PART I - ADMINISTRATIVE

Section 1. General administrative information

Title of project **INNOVATION PROPOSAL FUND: Construct fuzzy logic decision support system for watershed assessments in Oregon**	
BPA project number	**20069**
Contract renewal date (mm/yyyy)	
Multiple actions? (indicate Yes or No)	
Business name of agency, institution or organization requesting funding **E&S Environmental Chemistry, Inc.**	
Business acronym (if appropriate)	
Proposal contact person or principal investigator:	
Name **Mailing address** **City, ST Zip** **Phone** **Fax** **Email address**	**Timothy Sullivan** **P.O. Box 609** **Corvallis, OR 97339** **541 758-5777** **541 758-4413** **tsullivan@proaxis.com**
NPPC Program Measure Number(s) which this project addresses	
FWS/NMFS Biological Opinion Number(s) which this project addresses	
Other planning document references **Oregon Plan for Salmon and Watersheds; Oregon Plan Supplement for Steelhead, 1997; Oregon Watershed Assessment Manual, 1998; GWEB Priorities and Plans; Clinton Administration's Northwest Forest Plan 1993; Tillamook Bay Performance Partnership; South Santiam Watershed Council; Oregon State University. Federal agency involvement: USDA Forest Service, Natural Resources Conservation Service, Tillamook Bay National Estuary Project. Oregon State agency involvement: GWEB, Department of Fish and Wildlife.**	
Short description **Develop a knowledge-based decision support software system that will interface with output from watershed assessments based on the Oregon Watershed Assessment Manual. The fuzzy logic system will classify stream reaches according to water and habitat quality, identify priority areas for restoration and monitoring, and summarize appropriate restoration options.**	
Target species **steelhead, salmon, resident fish, wildlife**	

Section 2. Sorting and evaluation

Subbasin
Systemwide

Evaluation Process Sort

CBFWA caucus	CBFWA eval. process	ISRP project type
X one or more caucus	If your project fits either of these	X one or more categories

			processes, X one or both		
X	Anadromous fish		Multi-year (milestone-based evaluation)		Watershed councils/model watersheds
X	Resident Fish	X	Watershed project eval.		Information dissemination
X	Wildlife				Operation & maintenance
					New construction
				X	Research & monitoring
					Implementation & mgmt
					Wildlife habitat acquisitions

Section 3. Relationships to other Bonneville projects

Umbrella / sub-proposal relationships. List umbrella project first.

Project #	Project title/description

Other dependent or critically-related projects

Project #	Project title/description	Nature of relationship

Section 4. Objectives, tasks and schedules

Past accomplishments

Year	Accomplishment	Met biological objectives?

Objectives and tasks

Obj 1,2,3	Objective	Task a,b,c	Task
1	Develop a decision-making framework	a	Evaluation of appropriate data to input into the model
		b	Development of the data catalog
		c	Development of the knowledge-base that describes logical relations among ecosystems states and processes of interest in the OWAM assessment
		d	Develop output format and presentation of results

Obj 1,2,3	Objective	Task a,b,c	Task
2	Test framework	a	Run model iterations for both Trask and South Santiam watersheds
		b	Provide draft version to South Santiam Watershed Council and Tillamook Bay Performance Partnership for testing
		c	Compare quality of outputs from both iterations as well as to the current knowledge of ecosystem states in the test watersheds
3	Revise draft framework and provide final framework to GWEB	a	Submit review draft version of model to peer reviewers
		b	Make revisions according to review panel concerns and watershed council comments to make it more educational, user friendly, and rigorous
		c	Provide final framework to GWEB
4	Provide training	a	Conduct regional and statewide training workshops

Objective schedules and costs

Obj #	Start date mm/yyyy	End date mm/yyyy	Measurable biological objective(s)	Milestone	FY2000 Cost %
1	11/1999	07/2000			20
2	07/2000	09/2000			50
3	09/2000	11/2000			20
4	10/2000	11/2000			10
				Total	100

Schedule constraints

None

Completion date

BPA funding scheduled to end in 2000. GWEB funding to continue to 2001.

Section 5. Budget

FY99 project budget (BPA obligated):	$

FY2000 budget by line item

Item	Note	% of total	FY2000 ($)
Personnel			20,381.66
Fringe benefits			9,783.25
Supplies, materials, non-expendable property			1,943.95
Operations & maintenance			2,591.93
Capital acquisitions or improvements (e.g. land, buildings, major equip.)			0
NEPA costs			0
Construction-related support			0

PIT tags	# of tags:		0
Travel			3,887.90
Indirect costs			20,617.54
Subcontractor			35,133.64
Other	Fee (6%)		5,660.13
		TOTAL BPA REQUESTED BUDGET	100,000.00

Cost sharing

Organization	**Item or service provided**	**% total project cost (incl. BPA)**	**Amount ($)**
BPA		64.8	100,000
GWEB		35.2	54,325
		Total project cost (including BPA portion)	154,325

Outyear costs

	FY2001	**FY02**	**FY03**	**FY04**
Total budget	20,000			

Section 6. References

Watershed?	**Reference**
	Harris, L.D. 1984. The Fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity, University of Chicago Press.
	Hudson, W.E., Editor. 1991. Landscape Linkages and Biodiversity. Island Press, Washington, DC.
	Marcot, B.G., M.J. Widson, H.L. Li, and G.C. Castillo. 1994. Managing for featured, threatened, endangered and sensitive species and unique habitats for ecosystem sustainability. USDA Forest Service General Technical Report PNW-GTR-329.
	Pelley, J. 1998. NRC finds science, cooperation needed to support watershed management policy. Environ. Sci. Technol. 32:532A.
	Saunders, M.C., and B.J. Miller. 1996. NetWeaver: A tool for the construction and maintenance of object oriented knowledge bases. Proc., Eco-Informa 96: Global Networks for Environmental Information.
	Sullivan, T.J., J.M. Bischoff, and K.B. Vaché. 1998. Results of storm sampling in the Tillamook Bay Watershed. Report to Tillamook Bay National Estuary Project. E&S Environmental Chemistry, Inc.

PART II - NARRATIVE

Section 7. Abstract

The Oregon Watershed Assessment Manual (OWAM) has recently been designed, and is in the process of being refined, for use by watershed councils throughout Oregon to evaluate watershed health. A standard methodology for integration of assessment results and prioritization of restoration and monitoring actions is needed to allow the results of OWAM assessments to be effectively translated into on-the-ground actions. The proposed project will provide such a methodology, in the form of a knowledge-based decision support system to be constructed using NetWeaver and ArcView software. The primary goal of this project is to provide a tool to allow stakeholders to

identify and prioritize feasible restoration actions and monitoring strategies and to evaluate the ecological and economic effectiveness of those strategies for improving water and habitat quality in the subject watersheds.

The resulting decision framework will integrate current scientific understanding and watershed-specific site characterization. The model will be developed jointly by staff of E&S Environmental and Pennsylvania State University with the assistance of a Technical Advisory Committee of local experts. The proposed effort will build upon several other recently-developed and on-going decision support knowledge bases for water quality and habitat quality issues, in the Pacific Northwest and elsewhere. The resulting model will be tested by the South Santiam Watershed Council and the Tillamook Bay Performance Partnership and will receive a rigorous peer review prior to being released to the Governor's Watershed Enhancement Board for broad scale application statewide.

Section 8. Project description

a. Technical and/or scientific background

During the past several years more than 50 citizen-based watershed councils have been formed in Oregon with the goals of sustaining, enhancing, protecting, and restoring natural resources at the watershed scale. A few councils have been active in such efforts for several years and have assembled local teams of experts with which to conduct the required activities of acquiring relevant data, designing and implementing monitoring strategies, conducting watershed analysis, prioritizing and implementing on-the-ground restoration activities, and so on. However, the majority of the councils are new, have only limited access to the required expertise, and are "reinventing the wheel" at numerous locations throughout the state. Our conversations with members of many watershed councils throughout Oregon have revealed a need for access to scientific and technical expertise for a variety of activities, especially related to watershed assessment and evaluation of restoration options.

The present situation is that many of the councils throughout the State are struggling with issues related to the consensus decision making process, how to prioritize areas for information gathering and remediation, questions of monitoring program design and instrumentation, and how to identify and acquire existing sources of relevant data. It is difficult for these councils to move forward in an effective fashion on any front. To further complicate the situation, many of the councils are trying to work through significant issues of trust, of each other within the council and of state and federal agencies involved in the watershed council process.

The integration of watershed data and identification of priority areas for restoration are complex tasks. Both require an understanding of ecosystem processes and functions, land use patterns, and local vegetative and edaphic characteristics. Other factors are also often significant, including land ownership, local preferences for site and preservation options, and the distribution of rare and endangered species. Identification and prioritization of restoration sites can also be influenced by social and economic factors. Unfortunately, most restoration activities are opportunistic, with little regard for the interactions between the site-based restoration and overall ecosystem dynamics.

Ecosystem restoration and biodiversity principles are generally well understood (e.g., Harris 1984, Hudson 1991, Marcot et al. 1994). Often, these principles can be expressed as rules relating site characteristics to endpoint evaluation criteria reflecting ecosystem quality. A rule-based approach offers distinct advantages compared with more traditional approaches for landscape evaluation and classification. For example, rules tend to be easier to incorporate into a decision-making framework than more rigorous model-based approaches. Thus, development of evaluation systems based on rules are less expensive and time consuming than those based on process models. Also, because rules can incorporate social, economic, and other policy considerations, rule-based systems can be especially useful for testing the implications of various management decisions and the extent to which particular landscape modifications will meet planning goals. Finally, because rules can capture generalized information at a higher level of abstraction than numeric models, rule bases are often more transferable to new sites.

The Oregon Watershed Assessment Manual (OWAM) has recently been designed, and is currently in the process of being refined, for use by watershed councils throughout the state of Oregon to evaluate watershed health and develop action plans for restoration activities within the subject watersheds. One main objective of the OWAM development is to provide an assessment methodology that can be conducted with minimal expertise by the watershed councils themselves, and still provide rigorous evaluation of habitat and water quality conditions and a prioritization of restoration activities within the watershed. However, even though collection and compilation of the existing data may require limited technical expertise, evaluation of the data and subsequent watershed assessment requires the input of experts in the fields of fisheries, hydrology, water use, water quality, riparian assessment, sediment sources, and stream geomorphology. Many of these experts will not be available to all watershed councils, and those that are available may be limited in the time they have to give to the watershed council that they are assisting. Development of a rule-based decision-support model specific to the OWAM assessment methodology and associated data will allow the required expertise to be compiled into a structured knowledge base. This will permit the application of knowledge-based reasoning to evaluate the current state of each watershed system and to prioritize restoration actions and further data collection activities. Such an effort will then allow the results of each watershed assessment to be used effectively for ecosystem management.

Ecosystem management is the collective term currently used to embrace a scientific philosophy and set of methodologies for land-use management. Broad-based issues dealt with under the umbrella of ecosystem management include biodiversity, sustainability of ecological systems, maintenance of ecosystem health, and preservation of ecosystem integrity. Most problems associated with ecosystem management involve consideration of the impact of human activities across broad spatial and temporal scales. Furthermore, all contemporary problems in ecosystem management have a substantial existing knowledge base associated with them. This knowledge base evolves continuously as a function of new research and expanded human experience.

The fundamental problem in ecosystem management centers on how to use existing knowledge for land-use planning, problem solving, and decision making. This complexity is a consequence of several factors: (i) natural systems consist of hierarchies of objects (ii) there are large numbers of interactions among objects in ecosystems, (iii) the data and information used to describe them change in space and time, (iv) knowledge about the ecosystems is scattered among a variety of domain specialties, and (v) ecosystem management is only a component of the larger issue of environmental management. In the past, modeling of complex systems was approached using mathematical methods. This technique requires excessive simplification, which resulted in a significant compromise to reality. Integrative computer-based systems are the enabling technology for ecosystem management. In particular, knowledge-based reasoning methodologies provide a means for using complex knowledge bases for ecosystem management purposes.

In the computing sciences, a knowledge base is a formal logical specification for interpreting information and is therefore a form of meta database in the strict sense of the term. A knowledge base is a logical representation of a problem in terms of relevant entities in the problem domain and logical relations among them. Interpretation of data by a knowledge base engine provides an assessment of system states and processes represented in the knowledge base as topical entities. Use of logical representation for assessing the state of systems frequently is desirable or necessary because the current state of knowledge about a problem domain is too imprecise for classical mathematical methods such as statistical or simulation models and optimization, each of which presume very precise knowledge about the relevant mathematical relations. In contrast, knowledge-based reasoning provides logically and mathematically robust solutions for evaluating more imprecise information. Knowledge-based solutions are particularly relevant to ecosystem management because the topic is conceptually broad and complex, involving at least several abstract concepts (e.g., health, sustainability, ecosystem resilience, ecosystem stability, etc.) whose assessment depends on numerous interdependent states and processes. Logical constructs are useful in this context because the problem can be evaluated as long as the entities and their logical relations are understood in at least some general way and can be expressed by subject matter authorities. Logic-based analysis also is not in direct competition with other, more traditional forms of analysis. Instead, knowledge-based representations can be used as logical frameworks within which results from many specific mathematical models are integrated to yield assessments of more abstract topics such as ecosystem health, sustainability, etc.

NetWeaver is a knowledge base construction, maintenance, documentation, and debugging tool written at Pennsylvania State University to provide an efficient knowledge engineering environment for cross platform knowledge based systems development. It provides an ideal foundation for integration of watershed health data and structuring of remediation plans. NetWeaver is written in C++ and reads and writes platform-independent ASCII scripts that can be read by an embedded inference engine in stand-alone applications. Fuzzy logic is used to handle missing data, to evaluate between competing goals, and for the classical use of determining a variable's membership in a given class.

NetWeaver renders knowledge dependency (AND/OR) networks with a fully editable graphic representation so that the networks appear just like they would on the white board. Because the inference engine is built in, networks can be evaluated in real-time with nodes changing color to indicate their changing trueness levels. This ability to peer into the logical workings of a knowledge network greatly optimizes the knowledge engineering process by 1) providing the ability to run and evaluate freshly elicited knowledge in the presence of the domain expert, 2) enabling the knowledge engineer to trace the logic structure from data to conclusions, and 3) allowing the knowledge engineer to quickly identify and edit errors and inconsistencies in the logic.

b. Rationale and significance to Regional Programs

According to a report released in October, 1998 by the National Research Council, watershed management has been difficult to implement throughout the United States because of a lack of effective scientific tools and poor cooperation among governmental agencies and private organizations. One of the report's most significant findings, said William Graff, chair of the report committee, "is that science is in the embryonic stages for supporting policy." Graff concluded that models are needed to link disparate fields into an interdisciplinary approach that is useful to managers, and also that even the best data and science are of little use if no organizational structures use and implement them. The report points to a gloomy picture of poorly developed technology and lack of appropriate data, despite a half century of government attempts at instituting watershed management (Pelley 1998).

The primary goal of the GWEB watershed assessment manual is to provide a tool to local stakeholders for evaluating the current health of the watershed in question. Implementation of the methodology presented in the manual provides users with a database with which to target areas for water quality improvement and fish habitat restoration. The final product is intended to be an action plan that, with appropriate monitoring, will result in on-the-ground restoration activities that will restore habitat quality and ecosystem functioning. Although the GWEB manual provides a step-by-step methodology for the compilation of data, interpretation of the data is often a difficult process, even for those with technical expertise in watershed evaluation. What is now needed is a rule-based knowledge system to aid in the interpretation of the data that result from implementation of a watershed assessment. Such data are inherently abstract and difficult to describe mathematically. Constructing a knowledge base specific to the GWEB assessment offers several advantages to watershed councils throughout Oregon:

1. **Watersheds are inherently abstract systems.** Due to the many components of watersheds and their interactions, evaluation of watershed health can be a rather difficult process. It requires the understanding of many technical fields as well as their interactions. A knowledge-based decision support system will allow the experience of many experts in their respective fields to be compiled into a knowledge base that integrates these various disciplines in a practical and understandable fashion. This will allow each watershed to be evaluated as a whole ecosystem and will provide a prioritization of actions that will help to restore or maintain the function of that ecosystem.
2. **Assessments are limited by the scale of available data.**
   Watershed assessments are largely limited by the quality and scale of the input data and the scope of the analyses conducted on those data. However, methodologies can be misused by interpreting the output data at scales that are beyond those of the available input data and therefore beyond the scope of science-based assessment. Using a model to evaluate assessment

data will reduce the chances of misinterpretation of the data by maintaining an appropriate scale within the analysis.

3. **Watershed councils often lack technical experts in all fields necessary to properly evaluate a watershed's health.** Watershed councils are dependent upon their technical advisory committees (TAC) for the evaluation and interpretation of existing data, to formulate and prioritize potential restoration projects, and to interpret the output from a GWEB assessment. Many TACs are limited in the expertise that is available and many experts are limited in the time they have available to devote to such assessments. Evaluation of data resulting from watershed assessments is a laborious process and can be very time consuming. Many state and federal natural resource professionals are assigned to rather broad areas limiting their time to invest in interpretation of watershed assessment data for each watershed council that falls under their jurisdiction. A knowledge-based decision support system will allow watershed councils to evaluate watershed assessment data without the need for all areas of specific technical expertise to be represented on the TAC. Additionally, this tool will allow for less dependence on state and federal employees who have limited time to devote to these evaluations.
4. **Removes the bias of the interpreter**. Interpretation of watershed evaluations is a difficult process due to the many fields of study that are incorporated. Often these evaluations are conducted by a limited number of researchers with technical expertise in one or two of the required fields. This can lead to a natural bias in the interpretation, in which higher priorities are given to those areas for which the interpreter has the greatest amount of experience and expertise. Use of an objective decision support system will reduce these biases and result in outputs that prioritize actions based on unbiased interpretation of available data.
5. **Identifies data gaps.** Ideally, assessment teams would be able to assemble a list of all topics they want to include in an assessment, assemble a list of data requirements needed to address those topics, and find they have all the required data. However, the reality is that assessments need to be conducted with incomplete data. There may be some missing observations for several to many data types. There may be no data at all for some variables of interest. One solution to the problem of missing data is to tailor the assessment to existing data. However, this is a poor way to conduct an assessment of watersheds with complex inter-relations because it is extremely difficult to infer what is not known about the data that might be relevant for determining observed ecosystem states and processes. Instead, it is preferable to construct a model that reflects our best understanding of how ALL states and processes relevant to the assessment are inter-related. The decision support inference engine uses simple rules to infer the influence of missing data based on how many states and processes use the information, and at what level the information enters the knowledge base structure.

Completion of this project will result in a fuzzy logic decision support model that will allow watershed councils to evaluate data collected as a part of the OWAM assessment and prioritize the restoration and data collection activities in their watersheds without the need to have technical experts in all of the related scientific fields evaluate the data. The model will also provide a more in-depth analysis than could be done on a watershed-specific basis because its development will be based on the experience of experts and published information in each of the relevant scientific fields. This cumulative knowledge will be incorporated into the development of the knowledge base.

A number of scientific and stakeholder benefits will result from the proposed work. These include:

- Placement of watershed analysis output in a format that can be readily used by watershed councils for decision making
- Improved ability to evaluate the ecological results and economic implications of restoration options,
- Improved ability of stakeholders to allocate resources for restoration activities to maximize the ecological and/or economic benefit, and
- An objective basis for formulating an Action Plan for restoration, monitoring and further research.

c. Relationships to other projects

NetWeaver was introduced in 1991 by Dr. Michael Saunders of Pennsylvania State University. It has steadily evolved since its introduction, and now provides a radically different form of knowledge representation that offers several critical advantages over rule-based methods that make it ideally suited for use in landscape analyses for ecosystem management. Key features of the system include a highly intuitive graphical user interface, object-based networks of logical propositions, and fuzzy logic. Fuzzy logic representations are more intuitively satisfying than classical bivalent logic, as well as far more precise and compact compared to classical rule-based representations. Implementation of the user interface together with NetWeaver's object-based representation supports design of modular knowledge bases. Modularity in turn enables effective, incremental evolution of knowledge base structures from simple to complex forms.

Ecosystem management fundamentally is concerned with integrated management, and this presupposes integrated analysis. Although the literature on ecosystem management has clearly articulated the need for integrated management since inception of the concept, effective demonstrations of integrated analysis to support ecosystem management have been conspicuously lacking until the last few years. Several knowledge base development projects are now underway at both the US Forest Service's Pacific Northwest Research Station and Pennsylvania State University. Initial efforts are focusing on integrated analysis for specific spatial scales. Progress to date provides strong evidence that it is entirely feasible to construct NetWeaver knowledge bases for ecosystem management despite the conceptual scope and complexity of the problem domain. A few examples of recent prototype knowledge bases include:

1. An ecological site classification for Great Britain that evaluates species site suitability for the afforestation program of the British Forestry Commission.
2. Evaluation of the suitability of biophysical land units for inclusion in reserve systems for maintaining biodiversity (cooperative project between PNW Station, University of Colorado, and University of California at Santa Barbara).
3. Watershed condition assessment for the US Environmental Protection Agency.
4. Surface water chemistry evaluation for assessment of potential acidic deposition impacts (U.S.D.I National Park Service and Fish and Wildlife Service with Penn State University)
5. Ozone induced foliar damage warning system (U.S.D.I National Park Service and Fish and Wildlife Service with Penn State University)

d. Project history (for ongoing projects)

(Replace this text with your response in paragraph form)

e. Proposal objectives

The overall goal of this study is to provide a tool for stakeholders to identify and prioritize feasible restoration and monitoring strategies and evaluate the ecological and economic effectiveness of those strategies at addressing problems with watershed-level functions. We wish to produce a knowledge-based fuzzy logic model specific to the OWAM assessment methodology to evaluate and prioritize both restoration activities and data/research needs for watershed councils.

Additional goals are to:

- Integrate output from OWAM assessments in a clear, concise, educational, and easily understood fashion,
- Coordinate with community-based Watershed Councils to identify and prioritize restoration goals and options,
- Develop a decision making framework integrating current scientific understanding and watershed-specific site characterizations, coupled with community-based prioritization strategies, for generating and prioritizing potential restoration activities;
- Obtain rigorous technical review and field testing of draft decision support system,

- Evaluate the impact of using this framework on stakeholder decision making and transferability of the methodology by testing it on two watersheds in Oregon, and
- Revise the draft framework and provide final decision support system to GWEB.

Specific objectives are to 1) develop a decision-making framework that will organize OWAM assessment output and provide recommendations and priorities for restoration actions and monitoring efforts, 2) test the framework by applying the framework to the two test case watershed assessments, 3) based on peer review and the results of the model testing, revise the draft framework and provide a final knowledge-based decision support system to GWEB, and 4) provide training to watershed councils throughout Oregon.

The final deliverables will include the completed model, a final report that describes the methodology, a manuscript for the peer-reviewed literature that describes the model and its test applications, and a series of training workshops around Oregon to train watershed councils in its utilization.

As a test case, we propose to implement and evaluate the prioritization framework in two medium-size watersheds in western Oregon: the South Santiam watershed and the Trask watershed, which is part of the Tillamook Bay watershed. Both watersheds have active stakeholder groups in the form of a Performance Partnership of agencies and stakeholders in Tillamook and an active watershed council for the South Santiam watershed, formed at the direction of the Governor's Watershed Enhancement Board (GWEB) and charged with bringing together stakeholders to initiate watershed restoration and enhancement activities. These two watersheds were selected because both have been the subject of a recent OWAM assessment, they represent a range of ecological, geomorphic and socioeconomic conditions, and because a number of spatially explicit datasets capable of supporting the types of analyses envisioned in this proposal are currently available for these watersheds.

The South Santiam watershed encompasses approximately 3400 km^2, and includes the communities of Scio, Lebanon, Waterloo, Cascadia, Lacomb, and Sweet Home. The watershed is the main source of drinking water for the city of Albany and an important steelhead habitat. While substantially modified since the 1850's, relative to other watersheds in the region it is a less-disturbed system.

Tillamook Basin encompasses 1400 km^2 of primarily forest and agricultural land drained by five rivers. It includes the cities of Tillamook, Bay City, and Garibaldi. The bay and rivers are recognized as some of the most productive salmon fishing waters in Oregon. The lowland areas of the basin support about 30,000 dairy cattle and produce half of Oregon's cheese. Numerous water quality and habitat quality problems have been under investigation by E&S Environmental Chemistry, Inc. and other research partners of the Tillamook Bay National Estuary Project, including contamination of river and bay waters with fecal coliform bacteria (FCB), elevated river temperatures, and excessive sedimentation of the lower rivers and the bay. Of the five Tillamook area watersheds, the Trask has the highest loading of FCB and the second highest loading of suspended sediments (Sullivan et al. 1998). A wide range of restoration activities are planned or ongoing within the Trask and other Tillamook Bay area watersheds.

f. Methods

The proposed project will be implemented as a collaborative effort among the staff of E&S Environmental Chemistry, Inc., E&S Environmental Restoration, Inc., and The Pennsylvania State University. Timothy Sullivan, President of both E&S companies, will serve as Principal Investigator. Michael Saunders, Associate Professor of PSU and senior author of the decision support software with which the project will be implemented, will serve as consultant on the project and will coordinate the model development. The project team, with the assistance of a Technical Advisory Committee (TAC) will design the decision support software. Output content, format, parameter settings, and education components will be determined through a series of bimonthly meetings among E&S staff and the TAC, between which model development and programming will occur.

Knowledge Base

The application framework that will be used to construct the OWAM specific model is Ecosystem Management Decision Support (EMDS). It provides a framework or structure for conducting environmental assessments and integrates state of the art geographic information systems (GIS) and knowledge based reasoning technologies. To accomplish the environmental assessment, we will begin by constructing a data catalog that identifies the source of all GIS themes that can enter into the assessment. The second step is to construct a knowledge base that logically describes the relationships between ecosystem states and processes of interest in the assessment. EMDS provides the environment for constructing the knowledge base with NetWeaver, and ArcView provides the environment for constructing the data catalog.

In the development of a knowledge based decision support system (KBDSS), the knowledge engineer (KE) must undertake the difficult and time consuming task of eliciting heuristics from an acknowledged expert in each problem domain, and representing those heuristics in a machine readable form for use within the final application. Historically, this activity has proven to be the most time consuming aspect of KBDSS development as it requires the KE to develop a working understanding of the problem domain, schedule contact time with each expert, represent the elicited knowledge in a concise and understandable format, test the heuristics with cogent and comprehensive example situations, compare the knowledge base (KB) output with the experts' decision, diagnose and debug the KB, and repeat the testing procedure with the experts until a satisfactory facsimile of their expertise has been developed. Once the KB has been satisfactorily completed, the remaining KBDSS development tasks (i.e. development of a graphical user interface, connections to databases, installation on the user's computer platform, etc.) are considerably more straightforward computer science oriented issues.

The problems associated with knowledge elicitation and representation are particularly acute in the area of natural resource management. In developing this type of KBDSS, the multidisciplinary nature of the problem domain must be reflected in the application. A further complication in the area of natural resource management lies in our imprecise understanding of how natural systems work. Inevitably, all descriptions of nature are approximations. The process of arriving at a management decision involves the concatenation of numerous approximate descriptions. Consequently, KBDSS applications must provide meaningful representations of uncertainty.

Saunders and Miller (1996) described a KE methodology that will be used for the proposed project. It facilitates the development of KBDSS for agriculture, natural resource management, and other complex systems with high levels of uncertainty.

There are numerous approaches available for representing and implementing knowledge bases. These approaches include production rules, semantic networks, Bayesian belief networks, neural networks, and others. Dependency networks are typically used to graphically depict logical relationships between data and conclusions, and hence provide a very useful shorthand for representing the heuristics of a domain expert during the knowledge elicitation process. In this approach, the conclusion is reached by following paths leading from observations (i.e. data) through the logical connectors between and among those observations. The logical connectors typically consist of "AND" and "OR" nodes. All paths to an "AND" node must be true in order to proceed. Only one path to an "OR" node must be true. Dependency networks can be nested within one another so that the conclusion reached in one or more networks can be used as input to another, higher level network.

Although dependency networks are useful for knowledge representation, the cumbersome process of moving from paper to code, and testing and editing of the knowledge base remain as some of the most difficult aspects of KBDSS development. It is during this process that most knowledge representation errors occur, and when they are most troublesome to detect. Hard copy dependency networks are difficult to test with scenarios involving actual data, and KB quality can only be critiqued through the performance of the prototype application. This functional lack of independence of the KB from the KBDSS application inhibits the diagnosis and correction of flaws in the heuristics. Ideally, the KB, as a collection of dependency networks, should be independently executable so that testing and debugging can be carried out during and immediately after knowledge elicitation. If the domain expert can immediately see and verify the operation of his/her heuristics, the immediate feedback that would result would immeasurably reduce the overhead of KB development, and would optimize the accuracy and completeness of the KB before it is coded into an application. Executable dependency networks would optimize the diagnosis of logical inconsistencies and errors by permitting the KE and the domain expert to trace KB conclusions from data, through nested hierarchies of dependencies, to conclusions. In order to execute a knowledge base as a collection of dependency networks, an inferencing methodology must be developed. A simple yet powerful inferencing methodology would be a distributed approach that imbues logical connectors (e.g. AND and OR nodes) with functionality, permits the assignment and instantiation of arguments for comparison with data values, and propagates those interpreted data via their logical connections to other data, forward to conclusions. This distributed approach would facilitate the documentation of the KB by permitting the KE to enter comments, explanations, and referencing information for each component of the dependency network.

Finally, the knowledge base as a collection of dependency networks and distributed inferencing methodology should be embeddable into the KBDSS. This would eliminate the necessity of translating from the hard copy dependency network representation into the formalization required by most knowledge based system development tools or shells.

An object oriented software application was developed at Penn State University that implements the above described KB development methodology. This software, called NetWeaver, is written in C++ and runs under the Macintosh and Microsoft Windows operating systems. NetWeaver provides the software tools to construct dependency networks with a fully editable graphic representation. All typical editing functions are available (e.g. Cut , Copy & Paste) and can be used on single nodes or whole sections of a network.

Three major object classes are used to encode the knowledge base: Data links, Goals, and Goal Groups. Data links manipulate data, Goals encode information, and Goal Groups derive knowledge.

<u>Model</u> <u>Development</u>

The state of Oregon is a complex mosaic of ecosystems, ranging from high deserts to coastal rainforests. The model will need to address assessment in each of these different types of ecosystems. We will begin with a more general knowledge base, with rules that will be applicable across the state. Once this has been completed, we will adjust parameter the values of the dependency networks to adjust the assessment according to the different ecoregions found in Oregon. This type of regional adjustment was used in recent applications of NetWeaver for assessment of potential acidic deposition sensitivity and effects of lakes and streams throughout the United States for the National Park Service. Thus, the final model will be sufficiently generic as to be applicable statewide, but will have a somewhat different version for each of the ecoregions represented in the state.

Development of the decision support model for OWAM assessments can be broken into six parts:

1. Evaluation of appropriate data to input into the model.

Evaluation of the data needed to address the specific goals of the OWAM assessment will be conducted to decide what data needs to be compiled to successfully complete an assessment of both fish habitat and water quality at the scale of the OWAM methodology. Much of this has been completed and evaluated in the construction of previous knowledge bases for summer steelhead and salmonid habitats, as well as other watershed assessments.

2. Development of the data catalog.

It will be important that the watershed councils be able to create a data set from the OWAM assessment that is in a structure that can be easily input into the model. EMDS and NetWeaver require that the data be input as a GIS theme. This would require that much of the data be digitized. However, the model uses an attribute table that can exist in many formats, including Microsoft Access and dBase. The need for digitizing can be reduced by relating the different assessment modules to one digitized layer. For example, when conducting the GWEB assessment for fish habitat, the assessment has been designed so that factors such as riparian condition, fish distribution, water use and low flow history are all related to the Channel Habitat Type (CHT) generated in the early parts of the assessment. By simply digitizing the CHTs, the rest of the information can be incorporated in the attribute table for the CHT layer. However, the advantages and disadvantages of using data in this manner need to be evaluated versus having each one of the data layers digitized individually. This project will address this issue and attempt to minimize the need for digitizing. However, many of the needed GIS coverages (zoning, ownership, land use, vegetation, soils, roads, etc.) are readily available in a GIS format from groups such as the BLM, State Service Center for GIS, USFS, ODFW, and County GIS Centers and would require very little processing prior to being input into the data catalog.

Spatial data sets will be selected that are available to all the watershed councils of Oregon. We will, however, construct the model so that the councils can tailor it to the data that they have available. This will result in a minimum data set needed to implement the model, which will be statewide coverages and coverages generated as a result of conducting a GWEB assessment. The council will then have the option of replacing the "basic" coverages with improved coverages that may be available for their watershed.

3. *Development of the knowledge base that describes logical relations among ecosystem states and processes of interest in the OWAM assessment.*

Knowledge bases are currently available for watershed assessment of salmon and summer steelhead habitat as well as water quality issues. These existing knowledge bases will provide the framework for constructing a knowledge base specific to the OWAM assessment goals. It will address both fish habitat and water quality issues. To construct the knowledge base, we will use published data and the experience of experts in the fields of fisheries, hydrology, water quality, channel habitats, channel modification, riparian evaluation and water use.

4. *Development of output format and presentation results.*

The GWEB assessment currently targets both fish habitat restoration and water quality improvement. Output from the model will address each one of these targets specifically, although some of the data will be used in both evaluations. For example, sediment sources and turbidity are both fisheries and water quality issues, so the sediment source evaluation will be used in both components of the model.

The output will rank each of the sixth field watersheds according to restoration needs and use by fish. Rankings will be evaluated according to a knowledge base that describes the importance of fish use (both historical and current), channel habitat types, species occurring in the watershed, sediment sources, channel modification, and low flow conditions. The model will begin by prioritizing areas that are important to the fish species occurring in the watershed, and then evaluate the current conditions of those stream reaches. It may also be possible to identify and prioritize those activities that may have cumulative effects. After the model ranks each of the subbasins, restoration activities that will help to restore the ecosystem function that has been degraded will be recommended for each of the basins. Included with these recommendations will be maps (generated during the assessment) showing scores of stream reaches for each category to help in the decision of where restoration activity should occur. Table 1 shows one possible format for the model output. However, it is important to note that the GWEB assessment is not a reach-level assessment. The goal is to help watershed councils identify the types of impacts and their relative locations in the watershed according to areas of key fish habitat with high restoration or protection potential.

Many factors can be included in the ranking of potential restoration activities. One factor may be the ownership of the property in question. Ranks can be given according to needs for fish habitat, although watershed councils may be limited in access to the land if it is privately owned. Consequently, restoration activities can be ranked by those areas that have the highest probability of completion. Another possible ranking factor is the ease of implementation of the restoration project. Some restoration activities may be easier and more cost effective than others, and these factors can be incorporated in the ranking. This will result in a "shopping list" of restoration activities that the watershed council can consider for various stream reaches. The involvement of the South Santiam and Tillamook Bay Performance Partnership will be invaluable in this part of the model development to help develop criteria to rank activities with the highest probability of completion.

Water quality outputs will be based on the water quality, sediment sources, and hydrology components of the GWEB manual. The model will begin by prioritizing the basins according to the perceived importance of their water quality issues and then generate an output that will prioritize activities that will help improve water quality conditions. Again, the model may be able to be developed to give higher priorities to those activities that may have cumulative effects.

Table 1. Example criteria for decision system output.	
Potential in-stream habitat quality Fish utilization Spawning/rearing habitat Problem areas for water quality Water temperature Fecal coliform bacteria Nutrients Sediment flux (TSS, turbidity) Toxics pH/oxygen demand Low-flow water quality Episodic water quality Problem areas for habitat quality In-stream structure In-stream refugia Large woody debris (LWD) LWD recruitment Streambank erosion Substrate condition Riparian condition Low-flow hydrology Problem areas for access Culverts Impoundments Connectedness	Potential remedial actions Riparian planting Livestock fencing Wetlands construction/enhancement In-stream water rights Point source identification and remediation Nonpoint source identification and remediation On-site sewage systems repair/replacement Culvert removal/replacement Road decommissioning Road erosion control Slide stabilization Hardwood to conifer conversion Wildlife habitat enhancement In-stream barrier removal Feasibility Ownership Cost/benefit Permitting and environmental regulations Ease of implementation Restoration Priority High Medium Low

5. *System Testing*

Initial testing will be conducted by members of the Technical Advisory Committee (TAC), composed of experts chosen for their experience and expertise with OWAM assessment methodologies, watershed science, fisheries biology, and knowledge-based decision support systems (Table 2).

Once the knowledge base is constructed, it will be tested in two watersheds (South Santiam and Trask River) where GWEB assessments have already been conducted and watershed conditions summarized. These watersheds will be used to test the effectiveness of the model and the knowledge base. Additionally, the model will be given to the these two stakeholder groups as a test version to evaluate the ease of use by non-technical watershed council members. The results produced by the watershed council will be compared to the results obtained by the project team to evaluate the ability of the stakeholders to utilize such a tool. The council members will also be asked to comment on the "user friendly" environment of the model run and how it can be improved. The final review draft version of the model will be reviewed by a technical review team that will include Ken Bierly (GWEB), Kelly Moore (ODF&W), staff of Defenders of Wildlife (contact: Sara Vickerman), and Gordon Reeves (USDA-Forest Service).

Table 2. Technical Advisory Committee		
Individual/Group	Affiliation	Area of Expertise
Todd Buchholz	Willamette National Forest	Fisheries Biology
Reed Noss	Oregon State University	Watershed Science
Bruce Follansby	Tillamook Bay Natl. Estuary Project	Watershed Assessment, Restoration Ecology
Keith Reynolds	USDA Forest Service	KBDSS
Ann Stark	Tillamook Coastal Watershed Resource Center	OWAM Assessment
Sue Gries	South Santiam Watershed Council	OWAM Assessment

6. Development of a user-friendly product that can be distributed to watershed councils.

After the model has been constructed and evaluated by members of the TAC and on the test watersheds, a final package will be developed that can be used by watershed councils throughout Oregon, most of which will be conducting watershed assessments following the OWAM protocol. In construction of the GWEB manual, one of the primary objectives was to provide a methodology that would not only assess the current health of the watershed, but also educate the council that conducted the assessment. Consequently, it is imperative that the educational value of the data interpretation component of the assessment be maintained. We will develop the fuzzy logic model with educational goals in mind. This can be achieved in several ways. During the model iterations, there will be pop-up menus that will address interpretation issues as well as decisions that are inherently necessary in any data interpretation exercise. Outputs will provide rationales for the decisions and priorities of restoration activities so that council members can learn why certain activities or areas received high priority. The end product will be designed to both rigorously interpret the data compiled in the assessment and also educate the council regarding the use of scientific knowledge to interpret watershed scale data and the relationship between watershed health and restoration options.

g. Facilities and equipment

E&S Environmental Chemistry, Inc., based in Corvallis, has been conducting water quality research, watershed analyses, and environmental assessments nationwide since 1988. Clients include nearly all federal agencies with natural resource responsibility, three national laboratories, and environmental quality departments in seven states. E&S has substantial expertise and experience in statistical monitoring design and implementation, water quality and flow instrumentation, GIS, aquatic biota, fisheries, watershed characterization, nonpoint source assessment, QA/QC, water quality data interpretation, and environmental education.

E&S Environmental Restoration, Inc., with offices in Corvallis and Sweet Home and a new office planned for Tillamook, is currently one of the largest employers of graduates of the federal Ecosystem Workforce Training Project in Oregon. The staff of E&S Environmental Restoration are highly qualified to conduct a wide variety of on-the-ground restoration, enhancement, and data collection activities, and to train citizen-based groups in proper techniques, effective approaches, and safety issues.

E&S offers extensive experience with GIS-based resource modeling, and has used GIS/image processing approaches to link historical water quality to changing land use practices within watersheds. E&S has used GIS, remote sensing and water quality models in support of acid rain research, identifying regional ecological and geographic patterns, assessment of groundwater contamination, and other natural resource issues. In addition, E&S offers services in environmental assessment and evaluation, computer mapping and graphics, database management, and integrated ecological assessment. To support this work

E&S uses a high speed Ethernet computer network with eight dedicated workstations and over 20 Gbytes of disk storage. Software includes AutoCAD, WordPerfect (5.2), WordPerfect (6.1 for Windows), Aldus PageMaker, Word, SigmaPlot, CorelDraw, the Cornell Ecology Package, and other specialized programs. E&S uses a variety of database managers including SAS Access to PC file formats, dBase, Paradox and Access.

E&S has the necessary hardware and software available in-house to accommodate any GIS project. We use Pentium machines running Windows NT to perform GIS tasks. In addition to PC Arc/Info 3.5 and ArcView 2.1, E&S now has Arc/Info 7.1 for Windows NT. This package allows the full power and capabilities of the UNIX version to be run from a desktop computer. We have several tools available for image processing of aerial photography including large-scale high-precision digitizing tablets, Arc/Info, Arc/Info GRID, PCI, and Surfer. The sophistication of these tools enables E&S to provide a multitude of analyses on spatial data. We have developed routines to easily transfer import and export data in Arc/Info interchange format.

E&S staff have developed specialized software linkages allowing GIS-based statistical analysis of spatial data. These include the application of nonparametric statistics, mutivariate analyses, kriging, and statistical sampling design, all of which are easily incorporated into our GIS analyses.

E&S has software/hardware interfaces which allow efficient data transfer via the Internet and which contain data conversions for Arc/Info, Intergraph, AutoCAD, MOSS, MIADS, Erdas, PAMAP, GRASS, SPANS, and ELAS. Data output includes full color maps and graphics in a variety of formats and sizes. Large format (D and E size) plots are produced on an HP DesignJet 250C plotter.

In addition to existing in-house computing facilities, E&S also has remote access to multiple federal and state facilities. E&S has a broad base of experience with obtaining digital data from the U.S. Environmental Protection Agency, U.S. Geological Survey, U.S. Fish and Wildlife Service, and various state agencies and data centers.

Metadata and file transfer standards play an important role in the day-to-day operations of E&S. E&S is continually involved in the processing and exchange of spatial data. Currently on-site, E&S has descriptions and instructions for the Spatial Data Transfer Standard (SDTS)/Federal Information Processing Standard (FIPS) 173, Federal Geographic Data Committee (FGDC) standards, and Tri-Service Spatial Data Standards. In the documenting and transferring of spatial data, E&S adheres to the guidelines as set forth by these standards. This is done so that data not only have a known source and heritage but also so that data can be accessible to multiple computer platforms and software. E&S has broad experience in the areas of database design and management. Examples include assisting the U.S. Fish and Wildlife Service in establishing metadata standards, designing the U.S. National Oceanic and Atmospheric Administration's Paleological/Sediment relational database, and coordinating the Rensselaer Polytechnic Institute's Adirondack GIS/water chemistry database. Other agencies that E&S has designed and managed databases for include the U.S. Department of Energy, Environmental Protection Agency, the Oregon Department of Environmental Quality, and the U.S.D.A. Forest Service.

Technical/Library Facilities

E&S offices are located in close proximity to three major academic/research institutions that contain extensive natural resource library facilities. These include Oregon State University, the U.S. Environmental Protection Agency's National Health and Environmental Effects Research Laboratory, and the USDA Forest Service Research Laboratory. All are located within two miles of E&S facilities and are available for use by E&S staff.

h. Budget

The estimated cost for the proposed project for FY2000 is $154,325. An additional $20,000 will be requested from GWEB to cover training costs during FY2001. The proposal requests $100,000 from the Bonneville Power Administration through the Innovative Proposal Fund. The balance of the funding required to complete the project will be requested from GWEB. The funding amount requested from BPA for each budget item is 64.8% of the anticipated cost for that item, reflecting the fact that 64.8% of

FY2000 funding is requested from BPA. The cost justifications presented below are for the entire costs, including both the BPA portion and the GWEB portion.

Funds requested for personnel are to cover the salaries of T. Sullivan, J. Bischoff, K. Vaché, and secretarial support. Sullivan's salary is proposed at the current level. The salaries of Bischoff and Vaché reflect the salary raises that are scheduled for those personnel in FY99. Fringe and overhead rates are based on average values for the last five completed years. The rates for three of these years were audited and approved by the U.S. Department of Energy. DOE has not yet audited E&S rates for the two most recent years.

Materials and supplies are budgeted at $3,000 to cover the costs of purchased data layers, photocopies, postage, and routine project supplies. Computer resources are budgeted at $4,000, based on a standard rate of $8.00 per hour for E&S computer facilities. The travel budget of $6,000 includes three trips for Saunders from Pennsylvania to Oregon @ $800 each, one trip for Miller from Pennsylvania to Oregon @ $800, one trip for Bischoff from Oregon to Pennsylvania @ $800, and $2,000 for in-state travel (mileage and per diem at federal rates) to attend GWEB meetings, for travel by TAC member Follansby to attend TAC meetings, and for travel to training workshops.

The breakdown of subcontractor expenses is as follows. Saunders will be compensated at his standard consulting rate of $800 per day for 31 days. Miller's costs are based on his salary and fringe rates at PSU ($20,660 for 0.5 FTE). TAC members will be reimbursed for their time at their standard consulting rates: Noss, $3,200 @ $80/hr; Follansby, $3,000 @ $30/hr. Federal employees who will participate on the TAC (Buchholz, Reynolds) are not requesting BPA funding. Staff of the Tillamook Bay Performance Partnership and South Santiam Watershed Council will be reimbursed for testing efforts and TAC participation at a rate of $40/hr, for a total cost of $1280 per watershed.

A fee of 6% is added to the total cost. E&S generally charges a fee of 8% for environmental research, but has reduced the fee request for the proposed project. As a small business, E&S depends upon fees for business development and equipment acquisition to keep abreast of changing technologies.

Section 9. Key personnel

Name	Title	Role in Project	FTE
Timothy Sullivan	President, E&S	P.I., water quality, restoration ecology, watershed science	0.14
Michael Saunders	Associate Professor, PSU	KBDSS	0.12
Joseph Bischoff	Ecologist, E&S	Database, GIS Coordinator	0.50
Bruce Miller	Project Assistant, PSU	Programmer, GIS	0.50
Kellie Vaché	Geologist, E&S	Database, Hydrology	0.10

TIMOTHY J. SULLIVAN, President, E&S Environmental Chemistry, Inc. and E&S Environmental Restoration, Inc.

Education

Ph.D., Biological Sciences/Environmental Chemistry, Oregon State University - 1983
M.A., Biological Sciences, Western State College of Colorado - 1977
B.A., History, Stonehill College - 1972

Experience

Dr. Sullivan's expertise includes water quality, watershed analysis, nonpoint source pollution, episodic processes controlling surface water chemistry, and environmental assessment. Dr. Sullivan has worked during the past year as a member of a team led by Dr. Saunders to construct a water quality decision model for the National Park Service. As President of E&S Environmental Restoration, Inc., an ecosystem workforce employer, Dr. Sullivan has overseen the completion of over 50 environmental restoration projects since 1996. His research experience includes the following:

- Authored the State of Science and Technology Report for the National Acid Precipitation Assessment Program (NAPAP) on historical acidification of lakes and streams throughout the U.S.
- Compared and contrasted paleoecological inferences and process-based model hindcasts of lakewater chemistry for a suite of statistically-selected lakes.
- Directed field research project for the Alaska Department of Environmental Conservation on the Kenai Peninsula to investigate forest effects from industrial atmospheric emissions of nitrogen.
- Served as member of NAPAP's working group that prepared the aquatic portions of the 1990 Integrated Assessment (IA), NAPAP's policy document for Congress. Also authored the aquatic sections of NAPAP’s 1996 Report to Congress.
- Served as project manager for a research project to test the watershed nitrogen model MERLIN (Model of Ecosystem Retention and Loss of Inorganic Nitrogen) against the results of ecosystem manipulation experiments in Europe.
- Served as project manager for a project aimed at implementing watershed planning for the three principal watersheds in Polk County, Oregon, and providing guidance regarding watershed management and the formation of watershed planning councils.
- Serving as project manager for E&S’s role in the construction and management of a diatom paleoclimate data cooperative for North and South America.
- Serving as principal investigator for the Tillamook Bay National Estuary Project for several water quality monitoring projects to evaluate the concentrations and loads of nutrients, sediment, and fecal coliform bacteria in the five rivers that flow into Tillamook Bay, Oregon.
- Serving as project manager for modeling projects to assess aquatic effects of air pollutants throughout the southern Appalachian, Rocky, Cascade, and Sierra Nevada Mountains.

Dr. Sullivan has published over 50 peer-reviewed journal articles, books, and book chapters, including four papers in *Nature* since 1986. Selected, representative, publications are listed below:

Bernert, J.A., J.M. Eilers, T.J. Sullivan, K.E. Freemark, and C. Ribic. 1997. A quantitative method for delineating regions: an example for the Western Corn Belt Plains Ecoregion of the USA. *Environ. Mgmt.* 21:405-420.

Sullivan, T.J. 1997. Ecosystem Manipulation Experimentation as a Means of Testing a Biogeochemical Model. *Environ. Mgmt*. 21(1):15-21.

Sullivan, T.J., B. McMartin, and D.F. Charles. 1996. Re-examination of the role of landscape change in the acidification of lakes in the Adirondack Mountains, New York. *Sci. Total Environ*. 183(3):231-248.

Sullivan, T.J. and B.J. Cosby. 1995. Testing, improvement, and confirmation of a watershed model of acid-base chemistry. Water Air Soil Pollut. 85:2607-2612.

Sullivan, T.J. 1993. Whole ecosystem nitrogen effects research in Europe. Environ. Sci. Technol. 27(8):1482-1486.

Sullivan, T.J. 1991. Long-term temporal changes in surface water chemistry. In: Charles, D.F. (Ed.), Acid Deposition and Aquatic Ecosystems: Regional Case Studies, Springer-Verlag, New York.

Sullivan, T.J., D.F. Charles, J.P. Smol, B.F. Cumming, A.R. Selle, D.R. Thomas, J.A. Bernert, and S.S. Dixit. 1990. Quantification of changes in lakewater chemistry in response to acidic deposition. Nature 345:54-58.

Sullivan, T.J., N. Christophersen, I.P. Muniz, H.M. Seip and P.D. Sullivan. 1986. Aqueous aluminum chemistry response to episodic increases in discharge. Nature. 323:324-327.

MICHAEL CRAIG SAUNDERS, Associate Professor, Department of Entomology, Penn. State University

Education

B.S., 1975, Zoology, Duke University
M.S., 1978, Biology, Old Dominion University
Ph.D., 1984, Entomology, University of Georgia

Recent Funded Research Projects (Selected Examples)

- 1991. Revision and expansion of the ForestHealth expert system crown injury assessment module. U.S. Forest Service. B.L. Nash, M.C. Saunders, D.D. Davis. Amount: $24,000
- 1992. Refinement of the treatment advisor, digitizing utility, and knowledge base tool in GypsES. U.S. Forest Service. M.C. Saunders, M.A. Foster. Amount: $33,000.
- 1992-1994. Enhancement and windows compatibility for the ForestHealth foliar injury assessment module test routine. U.S. Dept. of Interior, National Park Service. Amount: $71,390.
- 1994. Design of a Decision Support System for Forest Ecosystem Management. USDA Forest Service. M.C. Saunders. Amount: $10,000.
- 1994-1997. Development of a Prototype Knowledge-based Decision Support System for Air Quality Related Values Analysis Reviews. USDI National Park Service & Fish and Wildlife Service. M.C. Saunders. Amount: $298,532.

Selected Publications

Nash, B., K. Tonnessen, K. Heuer, N. Davis, M. Saunders, and B. Miller. 1997. Using the AQUIMS Air Quality Decision Support System to Identify Natural Resources at Risk from Air Pollution. Proc. ACSM/ASPRS Ann. Conv.: Resource Technology 4:362-379.

Reynolds, K., M.C. Saunders, B. Miller, J. Slade, and S. Murray. 1997. Knowledge-based Decision Support in Environmental Assessment. Proc. ACSM/ASPRS Ann. Conv.; Resource Technology 4:344-352.

Saunders, M.C. and B.J. Miller. 1997. A graphical tool for knowledge engineers designing natural resource management software: NetWeaver. Proc. ACSM/ASPRS Ann. Conv.; Resource Technology 4:380-389.

Saunders, M.C. and B.J. Miller. 1996. NetWeaver: A tool for the construction and maintenance of object oriented knowledge bases. Proc., Eco-Informa 96: Global Networks for Environmental Information.

Nash, B., M. Saunders, B. Miller, K. Tonnessen, D. Davis, J. Carriero, E. Porter, T. Maniero, J. Christiano, S. Silva, K. Heuer, and E. Phillips. 1996. AQUIMS: a computerized system for interpreting and integrating information on air pollution effects on natural resources. Proc., Eco-Informa 96: Global Networks for Environmental Information, Lake Buena Vista, FL, Nov. 4-7, 1996. pp. 575-580.

Coulson, R.N., W. Daugherity, E.J. Rykiel, J. Saarenmaa, and M. Saunders. 1996. The pragmatism of ecosystem management: Planning, problem solving, and decision making with knowledge-based systems. Proc., Eco-Informa 96: Global Networks for Environmental Information. Lake Buena Vista, FL, Nov. 4-7, 1996. pp. 575-580.

Reynolds, K., M. Saunders, R. Olson, D. Schmoldt, M. Foster, D. Latham, B. Miller, J. Steffenson, L. Bedmar, and P. Cunningham. 1996. Knowledge-based Information Management in Decision Support for Ecosystem Management in the Pacific Northwest U.S. Artif. Intel. Appl. in Nat. Resourc. Manag. 10(2):9-22.

Saunders, M.C., R.N. Coulson, and L.J. Folse. 1993. Natural resource management and agriculture, applications of artificial intelligence. pp. 149-162 in Kent, A. and J.G. Williams (eds.). Encyclopedia of Microcomputers. Vol. 12, Multistrategy Learning to Operations Research, Microcomputer Applications. Marcel Dekker, Inc., New York.

Nash, B.L., M.C. Saunders, B.J. Miller, C.A. Bloom, D.D. Davis, and J.M. Skelly. 1992. ForestHealth, an expert advisory system for assessing foliar and crown health of selected northern hardwoods. Can. J. For. Res. 22:1770-1775.

Saunders, M.C., R.N. Coulson, and J. Folse. 1990. Applications of artificial intelligence in agriculture and natural resource management. pp. 1-14 in Kent, A. and J. Williams (eds.). Encyclopedia of Microcomputers. Vol. 25, supplement 10. Marcel Dekker, Inc., New York.

Coulson, R.N., C.N. Lovelady, R.O. Flamm, S.L. Spradling, and M.C. Saunders. 1990. Intelligent geographical information systems for natural resource management. In Turner, M. and R. Gardner (eds.). Quantitative Methods in Landscape Ecology: Expert System Applications. Paris, France.

BRUCE JOHN MILLER, Project Assistant, The Pennsylvania State University

Education

B.S., 1982, Pennsylvania State University - Behrend

Professional Development

- International Conference/Workshop on Integrating Geographic Information Systems and Environmental Modeling, Santa Fe, NM - January 1996
- Workshop on Utilizing Internet Resources for Natural Resource Management, Frisco, CO - March 1995
- International Forest Resource AI Workshop, University of Alaska at Anchorage - June 1994
- International Conference/Workshop on Integrating Geographic Information Systems and Environmental Modeling, Breckenridge, CO - September 1993
- Geographic Information Systems in Natural Resource Management, Colorado State University - June 1991
- Process Control Expert Systems, Detroit Engineering Society, Detroit, MI - April 1990

Employment Experience

Project Assistant, Pennsylvania State University, 1992-present. Major projects:

- AQUIMS - Air Quality Management System for USDI National Park Service and Fish and Wildlife Service. Windows™-based decision support system for management of air quality related data and knowledge bases.
- Douglas Fir Doctor - Knowledge-based system for diagnosis and management of Douglas Fir pests.
- Artificial intelligence consultant on Chesapeake Bay Watershed Water Quality project, funded by the U.S. EPA.
- Developed NetWeaver, a Macintosh-based graphical tool for debugging, maintaining and documenting knowledge bases. Builds platform independence knowledge scripts read by a knowledge inference engine.
- Developed Soil TaxES (Soil Taxonomy Expert System), a joint venture between PSU, Cornell University, and USDA Soil Conservation Service to automate mass identification of soil taxonomies. First system of its type to utilize expert system technology in a batch processing mode to analyze archived data. UNIX and Informix based.
- Wrote Forest Health, a USDA Forest Service and USDI Park Service funded project for evaluating the vigor of eastern hardwood forests utilizing object oriented modeling and computer assisted training.

Selected Publications

Miller, B.J. and M.C. Saunders. 1994. A User's Guide to NetWeaver™. Penn State Univ.

Miller, B.J., M.C. Saunders, and B.L. Nash. 1992. Forest Health User's Manual. Penn State Univ.

Nash, B.L., M.C. Saunders, B.J. Miller, C.A. Bloom, D.D. Davis, and J.M. Skelly. 1992. ForestHealth, an expert advisory system for assessing foliar and crown health of selected northern hardwoods. Can. J. For. Res. 22:1770-1775.

Nash, B.L., M.C. Saunders, B.J. Miller, C.A. Bloom, D.D. Davis, and J.M. Skelly. 1992. The ForestHealth Expert Advisory System as a diagnostic and training tool for assessing tree health. Proc. Intl. Conf. on Computers in Extension.

Saunders, M.C., A.J. Muza, J.W. Travis, B.J. Miller, D.D. Calvin, E.G. Rajotte, and M.A. Foster. 1989. Integration of pest management recommendations by an expert system. Artificial Intelligence Applications in Natural Resource Management. 3:64-66.

Description of New Computer Software Developed (Selected Examples)

- Miller, B.J. 1996. NetWeaver-Delphi Prototype
- Miller, B.J. and M.C. Saunders. 1996. NetWeaver 12.
- Miller, B.J. and M.C. Saunders. 1996. AQUIMS 2.0. Air Quality Information Management System
- Miller, B.J., K. Tonneson, et al. 1995. Acid Deposition Knowledge base for AQUIMS.
- Miller, B.J. 1995. NetWeaver DLL: Dynamic Link Library version of the NetWeaver engine.

JOSEPH M. BISCHOFF, Watershed Analyst and Wetlands Ecologist, E&S Environmental Chemistry, Inc.

Education

M.S. Wetlands and Watershed Ecology, University of Louisville 1997
B.S. Biology, University of Cincinnati 1994

Experience

Mr. Bischoff has 5 years experience in education and research. His expertise include wetland systems, particularly vegetational, hydrological, and biogeochemical analysis of wetlands, and ecosystems ecology focusing on the role of landscape features in controlling water quality. He is experienced in database management and geographic information systems (GIS) technology. His relevant experience includes the following:

South Santiam Watershed Assessment, Western Cascades, Oregon. Mr. Bischoff is directing a comprehensive assessment according to the Oregon Watershed Assessment Manual for the South Santiam Watershed Council that includes water quality, hydrology, water use, sediment sources, riparian areas, channel habitat types, fisheries, and channel modification. The final product will include an environmental restoration action plan as well as a comprehensive analysis of the current state of the South Santiam Watershed.

Water Quality Analysis of the Tillamook Bay Watershed, Tillamook, Oregon. Mr. Bischoff is a part of an E&S team which has conducted intensive water quality monitoring and research since 1996 in the five rivers that flow into Tillamook Bay. The study includes routine monitoring at some sites and frequent-interval, storm-based sampling at others. Concentrations are measured and load estimates calculated for fecal coliform bacteria, total suspended solids, and nutrients on a storm-event basis and annual average basis. Intensive sampling was conducted on the Tillamook and Trask Rivers at frequent intervals during large storm events to determine the river segments that provided the largest bacterial loads. These were statistically related to land use percentages in the watershed subbasins that contributed discharge to the various river sampling points. Based on the monitoring data collected and the results of these analyses, a monitoring plan was prepared for inclusion in TBNEP's Comprehensive Conservation Management Plan (CCMP).

Huntington Watershed Project, Adirondack Park, NY. Mr. Bischoff conducted research as a part of the Huntington Watershed Project to link hydrologic and biogeochemical controls on nitrogen fluxes through wetland ecotones of the Adirondack Park, NY. He established and delineated the experimental plots, and performed analyses including plant identification, experimental design, plant community composition, biomass, and carbon/nitrogen content.

Acidic Deposition Research, Adirondack Park, NY. Mr. Bischoff conducted routine limnological monitoring (light, nutrients, dissolved oxygen, chlorophyll, and temperature), and collected zooplankton and phytoplankton from remote lakes in the Adirondack Park, NY to produce a baseline for lake recovery from acidification.

Selected Publications

Sullivan, T.J., J.M. Bischoff, and K.B. Vaché. 1998. Results of Storm Sampling in the Tillamook Bay Watershed, Final Report to the Tillamook Bay National Estuary Project, E&S Environmental Chemistry, Inc., Corvallis, OR.

Sullivan, T.J., J.M. Bischoff, K.B. Vaché, M. Wustenberg, and J. Moore. 1998. Water Quality Monitoring in the Tillamook Watershed, Final Report to the Tillamook Bay National Estuary Project, E&S Environmental Chemistry, Inc., Corvallis, OR.

Bisc/hoff, J.M., P.A. Bukaveckas, M.J. Mitchell, and T. Hurd. Nitrogen storage and cycling in a forested wetland: implications for watershed N processing. In review.

KELLIE B. VACHÉ, Research Analyst and Database Manager, E&S Environmental Chemistry, Inc. Responsibilities include database design and development, hydrological analysis, data analysis, programming, database management, systems maintenance, network administration, and water quality sampling.

Education

B.S., Geological Sciences, University of Washington, Seattle, WA 1994
M.S., Water Resource Engineering. Oregon State University, Corvallis, OR In Progress

Database Management and Programming Experience

Lead software developer for the E&S nonpoint source pollution model. Project involves the rewriting of a model which uses climate and landuse data to calculate nonpoint source pollutant loads into user-friendly Windows format, using Visual Basic.

Lead database analyst for the NOAA paleoclimate data cooperative for North and South America. Lead responsibility for database design and implementation (in conjunction with the Academy of Natural Sciences of Philadelphia). The project is designed to provide the climate change community with improved, more accessible estimates of historical climate. Currently using Visual Basic and Microsoft Access to develop the integrated database structure.

Database manager for Adirondack watershed database, a comprehensive GIS/water quality database of 57 lakes and their watersheds in the Adirondack Mountains, NY. This database has been developed by E&S for the U.S. Environmental Protection Agency, and is being used for analysis of controls on nitrogen cycling in forested ecosystems and the interactions between landscape characteristics and atmospheric pollution.

Analyst for U.S. Department of Energy land use/landscape characterization study in the northeastern United States. The study was designed to evaluate spatial patterns in surface water chemistry in an effort to refine understanding of relationships between landuse and water chemistry.

Primary analyst for E&S watershed studies (1994-present).

Publications

Mr. Vaché has published 15 journal articles and technical reports, including:

Raymond, R.B., J.M. Eilers, J.A. Bernert, and K.B. Vaché. 1998. Lacamas Lake watershed restoration project program Review. Report to Dept. of Public Works, Clark County, WA. E&S Environmental Chemistry, Inc.

Raymond, R.B., J.M. Eilers, J.A. Bernert, and K.B. Vaché. 1998. Lower Deschutes River studies. Water Quality and Biota. 1997 Final Report. Submitted to Portland General Electric. E&S Environmental Chemistry, Inc.

Bernert, J.A. and K.B. Vaché. 1997. Geographic Nutrient and Total Sediment (GNATS) Model Description and User Guide. Version 1.0. Prepared for the Oregon Department of Environmental Quality, Portland, OR. E&S Environmental Chemistry, Inc.

Sullivan, T.J., J.M. Eilers, B.J. Cosby, and K.B. Vaché. 1997. Increasing Role of Nitrogen in the Acidification of Surface Waters in the Adirondack Mountains, New York. Water Air and Soil Pollution. 95:313-336

Sullivan, T.J., D.F. Charles, B. McMartin, J.A. Bernert, K.B. Vaché, and J. Zehr. In Press. Relationship Between Landscape Characteristics, History, and Lakewater Acidification in the Adirondack Mountains, New York.

Bernert, J.A. and K.B. Vaché, 1996. Calibration of a Water Quality Model for Muddy Creek Watershed, Prepared for Institute for a Sustainable Environment, University of Oregon. E&S Environmental Chemistry, Inc. Corvallis, OR.

Eilers, J.M., R.B. Raymond, K.B. Vaché, J.W. Sweet, C.P. Gubala, and P.R. Sweets. 1996. Lacamas Lake Watershed Water Quality Monitoring Program. Prepared fro Clark County, WA Department of Community Development Water Quality Division. E&S Environmental Chemistry, Inc. Corvallis, OR.

Vaché, K.B. 1995. Adirondack Watershed Assessment Database. Prepared for Renssalaer Polytechnic Institute. E&S Environmental Chemistry, Inc., Corvallis, OR.

Section 10. Information/technology transfer

The technology developed in the proposed project will be distributed through GWEB. Members of the project team will train appropriate GWEB staff in the model application procedures. Workshops will be offered to watershed council members and other interested parties at two of the GWEB annual meetings. In addition, a series of regional training workshops will be offered throughout Oregon, and advertised in conjunction with GWEB's on-going communication efforts. Results of the model development and testing will be communicated to the scientific community via a final technical report to BPA and a manuscript for the peer-reviewed literature.