A REGIONALIZED ASSESSMENT OF THE INFLUENCE OF RURAL NONPOINT SOURCE POLLUTION ON THE ECOLOGICAL INTEGRITY OF STREAM ECOSYSTEMS AND AN EVALUATION OF ASSOCIATED POLLUTION CONTROL MANAGEMENT

A Proposal Submitted to the U.S. Environmental Protection Agency

Region VII

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by

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INTRODUCTION

Nonpoint source pollution (NPSP) is defined by the U.S. Environmental Protection Agency as precipitation-driven stormwater runoff, generated by land use activities such as agriculture, construction, urbanization, mining, and silviculture. These activities result in pollutants entering surface and ground waters through runoff, seepage, or percolation (Terrell and Perfetti 1989). Of the activities listed above, agricultural practices appear to generate the greatest amount of NPSP, and it has been estimated that two-thirds of the water basins in the United States are affected by agricultural NPSP (Duttweiler and Nicholson 1983, Schaller and Bailey 1983). Common forms of NPS pollutants resulting from agriculture include sediments, pesticides, nutrients, and wastes from plant and animal production.

Maintaining the quality of our water resources is of the utmost importance to maintain the quality of life and the present standard of living. Consequently, considerable effort is being expended to identify and characterize agricultural NPSP pollution. This recent focus is of extreme importance to states that are dependent, to a large extent, on an agriculturally based economy and way of life. To determine exactly how NPSP is impacting water and environmental quality, and to formulate and implement methods of controlling these causes of reduced water quality are formidable tasks due to the subtle and often complex forces at work. Any change in the land surface, either natural or anthropogenic, may result in changes in the physical, chemical, or biological integrity of aquatic systems.

The challenge is to approach the problem of NPSP in a holistic, systematic manner that will permit an assessment of the general health and integrity of ecosystems at risk. Simply investigating isolated aspects of aquatic ecosystems, or the ecosystems that contribute to NPSP, e.g agroecosystems, are not sufficient for a complete understanding of NPSP problems. Only by integrating the ecosystems within a specific landscape unit can we fully investigate and mitigate the effects of NPSP. The landscape unit that we have chosen for integrating the effects of NPSP on aquatic ecosystems is the watershed, recently recognized as critical in the investigation and management of NPSP (Duttweiler and

Nicholson 1983, Phillips 1988). This approach allows us the greatest flexibility in investigating NPSP because we can relate the information collected at the individual stream segment sampling site to processes that occur at the level of the watershed and the ecoregion.

The University of Kansas, Kansas Biological Survey (KBS) proposes a joint investigation with the University of Nebraska (Lincoln), and Iowa State University to assess the influence of land form and land use practices on the generation of NPSP in the three-state region (Kansas, Nebraska, Iowa), and the effect NPSP has on the physical, chemical, and biological integrity of streams draining watersheds in regions dominated by agriculture. In subsequent years, we will expand our efforts to investigate NPSP generated from other activities. The ultimate goal of this investigation, obtainable within a very few years, is to provide viable solutions to NPSP problems, solutions that provide the greatest effectiveness in mitigation, with the greatest flexibility and the least disruption to those currently responsible for NPSP. A geographically-based, regionalized approach that integrates several spatial scales, from the individual stream segment to the ecoregion, will be adopted to organize, analyze, and integrate landscape data (land form and land use), geophysical data (soils, topography), and environmental data (biological, water quality) in an attempt to assess the isolated, combined, and cumulative effects of various land management and land use practices on aquatic systems.

To accomplish this goal, it is necessary to obtain baseline data from several systems impacted by such NPSP activities as, agriculture, urbanization, mining, and timber harvesting. During the first year of this project, we will concentrate on agriculturally generated NPSP by gathering baseline data in watersheds in which agricultural activities are a prominent land use category. These data are necessary to meet both our immediate objectives and long-term goals. During subsequent years, we will continue to monitor the watersheds targeted during year one, and monitor additional agricultural watersheds throughout the three-state region. All watersheds will initially be located in the Western Corn Belt Plains Ecoregion (Omernik 1987).

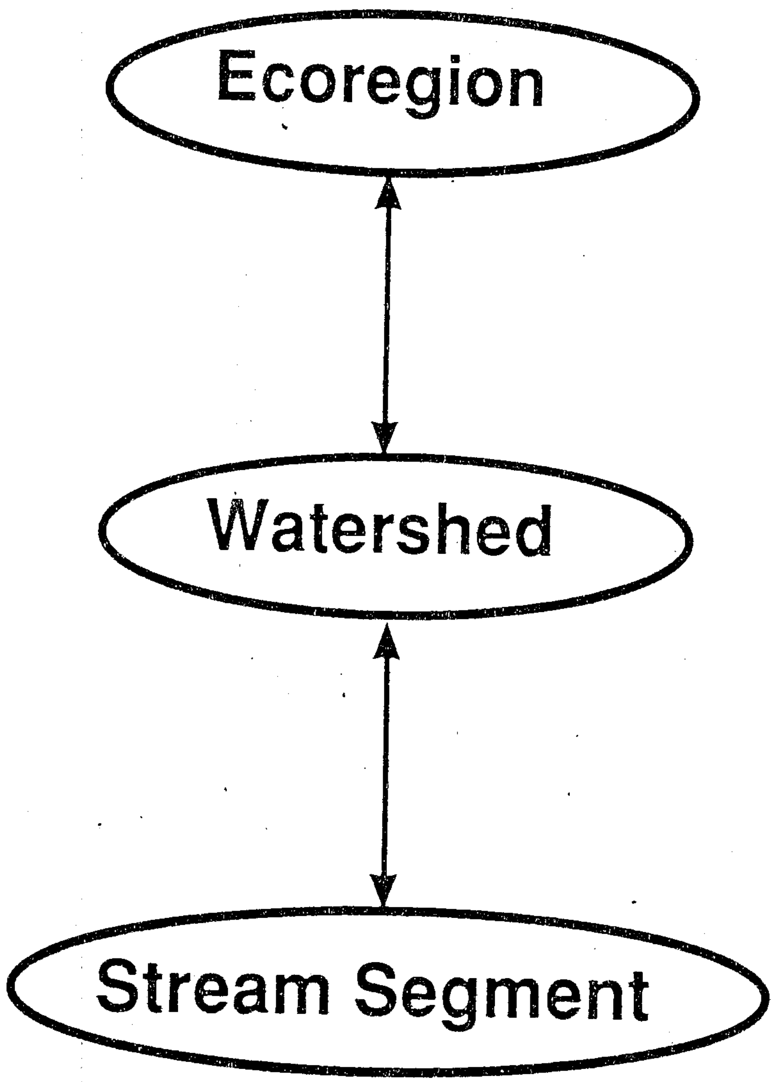
Within a short time, we will expand our efforts into urban watersheds to evaluate NPSP problems associated with urban areas (e.g., storm water runoff). Over the next several years, we plan to extend this initiative into all aspects of NPSP, utilizing the philosophical approach outlined below. This initiative will combine long term, baseline monitoring of watersheds with experiments performed in the field, and will utilize Geographic Information Systems (GIS) and the newest remote sensing technologies available, to develop the analytical methodologies that will be critical in identifying and solving the problems associated with NPSP. Additionally, the integrated systems approach that we have developed to investigate this large problem (see below), will provide information that can be utilized in a number of programs at the EPA, the most prominent being the Environmental Monitoring and Assessment Program (EMAP). The general plan for the study to be conducted consists of four basic components: 1) scales of analysis, 2) research objectives, 3) approach to meet research objectives, and 4) the method of implementation of the approach. We discuss each component in detail, and follow with the detailed work plan for the first year.

SCALES OF ANALYSIS

Environmental scientists are confronted with a host of significant concerns including the evaluation of changes in biodiversity, comparative risk assessment, monitoring the occurrence and effects of environmental modification, and quantifying environmental health. Development of analytical techniques and models to address environmental issues is complicated by the fact that such techniques and models must accommodate a broad spectrum of landscape scales. In other words, environmental analysis must take place in landscape units as small as one acre, or potentially, over regions as large as a biome.

The analysis of NPSP must address three major issues: 1) identification of factors that contribute to the production of nonpoint source contaminants, 2) characterization and quantification of the effects of the contaminants on the aquatic ecosystem, and 3) determination of the most appropriate methods of mitigating those effects. Addressing these issues also requires the integration of three spatial scales, individual stream segments, entire watersheds, and the ecoregion level (Figure 1). These

SCALES OF ANALYSIS



scales or levels form a natural hierarchy of structure and function, with each level being an aggregation of the components and processes that comprise the lower level.

In order to identify, characterize, and quantify the effects of NPSP on aquatic ecosystems (issues 1 and 2 above), it is necessary to begin with an examination of individual organisms (or even physiological and biochemical processes within individual organisms). Because most organisms have individual ranges that vary in size from a few meters to a few hundred meters, most of their activity will occur within a short segment of stream. Consequently, any investigation of the effects of NPSP on the ecosystem must begin at the level of the stream segment. Data gathered at the this level, which we can obtain as often as necessary, provide information about the short-term effects of NPSP. For example, changes in the microhabitat distribution of individual fish in response to increased sediment load from runoff events, may occur for only a short period of time, but could be critical if the change occurs during spawning. Such a change can only be detected at the level of the stream segment.

In order to understand the causal mechanisms behind NPSP generated changes occurring within the stream segment, it is necessary to look at phenomena that generally occur elsewhere in the watershed and at the landscape structure encompassed by the watershed level of organization. Organisms within each stream segment are impacted not only by NPSP entering into the stream channel at that location, but also by the NPS contaminants that have entered the channel from the entire upstream watershed. Therefore, there is a critical need to incorporate the spatial dimensions of landscapes into environmental modeling efforts (Forman and Godron 1986, Ritchie and Engman 1986, Urban et al. 1987, Huggins et al. 1990). Numerous aspects of landscape structure at the level of the watershed can have considerable impact on the generation of NPSP. The types and amounts of patches of different land use classes, for example, as well as their location within the watershed, their size, shape (fractal dimension), and the amount of edge are all factors that can magnify or mitigate the effects of NPSP.

Just as process and components at the stream segment level must be integrated at the watershed level, watershed level information must be combined and analyzed in the broad perspective of landscape regions. Landscape regions (e.g. ecoregions) are comprised of integrated complexes of similar terrain, soils, climate, vegetation, and land use (Bailey 1983, Moss 1983, Omernik and Gallant 1989). Such regions are believed by some to act as systems, and may exhibit "uniform" response to environmental change.

Ecoregions may exhibit unique spatial and temporal structure (Forman and Godron 1981) that arises from a variety of phenomena and processes. In environments where humans are not a significant factor, spatial structure may reflect the pattern of vegetation communities and/or soils that tend to develop in a particular mosaic pattern under a set of geologic, topographic, and climatic circumstances. Where humans are significant organisms in the environment, the spatial structure of the surface will be related to the segmentation of the landscape resulting from land ownership, land use (including settlement, cropping, grazing, and mineral extraction processes), transportation, energy resource development, and urbanization. Therefore, characterization of land cover and land use activities within watersheds can be used as a step in the process of refining the boundaries between ecoregions.

STUDY OBJECTIVES

The major study objective at the level of the stream segment is the identification and development of indicator variables that can be used within the proper analytical framework to measure the effect of NPSP on aquatic ecosystems. Our work will focus on indicators that can be measured in the field, and those measured by remote sensing techniques. We expect these indicators to be directly applicable to EPA's Environmental Monitoring and Assessment Program, and the sites at which the indicators are developed and monitored can serve as off-frame sites for EMAP.

Ecosystem level analysis requires that several types of indicators be developed. To measure NPSP, indicators of ecosystem exposure are necessary. These require measuring a series of water quality variables including concentrations of agrichemicals such as atrazine and alachlor, nutrients such as various forms of N, P, and C, and eventually, concentrations of heavy metals. Additional indicators of exposure can be developed by measuring concentrations of chemicals in the tissues of aquatic organisms, or by examining various genetic parameters, e.g. mitochondrial DNA variation. Habitat indicators of the aquatic and the adjoining riparian and agroecosystems also must be developed and measured. Both instream and nearstream habitat must be quantified, using indicators such as the Habitat Development Index (HDI, Huggins and Moffett 1988), because the effects of habitat quality and NPSP on aquatic biota must be clearly distinguished. Our past NPSP studies (e.g., Anderson 1990, Huggins et al. 1990) have successfully utilized various quantitative measurements of most variables identified by the U. S. Environmental Protection Agency as primary, secondary, and tertiary habitat assessment parameters deemed useful in bioassessment (Plafkin et al. 1989). In fact, our development and use of micro- and macroscale habitat variables (both instream and nearstream parameters) in prior NPSP studies has allowed us to move beyond the simplified, single index approach utilized in current rapid bioassessment protocols. These habitat indicators must then be integrated with the larger landscape-scale patterns that exist at the level of the watershed.

As ecosystem level analysis proceeds at the watershed level, a regional framework for analyzing patterns of environmental resources must be developed for the purposes of monitoring and assessment. This regional framework, or ecoregions analysis os based on the hypothesis that ecosystems and their components display regional patterns that are the result of causal and integrating factors such as soils, vegetation, land use, climate, and geology (Omernik 1987). The ecoregions concept has been tested in a number of states for a variety of applications related to water quality assessment and monitoring (Omernik and Gallant 1990).

A region can be simply defined as a homogenous area specified by the objectives and purposes of the environmental analysis. In the context of ecosystems level analysis for NPSP, the delineation of regional boundaries based on causal and integrating factors and their patterns of occurrence is a complex task that depends not only on the scale of analysis but also the seasonal and multi-year variations in resource quality and quantity. Remote sensing and geographic information systems (GIS) provide an opportunity to approach this problem by incorporating a nested hierarchy of multiple-scale databases for landscape evaluation. Our principal objective is to characterize and model landscape structure at differing scales using unique analytical capabilities of GIS and the spatial data derived through remote sensing.

We anticipate that this portion of the study will involve close collaboration with scientists at EPA/Corvallis, EPS/Las Vegas, and the USGS/EROS Data Center. An important focus of the initial work will be to conduct a critical analysis of the methods now used to characterize landscape spatial structure, identify the extent to which those methods might be relevant to environmental monitoring and assessment, and evaluate current methodologies used to define ecoregions. Subsequently, several remote sensing/GIS techniques (modified or newly developed as required) will be tested using field data gathered at individual sites within the watersheds.

APPROACH

The fundamental approach we will apply to meet our objectives is an integrated systems approach in which we integrate both horizontally within each spatial level and vertically between spatial scales (Figure 2). The two features that must be integrated are ecosystem structure and function because: 1) structure and function can be defined and used operationally in ecosystem analysis, and 2) a framework of structure and function allows an evaluation of the effects of ecosystem stresses in terms of ecosystem response, i.e., a change in state (structure) or dynamics (function) as a consequence of stress (Kelly and Harwell 1989).

The prevailing logic, either implicitly or explicitly stated in the literature, is that while it is desirable to study both structure and function in an integrated systems approach, it is possible only to investigate either one or the other as separate aspects of the ecosystem (e.g., Duttweiler and Nicholson 1983, Cairns and Pratt 1986, Hunsaker and Carpenter 1990). As a result, considerable effort in the past, has been expended generating indicators of either structure or function. To our knowledge, none of these indicators have proven to be a panacea for those charged with assessing and monitoring ecosystem health. Although years of searching have not produced satisfactory indicators, the present

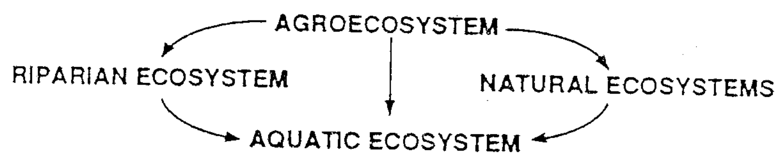
APPROACH

Integrated systems – vertical and horizontal integration of spatial scales of analysis

- **Integrate watersheds at the ecoregion level**

  Refine the characterization of ecoregions by identifying and integrating properties of all watersheds within a geographic region.

- **Integrate ecosystems within watersheds**



  Integration of the structural components of these ecosystems within the framework of ecosystem function is a problem of analysis. Structural equation modeling provides the analytical methodology that integrates ecosystem structure and function while providing a measure of ecosystem dynamics.

- **Integrate processes within stream segments**

  Identify indicators of ecosystem structure

  - Stresses – Natural (drought)
    Anthropogenic (chemical)
  - Taxonomic groups
  - Habitat structure
  - Genetic/molecular bioindicators

  Determine functional relationships

  - Nutrient cycling – N, C, P
  - Energy flow
  - Biological – Demographic
    Ecological (predation)
  - Geophysical

(and future) emphasis in most studies is to identify additional indicators in hopes of finding something that will provide the "magic bullet" for solving environmental problems (e.g., Hunsaker and Carpenter 1990). It is often proposed that indicators be combined in some manner, e.g. an index, that can indicate whether the environment is healthy or unhealthy, (nominal or subnominal, respectively, in EMAP terminology).

We believe that the inability to develop acceptable indicators is the result of unrealistic expectations, and the lack of an analytical methodology that can truly integrate indicators into a framework of ecosystem structure and function. In fact, indicators are expected to perform functions that they inherently can not perform. As a partial list, they are expected, 1) to be easily and accurately measured in all similar ecosystems, 2) to represent some critical aspect (or be highly correlated to some critical aspect) of ecosystem structure or function, 3) to exhibit low variability with respect to natural ecosystem variation (e.g. seasonal or diurnal), while at the same time be extremely responsive to perturbations from numerous anthropogenic causes, and most critically, 4) be able to stand alone (or in combination with other variables as an index) as a reliable and unambiguous indicator of ecosystem health. We feel that it is not possible for any indicator or index to fulfill these criteria.

The problem is not with the indicators. The problem is a lack of clear guidelines as to how to utilize indicators appropriately, as well as a lack of emphasis on the development of methods that place indicators in the proper conceptual framework. The major difficulty is that there is no clear, objective, independent criterion to distinguish nominal from subnominal condition; hence, the indicators themselves are often used as the criteria for assessment. Consequently, a determination of which ecosystems are nominal or subnominal can change as more ecosystems are sampled. In fact, this is expected (Hunsaker and Carpenter 1990).

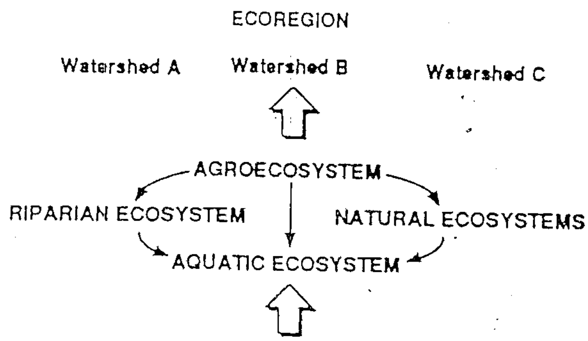
The problem with this approach can be made clear with an analogy to human health. If we wish to find an indicator for good health, we may choose body temperature as that indicator. We measure the temperature of 100 individuals and find that the majority of them have a body temperature between 98°F and 99°F. By the rationale often used to determine ecosystem health, we would conclude that because the majority of individuals have a temperature of 98°F-99°F, then 98°F-99°F is healthy. However, a temperature of 98°F-99°F is not healthy simply because a majority of our sample has that temperature. In fact, they have that temperature because they are healthy. What really determines health is proper physiological and biochemical function within the body, which occurs at 98°F-99°F. Physiological and biochemical function is the objective and independent criterion for determining health. Although temperature is an indicator that can be used to determine how close an individual is to the optimum of the criterion, temperature is not the criterion itself. Unfortunately, despite recent attempts to draw parallels between human health and environmental health (see Schaeffer et al. 1988), there are no clear ecosystem parallels to physiological and biochemical functioning. However, this does not mean that indicators should not be used to assess ecosystem health. The critical question becomes what is the role of indicators in ecosystem analysis?

We do not advocate abandoning the use of indicators in ecosystem studies. Quite the contrary, we feel that ecosystem analysis is impossible without indicator variables. What we do advocate, is 1) establishing an independent, objective criterion for determining ecosystem health (nominal versus subnominal condition), and 2) placing indicators into a framework of ecosystem structure and function in such a way that the criterion can be evaluated. These steps require the establishment of a network of structural components and functional pathways that represent cause and effect relationships within and between ecosystems. To identify and quantify ecosystem structure, a series of indicators of the structural components of the ecosystem must be established. However, only when indicators are integrated into a single ecosystem model of structure and function, can overall ecosystem health be assessed. Successful integration of these structural components with ecosystem function is simply a problem of developing and applying the correct analytical methodology.

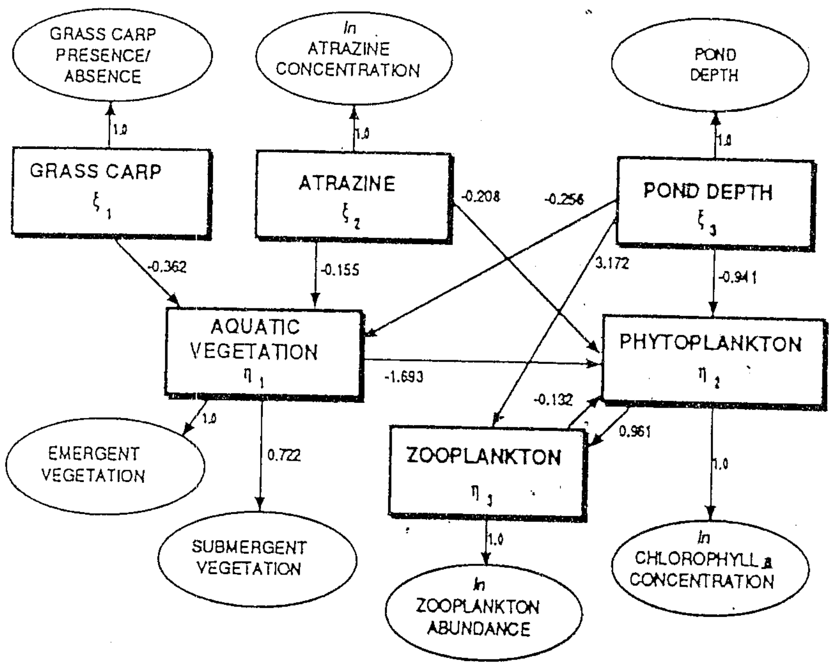
We have recently developed a methodology (Figure 3) that enables us to integrate indicators of ecosystem structure with the functional relationships between these indicators in a statistical model where the measure of ecosystem health is the measure of the stability of the ecosystem (Johnson et al.

STRUCTURAL EQUATION MODELING

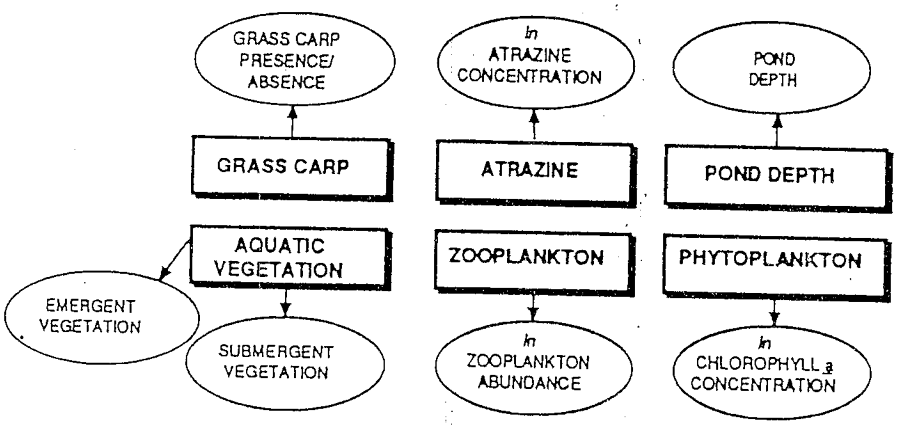
Integration of ecosystem structure and function allows a measure of the direct and indirect effects of any environmental stress on all structural components of the ecosystem and allows a measure of ecosystem stability



- Combine models from different watersheds for ecoregion analysis
- Combine models from different ecosystems into watershed model



- Use data from field sites to calculate quantitative measures of effects
- Hypothesize functional relationships (arrows) between structural components



- Identify and develop indicators (circles) of structural components (boxes) of ecosystems

1991, in review). We have successfully used this methodology in analyses of the effects of atrazine on pond mesocosm ecosystems (Johnson et al. 1991, Huggins et al. in review, Johnson et al. in review), and a watershed-scale analysis of the effects of NPSP on aquatic ecosystem structure and function (Huggins et al. in prep). This latter analysis has demonstrated that it is possible to integrate within and between ecosystems and spatial scales, and will serve as the model for our future investigations.

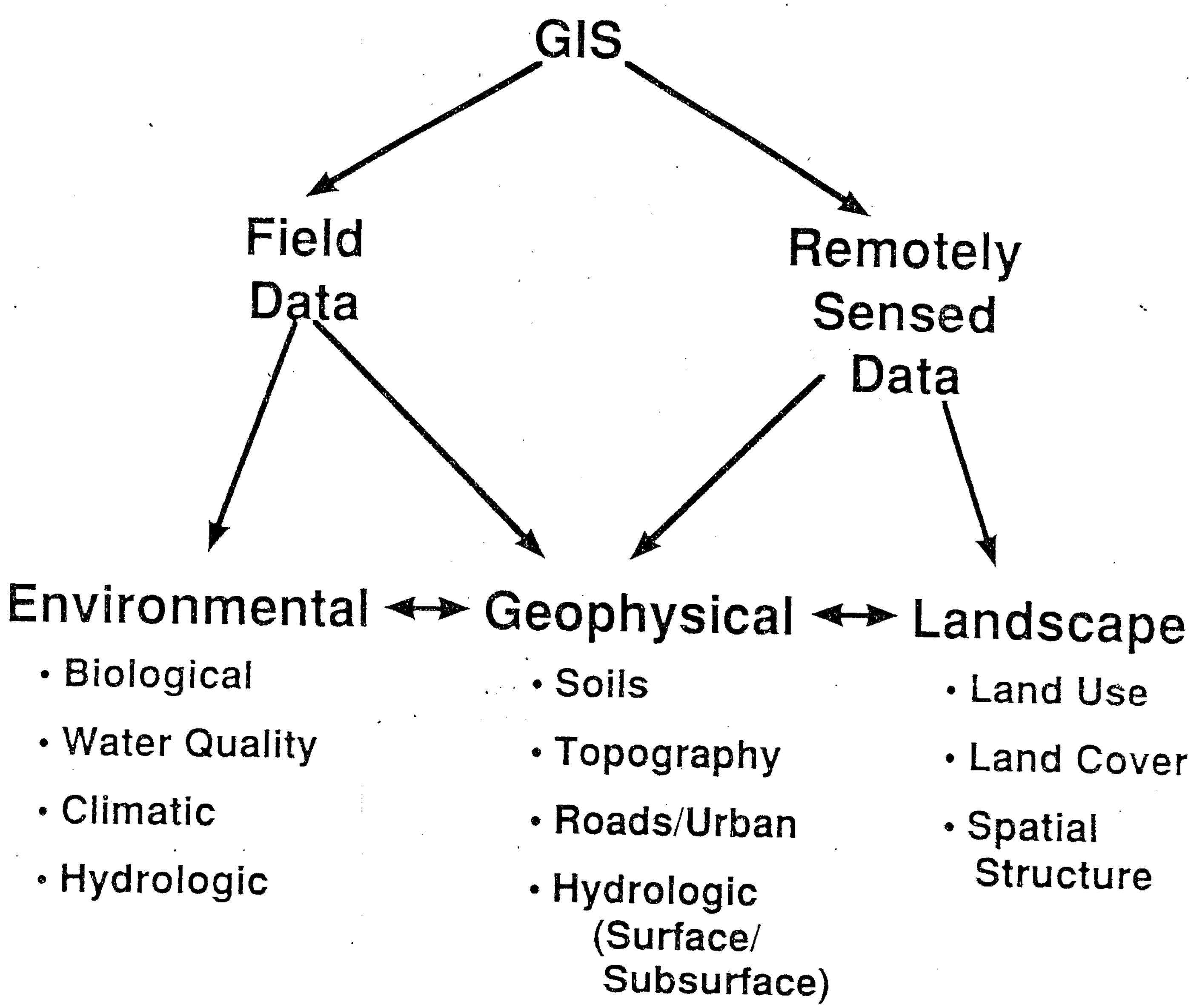
IMPLEMENTATION

Because this project is geographically based and spans three levels of spatial analysis, the only possible framework in which to effectively implement this research is within a Geographic Information System (GIS) (Figure 4). All data collected can be georeferenced, and the GIS can integrate these data over the different spatial scales. Environmental and geophysical data collected in the field can be associated spatially with other geophysical data available from maps. Remotely sensed data, both close-range data collected at the stream segment, and more traditional remote sensing data from aerial photography and satellite imaging collected at the level of the watershed and the ecoregion, can be integrated with the other data types within the GIS. Remote sensing and GIS technologies offer opportunities for providing indicators that define and characterize landscape regions and spatial variability, and for quantifying spatial and environmental parameters that can be used in our structural equation modeling efforts.

GIS and remote sensing are useful tools for regional assessment of biodiversity and landscape structure (Scott et al. 1987). Typically, most such work is founded on relatively small scale (1:250,000) source maps and ancillary data. Products and assessments derived form these small-scale GIS applications appear best suited for projects that require large areal coverage in short time periods. However, they depict only the most coarse elements of landscape structure and ecological interrelationships.

Larger scale (1:100,000 - 1:10,000) high spatial-resolution data are needed to fully characterize and analyze spatially complex environments and relate this complexity to individual watersheds and

IMPLEMENTATION



individual stream segment locations within those watersheds. We suggest that the best approach for using GIS and remote sensing data is to construct a GIS that incorporates a nested hierarchy of multiple-scale databases; i.e. systems that allow the small-scale synoptic view to be quickly obtained and used, but that can be augmented and enhanced as time and funds permit. Successful implementation and use of a "hierarchical GIS" will result in: 1) a better understanding of the manner in which ecoregions and landscape structure can be defined and characterized using different scales of source data (including remotely sensed data), 2) development of techniques for landscape analysis that permit exploitation of the full power of GIS analytic capabilities, 3) development of methods for data integration and spatial analysis across multiple-spatial scale databases, and 4) identification of the linkage between landscape structure and ecosystem processes as they relate to NPSP, which are then integrated via structural equation modeling.

In later stages of the investigation, we will integrate newly developed methods of data analysis with information delivery to users. Advanced techniques in GIS user interfaces, visualization, animation, and digital cartography will be developed. Remote sensing and GIS technologies, properly linked and integrated, have the potential for providing far more than simply sophisticated environmental data gathering. These technologies provide us with the opportunity to explore and test relationships between landscape structure and NPSP in ways not previously feasible. They are a unique and powerful means of manipulating, integrating, and analyzing information that will lead to improved or new methods of identifying, characterizing, and mitigating the effects of NPSP.

WORKPLAN

The workplan presented below is organized into four broad-scale, interrelated projects. The completion of each of these projects is critical to the success of the others, and to meeting the overall objectives of the investigation. However, each project is described individually for ease in presentation.

LONG-TERM WATERSHED MONITORING

The purpose of this aspect of the investigation is to establish the watersheds that will be monitored over several years (3-5 years) as the focus of the data-gathering activities for the assessment of the effects of NPSP on aquatic ecosystems. We feel that a period of 3-5 years for monitoring of the watersheds is necessary because: 1) data acquired on a seasonal basis may require several years to insure that normal seasonal variation is experienced, 2) this period of time spans the EMAP cycle of site visits (4 years, Hunsaker and Carpenter 1990), allowing an evaluation of the EMAP sampling procedure, 3) the complexity of the NPSP problem requires considerable data to disentangle cause and effect, and 4) establishing a regionalized field program is a time consuming and often protracted venture that may consume a year or more before all watersheds can be fully instrumented and monitored. Therefore, even though the period of this study is three years, we view these three years as the beginning of our efforts, not as the end.

This project consists of two main tasks, selection of watersheds, and determination of the data to be collected within each watershed. We outline the work plan in this section, and discuss in detail the specific techniques and methodologies used in the water quality analyses in the Quality Assurance section.

Watershed Selection Process

The selection process for watersheds to be monitored is outlined in Figure 5. Fifteen watersheds eventually will be chosen from a series of candidate watersheds identified during the first year. We will choose and initiate sampling in five or more watersheds as part of the first year's monitoring activities. Initially, all watersheds will be in the Western Corn Belt Plains ecoregion

Watershed Selection Process

Criteria	Source of Information
Western Corn Belt Plains ↓	US EPA Ecoregion Map
Watershed Size ↓	
No Urban Development ↓	USGS 1:24000 Topographic maps
Perennial Flow ↓	Field Observation
Basin Land Use ↓	Soil Conservation Service (or other sources, e.g. remote sensing)
No Anomalous Features ↓	Morphometric Analyses Field Observation
Existing Watershed Data and Ongoing Research ↓	Literature Search • Professional Publications • Agency Reports and Open File Data Correspondance with Knowledgeable Parties
Watershed Candidates	Assessment of Watershed Candidates and Regional Representation

(Omernik 1987) of Kansas, Nebraska, and Iowa. We will concentrate on small stream networks (3rd-4th order) in relatively small watersheds (<30 sq. mi.) because they are less costly and easier to study; they are often less complex and have a higher potential for isolating variables of interest, and represent ecosystems with maximum terrestrial/aquatic interface. Additionally, because large basins are typically aggregates of smaller basins, identifying and resolving relationships among variables within the more manageable smaller basins will directly contribute to large-basin management. We will attempt to include watersheds that vary in the proportion of land in a specific use or cover type, e.g., pasture, row crop, or forest. Only by investigating watersheds that display a range of variation in the amounts and types of land use and land cover can we adequately disentangle the numerous factors that potentially contribute to NPSP. We will also attempt to utilize watersheds in which previous work has been or is currently being conducted by federal and state agencies. If available, current or previously collected data can provide several benefits including: 1) a historical framework for the interpretation of current interactions among the structural components of the various ecosystems, 2) an opportunity to determine if data collected in past monitoring efforts can be utilized in current study initiatives, and 3) increase the communication among the various organizations that attempt to monitor and assess ecosystem health and integrity.

For the initial study, we will choose watersheds in which there is no urban development, in order to avoid the confounding problems associated with the point source effluent discharges associated with urban areas. However, because livestock confinements can contribute substantially to NPSP, we will incorporate some watersheds in which there are active livestock operations. Additional criteria used to select watersheds include perennial flow of the stream, and lack of anomalous features, e.g. large impoundments.

Once a group of candidate watersheds have been identified, final choice will be determined after site visits and discussions with local, state, and/or federal officials (e.g., Soil Conservation Service personnel). Potential stream segment sample sites within each watershed will be selected, and land owners of those sites will be contacted for permission to work in the stream channel, establish routes of ingress and egress to study sites, and to leave equipment on their property (e.g. automated water samplers). Our experience with land owners has been that they are willing to cooperate and provide access to the stream once the project has been explained to them. The establishment of permanent sample sites will be determined by ease of access, permission of the land owner, and characteristics of the stream channel (see below). Five stream segments within each watershed will be chosen as the sites at which all seasonal and event-related sampling will be conducted.

Climatic

After the watersheds have been chosen, we will identify all existing sources of climatic data with, an emphasis on precipitation. In order to relate precipitation to surface runoff and NPSP, it is necessary to measure some basic climatological parameters such as rainfall and humidity. If these data are not available from the immediate vicinity, we will install meteorological stations as necessary.

Land Use/Land Cover

Land use/land cover variables will be generated by remote sensing and Geographic Information Systems (GIS) techniques. The primary base map of land use/land cover for each watershed will be generated utilizing the most current NAPP (National Aerial Photography Program) film positive transparencies. Kansas watersheds initially will be mapped from 1986 NAPP color infrared transparencies, Nebraska watersheds from 1987-88 color infrared film and 1990 black-and-white NAPP transparencies will be used for mapping Iowa watersheds. Supplemental aerial photography will be acquired, when possible, to supplement existing NAPP photography and allow observation of both "leaf-on" and "leaf-off" conditions. The initial use of leaf-on and leaf-off photography should enhance interpretation and delineation of small land parcels. We will also utilize satellite imagery in the development of the land use/land cover maps, as well as in the development of indicators of the spatial characteristics of the watershed (see Remote Sensing section below).

Manual interpretation of the aerial photographs will be necessary to determine the land use characteristics suspected as important in the generation of NPSP. Criteria used to standardize interpretation of aerial photographs will include: 1) minimum width of riparian vegetation that can be detected along the stream will be 20 meters, 2) active livestock operations will be indicated by bare ground livestock lots or storage areas containing bales of hay, 3) a minimum mapping unit of 2.5 acres (approximately 1 hectare) will be used for all polygon classes, and 4) areas with 0-30% canopy closure will be identified as rangeland, and areas of 31-100% canopy closure will be classified as forest.

During photo interpretation, point, line, and polygon landscape features will be identified and transferred to mylar overlays. A land use/land cover classification scheme (Table 1) developed during a pilot study will be used as a guide for the interpretation. If additional land cover classes are determined to be necessary, they can be added at any time. Accuracy of the photo interpreted data will be assessed by ground truth at selected locations within the watersheds. A systematic sampling scheme developed during the pilot study will be used to determine cover classes at known points. Section roads will be used as transects through the watersheds, with the land cover recorded every 1/5 mile along both sides of the road. At intersections of section roads, land cover will be recorded from all four corners. Accuracy of the photo interpretation will be determined following ground-truth. Accuracy in our previous study (Huggins et al 1990) averaged approximately 85%, even with photographs that were three years old. All land use/land cover information will be transferred from the mylar sheets to rectified base maps using a Kargl Projector. Base maps will then be digitized using pcARC/INFO and stored in separate data files. Crops and crop management practices associated with individual crop and pasture parcels will be obtained from the yearly ASCS (Agricultural Stabilization and Conservation Service) crop management and compliance photography, and used to annually update the attribute files for these parcels. This approach will enhance land use mapping accuracy and allow the current status of critical landscape variables to be investigated concurrent with seasonal and annual water quality and ecological field data. In addition to the land use/land cover information, the stream network, roads, and other point and line data will be digitized and placed into data files in the GIS. We have found that these types of data are more accurate when taken from photographs than when taken from standard 7.5 min USGS topographic maps (Huggins et al 1990).

TABLE 1. Land use/land cover classification scheme (minimum classes and geophysical characterization.

Polygon classes	Point Classes	Line Classes
1) Cropland, nonspecific (no visual conservation practices)	1) House	1) Interpreted stream channel and/or
2) Cropland with contour cropping	2) Farm (house with several out buildings)	2) USGS stream channel from dated 7.5 "topographic" maps
3) Cropland with grass waterways	3) Farm with livestock (active)	3) Road network
4) Terraced cropland with grass waterway	4) Farm with livestock facilities (inactive)	4) Road ditch erosion
5) Cropland with parallel terraces	5) Stream sampling site	5) Windbreaks/hedgerow
6) Rangeland/pasture/hay fields (<30% canopy closure)	6) Quarries/strip mining site	6) Field tile network
7) Forest/woodland (includes riparian zones of width $\geq$ 66 ft and >30% canopy closure)	7) Solid waste landfill	7) Elevation contours
8) Property (developed farm, housing or industry property)		
9) Water body		
10) Wetlands		
11) Quarries/strip mining		
12) Solid waste landfill (i.e. county and municipal landfills)		
13) Soil mapping units		
14) Surface geology mapping units		
15) Subsurface hydrologic and geologic attributes (i.e. depth to groundwater)		

Soils data will be added to the GIS by digitizing mylar overlays of SCS county soils maps. Infiltration rates and the erodibility of the soil are the main types of information necessary to characterize NPSP potential of the land cover classes. Digitizing the topographic information from the 7.5 minute USGS maps will allow us to generate slope and aspect within the watersheds. These data are critical in evaluating runoff, and therefore, NPSP potential. Additional data to be entered into the GIS include surface and subsurface geological features, depth to groundwater, groundwater recharge areas, field tile drainage networks, and tile effluent sources.

By overlaying the individual layers of the GIS, we can generate a large number of land use variables. In our recent pilot study, we identified 65 of these variables including measures of area, edge, number of polygons of specific land use classes, and the area of land use/land cover classes within a buffer zone next to the stream channel, as possibly contributing to or mitigating the effects of NPSP. We expect additional indicator variables to be developed, and we will concentrate on evaluating these variables with respect to their ability to directly and indirectly influence water quality.

A subbasin approach to data analysis will be utilized, with the subbasins generated by the GIS (Huggins et al. 1990). Using the pcARC/INFO "clip" function, we will generate a basin for each sampling site (stream segment) that will include all land contributing to the drainage at that site. Consequently, each watershed will contain five subbasins. Each subbasin will be analyzed by including all upstream land draining to a sample site, and by including only the land between stream segment sample sites.

If necessary, remotely sensed data will be obtained each summer to update the land use/land cover classifications, identify new road or urban developments, and verify the location of the stream channel (i.e., check for flood or anthropogenically induced changes in the location). However, communication with local authorities (e.g., county engineers, SCS agents, district watershed managers) and use of annual ASCS photography should minimize the need for additional aerial photography. We anticipate that a minimum of photo interpretation and redigitizing will be necessary in the 2nd-5th years of the monitoring program.

Stream segment-Habitat

At each stream segment sample site, a number of instream and near-stream habitat variables will be measured (Table 2). These variables will be used to establish the relationships among water quality, biota, and instream/near-stream habitat, and to evaluate the effects of agricultural or rural development activities on these habitat features. Typically, measurements of each variable will be taken at three locations in each stream segment, the upper, middle and lower points. The expense in measuring some water quality parameters (e.g., pesticides) will limit sampling to two locations. Vegetation along the bank will be recorded as riparian, row crop, or pasture/rangeland. Row crop and pasture will be identified if there is direct contact with either bank; otherwise, the vegetation will be considered to be riparian. Width of the riparian vegetation will be measured with a tape measure at the three points mentioned above. During the first year, the woody vegetation and ground cover conditions (vegetation density, diversity, patchiness) will be assigned to one of four general categories (Table 3). Vegetative canopy closure will be obtained from transects established at the three sample points. A concave, spherical densiometer Model B (Lemmon 1956a, 1956b) will be used to estimate canopy density at five points along each riparian transect and corresponding stream cross-sections following the methodology of Platts et al. (1987). Average values for transects and stream segments will be used as measures of shading. Also included in the evaluation of riparian conditions will be an estimate of the livestock damage to the vegetation. Four categories of livestock damage will be subjectively assigned: 1) 0 = no livestock access, 2) 1 = livestock access indicated by paths to stream channel and the presence of fecal material, 3) livestock damage indicated by active areas of erosion, increased deposits of fecal material, but limited browse damage, and 4) active erosion, large amounts of fecal material present, and noticeable browse damage to the vegetation. Assessments will be made for both the left and right bank.

TABLE 2. Selected geomorphic/stream habitat, water quality, biotic and land use/cover variables used in ANOVA and linear multiple regression analyses.

Variable	Description of Variable	Unit of Measurement
	<u>Geomorphic/Stream Habitat</u>	
ORDER	Stream order	Number
GRADIENT	Stream gradient	Meter/Kilometer
HAB-FREQ	Frequency of habitat occurrence	Count
CHANWDT	Stream channel width	Meters
TANIMACC	Total livestock access & riparian damage (left/right)	Score
RIPVEG	Woody vegetation density and diversity	Score
NUMERBN	Number of sections of eroding bank (left/right)	Number
AVGLENEB	Average length of eroding bank	Meters
AVGBNKH	Average height of eroding bank	Meters
AVGBKAN	Average bank angle of eroding bank	Degrees
#UNDRCT	Number of bank under cuts	Meters
AVGLENU	Average length of bank under cuts	Meters
INCSNDPT	Average cutbank incision depth	Meters
INCSNHT	Average cutbank incision height	Meters
FINEDED	Length of stream channel with fine debris	Meters
COARSDED	Length of stream channel with coarse debris	Meters
HEAVYDE	Length of stream channel with heavy debris	Meters
DEBRISJM	Number of debris jams	Count
DLI	Debris loading index	Score
AVGSHAD	Average canopy density for site	Grid Units
# POOLS	Number of pools	Count
AVGPLLTH	Average length of pools	Meters
AVGPLWTH	Average width of pools	Meters
AVGPLDTH	Average depth of pools	Meters
COARPOM	Pool bottom covered with coarse particulate organics	Percent
FINEPOM	Pool bottom covered with fine particulate organics	Percent
AQUAVEG	Absent = 0, algal mats = 1, macrophytes = 3	Score
% BEDROC	Pool bottom of bedrock	Percent
% COBBLE	Pool bottom covered with cobble	Percent
% GRAVEL	Pool bottom covered with gravel	Percent
% SAND	Pool bottom covered with sand	Percent
% HC/MUD	Pool bottom covered with hard clay or mud	Percent
# RIFFLES	Number of riffles	Count
RIFLLENG	Average length of riffles	Meters
RIFLWDTH	Average width of riffles	Meters
RIFLDPTH	Average depth of riffles	Meters
COARSPOM	Riffle bottom covered w/coarse particulate organics	Percent
FINEPOM	Riffle bottom covered w/fine particulate organics	Percent
AQUAVEG	Absent = 0, algal mats = 1, macrophytes = 3	Score
% BEDROC	Riffle bottom of bedrock	Percent
% COBBLE	Riffle bottom covered with cobble	Percent
% GRAVEL	Riffle bottom covered with gravel	Percent
% SAND	Riffle bottom covered with sand	Percent
% HC/MUD	Riffle bottom covered with hard clay or mud	Percent
# RUNS	Number of runs	Count

Variable	Description of Variable	Unit of Measurement
	Geomorphic/Stream Habitat	
AVGPLLTH	Average length of runs	Meters
AVGPLWTH	Average width of runs	Meters
AVGPLDTH	Average depth of runs	Meters
COARPOM	Run bottom covered w/coarse particulate organics	Percent
FINEPOM	Run bottom covered w/fine particulate organics	Percent
AQUAVEG	Absent = 0, algal mats = 1, macrophytes = 3	Score
% BEDROC	Run bottom of bedrock	Percent
% COBBLE	Run bottom covered with cobble	Percent
% GRAVEL	Run bottom covered with gravel	Percent
% SAND	Run bottom covered with sand	Percent
% HC/MUD	Run bottom covered with hard clay or mud	Percent

TABLE 3. Rating score for assessing ground cover conditions in riparian zones.

Rating	Description
3	woody plant density >90%; diverse trees, and shrubs
2	woody plant density 70-90%; fewer species, some thin areas
1	woody plant density 50-69%; thin areas common; few trees
0	woody plant density <50%, many thin & bare areas; few trees or shrubs

We feel that the subjective measurements of riparian vegetation condition and canopy closure are adequate, but they probably can be improved. To this end, a major thrust of our study initiative will be to develop objective and reliable remotely sensed measures of many of these variables. We address the development of those measures in a later section.

The frequency, length, height, and bank angle will be measured for all areas of active bank erosion (Platts et al. 1987). Five or more (depending on length) separate leveling rod or tape measurements of bank height, and bank angle measurements (percent slope determined by a clinometer and straight edge) will be made at each area and along each bank. Areas of streambank undercutting provide habitat for macroinvertebrates and cover for fish. Consequently, these areas usually support high fish biomass. In addition, the extent of undercutting is a good indicator of how well stream banks are protected (Platts et al. 1987). Variables used for determining the characteristics of the stream bank undercut will be similar to Platts et al. (1987), and include total length of undercut, mean incision depth and height (minimum of 5 measurements). These measurements will be taken regardless of the water level in the stream. Submerged or partially submerged incisions will be identified to facilitate separate measurements of these accessible microhabitats.

Instream habitat and erosion measurements will be calculated for the entire sample site. The terms "pool", "riffle", and "run" have been observed to be subjective (Oswood and Barber 1982), but these terms will be used to define the major stream habitats found within the sample sites. To maintain consistency, determination of pools, riffles, and runs will be based on definitions provided by Huggins and Moffett (1988), developed specifically for Kansas stream systems. Average length, width, and depth of all habitats occurring within the sample sites will be made from transects (5 lengthwise transects, 5 depth measurements along each of 5 widthwise transects), and will be used to generate the habitat characteristics for all areas sampled for fish and aquatic macroinvertebrates. A pool/riffle or run/bend ratio will be calculated for each stream segment and adjacent reach. The ratios will be calculated by dividing the mean distance between riffles or bends by the mean stream width (Plafkin et al. 1989).

Visual estimates of organic and inorganic substrate composition will be made at the 25 sample points along the 5 transects used for the depth measurements. Additionally, organic composition will be determined through chemical analyses (see below). Quantification of the amount of bedrock in the stream channel will be made if water clarity allows, otherwise, identification of the bottom rock formation will be performed by probing with a rod. The dominant class of particulate organic matter (coarse or fine) will be recorded as will the occurrence of cobble, gravel, sand, or clay/mud. At each of the 25 sample points, only a single bottom substrate will be recorded, and the percentage occurrence of the bottom substrate within the sample site will be generated by the proportion of the 25 sample points sharing that substrate type. The presence of aquatic vegetation will be recorded as: 1) 0 = absence of algal mats and macrophytes, 2) 1 = algal mats present, and 3) 3 = presence of macrophytes. Once again, we will actively develop new sampling procedures to provide better estimates of aquatic vegetation.

Instream habitat development will be evaluated using the Habitat Development Index (HDI) developed by Huggins and Moffett (1988). The HDI provides a method of quantifying gross differences in habitat complexity that can affect macroinvertebrate and fish species' richness. Instream habitat evaluation will be made under normal flow conditions.

A visual estimate of organic debris will be made following the conditions of Silvey et al. (1977) and a Debris Loading Index (DLI) will be calculated for each stream segment. The four debris categories and their metrics are described in Table 4. An additional measure of debris, the number of debris jams, will also be used to characterize the stream channel.

TABLE 4. Categories and weights used to compute the debris loading index used in this study (modified from Sivey et al. 1977).

Size Categories	Length of Channel Affected (%)	Index Value
I. FINES: Twigs, leave fragments and pieces less than 5 cm average diameter	0-10 11-30 >30	1 2 3
II. COARSE: Branches, limbs and pieces 5-20 cm diameter up to 2.5 m length. Also included rood wads of any size.	0-10 11-30 >30	4 6 9
III. HEAVY: Logs, trees, branches, stumps and pieces greater than 20 cm diameter	0-10 11-30 >30	5 10 15
IV. DEBRIS JAMS: Existing or potential stream block feature	number multiplied by Index Value	10

Stream segment-Physical

A series of standard physical measurements will be taken at each stream segment sample site (Table 5). These are briefly outlined below.

Flow measurements will be taken to determine site discharge. The most appropriate cross-sectional area will be selected (Linsley et al. 1975) for the measurements of flow and discharge. These will be located immediately upstream or downstream of the stream segment. Flow velocity will be measured with a Swoffer Model 2100 flow velocity meter. Flow rate will be determined from velocity and depth measurements according to standard hydrologic procedures (Linsley et al. 1975).

Air temperature will be recorded immediately above the stream at the upper, middle, and lower end of the stream segment. An average temperature for the stream segment will be calculated. Water temperature will also be measured at these three locations using a Corning pH/C 107 meter. Again, an average water temperature value will be calculated for the stream segment. Conductivity, turbidity, total suspended solids (TSS), volatile suspended solids (VSS) will be measured either in situ, or from water samples collected at the site. We address the specific methods used in the Quality Assurance

REGULAR RECORD SHEET

STREAM______ DATE________ ID BY____________

SITE A.T W.T WIDTH DEPTH VEL. COVER

COND. TURB. P N PH DO TDS

COMMENT: ____

SITE A.T W.T WIDTH DEPTH VEL. COVER

COND. TURB. P N PH DO TDS

COMMENT: ____

SITE A.T W.T WIDTH DEPTH VEL. COVER

COND. TURB. P N PH DO TDS

COMMENT: ____

SITE A.T W.T WIDTH DEPTH VEL. COVER

COND. TURB. P N PH DO TDS

COMMENT: ____

SITE A.T W.T WIDTH DEPTH VEL. COVER

COND. TURB. P N PH DO TDS

COMMENT: ____

section.

TABLE 5. Field site measures of biological, water quality, geomorphic and hydrological parameters.

<u>Biological</u>

- Primary production*
  1) Benthic (i.e. periphyton)
  2) Planktonic (i.e. water column)
- Chlorophyll
  1) Benthic (i.e. periphyton)
  2) Planktonic (i.e. water column)
- Periphyton biomass (ash free dry weight)
- Macroinvertebrates
  1) Richness
  2) Abundance
  3) Biomass
  4) Pesticide content*
- Fish
  1) Richness
  2) Abundance
  3) Biomass
  4) Pesticide content*
- Other
  Microbial*
- Habitat (see Geomorphic/habitat section)
  Macrohabitat (in- and near-stream)
  Microhabitat (instream microhabitat)

<u>Chemical</u>

- Total organic carbon
  (and particulate organic carbon)
- Chemical oxygen demand (COD)
- Trace Metals*
- DO
- pH
- Total Alkalinity
- Total Hardness
- Ammonia Nitrogen
- Nitrate Nitrogen
- Inorganic Nitrogen
- Organic Nitrogen
- Total Nitrogen
- Total Phosphorus
- Reactive Phosphorus
- Pesticides

<u>Physical</u>

- Air Temperature
- Water Temperature
- Degree Days (by calculation)
- Turbidity
- Conductivity
- TSS
- VSS
- TDS
- Flow rate and discharge
- Particle Analysis (water column)*
  1) Inorganic
  2) Organic
     a) algal
     b) non-algal
- Meteorological data*

<u>Geomorphic/Habitat (in-/near Stream)</u>

- Depth
- Width
- Length
- Habitat Development Index (HDI)
- Near Stream Vegetation (riparian, row crop or pasture/rangeland/hay meadow)
- Canopy closure
- Livestock assess/damage
- Debris Loading Index (DLI)
- Bank Erosion
- Habitat Complexity
- Pool/riffle and/or run/bend ratio
- Channel and bank modifications (e.g. channelization, berms, levels)

*Optional or to begin in year 2 or 3

We anticipate that watersheds will be distributed across the entire Western Corn Belt Plains Ecoregion which means that some watersheds will be 200-300 mi farther north than others. To facilitate comparisons among these disparate watersheds, we will calculate degree days for all sampling events. This measure will allow us to begin to partition out the affect of latitude and general climatic differences on water quality.

Stream segment-water quality

A series of water quality parameters (Table 5) will be measured from three locations within each stream segment sample site, and during the runoff event-related sampling. Several parameters will be measured in situ. Stream pH will be measured using a Corning pH/C 107 meter (or equivalent), standardized for pH measurements using a two-point calibration technique (pH 7.0 and pH 10.0 buffers). Stream conductivity and dissolved oxygen (DO) will be measured using a YSI Model 58 dissolved oxygen meter and a YSI model 33 S-C-T meter. The DO meter will be calibrated for each stream basin and each site based on the average elevation for the basin as determined from USGS 7.5 minute topographic maps. Total dissolved solids will be measured in situ utilizing a digital TDS meter with automatic temperature compensation. Each of these variables will be measured at the three locations. In addition, stream water from each of the three locations will be filtered through glass-fiber filter disks (without organic binder) using a hand pump and filtration apparatus. The volume of water filtered (volume filtered within 10 minutes or less) will be recorded and the filters frozen for later analysis of total and volatile suspended solids (TSS and VSS).

The remaining parameters will be measured from water samples shipped to the Kansas Biological Survey Ecotoxicology Laboratory. Two grab samples from each of the three locations within the stream segment will be collected in 1 liter cubitainers. In addition, a grab sample for pesticide analysis will be taken from the upper and lower sites and placed in 500 ml glass bottles with teflon lined closures. One of the two cubitainers will contain no preservative; this sample will be analyzed for total alkalinity, total hardness, and turbidity soon after sampling in a mobile laboratory. The other cubitainer sample will be spiked with an acid preservative, both samples will be cooled to 4° C, and returned to the Ecotoxicology Laboratory for analysis of chemical oxygen demand (COD), total organic carbon, total phosporus, ammonia nitrogen, nitrate+nitrite nitrogen, inorganic nitrogen, and total organic nitrogen (optional). Additionally, through the acquisition of a PC-controlled gas chromatograph/mass selective detector system (GC/MS), we will be able to measure most of the commonly detected agripesticides in water (e.g. atrazine and alachlor). A listing of target pesticides for the Western Corn Belt Plains ecoregion will be prepared utilizing the U. S. Environmental Protection Agency's physiochemical database system (STORET). Those pesticides commonly occurring in surface waters in the ecoregion will be targeted for analysis, if practical, using GC/MS analytical methods. These measures of nutrients and pesticides are critical to any study of NPSP because they are the primary pollutants entering the aquatic ecosystem.

All of the sampling described above will be conducted on a seasonal basis, at least in the spring, summer, and autumn. Sampling during the late winter will be attempted, but may not be possible depending on the weather. All seasonal sampling will be conducted under normal base flow conditions. Additionally, we will not conduct seasonal sampling within 100 hours of a runoff event. We will visit each site at least once during each season for a full sampling effort. Because a large portion of the sediment, nutrients, and pesticides that eventually make their way into the aquatic ecosystem are being transported from the surrounding watershed during the runoff events, we will place an ISCO automated water sampler at each stream segment sample site to collect time sequential water samples related to the runoff event. The sampling event will be initiated by an increase in stream flow as monitored by a liquid level sample actuator. We will attempt to collect as many runoff event samples as possible. Samplers will be located on the bank above stream, with a teflon suction line and stainless steel strainer extending into the water. Automated samplers will be flow activated, and will collect 24 samples over any specified period of time. Upon notification by the SCS agent (or other local authority) of a rainfall event, a field assistant will travel to the watersheds to collect the water for laboratory analyses, and to reset the sampler for the next rainfall event. Samplers will be operated by using a nickel-cadmium battery, so the field assistant will visit each site approximately every two weeks during the seasonal sampling period to check on the condition of the sampler and battery, as well as collect the data from the meteorological station (if present) at the base of the watershed.

Acquisition of a GC/MS system is the priority for the first year of the grant. During subsequent years, we will acquire an Atomic Absorption spectrometer and graphite furnace to perform trace metals analyses using electrothermal atomic absorption spectrometry, and a high-pressure liquid chromatograph system (HPLC) to compliment the GC/MS approach for organic analyses. Alternatives to atomic absorption spectrometry for trace metal determination will be explored, especially emission spectroscopy using inductively coupled plasma methods. We anticipate bringing these types of analyses on-line within a short period of time. The trace metals analyses will be especially critical when we expand our efforts to include urban watersheds.

Stream segment-Biota

The biological variables include measures of primary producers, periphyton, and the macroinvertebrate, fish communities.

Periphyton is the most important source of primary production in lotic systems (Grzenda and Brehmer 1960, Brown and Austin 1971) and is the primary source of food for the higher trophic categories. By definition, periphyton is attached to the substrate and is dependent on stream flow for essential nutrients. This relationship makes periphyton valuable as an indicator of water quality. Periphyton function to purify waters through the removal of nutrients, and excessive growth of periphyton is often an indication of nutrient enrichment in the stream. While a highly productive stream may provide abundant food for primary consumers, extreme variability in dissolved oxygen resulting from intensive photosynthesis and respiration, and anaerobic conditions resulting from algal death and decomposition may result in reductions in water quality (Huggins et al. 1990).

Periphyton biomass will be estimated in two ways. Chlorophyll content of the periphyton and the ash-free dry weight of periphyton colonizing stream periphytometers will be measured. The periphytometer to be utilized in this assessment will be a Wildco^{R} periphyton sampler developed at the request of the U. S. Environmental Protection Agency and other parties interested in testing for comparative conditions of water quality. This periphytometer resembles the one used by Patrick et al. (1954) in having a deflector upstream of the slide mount to reduce the effects of flow. The apparatus is self-righting so that harsh flow conditions can be accommodated.

Two or three periphytometers will be placed at each stream segment sample site, in an attempt to retain an adequate sample even if runoff events should remove some of the periphytometers. Samplers will be placed in locations most representative of the stream segment's canopy and flow conditions. Initially, periphytometers will be allowed to remain in the stream channel for only six to seven days. We found during our pilot study that while longer periods of colonization (e.g., three weeks) provides more than sufficient time for colonization and growth of periphyton, this extended time period provides the chance that extreme flow conditions (e.g., runoff events) can remove periphyton from the samplers and compromise the interpretation of the data. Consequently, we will attempt to obtain periphyton measures within the time frame of the initial sampling period (six to seven days). However, we may have to extend this sample period if periphyton colonization is not sufficient. Chlorophyll content will be determined in two ways. Concentrations of two photosynthetic pigments, chlorophyll a and pheophytin a, will be determined spectrophotometrically or with a fluorometer. Typically, fluorometry is more sensitive than spectrophotometry, and because of the short colonization period with the anticipated low periphyton growth, the fluorometry method will be preferred. After chlorophyll extraction, the ash-free weight of the sample will be determined and the autotrophic index of the sample calculated (Weber 1973). We are also developing remotely sensed indicators of primary productivity which we discuss below.

Macroinvertebrates will be collected at each sampling site using a timed, qualitative sampling method in which pool, riffle, and run microhabitats are sampled for one minute each using a kick method (Huggins et al. 1990). The bottom substrate, submerged roots, vegetation, detritus, and other habitat elements are kicked to dislodge macroinvertebrates, which are collected in a 500 micron mesh D-frame dip net held immediately downstream of the disturbed area. In the case of slow moving water, the dip net will be moved across the top of the disturbed area. After collection, macroinvertebrates and detrital material will be preserved in 95% ethanol in separate collections for each macrohabitat within the sample site. If the organic content of the detrital sample is high, a small amount of formalin will be added to the sample. Later, macroinvertebrates are separated from detrital material and preserved in 85% ethanol.

Macroinvertebrates, with the exception of specimens from the insect family Chironomidae, will be examined with dissecting microscopes and identified to genus (or morpho-group) when possible. The aquatic reference collection housed at the Kansas Biological Survey will be used to verify identifications. Chironomids will be slide mounted and identified to as low a taxonomic level as possible. The Kansas Biological Survey is fortunate to have Dr. Leonard Ferrington, a internationally recognized expert in the taxonomy and ecology of Chironomids, who will be available to verify the identifications of the specimens. We will count the specimens, and determine the body mass of each species, so that we will have numbers of species, numbers of individuals, and biomass data for each sample.

Fish at each stream segment sample site will be sampled by both seining and electroshocking techniques. After initial examination of the site, representative portions of the available macrohabitats (pools, riffles, runs) will be blocked with 3/8 inch mesh block seines. Each blocked sample will be seined intensively for fish with the appropriate length seine. Seining will be terminated when seining yields no fish. During our pilot investigation, we determined that seining alone probably did not adequately sample bottom-dwelling fish or those fish that live in bank incisions (e.g. Catastomatidae). Therefore, after seining, we will use electrofishing techniques to finish sampling. A portable backpack shocker (e.g., Coffelt[R] model BP-3) will be used within the block segments and shocked fish will be collected directly or as they drift into the seine. The largest areas of the macrohabitats in each sample site will be sampled for fish. However, when sample sites consist of multiple macrohabitats of relatively small size, several pools, riffles, or runs may have to be blocked and seined. Mean length, width, and depth values for each habitat area sampled for fish will be determined from transect measurements, and the fish yield will be calculated on a per unit volume basis.

biomass
species
no.

All fish will be preserved in the field in 10% formalin. When returned to the laboratory, fish will be rinsed and stored in 60% isopropyl alcohol for later identification, enumeration, and weighing. All specimens will be identified to species. Additional information collected include body mass, external condition (disease, tumors, fin damage, and externally apparent skeletal anomalies), and age (size). Fish will be grouped into age cohorts (or size classes) when possible for later demographic analyses.

Because of the recent interest in the Index of Biotic Integrity (IBI, Karr et al. 1986, Hunsaker and Carpenter 1990, Karr 1991), we will apply a modification of this index to our fish data (Table 6). The modification is necessary because several taxa of fish that play a prominent role in the original index are poorly represented in the Western Corn Belt Plains Ecoregion. The regional application of the IBI in regions exhibiting low species richness has proved difficult and often required extensive modification of original IBI metrics (Miller et al. 1988). Only 11 of the original 12 metrics will be utilized (proportion of individuals as hybrids will be excluded), and the scoring criteria may be modified

TABLE 6. Modified IBI Index and Associated Metrics Used in this Study (modified from Karr 1981 and Fausch et al. 1984).

Category	Metric	Scoring Criteria 5	3	1
Species richness and composition	1. Total number of fish species	Score taken from fig. 4 in Karr et al. (1986)		
	2. Number/identity darter species	2 sp		1 spnone
	3. Number/identity sunfish species	4 sp	3-2 sp	1 sp
	4. Number/identity sucker speices	2 sp		1 spnone
	5. Number/identify intolerant species	>3 sp	2 sp	1 sp
	6. % individuals as green sunfish	<5%		5-20%>20%
Trophic composition	7. % individuals as omnivores	<20%	20-45%	>45%
	8. % individuals as insectivorous cyprinids	>45%	45-25%	<20%
	9. % individuals as piscivores (top carnivores)	>5%	5-1%	<1%
Fish abundance and condition	10. Total abundance			
	11. % individuals with disease, tumors, fin damage, and skeletal anomalies	0-2%	>2-5%	>5%

further to customize the index to the ecoregion. Karr (1991) has recently stressed the importance of this modification and customizing process as a way to increase the information content of the index.

Statistical analyses

The major focus of the data analyses will be the structural equation modeling to elucidate the structure and function of the aquatic ecosystem, and the relationships among the riparian ecosystem, the agroecosystem, and the aquatic ecosystem (Figure 3). This methodology is described in detail in Johnson et al. (1991, in review) and examples of structural equation modeling of pond ecosystems are provided in Johnson et al. (in review) and Huggins et al. (in review). Briefly, this methodology involves hypothesizing a model of ecosystem structure and function. Structural components include biotic and abiotic features such as periphyton, macroinvertebrates, fish, habitat, and concentrations of nutrients and pesticides. Functional relationships are the cause-and-effect interactions within the ecosystem. Once the hypothesis of structure and function has been posed, indicators of the structural components of the ecosystem are identified (see below). The model is then specified mathematically, and the appropriate parameters are estimated by maximum likelihood techniques. This modeling procedure has several advantages over current environmental modeling techniques. 1) Measurement of the indicators is separated from the conceptualized ecosystem. For example, possible indicators of fish within the aquatic ecosystem could be numbers of fish, biomass, age structure, or IBI. This means that several indicators can be tested in the modeling process, and the best ones chosen to represent the structural components of the ecosystem. This aspect of structural equation modeling will be especially useful in the generation and testing of indicators for use in EMAP. 2) The hypothesized ecosystem structure and function is validated statistically as part of the analysis. This validation is in the form of a chi-square goodness-of-fit test that tests if the ecosystem model actually fits the data. 3) The analysis provides the total, direct, and indirect effects of every structural component on every other structural component. These effects are in the metrics of the indicators, and consequently there is no need to convert all structural components to a common currency, i.e. the model need not be couched in terms of energy flow or nutrient flux as many current input-output models require. 4) A statistical test of the significance of the hypothesized interactions between any two structural components of the ecosystem is provided. A t-value is provided that can be compared against values in a table of the normal distribution to determine if the hypothesized interaction is significantly different from zero, i.e. does the hypothesized interaction actually exist in the ecosystem? 5) A measure of ecosystem stability is provided that can be used to evaluate the present status and infer future condition of the system. 6) "Missing" structural components of the ecosystem can be suggested in the course of the modeling process.

This modeling technique was first applied to ecosystem analysis by investigators at the Kansas Biological Survey, who continue to develop its potential to assess ecosystem health and integrity. This analytical methodology promises to provide answers to many questions concerning the effects of stresses on ecosystems.

In addition to the structural equation modeling, we will use a series of standard statistical procedures (e.g. ANOVA, cluster analyses, regression analyses) to test hypotheses dealing with small-scale mechanistic questions. We have available the Number Cruncher Statistical System (NCSS) on a microcomputer that can perform extremely sophisticated statistical analyses. Also, we have access to the mainframe computers at each University, all of which are equipped with standard statistical library packages such SAS, SPSS, BMDP, and Minitab.

DEVELOPMENT AND VALIDATION OF REMOTE SENSING TECHNIQUES FOR USE IN NPSP ANALYSES

Close-range remote sensing of streams and rivers

Modern remote sensing technology includes a wide variety of instruments designed to measure reflected solar radiation, primarily in the visible and infrared wavelengths. These instruments can be as simple as a camera and film or as complex as a multispectral scanner attached to an earth-orbiting satellite. NASA's Earth Observation System (EOS) program has proposed a space platform which will support numerous earth environmental measurement instruments. One of the most important instruments is the High Resolution Imaging Spectrometer (HIRIS), to be deployed in the mid 1990's. HIRIS's ability to collect narrow band (ca. 11 nm) reflectance measurements for 192 channels will greatly increase the ability to discriminate between subtle variations in surface color and reflected infrared energy. For example, HIRIS prototype data were used by Gross and Klemas (1986) to discriminate between species of marsh vegetation, which were indiscriminable using present Landsat and Spot technology. The portable, hand-held narrow band spectroradiometer allows remote sensing investigators to attain similar spectral resolution as HIRIS, but with greater spatial resolution in ground-based experiments, enhancing the development of refined spectral reflectance models. Close-range and low-altitude spectroradiometry has inherent value, particularly if the spatial scale of the target is relatively small, but also serves to prepare us to use the tremendous HIRIS data base when it becomes available in the near future.

The use of remotely sensed information for measuring and monitoring surface water conditions has long been of interest to aquatic ecologists and resource managers (e.g., Strandberg 1966, Tyler and Stumpf 1989). Aquatic parameters most often analyzed are suspended solids, chlorophyll content, chemical composition, and temperature. A collective goal of the various remote-sensing efforts is to be able to analyze surface waters from airplane or satellite altitudes and characterize them with respect to the parameters listed above. Many investigators have observed a correlation between remotely sensed spectral measurements of surface waters and phytoplankton biomass (e.g., Wezernak et al. 1976, Stumpf and Tyler 1988). However, very few studies have investigated the spectral reflectance patterns of benthic vegetation in shallow waters (e.g., Lyzenga 1978, Ackelson and Klemas 1987), and none in flowing water systems. Four troublesome variables commonly encountered in the remote sensing of underwater objects have been addressed in these studies: water depth, water clarity, surface reflection, and underlying substrate reflectance. Remote sensing of benthic substrates will require accountability or control of these variables.

Several studies have conducted close-range remote sensing of surface waters using portable spectroradiometers (e.g., Ritchie et al. 1976, McKim et al. 1984, Kondratyev er al. 1987). Particularly, an ongoing collaborative study with the KU-Kansas Applied Remote Sensing program (KARS), NU-Center for Advanced Land Management Information Technologies (CALMIT), and Creighton University conducted at the University of Kansas' Nelson Environmental Studies Area (NESA) experimental ponds facility, uses a portable spectroradiometer to explore the relationship between spectral reflectance, phytoplankton biomass, and turbidity, in experimentally manipulated mesocosms (Rundquist et al. 1990). This remote sensing study, which represents the lentic (ponds, lakes) portion of the project, is unprecedented in the level of in situ experimentation conducted in the development of spectral reflectance models. Although still in its preliminary stages, some useful insights have been gained concerning spectral band ratios that may best estimate phytoplankton biomass (Rundquist et al. 1990). In particular, the use of ratios of spectral reflectance at two distinct bands (color ratioing, Fraser 1975) to discriminate between phytoplankton chlorophyll density treatments proved to be more successful than numerical integration of broad bands under the spectral response curves. Color ratioing was highly predictive for phytoplankton chlorophyll density using bands 539.1 nm : 460.9 nm (Rundquist et al. 1990).

An experimental stream pool pilot study was initiated in summer 1990 in collaboration with the KU-NESA pond study to explore the feasibility of remotely sensing attached algal biomass on stream benthic hard substrates, and yielded very encouraging preliminary results. Nine replicate pools (25 cm deep, 1.6 m diameter), gravity fed from a nearby reservoir (ca. 0.75 L/min, 1.5 hr turnover time) and lined with natural and artificial stream substrates (gravel, rocks, tiles) were scanned with the radiometer after a three-week incubation period. All pools were biologically similar. Spectral reflectance patterns of stream benthic substrate were also very similar, with characteristic chlorophyll absorption maxima (troughs on the spectral reflectance curves) in specific blue and red bands compared to a periphyton-free control described below. These results were especially encouraging for the remote sensing of periphyton, given that little growth on substrates was visually detectable (no ground truth samples could be taken at this point of the experiment). One important result of these very preliminary data analyses was differential spectral absorption by the periphyton chlorophyll (absorbed primarily in the red bands, 660-679 nm) and the phytoplankton chlorophyll present in the water column of the pools (absorbed primarily in the blue bands, 430-44- nm). This was determined by comparison to the spectral reflectance curves of a blank control pool (experimental stream substrates with no periphyton), covered first by well-water (with no phytoplankton in the water column), and then by water taken from the experimental pools (containing phytoplankton in the water column). A second experiment was conducted following the initial observations and measurements, involving removal of benthic algal grazers by the addition of a predator. Radiometric measures of all stream pools were taken, as were ground truth samples for phytoplankton and periphyton chlorophyll densities, and macroinvertebrate density. Those data are presently being analyzed.

We propose to continue our development of these close-range remotely-sensed indicators through experiments performed at NESA, and through observations collected in streams in the watersheds chosen for study in the Long-term Watershed Monitoring Project described above. The objectives of this investigation are:

1. To continue to collect baseline reflectance data from experimental stream pools to refine models that predict periphyton chlorophyll content from patterns of reflectance.
2. To explore the effects of water depth, turbidity, and surface reflection on chlorophyll spectral reflectance, to either circumvent or incorporate these effects into a refined model.
3. To apply close-range spectroradiometry to a series of natural stream sites in the watersheds involved in the NPSP project.

To meet these objectives, the following experiments will be performed during the summer of 1991:

1. Chlorophyll and sediment dilution experiments (as single and interacting variables) will be conducted utilizing white, black and macrophyte colonized panels as the targets for radiometry. Located at a series of discrete depths, these panels will be used to evaluate unit-volume versus unit-area based models as methods of measuring phytoplankton abundance and for determining the contribution of the

bottom substrate to the spectral reflectance patterns. This experiment will be conducted at the pond facility at NESA, where conditions can be controlled to a large extent. Spectral reflectance measurements will be made by a spectroradiometer with boom-mounted SE590 sensor head available through CALMIT.

2. Atrazine addition experiments will be conducted to determine how short-term responses of phytoplankton to herbicide additions can be monitored using spectroradiometry. This experiment will be conducted at NESA in the pond mesocosms. A series of plastic-encased limnocorrals will be established in the mesocosms. Several doses of atrazine with several replicates of each, will be used. Spectral reflectance measurements will be made with the boom-mounted spectroradiometer that can be extended above the limnocorrals.

3. In situ spectroradiometer observations will be made in the watersheds monitored to assess the effects of NPSP on aquatic ecosystems. The spectroradiometer will be mounted on a pontoon boat outfitted with a boom, so that the sensor head can be extended over the larger pools in the stream. Smaller, narrower sections of the stream will be measured using a hand-held radiometer. Spectral measurements will be made in watersheds in conjunction with the regular summer sampling period for those watersheds, providing the necessary ground truth data. Reflectance patterns will be correlated with periphyton and phytoplankton biomass data.

Close-range remote sensing of terrestrial vegetation canopies

Regardless of whether changes in vegetation characteristics are the result of climate change, pathogen or herbivore outbreaks, or alterations of land use practices, mapping and monitoring methods are needed that enable the detection of environmental condition and trends. The methodologies for detecting subtle environmental differences over broad geographic areas are largely undeveloped. Many monitoring strategies rely on either subjective observations or small sample plots (e.g., rangeland trend plots). Satellite imagery has been used for a variety of environmental studies such as determining aboveground plant biomass (Maxwell 1976, Tucker 1979), estimating leaf area (Wiegand et al. 1979, Running et al. 1986) and mapping vegetation (Bauer et al. 1979, Hoffer 1984, McGraw and Tueller

1983, Mueller-Dombois 1984, Price et al. 1985, Tucker et al. 1985, Wilson and Tueller 1987). Large-area changes in landscape have been monitored using multitemporal satellite imagery to create change detection maps (Robinove et al. 1981, Carneggie et al. 1983, Pilon et al. 1988).

In most cases, efforts to monitor vegetative conditions with remotely sensed spectral data have been limited to vegetation communities that show abrupt changes in physiognomy and spectral characteristics. These have been mainly forest and desert systems monitored for deforestation and decertification (Robinove et al. 1981, Mann et al. 1984, Woodwell et al. 1984, Rock et al. 1986, Woodwell et al. 1987, Vogelmann and Rock 1988). Less is known about the multispectral reflectance patterns associated with natural environments (Price et al. 1985).

Given the national initiative for the development of remote sensing instruments such as HIRIS (see above), and the need to improve environmental monitoring techniques, a study of narrow band spectral reflectance patterns associated with specific vegetation types needs to be undertaken. As a first step in the process of developing multispectral reflectance patterns for different vegetation types within a watershed, we will initiate an investigation of the spectral properties of prairie vegetation.

In the past, NASA has supported research efforts to study spectral reflectance properties of tallgrass prairie environments on the Konza Prairie (Asrar et al. 1986, Weiser et al. 1986, NASA 1987, Asrar et al. 1988, Irons et al. 1988, Asrar et al. 1989, Cooper and Asrar 1989, Sellars et al. 1990). However, most of these projects examined the reflection differences in burned versus unburned tallgrass prairies. There have been few investigations into the use of spectral reflectance measurements to differentiate or characterize major prairie vegetation types in the Western Corn Belt Plains Ecoregion, or even in this general area. Asrar et al. (1986), used ground level digital imagery to distinguish among bare soil, senescent vegetation, and green vegetation. Merchant and Roth (1981) used Landsat Multispectral Scanner (MSS) data to successfully map nine vegetation types in the Cimarron National Grassland in southwestern Kansas.

Additional work is needed to study the sensitivity of narrow-band spectral information to environmental variation of prairie vegetation. Such studies will provide a wealth of information about the sensitivity of spectral measurements in biotic and abiotic characteristics of the environment. More specifically, it will provide answers to questions such as: 1) how accurately can different land cover types be discriminated using multispectral measurements, 2) how does the ability to discriminate land cover vary from year-to-year, 3) what are the spectral response patterns associated with healthy plants compared to vegetation that is stressed by climatic shifts or environmental contamination, and 4) what sections of the electromagnetic spectrum are optimal for discriminating among land cover types and plant stress?

The ultimate goal is to be able to develop analytical techniques that can be used when narrow-band spectral information will be available through the Earth Observation System (EOS) satellites, perhaps by the mid 1990's. Meeting this goal requires that these techniques be developed and validated, and at the present time, this can be done only at a reduced spatial scale. Consequently, we propose to determine how remotely sensed data can be used to inventory, monitor, and assess the conditions of prairie vegetation within a small geographic area. The specific objective is to examine spatial and temporal variation in narrow-band spectral reflectance patterns for six prairie environments. We feel that prairie environments represent one of the simplest vegetation types that occur within watersheds, however we anticipate utilizing the results of this investigation to develop similar techniques for more complex vegetational environments, e.g., riparian forests. This investigation will be conducted on the Rockefeller tract of NESA of the University of Kansas, where an extensive data base on past and present land use and land cover already exists (see below). Micro-scale studies at this location will allow us to account for the biotic and abiotic variables that may influence the spectral reflectance patterns of the vegetation.

The next step is to move from the micro-scale to the ecosystem and watershed level. However, as the study area increases, so does the variability of the environment. We are presently developing monitoring strategies that incorporates a geographic information system (GIS) to control this environmental variation. Such control will allow researchers to study spectral variation associated with biotic variation, which is more sensitive to environmental change. The use of a GIS for environmental control will allow the principles learned at the micro-scale to be extended to the level of the ecosystem or watershed.

Since 1947, the University of Kansas has secured approximately 1,625 acres of land reserved for environmental research and educational purposes. These lands are collectively referred to as the Kansas Ecological Reserves. One hundred sixty acres of the Reserves, called the Rockefeller tract, have been managed for the purpose of studying the effects of management practices on prairie vegetation (Fitch and Hall 1978). Six management treatments on the Rockefeller tract include: untreated native prairie, agricultural lands reseeded to grasses in 1956 and left untreated, reseeded and biennially burned, reseeded and grazed, reseeded and mowed with the hay removed, and reseeded and mowed with hay left in place on the ground. Since 1962, treatment and management of the Rockefeller tract has been controlled and documented. These advantages and the relatively small geographic distribution of 160 acres make this an ideal site for the development of the remote sensing based vegetation analyses.

A Spectron Engineering SE590 field-portable spectroradiometer will be used to collect measurements from each of the six prairie environments. Variation in solar illumination will be minimized by taking reflectance measurements on cloudless days between 1000 and 1500 hrs CDT. Field measurements will be taken three times during the growing season.

Factors affecting surface reflectivity are the surface geometry of the land cover types, the proportion of plants and soils covering the ground surface, vegetation productivity, canopy texture, canopy structure, and plant and soil moisture content. Methods used to obtain measurements of these factors are described below.

Micro-relief of the canopy surface will be quantified using measurements taken from a 1.0 m x 0.5 m quadrant that will be subdivided into 10 cm x 10 cm grid cells (Floyd and Anderson 1987). The quadrant will be positioned 10 cm above the canopy surface of each plot. To quantify the variability in surface relief, depth measurements will be taken at the intersections of the grid cells. The measurements will be made from the bottom of the sampling frame to the top of the canopy. The depth of the canopy will be estimated using the average of 10 distance measurements from the ground to the top of the canopy.

Percent surface cover for each plot will be quantified using 50 point-intercept measurements systematically taken within the gridded sample frame (Floyd and Anderson 1987). Estimates of cover will be made for bare soil, litter, and plant species. Surface texture and geometric characteristics of the canopy will be measured using the method of inclined needles (Wilson 1960). Canopy structure in this study is defined as the average number of foliage layers intersected by a rod dropped vertically through the vegetation. Plant biomass production by species will be estimated using a weight estimate/clipping technique (Carande and Jameson 1986).

The effects of external canopy moisture on spectral reflectance will be minimized by taking the measurements during very low precipitation periods in the summer and after 1000 hrs CDT, when the morning dew has evaporated (Printer 1986). Soil and vegetation moisture content will be estimated by determining the difference in weight between pre-dried and post-dried samples of soil and vegetation.

The environmental characteristics of each plot at the time of sampling will be photographically documented using 35mm color slide film. The ambient air temperature, relative humidity, and general weather conditions will be recorded for each plot at the time of sampling. Weather measurements will be obtained from a weather station located on the Ecological Reserves within 0.5 km of all study sites.

Spectral differences within and between treatments will be tested using Analysis of Variance (ANOVA). Correlation analyses will be used to test for significance and strength of relationships among environmental factors and radiometric measurements. Differences among spectral response patterns will be quantified using a curve comparison algorithm. Due to high multicolinearity among spectral data, Principal Components Analysis (PCA) will be used to extract noncorrelated information from the 255 bands. Correlation analysis will be used to identify the environmental factors most strongly associated with the factor scores. The factor scores will be used in regression analyses to measure the strength of association among the spectral data and environmental variables. It will then be possible to select the bands that best discriminate among prairie environments. The optimal sampling period during the growing season will be determined by calculating spectral similarity indices to determine the time of summer when spectral patterns are the least similar.

In July of 1989, three spectroradiometer measurements were made on each of the prairie environments. Analysis of these data suggest that each of the six environments have a unique spectral response pattern. However, it has not been possible to determine the major environmental factors that are responsible for these differences. These results are encouraging, and indicate that the development of these remote sensing-based methodologies for vegetation analyses are possible within the near future.

LANDSCAPE REGIONALIZATION AND LANDSCAPE STRUCTURE

Landscape regions are areas of the earth's surface that exhibit unique "internally homogeneous" combinations of environmental and, often, cultural phenomena (Grigg 1965). These phenomena may include climate, terrain, land cover, land use, soils, and biota. The specific elements considered, their assumed relative importance and the definition of acceptable "homogeneity" vary greatly among the many extant landscape regionalization efforts (e.g., Bailey 1983, 1988, Omernik and Gallant 1989, USEPA 1991). It is noteworthy however, that most regionalization schemes have been derived subjectively and without benefit of automated techniques such as satellite remote sensing and GIS.

Landscape regions have, on several occasions, been shown to be related to nonpoint source water pollution. Omernik's U.S. Ecoregions and the USDA/Soil Conservation Service's Major Land Resource Areas have both been found useful for sitting water monitoring stations, establishing biocriteria and regionalizing water quality (Crisp 1990, Hughes 1989, Hughes et al. 1990). It has been suggested that if such regions could be subdivided and characterized more fully, they could provide a basis for long term monitoring of water quality, predicting effects of pollution abatement measures, extrapolating site-specific information and setting standards and realistic management goals (Omernik 1991, Crisp 1991, personal communication). The extent to which automated remote sensing image analyses and GIS could contribute to region definition and characterization is not known.

Landscape regions are frequently observed to possess unique internal spatial structure. Spatial structure is manifested in edges that partition the landscape into "patches" of homogeneous land cover

(Forman and Godron 1981, 1986). It is widely recognized that landscape structure impacts, among other things, wildlife (Lyon et al. 1987, Thomas et al. 1989) and climate (Pielke and Avissar 1990). In nonpoint source pollution applications, edges are known to influence overland flow of water and movement of nutrients, and to influence pollutant entry into streams and ponds via their influence on processes of filtering (as in buffer strips), though many details remain unresolved (Naiman et al. 1989).

At a much smaller scale, inter-regional edges (including gradients/ecotones) also bound landscape regions and separate one region from its neighbors. These edges differ significantly in character from intra-regional edges. The scale-related aspects of edges have been noted by several authors (Meetenmeyer 1989, Turner et al. 1989). Hierarchy theory appears to offer a possible means for extrapolation between scales, but actual applications are scarce (Allen et al. 1982, O'Neill et al. 1986).

In spite of the fact that landscape edges are known to be important factors in nonpoint source pollution, there is little agreement on means to define edge position or to characterize edge types. One reason is the wide variation of scales involved - from field to biome - and the accompanying disparities in edges. Edge importance varies with application and scale (Merchant 1990).

Many techniques have been developed to characterize landscape structure through measurements of diversity, grain size, patch shape, and other factors (O'Neill et al. 1988, LaGro 1991). The fact, however, that all of these depend on some prior land cover classification or segmentation of the earth's surface is usually given little attention. In fact, landscape structure is imposed by the manner in which classification and segmentation (i.e. <u>edge definition</u>) are carried out.

Images obtained by remote sensing, visually interpreted, are often used to qualitatively characterize landscape structure and help define landscape regions. However, the complex interrelationships between landscape, sensors, time of observation (i.e., season, year), image analysis techniques employed, cartographic presentation methods and other phenomena are poorly understood (Table 7) (Lockheed Engineering 1983, Ritchie and Engman 1986, Woodcock and Strahler 1987).

TABLE 7. Some factors affecting landscape edge representation (from Merchant 1990)

<u>Sensor</u>

- o Spatial, spectral, radiometric, temporal resolution
- o Viewing angles

<u>Landscape</u>

- o Spatial structure (patch size, interspersion)
- o Vegetation physiognomy, canopy closure (soil background)
- o Land cover composition, diversity and phenology, contrast
- o Latitude, topographic, climatic circumstances

<u>Analysis</u>

- o Strategy (single or multidate, supervised or unsupervised)
- o Analyst decisions (class number)
- o Cartographic decisions (generalization, classification techniques)

<u>Other</u>

- o Solar illumination
- o Atmospheric conditions

Therefore, automated and quantitative methods to evaluate spatial structure and define regions are rarely employed. If we are to use satellite remote sensing, digital image analysis, and GIS to aid in landscape regionalization and characterization of spatial structure, these complex relationships must be defined. We propose to begin to explore means for automated characterization of edges and bounding of landscape regions, and to examine methods by which these can be used to examine the effects of nonpoint source pollution on ecosystems.

Successful implementation and use of remote sensing and GIS in nonpoint source pollution assessment will require development of: 1) a better understanding of the manner in which landscape structure, landscape regions, land use and land cover can be defined and characterized using different scales of remotely sensed data and other digital spatial data (Forman and Godron 1986, Ritchie and Engman 1986); 2) development of techniques for environmental analysis that permit exploitation of the full power of GIS analytic functions and remote sensing, <u>integrated and used in concert</u>; 3) development of methods for data integration and spatial analysis across multiple-scale spatial databases (O'Neill et al. 1986); 4) identification of linkages between components of landscape and environmental assessment via spatial modeling; and 5) development of sophisticated methods for information delivery to users. This project will begin to address some of these needs in the context of requirements of the U.S. EPA and the agencies and organizations with which it cooperates and interacts. Our research will be founded upon the results of many previous investigations, but will employ important recent technical innovations in unique ways that will significantly increase the value and applicability of remote sensing and GIS-based spatial analysis for providing decision support for problems associated with nonpoint source pollution.

It is important to note that the work outlined below will be fully integrated with: 1) ongoing research on Landsat-based crop inventory in eastern Nebraska funded by the Nebraska Department of Environmental Control (NDEC) and the U.S. Environmental Protection Agency; 2) research on integrated remote sensing/GIS strategies for development of hierarchical land cover databases along portions of the Platte River about to be funded by NDEC and USEPA; and 3) current cooperative work on the use of coarse-resolution satellite data for continental land cover assessment supported by the U.S. Geological Survey EROS Data Center and the University of Nebraska-Lincoln Conservation and Survey Division. These projects will totally complement one another. Moreover, it is expected that cooperative activity will lead to greater interaction between the agencies involved.

Objectives

1. To determine the manner in which components of landscape structure (e.g., edge, patch size and configuration, grain, interspersion, vertical structure, connectivity) are represented at different scales.

2. To develop means of detecting, characterizing, and modeling change in landscape structure, land use, and land cover (including ecotones and edges) that take advantage of remote sensing and the unique and powerful spatial analytic capabilities of GIS.

3. To explore means by which results of site-specific data collection can be extrapolated through a hierarchy from local to regional applications.

4. To develop prototype hierarchical linkage techniques for data integration and analysis that employ multiple-scale databases.

5. To develop and test alternative methods for defining and demarcating landscape regions (e.g. ecoregions) useful in assessment and modeling on nonpoint source pollution processes, and to assess and model relationships and interactions between landscape regions (including their spatial structure) and environmental processes in selected regional landscapes.

Methods

This research will involve close collaboration with scientists at EPA Region VII, EPA/Corvallis, EPA/Las Vegas, and USGS/EROS Data Center. An important focus of initial work will be to conduct a comparative analysis of methods now used to define landscape regions and characterize landscape spatial structure, and to identify the extent to which such methods might be relevant to environmental modeling and assessment. Subsequently, several techniques (modified or developed new as required) will be tested on sites distributed in a variety of landscapes within Region VII.

Task 1

We will initiate our work with an extensive literature review on sensor-landscape interaction, methods of landscape regionalization, and techniques for characterizing landscape structure with specific attention to potential applications to nonpoint source pollution.

Task 2

In order to begin to better understand the complex interrelations between landscape, sensors and analysis methods, carefully controlled multiple scale observations over transects cutting across Region VII will be made in order to identify relationships between specific elements of spatial structure, time of observation and scales of observation (e.g., sensor spatial resolution). Each transect will be about nine miles wide. Edge characteristics, components of edge and other elements of spatial structure will be defined via photo interpretation and field investigation. Alternative types of satellite data and data analysis methods will be tested to determine the effects of scale/sensor/analytic techniques on edge definition. Results of this work are expected to lead to better understanding of sensor-landscape interaction, and to produce recommendations for new and improved data collection and analysis strategies. We expect also to generate our initial hierarchical GIS model from these results. Neural networks, expert systems, fuzzy set theory, and other new tools will be evaluated in our work as time permits.

Task 3

We will develop a taxonomic and hierarchical approach to edge characterization based on the use of multiple scales of source materials including aerial photography and satellite remote sensing.

Task 4

We will work with James Omernik (EPA/Corvallis) and with Dennis Lytle (USDA/Soil Conservation Service) to examine means for redefining, subdividing, and characterizing landscape regions. The focus will be on Omernik's ecoregions within Region VII and the USDA Major Land Resources Areas occurring in Region VII. Potential applications of automated GIS and satellite remote sensing methods will be explored. Applications to nonpoint source pollution problems will be evaluated.

MECHANISTIC AND SMALL SCALE PROCESSES

During the course of this study, we will initiate projects designed to investigate the mechanisms underlying the functional processes that link structural components of the ecosystems. In order to properly establish and understand the functional pathways necessary to model the ecosystem, we must understand processes such as energy flow, nutrient flux, ecological interactions (e.g., competition and predation), demography (e.g., survival, reproduction, age structure), and genetics (e.g., variation, diversity). These investigations will be undertaken with the goal of developing specific indicator variables that can be used to indicate ecosystem exposure and response to stress. We anticipate that these projects will be reduced in scope compared to the projects outlined above, but they are no less important to the success of the overall objective of this study initiative; the evaluation of the effects of NPSP on aquatic ecosystems.

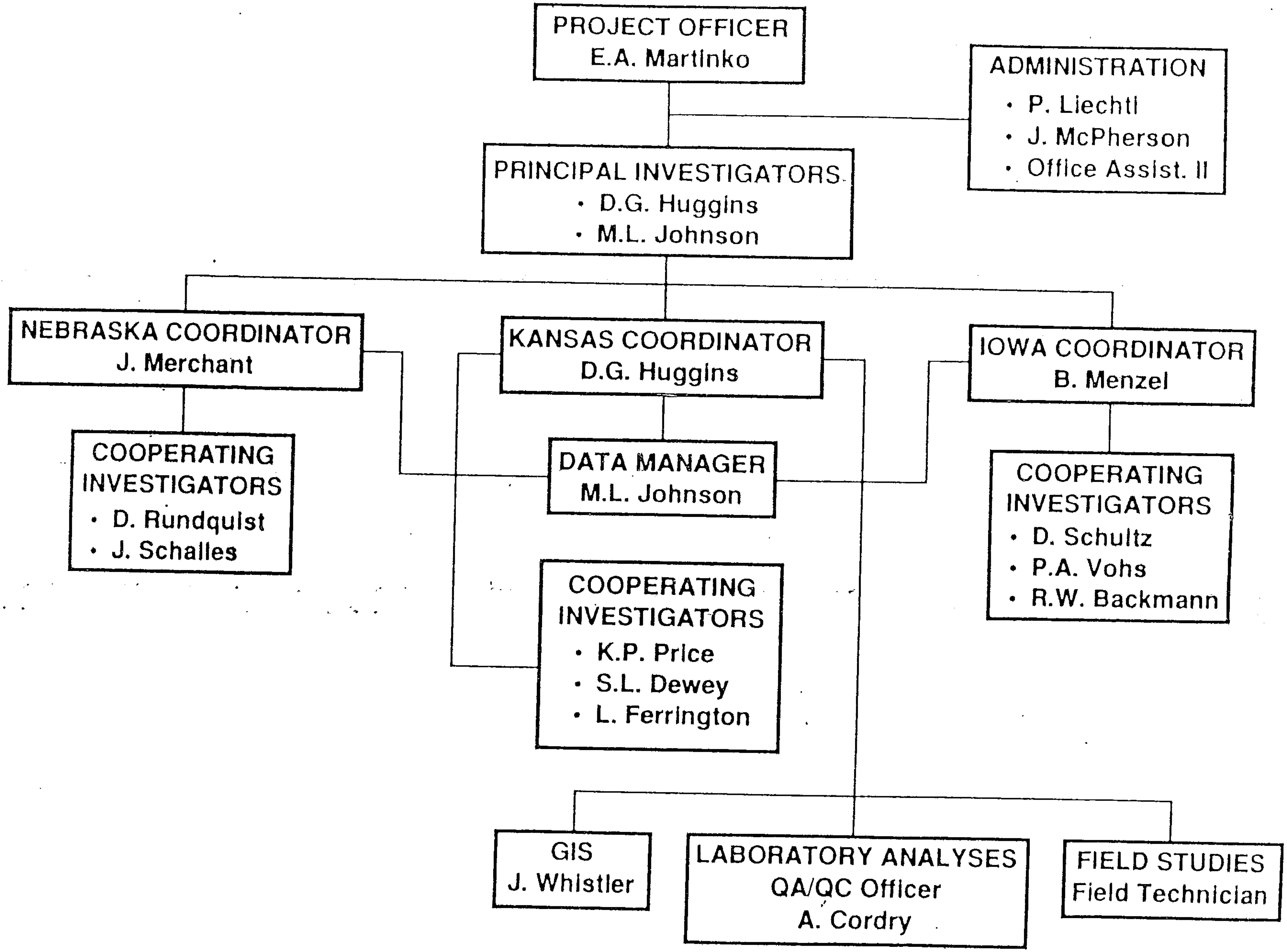
PROJECT ORGANIZATION AND TECHNOLOGY TRANSFER

Organization

The Project Manager will be Dr. Edward A. Martinko, Director of the Kansas Applied Remote Sensing Program (KARS) and the Kansas Biological Survey (KBS) (Figure 6). Dr. Martinko will be the primary responsible party and will be responsible for the administration of the entire project. Dr. Martinko has been responsible for the management and administration of grants and contracts totaling several million dollars over the last 15 years. Assisting Dr. Martinko in the day-to-day administration will be Paul Liechti, Assistant Director of the KBS, and Judy McPherson, Accountant and administrative assistant for KBS. Additionally, we will be employing an entry level Office Assistant to help with general business pertaining to the project (e.g., preparation of manuscripts for publication, progress reports).

The principal investigators for the project will be Dr. Donald G. Huggins and Dr. Michael L. Johnson. Dr. Huggins is Director of the Ecotoxicology Program within the KBS, and Dr. Johnson is a Research Associate with the KBS. They will be responsible for the organization and coordination of the scientific portion of the investigation. Additionally, Dr. Huggins will be the coordinator of activities for the University of Kansas, including the Geographic Information Systems analysis, the laboratory water quality analyses, and the field aspects of the investigation (see below). Drs. James Merchant and Bruce Menzel will be the site coordinators for the University of Nebraska and Iowa State University, respectively. They will be responsible for organizing and coordinating the activities at each university, as well as coordinating the activities among the three universities. Dr. Johnson will be the data manager for the project. His responsibilities will include obtaining data from the various investigators for inclusion in the project database, data analyses pertaining to the watershed level investigation, and insuring the completion of project reports.

In addition to Drs. Huggins, Johnson, Menzel, and Merchant, a group of cooperating investigators will be responsible for performing and/or supervising the investigations outlined in the workplan and supporting documents.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COOPERATING INVESTIGATORS
• D. Rundquist
• J. Schalles
DATA MANAGER
M.L. Johnson
COOPERATING INVESTIGATORS
• D. Schultz
• P.A. Vohs
• R.W. Backmann
COOPERATING INVESTIGATORS
• K.P. Price
• S.L. Dewey
• L. Ferrington
GIS
J. Whistler
LABORATORY ANALYSES
QA/QC Officer
A. Cordry
FIELD STUDIES
Field Technician

The water quality laboratory will be located at the Kansas Biological Survey. Dr. Arthur Cordry will be the analytical chemist in charge of the laboratory, and will function as the QA/QC officer. Daily management of the geographic information systems activities will be done by Jerry Whistler, who is presently responsible for the daily operation of the KARS program. The field investigations will be supervised on a daily basis by a field technician. This individual will be responsible for all of the field equipment, the continued operation of the automated samplers, shipping samples, and initial data entry.

Technology Transfer

To facilitate communication between the Environmental Protection Agency Region VII office and the investigators on the project, we will offer a one-half day workshop (or longer if necessary) for EPA personnel at the end of each grant period. These workshops will be a combination of short presentations on various aspects of the investigation, and open discussions between EPA personnel and investigators on the project. Because we anticipate funding over a number of years, we view these workshops not only as a means of informing EPA about the current state of our investigations, but also as an opportunity for the exchange of ideas and the refining of our studies based on the experience, concerns, and information available from EPA personnel.