing given an air of respectability by the use of computers.

I am acquainted with some successes in modeling, ranging from simple algorithms that simulate one aspect of a system to more complex creations. Probably the best example with which I am acquainted is the ILWAS (Integrated Lake Watershed Acidification Study) model (Goldstein et al. 1984); a general theoretical and quantitative framework to understand changes in lake acidity related to levels of atmospheric acidic deposition. The initial problem that led to the development of the model was complex, requiring the integration of information from many disciplines. The model is mechanistic and uses a minimum of simplifying assumptions so that it can be applied to systems other than those for which it was initially developed. I consider its development to have been a rousing success.

I have been acquainted with the ILWAS model nearly from its beginning. It would be a misrepresentation to say that its development came easily. The problem was complex, the data were diverse, and the scientific drama included both protagonists and antagonists. In spite of these hurdles, the product succeeded in accomplishing its goals. I am aware that the problems of modeling forest decline, that of adding the complexity of the functions of a living organism to ecosystem processes, are not trivial. In spite of these obstacles, model development must be carefully considered if we are serious about understanding the effects of air pollution on forests. Many aspects of the experimental design that I have outlined above can be guided by the structure of a mechanistic model. In summary, development of a mathematical model would be a major intellectual achievement, and an invaluable tool for understanding forest response to air pollution.

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BACKGROUND FOR THE SYNTHESIS AND INTEGRATION OF FOREST RESPONSE TO ATMOSPHERIC DEPOSITION

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INTRODUCTION

Concern about the potential effects of atmospheric deposition on forests is derived from three sources. The first is the apparent effect of atmospheric deposition on some aquatic systems. The second, considered a possible leading indicator of what could happen in the United States, is the effect of atmospheric deposition on European forests. The third source is a small number of published and unpublished studies which claim to show an overall reduction in growth of some forests in the eastern and southeastern states.

The National Acid Precipitation Assessment Program (NAPAP) Section V (Terrestrial Systems) has developed a joint program between the Environmental Protection Agency (EPA) and the U.S. Forest Service. This joint program, called the Forest Response Program, conducts numerous studies on aspects of the relationship between atmospheric deposition and forest condition.

This paper is based on a project entitled *A Review of the Statistical Methods for the Evaluation of Atmospheric Deposition Influences on Forests* (ADIF/STAT). Because statistics consist of the studies of the general methods of inference for scientific research, thorough presentation must encompass an understanding of the entire scientific problem as well as the statistical methods used to evaluate the problem. Therefore, we have considered the general conceptual basis of the research, problems of experimental design, and problems of interpretation, as well as statistical methods. In particular, we are attempting to understand the relationship between studies of atmospheric deposition and the general problems of forest ecology.

Summary

To understand a complex ecological problem such as the effect of atmospheric deposition on forests requires diverse approaches. Diverse studies using different approaches need to be funded. The use of statistical methods limits the ability to quantify the effect (Ware and Louis 1983). New methods need to be developed for analyses of growth patterns especially in situations where early inadequate statistical methods caused some people to abandon the approach altogether.

Pilot studies need to be developed to help in the design of long-term monitoring studies, to screen for variables, and to estimate efficient sampling intensities. Models of tree and stand dynamics must be constructed to estimate the forest-wide effect of a particular cause and effect mechanism, to provide a null model, and to aid in risk assessment and forest valuation.

Statistical analyses of both short and long-term effects of climate and weather on forests and trees need to proceed. Such natural factors greatly affect the process of atmospheric deposition. However, it is imperative that this effort be directed at the effect on forests not just general climatic modeling.

Three _Obiter Dicta_

1. Research on the effects of atmospheric deposition on forest condition is difficult and complex. Because of the importance of this research, the quality of the research must be superior.

2. Successful analysis of this problem will require state-of-the-art statistical methods and development of new methods. Statistical methods, as well as atmospheric deposition research, are evolving sciences. As such, they will require care in development and interpretation.

3. The scientist or administrator must be aware of the distinction between scientific understanding and risk assessment. This vigilance is especially necessary in this case because risk assessment will have to proceed in the absence of complete scientific understanding. Particular statistical methods have been developed specifically for use in risk assessment and these should be distinguished from the more usual methods used in scientific inference.

ECOLOGICAL FOUNDATION OF ATMOSPHERIC DEPOSITION RESEARCH

Variation is the central concern of evolutionary biology. In ecology the variation occurs as a complex of interactions. Thus the warnings from the study of evolution must be heeded: Multiple causes and multiple effects are the rule, not the exception. In particular, necessity and sufficiency must not be confused with causation. Most ecological causes are neither necessary nor sufficient for their effects. For example, smoking is neither a necessary nor a sufficient condition for lung cancer. Many people who smoke do not get lung cancer and some people who get lung cancer do not smoke. However, there is a clear pattern of causation (Hull 1974).

Because of the complexity of ecological systems, we must be aware of the limits to our ability to understand them. In particular, when considering models of ecosystems, it may be useful to recall the argument of Richard Levins (1966) that no single model in ecology can simultaneously maximize the three desirata of reality, generality, and precision. It appears to be an empirical fact that we can only achieve two of these in any one model. Which one we sacrifice depends upon our research methods and on the purpose of the research.

This leads to an important dilemma in atmospheric deposition research. We need reality and precision in our understanding to make accurate assessments of the impact of atmospheric deposition on particular forest systems. However, this implies the sacrifice of generality. Two problems arise from this.

First, it creates an intellectual frustration for the scientist who wishes to search for general laws and patterns. It also creates administrative frustration in that decisions to act in one region cannot necessarily be based on situations in nearby regions.

Second, from a statistical point of view, our sample sizes are smaller than we would use for generalized studies. If two geographic areas are subject to the same patterns of causation, we could consider them replicates. However, the complexity of the forest ecosystem may force us to consider them as different systems.

Will atmospheric deposition research simply be reduced to a series of case studies? This is a historic problem in forestry research. As G.W.S. Trow (1984) phrases it, forestry is somewhere; whereas science is everywhere and nowhere. Thus, specific forests must be considered at particular times to achieve the understanding a forester needs. In contrast, a scientist may consider any forest as an example of how forests function. In forestry the general does not contain the particular.

CONCEPT OF FOREST CONDITION

The concept of forest condition lies at the beginning of any atmospheric deposition research. Yet, this concept is perhaps the most elusive of all. From the forest ecology perspective, there is no natural concept of condition. Condition is not a property of forests the way atomic weight is a property of an element. Condition is a human interpretation placed on the forest in the presence of a complex human context. Thus there are a large number of measures of forest condition. Even the classification of the possible forms of forest is not clear. However, they include indicies, symptoms, bioassays, and dynamic properties at several levels.

Condition measures may be properties of both individuals and ensembles of trees, stands, and forests. Biomass, timber volume, growth, reproduction, diversity, evenness, frequency of rare species, foliar damage, crown dieback, stability, persistence, and resilience all apply to one or more of these groups.

Forest condition is a subjective evaluation similar to the judgment a forester makes in determining the level that a forest is stocked. Ideally, we would prefer to have baseline data on forest study sites before there was any atmospheric deposition. This would provide an index for assessing the impact of atmospheric deposition. Different researchers will do this in different ways. The ecologist thinks of reproduction, while the forester thinks of measuring radial or basal area growth. In Germany, the state of *Waldsterben* has been quantified by categorizing trees as to crown vigor.

Apart from the obvious problems of choosing the measure by which to quantify the forest condition, there are some statistical issues which should be considered. Objective measures (i.e., radial increment) may have utility if the variation in their changes can be explained in a valid statistical manner. Subjective measures (i.e., observer ratings of crown vigor) result in variability among observers and observer awareness. For example, a Frazer fir on Mount Mitchell may appear healthy to one observer but sickly to another scientist who recognizes that the tree has been infested with balsam wooly aphid. Consider the situation reported by Schutt and Cowling (1985):

> "During 1984, the forest disease situation in Europe grew worse. Symptoms are now found on almost every species of forest tree and on several shrubs and herbs."

Was the situation really so much graver in 1984 than it was in 1983, or is this an example of increased observer awareness? There needs to be developed statistical procedures for comparing observer ratings. Also, observers should be adequately trained to achieve a high degree of standardization.

THE MAJOR APPROACHES TO THE STUDY OF THE EFFECTS OF ATMOSPHERIC DEPOSITION

Following an analogy with medicine and public health, we propose two major conceptual approaches to the study of the effect of atmospheric deposition on forests:

(1) The epidemiological approach, and

(2) The physiological approach.

The epidemiological approach is characterized by broad surveys of forest condition and a search for patterns of condition that may be related to patterns in other aspects of the environment including atmospheric deposition. The physiological approach is characterized by more focused studies on the effects of environmental states on the well-being of individual trees. The general research strategy is for the epidemiological studies to uncover patterns of condition which then suggest particular hypotheses to be tested in a physiological study. The results of the physiological study must then be projected over an entire forest system to reconstitute the pattern of forest condition. This reconstitution is usually achieved through a model of the forest system, most commonly through the use of a tree and stand dynamics model (Figure 1). It is important to remember that scientists with different research styles will implement the different components of the overall strategy. We need to complete one cycle to guide in the design of future research at all levels.

In both approaches we need a control. In epidemiological studies a control is the mechanism for the elimination of confounding variables. This usually involves comparison of the patterns of condition in forests that have varied amounts of atmospheric deposition.

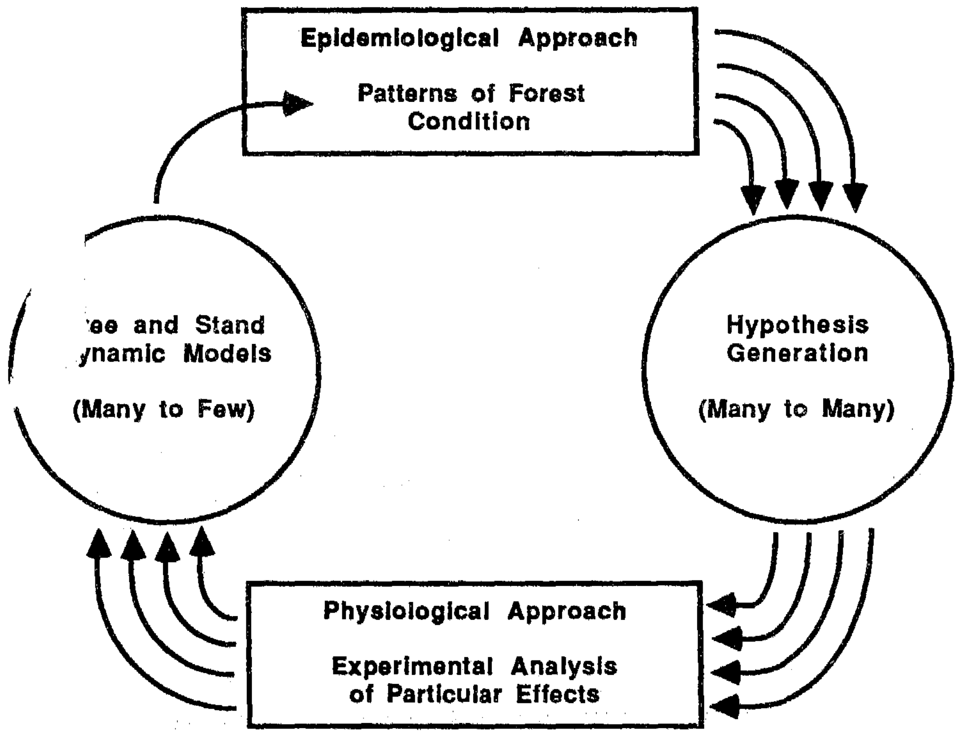

Figure 1.

This means that we must compare forests that are in different locations, compare the same forest at different times, or both. It is impossible to compare two forests that are equal in all respects except the amount of atmospheric deposition. Confounding variables are always present and their effects may overwhelm or mask the effect of atmospheric deposition. Therefore, the control in epidemiological studies consists of accounting for the other variables. In physiological studies consideration of control is more apparent and equally important. Some trees receive no treatment effects but are otherwise treated in just the same manner as those which do receive the treatment effect. Nonetheless, controls may require some thought as to the choices. For example, in a simulated acidic deposition experiment, we must establish which pH is to be used as the control. We certainly would not want to use a pH of 7. Should we use the average of rainfall over the U.S. or over the range of the experimental species? These questions often require more than casual thought.

THE EPIDEMIOLOGICAL APPROACH

As a practical matter, the condition (however measured) of any two forests or stands is likely to be correlated to some degree. The amount of correlation depends a great deal on how close the two are in space and time. Forests far from each other may be quite uncorrelated; but this cannot be assumed out of hand. Thus different forests are not generally independent samples. This means that ordinary statistical methods are not suitable and that the techniques of time series analysis must be brought to bear on any epidemiological style investigations of forest condition. The term "time series analysis" refers to a body of (rather sophisticated) statistical methods for dealing with systems that are correlated through time. Similarly, there is a newer and less comprehensive body of methods for analyzing "spatial series" of systems correlated through space (Ord 1979). (For a variety of reasons spatial series analysis is technically more difficult than time series analysis.) The use of ordinary statistical methods on time series data constitutes one of the more frequently seen major blunders in the published literature.

Maps

An important first step in analyzing epidemiological data is to produce maps which serve to organize information and act as a reminder of the spatial patterns of dependency that can exist in the different systems being studied. Generally, maps that show aerial extent like in political regions provide little assistance by themselves. Maps that show the distributions of values of forest condition over an area (i.e., have isopleths of condition) are far more valuable. These maps must be accurate. Usually only a few points will be known and the rest interpolated. Frequently the value of these "known" points are the result of estimates which are subject to some error. Such sources of error must be quantified to establish the accuracy of the map.

Epidemiological Studies of Growth

There are many reasons why growth is the most commonly used index of forest condition. Historically, apparent declines in growth have triggered much of the concern about the effects of atmospheric deposition on forests.

Growth of forest trees is studied by two major methods:

(1) Remeasurement

(2) Tree ring analysis.

These two methods are complementary because both work to establish overall patterns of forest tree growth in space and time. These patterns become the objects of further research as their causes are sought.

It is difficult to locate study plots of trees using either method. There are two possible methods for locating study sites: Random sampling and sampling that is proportional to perceived threat. Scientifically, plots should be randomly placed within a large study forest or region. However, from a risk assessment point of view, we must consider the "leading indicator" forests to search out "hot spots" of damage and place plots in these locations. If the second method is used, it is crucial to keep in mind that extrapolation to other areas or to a region may not be scientifically valid.

Growth may be measured in many ways including radial, basal area, volume, and height growth. Each method has its advantages and disadvantages. Basal area growth is probably the most common method.

Growth of an individual tree is a function of both age and time regardless of the method used. As with any essentially demographic endeavor, these two variables are related but not identical. We are proposing a standardized method of plotting raw data from either tree ring or remeasurement studies. This method uses a three dimensional graph which plots growth directly as a function of age and time for each individual tree in a study area. The shape of the surface produced by such a plot gives valuable preliminary information about the regularity of the data and the patterns contained within it. We emphasize again how important it is in any study to plot the raw data as a first step in the analysis.

Remeasurement Studies

Certainly the most straightforward way to determine growth rates in trees is to repeatedly measure individual trees through time. The disadvantages with this method are that the trees must continue to exist through time and that the series can be no longer than the length of the study. In practice, it is unusual to find a series that is over 30 years old. On the other hand, most putative pollution events are of recent origin. An advantage of this method is that collateral information such as stand density can be obtained at the same time. This is not the case with tree ring studies.

Tree Ring Studies

Dendrochronology and dendroclimatology are studies that help us understand the effects of atmospheric deposition on forests. Earlier simplistic studies were unsuccessful and have caused some to give up on the technique prematurely. However, recent work using new and sophisticated time series methods have a brighter future (Cook 1985).

Trees are natural data recorders (Creber 1977) and a host of factors affect the pattern of ring widths through time including atmospheric deposition. We need to extract the effects of the pollution problem out of the effects of other factors.

Each of these methods of study have a diminished ability to deal with the ends of series. If we have a record 200 years long, the methods work much better in the middle of the series than in the last 15 years. Unfortunately, this is exactly where we expect evidence of pollution effects to occur. We can see that tree ring studies must be complemented with remeasurement and stand history studies to compensate for this weakness.

Other data may be contained in tree rings besides their width. Density and detailed intraring patterns of early and late wood are currently under intensive investigation. Also various chemical elements are contained in the rings and the variation in their concentrations is a potential indicator of the amount and type of deposition. Most of the problems with this approach are technical. In particular, the question of translocation of elements between rings can only be answered by careful experimentation. If the technical aspects of this approach can be resolved successfully, the extension of statistical methods developed for width data will be relatively straightforward.

Climate and Weather: Famous Natural Factors

Climate and weather constitute the largest single constellation of natural factors affecting forest condition. Perhaps the most significant aspect of these factors is the number of scales in space and time over which they can vary. Actually the division between weather and climate is already a distinction of time and space scales. Climate occurs over longer periods of time and larger areas. Weather is more local in both space and time. Both local and global aspects are important in the analysis of atmospheric deposition.

For example, local rainfall can be tremendously variable (Eynon and Switzer 1983), especially in areas of topographic diversity. In some areas rainfall is even and relatively continuous and in others it can be highly episodic. Snow and other climatic effects can also be episodic or continuous. This diversity leads to a class of serious statistical sampling problems: In sampling rainfall for acidity, for example, should the sampling be periodic or episode induced? These two methods are each appropriate for different rainfall regimes, but may not be comparable. We have seen one study in which it was proposed to use one method in one state and the other in another. Much more attention must be given to this design issue.

A similar problem arises when one considers the response of some measure of forest condition to weather. Tree and stand response may be continuous or threshold and may therefore demand different sampling methods. In general, it is important to concurrently measure both a forest response to weather and climate along with weather and climate themselves. There is the possibility of a nonlinear relationship between forest condition and measure of weather.

The global or large scale pattern of wind and rain is also exceedingly complex. Here we are most concerned with secular trends over the last few decades and over large forest regions. There is some evidence of decade scale trends in weather, especially rainfall and minimum winter temperatures, that correspond closely in time with the onset of potential atmospheric deposition. The nature of these trends and of the response of forest condition to them (whether continuous or threshold) must be well understood before the effects of atmospheric deposition can be quantified.

Pollution: A Famous Human Factor

The diversity of things deposited from the atmosphere onto forests is staggering. These substances include literally hundreds of chemical species, dust, soot, and so forth. With this many chemical species possible, the number of interaction effects is potentially in the many thousands. This is worth keeping in mind because any two species taken together may be very nonadditive in their effects on forest condition.

An important aspect of any deposited substance is its spatial and temporal pattern. Comparison of patterns of deposition with patterns of condition using spatial models is a much more powerful test of the potential relationship that comparing a series of points. One of the most promising areas in ADIF research is the development of spatial models of patterns of deposition and condition using new spatial series modeling methods and statistical methods such as kriging. Most of these methods were developed by statistical geographers and geophysicists and are now just beginning to be applied to atmospheric deposition research.

Particular pollutants are often characterized by the spatial distribution of their sources. Some pollutants are characterized as point source pollutants such as are emitted from a particular power plant. Others are called nonpoint source pollutants as from automobiles. Models of these two types of systems may help us picture the spatial pattern of pollution which can then be compared to patterns of forest condition.

Rainfall: An example of a combination of natural and human factors

Rain exemplifies the complexity of determining what is a natural and what is a human factor. It is both:

1. A natural factor affecting growth of trees directly.

2. A major source vehicle for atmospheric deposition.

The interactions between these two may be complex. For example, suppose we consider varying both the amount of rain and the pH of the rain. Holding either constant and varying only one might produce simple results. But the overall response of forest condition to the combination is not known. In other words, a three-dimensional graph of forest condition as a function of amount of rain and pH would produce a surface which is the response. We do not know what this response surface would actually look like.

Rainfall also has long-term complex effects such as its effect on the water table in a given region. But clearly the water table is also greatly affected by human use.

Hypothesis Generation

Hypotheses about the specific mechanisms of action of particular factors on aspects of trees and forests can come from many sources including general scientific knowledge, common sense, and imagination. But certainly an important source of hypotheses are the patterns of forest condition generated by the epidemiological style studies. If a pattern of forest condition is found in space or time, it can be compared to patterns of various factors in the environment to generate new hypotheses.

It may be convenient to classify the factors which could ultimately affect forest condition. For example, if a decline in growth was detected over a region, many possible factors would have to be considered in attempting to account for the decline.

I. Natural factors.

A. Present and known. These are the factors assumed to affect all forests to some degree such as age or climate.

B. Present and unknown. These are natural factors currently undiscovered by science. Unknown mechanisms of root competition might be an example.

C. New. These are factors which, although natural, have only been affecting the trees and forests recently. A newly invaded disease organism might be an example.

II. Human Factors.

A. Present and known. Factors such as logging.

B. Present and unknown. These would include pollutants whose effects are not known and not considered. Low level, but chronic, factors might be a common case here.

C. New. Factors that have appeared in the environment only recently which may affect it. Many kinds of atmospheric deposition fall under this category.

Hypothesis generation is especially important in the area of unknown factors. Progress will not occur unless many new hypotheses are generated and tested.

THE PHYSIOLOGICAL APPROACH

The physiological style of research enjoys great success in many areas. In the study of the effects of atmospheric deposition on forests, it takes the form of examining a particular effect in a controlled experimental design and characterizing physiological processes.

For the purposes of these kinds of studies, the forest can be thought of as consisting of a large number of compartments of various sizes which divide up the dynamic structure of the forest. Thus the compartments are bite sized pieces of reality which can be subjected to experimental analyses. However, for the purpose of the experimental analysis of causation, these compartments are assumed to be independent of one another.

Compartments are often the various parts of a tree such as the crown, or leaves. They can also be components of the soil, sets of competing species, or many other aspects of the forest ecosystem. Thus a study might be carried out on the effect of ozone on foliage health in a particular species while another study could be carried out on the effect of ozone on the formation of ectomycorrhizae in the same species. The compartment approach assumes that there is no important interaction between foliage health and the formation of ectomycorrhizae.

Once a potential effect and a particular compartment has been identified, from a statistical point of view it is relatively straightforward how to proceed. The problems of design and statistical analysis for physiological style research are much better understood and are generally well known. The first rule is to consult a statistician before beginning the experiment. Beyond that the many standard texts and review articles contain the necessary information.

Many experimental designs lend themselves to analysis of variance; and here the standard advice of randomize and replicate must be emphasized as strongly as possible. Despite the fact that this is a well known area, many workers still confuse replication with subsampling (Hurlbut 1984). Many workers also do not fully exploit the logical structure of the experimental design in setting up the analysis of variance. And pretreatment techniques which can be important in field experiments ought to be considered more frequently.

Simulated acid rain studies are an important general technique. Concern in the design must be focused on the choice of pHs to be used and on the mechanism by which the "rain" is physically applied. Standardization of the second has yet to be accomplished, but the work of the pesticide researchers might profitably be considered here.

From the analysis and design point of view, the ideal approach is a dose-response study analysis using standard statistical methods (e.g. probit analysis). The remaining concerns overlap into risk assessment:

1. Low dose extrapolation. Often it is necessary to use higher doses in the experiment than occur in nature to get definite results. The dose-response curve must then be extrapolated to lower values for application to nature. Some statistical procedures have been developed for this.

2. Chronic long-term extrapolation. Often an experimental procedure only lasts a mere fraction of the

life of a tree. Therefore results need to be extrapolated over longer periods and often over older ages as well since many experiments use only seedlings.

MODELING TREE AND STAND DYNAMICS

Once a particular experimental analysis has uncovered the effect of a given cause, it is necessary to evaluate the importance of that cause in creating the pattern of forest condition that has been observed. In other words, we need to see if this particular mechanism actually is operating at a significant level in nature and can contribute significantly to the reconstitution of the pattern discovered through epidemiological investigations.

The only real method that exists for such evaluation is modeling of the dynamics of trees and forests. In this sense, a model is a mathematical method for "balancing the books" on forest growth or some other measure of condition. There are numerous inputs to the model but only one "balance", namely the actual pattern of forest condition. A model acts as a summary of two kinds of knowledge. First, it encapsulates the general biological principles that apply to tree and stand dynamics. Second, it summarizes the actual data known about a particular system. There is a long tradition in forestry and systems ecology of such models. The methods that have been developed constitute a great resource for workers in atmospheric deposition. In forestry, in particular, these are known as "growth and yield" models.

As shown in Figure 1, models of tree and stand dynamics synthesize the information obtained from experimental studies in such a way as to evaluate how the cause-and-effect mechanisms studied account for the pattern of forest condition. We are convinced that progress in the solution of the atmospheric deposition problem will only come through repeated iterations of the cycle illustrated in the figure. In particular, an early attempt to complete one cycle is crucial to planning future work. In other words it is important to evaluate the data and knowledge that we have as it is being acquired rather than waiting until the end. This means that we can learn from experience and apply new knowledge. Science is an iterative process.

Early modeling is also important. In the absence of specific atmospheric deposition effects, the model produced is a null model of tree and stand dynamics. This accounts for their behavior in the absence of any atmospheric deposition. Such models are necessary to realistically determine if there is any atmospheric deposition effect.

Finally, modeling is fundamental to any efforts at risk assessment. The processes implied by any particular study must be projected over entire forests and regions to establish their impact on condition and hence their ultimate impact on forest and land value.

In summary, modeling is a method for quantifying atmospheric deposition on forest condition. This is the method we will use to synthesize our knowledge into a usable package. We must exert effort toward synthesis to make it a part of our acidic deposition solution. It will not come about merely by accident or simply because a conference is held.

ACKNOWLEDGEMENTS

This paper arose from my thoughts about work done jointly with Tommy Dell and Paul Van Deusen of the Southern Forest Experiment Station. As part of the Vegetation Survey of the Forest Response Program, we ran a "Distributed Seminar" or "Seminar by Mail" in which selected works were mailed out weekly to a team of 13 forest biometricians, statisticians and quantitative ecologists. These 13 were chosen both for expertise and diversity as part of a philosophy of "replicating statisticians" in an area where there are no obvious "canned" approaches. Over a period of 8 weeks, there were 27 articles, 13 proposals, several maps and associated materials sent out. The team members responded each week by reviewing these documents, proposing alternative ideas and methods, and suggesting areas for future work. While I take full responsibility for the conclusions presented here (and indeed some of the participants would strongly disavow them), it is certainly the case that they stimulated me greatly.

In addition to Tommy Dell and Paul Van Deusen, the participants were: Robert L. Bailey, Bruce E. Borders, Janice A. Derr, William L. Hafley, Carl W. Mize, J. Keith Ord, Robin Reich, Marion Reynolds, Michael G. Shelton, Robin A. J. Taylor, Michael Wade, William G. Warren, and Lee C. Wenzel. Thank you all.

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CALIFORNIA FOREST RESPONSE PROGRAM

DRAFT PLAN

REVISION IN RESPONSE TO THE PLANNING CONFERENCE

HELD AT ASILOMAR IN PACIFIC GROVE, CALIFORNIA

February 22-24, 1987

Sponsored by:

California Air Resources Board
Western Conifers Research Cooperative

DRAFT

March 23, 1987

SUMMARY

The California Forest Response Program (CFRP) is designed to determine the current and potential effects of acidic deposition and associated air pollutants on the forests of California. The Program is managed by the California Air Resources Board, and is also supported with resources and expertise from the Western Conifers Research Cooperative, a part of the national Forest Response Program.

This Plan will serve as the foundation for the California Forest Response Program research effort. The Research Plan describes the CFRP's objectives, the overall plan for achieving the objectives, and the specific projects to be implemented. Development of a plan ensures that individual projects are integrated within the CFRP, and that the CFRP is compatible with the framework of the Western Conifers Research Cooperative and the National Forest Response Program.

The CFRP plan has been developed through the cooperation of the California Air Resources Board (CARB) and the Western Conifers Research Cooperative (WCRC). Input was received from workshops held in February and provided by staff of the WCRC and CARB. Formal written peer reviews were an integral part of the planning process.

The objective of the CFRP is to evaluate the effects of atmospheric pollution on California forests and to determine the mechanisms of these effects. The plan approaches this task simultaneously statewide, regionally and at intensive sites. Ponderosa pine is the focus of effort of the CFRP plan. The plan is integrated by the biological linkages between the physiology of seedlings, growth responses of mature trees, dynamics of forest stands, and patterns in regional and statewide forests.

This plan proposes to support the development of dose-response relationships and process-driven models of mature tree response and stand dynamics by using studies of the correlation between acidic deposition and forest condition and using experimental studies of the mechanisms of the effects of acidic deposition. The major program output will be an assessment of the effects of acidic deposition and other air pollutants on California forests.

Disclaimer

The draft Research Plan presented here is for the purpose of discussion only. It does not imply a commitment of funds or personnel by the California Air Resources Board or by the Western Conifers Research Cooperative.

1.0 INTRODUCTION - RESPONSIBILITY OF THE CALIFORNIA AIR RESOURCES BOARD

In 1982, the California legislature passed the Kapiloff Acid Deposition Act which set up a 5-year research and monitoring program to be implemented by the California Air Resources Board (CARB). This program was intended to "determine the present and potential environmental, public health and economic effects of continued acid deposition" in the State.

This mandate forms the rationale for the initiation of a California Forest Response Program (CFRP). An assessment of the effects or potential effects of acidic deposition, alone or in combination with other air pollutants, on forest resources will be required as part of the final report of the Kapiloff program. The initial year of the CFRP will be under the mandate of the Kapiloff Acid Deposition Program; subsequent years will continue under management of the California Air Resources Board and will additionally be supported by resources and expertise of the Western Conifer Research Cooperative. It is anticipated that other state and federal funds will also be used to support CFRP projects.

1.1 Western Conifers Research Cooperative and the National Forest Response Program

The national Forest Response Program (FRP) is part of the National Acid Precipitation Assessment Program (NAPAP). The FRP is administered and funded jointly by the Environmental Protection Agency (EPA) and the U. S. Forest Service (USFS) and receives financial and technical support from the National Council of the Paper Industry for Air and Stream Improvement (NCASI). The FRP research is conducted by four research Cooperatives operating within regions corresponding to major forest types: spruce-fir, southern commercial, eastern hardwoods, and western conifers. Additional research as well as support for the four regional Cooperatives is provided by the Atmospheric Exposure Cooperative (AEC) and the National Vegetation Survey (NVS).

The Western Conifers Research Cooperative (WCRC) is the research program charged with investigating the effects of acidic deposition and associated pollutants on coniferous forests in the western United States (WA, OR, CA, NV, ID, UT, AZ, NM, MT, WY, CO). The Cooperative is administered by the U. S. Environmental Protection Agency at the Environmental Research Laboratory in Corvallis, OR.

1.2 Assumptions

The assumptions we have made in developing the plan are:

(1) Forest effects research under this plan will begin with the 1987 field season.

(2) The research will continue for a minimum of 5 years.

(3) The funding level will be approximately 3 million dollars for the 5 years.

(4) The California Air Resources Board and the Western Conifers Research Cooperative will share the cost of the research.

(5) The phrase "acid deposition" as used in the draft plan is defined as sulfur and nitrogen compounds and associated pollutants such as ozone, heavy metals and hydrocarbons.

(6) Forests are defined as all California forests and woodland vegetation dominated by trees, but not other woody vegetation such as shrub-dominated chaparral.

1.3 Planning Conference and Peer Review

The California Forest Response Program Draft Plan was subjected to careful technical review by experts in the various fields of forest response to atmospheric deposition. Written peer reviews were solicited preliminary to a planning conference which was held February 22-24, 1987, at Asilomar Conference Center in Pacific Grove, California. Preparations for discussion of the plan were facilitated by the presentation of ten review articles at the outset of the conference. Six workshops were conducted at the conference, each concentrating on a section of the draft plan (Sections 4-9). The conference participants are identified in Appendix V. Their written peer reviews are provided in Appendix IV. The review articles were published with the preconference materials distributed to the conference participants. These articles were also peer reviewed by conference participants, and final versions are in preparation for publication in the conference proceedings. The revised draft plan presented in the following pages was developed by the chair persons in response to the peer reviews and discussions at the conference.

2.0 PROGRAM OBJECTIVES

The goals of the California Forest Response Program (CFRP) are to evaluate the effects of acidic deposition and associated pollutants on California forests and to determine the mechanisms of these effects.

Other than geographic interest, these goals are identical to the goals of the NAPAP Forest Response Program (FRP). Policy and Scientific Questions have been developed within the FRP to provide focus. In the following paragraphs, these policy and scientific questions are adapted for the California Forest Response Program.

Each policy question is broad in scope. To provide a basis for the formulation of scientifically testable hypotheses, each Policy Question has been broken into Scientific Questions. These Scientific Questions form the conceptual organization for the research effort to be described in this plan.

Policy Question 1: Is there a significant problem of forest damage in California which might be caused by acidic deposition, alone or in combination with other pollutants?

Scientific Question 1.1: Are changes in forest condition greater than can be attributed to typical trends and levels of natural variability?

Scientific Question 1.2: What spatial patterns exist in forest condition and how do these patterns relate to spatial patterns of pollutant exposure?

Policy Question 2: What is the causal relationship between acidic deposition, alone or in combination with other air pollutants, and forest damage in California?

Scientific Question 2.1: What is the effect of atmospheric pollutants on forests through the mechanisms of:

(1) Direct toxicity to roots, mycorrhizae, or soil microbial populations by mobilized metals in acidified soil water;

(2) Nitrogen toxicity to mycorrhizae;

(3) Increased leaching of soil nutrients resulting in reduced nutrient availability?

Scientific Question 2.2: What is the effect of atmospheric pollutants on forests through the mechanism of increased leaching of foliar nutrients?

Scientific Question 2.3: What is the effect of atmospheric pollutants on forests through the mechanism of altered photosynthesis, respiration, and carbon allocation patterns with possible induction of water and/or nutrient stress?

Scientific Question 2.4: What is the effect of nitrogen compounds, possibly in combination with oxidants, on forests through the mechanism of delayed cold hardening or early break in dormancy resulting in increased winter damage?

Scientific Question 2.5: What is the effect of atmospheric pollutants on forests through the mechanism of disruption of reproduction and regeneration?

Scientific Question 2.6: What is the effect of atmospheric pollutants on forests through the mechanism of altered susceptibility to pests and pathogens?

Policy Question 3: What is the dose-response relationship between acidic deposition, alone or in combination with other pollutants, and forest damage in California?

Scientific Question 3.1: What is the dynamic response of forests to specified levels of atmospheric pollutants?

The proposed approach for addressing these Policy Questions is outlined in the next section (3.0). The key elements of the proposed research are introduced and justified. The details of the CFRP Research Plan are then provided in Sections 4-9.

3.0 OVERVIEW AND JUSTIFICATION

3.1 California Forest Response Program Overview

Policy Question 1: The approach to answering the Scientific Questions outlined under the first Policy Question will be to characterize the current and historical condition of California forests, to characterize the exposure of California forests to air pollution and to determine what part of the variability in forest condition may be attributed to air pollution exposure rather than natural variability or other stresses.

The CFRP will use existing data as the basis for an initial statewide assessment of forest condition. The CFRP will summarize and evaluate existing data sets which characterize current and historical conditions in the forests of California. As these data sets are evaluated it may become necessary to propose the initiation of new surveys.

Forest condition will be characterized in greater detail for a single important forest type, ponderosa pine. The CFRP will characterize forest condition in even more detail locally for this forest type growing on the west slope of the Sierra. The approach to characterizing forest condition statewide and regionally is described in Section 4.0.

The CFRP will characterize forest condition in great detail for ponderosa pine forests at intensive research site(s) to be established on the West Slope of the Sierra. These intensive research sites will serve a number of functions. Section 6.0 discusses in detail the functions of these intensive research sites.

The CFRP will summarize and evaluate existing monitoring data to determine exposure levels in forested regions of the state. We will focus any new monitoring efforts on the west slope of the Sierra and on the individual ponderosa pine intensive research site(s). These efforts are presented in Section 5.0: Atmospheric Monitoring.

The synthesis and integration activities of the CFRP will determine if there are any correlations between air pollution exposure and forest condition. This determination will be made on a statewide basis by the end of the first year of the CFRP to enable these results to guide the subsequent development of research efforts. These efforts are described in Section 9: Synthesis and Integration.

Policy Question 2 and its associated scientific questions will be approached through a process of hypothesis testing to determine the mechanisms of air pollution effects and forest response. The Scientific Questions will provide the initial hypotheses for testing. Each test will provide information necessary for the prioritization, development and testing of subsequent hypotheses.

Each of the Scientific Questions associated with Policy Question 2 may be phrased as one to several hypotheses. The CFRP will examine these hypotheses only for the ponderosa pine forest type, and more specifically for the single species, ponderosa pine. There are several efforts currently under way to determine the mechanisms of damage to ponderosa pine caused by air pollution. The CFRP will cooperate fully with those efforts, and will support and emphasize cooperative efforts to model the response of whole trees and forest stands to acidic deposition and other air pollutants. Experimental work conducted under the CFRP to determine mechanisms of effects will be conducted at intensive ponderosa pine research site(s) located on the west slope of the Sierra.

The CFRP will take a two-step approach to establishing research sites. A single primary research site will immediately be established in an area of the west-slope ponderosa pine region with low exposure to atmospheric pollution. This site will serve as the focus for initial development of tree and stand level models. Experimentation under clean conditions will provide the necessary information to develop the basic stand and tree level models for ponderosa pine. As model development proceeds and further information is required, secondary research sites will be established in areas of increased air pollution.

The CFRP Permanent Forest Research Sites are described fully in Section 6.0. Hypothesis development and testing are discussed in Section 6.0 and again emphasized in Section 7.0.

Policy Question 3: Our approach to determining the dose-response relationship between air pollution and forest damage is to concentrate our efforts on a single forest type, ponderosa pine, and to develop both conceptual and quantitative models linking air pollution doses with ponderosa pine response.

The correlative and experimental studies conducted at the intensive research sites will be integrated by means of the development of a process driven model of mature tree response. In other words, the research at the intensive sites will be guided by the concern for producing the data necessary for a mature tree response model.

The culmination of this approach will be to provide the necessary information to assist in the development of the mature tree model and the stand model described in the section on Synthesis (Section 9.3).

3.2 Justification and Rationale

The goal of the California Forest Response Program is to evaluate the effects of air pollution on California forests and to determine the mechanisms of these effects.

Achieving this goal is difficult because of the extent of forests in California and the correspondingly large diversity of forest types, climate, soils, topography and pollutant regimes. Air pollution effects on forests are often small in comparison with natural variability of forest processes and the influence of other stresses. Determining whether pollution effects exist requires in most cases an intensive and focused research effort. Conducting this level of effort for all California forests is not possible.

In response to this complexity, the CFRP is designed to address three levels of investigation (Table 1) ranging from broad surveys of statewide forest condition to intensive research at local sites. The proposed program evaluates the condition of all California forests, but focuses most of the resources on a single forest type with a relatively high exposure to atmospheric deposition. This ensures that a research program can be designed with enough statistical power to detect any significant pollution effects that may be occurring in this forest type.

The intensity of research will increase as the area under consideration decreases. Thus, the statewide survey of the condition of all California forests will utilize mainly existing data summaries while work at the intensive sites will generate and analyze new data. At the broadest level of investigation, the statewide assessment of existing information on forest condition can be completed in 1 year, providing information for the design of subsequent research.

Table 1. Level of Effort Related to Geographic Extent of Tasks.

LEVEL OF EFFORT	GEOGRAPHIC RANGE FOR CHARACTERIZATION OF POLLUTANT EXPOSURE AND FOREST CONDITION: LEVELS OF INVESTIGATION	PRIMARY TYPE OF ANALYSIS USED
Least Intensive	1. Statewide, all forests	Existing summaries compiled no new analyses of data performed
	2. West slope Sierra, ponderosa pine, along west slope gradient	Existing summaries compiled, additional analyses of existing data, new analyses of existing data, collection and analyses of new data
Most Intensive	3. Intensive sites	Collection and analysis of data

Biological levels of organization serve to integrate research conducted at different spatial levels. Figure 1 depicts this integration. While each biological level represents the focus of a particular research project, the program is designed so that outputs from one level serve as inputs to other levels. The mechanisms by which the levels will be connected are shown in Figure 1 as the text attached to the arrow connecting one level to the next.

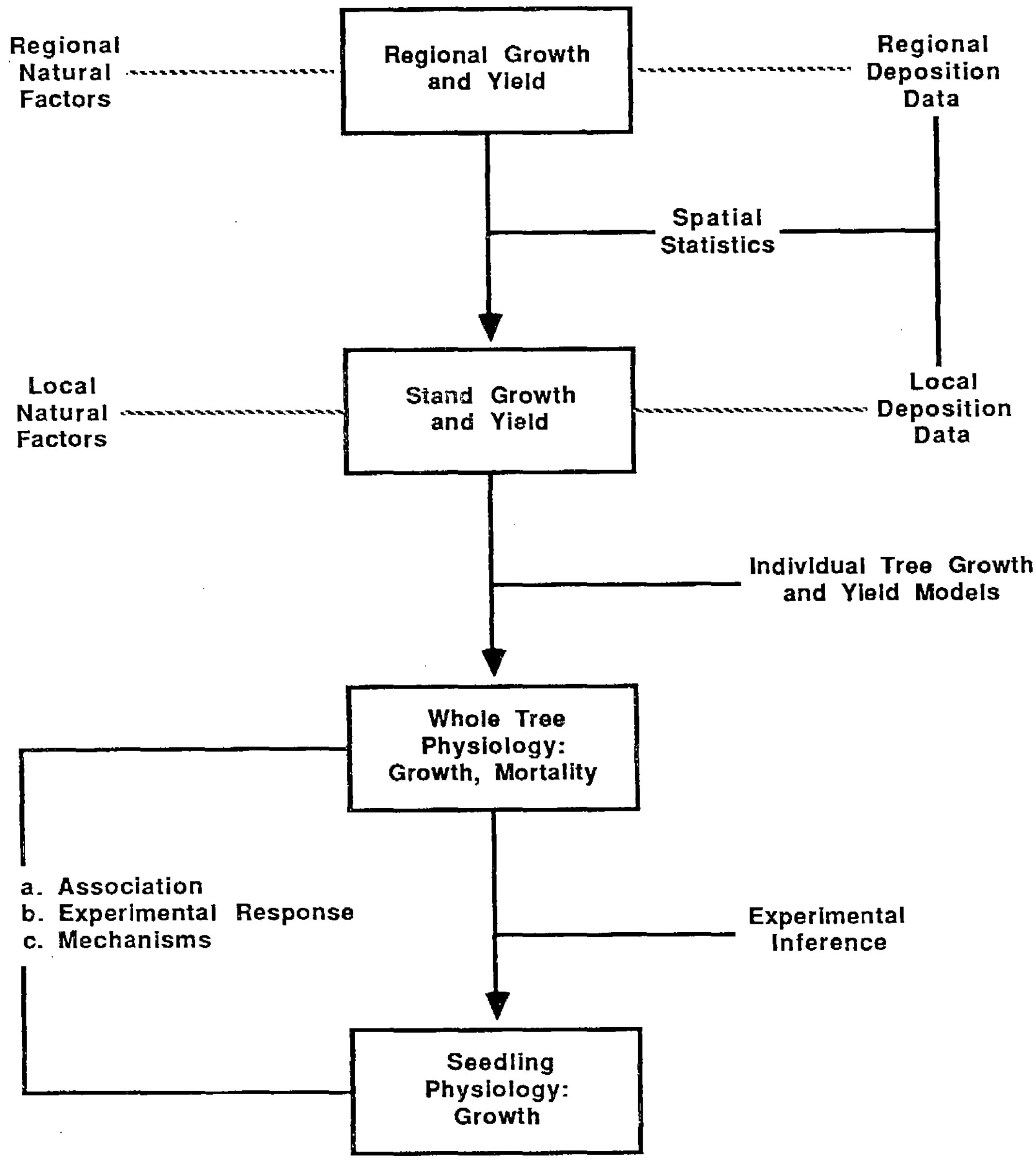


Figure 1. Biological Levels of Organization

The organization of the CFRP by levels of effort integrated by biological levels of organization has distinct advantages. As the less intense levels can be completed early, intermediate assessments can be made in advance of the culmination of the entire program. Results from one level can be used to generate hypotheses for testing at other levels. Finally, this approach explicitly recognizes the need to conduct physiological studies simultaneously with ecological and regional studies.

3.2.1 Selection of Forest Type

The California Forest Response Program is designed to focus the most intensive research efforts on a single forest type and to evaluate the differential response of this forest type to a range of pollution exposures. The forest type was selected based on the following criteria:

(1) The importance in California as determined by extent and economic and ecological value;

(2) The exposure to a range of pollutant levels, including levels approximating the high and low exposures for forested areas in the state;

(3) The characterization in terms of growth and stand dynamics, and the physiology and genetics of the dominant tree species; and

(4) The current focus of other studies, allowing opportunities for collaboration.

The ponderosa pine component of the mixed-conifer forest on the west slope of the Sierra meets these criteria. It extends from the San Bernardino Mountains to northern California and is a major economic, recreational and environmental resource. A regional pollution gradient extends from south to north along its range. There is a large amount of background information on growth and physiology of ponderosa pine and some information on its response to ozone and SO_2. Ponderosa pine is the focus of current or proposed research by EPRI, the NAPAP Forest Response Program, the U. S. Forest Service and a number of universities.

Although a number of species are important components of the mixed conifer forest type, the CFRP Plan includes field studies at sites which include stands of >80% basal area dominance by ponderosa pine and stabilized height growth. Research on the mechanisms of pollutant effects will be conducted only on ponderosa pine allowing for greater replication within the existing budget constraints. Increased replication adds to the statistical ability of the experimental design to detect pollution effects. Since pollution effects are likely to be small relative to the natural variability or "noise" in most forests (particularly on a regional basis), only an intensive research design will be able to detect any existing effects.

3.2.2 Integration

Focusing on the relationships between biological levels of organization facilitates integration within the CFRP and other related programs. Because the CFRP will be conducting only a portion of the research in California related to the effects of atmospheric deposition on forests, it is critical that the CFRP maximize collaboration with ongoing research programs and avoid unnecessary redundancy. The structure of the CFRP is comprehensive so that most related studies can be located within this framework. Critical gaps in the overall research effort can be easily identified and given priority by the CFRP. This theoretical framework could allow the CFRP to exercise an integrative role in the forest effects research community in California.

3.3 Summary of Personnel Organization

Figure 2 summarizes the organization of personnel involved with the California Forest Response Program. In the figure, the lines connecting the personnel indicate relationships of authority and responsibility.

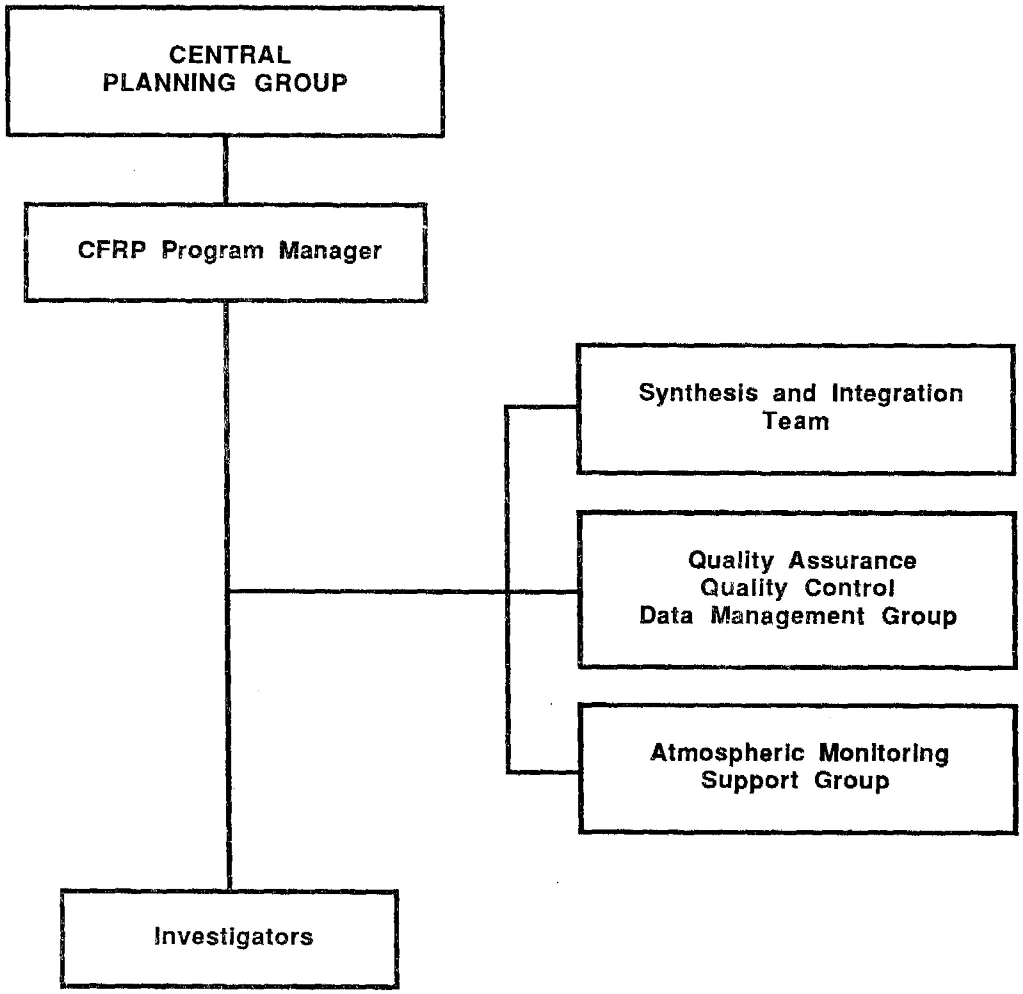


Figure 2. CFRP Personnel Structure

The Central Planning Group will include members from the CARB and from WCRC, as well as other individuals mutually agreed upon. These other individuals will represent organizations with research efforts in forest response to air pollution. The responsibilities of this group will be to review the program outputs and modify the program plan to continue to meet the plan objectives.

The CFRP will have a Program Manager who will be directly responsible to the CARB. The Program Manager will execute the plan, supervise the Synthesis and Integration Team and the Atmospheric Monitoring Support Group and will work with the Data Management Group. The Program Manager will administer all research projects connected with the CFRP. Although the Program Manager is a staff member of the CARB, he will work closely with the Central Planning Group and in particular the Program Manager of the WCRC to promote cooperation, coordination and efficiency.

The Synthesis and Integration Team will include CARB staff members and consultants. The Synthesis and Integration Team is responsible for producing program-wide outputs and for ensuring that the CFRP as a whole functions effectively and efficiently at the technical level.

The Data Management Group includes the QA/QC Specialist from the WCRC, a Data Base Resource Manager (CARB staff), a representative of the investigators, and possibly, the QA Officer of the national FRP (if the CFRP Manager desires him as an observer/advisor). Their function will be quality assurance and quality control and data management.

The Atmospheric Monitoring Support Group will be constituted of ARB air monitoring staff, and selected technical experts, including the liaison with the Atmospheric Exposure Cooperative (AEC of the FRP). Their responsibilities will include 1) enhancing the existing air quality data base for forested regions of California, 2) assisting in permanent forest research site selection, and 3) planning and coordinating all CFRP atmospheric monitoring activities.

The Principal Investigators will be researchers conducting specific research projects. They will be selected through open competition in response to requests for proposals issued by the CARB or the WCRC. They will be supervised by the Program Manager.

4.0 CFRP RESEARCH TO CHARACTERIZE FOREST CONDITION

4.1 Objectives and Approach

To characterize forest condition, the CFRP will:

(1) Characterize the condition of all California forests using existing data bases (Statewide survey);

(2) Begin to characterize the conditions of ponderosa pine forests on the west slope of the Sierra by conducting new analyses of existing data bases, and by designing and carrying out new surveys of forest condition if necessary (Regional survey); and

(3) Characterize the condition of the ponderosa pine forests at intensive site(s) in great detail with new intensive surveys and experimentation (Permanent Forest Research Sites).

The statewide survey will be used to determine if there is a correlation between forest condition and exposure. The regional survey will help select and determine the representativeness of the intensive study site(s), and will enable the extrapolation of results from the intensive site(s) to the wider region of the west slope ponderosa pine forest.

The planned statewide survey of forest condition in California will make use of an epidemiological approach. This approach makes use of broad surveys of forest condition in California, either already conducted or planned, to characterize spatial patterns throughout California, and more specifically, on the western slope of the Sierra Nevada.

These statewide surveys are the first step in characterizing spatial or temporal patterns in forest condition that may be correlated with pollutant concentrations. The results of these studies may suggest hypotheses that can be tested using physiological and ecological approaches. The more detailed manipulative or intensive site studies may in turn provide information that can be used to choose variables for use in future large-scale surveys in California. These interactions among research areas will be expedited by the use of models as part of the integration and synthesis projects described in Section 9.0 of this plan.

4.2 Inventory and Evaluation of Existing Statewide Forest Data Bases

To develop a data base on forest condition statewide, all existing data bases on forest condition in California will be inventoried. Sources of this forest information will include:

California Department of Forestry (State Forest Inventories)

Forest Inventory Analyses (FIA) (USFS)

Timber Management Inventory (TMI) (USFS)

Data bases of forest plot measurements (NPS, USFS)

Pest-pathogen surveys (USFS)

Industry-sponsored inventories (NCASI and commercial timber companies)

Visible symptom data bases (NPS, USFS)

Dendrochronology data bases

Remote sensing data bases

A project currently under way by Energy Resources Consultants (ERC) under contract to the ARB is making use of the California Department of Forestry's GIS data base to inventory the distribution and sensitivity of tree species in California to various air pollutants. Tree ring inventories for the western United States, including California, are being compiled by the Tree Ring Lab at University of Arizona under contract to WEST Associates (Western Energy Supply and Transmission). These inventories should be available by March 1988.

This data base inventory task will be carried out by an investigator who will be selected as soon as possible. The initial task will include the identification of existing data bases and the determination of the content, structure, availability and quality of those data bases. No actual data will be collected or analyzed as part of this inventory effort.

The investigator will then evaluate these data bases in terms of applicability and quality. Many of the existing data bases such as FIA and various dendrochronological data bases were not designed to evaluate air pollution effects. Their applicability for meeting the objectives of the CFRP will be evaluated. Data quality also varies greatly between data sets. Procedures for quality assuring existing data sets are described in the CFRP QA Plan (Section 8). The investigator will recommend minimum acceptable standards for data quality.

Once the data base inventory is complete, CFRP personnel will conduct a week-long workshop to evaluate the available data. Participants will include those who have assembled or worked with the data bases under consideration. The ARB/ERC forest sensitivity data base and the WEST Associates' dendrochronology data base will be presented at this meeting.

The outputs of this workshop will include: 1.) an evaluation of the usefulness of existing survey data, 2.) recommendations for parameters that should be remeasured to look for trends that may be attributed to air pollution, including acidic deposition, and 3.) recommendations for other survey methods that might be developed and used to assess forest condition statewide. Workshop participants will help to formulate an RFP to develop a statewide forest data base using existing inventories and supplemental field observations. The compilation of regional-scale survey information on the ponderosa pine forest type will be emphasized in this task.

4.3 Optional Tasks to Characterize Forest Condition in California

Although not within the current scope of the CFRP, a number of additional projects have been recommended to help characterize forest condition in California to detect acidic deposition/air pollutant effects.

(1) Dendrochronology Gradient Study

This effort would relate the statewide tree-ring data with results obtained from a full-stand study of tree rings at each of the intensive sites along the pollution gradient within the ponderosa pine forest type.

(2) Remote-Sensing Surveys

Spectral data obtained from satellite imagery (Thematic Mapper [TM]) could be used to survey forests statewide at regular intervals. Spectral reflectance characteristics would have to be linked with forest condition by use of ground-based measurements. Existing TM scenes (available since 1982) could be calibrated to help locate intensive sites for forest effects research.

4.4 Implementation of Statewide Forest Survey Work

A statewide forest survey Request for Proposals will be issued immediately to select a contractor to: (1) inventory statewide forest data bases; (2) begin to evaluate these data bases; (3) organize the data base evaluation workshop and, (4) recommend future work to organize and augment survey data on statewide forest condition in California. A second RFP will be issued following the evaluation workshop to select a contractor to actually assemble the data base and proceed with additional field survey work. This contractor will collaborate with the intensive site group to help focus survey work within ponderosa pine forest areas of the state. The rationale for this emphasis is to verify the regional representativeness of the intensive sites.

Regional survey work will not be completed under the present budget and time constraints of the 5-year CFRP. Optional projects listed in this plan may be funded by other research organizations or under an expanded CFRP.

5.0 ATMOSPHERIC MONITORING TO CHARACTERIZE FOREST EXPOSURE

5.1 Objectives and Approach

To establish correlations between deposition and forest condition, it is necessary to obtain quantitative estimates of air pollutant concentrations and meteorological variables. Both ambient concentrations and the movement of air to plant and soil surfaces engender the flux of atmospheric constituents to those surfaces. The ambient concentrations can take the form of suspended particles, gases, raindrops, or fogs. The atmospheric constituents relevant to forest response are ozone, sulfur-containing compounds, nitrogen-containing compounds, and reactive species which hasten the conversion of non-acidic precursors to acidic atmospheric constituents.

The objectives of the air quality measurement component of the California Forest Response Program are:

(1) To characterize exposure of forests at the study sites to air pollutants and deposition;

(2) To establish the differences in air and deposition exposures among the study sites;

(3) To define air and deposition quality exposure regimes suitable for the characterization of dose-response relationships; and

(4) To establish trends in atmospheric exposure in California's forested regions.

This section outlines a conceptual plan for the attainment of these objectives. It first identifies existing or planned air quality and deposition data bases in forested areas of California which can be examined in the preparation of an operational experimental plan. These date bases can be examined to address monitoring objectives 1 and 2 in a preliminary manner and can serve as a basis for site selection. Next, the observables, averaging periods, and measurement methods are presented. Several of these measurement methods are subject to substantial interferences, and their current developmental status is evaluated to ascertain their ability to meet the program objectives. Sampler siting criteria are then defined. These criteria may not be identical to those required for measuring tree response. Finally, the uses of air quality data and methods of implementing this monitoring plan are presented.

5.2 Regional Air Quality/Deposition Data Base Compilation

No existing air and deposition quality monitoring networks are capable of meeting the measurement objectives of the California Forest Response Program. The major deficiencies of these existing networks are: 1) they do not contain the full range of observables which are suspected of being important to forest exposure; 2) few sites are located in regionally representative forested areas; 3) measurement methods are not equivalent between networks; 4) many measurements are episodic rather than continuous; and 5) data are widely dispersed and are not accessible from a common source.

The fifth deficiency can be remedied, to a certain extent, by compiling relevant information from the existing data bases. This information can then be examined to: 1) identify existing sampling sites which may be enhanced for forest response measurements; 2) increase the probability of selecting study sites with large differences in pollutant exposures; and 3) evaluate the precision, accuracy, and validity of measurement technology for meeting CFRP objectives.

The following monitoring networks have produced data from forested areas of California which might be subjected to this examination:

(1) The National Park Service has conducted ozone and meteorological monitoring in Yosemite and Sequoia National Parks during summer months from 1985 through 1987 for the purpose of determining forest exposure. These data are available as hourly averages. Additional sites are being installed in 1987.

(2) The California Air Resources Boards' California Acid Deposition Program has taken week-long wet deposition samples at Quincy, Norden, Lake Tahoe, Yosemite, Mammoth, Ash Mountain, Giant Forest, Emerald Lake, and Lake Isabella. Some of these data date from 1982. Hydrogen, sodium, potassium, calcium, magnesium, ammonium, chloride, nitrate, and sulfate ions are routinely measured on these samples. A dry deposition component of this network is currently being installed with two stations in the Sierra Nevada forests at Yosemite and Sequoia National Parks. The dry deposition sites will measure ozone, meteorology, sulfur dioxide, nitrogen dioxide, nitric acid, and ammonia gases during daytime and nighttime periods. PM10 and PM2.5 size fractions will be quantified for soluble sulfate, nitrate, chloride, ammonium, sodium, magnesium, potassium, calcium, and hydrogen ions. Periodic fogwater sampling is also being contemplated at these sites which are scheduled to begin monitoring by September, 1987.

(3) Southern California Edison is conducting its Eastern Brook Lakes Watershed study on the eastern slopes of the Sierra Nevada Mountains since 1984. Air quality, rainfall, and meteorological measurements have been obtained.

(4) UC Davis has conducted several short-term measurements of rainfall in the Lake Tahoe region in 1972, 1977, and 1978.

(5) The National Park Service, in cooperation with UC Davis, is making fine particle chemical measurements in support of visibility studies at Yosemite, Lassen, and Sequoia National Parks.

(6) The U.S. Geological Survey has conducted its wintertime snow sampling network at numerous forested sites in the Sierra Nevada Mountains since 1983. The snow cores have been chemically characterized for a number of species.

(7) The National Acid Deposition Program's National Trends Network also provides wet deposition data from forested areas of California.

Data compilation and extrapolation for some air quality parameters (O_3, SO_x) in forested regions of California are now being performed by Energy Resource Consultants (ERC) and Science Applications, Inc. (SAI), under contract to the ARB. This data base will be expanded under the CFRP to include other variables of interest for which data are available. This air quality/deposition data base can be enhanced with measurements from the monitoring programs identified above.

Air quality modeling might also be of value in the site evaluation and selection process. For example, SAI is applying an ozone transport model to the Sierra Nevada Mountains (funded by the National Park Service). Transport modeling in the Southern Sierra has also been included as part of the ARB's Integrated Watershed Study. The results of these modeling efforts are complementary to the data bases in identifying potential monitoring sites. Neither these models, nor the meteorological and air quality data on which they operate, are accurate enough to replace actual exposure measurements.

5.3 Air Quality Measurements

Table 2 summarizes the observables which need to be measured to meet the monitoring objectives of the CFRP. Averaging times and sampling frequencies are a compromise between that which is required to gain enough sample for subsequent analysis and those which have been hypothesized to be important for tree exposure. "Event" averaging times are variable and depend on the length of the fog or precipitation period. They are typically on the order of a few hours.

A priority has been assigned to each observable based on the developmental status of its measurement methods and its perceived importance to forest effects. Ozone has been given top priority since its effects on plant life are well documented and measurement methods are well established. Meteorological variables are second in priority since they are needed to estimate deposition velocities and measurement capabilities are established. Rainfall and other gases have been given a third priority because little is known about their direct effects on forests and measurement methods are semi-established.

Table 2. Observables, Priorities, Averaging Times, and Measurement Methods for Exposures To Acidic Species

OBSERVABLE	PRIOR-ITY	AVERAGING TIME	SAMPLING FREQUENCY	MEASUREMENT METHODS
GASES				
Ozone	1	1 - hr	24/day	Ultraviolet Absorption
Sulfur Dioxide	3	1 - week	weekly	Impregnated filter
Nitrogen Dioxide	3	1 - week	weekly	Impregnated filter
Ammonia	3	1 - week	weekly	Impregnated filter
Nitric Acid	3	1 - week	weekly	Denuder difference
METEOROLOGY				
Wind Speed	2	1 - hr	24/day	Cup anemometer
Wind Direction	2	1 - hr	24/day	Wind vane
Sigma Theta	2	1 - hr	24/day	Wind vane
Temperature	2	1 - hr	24/day	Themister
Relative Hum.	2	1 - hr	24/day	Lithium chloride cell
Precipitation	2	1 - hr	24/day	Tipping Bucket
Time of Wetness	2	1 - hr	24/day	Conducting Cell
Radiation	2	1 - hr	24/day	Ultraviolet Adsorption
RAINFALL				
Ions (hydrogen, sulfate, nitrate, chloride, ammonium, sodium, magnesium, potassium, calcium)	3	event	per event	Wet bucket collection outside the forest canopy followed by specific ion electrode, ion chromatographic and atomic absorption analysis.
Organic Acids	5	event	per event	Wet bucket collection followed by ion chromatographic analysis
Hydrogen Per-oxide	5	event	per event	Wet bucket collection followed by peroxidase analysis.
THROUGHFALL				
Ions (See rainfall)	4	event	per event	Same as rainfall.
Organic Acids	5	event	per event	Same as rainfall.
Hydrogen Per-oxide	5	event	per event	Same as rainfall.

Table 2. (continued)

OBSERVABLE	PRIOR-ITY	AVERAGING TIME	SAMPLING FREQUENCY	MEASUREMENT METHODS
FOGWATER				
Liquid Water	4	event	per event	Droplet impaction collectors.
Ions (see rainfall)	4	event	per event	Same as rainfall.
Organic Acids	5	event	per event	Same as rainfall.
Hydrogen Peroxide	5	event	per event	Same as rainfall.
PARTICLES	4	1 - week	Weekly	Collection on substrates through sizes selective inlets with chemical analysis for species listed under rainfall.
SURROGATE SURFACES				
Leaf washing	4	1 - month	monthly	Washing of Ligustrum leaves followed by chemical analysis.
Artificial glass Surfaces	4	1 - month	monthly	Teflon, plastic, plates, or other materials followed by washing and chemical analysis.

Particulate, fogwater, and throughfall measurements have been assigned a fourth priority since substantial evaluation of the measurement methods is required to determine their performance in routine monitoring. Organic acid and hydrogen peroxide measurements have been assigned a fifth priority because they are costly and of unestablished validity at this time. These priority levels provide a convenient method of estimating costs for various levels of monitoring complexity.

The gas, particle, and fog measurements cited in Table 2 quantify, for the most part, ambient concentrations rather than deposition to surfaces. While an operational monitoring plan will provide for quality control and quality assurance activities which will give estimates of precision and accuracy for these measurements, the validity of the measurements as applied to deposition have never been established. For example, the ion concentrations in individual throughfall samples can be precisely reproduced by replicate ion chromatographic analysis, yet throughfall measured from different samples under the same forest canopy have been shown to differ by up to an order of magnitude.

Several tests need to be performed as part of the CFRP, or as part of other supporting studies, to evaluate these measurement methods. These tests would include:

(1) Spatial Variability o: Throughfall. A large number of containers should be located in a ponderosa pine canopy and the minimum number and spacing of these containers as a function of coefficient of variation should be determined from the measurements.

(2) Comparability of weekly, event, and sub-event sampling. Samples would be taken at times during an event and for periods of less than a week to determine whether or not extremely high concentrations are present for very short periods. These acute exposures, if they are found, may be more damaging than long-term exposures.

(3) Sample Stability. Several substances have been found to change both during sampling and in the intervening period between sampling and analysis. The magnitude of these changes needs to be assessed via controlled laboratory and field experiments.

(4) Deposition velocity measurements. Little is known about the deposition velocities for acidic atmospheric constituents in forested areas. Micrometeorological measurements of these velocities at representative sites need to be measured and related to the commonly measured meteorological observables for widespread application to the measured ambient concentrations.

These tests can be conducted as special intensive studies along with the routine measurements specified in Table 2. Additional intensive studies may be required during the CFRP to address specific questions which arise from the interpretation of the data obtained from both atmospheric and forest monitoring.

5.4 Sampling Sites

The aims of forest response testing and ambient air quality monitoring may be incompatible with respect to sampler siting. Ideally, the atmospheric conditions in the vicinity of the trees being studied would be measured. It is well known, however, that large stands of trees interfere with the representativeness of air quality and meteorological measurements because: 1) trees present absorption and impaction surfaces which remove particles and gases from air; 2) trees emit pollen and gases which are collected on atmospheric sampling substrates; and 3) trees interfere with the normal transport and dispersion of atmospheric constituents.

Atmospheric sampling sites will be selected to measure observables which are present at regionally representative levels. This will, in most cases, preclude sampler siting directly in the stand of trees being studied. Access, security, and power requirements also mitigate against a one-to-one correspondence in location of the tree-stand and atmospheric sampling station, though the distances between them should be as small as possible.

Sampling sites must be selected to meet both representativeness and operational criteria. The representativeness criteria include:

(1) A distance of at least 20 m from trees.

(2) A distance between the samplers and nearby obstacles which is at least twice the height of the obstacle above the sampler inlet and a minimum of 2 m.

(3) Unrestricted airflow for a minimum arc of 270° around the sampler.

(4) Point sources of gaseous and particulate emissions (i.e. vents or ducts) are absent on the support structure.

(5) A distance from major highways and point sources of 1 km or more.

(6) A sampler inlet elevation of at least 1 m above the support surface and from 2 to 15 m above ground level.

The operational criteria include:

(1) A minimum of 50 amp electric service with separate breakers for each sampling unit.

(2) Security from other than designated personnel.

(3) Permission for use for a period of 5 years or longer.

These regional-scale ambient sampling criteria are ideals which may be impossible to attain in actual practice. It is probable that these requirements are more restrictive than those applied to the selection of stands of trees to be studied, and a balance of the forest response and air quality siting requirements must be made in the site selection process.

5.5 Uses of Atmospheric Monitoring Data

The observables specified in Table 2 will provide the information necessary to attain objectives 1 through 4 as stated in section 5.1.

The exposures at CFRP study sites will be determined by calculating dosages (the product of concentration and time) for various averaging times. Joint frequency distributions of exposures to several species can be determined from the collected data to explore the potential for synergistic air quality effects on ponderosa pine trees. This analysis will attain Objective 1.

These exposures can be compared among the different sampling sites to separate "clean" from "dirty" areas, as defined by the degree of exposure. Tree response variables can be grouped according to these categories and significant differences can be sought. This will attain Objective 2.

Multi-year air and deposition quality exposure regimes can be defined, and the frequency of occurrence of these regimes within a given year can be determined. These regimes are likely to be complex combinations of gaseous, wet, particulate, and meteorological variables, and they are probably best defined on an empirical basis using multivariate methods such as principal components analysis or discriminant analysis. Observations of forest response can also be categorized by the frequency of occurrence of these regimes, and different responses for different regimes can be sought, thereby attaining Objective 3.

Finally, if the measurements in Table 2 are taken for a multi-year period, average exposures at a single site can be compared from year to year to determine whether or not exposures are increasing or decreasing. Many pollution control measures are being implemented in the urban areas of southern and central California for the purpose of improving urban air quality and attaining national and state standards. These emissions reductions may yield the additional benefit of lower exposures in California's forested areas. Time series analysis can be applied to the collected data with appropriate weighting by meteorological regimes in order to attain Objective 4.

5.6 Implementation

The measurement program outlined in Section 5.3 is feasible, but potentially costly. It should only be undertaken after a careful operational program plan, such as that prepared for ARB's South Coast Air Quality Study (SCAQS), has been prepared. This plan would specify measurement method tests, standard operating procedures, quality control, quality assurance, data management, data validation, and data reporting in much greater detail than is possible in this conceptual plan. To the greatest extent possible, this operational plan should take advantage of other atmospheric measurement programs which might enhance the CFRP efforts. The National Park Service ozone monitoring and the ARB wet and dry deposition monitoring programs identified in Section 5.2 are the two most promising candidates for overlap with the CFRP.

In addition to these ongoing programs, special studies are currently being conducted at the Atmospheric Science Research Center of the State University of New York in throughfall and fogwater measurements as part of their Mountaintop Cloud Chemistry Program which might be enhanced to perfect these monitoring techniques for routine applications. The California Institute of Technology is also conducting tests of fogwater measurement systems and sample stability under ARB sponsorship which are directly relevant to the CFRP measurement needs. The Institute of Ecosystem Studies of the New York Botanical Garden is comparing various surrogate surfaces for the measurement of deposition to plants. Enhancements to these tests which would directly address measurement issues relevant to CFRP are a cost-effective method of performing these tests.

Of greatest immediate importance is the selection of a "clean" site for forest response measurements. Though section 5.2 identified numerous data bases which might be examined in the selection of such a site, some verification of its cleanliness will be needed prior to beginning expensive manipulative studies on tree stands. This verification can be performed with simple and inexpensive passive samplers placed over a large geographical area. Such passive samplers are available for SO_2, N_2, ozone, and soluble and insoluble dustfall. Though these samplers yield only long-term averages (on the order of one month), this should be sufficient for determining the absence of major concentrations of air pollutants.

The operational program plan will be prepared by an Atmospheric Monitoring Support Group, constituted of ARB air monitoring staff, and selected technical experts, including the liaison with the Atmospheric Exposure Cooperative. The first activities of the Atmospheric Monitoring Support Group will be to: 1) enhance the existing air quality data base for forested regions of California; 2) select appropriate locations for the study sites, in cooperation with the site planning groups; 3) finalize the observables and measurement methods, after a thorough evaluation of current technology; 4) prepare requests for proposals to install and operate the atmospheric monitoring network; and 5) transfer the technology of network operations to ARB staff.

6.0 ESTABLISHMENT AND OPERATION OF PERMANENT FOREST RESEARCH SITES

6.1 Functions of Sites

The primary outputs and the major assessment tools of the CFRP will be mechanism-driven whole tree and stand-level models for ponderosa pine (section 9.0). Development of these models requires specific information on the physiology and response to stress of mature ponderosa pine growing in natural stands. Acquiring this information will involve both manipulations of ponderosa pine stands and repeated measurements through time of physiological and structural components of these systems. Therefore, the establishment of permanent forest research sites is an essential step in the successful implementation of the CFRP Research Plan.

Within the research framework of the CFRP (Fig. 1), the intensive research sites serve the following functions:

(1) Provide measurements of forest structure and processes necessary for development of tree and stand models.

(2) Provide a record of changes through time of the condition of a particular forest under known pollutant exposure (long-term monitoring).

(3) For (1) and (2), provide results that can be used in support of regional assessments of forest condition and trends.

(4) Provide a location for experimental manipulations of seedlings and trees where environmental parameters are well characterized and concurrent stand-level research facilitates the extrapolation of experimental results to natural systems.

(5) Serve as foundation sites for attracting collaborative research efforts with programs outside of the CFRP.

6.2 Approach

The CFRP will take a two step approach to establishing research sites. A single primary research site will immediately be established in an area of the west-slope ponderosa pine region with low exposure to atmospheric pollution. This site will serve as the focus for initial development of the tree and stand level models. As model development proceeds and further information is required, secondary research sites will be established in areas of increased air pollution.

6.2.1 Rationale for Approach

Initial model development will require information on basic physiological and ecological processes unaltered by air pollution induced stress (Section 9.0). Responses of these processes to air pollution will then be investigated through the use of controlled exposures and other manipulations of saplings and trees (Section 7.0). Both of these efforts require a site where air pollution has not yet influenced ecosystem processes and where low pollution levels provide a baseline regime for comparison with experimental additions of pollutants.

When the basic models are sufficiently developed, secondary sites with higher ambient pollution levels will serve to:

(1) Provide information for validation of model outputs, and

(2) Generate new hypotheses of the response of ponderosa pine forests to air pollution through comparison of the differential responses of forest sites to different pollutant exposures (gradient study).

The primary research site would serve as the "clean" site in a subsequent gradient study. Selection of the secondary sites would depend in part on the results of the research at the primary site. For example, if an evaluation of the tree and stand models showed ponderosa pine forests to be most sensitive to heavy metals, then secondary sites with different exposures to heavy metals might be chosen. Other results of model sensitivity analysis would lead to secondary site selections based on other pollutants. The key point is that work at an initial low pollution site is required before sites with higher pollution can be efficiently chosen.

6.2.2 Implementation of Approach

Implementation of the CFRP Research Plan at the intensive research sites requires completion of the following tasks:

(1) Identification within the west slope ponderosa pine forest of areas of low pollution.

(2) Selection of a primary research site.

(3) Experimental design.

(4) Instrumentation of site for atmospheric monitoring.

(5) Site characterization.

(6) Characterization of pollution regimes.

(7) Measurement of physiological and ecosystem variables in support of model development.

(8) Decision on establishment of secondary sites based on results of modeling efforts.

Although the research tasks are listed sequentially, tasks 1-3 will overlap to some degree as will tasks 4-7. The procedures for identifying regions of low air pollution, instrumenting the primary site, and monitoring air quality at the site are described in Section 5.0. Site selection criteria are given in Section 6.3 and experimental design will be discussed in 6.5. Site characterization and research implementation will be covered in Sections 6.4 and 6.7, respectively.

6.3 Site Selection Criteria

To perform its designated functions, the primary site must be located by the following criteria:

(1) Site will be located on the west slope of the Sierra Nevada in California.

(2) Pollutant levels at the site must be low.

(3) Site should contain stands of different ages with some stands that meet the criteria of >80% basal area dominance by ponderosa pine and stabilized height growth.

(4) Site characteristics should be representative of a broad region of this forest type and not a unique case that would produce models of low generality.

(5) The site must meet technical criteria for site establishment such as access, security, stability, and permissions for necessary site manipulations.

There is no established definition of "low" air pollution exposure. Evaluation of potential sites will have to consider both the range of pollution concentrations and deposition rates occurring for California forests (relative low exposure) and current knowledge of forest sensitivity to pollutants (absolute low exposure). Both types of information are limited, so final criteria will be somewhat subjective. Acquisition of air quality data is described in Section 5.0. Sensitivity data is available in the literature and from current programs including the WCRC.

Availability of different age stands at the primary site will assist in the development of a more general model. By focusing on pure stands of ponderosa pine with stable height growth, development of the basic model will be simplified.

Additional criteria for selection of the primary site include availability of information on site characteristics, site management, and disturbance history. The presence of ongoing research programs at the site which could offer a foundation for CFRP research and possibilities for collaboration is another desirable site characteristic. This includes existing deposition monitoring.

6.4 Site Characterization

Among the first work to be done at the primary research site will be the characterization of physical and biological parameters. The primary purposes of the initial site characterization are to:

(1) Confirm the degree to which the site is regionally representative;

(2) Provide improved estimates of natural variability of parameters of forest condition at the site for use in modifying experimental designs;

(3) Provide information about basic site characteristics for use in evaluating the results of research at the site; and

(4) Provide criteria for selecting similar sites along a pollution gradient if early modeling results support that approach.

Table 3 is taken from the results of a November, 1986 workshop held by the Eastern Hardwoods Cooperative (EHC) of the National Forest Response Program. The EHC is funding several gradient studies in the eastern United States. The variables in Table 3 were selected by the EHC for characterizing each of the intensive research sites along their gradients. These variables will also be used to characterize the CFRP sites.

Table 3. Site variables for use in initial site characterization.

PHYSIOGRAPHY

- Slope
- Aspect
- Elevation
- Latitude/Longitude
- Slope position
- Site quality/site index
- Pertinent micro-relief

BEDROCK

- Type
- Depth to bedrock

VEGETATION

- Forest type/association
- Basal area
  - Stand
  - Species
- Stems/area
- Site index
- Species composition
- Age of canopy dominants
- Age structure by stratum
- Estimate of crown closure (by spherical densitometry)
- Diameter distribution
- 100% stocked stands
- Understory

SOILS

- Profile Descriptions
  - % Large fragments, fines
  - Thickness
  - Texture analysis
  - % Base saturation
  - Total N
  - Available P
  - Extractable cations
  - % Organics
  - Surfur

TREES

- Species
- DBH
- Crown class (D, C, I, S)
- Tree condition
- Dieback and mortality
- Crown density
- Crown ratio

HISTORICAL DATA

- Anything available, qualitative, or quantitative
- Historical vegetation type, Kuchler's potential type
- Bailey's ecoregion
- Disturbance history
- Climatic records, past 10 years

6.5 Measurement of Response Variables

The major functions of the intensive research sites are listed in Sections 6.1 and 6.2. These can be summarized as providing data in support of model development, model validation, and quantifying changes in ecosystem function through space (gradient study) and time (long-term monitoring). Part of designing a research plan for the intensive sites involves deciding which ecosystem variables need to be measured (i.e. what data needs to be collected) to fulfill the site functions.

These variables are divided into two groups:

(1) Variables likely to be needed in the development of any physiologically based model and for evaluating changes in forest condition.

(2) Additional variables determined by the results of the model evaluation and development scheduled to lead off the implementation of the CFRP Plan (Section 9.0).

Variables in group (1) are listed in Table 4. The list was developed from consideration of the mechanisms of pollution effects described by the Scientific Questions. The S.Q.s represent a consensus on which mechanisms are likely to be important in determining the effects of air pollution on forests (Section 2.0). These mechanisms should be considered in model development and in developing spatial or temporal monitoring schemes. The variables in Table 4 are likely to change in response to pollution stress if the associated mechanisms are important. They will be measured at the primary site to provide a baseline for comparison of the primary site with any future secondary sites. Some of the variables such as photosynthetic response curves and tissue water relations will be of direct use in building the physiological models. Further justification for the selection of these variables may be found in Appendix IV, Report of the Intensive Site Working Group.

As the models are developed, sensitivity analyses will demonstrate that some mechanisms are of primary importance including mechanisms not currently considered. The initial model evaluation and conceptual development will be used to define what additional information on the functioning of ponderosa pine trees and stands is required to complete the models. Research at the primary site will be expanded and modified to provide this additional information.

Table 4. Response variables to be measured initially at the primary site. Scientific Questions are listed in Section 2. Many variables could have been selected for S.Q. 2.3. The variables that were chosen are the most useful integrators of the mechanisms under this broad Scientific Question.

SCIENTIFIC QUESTION		PARAMETERS
2.1	(1)	Soil solution chemistry in rooting zone, expecially metals.
	(2)	Soil solution chemistry in root zone, especially NH_4^+ and NO_3^-, and xylem nitrate.
	(3)	Soil solution chemistry below rooting zone, soil nutrient avalibility.
2.2		Throughfall chemistry, foliar nutient content, litter nutrient content.
2.3		Radial growth patterns, growth efficiency (LAI/stemwood ratio/height growth), visible foliar symptoms, photosynthetic response curve, tissue water relations.
2.4		Annual spring surveys for winter damage; assessing appropriate weather data.
2.5		Characterization of stand age classes.
2.6		Current and, if information is avaialbe, past pest/pathogen occurrences at sites.

6.6 Long-term Monitoring

Another of the functions of the intensive sites will be for long-term monitoring of forest condition. Pollution induced trends in forest condition are likely to be subtle and may need to be monitored for many years before they can be distinguished from natural trends. Trends in forest condition at the intensive sites will be followed through the remeasurement of selected variables at yearly or greater intervals. Results from the primary site will help to define normal variability in ponderosa pine processes and condition for comparison with results from the secondary sites. The specific variables for use in long-term monitoring will be selected based on the initial results of the CFRP model development and on the results of a planning effort currently being undertaken by the National Vegetation Survey of the Forest Response Program.

6.7 Implementation of Intensive Site Research

Development of Workplans:

A single Request for Proposals will be issued covering site selection, site characterization and evaluation of response mechanisms at the primary and, if developed, secondary sites. The project will be subject to open competition and proposals will be evaluated on the ability of the investigators to meet the objectives and complete the tasks as outlined in this plan.

In the interest of Quality Assurance, one group of investigators will be selected to conduct the field work at all sites and for the entire length of the study. Proposals will be requested for a 4 year effort, but funding decisions and commitment of funds will be made annually following review of results to that date. The proposals will be peer reviewed. The investigators for the top ranked proposal will then work with CFRP management and QA Staff to develop final workplans and QA plans.

The first four steps in implementing research at the sites will be conducted as part of the preparation of the proposals. These steps are:

(1) Identify existing data on potential sites.

(2) Evaluation of potential sites by the criteria in Section 6.3.

(3) Site selection.

(4) Preliminary experimental design.

Completion of the experimental design will require the results of the initial model evaluations. The Synthesis and Integration Team (Section 9.0) will ensure the integration of the modeling and experimental design efforts. Changes in the intensive site work plan including the decision on development of secondary sites will be made as necessary in response to results of the modeling and field work. These results will also be used to plan controlled exposures and other mechanistic studies as described in Section 7.0.

7.0 HYPOTHESIS TESTING TO DETERMINE MECHANISMS OF EFFECTS

7.1 Objectives

Policy Question 2 states the general objective of hypothesis testing to determine mechanisms of effects in the context of the California Forest Response Program: What is the causal relationship between acidic deposition, alone or in combination with other air pollutants, and forest damage in California? To determine the causal relationships between acidic deposition and other air pollutants and effects on California forests, the CFRP will answer Scientific Questions 2.1 through 2.6.

Each Scientific Question may be investigated by means of manipulative experiments. The results of these experiments will provide the basis for understanding the role of that particular mechanism of damage on California forests by:

(1) Determining if there is a cause-effect relationship between certain air pollutant exposures and measurable effects on physiology and growth of ponderosa pine growing in California.

(2) Quantifying the dose-response relationships between the particular pollutant and ponderosa pine physiology and growth.

(3) Examining the influence of environmental stress on physiology and growth of ponderosa pine in response to certain air pollutants.

(4) Providing the information necessary to utilize as fully as possible the dose-response relationship for ponderosa pine seedlings for the understanding of mature tree physiology.

(5) Generalizing to other ponderosa pine forests.

(6) Enabling the assessment of other California forest types that may be at risk to injury from current air pollution levels.

Policy Question 2 will be answered by means of the development of conceptual and quantitative models of ponderosa pine growth, physiology and stand dynamics incorporating the results of the investigation of the mechanistic hypotheses. Therefore the overriding objective is the presentation of the results of these investigations in a form usable for incorporation in conceptual and quantitative models.

7.2 Approach

The extent of scientific investigation suggested by these 6 scientific questions is vast. It is necessary, therefore, to prioritize these hypotheses based on their relative potential for explaining effects. The CFRP will prioritize the investigation of mechanistic hypotheses based on the results of the early efforts of the program to summarize all available information on the correlation between deposition and forest condition in ponderosa pine forests. These hypotheses of correlation are under investigation currently by diverse groups of researchers under the auspices of the FRP, EPRI, NCASI, SCE (Southern California Edison), and WCRC. Synthesis and integration activities of the CFRP will consider studies both within the CFRP and outside the CFRP to assist in the prioritization of these hypotheses.

In general, the approach of the CFRP to hypothesis prioritization and testing will be to:

(1) Establish correlations between exposure and effects through the research outlined in Sections 4.0, 5.0 and 6.0, and summarization of research conducted outside the CFRP.

(2) Coordinate the prioritization of mechanistic hypotheses for ponderosa pine.

(3) Cooperate with and support research efforts to test these mechanistic hypotheses.

(4) Emphasize and support efforts to incorporate the results of mechanistic experiments in mature tree physiological models and stand models for ponderosa pine.

Within this approach, the investigation of mechanistic hypotheses is a three-step process which integrates the planning, investigative and synthetic stages of the California Forest Response Program: Step 1 - Prioritize hypotheses, Step 2 - Test hypotheses, and Step 3 - Incorporate results of hypothesis testing in models of ponderosa pine growth and physiology for whole mature trees and stands.

This three-step process is circular rather than linear. The incorporation of experimental results from hypothesis testing into the models will lead to the generation of new hypotheses and to the reprioritization of the original hypotheses.

7.3 Integration with System Level Investigation

There are two aspects of the California Forest Response Program that will serve to maintain a high degree of integration. The first is that manipulative experiments will be integrated with system level investigation at the intensive research site(s). All experimental work will be conducted at, or coordinated carefully with the intensive research site(s). The manipulative experiments will benefit from the complete characterization of forest condition and air pollution exposure at the intensive research sites. Characterization of forest condition at the intensive research site(s) will show if and how the site is representative of wider forest regions. The results of the experimentation will therefore be more translatable to whole forest stands and to other parts of the range of ponderosa pine.

The second integrating aspect of the California Forest Response Program is that the manipulative research will be focused by the objective of providing information necessary to produce models of ponderosa pine growth, physiology and stand dynamics. In particular, a model of mature tree growth and physiology will be the unifying output of the California Forest Response Program.

7.3.1 Mature Tree Model - Background

The Southern Commercial Forest Research Cooperative recently held a workshop to discuss and obtain answers to two questions:

(1) What are the "best" approaches which should be taken to quantify the effects of airborne chemicals on mature trees in forest stands?

(2) What is the expected value of the information from studies on the response of seedlings to airborne chemicals in terms of understanding and predicting the response of mature trees to the same airborne chemicals?

The results of this workshop are included in Appendix I. In summary, there was unanimous agreement that studies on mature trees in forests should be framed within a "process-driven model" approach. The workshop participants further agreed that "correlative" and "experimental" studies are most appropriate when interfaced with process-driven models that address a particular species and stand condition.

A whole tree model based on physiological processes is the tool of consensus. It is the best tool to be used for synthesis and integration for assessing the effects of air pollution on California forests, and for determining dose-response relationships. Therefore, the manipulative work conducted under the CFRP must be carefully coordinated to provide the data required by the synthesis and integration team to produce the model. This work must help to make the best use possible of the results of seedling experiments in the understanding of mature tree response.

7.4 Mechanistic Experiments

There are several approaches to experimental work to determine cause and effect and dose-response relationships. A large-scale approach in which whole stands are manipulated through thinning, irrigation, induced drought, and fertilization can provide an understanding of the relationships within stands of ponderosa pine trees under different types of stress. A smaller-scale approach includes seedling controlled exposure experiments, whole branch experiments and zonal air pollution systems. The weakness of the first two small-scale approaches is that they are not directly translatable to mature whole trees. The zonal air pollution systems are still experimental. There are no proven protocols which reliably control environment and exposure for whole trees, parts of whole trees, or parts of forest stands.

Ponderosa pine has been the subject of some of the earliest and longest standing research efforts to determine the mechanisms of damage to forests and trees by air pollutants, particularly ozone. The Electric Power Research Institute (EPRI) is currently undertaking to fund the efforts of researchers to determine the response of ponderosa pine genotypes to ozone and acidic deposition under two levels of soil moisture availability. To avoid duplication of effort and to foster efficiency in the use of CFRP funds, the CFRP will follow this EPRI effort closely. However, because of the weaknesses of seedling exposure experiments, it is unlikely that additional seedling studies will advance our knowledge substantially.

Three aspects of seedling structure and physiology make them unsuited to provide information which can be extrapolated to mature trees: (1) they do not have a complete set of needles of various ages, (2) they do not have stored resources which can be reallocated in response to stress, and (3) they are not reproductively mature. The first two characteristics are overcome through the use of ponderosa pine saplings 3-5 years old. The use of saplings for physiological monitoring under environmental stress and air pollution exposure, although more difficult than use of seedlings, seems a reasonable compromise for obtaining the data necessary for a mature tree model.

Regardless of the form that the experimental studies will take, manipulative research initiated under the CFRP must meet the following criteria:

(1) It must be carefully coordinated with other research programs to avoid duplication of effort.

(2) It will concentrate on mechanistic hypotheses of high priority as determined by the planning and synthesis stages of the program.

(3) It must be aimed at providing data for a mature tree model. In other words, it will span the gap between seedling response and mature tree response.

7.5 Implementation

The first intensive research site will be established as part of the first year activities of the CFRP (Section 6.0). The request for proposals for this initial site selection and establishment will include a section addressing the objectives of the hypothesis testing outlined here. One group of investigators will be selected for the entire intensive site research project. They will be responsible for designing and establishing a stand of ponderosa pine saplings during the second year of the CFRP for subsequent experimentation. The Controlled Environment Experiments Working Group recommended that this sapling stand be established by planting 2-0 seedlings of known genetic origin to provide 3-5 year old saplings for experimentation in the third through fifth years of the CFRP (See Appendix IV - Final Report of the Controlled Environment Experiments Working Group).

The Program Manager of the CFRP will direct the Synthesis and Integration Team to prioritize the Scientific Questions based on the results of the first year of the CFRP and other relevant programs and projects. The Program Manager will review the recommendation of the Synthesis and Integration Team, and present the prioritization to the Central Planning Group. The Central Planning Group will make a final prioritization of the hypotheses, and outline the objectives to be addressed by the subsequent plan to be developed by the Intensive Site Investigators.

The second year responsibilities of the intensive site research group will include the development of an experimental design for conducting manipulative research. This experimental design will be reviewed by the Program Manager and the Central Planning Group, and evaluated based on how well the plan addresses the objectives outlined by the Central Planning Group at the end of the first year of the CFRP. The experiments proposed may include stand level manipulations, whole tree exposure, and branch exposure, as well as sapling exposure. The third through fifth year responsibilities will include the implementation of the experimental design.

This project will be reviewed annually. The work at the intensive research site will be carefully coordinated by the CFRP Program Manager, synthesis and integration efforts and the Central Planning Group.

8.0 QUALITY ASSURANCE AND QUALITY CONTROL

8.1 Introduction

The Quality Assurance Program for the California Forest Response Program is designed to ensure that data produced in the CFRP is of known and sufficient quality to meet its intended use for synthesis and integration. Quality assurance programs are typically comprised of Quality Control (QC) and Quality Assurance (QA) activities. These and other important terms are defined in Table 5.

Quality Assurance programs utilize the experience and expertise of investigators to assure data quality. Investigators routinely track the quality of their work and are in the best position to evaluate and summarize the level of data quality. A structured QA program requires that a QA plan, describing those routine QA/QC activities, be developed by investigators during the initial planning stages of their research projects. Quality Assurance plans formalize and document the routine QC activities performed.

An independent QA staff provides assistance in developing the plan, and supplies review and evaluation of the planned QA/QC activities. The investigators then document their QA/QC and research activities closely as the research progresses. This documentation provides a long-term record for the investigator, cooperating investigators, Synthesis and Integration Team, the QA staff, and program management. An independent review of the research project completes the documentation cycle.

The foundation of any large, integrated QA program, such as the CFRP, is the Quality Assurance Plan. The Quality Assurance Plan details the overall policies and objectives, project quality objectives, and operational responsibilities within the QA program. The following sections represent a draft Quality Assurance Plan for the CFRP. We begin, however, with the objectives of the CFRP.

8.2 CFRP Objectives and Approach: Foundations of the CFRP Quality Assurance Program

8.2.1 California Forest Response Program Objectives

The objectives of a research program determine the types of research that will be conducted and the types of data that will be produced. These in turn determine the specific QA/QC procedures that will be required.

Table 5. Definitions of common QA terminology.

TERM	DEFINITION
Quality Control (QC)	Quality Control is a set of routine activities conducted during a research effort to monitor quality in sample collection, analysis, and recording. It is a scientific function performed by research staff.
Quality Assurance (QA)	Quality assurance is a program of planned systematic activities conducted before (planning/training), during (QC), and after (QC evaluation/feedback) a research effort to assure that specified data quality criteria are achieved for a given project. It is a research and management function which continually evaluates the adequacy and effectiveness of QC activities and provides for correcting problems where necessary. Quality Assurance programs include the organization, management, and documentation of quality control activities.
Data Quality	Data quality is a measure or description of the types and amount of error associated with a data set. The quality of a data set is defined in terms of five characteristics of data: precision, accuracy, completeness, representativeness, and comparability. The first three characteristics are typically quantative; the later two qualitative. The purposes for describing these characteristics are: (1) To make sure that an appropriate level of control is execised over sources of error that can be controlled. (2) To make sure that sufficient information is obtained to describe all known sources of error, even types that cannot be controlled, to the extent possible.
Data Quality Objectives	Data Quality Objectives are statements about precision, accuracy, completeness, representativeness, and comparability of data needed to support specific decisions, e.g. hypothesis rejection. Data Quality Objectives are used as a starting point for designing a data collection system which generates data of known and sufficient quality, and specifying its associated QA/QC activities.
Known Quality Data	Data for which information on precision, accuracy, completeness, representativeness, and comparability is documented. Where these parameters are not measurable, quantitative and qualitative estimates are substituted.
Sufficient Quality Data	Data for which the above quality attributes meet pre-set criteria. The criteria are developed independently for each unique research situation. For example, data users (decision makers) examining growth effects over 5-year intervals may require different measurement precision to detect the same effect as those examining effects over 20-year intervals. Ideally, the data user could specify exactly the quality needed to make a decision; however, decision makers have not reached that stage in forest ecosystems research and scientists are left with a broader interpretation of "sufficient".

Table 5. Definitions of common QA terminology. (continued)

TERM	DEFINITION
Standard Operating Procedures	A documented procedure which describes an operation, analysis, or action which is commonly accepted as the preferred methods for performing certain routines or repetitive tasks. Standard operating procedures were designed for the national FRP through a series of workshops for investigators, and documented in FRP QA Methods Manuals. Their purpose is to provide a standard for comparability of research methods and relieve documentation burden on investigators.
Verification	The electronic or manual comparison of two versions of a data set to ensure that they are identical. For example, computer data files are "verified" when the data represent the actual measurements collected on field data sheets.
Validation	The evaluation of each verified record relative to other data of the same type. Validation is designed to identify errors made during the collection of data. For example, outlier analysis would detect a transpositional error made on a field data sheet.

The objective of the CFRP is to evaluate the effects of acidic deposition and other air pollutants on California forests and to determine the mechanisms of these effects. The data from this program are primarily intended to support regulatory decisions on the emission of atmospheric pollutants in California. Meeting this objective requires a very complex research program with equally complex QA requirements.

Research activities within the CFRP include literature and data surveys, atmospheric monitoring, assessment of forest condition using forest surveys and intensive site research, and determination of physiological mechanisms of tree response to pollutants. Many of these activities lie outside the realm of analytical chemistry for which most QA protocols have been developed. Application of QA methods to forestry research often requires modification of standard QA protocols.

8.2.2 Necessity for Quality Assurance

There are several aspects of the CFRP that increase the need for a strong QA program. The most important is the intended use of data. Regulatory actions are often challenged. Full documentation of procedures and results and accompanying information on data quality are necessary for successfully responding to a legal or scientific challenge. Other reasons include:

(1) The CFRP includes comparisons of results between different sites. Since differences in measured parameters are likely to be small, standardization of procedures and rigid control of data quality are essential.

(2) Comparison of CFRP data with results from other programs requires proper documentation of procedures.

(3) The CFRP is a long-term program. Procedures must be standardized through time and any changes properly documented and compared to the replaced procedure.

8.2.3 Adoption of the National Forest Response Program QA Plan

The national Forest Response Program (FRP) is charged with assessing the current and potential effects of atmospheric pollutants on forests in the United States. The data from FRP research projects will be used to support regulatory decisions on the control of atmospheric emissions. Thus, the research objectives and QA requirements of the FRP and the CFRP are very similar.

The FRP has an established QA Program responsible for QA/QC of more than 70 projects in an integrated national forest research program. This program is described in the accompanying "Quality Assurance Implementation Plan for the Forest Response Program" (Appendix II). The CFRP will meet its QA needs by implementing the FRP QA Program. All research projects within the CFRP will be subject to the requirements of the FRP QA Program. The FRP QA Staff will assume responsibility for QA/QC activities involving CFRP projects.

This approach offers a number of advantages to the CFRP including:

(1) Utilizing the unique expertise of an on-going forestry QA program.

(2) Realizing cost savings by not having to establish a new QA program.

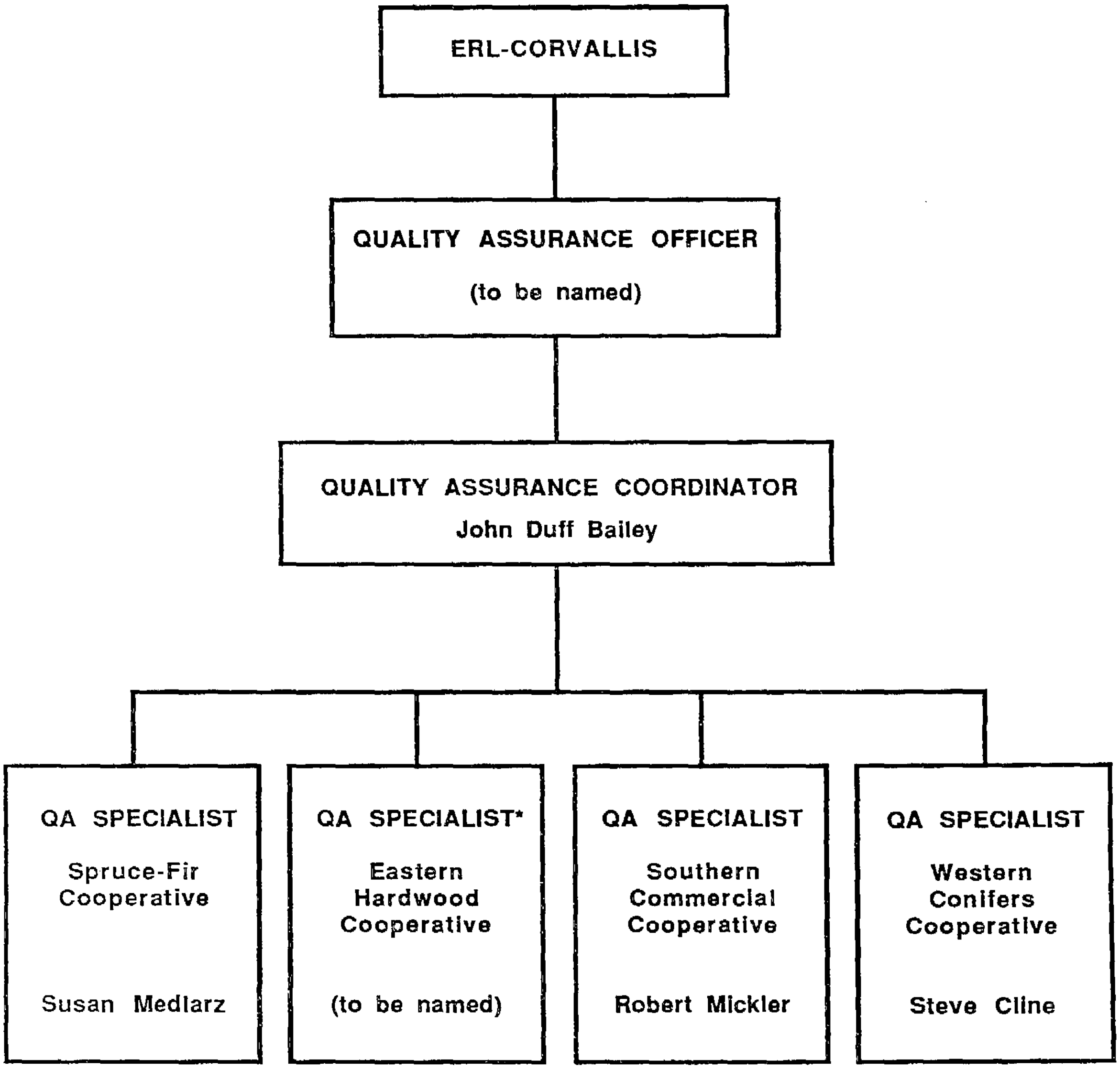
(3) Increased comparability of data with results from the FRP.

The national FRP QA Program is briefly described in the following section, which lists the most important aspects of the structure and functioning of that QA program, and emphasizes its relationship to the CFRP. More details on the FRP QA program can be found in the attached QA Implementation Plan (Appendix II).

8.3 National Forest Response Program QA Program

8.3.1 Quality Assurance Management Structure

The organization of the Forest Response Program QA Staff is shown in Figure 3. The responsibility of organizing and managing the QA Program belongs to the QA Officer at the EPA Laboratory in Corvallis, Oregon. The QA Officer will be supported initially by four trained individuals: (1) a QA Coordinator, located at Corvallis to assist in program implementation and to coordinate QA Staff activities; and (2) three QA Specialists located at Research Cooperative offices to provide QA support to the Cooperative and associated researchers.



* Responsibilities/duties currently held by Steve Cline

Figure 3. Quality Assurance Staff organization structure of the national FRP. Steve Cline, QA Specialist for the Western Conifers Cooperative, will support the CFRP.

8.3.2 Objectives of the National Forest Response Program QA Program

The goal of the FRP QA Program is to ensure that FRP data are of known and sufficient quality to meet their intended use for the assessment of atmospheric deposition effects on forest ecosystems. This goal translates into four specific objectives for the FRP QA program:

(1) Provide guidance, reinforcement, and resources to the investigators for the implementation of QA activities;

(2) Assure comparability of research and QA activities across sites and over time;

(3) Examine, evaluate, and adjust research and QA activities to assure continued compliance with standardized or approved protocols and procedures; and

(4) Provide evidence of research data quality through qualitative and quantitative evaluations.

The procedures followed by the FRP QA Program to meet these objectives are described in Section 2.0 of the Implementation Plan (Appendix II). The CFRP will adopt the QA objectives and procedures of the national FRP.

8.4 Implementation of the Forest Response Program QA Plan within the California Forest Response Program

8.4.1 Management Structure and Responsibilities

The organization of the CFRP QA staff is shown in Figure 4. Ultimate responsibility for the development and implementation of the CFRP QA Plan lies with the CFRP Manager. The manager is assisted in meeting these responsibilities by the WCRC QA Specialist. The primary responsibilities of FRP and CFRP personnel are listed in Table 6.

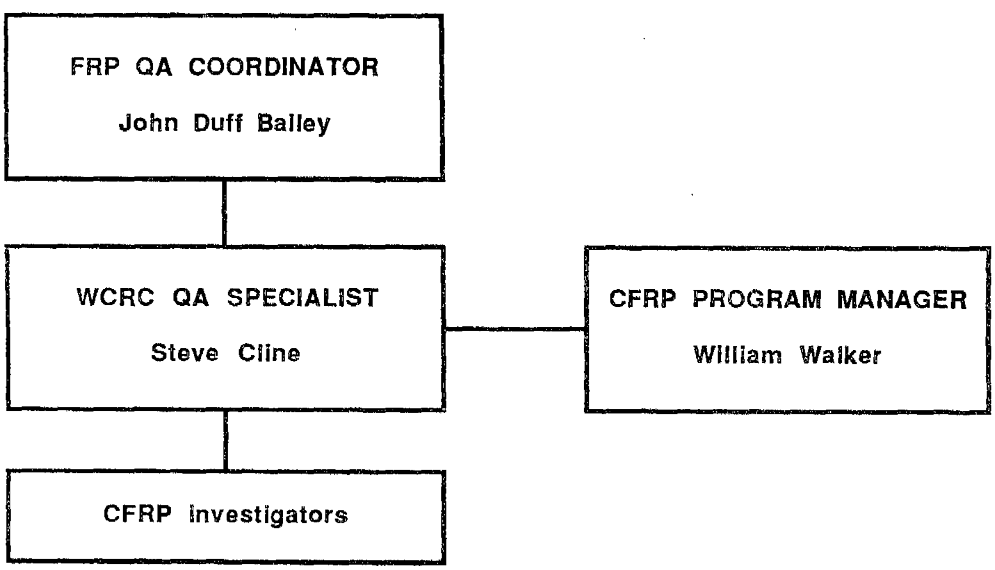


Figure 4. Organization structure of the California Forest Response Program (CFRP), QA Program. FRP = National Forest Response Program, WCRC = Western Conifers Research Cooperative.

Table 6. Major responsibilities of the CFRP QA Staff.

POSITION	RESPONSIBILITES
FRP QA Coordinator	Coordination of CFRP QA Program with other FRP QA activities.
CFRP Manager	Development of CFRP QA Plan.
	Implementation of CFRP QA Plan.
	Inclusion of QA requirements and instructions in all Requests for Proposals (RFPs)
WCRC QA Specialist	Assist CFRP Manager in development and implementation of QA Plan
	Review and approve CFRP QA Plan and QA sections of all RFPs
	Review all QA Project Plans, assist in revisions, and recommend approval
	Assist in implementation of QA Project Plans including conducting project audits
	Document QA activities
	Oversee archiving of project data in central data base
	Serve on S & I Team
Principal Investigator	Develop and implement QA Project Plans

The QA Specialist is responsible for conducting tasks associated with implementation of the CFRP QA Plan. These include; 1) interacting with CFRP investigators and the CFRP Manager to inform them of QA requirements, 2) standardizing techniques for the legitimate comparison of results among sites, 3) auditing sites to ensure compliance with standardized or approved procedures and protocols, 4) evaluating the quality of the final data bases, and 5) overseeing the archiving of project data in a central data base. The QA Specialist will also serve as a member of the Synthesis and Integration Team (section 9).

The majority of QA/QC activities are conducted by the investigators during the research effort. Prior to the initiation of research, an investigator develops a QA Project Plan with the assistance of the QA Specialist. The QA Project Plan details all planned QA/QC activities (and should complement the research plan), including systematic checks on the procedures, equipment, and personnel. Details on the preparation of QA Project Plans are found in Appendices A, B, and C of the national FRP QA Implementation Plan (attached).

The systematic checks are designed to monitor repeated measurement error (precision) and accuracy. Limits of acceptability for precision and accuracy, called Data Quality Objectives, are included in the QA Project Plan for each variable to be measured. Investigators are responsible for meeting these Data Quality Objectives and for developing and documenting the system used to produce usable results.

The investigator and QA Specialist interact to ensure the development of an appropriate QA Project Plan, where all QA concerns are addressed (Figure 5). Disputes over QA requirements will be resolved by the QA Officer and CFRP Manager. The QA Project Plan is approved by the QA Officer on the recommendation of the QA Specialist when fully developed. The QA Project Plan must be approved prior to funding the research. QA Project Plans are revised and additional information is requested by the QA staff as the research project is modified or updated.

The QA Specialist will use the QA Project Plan and appropriate national support documentation when reviewing research projects. Therefore, it is imperative that the information in the plans is correct and as complete as possible. A well developed QA Project Plan saves a considerable amount of effort during reviews. Following a research project review, the QA Specialist files a report documenting the review and any concerns which may have surfaced. The investigators are asked to reply to the review report, and possibly revise the QA Project Plan. These interactions and exchanges continue for the duration of the research project.

Finally, the QA Specialist will oversee the transfer of project data into the CFRP data base. This responsibility may include assistance in communication between the Database Resource Manager and investigators, the explanation of QA requirements for data handling and transfer, or assistance in translating non-standardized data codes and formats.

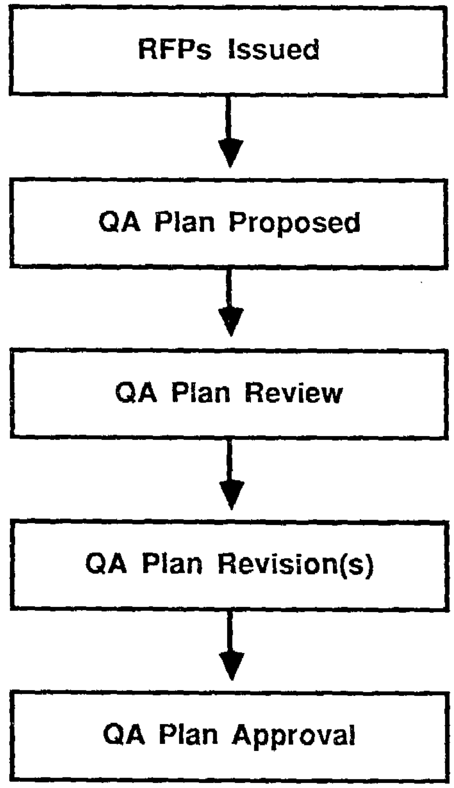


Figure 5. Process for obtaining Quality Assurance approval for a research project.

8.4.2 Supporting Documentation

A number of QA documents were developed for the national FRP and will serve as foundations for the CFRP QA Program. The most important is the QA Implementation Plan for the FRP (attached Appendix II). Since the CFRP QA Program will be part of the FRP QA Program, all protocols described in the FRP QA Plan will be followed in the CFRP.

The FRP QA Program has developed four QA Methods Manuals to provide standard operating procedures for the appropriate standardization of procedures and, thus, comparability of data between sites and projects within the FRP. The four manuals are:

(1) Site Classification and Field Measurements;

(2) Exposure Systems and Physiological Measurements;

(3) Experimental Design and Data Management; and

(4) Laboratory Analytical Techniques.

These manuals were developed in a series of workshops for scientists involved in the national FRP. The standard operating procedures represent a consensus on standard research methods and QC, not standard science. They should be of use to investigators in developing and documenting standard protocols for projects within the CFRP. Investigators may elect to use alternate methods that are more appropriate to their research. Deviations from the Methods Manuals need to be documented and justified. Alternative methods should be compared to the standardized methods to ensure that similar research conducted at different sites is comparable. The QA Specialist will review the alternative procedure and comparability factor as part of the QA Project Plan review.

For all CFRP projects, data quality estimates will be adapted from the national FRP, as will requirements for sample and data custody, training, preventative maintenance, calibration, quality control checks, and documentation. Individual proposals will detail these requirements at a project level as part of the QA Project Plan.

8.4.3 Requirement for Individual Projects

Investigators must be made aware of their QA responsibilities in sufficient detail and prior to the commitment of funds or services to successfully implement a QA program. For this reason, Requests For Proposals (RFPs) should contain sufficient information about the constraints on research (e.g. site selection criteria, design limitations, specific objectives, and QA) such that returning proposals fit the overall CFRP design.

RFPs released by the CFRP must 1) outline responsibilities for QA, and 2) present specific details for the preparation of QA Project Plans to be attached to a proposal. These specifics are described in Appendices A, B, and C of the FRP QA Implementation Plan (attached). Appendix A provides guidelines for the development of QA Project Plans for research projects collecting environmental measurements. Appendices B and C provide guidelines for projects using existing information (e.g., literature reviews or data base analyses) and projects for model development, respectively.

With this information, the investigator designs a QA program and begins the approval process described in section 8.4.1. The investigator therefore is fully aware of the QA requirements on his project and the level of effort (cost) required to execute the QA program. The project budget and schedule should reflect this knowledge.

RFPs issued by the CFRP may be grouped into 7 broad categories:

(1) Information (literature and data) Collection for analysis or summary.

(2) Air Monitoring/Methods Development in support of field research.

(3) Forest Surveys/Methods Development.

(4) Intensive Research Sites.

(5) Experimentation/Field Manipulations.

(6) Modeling.

(7) Data Base Management.

This will result in a natural grouping of quality assurance activities, described in the following sections.

8.4.3.1 Information Collection:

Information collection projects, such as literature reviews, surveys of data bases, and white papers, are relatively simple to quality assure. Since environmental measurements are not taken and original data are not recorded, standard protocols and quality control checks are unnecessary. However, these projects require: 1) good documentation of information sources, and collection, cataloging, and synthesis procedures; 2) appropriate security measures (especially with data) to avoid unwanted manipulations of the information; and 3) estimates of the quality of information (again, especially when collecting and synthesizing data). These estimates can be quantitative (preferably) or qualitative and will dictate the appropriate uses of the information.

Because of the importance of this category of research, proposals for information collection projects should detail plans for accomplishing these three objectives. More detailed information on QA requirements can be found in the national FRP QA Implementation Plan (Appendix II). Particular attention should be given to assessing the quality of existing data because that estimate determines the validity of comparisons among existing and newly collected data.

8.4.3.2 Air Monitoring/Methods Development:

The Atmospheric Exposure Cooperative (AEC) of the FRP is currently developing a QA Plan for application to monitoring efforts at environmental research sites. This plan will follow the basic format of the current FRP QA Plan and will be implemented by the CFRP QA staff as part of their QA duties. The AEC is also developing standard protocols for atmospheric monitoring at forest sites. To facilitate comparability of data, these protocols will be used where appropriate by the CFRP.

Air monitoring projects are expected to adhere to all equipment, site selection criteria, maintenance, calibration, and performance checks required by the CFRP. These QA/QC procedures should be detailed in the QA Project Plan in the format given in of the FRP QA Implementation Plan (Appendix II). Operating sites will be included in the FRP equipment audit cycle which will require at least one annual inspection and challenge of all equipment. This procedure is in addition to routine performance checks conducted by the site operator.

Air monitoring methods development projects will require a detailed description of the test and prescribed criteria for the selection or dismissal of a given procedure or piece of equipment. Like information compilation studies, good documentation of the work done is crucial for relaying information to associates and program managers and for future evaluations of the project (or reevaluations). Proposals should detail the testing procedures (with evaluation criteria) and documentation procedures.

8.4.3.3 Forest Survey/Methods Development

Forest survey work is common in the national FRP; the CFRP will utilize established QA procedures for this category of research. Forest survey projects may choose to use the standard operating procedures and QA set forth in the QA Methods Manuals for Site Classification and Field Measurements, where appropriate. Regardless, comparability to these procedures must be established.

Quality Assurance Project Plans should fully explain: 1) the design, duration, and parameters involved in the study; 2) the equipment and personnel required; 3) training requirements; and 4) potential quality checks and performance evaluations. In addition, some forest survey projects may be required to verify the quality estimates of information compilation projects (section 8.4.3.1) through remeasurement of plots, inspection of plots, or verification of a measurement procedure.

Forest survey methods development projects will be required to address the same issues as air monitoring methods development (section 8.4.3.2). Forest survey methods development will typically de-emphasize equipment development and emphasize statistical methods development; therefore, proposals for forest survey methods development should detail the planned testing procedures (including prescribed decision criteria) and documentation activities.

8.4.3.4 Intensive Research Sites:

Intensive research sites are also common to the national FRP, which has established standard operating procedures and QA. Again, intensive research site projects may reference the QA Methods Manuals for Site Classification and Field Measurements or provide a measure of comparability between the standardized and project specific procedure. The same details and format will be required in proposals as are required for forest survey projects (section 8.4.3.3) with more emphasis on organization of site specific data for combination with correlated chemical and physiological research.

Site selection criteria are provided in the site selection criteria section of the CFRP Research Plan.

8.4.3.5 Experimentation/Field Manipulation:

Experimental and manipulative research will encompass a wide range of research activities: exposure systems work under controlled and field conditions, soil and plant material manipulations, and physiological processes work. Projects will be expected to provide comparability with the appropriate QA Methods Manuals: Exposure Systems and Physiological Measurements, and Analytical Laboratory Techniques. Quality Assurance Project Plans should follow the guidance in the FRP QA Implementation Plan (Appendix II) very closely for detailing the project QA/QC (especially statistical aspects).

8.4.3.6 Modeling:

Modeling projects, like information collection projects, are not concerned with the collection of environmental data and the corresponding QA/QC concerns (standardized methods, accuracy and precision checks, etc.). However, modeling projects should be concerned with proper manipulations and documentation. The CFRP QA program will ensure 1) sufficient documentation of models selected, 2) proper technical review of that information, and 3) appropriate testing of models (e.g., sensitivity testing).

Quality Assurance Project plans for this category of research should follow the guidelines established in the national FRP QA Implementation Plan, (Appendix II).

8.4.3.7 Data Base Management:

The CFRP will be accumulating data from a wide range of projects and research activities, and will be integrating data according to the procedures outlined in the Synthesis and Integration section (Section 9). The WCRC is currently developing in conjunction with other units of the national FRP, a professionally operated centralized data base for archiving all data produced by WCRC projects. The result of this effort will be a secure and well documented data base.

The CFRP will utilize the WCRC data base management system for data from CFRP projects. The data base will form the collection center for data utilized by the Synthesis and Integration Team and may form, ultimately, a permanent repository for CFRP data. The QA/Data Management Group, as advisor to the CFRP Manager, will issue an RFP in 1987 to pursue the development of an appropriate data base management system given the needs of the CFRP, WCRC, and Synthesis and Integration Team. The QA/Data Management Group will issue an RFP in 1988 to implement that design. As currently budgeted, the data base would represent only a collection center and archive. Should program management require a more complex system, additional funding would be required.

The WCRC QA Specialist will oversee the transfer of data from the projects into the data base. The CFRP will utilize procedures established in the national FRP QA Methods Manual for Experimental Design and Data Management for data transfer and access. In general, the investigator maintains the right to approve the use of their data by any person outside of the CFRP management staff for the duration of the CFRP. The system is regulated so that the prerogative of the investigators to publish their own data is in no way impaired.

9.0 SYNTHESIS AND INTEGRATION

9.1 Objectives and Approach

The Synthesis and Integration Section of the CFRP is responsible for producing program-wide technical outputs consistent with the objectives of the research plan. Synthesis and integration will determine the usefulness of the research outputs for assessment strategies based on the policy needs of the California Air Resources Board. In addition, it will ensure that the CFRP as a whole functions effectively and efficiently at the technical level.

The specific goals of synthesis and integration are to:

(1) Provide a clear assignment of responsibility for delivery of program-wide outputs;

(2) Provide guidance in the selection and ranking of the best ,candidate hypotheses, to provide guidance in establishing data quality objectives and other aspects of QA/QC;

(3) Facilitate coordination among investigators and support groups, and between the CFRP and similar research efforts;

(4) Ensure that the relevant data and information needed for synthesis are produced by the investigators and support groups in a timely manner;

(5) Produce answers to program-wide scientific and policy questions. Answers will be put together from very diverse sources of information coordinated by the integration efforts.

The CFRP will be organized in such a way as to facilitate the integration of the secondary projects within the program as well as integration with other forest response studies. The organization is essentially centered around the development of a process-driven mature tree model which uses various aspects of correlative and experimental approaches to explain the causes of forest damage due to acidic deposition and other pollutants.

Centering the synthesis and integration efforts on a process-driven mature tree model has obvious advantages. Correlative and experimental approaches can only indicate the statistical significance of observed changes in growth or dysfunction symptoms with measured parameters of environment and forest structure. Neither approach can by itself prove or disprove that a suspected causal factor is or was, responsible for the observed symptoms regardless of the statistical significance of the correlations. Methods from both approaches will be most valuable when applied within a research strategy which seeks to interpret results within the context of known biological mechanisms. Thus the biological levels of organization depicted in Figure 1 incorporate the various research approaches in such a way as to allow for intermediate assessments of research elements, allows outputs of one level to be used as inputs for other levels, and allows for testing, rejecting, and reformulating of hypotheses in a concurrent fashion.

The major program-wide outputs which will result from synthesis activities are:

(1) An assessment of the effects of acidic deposition and other air pollutants on California forests.

(2) An understanding of the mechanisms by which acidic deposition and other air pollutants influence California forests. Intermediate outputs which are necessary precursors for the major program-wide outputs include:

(1) An evaluation of the extent and magnitude of recent changes in forest conditions.

(2) An assessment of the role of non-air pollution factors in forest growth and associated visible symptomology.

(3) An evaluation of the role of acid species and other pollutants on forest decline.

(4) A projection of responses under alternative deposition scenarios.

(5) A process-driven mature tree model sensitive to perturbation by pollutant exposure.

(6) A stand-level model of forest dynamics sensitive to perturbation by pollutant exposure.

(7) An extrapolation from the stand-level model to region-wide forest responses.

Not all of these intermediate products will result from research initiated by the CFRP. It is important to recognize the role of the CFRP in coordinating efforts other than those directly funded by the CFRP, to ensure critical intermediate products are completed and used to their fullest potential in generating the major program outputs.

The mechanism by which these outputs will be generated is given schematically in Figure 6. As depicted in the figure,. the program is tightly integrated, that is the categories of analyses are not mutually exclusive. For example, many parameters measured for spatial comparisons of forest condition would also be appropriate for making temporal measurements of condition.

9.2 Integration

The CFRP will adopt a similar approach to integration as that used by the national Forest Response Program. Under this plan there are four broad integration activities: planning, tracking, evaluation and data acquisition. Taken together, these activities will represent steps in a process designed to provide relevant and timely data for synthesis and the formulation of program outputs.

PLANNING: A Central Planning Group will be established immediately. The Central Planning Group will include staff from CARB, WCRC, and other members mutually agreed upon by those two organizations. The responsibilities of this group will be to ensure continuity within the program as well as establish the objectives of the program in a clear, unambiguous fashion. This perspective will be important to assure that the research undertaken yields the data required to produce the major program outputs via synthesis activities. Planning activities will be in response to the needs expressed by the policy clients, the program objectives, and research outputs generated on a yearly basis.

TRACKING: A computerized tracking system will be established during the first year of the CFRP for cataloging critical information from CFRP projects, relevant projects outside the CFRP, and key literature references. All of these activities will allow regular assessment of the CFRP's focus and direction. This in turn will provide a means of avoiding duplication of effort, assurance of adequate coverage of the Scientific Questions, and production of relevant data and information. This tracking system will be the responsibility of the CFRP Data Management Group, which includes the CFRP Program Manager, a staff member from the CARB who will serve as Quality Assurance/Quality Control liaison and the Quality Assurance Specialist of the WCRC.

EVALUATION: The evaluation of research in progress will be the responsibility of a Synthesis and Integration Team. This team will be made responsible for determining how project results can best be utilized in the production of program outputs. The Synthesis and Integration Team will provide and arrange for cooperation among investigators through diplomacy and conscientious use of the data tracking system. The Synthesis and Integration Team will evaluate the relevance and appropriateness of the current research and will evaluate the content and timeliness of the research results, since results have to be available in time to meet program output deadlines.

DATA ACQUISITION: Finally, the Synthesis and Integration Team will acquire critical information and data from investigators for use in evaluation of research hypotheses, synthesis of projects, and redirection of future activities. The Synthesis and Integration Team will work closely with the Data Management Group to ensure the proper data format, transfer, and usability of all research output. The Synthesis and Integration Team will report to the Program Manager and to the Central Planning Group who will jointly plan and direct future activities of the CFRP.

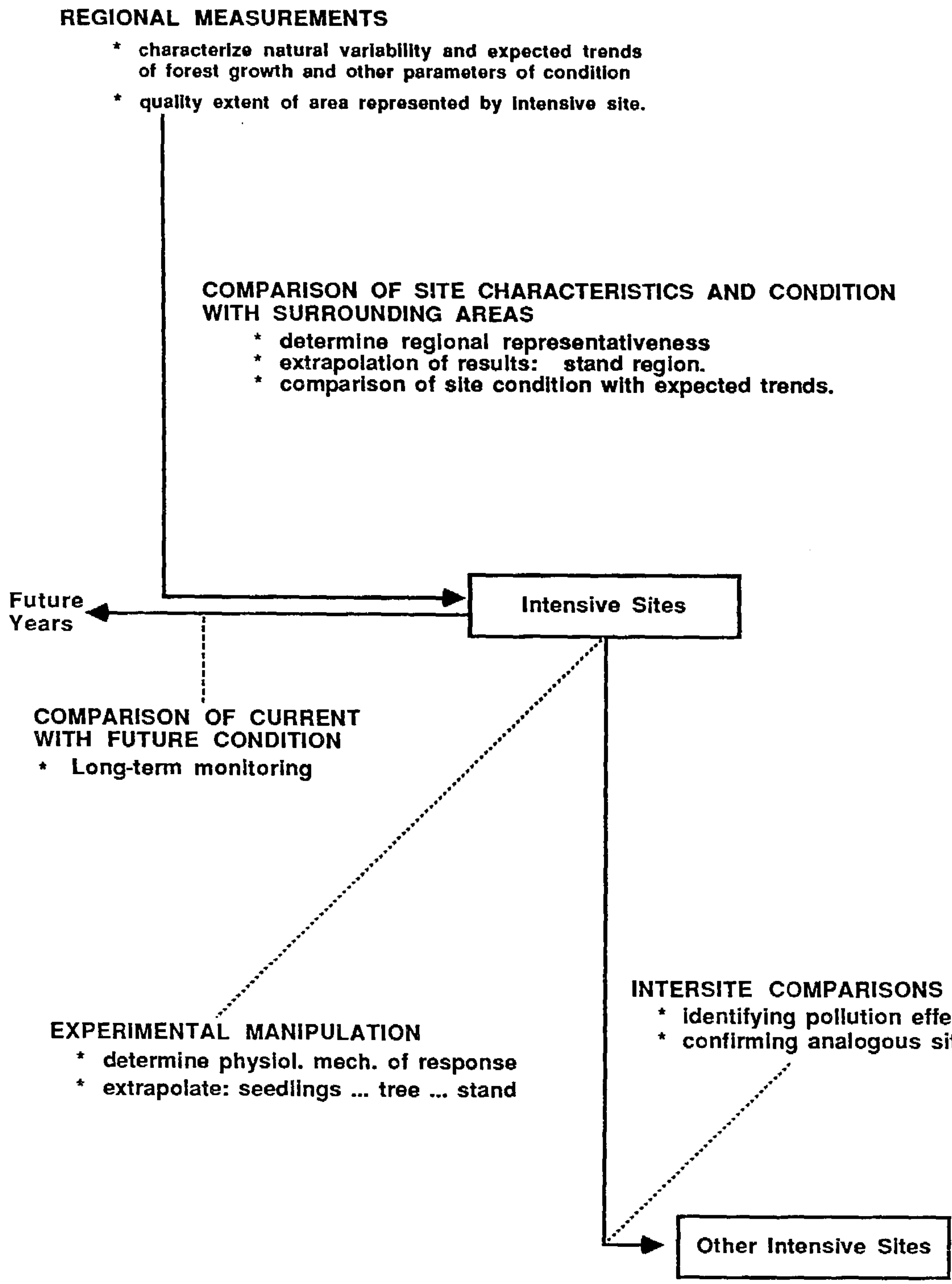


Figure 6. Analyses linking levels of organization in California Forest Response Program. Capitalized text designates type of analyses, while (*) designates purpose of analyses.

9.3 Synthesis

Much of the early effort of the CFRP is devoted to determining if problems currently exist in California forests which may be caused by air pollution. Since early outputs will evaluate recent changes in forests and determine the role of natural stresses in any negative changes, the following synthesis activities will be established.

The S&I Team will generate a series of summary statements that address the state and usefulness of vegetation survey data, California deposition data, experimental results of tree seedling data, and other studies in California relevant to the CFRP. These summary statements will be useful in gaining a complete picture of available data, its usefulness, and its application in directing the research of the CFRP. Collection of these summaries will aid in justifying site selection, forest type selection, the measurement methods at intensive sites, as well as provide the linkages necessary for extrapolation from intensive site work to regional surveys.

The Synthesis and Integration Team will use statistical analyses of temporal and spatial data on a regional scale to characterize natural variability and the expected trends of forest growth and other parameters of forest condition. The CFRP must ensure that the best statistical methods are used to analyze the data. In general, it is likely that several types of data will be analyzed for achieving the research output. These would include dendrochronological data, vegetation survey data, forest inventory data. Once these data have been analyzed they could be used to quantify the extent of the area represented by the CFRP intensive sites. Again, at these intensive sites similar data would be evaluated in a statistically sound manner, which would determine the regional representativeness of the intensive sites, would allow extrapolation of the results from the stand to the region, and would provide the basis for a comparison of site condition with expected trends of forest condition. In addition the initial survey at the intensive sites would provide a statistical basis for future intersite comparisons.

Seedling growth and physiology studies with ponderosa pine are currently under way , using three different approaches; correlation, experimentation, and process-driven modeling. Additional work conducted by the CFRP at the intensive sites will be designed with the goal in mind to provide the necessary data to develop dose-response relationships for mature trees. The experiments should incorporate relevant and easily verifiable measures of response. Following this approach should ensure that the data can be extrapolated to whole tree physiology and growth relationships which in turn will establish the basis for regional assessment (Figure 1).

The culmination of the integration and synthesis of all available data and information on the dose-response relationships for ponderosa pine will be a coordinated effort to synthesize a mature tree model. In this effort the CFRP should play the role of supporter, facilitator and coordinator for the ongoing efforts of the national FRP, EPRI and NCASI. As versions of the mature tree model for ponderosa pine are developed, the CFRP will test the model and use it to project responses of ponderosa pine to alternative deposition scenarios.

A second model, to predict ponderosa pine stand dynamics, will be developed through the use of research outputs from the seedling and whole tree studies, and by intensive site process studies. The development of this model will require the incorporation of physiological mechanistic information in the specification of individual trees. It also recognizes that a stand is not simply the sum of its individual trees but rather the result of many complex interactions between the individual trees. From the beginning, progress on given mechanistic hypotheses will be tracked. If results suggest that a given mechanism will be important, the effect will be incorporated into the model. By following this approach, association results from the first phase of the work can provide early results and insights into further planning. The development of this model will be a function of the coordination by the CFRP of in-house and external modeling efforts.

Regional estimates of the response of forests to atmospheric pollution will be produced by spatial statistical extrapolation on the results of modeling single stands and by evaluation of the regional survey data previously discussed. The Synthesis and Integration Team will be responsible for conducting this research.

Finally, the CFRP Synthesis and Integration Team will use several models to project responses under alternative deposition scenarios. One approach will be to utilize the stand models discussed above. Another approach will be to use statistical projections using methods from econometrics. A third approach will be to use existing models and assessment frameworks for an early estimate of responses under different deposition regimes.

10.0 RESEARCH SCHEDULE AND PROPOSED BUDGET

1987

QA/QC:

QA/QC Organization QA Support for Initial Projects	$ 20K
Data Base Design RFP	$ 30K
Synthesis and Integration	
Set up Synthesis and Integration Team. Develop Synthesis and Integration Plan. Establish integration between projects.	
S&I RFP to review state of the art of ponderosa pine modeling	$ 50K
Forest Condition	
RFP to compile existing data on forest condition statewide and regionally. Determine usefulness of data bases, hold conference to plan and design additional surveys if deemed necessary. effects on California forests.	$ 70K
Intensive Forest Research Site - Mechanistic Research	
RFP to select intensive research sites. Begin characterization. Design manipulative research.	$ 75K
Atmospheric Monitoring	
Locate one of the dry deposition sites at the intensive forest research site.	......
1987 TOTAL	$ 245K

1988

QA/QC:

QA Support for Projects	$ 25K
Data Base Implementation	$ 25K
Synthesis and Integration	$ 50K
Forest Condition	
Employ survey techniques to enhance statewide and regional forest condition characterization	$ 130K
Intensive Forest Research Site - Mechanistic Research	
Begin monitoring forest condition at intensive research sites. Establish research projects at intensive sites.	$ 250K
Atmospheric Monitoring (ongoing)	.....
1988 TOTAL	$ 480K

1989

QA/QC:

QA Support for Projects	$ 25K
Data Base Implementation	$ 25K
Synthesis and Integration	$ 100K
Forest Condition	
Continue statewide and regional forest condition characterization. Compare regional to intensive sites	$ 50K
Intensive Forest Research Sites - Mechanistic Research	
Establish additional permanent forest research sites. Begin monitoring forest condition at intensive research sites. Establish research projects at intensive sites.	$ 600K
Atmospheric Monitoring	
Establish facilities to monitor air quality at additional permanent forest research sites.	$ 200K
(Priorities 1-3 of Table 2)	
1989 TOTAL	$1000K

1990

QA/QC:

QA Support for Projects	$ 25K
Data Base - Archive and Review Data	$ 25K

Synthesis and Integration

Continue and expand S&I activities. Compile research outputs. Synthesize output data. Reform hypotheses.	$ 150K

Forest Condition

Complete

Intensive Forest Research Site - Mechanistic Research

Complete monitoring forest condition at intensive research sites. Complete research projects at intensive sites.	$ 400K

Atmospheric Monitoring (Priorities 1-3 of Table 2)	$ 150K
1990 TOTAL	$ 750K

1991

QA/QC:

Complete Quality Control and Quality Assurance activities. Prepare data for Synthesis and Integration $ 50K

Synthesis and Integration

Complete Synthesis and Integration. Address program objectives. Assessment. $ 300K

Forest Condition

Complete

Intensive Forest Research Site - Mechanistic Research

Complete

Atmospheric Monitoring

Continue monitoring atmospheric deposition at permanent forest research sites. (Priorities 1-3, Table 2) $ 150K

Plan CFRP research continuation

1991 TOTAL $ 500K

PROGRAM SUMMARY

QA/QC	250,000
S&I	650,000
Atmospheric Dep.	500,000
Forest Characterization	250,000
Intensive Sites	1,325,000
PROGRAM TOTAL	$ 2,975,000

APPENDIX I

MATURE TREE MODEL WORKSHOP REPORT

MATURE TREE RESPONSE WORKSHOP
Sponsored By
Southern Commercial Forest Research Cooperative
December 8-10, 1986
St. Louis, Missouri

Purpose

Ten scientists with diverse experience in research on physiology and growth of trees in forests were invited to the workshop to discuss and obtain a consensus on answers to the following two questions:

1. *What are the "best" approaches which should be taken to quantify the effects of airborne chemicals on mature trees in forest stands?*

2. *What is the expected value of the information from studies on the response of seedlings to airborne chemicals in terms of understanding and predicting the response of mature trees to the same airborne chemicals?*

Workshop Participants

The following persons participated in the workshop:

Phillip M. Dougherty	University of Georgia
E. David Ford	University of Washington
Leo J. Fritschen	University of Washington
David M. Gates	University of Michigan
Kimberly C. Joyner	North Carolina State University
Paul R. Miller	USDA Forest Service
George E. Taylor	Oak Ridge National Laboratory
Robert O. Teskey	University of Georgia
James N. Woodman	North Carolina State University
Robert Zahner	Clemson University

Definitions

The workshop focused on the approaches or strategy for conducting cause-and-effect studies on individual mature trees growing in natural forest conditions. (It did not address the question of what is the proper function or role of mature tree research in the Forest Response Program). The criteria used to judge the *"best"* approaches were that the scientific information that they provided be reliabily assessed, interpreted, and extrapolated to similar forest situations. The information to be obtained from individual trees should be reproducible on other trees and lend itself to integration into physiologically-oriented stand-level growth models. (Participants felt that conventional forest growth and yield models were designed for different objectives and are not appropriate for this purpose).

"Mature" trees were defined as trees which are generally sapling-size or larger. Other important characteristics are:

- sexually mature
- full compliment of foliage age classes (for conifers)
- some crown class definition; live crowns do not extend to ground because of competition with other trees

Study trees should be growing in stand conditions which are representative for the species in terms of stand dynamics, competition, microsites, and pollution inputs.

Research Approaches

As a step in the process of understanding and agreeing upon the best research approaches, workshop participants identified and discussed various aspects of three basic research approaches which have been used for studies on mature trees in stands. They were:

1. *"Correlative" approach* - This approach seeks to establish correlations between observed tree growth or dysfunction symptoms with estimated or measured conditions surrounding the trees, e.g., above and below ground environmental factors, biotic factors, or temporal and spatial gradients of airborne chemicals. This approach has been used by a number of investigators to correlate visible injury symptoms or changes in tree growth (e.g., ring widths, premature loss of foliage, or the presence of biochemical/physiological markers) with air pollution gradients.

2. *"Experimental" approach* - This approach uses controlled manipulations of stress-inducing factors on trees, or on parts of trees, to detect visible or invisible symptoms of injury, changes in growth rates, or changes in physiological processes to assess the relative importance of the stress factors on the growth or health of the tree. This has been the main approach used to assess impacts of air pollution on many agricultural crops. It usually includes empirical experiments in which concentrations of airborne chemicals have been excluded and/or manipulated under field or laboratory conditions using open-top exposure chambers or continuous stirred reactor chambers (CSTR's). Results are typically described in terms of "dose-response curves" or pollution threshold values which define the chemical doses needed to produce visible injury symptoms and/or cause a significant reduction in crop yields or growth rates. This approach is used to test hypothesized mechanisms and to find sensitive "bioindicator" clones of plants which can help in the identification and classification of harmful concentrations of some pollutants (usually gases).

3. *"Process-driven model" approach* - The "process-driven model" approach uses various aspects of the "correlative" and "experimental" approaches within a more biologically oriented research strategy or architecture to explain effects of airborne chemicals on growth processes within individual trees. Correlation and empirical experimental techniques may be used in a series of designed

studies to establish the cause-and-effect mechanism through which a suspected airborne chemical affects basic physiological processes related to growth and development of the tree. The focus of studies is on establishing that observed changes in tree growth or dysfunction symptoms are, or are not, primarily caused by the actions of the suspected chemical stress on one or more physiological processes. Studies are designed within the context of understanding and predicting how natural and airborne chemical stresses interact on basic physiological processes to change growth of individual trees in a dynamic physical and airborne chemical climate.

Discussion

Tree growth is the end product of various genetic and environmental factors acting on physiological processes in trees as shown in the schematic diagram in Figure 1. Direct experiments on large trees are difficult to perform because of their large sizes and complex physiology. The size of trees is important because it affects both their ability to recovery from injury or stress and the relative persistence of effects from environmental factors. Growth of large trees contributes to a complex and persistent forest microclimate which in itself can have a major effect on the growth of mature trees.

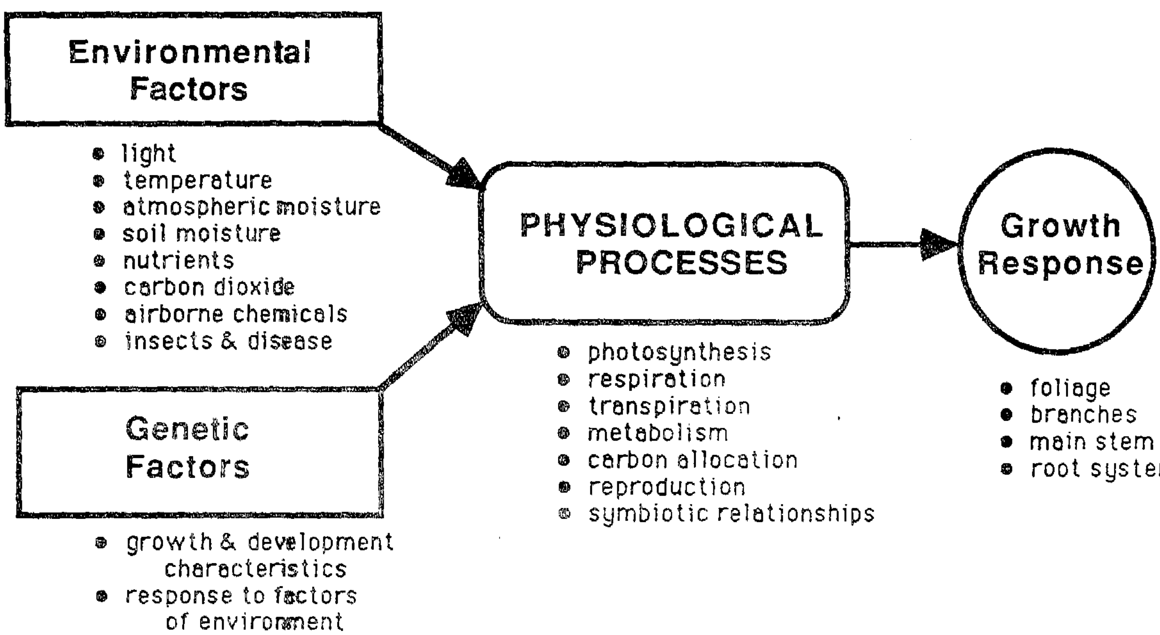


Figure 1 Diagram showing relationship of tree growth to genetic and environmental factors.

The "correlative" and "experimental" approaches (as stand-alone approaches) can only indicate the statistical significance of observed changes in growth or dysfunction symptoms with measured parameters of environment and forest structure. Neither approach by itself can prove or disprove that a suspected causal factor is, or was, responsible for the observed symptoms regardless of the statistical significance of the correlations. Correlation studies on individual mature trees are most valuable in identifying the major factors associated with observed symptoms and in developing testable hypotheses. By themselves, they cannot account for the actions of unmeasured factors or the effects of the interactions of all contributing factors on the observed symptoms. Similarly, although results from an empirical experiment may indicate that a suspected factor is involved in producing observed symptoms on a tree in a particular stand, it cannot by itself prove that the same factor is responsible for similar symptoms in other forests. Methods from both approaches will be most valuable when applied within a research strategy which seeks to interpret results within the context of known biological mechanisms.

"First principle" physiological process models are available for explaining and predicting (to limited degrees) the effects of environmental and genetic factors on carbohydrate production, carbon allocation, water uptake, nutrient uptake, cell division, etc., within mature trees. Although the quantitative aspects have not been developed for most tree species, generalized models have been accepted accepted by most forest tree physiologists.

Figure 2 is a schematic illustration of a generally accepted physiological process model for mature as presented at the workshop by David Ford. It may be understood by seeing how an airborne chemical might impact growth of a tree by reducing its rates of photosynthesis. The impact of reduced photosynthesis could "drive" changes in all the processes depicted in the diagram. First, it could reduce the amount of carbohydrates available for growth of foliage (leaf area) and roots. A reduction in root growth would increase the tree's vulnerability to adverse effects of droughts (less water flux) and microsite nutrient deficiencies. Sustained chronic water and nutrient stresses could lead to further reductions in photosynthesis, leaf area, carbohydrate production, etc. Any major reductions in carbohydrate reserves would both reduce the amount and change the allocation of carbohydrate going into growth of roots, shoots, foliage, and stemwood.

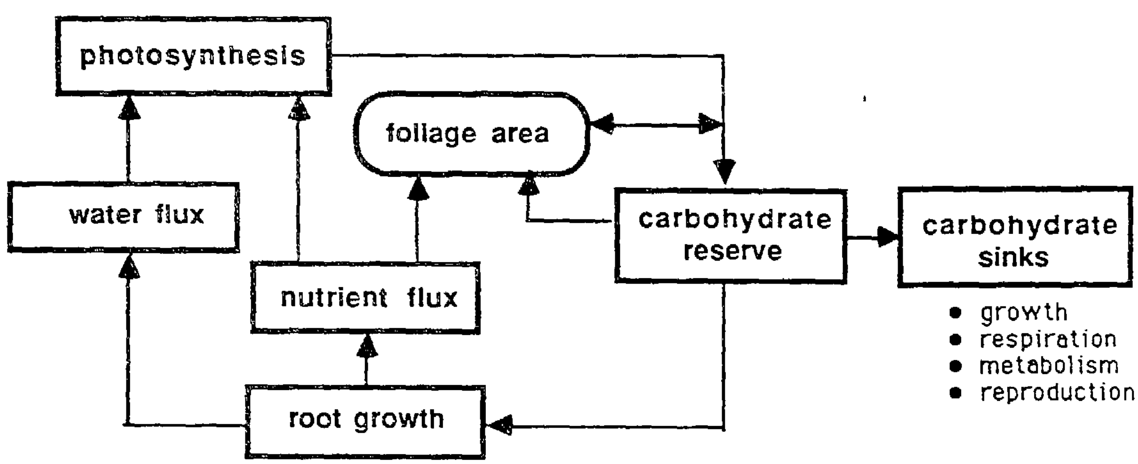


Figure 2 General schematic diagram of a "process-driven" model showing the inter-relationships of major physiological processes which are controlled by environmental factors (from E.D. Ford, 1982 Scottish Foresry 36:9-24).

The relationships shown in this "process-driven" model helps explain why a given concentration or deposition rate of a particular airborne chemical, or set of chemicals, may or may not affect tree growth. Tree growth and development is primarily dependent upon the environmental and stand factors where the tree grows. Favorable environmental conditions could reduce the potential impact on growth because the lower photosynthesis rates are partially or completely compensated by higher rates of other processes. Reduction in photosynthesis would have its greatest impact on trees growing in unfavorable or stressful site conditions.

The age and size of a tree also is a major factor in determining how a tree might react to stress factors. The hypothetical relationship of the three major stages of forest growth with tree age is shown in Figure 3. The growth of seedling- to pole-size trees in Stage 1 is proportional to their age. This is the stage of growth when competition-induced mortality is highest and leaf area of the forest and of surviving trees is also increasing. The environmental factors most likely to limit growth during this stage are light, carbon dioxide, soil nutrients, and water.

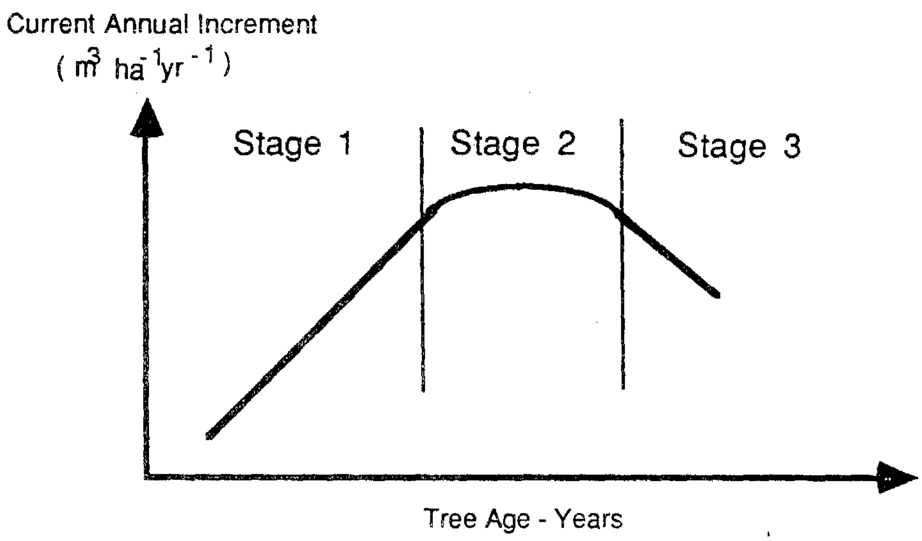


Figure 3 The relationship of tree age to three stages of forest growth in an even-aged forest.

Forest growth and leaf area index are highest and the most stable in Stage 2. Growth and survival of individual trees are particularly sensitive to environmental factors which reduce carbohydrate production and leaf area in the trees.

Forest growth declines in Stage 3. A combined effect of natural aging and tree size causes a gradual reduction in forest leaf area index and growth. Individual trees are most susceptible to climatic stresses and effects from insects and diseases. Any stress which reduces photosynthesis and nutrient flux, increases respiration, or worsens the effects of water stress, will have a significant impact on tree growth.

Answers To Two Questions

1. *What are the "best" approaches which should be taken to quantify the effects of airborne chemicals on mature trees in forest stands?*

There was unanimous agreement that studies on mature trees in forests should be framed within a "process-driven model" approach. It provides a mechanistic framework which is needed for proper interpretation of results from studies on trees of different species, ages, climates, and stand conditions. "Correlative" and "experimental" studies are valuable and most appropriate when interfaced with process-level models that address a particular species and stand condition. The value of integrated, multidisciplinary studies (i.e. several investigators looking at different aspects of the same tree or stand) in pursuit of this goal was highly recommended.

2. *What is the expected value of the information from studies on the response of seedlings to airborne chemicals in terms of understanding and predicting the response of mature trees to the same airborne chemicals?*

Workshop participants expressed the opinion that although results from studies with seedlings may have some qualitative value, *their quantitative value* (in terms of predicting effects on growth of mature trees) *is very limited*. Airborne chemical dose-response relationships (i.e. growth loss per certain dose of chemicals) in seedlings will not be representative of dose-response relationships of mature trees for the reasons outlined above with Figure 3. The most critical differences between the physiology of seedlings and mature trees are listed in Table 1.

Information derived from studies on seedlings will have their greatest potential value in:

- providing some information on species at risk to airborne chemicals (not necessarily loss in productivity);
- testing the genetic differences within and between seedlings of tree species;
- identifying mechanisms of pollutant action at the tissue and cell level;
- assessing risks of airborne chemicals on forest regeneration (assuming a process driven approach was used to design the experiments);
- identifying genotypes and/or clones which are sensitive and tolerant of some gaseous airborne chemicals; and
- identifying the combinations of airborne chemicals, climate, and microsite factors under which airborne chemicals may cause visible or invisible injury to trees.

Acknowledgements

Greatful thanks go to the following people who reviewed a draft of this report and made many helpful suggestions: Ellis Cowling, David Ford, Phil Dougherty, Kim Joyner, Paul Miller, George Taylor, and Bob Teskey.

J. N. Woodman 12/17/86

Table 1 The following significant differences between the physical and physiological characteristics of seedlings and mature trees are likely to affect experimental results and their extrapolation to mature trees in forests.

1. **Water relationships**

   a. aerodynamic resistance
   b. stomatal conductance; - intrinsic differences related to:
      1) raising of seedlings (natural vs. artificial growing conditions)
      2) morphology of stems, branches, and foliage
      3) position in a forest canopy
      3) numbers of needle age classes
      4) types of foliage (i.e. "sun" vs. "shade" leaves)
      5) mutual shading of lower brances and foliage
   c. water deficits and heat balance
      1) stomatal conductance
      2) length of water path
      3) rooting volume per unit of foliage
      4) buffering from capacitive water storage (different rooting depths)
      5) cuticular resistance
      6) foliage shading architecture (especially hardwoods)

2. **Carbohydrate relationships**

   a. acclimatization of the photosynthetic process to shade
   b. competition between carbohydrate uses ("sinks") increases as trees get larger; this is (this is often a factor limiting growth in large trees)
   c. carbohydrate storage
      1) storage is a distributed system relative to growth
      2) storage for root growth is relatively specific in its location in mature trees

3. **Nutrient balance**

   a. seedlings are in "net accumulation" phase of life; older trees may be in the "cycling" phase
   b. different mycorrhizal associations

4. **Patterns of growth**

   Patterns of root, shoot, and vegetative growth are usually very different

APPENDIX II

NATIONAL FOREST RESPONSE PROGRAM

QUALITY ASSURANCE IMPLEMENTATION PLAN

DRAFT

QUALITY ASSURANCE IMPLEMENTATION PLAN

for the

FOREST RESPONSE PROGRAM

National Acid Precipitation Assessment Program

Task Group V: Terrestrial Effects

Document Control Number

QA9.01.85

U.S. Environmental Protection Agency

Corvallis Environmental Research Laboratory

200 S.W. 35th Street

Corvallis, Oregon 97333

Nov 1986

Revision 1

QUALITY ASSURANCE IDENTIFICATION FORM

Document Title: Quality Assurance Implementation Plan for the Forest Response Program

Organization: Corvallis Environmental Research Laboratory

Address: U.S. Environmental Protection Agency
200 S.W. 35th Street
Corvallis, Oregon 97333

Responsible Official: Roger Blair Phone No. (FTS) 420-4662
Title: Forest Team Leader, Forest Response Program

Quality Assurance Officer: John Duff Bailey (Acting) Phone No. (FTS) 420-4324

Plan Coverage: This plan sets forth the quality assurance requirements pertinent to all Forest Response Program research and development tasks involving the systematic collection and evaluation of physical, chemical, biological, and other data related to the effects of air pollutants on forest ecosystems.

Concurrences:

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(1) Name Gary J. Foley
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Signature ______________________ Date __________

(2) Name Ronald D. Lindmark

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Signature ______________________ Date __________

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Title Chief, ERL-Corvallis Air Branch, U.S. EPA

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Signature ______________________ Date __________

Comments:

Table of Contents

Table of Contents (cont'd)

EXECUTIVE SUMMARY

The Forest Response Quality Assurance (QA) Program is designed to ensure that data produced in the Forest Response Program is of known and sufficient quality to meet its intended use for the integration of research results and the assessment of the effects of acidic deposition and associated pollutants on forest ecosystems. This entails interacting with investigators and Cooperative Directors to inform them of national QA requirements, standardizing techniques for the legitimate comparison of results among sites, auditing sites to ensure compliance with standard or approved procedures and protocols, and evaluating the quality of the final data bases determined from the quality of their parts.

The majority of the quality assurance work is conducted by the investigators during the research effort. This work consists of systematic checks on the procedures, equipment, and personnel to monitor repeated measurement error (precision) and accuracy. Limits of acceptability for precision and accuracy, called Data Quality Objectives, are described for each variable to be measured in the Forest Response Program (FRP). Data Quality Objectives will also be described for critical decision points reached while testing proposed hypotheses within the FRP framework. The investigators will be responsible for meeting these Data Quality Objectives and for developing and documenting the system employed to produce usable results.

The QA Staff assists the investigators with these activities and monitors the research projects with off-site performance evaluation audits (standards and inter-laboratory exchange samples) and on-site systems audits (physical review of facilities and equipment). The information collected and evaluated by the QA Staff is archived nationally and is available should data integrity be questioned.

The program outlined in this document pertains, in its entirety, to all projects funded after FY86. Projects funded in FY86, and before, are responsible for compliance to select parts as defined in this document and the QA Staff.