D. ABSTRACT

Applying Spatial and Temporal Modeling of Statistical Surveys to Aquatic Resources
Research Category: Research Program on Statistical Survey Design and Analysis for Aquatic Resources

1. Sorting Code: 2001-STAR-D1; responding to Statistical Research Area 2

2. Title: Applying Spatial and Temporal Modeling of Statistical Surveys to Aquatic Resources

3. Investigators: N. Scott Urquhart (Co-Principal Investigator and Program director, CSU), Richard A. Davis (Co-Principal Investigator, CSU), Jennifer A. Hoeting (CSU), F. Jay Breidt (CSU), David M. Theobald (CSU), Hariharan K. Iyer (CSU), Don L. Stevens, Jr. (OSU), Alix I. Gitelman (OSU), Robin M. Reich (CSU), Steven B. Weisberg (SCCWRP), Kerry J. Ritter (OSU and SCCWRP), James C. Loftis (CSU), Alan T. Herlihy (OSU), Stephen W. Johnson (WQTI)

4. Institutions: Colorado State University (CSU), Oregon State University (OSU), Southern California Coastal Water Research Project (SCCWRP), Water Quality Technology, Inc. (WQTI)

5. Project Period: October 1, 2001 - September 30, 2005

6. Project Cost: $749,437, first year
   $2,998,331, total for four years

7. Overall Summary:

Objectives: This Program will extend existing EMAP survey design and analysis methodology to enhance the use of auxiliary information, to apply recent advances in statistical modeling techniques to aquatic resources, and to develop model-based methodology compatible with EMAP's multi-tiered studies; to implement these techniques on example data sets; to provide expert survey design and analysis assistance to States and Tribes; and to transfer that statistical expertise to States, Tribes and local agencies through a combination of supervised application of statistical tools and structured distance learning techniques.

Approach: The Program proposed here will initiate statistical research on several well-defined topics in model-based inference: Combining environmental data, local prediction of environmental responses, and the development and evaluation of indicators of environmental responses. We have identified some statistical research needs coupled with existing EMAP data sets. We will develop model-based analysis methods to meet those needs. We have established liaisons with some state, tribal and local organizations who are using (or plan to use) EMAP or EMAP-like surveys of aquatic resources. We will strengthen and expand those contacts to include all identifiable State and Tribal agencies who are using (or plan to use) EMAP, REMAP, or EMAP-like surveys of aquatic resources. We will assist those agencies in applying existing survey design and analysis methods, and, in particular, investigate and extend techniques for

incorporating auxiliary information in the design. In collaboration with those agencies and other State and Tribal organizations, we will identify further statistical research needs to be addressed by our statistical methodology research teams and extend model-based analyses as necessary. Further, we will explore various distance learning techniques with our collaborators, and use their feedback to refine our techniques.

Expected Results and Benefits: The Program proposed here will substantially improved methodology for assessing the condition of aquatic resources at all levels: national, multiple state regions, state, tribal, and local. The proposed program will also improve the awareness of that methodology by the parties who should use it, and will expand the cadre of statisticians with the experience and expertise to collaborate with aquatic scientists and resource managers on monitoring aquatic resources.

The Program is designed to accomplish five major goals:

- Extend model-based statistical methodology to cover the unique circumstances encountered in EMAP, and EMAP-related situations.
- Extend both existing and newly-developed model-based statistical tools more accessible to state, tribal, and local agency personnel, both the aquatic scientists and managers of aquatic resources.
- Expand the pool of personnel in the States, Tribes, and local agencies who have both understanding of and experience in using the statistical tools.
- Develop and train a cadre of statisticians with the experience and expertise to collaborate on monitoring aquatic resources.
- Develop three archetypes of rigorous probability- based, state or local monitoring programs, along with archetype model-based analyses, incorporating landscape scale features into the analysis. The existence of these archetypes will benefit EMAP's efforts to build state, tribal, and local infrastructure to monitor the condition of the Nation's aquatic resources.

Supplemental Key Words: public policy, decision making, community-based, monitoring, risk assessment, watersheds, surface waters, estuaries, Bayesian, GIS, landscape

E. OVERALL DESCRIPTION

1. *OBJECTIVES*

- Identify, develop, adapt and implement cutting-edge statistical techniques appropriate for the environmental sciences, emphasizing
  - aquatic resources,
  - spatial and temporal methods,
  - use of landscape-scale information, and
  - EMAP and EMAP-like data for evaluation of techniques.
- Facilitate the professional development of future environmental statisticians.
- Extend expertise on design and analysis to the States, Tribes and local agencies.

Context: The earth's environment is in a continual state of change. Organisms are born, live, reproduce and die, but may produce harmful by-products which threaten their own well being as well as that of other organisms. Humans are unique among the forms recognized to have inhabited the earth: Like others, we are influenced by the environment, but we are distinct from all others in that our actions can have major impacts on all other organisms on earth. As the human population grows we must understand the environment and our effect on it in order to preserve it as a place inhabited by future generations of humans. This makes a compelling case for the study of the environmental sciences. How should that proceed?

It has become apparent that the earth itself is the organism in need of study; local processes combine into regional processes, which in turn merge into global processes. Environmental studies immediately encounter a vexing reality: Variability is inherent in the earth's environment at every scale. The traditional views of the scientific method use experimental design to control that variability in the presence of responses of interest and explanatory variables, which often are manipulated. Thus, an opportunity exists to repeat experiments over and over while incorporating the three principles of blocking, replication, and randomization. Although this research paradigm applies to some narrowly defined problems in the environmental sciences, the processes of major interest typically exhibit strong spatial, temporal and exogenous variability for which control is impossible.

The **NATIONAL RESEARCH PROGRAM FOR APPLYING SPATIAL AND TEMPORAL MODELING OF STATISTICAL SURVEYS TO AQUATIC RESOURCES** (the Program) must focus on variability as it impacts on the environmental sciences, especially the aquatic sciences. From a classical perspective every environmental study and every datum within a study is unique and incomparable to any other datum. Yet the acknowledged variability has substantial structure which provides a reasoned context for relating the individually unique outcomes; our understanding of the structure of variability in a specific case may range from meager to substantial. Statistical models can be used to characterize that variability in ways which can form the basis for reasoned decision-making. For example, hierarchical statistical models offer a very powerful way of representing complex global phenomena through simple local structures. Traditional statistical goals of parameter estimation can be expanded to more basic goals of process prediction, for which tools such as Bayesian statistics can play a fundamental role.

Frequently, the variability mentioned above exhibits strong spatio-temporal structures in need of characterization, in conjunction with purported dependencies on explanatory variables.

That is, questions of "why" cannot be answered sensibly without first answering questions of "where" and "when." Space and time provide natural ways to stratify (often hierarchically) large problems into more manageable ones. Finally, the prediction of processes of interest usually is needed for small areas and specific points in time. Thus the nature of the variability observed in the environmental sciences often requires environmental statistics generally, and the Program in particular, to utilize spatio-temporal statistical models.

To meet the demands outlined above, the Program will have to do statistical modeling using powerful computational resources. In particular, the Program will have to develop further innovative and computationally-intensive methods such as resampling, subsampling, and Markov Chain Monte Carlo and other simulation-based methods to accommodate the realities of the environmental context. The relevance of developments coming from the Program will be tied directly to the development of relevant computer-intensive methods appropriate for fast workstations and super computers. One of the Program's major challenges will be to develop, adapt, and disseminate statistical methods for the massive data sets that future studies of the environment will engender, especially in a manner appropriate for use by the States, Tribes and local authorities. The most obvious source will incorporate data obtained from remote sensing platforms, as these devices continue their march toward increased spatial accuracy at higher temporal frequencies and over ever widening spectral band width. Massive increases in data volume have emerged over the horizon: NASA launched the Earth Observing System (Landstat 7) in 1999; it produces data sets three orders of magnitude larger than the older ones used to study global geophysical and ecological problems! The areas of data exploration and visualization are critical to understanding and communicating the results of environmental studies; these areas of statistics can best be described as embryonic. The Program must nurture and expand these areas, as much more massive data sets than we currently deal with arrive on the scene. The increasing resolution of satellites can only be expected to increase, creating ever more acute problems in managing and suitably using the resulting data.

EMAP began in 1989 with the concept of using rigorous probability surveys to assess condition and determine trends in condition of environmental resources. In the intervening years, EMAP has developed an extremely flexible, widely-applicable, and robust methodology for designing probability surveys of aquatic resources (Overton, White, and Stevens, 1991; Larsen, *et al.*, 1991; Larsen, *et al.*, 1994; Stevens, 1994; Stevens, 1997, Stevens and Olsen; 1999; Stevens and Olsen; 2000). Simultaneously, EMAP has been developing corresponding design-based analysis methods to use with EMAP probability surveys (Diaz-Ramos, Stevens, and Olsen, 1995; Stevens and Kincaid, 1998; Urquhart and Kincaid, 1999; Kincaid, 2001; Stevens and Olsen, 2001). For the most part, the analysis methodology documented by EMAP has been those design-based methods appropriate to variable probability surveys.

Part of EMAP's objective is to demonstrate the multi-tier framework of the Committee on the Environment and Natural Resources (CENR) (Committee on the Environment and Natural Resources, 1996). This framework requires design and analysis methods that incorporate data from 3 resolution levels: (1) Spatially continuous monitoring and inventories, including remote sensing, that completely census specific properties across a large region (10,000km^2 or more); (2) Spatially subsampled surveys and monitoring that are designed to evaluate the status of a large region by sampling a subset of the total area; and (3) Intensive research sites that are selected due to their known ecological condition or suitability for experimental manipulation. Design-based methods by themselves are not suitable for this task, inasmuch as levels (1) and (3) are rarely

based on probability designs. Thus, the pure design-based methods used for EMAP's probability surveys need to be extended to model-assisted and model-based analysis techniques.

The Program proposed here will focus on using spatial and spatial-temporal model-based methods, Bayesian methodology, and incorporat landscape metrics evaluatable from remote sources, such as satellites.

Many of our pressing environmental problems have a multi-disciplinary character. Attacking such problems requires a team. The environmental statistician can contribute to the success of many such teams, but statisticians with suitable training and experience are in short supply. The research, development, and outreach proposed here is designed to heavily involve both doctoral students and post-doctoral fellows. This and other planned activities are designed to increase the cadre of available and experienced environmental statisticians.

The Request for Proposals (RFA) governing this proposal specifically directs the extension of the knowledge and methods developed under this proposal to the states and tribes. As the proposed Director has investigated this, it has become apparent that there quite a number of governmental authorities more local than a state which should be included in this extension effort. At least one such agency will participate in the research proposed here.

Specific Objectives: Most state-level and smaller agencies lack in-house statistical expertise in the depth required to perform a design-based analysis of a complex probability survey, much less to extend the analysis to use model-based techniques. Inasmuch as EMAP's long-term success depends on a state-level infrastructure capable of implementing multi-tier monitoring, and analyzing and interpreting the results, it is critical that sophisticated statistical analysis techniques be made accessible to that States, and that the States have personnel capable of using the techniques.

Our objectives for this Program are to extend existing EMAP survey design and analysis methodology to enhance the use of auxiliary information; to expand model-based methods compatible with EMAP's multi-tiered studies; to implement these techniques on example data sets, to apply recent advances in statistical modeling techniques to aquatic resources, and to make both existing and newly developed survey design and analysis methodology accessible to the States, Tribes, and local agencies.

2. ***APPROACH***: The RFA to which this proposal responds will establish a National Research Program on Statistical Survey Design and Analysis for Aquatic Resources consisting of two programs, one aimed at Statistical Research Area 1: Design-Based/Model-Assisted Survey Methodology; the other aimed at Statistical Research Area 2: Spatial and Temporal Modeling Incorporating Hierarchical Survey Design, Data Analysis, and Modeling. This proposal is directed toward Area 2. A parallel proposal, directed toward Area 1, is being prepared by Oregon State University. While either proposal will stand on its own, an especially strong overall Program will result from the interplay of these two institutions. The two Programs have been designed to capitalize on the strengths of the respective institutions, and to share resources. For example, the Program at OSU includes a project with a PI at CSU, because of his particular strength in Design-Based/Model-Assisted inference. Similarly, the Program at CSU includes an investigator at OSU, because of her interest in Hierarchical Bayes inference. The Proposed Directors, Stevens and Urquhart, have an established history of professional collaboration with one another, and both have recognized skills in developing statistical formulations for real world

problems. Furthermore they both have strong existing contacts within the community of potential users of statistical methodology for monitoring aquatic resources. For this reason, each of the Directors also has a time commitment on the proposal from the other institution. As we develop this proposal, we will point out additional areas where we have built-in links between the two proposed Programs.

The Program proposed here will consist of five projects:

★ COMBINING ENVIRONMENTAL DATA SETS
★ LOCAL PREDICTION FROM AQUATIC STUDIES
★ DEVELOPMENT AND EVALUATION OF AQUATIC INDICATORS
★ EXTENSION AND OUTREACH
★ INTEGRATION AND COORDINATION (as directed in the RFA)

Project 1, COMBINING ENVIRONMENTAL DATA SETS, will explore how to combine several types of environmental data: from intensively monitored sites, from a collection of sites selected according to some probability model, from complete coverage, as from satellite images, and from other sources, such as features of issued permits or historic land use. This project will utilize several data sets described below. It also will coordinate with and utilize the products of Project 3. This Project will address topics raised in focus areas 2.1 (area 2,focus point #1), 2.2, 2.3, 2.4, 2.7, and 2.9. Project 2, LOCAL PREDICTION FOR AQUATIC STUDIES will address 2.4, 2.5, and 2.6. As with Project 1, it will utilize products of Project 3, as appropriate. Project 3, DEVELOPMENT AND EVALUATION OF AQUATIC INDICATORS, will address the development of aquatic indicators at several scales. A major effort for this Project will be to identify and compute a number of landscape scale indicators which can then be evaluated in Projects 1 and 2. Project 3 also will consider the development of indicators at regional scale (focus area 2.8), at the site scale, an often ignored scale, and in collaboration with other investigators, the point scale. This project will start as a substantial effort which will be diminished during the life of the Program, the opposite of Project 4 which will start off small and increase as the program continues. This project, EXTENSION AND OUTREACH, concerned with providing users of environmental statistics with usable knowledge and tools, some developed by this Program, will begin with an evaluation of the statistical and sampling needs of various state, tribal and local agency personnel. Instructional materials will then be developed to meet those needs using a variety of methods described in the proposal for Project 4. Project 5, INTEGRATION AND COORDINATION, is concerned with providing suitable coordination among the other four projects, the companion Program, various users in the States, Tribes and local agencies, EPA personnel, other parties involved in research and development related to aquatic resources, specifically to include academic workers. The integration of these Projects with one another and the interaction with state, tribal and local agency personnel who collect, analyze, and interpret monitoring data is of such paramount importance that we have devoted a separate project to it. The Program Director is the Principal Investigator for this Integration and Coordination Project. The primary tasks here are to ensure communication between the three methodology Projects, to facilitate the forging of collaborative relationships between Program statisticians, EPA/ORD scientists, and state, tribal and local agency personnel, to demonstrate current and new statistical approaches using aquatic monitoring data, and to expand the pool of personnel in the States, Tribes, and local agencies who have both understanding of and experience in using the statistical tools.

The interdisciplinary team assembled for this proposal includes nine statisticians with diverse interests in spatial statistics, time series analysis, hierarchical analysis, sampling, environmental statistics, and statistical instruction; a geographer with strong skills in geographic information systems and large databases and landscape ecology; and four aquatic scientists with a wide range of skills and interests from measurement of water characteristics to the spatial distribution of macroinvertebrates.

The essence of our approach lies in our conviction, based on long experience, that a searching analysis of a real, moderately complex, data set almost always generates questions whose answer calls for an extension of existing statistical theory or methodology. We anticipate that the simpler of such research opportunities will become problems solved by the pre-doctoral students, more complex ones will be attacked by the post-doctoral fellows, and the most complex ones will challenge even the affiliated faculty supervisors. The identification of those questions requires a strong working relationship between the statistician and the (subject matter) scientist. Furthermore, a real collaboration, with the statistician becoming engaged in the application science, and the application scientist becoming engaged in the statistics, is the best way to foster understanding of the statistical methods.

Post-doctoral fellows and pre-doctoral students will be actively involved in all of the projects, except the last one. The first and second projects involve the identification, development, and implementation of statistical methodology. The general approach for them will be to identify several data sets relevant to the area under consideration, including ones from EMAP's field and laboratory activities, and have the apprentice statisticians analyze the data from any of several perspectives. These apprentices will be just that: apprentices. Each one will have a supervising professor and a supervising committee. This committee will be the graduate committee of the pre-doctoral student, and will function much the same way for the post-doctoral fellows. This will require frequent interactions of the apprentice with his/her supervising professor, and occasional interactions with his/her supervising committee. We also will actively involve the apprentices in the Integration and Outreach Project. This paradigm has the dual benefits of multiplying the effectiveness of senior personnel and simultaneously increasing the pool of seasoned environmental statisticians.

As proposals were being prepared, the Directors of the CSU and the OSU proposals contacted the personnel in States which are participating in EMAP-West, explaining the purpose of the Programs, and inviting their cooperation and collaboration. The responses have been uniformly positive. Some states, for example, Washington and North Dakota, described some future surveys where our assistance would be beneficial. In addition, we invited a stronger collaboration from 3 state agencies and an Indian Tribe who we knew were active in aquatic monitoring. All 4 organizations have provided letters of support, which are attached to the Extension and Outreach Project proposal. We expect this collaboration to be more than simply having the states provide data for the Program statisticians to analyze. Both Project Directors have been very successful in collaborative research endeavors; and we expect to be so again.

The collaboration is structured along the following lines: The Programs at CSU and OSU will provide statistical expertise on survey design, data analysis, and model-building; in exchange, the state collaborators will provide subject matter expertise in identifying and articulating the scientific and policy questions, scientific insight in model formulation, and access to data sets for model parameter estimation. The Programs will provide the content and delivery

of technology transfer; the states will provide guidance on what's needed, and feedback on the success and effectiveness of the delivery techniques.

The statistical scientists, faculty, post-doctoral fellows and graduate students, will need three additional kinds of support: a substantial computing resource, landscape characterization data for the "top-down analyses," and assistance in understanding the realities of aquatic systems as the impose restrictions on the statistical analyses. The Program proposes to purchase a substantial computing resource which will be available to all members of the team for heavy computing which is planned. As availability of computing platforms will change between now and when a machine could be ordered, we have not specified a specific machine; but foresee something like a Sun Blade 1000 model 2750. The director will facilitate the movement of relevant landscape data from external sources to the indicator development project to the statistical projects. Dr. Alan Herlihy of Oregon State University will meet with each of the project principal investigators to establish begin the process of incorporating the realities of aquatic systems into the statistical models.

Data Sources: Since 1990, the surface water component of EMAP has completed regionally extensive probability surveys of lakes in the Northeast and streams in the mid-Atlantic U.S. An extensive survey of streams from 12 western states in EPA regions 8, 9 and 10 was initiated in the summer of 2000. In addition, EMAP has funded or supported many smaller scale probability surveys of aquatic systems of special interest to individual EPA regions or state agencies. Some of these are summarized in Table 1. All of these sampling efforts are characterized by the use of probability surveys of a specified target population and common protocols in the measurement of aquatic indicators of condition. Many of the surveys include landscape-level indicators in addition to the point-level aquatic indicators. In addition to the probability site data, some surveys also sampled a number of hand-picked sites to represent the best (reference sites) and worst (test sites) condition systems in the area.

Table 1. EMAP/REMAP Surface Water Surveys

Survey	Target Population
EMAP - NE Lakes (1991-1996)	Lakes in NE US
EMAP -MAHA (1993-1996)	Wadeable streams in mid-Atlantic
EMAP - MAIA(1997-1998)	Streams/Rivers in mid-Atlantic states
EMAP - West(2000-2004)	Streams/rivers in western U.S.
REMAP-Region 1 (1993-1994)	Lakes in Maine
REMAP-Region 5 (1995)	Wadeable streams in Eastern Corn Belt
REMAP-Region 7 (1994-1995)	Streams/rivers in KS, NE, and MO
REMAP-Region 8 (1994-1995)	Wadeable streams Southern Rocky Mtns
REMAP-Region 9(1994-1995)	Streams and canals in Central Valley of CA

Survey	Target Population
REMAP-Reg. 10 (1994-1996)	Wadeable streams in OR, WA
EMAP - Indicator Dev (1992-1999)	Wadeable streams OR
EMAP - TIME (1991-ongoing)	Lakes and streams in NE and mid-Atlantic
EMAP - Oregon Pilot (1997)	All streams and rivers in Oregon
Oregon ODFW(1998 - ongoing)	Coastal streams in OR
Southern CA (1994 & 1998)	Southern California Bight - near coastal
South Florida	Marshes & Canals in Florida Everglades

Coordination: The program proposed here anticipates the need for collaboration and coordination with at least four identifiable groups of interested people: Between projects within the program proposed here; with other EPA-funded activities related to the one proposed here; EPA personnel; and potential users of the methods developed here. The management plan described subsequently includes components to assure cooperation among the first group of people; the last group is the focus on the next subsection.

EPA has funded or advertized the intent to fund several related activities with which the work proposed here will cooperate. The RFA to which this proposal responds included two Programs between which cooperation was required. The Program proposed here is directed toward Statistical Research Area 2: Spatial and Temporal Modeling Incorporating Hierarchical Survey Design, Data analysis and Modeling. The same announcement called for another Program directed toward Statistical Research Area 1: Design-Based/Model-Assisted Survey Methodology. The Program proposed here will cooperate closely with the Program directed toward area 1 by holding annual joint meetings, whose locations will alternate between CSU and the site(s) specified by the group awarded the other Program. This proposal from CSU is made with full awareness that a proposal for area 1 is being prepared by Oregon State University. As mentioned earlier, if CSU and OSU were awarded the respective cooperative agreements announced by the RFA, an especially fruitful cooperation between the two Programs would emerge due to the complementary strengths in the respective departments of statistics.

EPA also announced an intent to fund a second five years of a "National Center for Research on Statistics and the Environment" which currently is located at the University of Washington. The Program proposed here will cooperate with whatever group is awarded the second five years of this Center. EPA also has funded a STAR grant to Brian Bledsoe of the Department of Civil and Environmental Engineering at CSU. That project will be developing primary data related to macroinvertebrates in streams, one of the areas of application of interest to the director of this proposal. The program proposed here will cooperate with Bledsoe on the spatial analysis of data resulting from his project, to the extent of adapting or developing new methods of spatial analysis, if needed. He welcomes this opportunity for collaboration.

Our interaction with scientists and programs in EPA's Office of Research and Development (ORD) will assume at least two distinct forms: Important problems need to be identified, then solutions need to be obtained and communicated. We already have good

communication with several statisticians at EPA. Urquhart has worked with both statisticians and ecologists at the Western Ecology Division of the National Health and Environmental Effects Laboratory in Corvallis, OR. The research team has established contact with Daniel Heggem at the Environmental Sciences Division, Landscape Ecology Branch, of EPA's National Exposure Research Laboratory in Las Vegas, NV. He serves as the landscape lead for EMAP and has expressed an enthusiasm for collaborating with this proposed Program if it is funded.

The investigators feel they MUST greatly expand their base of contacts in ORD, especially among non-statistician researchers who are quantitatively knowledgeable. We will seek guidance from the Project Officer and ORD personnel identified by the Project Officer in developing these contacts. The Program's Director will assume major responsibility for this interaction, but include other Investigators whenever their skills will substantially enhance the interaction. The Director is recognized for his skill in developing statistical formulations for real world problems. These will require substantial travel on his part, but whenever feasible, other modes of communication will be used, such as the internet, the World Wide Web, e-mail, and emerging alternatives like computer-based video communication.

Once Program Investigators have developed solutions to problems of general interest to ORD scientists, they will communicate the results in appropriate manners to suitable audiences, including printed matter, computer-based materials, oral presentations, demonstrations, and journal articles. Note that two of the investigators have begun distributing research results as computer available materials, including materials on the World Wide Web and video tapes. The Information Services Division at OSU has a Communication Media Program which supervises televised classrooms for distance learning and the Department of Statistics at CSU has a long history of offering courses in a distance degree program. Distance instructional services at both CSU and OSU are available to projects such as the one proposed here, on a cost-recovery basis. We anticipate making substantial use of this sort of distribution of materials to scientists at ORD.

A **Consortium of Users of Environmental Statistics (CUES)** has been started and is described as a part of the proposal for Project 4.

3. ***EXPECTED RESULTS OR BENEFITS:*** The Program proposed here will substantially improved methodology for assessing the condition of aquatic resources at all levels: national, multiple state regions, state, tribal, and local. The proposed Program will also improved the awareness of that methodology by the parties who should use it, and expand the cadre of statisticians with the experience and expertise to collaborate with aquatic scientists and resource managers on monitoring aquatic resources. The Program proposed here has specific goals, all of which provide benefits to identifiable communities:

- Extend the model-based methodology design and analysis methodology to cover unique circumstances encountered by EMAP; specifically expand model-based methods compatible with EMAP's multi-tiered studies.
- make both existing and newly-developed model-based design and statistical methods available more accessible to state, tribal, and local agency personnel, both the aquatic scientists and managers of aquatic resources.

- ➢ Expand the pool of personnel in the States, Tribes, and local environmental agencies who have an understanding of and experience in using the statistical tools.
- ➢ Develop a cadre of statisticians with experience and expertise to collaborate on the design and analysis aspects of monitoring aquatic resources.
- ➢ Develop several illustrations of combining rigorous probability-based, state or local monitoring programs, with other kinds of data model-based analyses. The existence of these illustrations will benefit EMAP's efforts to build state, tribal, and local infrastructure to monitor the condition of the Nation's aquatic resources.

The results of the work proposed here will be made available through a variety of outlets. The results of the proposed research will be published in refereed journals. This provides the scientific community with access to the results, but probably not most of the other communities. The results will have to be communicated to various audiences in manners suitable for that audience. The program proposes to use a variety of communication media to include, but not be limited to, meetings with oral presentations, presentations on the World Wide Web, teleconferencing, web chat rooms, and media which may emerge during the life of this proposed Program.

The results of the Program will be presented at meetings of statistical and environmental science societies, for example, the JSM, The International Environmetrics Society, Ecological Society of America, and the American Fisheries Society. Manuscripts will be submitted to journals such as the Journal of Agricultural, Biological, and Environmental Statistics, Environmetrics, Journal of Environmental Management, Environmental Monitoring and Assessment, and Environmental Science and Technology. We will also create a web site for this program, describing the Program. Published documents, as well as some educational tools, will be made available on the web site.

4. ***MANAGEMENT PLAN AND MILESTONES***: The management plan will focus on obtaining appropriate personnel, data and equipment in a timely fashion so that the component projects can pursue their respective lines of endeavor with a minimum of administrative distraction. The director's immediate tasks will be facilitating the purchase and installation of three high-end scientific workstations, and to assist in the recruitment of post-doctoral fellows and graduate students in accordance with the needs of the component projects. In the case of graduate students, their recruitment will have to be coordinated with the academic units in which they will be enrolled. The director will meet at least monthly with principal investigators of each of the component projects, and more frequently when needed. These monthly reviews will be intended to identify both progress toward project goals and obstacles to continuing progress.

The Program Director, Urquhart, will have overall responsibility for the management and administration of the Program. That responsibility will include, but not be limited to :

- ➢ Coordinate the research activities of the individual Projects comprising the Program
- ➢ Track budgets and research progress
- ➢ Recruit graduate students and post-doctoral fellows.
- ➢ Organize meetings with the companion research Program on Spatial and Temporal Modeling

The geographical separation of the Investigators presents a management challenge, and is one of

the reasons we have budgeted substantial travel. Most of the faculty research time will occur during the summer, and we plan to have a colloquium of all the Program investigators once every summer. We may be able to schedule this colloquium to coincide with the annual joint meeting of the two Programs or an annual professional meeting, such as the Joint Statistical Meetings (JSM). We will also make full use of electronic communication, including conference calls, email, and video conferencing, to maintain tight links between the individual Projects. For the Projects centered at Colorado State University, we plan on frequent interaction between the Investigators.

To ensure that both Programs are meeting the primary objectives of the RFA, we have established An External Review Panel comprised of three nationally-known environmental statisticians. The Panel members were selected by Urquhart and Stevens, and contacted by Urquhart. The Panel members are Dr. Noel A. C. Cressie, Dr. Steven K. Thompson, and Dr. Jay Ver Hoef. Noel Cressie of Ohio State University is an internationally recognized specialist in both spatial statistics and environmental statistics. Steven K. Thompson of Pennsylvania State University has international stature as a sampling statistician with special interest in living natural resources. Jay M. Ver Hoef, an experienced statistician employed by the Alaska Department of Fish and Game, represents the perspective of state managers of environmental resources. These three have all agreed to serve as an external review panel twice for the Programs proposed by CSU and OSU. We currently expect the Panel to meet twice during the 4-year duration of the Programs, with each meeting taking no more than 2 days. We will try to schedule the Review Panel meetings so that the Panel has some substantive activity to review, and we have sufficient time to react to the Panel comments. The Panel members will receive honoraria and expenses for the meetings. If only one of the Programs is funded, presumably the Panel members would be open to some renegotiation of their responsibilities.

By staying abreast of the progress and obstacles of each project, the director can facilitate interactions among investigators all of the projects at suitable times and on appropriate topics. The nature of these interactions are explored further in Project 5: INTEGRATION AND COORDINATION.

The first year of the Program will begin with a meeting of the Program Directors and the Principal Investigators from this Program and the companion Program on Design-Based Analysis. The meeting should take place at one of the two home institutions. The purpose of the meeting will be to establish procedures for coordinating the programs; especially the outreach to the states. In most instances, the outreach activities should be joint activities, e.g., visits to state, tribes or local agencies should normally involve both Program Directors.

We expect that the Program to be funded in September on 2001. We will initiate recruiting activities for graduate students and Post Doctoral Fellows at that time. We expect to have at least one graduate student begin work almost immediately on notification of funding. Several current students at CSU have expressed substantial interest in participating in this Program. Recruitment of Post-doctoral fellows will begin immediately upon notification of the award of this cooperative agreement. Due to the realities of personnel policies, advertizing and completion dates students who have just completed their doctorates, it is unlikely that any post-doctoral fellows can be hired before 4 - 6 months after the award notification. The milestones listed subsequently reflect this reality.

The lag-time between the start of the Program and the arrival of Post Docs and Graduate students is compensated for by the subcontracts with SCCWRP and and Water Quality

Technology, Inc. (WQTI). We have identified a well-defined research areas for these subcontracts. SCCWRP will have personnel who can immediately begin work on Projects 3 and 1.

Recruitment of Post-doctoral fellows will begin immediately upon notification of the award of this cooperative agreement. Due to the realities of personnel policies, advertizing and completion dates students who have just completed their doctorates, it is unlikely that any post-doctoral fellows can be hired before 4 - 6 months after the award notification. The milestones listed below reflect this reality. By the end one year from the award date, these tasks should have been accomplished:

- ➢ Recruitment of all post-doctoral fellows and graduate students planned for the second year
- ➢ Purchase and installation of three high-end workstations, two for the GIS/landscape ecology indicator development, and one for statistical analysis
- ➢ Receipt of all EMAP data planned for statistical analysis and its installation on the common statistical analysis workstation.
- ➢ Determination of the priority of landscape indicators, and availability of 1/3 of this for use in the statistical analyses.
- ➢ The director will have facilitated an expansion of the membership in the Consortium of Users of Environmental Statistics (CUES), and have met with their representatives at least once.
- ➢ Detailed research plans will have been developed for each of the projects, and will have been forwarded to the project officer by 9 months after the award data.
- ➢ The first joint meeting of the directors of the two Programs foreseen by the governing RFA will have occurred, the first joint meeting of investigators should have occurred.
- ➢ Necessary contracts will have been negotiated and be in place.
- ➢ The first joint meeting with the Companion Program will have occurred.

By the end two years from the award date, these tasks should have been accomplished:

- ★ All projects will have completed their first annual report, and be well into their second year of research.
- ★ The external review panel will have reviewed progress and possibly recommended some changes in focus.
- ★ The landscape indicators will have be at least 80% complete and available for statistical analysis.
- ★ The second joint meeting with the Companion Program will have occurred
- ★ At least 5 manuscripts intended for submission to the refereed literature will have been drafted.

The third and fourth years from the award date will for the most part be continuation of activities begun in years 1 and 2, except that the indicator development work will decrease substantially and the outreach will increase from the earlier years. The second Review Panel meeting will be held towards the end of the second year, possibly in conjunction with the third General Meeting. Further trials will be conducted with the distance learning tools, and efforts will be made to publicize the availability of the tools. Additional research will be published or presented, with a target of 5 or more presentations and papers.

5. *GENERAL INFORMATION*: The Program has been carefully structured to address the primary objectives outlined in the RFA, namely (1) to support advances in the mathematical science of probability and hierarchical survey design and analysis and spatial and temporal modeling, and (2) to develop and extend the expertise on design and analysis to States, Tribes and local agencies.

The RFA to which this proposal responds will establish a National Research Program on Statistical Survey Design and Analysis for Aquatic Resources consisting of two programs, one aimed at Statistical Research Area 1: Design-Based/Model-Assisted Survey Methodology ; the other aimed at Statistical Research Area 2: Spatial and Temporal Modeling Incorporating Hierarchical Survey Design, Data Analysis, and Modeling. This proposal is directed toward Area 1. A complementary proposal, directed towards Area 2, is being prepared by Colorado State University. While either proposal will stand on its one, an especially strong overall Program will result from the interplay of these two institutions. The two programs have been designed to capitalize on the strengths of the respective institutions, and to share resources. For example, the Program at OSU includes a project with a PI at CSU, because of his particular strength in Design-Based/Model-Assisted inference. Similarly, the Program at CSU includes an investigator at OSU, because of her interest in Hierarchical Bayes inference. The Proposed Directors, Stevens and Urquhart, have an established history of professional collaboration with one another, and both have recognized skills in developing statistical formulations for real world problems. Furthermore they both have strong existing contacts within the community of potential users of statistical methodology for monitoring aquatic resources. As we develop this proposal, we will point out areas where we have built-in links between the two proposed Programs.

Colorado State University offers a very positive environment for studying spatial and temporal statistical processes. Interest in spatial science extends through many parts of the University. A proposal to create a Center for Geospatial Science and Modeling has advanced to tehvice president's level, with substantial support at lower levels. A graduate certificate in geospatial science already is in place, and plans are also well along for interdisciplinary graduate degrees (M.S. and Ph.D.) in geospatial science.

The Front Range Area of Colorado offers additional opportunities for collaboration in geospatial science. The National Center for Atmospheric Research (NCAR) in nearby Boulder, CO has major interests in the study of spatial and temporal processes, and is the home of the NSF-funded Geophysical Project. A close collaborative relationship already exists between CSU's Statistics Department and that Project; further collaborations will develop if this proposal is funded. Although that work is focused on studies of atmospheric processes, many of the same concepts may be useful in characterizing spatial and temporal processes in the environmental sciences.

EMAP has a data policy articulated in the EMAP Information Management Plan: 1998 - 2001 (Hale, S. J. Rosen, D. Scott, J Paul, and M. Hughes (1999)). Those making this proposal are aware of that policy, and will adhere to it. In fact, the proposed program will benefit greatly from this policy in obtaining needed data.

PERSONNEL: The Program proposed here will involve a spectrum of personnel with a variety of skills, many with experience very closely related to the objectives set out in the RFA.

N. SCOTT URQUHART (CSU and OSU) - Co-principal Investigator of the program, is a research professor at OSU through September, 2001, but also holds an appointment as a visiting research professor at CSU. If the cooperative agreement proposed here is funded, he will assume an appointment as a research professor at CSU. He has worked as an applied statistician with ecologists and in agricultural experiment stations, and has taught graduate statistical methods at Cornell University and New Mexico State University. He has supervisory and project management experience, primarily in academia, where he served as acting department head for nearly a year. For the past 10 years, he has held a research appointment in statistics at OSU funded to cooperate with EMAP. He has managed budgets for up to ten professionals and several graduate students. He has developed the trend detection perspective of EMAP, and worked with the development of many indicators. He has worked with ecologists and environmental scientists since he was an undergraduate at CSU in 1960. Dr. Urquhart, also a Fellow of the American Statistical Association, was awarded the Distinguished Achievement Medal by the Section on Statistics and the Environment of the American Statistical Association in 1994.

RICHARD A. DAVIS (CSU) - Co-Principal Investigator of the Program, is a professor and chair, Department of Statistics. He has substantial training and experience in time series analysis, and has extended those perspectives to spatial statistics. He, in collaboration with Robin Reich, teaches an advanced course in spatial statistics. The software developed for this course and made available on the web, has generated substantial interests among its users. He has substantial administrative experience in his position as department chair. In the program proposed here, he will assist with administration of the program and actively participate in Project 1.

JENNIFER A. HOETING (CSU) - Principal Investigator, Project 1, is an assistant professor of statistics. Her professional interests lie mainly in Bayesian hierarchical modeling. Her main research emphasis has been in developing methods for improving assessment of predictive uncertainty via Bayesian model averaging. Her recent research focus has been on developing methodology for modeling spatially correlated data. She has applied her expertise to a variety of problems, including modeling sandbar size in the Grand Canyon for the National Park Service, predicting presence/absence of rare species for the National Forest Service, and assessing mercury in lakes in Maine, the latter based in REMAP data, and in collaboration with Anthony Olsen of EPA.

F. JAY BREIDT (CSU) - Principal Investigator, Project 2, is an associate professor with expertise in time series and survey sampling. He recently came to CSU from Iowa State University. As part of the Survey Section of Iowa State's Statistical Laboratory, he worked extensively on design and estimation for surveys of ecological conditions and trends, including the National Resources Inventory. He has an interest in the local prediction problem from both a model-based perspective, as in this proposal, and in model-assisted inference, for small area estimation under the separate proposal being submitted by OSU for area 1.

DAVID M. THEOBALD (CSU) - Principal Investigator, Project 3, is a Research Scientist, Natural Resource Ecology Laboratory at CSU. He has applied his training in geography to a variety of natural resource and environmental problems in the six years since his doctorate. He

will provide the team's geographic perspective so that the work on spatial statistics can proceed in a suitable and relevant relation to the associated landscapes. His past work has been mainly in a terrestrial context; he welcomes the opportunity to expand that into an aquatics context. He will supervise a post-doctoral fellow in landscape ecology who will help define, develop and participate in the evaluation of landscape indicators, and will provide the team's expertise in managing large data bases.

HARIHARAN K. IYER (CSU) - Principal Investigator, Project 4, is a professor of statistics. He has interests and experience in linear models, experimental design, environmental statistics, and in the communication of statistical concepts to various audiences, and at various levels. He has developed and implemented web-based and web-assisted distance courses. With the help of a graduate student, he is currently developing tools for web-based computing related to analysis of data from mixed linear models. He also has worked closely with the National Park Service in assessing environmental air quality.

DON L. STEVENS, Jr (OSU) has supervisory and project management experience, both in academia and contract research. While at Eastern Oregon State University, he was Area Coordinator for Mathematics and Computer Science, and a Principal Investigator on a cooperative agreement from EPA to develop the sampling design for the Direct-Delayed Research Project. Subsequently, he has held positions as a General Supervisor and Project Manager for two on-site contractors at the USEPA Laboratory in Corvallis. In these roles, he has supervised an interdisciplinary staff of up to 14 persons, and managed projects on spatial sampling, development of indicators of forest health, ecoregion development, aquatic monitoring, and development of condition indicators for lakes and streams. He will serve as the director of the other program solicited by the RFA to which this proposal responds, and an investigator on Project 1 of this proposal.

ALIX I. GITELMAN (OSU) is an assistant professor who recently completed a doctorate in statistics with emphasis in hierarchical analysis, although her work was not on environmental problems. She will actively participate in the work on Project 1, in active collaboration with personnel at CSU. As beginning assistant professor at OSU, she expects to gain substantial exposure to environmental statistics, experiencing some of the same developmental opportunities as post-doctoral fellows have. If the OSU proposal is funded she will participate in the regular interactions planned there, too. This will give her a balanced view between the design-based and model-based views of the two programs.

STEPHEN B. WEISBERG (SCCWRP) is a biologist who specializes in the design and implementation of environmental monitoring programs. Dr. Weisberg joined SCCWRP as its Executive Director in September 1996. His present research efforts focus on the development of coordinated, integrated, cost-effective regional monitoring in the Southern California Bight. He will provide access to valuable data sets, and be a interface between the academic researchers of the proposed Program, and potential users of the methods to be developed.

ROBIN M. REICHT (CSU) is an associate professor of forest science with training and experience in forest biometry. He has applied spatial statistics to a variety of ecological

problems, and has made extensive use of landscape scale information, such as will be developed on Project 3. As a team member he will advise on that project, but his major efforts will be on Project 1 in providing a knowledgeable link between the needs of the potential user community and the research statisticians.

KERRY J. RITTER (OSU and SCCWRP) will complete her doctorate in environmental statistics at OSU while this proposal is being considered at EPA; there after she will assume a position at SCCWRP, a major cooperator in this Program. Her research has focused on defining parameters related to species richness, or more generally to taxonomic richness - the approachable and related concept for macroinvertebrates in streams. Her current work has focused on site-level matters; in Project 3, she will extend her work to the regional scale. Further she will provide knowledgeable access to the near-coastal data-base assembled by SCCWRP. She also will provide a setting to test some of the ideas developed in Project 1. Collaboration with this program will allow her continued professional development in much the same way as the post-doctoral fellows, an opportunity welcomed by her director at SCCWRP.

JIM C. LOFTIS (CSU) is a professor of civil engineering who has collaborated with Dr.Iyer in the teaching of a course in environmental statistics having a somewhat aquatic orientation. He has over 20 years of experience in the field of water quality monitoring and environmental statistics, including research with EPA on trend analysis for the National Lake Survey. Although his funding in this program is in the outreach, Project 4, his experience with water and environmental matters will be invaluable as a team member.

ALAN T. HERLIHY(OSU) is trained in environmental science and is quite familiar with environmental water chemistry. He has had a major role in organizing EMAP's data bases. He has been associated with EMAP since its inception. His aquatics background, understanding of statistical issues, familiarity with EMAP's data bases, and awareness of state, and local agency needs, will be invaluable to the Program. His skills and knowledge will be available to all of the projects by his funding under this Program.

In addition to the investigators funded by the Program, we have agreements with several organizations to collaborate with the Program, especially in the knowledge transfer arena. The collaboration will take several forms, depending on the particular situation. In some cases, the collaboration will have aquatic scientists from the outside organization working closely with a statistician within the Program. Their object will be to apply statistical methodology to a aquatic monitoring issue. For example, one such collaboration will be with the Oregon Department of Fish and Wildlife (ODFW). ODFW has been collecting information on the number of returning salmon in Oregon coastal streams for decades. Since 1997, the information has been collected using a rotating panel design, set up for ODFW with the assistance of EMAP Surface Waters (Stevens, 2000). The ultimate objectives of the study are to assess the annual numbers of returning Coho salmon, and to determine trends in those numbers. A letter expressing the support of ODFW is attached to the Integration and Coordination Research Plan.

Other organizations which have expressed willingness to collaborate with the Program include The San Francisco Estuary Institute, California State Water Resources Board, and the Miccosukee Indian Tribe. The Program Director has an established working relationship with

one or more individuals in each of these organizations. In each case, the organization has agreed to collaborate with the Program by providing the subject matter expertise in identifying and articulating the scientific and policy questions, scientific insight in model formulation, and access to their data sets for model parameter estimation. Letters of support from each of these organizations are attached to the Integration and Extramural Outreach Research Plan. Some of the scientists who have agreed to collaborate with us include

- ★ Bruce E. Thompson, Ph.D., Senior Scientist, Interim Executive Director Dr. Thompson is the Senior Scientist at SFEI where he directs the Estuary Monitoring and Research Program and is the Chief Scientist for the San Francisco Estuary Regional Monitoring Program (RMP).
- ★ Joshua N. Collins, Ph.D., Environmental Scientist Dr. Collins is a landscape ecologist and regional ecological planner with special expertise in the evolution and natural maintenance of streams and wetlands. Dr. Collins is the Program Manager for the Wetlands Regional Monitoring Program at SFEI.
- ★ Rainer Hoenicke, Ph.D., Environmental Scientist Dr. Hoenicke joined the staff of SFEI in 1994. He is now the Program Manager for the San Francisco Estuary Regional Monitoring Program for Trace Substances at SFEI.
- ★ Steve Jacobs, Ph.D. Fisheries Biologist. Dr. Jacobs is the Leader of the Coastal Salmonid Inventory Project for ODFW.
- ★ Ronald D. Jones, Ph.D., is Professor of Biology at Florida International University, and Director of the Southeast Environmental Research Center. He worked with EPA and EMAP on the South Florida Ecosystem Assessment Project, and is the designated Water Quality Expert for the Miccosukee Tribe of Indians.
- ★ John Woodling, Colorado Division of Wildlife, an aquatic scientist, has participated in the EMAP Western Pilot, and has an extensive set of fish species data from across eastern Colorado that he has offered to collaborate with the Program relative to.

6. IMPORTANT ATTACHMENTS - none

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