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Conceptual Framework for the National Pilot Project on Livestock and the Environment

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Conceptual Framework for the National Pilot Project on Livestock and the Environment

Abstract

Assessing the effects of alternative policies that regulate nonpoint pollution from concentrated animal feeding operations (CAFOs) requires insight into the interactions of livestock production practices, waste management technologies, and their impacts on the environment. CAFOs have been identified as a source of nutrient loadings that impair ground and surface water quality, and they can emit intense odor that impairs air quality. This report describes the conceptual framework and the integrated modeling system being developed to evaluate the economic and environmental impacts of alternative policies that abate pollution from CAFOs.

Keywords

Agriculture, Livestock, Environmental and economic impacts

Disciplines

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Livestock Series Report 2

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ABSTRACT

Assessing the effects of alternative policies that regulate nonpoint pollution from concentrated animal feeding operations (CAFOs) requires insight into the interactions of livestock production practices, waste management technologies, and their impacts on the environment. CAFOs have been identified as a source of nutrient loadings that impair ground and surface water quality, and they can emit intense odor that impairs air quality. This report describes the conceptual framework and the integrated modeling system being developed to evaluate the economic and environmental impacts of alternative policies that abate pollution from CAFOs.

THE CONCEPTUAL FRAMEWORK FOR THE NATIONAL PILOT PROJECT ON LIVESTOCK AND THE ENVIRONMENT

Economies of size and scale have exerted economic pressure on the livestock industry to become more concentrated. Growth and concentration in U.S. livestock industries have increased environmental pollution problems commonly associated with livestock production. A natural by-product of livestock production is manure, which can pollute surface water and groundwater and create odor problems. Manure management is now a key environmental issue across the United States. For example,

> [a]ccording to a summary of state nonpoint source water quality assessments prepared in 1989, over one-third of all agricultural nonpoint source pollution impairments in the nation were caused by livestock waste. . . According to this data base, 34 states reported that livestock waste impaired over 4,500 waterbodies nationwide (Painter and Long 1992).

The National Pilot Project on Livestock and the Environment (NPP) is an interdisciplinary research project to address environmental and economic issues associated with the evolving U.S. livestock industry. The NPP's Detailed Problem Statement describes these issues and the goals of the NPP.

This report presents the NPP's conceptual framework, including an outline of the methods used in conducting the project. Because the situation in Erath County is not unique, the NPP intends to formulate policy alternatives and research methodologies that can be applied to similar situations nationwide.

NPP Research Approach

Research for the NPP will be conducted along two complementary fronts. One involves developing an integrated system of interdisciplinary economic and environmental simulation models. This approach makes it possible to incorporate state-of-the-art scientific procedures and results into the NPP. The modeling system is designed to quantify the trade-offs between economic returns and environmental quality resulting from alternative policy scenarios.

Interdisciplinary integrated modeling has become a widely accepted conceptual framework for comprehensive economic and environmental analysis (Capalbo and Antle 1989). Such a holistic approach is key to understanding interactions between agricultural and environmental factors in determining the nature and intensity of pollution, as well as the policy implications for economic efficiency and environmental quality (Bouzaher et al. 1993).

The second objective concentrates on actual policy implementation and organizing institutional change to achieve environmental quality and economic efficiency. There are a number of interest groups involved in discussions of the impact of the livestock industry on environmental quality. These interest groups reflect environmental concerns, agricultural concerns, economic development concerns, and the concerns of affected individuals outside production regions. Representatives from these groups will constitute a national constituency committee, NCC, to develop policy alternatives for the NPP. The NCC provides a direct link with the political process of policy development and implementation.

This dual approach for the NPP is innovative because it addresses both the scientific foundation and political process in developing new policies to abate livestock pollution problems. Policy can best be implemented through research activities conducted in a framework that recognizes the importance of public and private institutions. Policy recommendations based on a proper understanding of the objectives of institutions, interest groups, and regulatory authorities can dramatically improve the probability of success in complex policy settings. This approach combines scientific research with the policy implementation process making it highly efficient for this project and for others involving applied policy analysis.

Expansion of the NPP to Other Problem Areas

An objective of the NPP is to extend the methodology and recommended policy from the NPP to other areas in the United States that are experiencing negative environmental impacts from livestock waste. Using the framework developed for the NPP, alternative livestock species and regional areas can be analyzed to determine the broader implications of economic and environmental sustainability of the U.S. livestock industry in general.

NPP Initial Program Site

The Upper North Bosque watershed in Erath County, Texas, is the NPP's initial program site for developing a basic understanding of the issues relating to dairy production practices, the resource base, environmental impacts, technologies, regulatory policy, and institutional considerations. Erath County provides a prime example of the relationship between environmental degradation, particularly agricultural nonpoint source pollution, and the national trend toward increased concentration in livestock production. Erath County has experienced significant degradation of surface water, groundwater, and air resources because of more than a 200 percent increase in the number of dairy cows located in the county (Jones et al. 1993). In 1989, the Texas State Soil and Water Conservation Board designated the Upper North Bosque River as the watershed most severely affected by agricultural nonpoint pollution in Texas (TIAER 1992a). Erath County merits particular attention both because of the necessity to correct the local environmental problems, and because of the potential to apply the lessons learned in Erath County to similar livestock growth areas nationwide.

Erath County is an area of rapid change for the dairy industry, and one in which environmental problems associated with existing dairy production systems have a high political and economic profile.

Project Organization

The National Pilot Project has seven work groups, each with specific research tasks centered around the major components: policy, surface water, groundwater, odor/air, economics, statistics, and data management. Some team members are assigned to several groups, enhancing the interdisciplinary nature of the NPP and allowing communication and integration across working groups. In addition, each working group has responsibilities related to environmental monitoring and modeling.

Environmental Monitoring System

Monitoring may be the best way to assess environmental quality, but the usefulness of monitoring data depends entirely on the design and implementation of the monitoring system. The NPP will design an environmental monitoring system using existing monitoring sites and develop new monitoring sites to provide the environmental data needed for the NPP. Potential sources of pollutants from livestock operations include animal confinement areas, waste water lagoons, manure storage sites, and waste application fields. Livestock waste has the potential to run off into surface water, leach into the groundwater, and create odor problems.

The environmental impacts of livestock production on surface water and odor will be monitored directly by the NPP. Groundwater will be analyzed by limited vadose zone monitoring, modeling efforts, and whenever possible by coordinating with projects that monitor and analyze groundwater in Erath County outside of the NPP. The monitoring system will provide data to assess environmental quality and to provide data necessary to validate and calibrate NPP simulation models.

Water quality and odor monitoring produces information for simulation model development, validation, and calibration; for understanding causal relationships; and for assessing the overall system performance and its predictive ability. The monitoring system is being designed to effectively monitor the impact of alternative management practices on water quality and odor levels in relation to rainfall runoff events. Also, improvements in water quality and odor levels in the watershed as a result of the NPP can be ascertained by comparing current samples with initial monitoring results.

Surface Water Monitoring

In addition to being one of the major milk production centers in the United States, Erath County was the focus of a Clean Water Act, or Section 319 project, the Nonpoint Source Management Program for the North Bosque Watershed (TIAER 1992b). As a result of the 319 project, 24 surface water monitoring sites operate throughout the Upper North Bosque Watershed. These sites include six PL-566 reservoirs and 18 stream sites. Of these, two reservoirs and ten stream sites were selected for more intensive monitoring, which includes monitoring meteorological conditions. The selection of sampling sites was based on the ability of each site to monitor the effects of dairies and other agricultural operations on water quality. Two intensively monitored small watersheds were selected with contrasting land use practices, one with minimal agricultural practices and the other with a high concentration of dairies.

Additional Surface Water Monitoring Sites

The NPP will build onto the existing monitoring system by constructing additional sampling sites at several locations in the watershed contingent on landowner cooperation. Additional monitoring stations have been identified at seven stream monitoring sites and two reservoir sites. This allows monitoring of several micro-watersheds with different hydrologic responses and expected dairy impacts. Also, two of the additional sites will monitor urban runoff from Stephenville (16,000 residents), the major urban area in the watershed. These sites will provide pollutant loading and abatement information.

Edge-of-Field Runoff Monitoring System

An edge-of-field monitoring system will be developed for the NPP. This monitoring is necessary to validate and calibrate the single and multifield model, the Erosion Productivity Impact Calculator (EPIC). This model simulates the flow and concentration of pollutant runoff at the edge of livestock waste application fields. Also, some of the selected field sites will be monitored for parameters in the vadose zone to allow initial validation of EPIC's vadose zone component. Eight automated runoff sampling devices will be used to develop the field runoff monitoring system.

Developing an edge-of-field monitoring site is difficult. Extensive physical modifications, including berms and diversions, must be constructed in the field to divert runoff properly through the measuring device. The field must be physically accessible at all times of the year. And the application of livestock waste must be measured and controlled. Potentially, application rates could be below the level necessary to properly maintain wastewater lagoons and manure storage areas. There is also the threat that the data collected by the monitoring site could be used against the landowner in an environmental lawsuit. Therefore, the landowner (dairy operator) of a potential field monitoring site must be highly cooperative and be willing to assume any associated risks. There are only a few potential participants because of these limitations.

Three landowners have tentatively agreed to participate in the field monitoring. Efforts continue to identify additional participants. A letter has been sent to landowners/dairy operators to ask them to participate in the field monitoring system. Because time is crucial, a field monitoring site will be developed at one of the participating dairies in order to examine field application of lagoon effluent. This site will serve as a pilot site to initiate data collection and to gain information on constructing a field monitoring site.

After all possible participants are identified, a statistical design based on stratification, randomization, and replication can be developed. The design will be subject to the normal design constraints of budget and information needs. The benefits of a statistically based plan are its ability to make inferences from the sample to the population with known statistical confidence, and the ability to defend the design (and hence the results) of the study as being without bias or prejudice. Because of the limited number of runoff sampling devices and the high cost of implementing monitoring sites, compromises on the replication number, factors, and levels will be needed. An initial statistical sampling design was developed to select sites for field runoff monitoring and will be modified according to the information needs of the updated set of willing participants (Carriquiry 1993a).

The monitoring data need to include specific variables: livestock waste application methods and rates, soil types, slopes, cropping systems, and filter-strip options. The goal of the NPP is to have the edge-of-field monitoring system developed as soon as possible.

Groundwater Monitoring

Due to limited resources, groundwater monitoring will be limited in the initial phases of the NPP. However, the EPIC model is being extended down into the vadose zone, and will be used in the NPP to model potential groundwater leaching. There will be some vadose zone sampling in order to validate the EPIC model. Although there is not an extensive groundwater monitoring system for the NPP, the potential impact of livestock waste on groundwater quality will be analyzed to the fullest extent possible through modeling, the limited vadose zone modeling, and by coordinating information gathering with other groundwater projects in the area.

Odor Monitoring

Odor is a significant problem associated with concentrated animal feeding operations (CAFOs) and will be addressed by the NPP through monitoring and modeling. A simplified description of the odor problem would include odor emissions at the source and odor transported from the source toward the edge of the farm and into neighboring establishments. The intensity of odor at the edges of farms is affected not only by odor emission rates at the source, but also by weather and other factors such as wind breaks between the source and the edge of the farm. In addition, odor intensity at the edge of the farm may actually result from the interaction of odor emissions at different nearby sources.

The odor working group has collected monitoring data on odor emission at the source and odor intensity away from the source. An odor panel with approximately six members measured odor during five odor measurement sessions on three farms in Erath County. A Barnebey-Cheney Scentometer and a Butanol Olfactometer were used to determine the order of magnitude concentration of dairy farm odor in ambient air. The intensity of odor from various functional sites on dairy farms was measured by the odor panel. These included sites upwind and downwind of dairy corrals and confinement buildings; manure handling facilities such as settling basins, retention ponds, and irrigation sprinkler guns, and solid waste application fields. Odor intensity was measured at the upwind and downwind property lines, and at receptor points within one mile of the dairy property. These data will be used to calibrate an odor dispersion model to conditions in Erath County.

Additional odor data may be collected if initial results from the odor dispersion model indicate that additional data are necessary to improve modeling performance. A statistically based sampling design for odor data collection is being developed (Carriquiry 1993b).

Mathematical Simulation Models

A powerful supplement and in some cases an alternative to directly monitoring resources to assess environmental quality impacts is to use biogeophysically based mathematical simulation models. These mathematical models describe and simulate the physical, chemical, and biological processes affecting the real-life system. In recent years, there has been increased interest in using simulation models to examine nonpoint source pollution control. Simulation models have several advantages: (1) they consider site-specific attributes, including land use patterns and management practices; (2) they use superior computing capabilities to allow simulation of real-life processes in greater detail; and (3) they allow evaluation of alternative public policies related to the environment before any policies are actually implemented.

Integrating simulation models into a comprehensive analytical framework for policy analysis is an important way to understand the nature of agricultural nonpoint source pollution. Modeling the interactions between agricultural and environmental factors and the policy feedback from these interactions is vital to the design of institutions for environmental protection. The framework being developed for the NPP parallels the conceptual framework of the Comprehensive Environmental Economic Policy Evaluation System (CEEPES) (Johnson et al. 1990). The CEEPES system was developed for a major EPA project addressing nonpoint sources of ground and surface water contamination, and has been successfully applied to analyze environmental policy issues associated with row crop production at farm and regional levels. CEEPES is an integrated set of simulation models that link the environmental fate and transport of agricultural pesticides and nutrients to cultivation practices, application levels, soil resources, parameters of agricultural income maintenance, regulatory policies, and regulatory programs. The NPP integrated modeling system will evaluate these factors for CAFOs.

The Agricultural Pollution Process

The nonpoint character of agricultural runoff often renders traditional point source pollution abatement policies inoperative. Point source policies are based on monitoring emissions from each individual economic agent relative to a given standard. In comparison, it is technically difficult and prohibitively expensive to monitor nonpoint pollutant emissions by individual farms. An alternative to individual monitoring has been developed using nonpoint production functions. Functional relationships between pollution emissions and production practices have been developed and are referred to as *nonpoint production functions*. These functions relate fixed asset technologies and management practices to the amount of pollution emission. The essential feature of a nonpoint production function is that it allows economically efficient policies to be based upon those factors that determine pollution rather than on the pollutant itself (Griffin and Bromely 1982). This is the basis of existing policies that regulate nonpoint source emissions through the permit process and on-site inspections of production practices.

There are many unresolved problems regarding the precise linkages among management choices, physical land characteristics, and the generation of agricultural runoff from dairy farms. The NPP is being designed to provide a comprehensive analysis of the economic impact of implementing alternative production practices that reduce pollution. This information should be used to identify the level of nonpoint source pollution possible at different levels of economic cost.

Overall Description of the NPP System

The NPP will include economic, biological, and geophysical process models and use data from the Upper North Bosque River watershed. The overall operational framework of the NPP is illustrated in Figure 1. The framework can be viewed as an integrated system where the results from one component serve as input to a linked component.

Basically, the first step in the NPP system is developing a potential policy addressing livestock waste. That policy is then analyzed by a farm-level economic model to determine the management response and its associated effect on the dairy farm's net income. The economic model also determines the nutrient loadings and odor emission levels from livestock waste produced by the farm. This information, in combination with data on environmental parameters such as weather and soil type, are input into environmental simulation models to determine the farm's actual contribution to pollution levels in the ground and surface water, and to odor. Results from the economic and environmental models are used to aggregate farm-level impacts across the entire watershed. The aggregate effects then recursively provide feedback to policy development, which can be refined and the analysis process restarted.

Policy Model

Substantive policy issues are central to the NPP. Existing policies are inadequate to abate nonpoint source livestock pollution. The policy model will develop alternative policy scenarios that overcome the weaknesses of existing policies. These scenarios will include an assessment of current

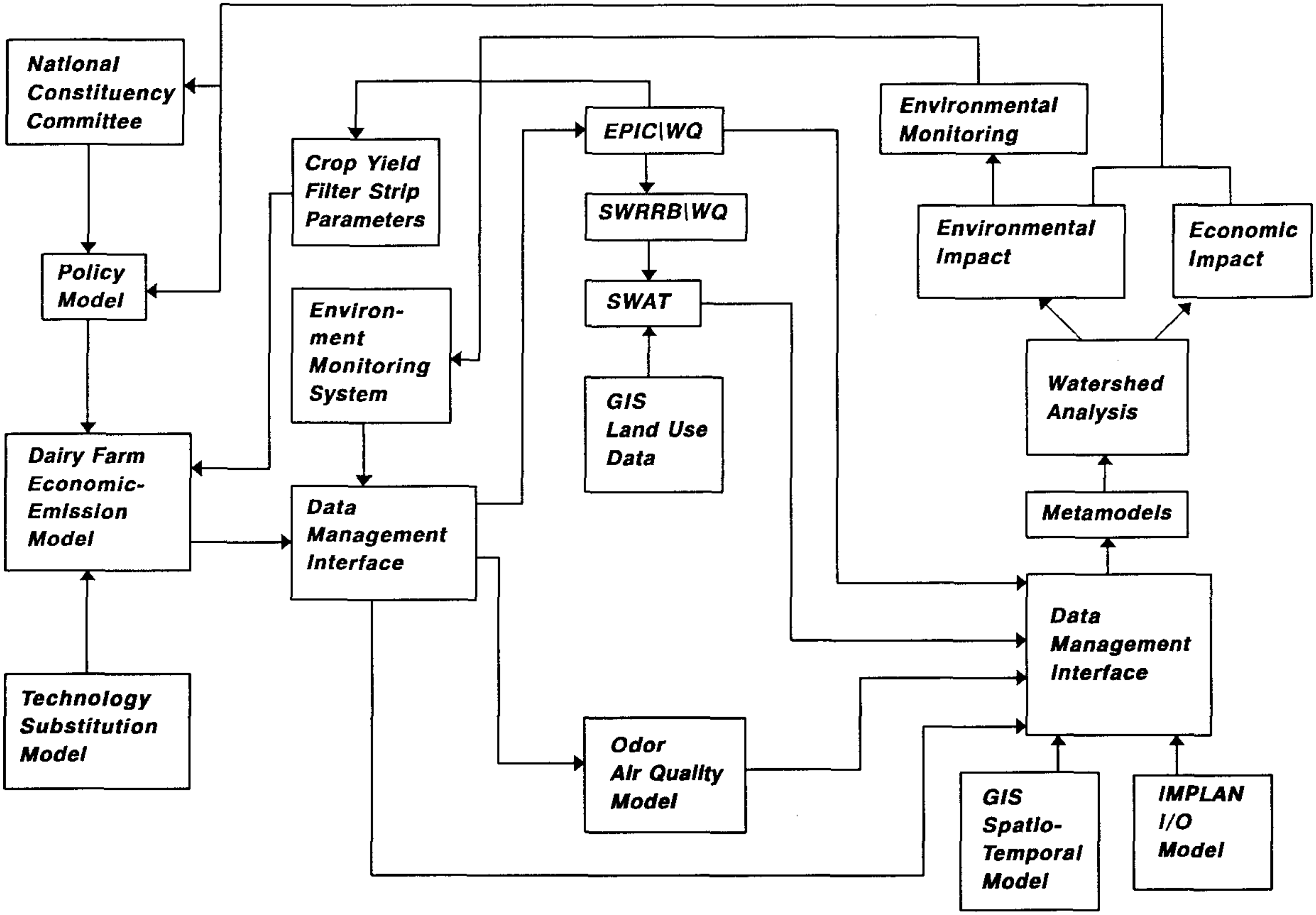

Figure 1. The conceptual framework for the NPP modeling system

policies and the development of viable alternatives. The NCC will provide direct input into the formulation of policy alternatives. The policy parameters will include monitoring and enforcement guidelines and their potential impacts on both small and large producers. The roles of federal, state and local agencies and organizations will also be examined. Effecting sustainable changes in the industry will require careful and detailed analysis in the development of new approaches for technology, management systems, policies, and regulatory schemes.

Growing environmental awareness emphasizes the emerging importance of developing nontraditional agricultural policies (Hrubovcak, Leblanc, and Miranowski 1990). An innovative policy scenario being considered by the NPP is to monitor and enforce nonpoint source pollution regulations at the micro-watershed level. This potential policy monitors the outlet of a micro-watershed for water quality. Once a water quality problem is detected in a particular stream segment, small portions of the stream can be isolated with automatic sampling equipment to identify the primary sources of contamination. When combined with appropriate institutional arrangements of organizing micro-watershed stakeholders and establishing watershed water quality standards, a micro-watershed based policy may represent a viable nonpoint source pollution monitoring control system (Jones, Turknett, and Butcher 1993).

The NPP design requires the policy working group to determine initial project policy parameters within which the work of all of the other project working groups is to be conducted. Policy parameters are determined through a careful assessment of current policies affecting the CAFO pollution problem, and subsequent recognition of viable alternatives. Several satellite policy projects are being implemented as part of the overall policy analysis of the NPP. These projects include the analysis of a Dairy Park concept that, in effect, creates an industrial site for CAFOs (Jones, Turknett, and Butcher 1993), and a project that analyzes the economic forces, including milk marketing orders and federal price support policies, that encourage concentration of livestock operations at the national level.

Dairy Farm Economic and Emission Level Model

The economic model is important because it identifies both the farm-level economic impact of alternative policies and the farm-level nutrient and odor emissions. This information serves as input data to the environmental simulation models. The farm determines the size and scope of the production practices and it is the source of the nutrients and odor being introduced into the environment. The economic model will simulate representative dairy farms in Erath County for small, medium, and large classifications. Modeling the dairy economic system by herd size is important because of the economies of size and scale in milk production and waste handling systems. The herd sizes will be characterized as small (225 head, milking 185 head), medium (400 head, milking 350 head), and large (1200 head, milking 1,000 head). The specified herd sizes correspond with previous NPP economic data collection efforts (Pagano et al. 1992).

The model's goal is to simulate a dairy's decision making process in order to evaluate the economic impact, nutrient loadings, and odor emission levels in response to various policy alternatives. A dairy's production decisions generate a joint distribution of milk production, input usage, nutrient loading, and odor emissions. A linear programming model will be used to capture the complex interrelationships among policy, economic, nutrient, and odor parameters at the dairy farm level. The simulated dairy will maximize profit subject to constraining resources and policies.

The success of the dairy farm economic model depends largely on its ability to simulate and measure nutrient and odor emissions into various media (air, water, soil) using alternative dairy production and waste management technologies. A portfolio of potential production systems that integrates the dairy facility, the manure management system, and the waste disposal fields will be incorporated into the model, and are referred to as *technology systems*.

The technology systems are being given considerable attention in the design of the economic model. The only way a dairy can decrease its nutrient loadings and odor emission levels into the environment is by decreasing cow numbers or by introducing improved livestock waste management systems. In order for the model to be successful, it must accurately simulate the loading and emission level reductions resulting from alternative technology systems.

The dairy economic model will identify technology systems and management methods that provide alternatives for dairies that are economically and environmentally efficient. The model's results will provide information to aid policymakers in designing new institutional systems and their policies to guide the livestock industry toward economic and environmental sustainability.

Economic and Environmental Model Linkages

It is important to make clear the linkage between the dairy farm economic model and the environmental simulation models. The economic model provides the nutrient loading and odor emission levels that are applied to the solid waste application fields and the lagoon effluent application fields. The environmental simulation models use this information in addition to meteorological, soil type, and other data to simulate nutrient assimilation by the soil, crops, and through volatization into the atmosphere. Excess nutrients that overload the assimilation capabilities will be quantified by the environmental simulation models as surface water runoff, groundwater leaching, or objectionable odor levels. Therefore, it is the environmental simulation models that determine the actual pollution levels. The environmental simulation models that will be used by the NPP system are discussed in the following sections.

Erosion Productivity Impact Calculator and Water Quality Model

The Erosion Productivity Impact Calculator and Water Quality (EPIC\WQ) model will be used to model crop growth, surface water runoff, and groundwater leaching from individual waste application fields. EPIC\WQ is one of the most comprehensive environmental simulation models available and was developed by an interdisciplinary team at the U.S. Department of Agriculture (Williams et al. 1990). It is a time-tested model that has proven to be quite useful, economical, and realistic in several applications, including evaluating impacts on water quality and soil erosion, both here in the United States and around the world (C.S. Jones et al. 1991). The specific applications for which EPIC\WQ has been used include crop production, soil degradation, crop yield response to varying input levels and management practices, response to climate and soils, climate change and global warming, and water quality. It was originally designed to help analyze alternative cropping systems and project their socioeconomic and environmental sustainability, with specific reference to soil erosion and productivity. The current version of EPIC\WQ includes Groundwater Leaching Effects on Agricultural Management Systems (GLEAMS) water quality model, which allows simulation of pesticide degradation and movement in the soil. EPIC\WQ can simulate the movement of pesticides and nutrients toward ground and surface water both in solute, and as applicable, sediment phases.

The spatial scale of EPIC\WQ is field scale. Therefore, an entire watershed analysis using EPIC\WQ would be unmanageable because of the extensive simulations required to cover all the soil, climate, hydrology, management, crop, chemical, and policy options. Given a regional soil database and a set of current and potential management alternatives, the number of simulations required to cover all possible options is significantly larger than can be accommodated by available resources. However, this extensive coverage is required to capture the heterogeneity of the physical environment as well as the agricultural production practices so that a meaningful aggregation of site-specific assessments is possible. An alternative to the enormous task of modeling each combination of physical parameters is to develop a statistically based, spatial sampling design. This reduces the number of simulation runs considerably, and at the same time retains the statistical validity of aggregation and extrapolation into the population. A sampling design will be developed by the statistical working group when the EPIC\WQ simulation runs are completed. For the NPP, EPIC\WQ will be expanded to a multifield version that allows the inclusion of filter strips in the assessment of surface water runoff. This new model is called APEX.

Simulation for Water Resources in Rural Basins—Water Quality (SWRRB-WQ) and Soil and Water Assessment Tool (SWAT)

EPIC\WQ is a field-based model that produces a detailed analysis of individual fields. However, both policies and the NPP must address the entire watershed. Therefore, there is a need to aggregate site specific results to the entire watershed. The SWRRB-WQ and SWAT models will be used for this purpose. The SWRRB-WQ routes field runoff and SWAT integrates with SWRRB-WQ to measure drainage in an entire watershed. The SWAT model was developed to predict the effect of alternative management decisions on runoff, sediment, and chemical yields with reasonable accuracy for ungaged rural basins, and has been applied to the lower Colorado River in Texas (Srinivasan et al. undated). SWAT is structured to interface with a Geographic Information System (GIS) database. SWAT, using the GIS, divides the watershed into subbasins by natural flow paths, boundaries, and channels required for realistic routing of runoff, sediment, and chemicals, thus preserving watershed configuration. Using pollutant concentrations and land use data, pollutants are routed through the watershed to the outlet point at Hico, Texas.

For SWAT, all land use in the watershed has to be quantified, which falls directly into a GIS application. SWAT's application to the lower Colorado River used U.S. Geological Survey digital elevation data, U.S. SCS STATSGO soil database, and the USGS LUDA database, all at the 1:250,000 scale. SWAT can incorporate increased precision on land use data. For the NPP, sectors with significant dairy and crop production activity could be tightly defined to improve the quality of input data. Furthermore, urban areas can be isolated in the land use map. As necessary, SWAT is structured to incorporate EPIC\WQ and APEX field simulations to facilitate added resolution for dairy application fields.

The first step in collecting land use data for the SWAT model is recognition of the primary pollution sources within the watershed. Once the watershed areas representing the greatest pollution potential are identified, land use data collection can be concentrated in those areas. LANDSAT images with post processing to determine land uses at a pixel level of about 1/4 acre will be used to determine land use. The goal is to identify individual agricultural fields, especially dairy waste application fields. The land use data will be one level of the GIS database being developed for SWAT.

Odor and Air Quality Model

As livestock herd sizes increase, the issue of nuisance odors and the resulting air contamination becomes more important. Odor contamination by CAFOs is an important yet often overlooked problem, so it must be included as part of any comprehensive project addressing environmental contamination by CAFOs because of the often direct relationship between best management practices (BMPs) to control livestock waste and its associated odor. For example, wastewater lagoons and land application of manure are considered BMPs, but implementing these BMPs creates potential odor problems.

While there are enforceable standards for many air pollutants, no quantitative measurement standards have been determined for odor. An odor model will be used in the NPP to examine nuisance dairy odor problems in Erath County. Odor monitoring data, in combination with meteorological data, will be used to develop an odor dispersion and odor emission rate model.

Regional Economic Impact Analysis

The increasing concentration of dairy cows in Erath County is creating tension and open conflict among dairy and nondairy interest groups over the issues of odors, flies, and the potential pollution of ground and surface water in the region. There are both benefits and costs of dairy operations to the local community. Dairy production is a primary source of agricultural income and accounts for most of the recent economic growth in Erath County and the surrounding Cross Timbers region. On the other hand, external costs of dairying to the community may include impacts to property and land values. To help clarify winners, losers, and the net effect on the local economy, the impact of the growth in the regional dairy industry will be estimated.

The purpose of the economic impact study is to develop an input-output (I/O) model of the region's dairy industry. This model will be used to estimate the impact of dairy operations on regional/local economic activity. The list of economic indicators that will be examined are identified in Bouzaher et al. (1993b).

The impact of the dairy industry on the economy of the five-county Cross Timbers region will be examined using a regional input-output model formulated with the Input Analysis for Planning Model (IMPLAN). Follow up studies will narrow the focus from the Cross Timbers region to Erath County. The regional I/O models will be developed specifically for the NPP and used to estimate the sensitivity of the region's economic base, household income, and employment levels to changes in the dairy industry. The analysis will be based on profiles of dairy production, costs and returns for representative small, medium, and large dairies, and the most up-to-date data on the economic sectors in the region.

The IMPLAN model will isolate the Cross Timbers region from the surrounding economy so that economic impacts of the dairy sector on this region can be estimated. Impacts of the dairy industry to the Cross Timbers region can be measured by estimating local expenditures by each dairy (the direct effect), then calculating indirect and induced effects using the IMPLAN model. These expenditures include labor, feed, energy, water, machinery, waste management, operating expenses, taxes, and other items. The sum of these effects (direct, indirect, and induced) equals the total impact of the dairy industry on the Cross Timbers economy.

GIS Spatio-Temporal Model

Spatial statistical modeling and analysis have been perceived as potentially useful components of several stages of the NPP. Spatial statistical models relax the common statistical assumption that all data are statistically independent. Ecological and environmental scientists have for a long time realized that nearby data tend to be more alike than data that are spatially distant. A spatial statistical model incorporates information concerning the location of data as a means to improve its predictive ability. A spatial statistical model will be developed specifically for the NPP to demonstrate the usefulness of this technique (Appendix A contains the complete details for this model).

A GIS using ARC-INFO software will develop and organize the spatial and temporal observations associated with this model. A GIS allows spatial data to be explored for spatial outliers and allows identification of structures in the spatial and temporal processes at work. The other major role of the GIS in spatial analysis is in building the spatio-temporal data set that will be used in the statistical modeling. The variables that influence the pollutant concentration at sampling sites are usually physical characteristics such as soil properties and precipitation. The GIS has the ability to manage a database of these variables indexed over space and time, and thereby create a data set that has the necessary information to conduct the spatio-statistical modeling.

Metamodels

Analysis of the nonpoint source livestock pollution problems in Erath County requires detailed simulation models. Furthermore, the nonpoint source pollution problem requires a watershed-based analysis. One method to develop watershed information for the NPP is to compile all of the simulation models for all possible policy, economic, and environmental parameters across the watershed. This method is computationally cumbersome and potentially infeasible. A much more efficient approach is to construct metamodels.

Constructing a metamodel involves statistical modeling of a simulation model's output, thereby creating a model of a model. Metamodeling produces response functions that characterize relationships implied by the structure of a simulation model relating variables that appear to be important to policy evaluation. The metamodeling process as described here for the NPP is adopted from Bouzaher et al. 1993a.

Metamodeling first involves experimenting with and observing outcomes from a simulation model and then estimating relatively simple parametric forms to approximate a restricted set of outcomes of the simulated processes. This allows the analysts to abstract from detail not needed for policy evaluations, and to use interpolation to estimate outcomes for experimental conditions that were not simulated with the process model. The parsimonious specification provided by response functions allows us to integrate the logical implication of diverse models and evaluate the consequences of alternative polices without having to return to the original process models for every possible combination of input conditions.

The concept of a metamodel arises from a hierarchical modeling approach where, from a complex and "messy" real phenomenon, we proceed to a well-structured simulation model and then to statistical modeling of the relationship between inputs and outputs of the simulation model.

After choosing the parameters to be varied and the outcome measures of interest, the metamodeling task is to approximate the relationship between these variables implied by the simulation model. The full experimental design phase identifies the values of the chosen parameters for which the simulation model is to be executed, and the outcome measures are recorded. The experimental design determines the number of simulation executions that will be required, and it must be undertaken with a view to the cost and time required for each execution of the simulation model. The experiment should call for computationally intensive simulations for only the most informative specifications of input variables. Finally, the last step of metamodel development consists of estimating response functions for the outcome measures of interest. The metamodel is then used to predict outcomes, essentially replacing the simulation model and the real process studied with a relatively simpler parametric form.

Metamodel development will proceed after the NPP's simulation models are fully functional. Metamodels cannot be specified a priori because they depend upon the results of the simulation models. Metamodels will be used wherever possible to improve the efficiency of analysis within the NPP.

Data Management

The NPP will generate a massive amount of input and output data. The data will be managed using data management interfaces to link the data required between models. TIAER will maintain the NPP's master database in Stephenville, Texas. The term *master database* means that final copies of all project work will reside in that database. The database will be managed using SAS (ver 6.07) on a Unix-based network, with a Sun SparcStation 10-40, Solaris 1.1 as a server. The project files will be organized by their status of submitted, current, previous, and backup, and will be controlled by the data manager. This organizational scheme will maintain file integrity throughout the project. Data files will be transmitted among users using a comma delimited format and, depending on the file's size, with a variable definition header either at the top of the same file or in an associated documentation file.

Model Integration

Several methodological issues arise as the physical and economic model components are brought together into an integrated system. Successful integration requires compatible mathematical structures for simulation models and consistent statistical criteria in developing the output of one model to serve as data input to a linked model. The numerous models, each requiring and creating large amounts of data, greatly increase the complexity of model integration.

The research sequence will be to quantify the physical and biological relationships between livestock waste and the environment and to quantify the economic relationships among policies, profitability, nutrient loadings, and odor emissions at the farm level. Nutrient loadings, odor emissions, optimal farm-level management practices, and physical environment parameters are necessary to compute the environmental simulation models. This provides localized information that is fed into the aggregation analysis through data management and metamodels. As illustrated in Figure 1, aggregate environmental and economic impacts provide feedback information to the national constituency committee and for the policy model. Aggregate environmental monitoring provides feedback to the environment monitoring system. This feedback is necessary to examine the validity of modeling results and to correct any weaknesses in the monitoring system.

The best way the individual components of the NPP can be integrated into one overall system is through effective intergroup communication. This is accomplished by NPP project participants serving in more than one working group and by working groups meeting regularly. Furthermore, a precise project management system has been developed based on a detailed diagram of the sequence of tasks and events necessary to integrate all components of the NPP. The project management system can be used to identify a critical path that will identify resource demands and estimate time needed to complete the project. The diagram also identifies the linkages among components within the NPP system. Given the large number of participants, nonmodeling components, and modeling components of the NPP, the project management system provides a framework to document and monitor model integration and progress toward project completion.

Measuring Project Success

An item that has been discussed but not resolved is, "What is the NPP's measurement of successful pollution abatement?" In simple terms, the issue is whether a broad range nutrient loading and odor emission reduction will suffice as a target for successful pollution abatement when examining policy alternatives, without directly tying nutrient loading and odor reduction to specific improvements in water and air quality. Establishing a broad range as a nutrient load and odor emission reduction target is feasible and attainable within the current level of project funding.

However, there is still considerable interest in linking nutrient loading and odor emission reduction, due to implementation of BMPs, to improvements in water and air quality. The advantage of a water and air quality target for policymaking is that in many cases it creates the potential to link the target to a regulatory quality standard. Currently most states, including Texas, do not have existing nutrient standards.

There are a number of important considerations for setting any standards. First, improvements in water quality benefits from the NPP may be delayed because of the pollutants already in the soil and subsurface moisture. These pollutants have the potential to migrate toward surface water and groundwater, and may have a negative impact on future water quality measures. Best management practices may be put into place and pollutant emissions reduced, as a result of the success of the NPP, but water quality may not improve immediately. Second, stochastic weather patterns will significantly influence water quality measures. These issues complicate the setting of NPP modeling success measures. But central to the success of the NPP is completing and integrating the modeling efforts already identified.

Summary

The principal objective of the National Pilot Program is to coordinate policy for livestock and the environment by accelerating both science and policy development. This may include existing policies as well as development of new policy and institutional arrangements. The NPP will simultaneously investigate technologies, management practices, institutions, and policies that can correct the negative impacts of livestock production systems on environmental quality. The development of these systems must consider technology adoption and the institutional setting for sector regulation and industry development policy. Sustainability is important not only for environmental systems but for the systems that produce technology, management practices, and the regulatory and policy environment within which the livestock industry must function, grow, and adapt.

Informational needs and detailed model integration procedures will be refined as models are constructed, tested, and verified. This innovative design for the NPP is formulated to efficiently identify the mix of existing and new agricultural and environmental policies and institutions that will be politically sustainable and will improve the harmony of livestock production with environmental quality.

APPENDIX A. SPATIAL STATISTICAL MODELING OF SURFACE WATER DATA IN ERATH COUNTY: A POSITION PAPER

Noel Cressie and James J. Majure

The role of statistical theory and methods in characterizing uncertainty is well appreciated in science and engineering. Much of it is based on the random sample paradigm that says that all data are statistically independent. However, scientists and engineers working on ecological and environmental problems have for a long time realized that nearby data tend to be more alike than those far apart.

Deterministic (nonstatistical) models can be developed in an attempt to capture the physical, chemical, and biological mechanisms present, but there is often a residual uncertainty that can only be captured by statistical means. Consider, for example, water-transport models in hydrology. There is (a) model uncertainty in that, by definition, a model is an abstraction of reality; and (b) uncertainty in the specification of model parameters and initial conditions. When a water transport model is run, values will be produced in regions where there are no data; some values will be more uncertain than others, depending on how close and how variable neighboring data are.

A deterministic model has no internal mechanism to quantify uncertainty. It is possible to run sensitivity studies by varying parameters and initial conditions, but there is still an implicit assumption that the existing data (used to calibrate the model) are free from error. On the other hand, a statistical model looks for and quantifies uncertainty from the outset; furthermore, a spatial statistical model discards the inappropriate independence assumption referred to earlier (Cressie 1991).

A GIS will be used in close coordination with the statistical modeling. As well as its superior graphics display capabilities, the GIS plays two important roles in the spatial analysis. The first role is that of a dynamic exploratory data analysis (EDA) tool. The GIS allows spatial data to be explored for spatial outliers or anomalous values, and allows identification of structures in the spatial (and temporal) processes at work. These structures will need to be incorporated into the statistical model.

The other major role of the GIS in spatial analysis is in building the spatio-temporal data set that will be used in the statistical modeling. The variables that influence the pollutant concentration at sampling sites are usually physical characteristics such as soil properties and precipitation. The GIS has the ability to manage a database of these variables indexed over space and time, and thereby create a data set that has the necessary information to conduct the spatio-statistical modeling.

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The NPP project has within it a small demonstration study on spatial statistical modeling and analysis. Surface water monitoring data from an earlier project (EPA 319 Project), will be used to demonstrate the usefulness of spatial statistics. This appendix gives the blueprint for the demonstration.

Strategy

In much of Texas, and certainly in Erath County, major storms have an enormous effect on pollutant concentrations in surface water. Because the time scale of these storms is so short, it is necessary to carry out spatial modeling that is sensitive to the dynamics of a typical storm. Thus, the model will include a temporal component in the spatial model as well.

Data from any environmental study are usually multivariate. That is, a sampling site at any particular time point may have simultaneous measurements on Nitrate, Ammonia, Orthophospherous, Dissolved Oxygen, Specific Conductance, and so forth. For the purposes of this demonstration study, we shall concentrate our efforts on one particular pollutant. The choice of pollutant will be made after exploratory spatial data analysis conducted in the GIS; the pollutant whose variogram exhibits the most spatial structure will be chosen as the variable to model.

Not all surface water data are based on storms. Some are taken from streams with permanent flow and others are located in reservoirs. It is clear from the literature survey that storm-based measurements need to be distinguished from nonstorm measurements. Therefore, the data will be stratified into two parts; different model parameters will be fit to these two parts and predictions will take into account the presence or absence of storm-based runoff.

In a sense, regressors in a regression model provide a potentially continuous sequence of strata. That is, regressors such as precipitation, soil properties, and spatial location allow much of the variability in the data to be "explained." The remaining variability (sometimes called error) can then be characterized using spatial (and temporal) statistical models. The classical approach that assumes the errors are independent and identically distributed does not recognize the presence of local effects that lead to nearby data being more alike than those far apart.

Spatial Statistical Models

Let $Z(\underline{s};t)$ denote the pollutant concentration (or perhaps some suitable transformation such as its logarithm) at location $\underline{s}$ and time t. We shall present below some initial approaches that will be taken to model the variable Z.

First, we propose to stratify Z into two mutually exclusive variables Z_1 and Z_2, representing the pollutant concentration during a storm and the pollutant concentration otherwise. (Further stratification may be needed into reservoir/nonreservoir; careful exploratory data analysis will determine if this is necessary.) Decompose Z_1 and Z_2 into *deterministic* large-scale variation (mean) plus *stochastic* small-scale variation (error):

$$Z_\rho(\underline{s};t) = \mu_\rho(\underline{s};t) + \delta_\rho(\underline{s};t); \qquad \rho = 1,\ 2. \tag{1}$$

Further, express $\mu_n(\underline{s};t)$ in terms of k regressors $\underline{x}(\underline{s};t)$:

$$\mu_\rho(\underline{s};t) = \underline{x}(\underline{s};t)'\underline{\beta}_\rho; \qquad \rho = 1, 2, \tag{2}$$

where $\underline{x}(\underline{s};t) = (x_1(\underline{s};t), \ldots, x_k(\underline{s};t))'$ is a k x 1 vector whose entries correspond to such data (at location $\underline{s}$ and time t) as precipitation, soil properties, spatial location, basin characteristics, distances to upstream dairies, and so forth. In (2), we might have the same regressors but different coefficients for the two strata; it is easy to modify the model to allow for possibly different regressors.

Based on ordinary least squares fitting of $\underline{\beta}_1$ *and* $\underline{\beta}_2$ (or a two-stage procedure that recognizes statistical dependence between pollutant concentrations), one can define the residuals

$$\hat{\delta}_\rho(\underline{s};t) \equiv Z_\rho(\underline{s};t) - \underline{x}(\underline{s};t)'\hat{\underline{\beta}}_\rho; \qquad \rho = 1, 2, \tag{3}$$

where $\hat{\underline{\beta}}_1$ *and* $\hat{\underline{\beta}}_2$ are the ordinary least squares estimators of $\underline{\beta}_1$ *and* $\underline{\beta}_2$.

Now the spatial (and temporal) dependence can be characterized through the variogram,

$$2\gamma_\rho(\underline{h};u) \equiv var(\delta_\rho(\underline{s} + \underline{h};t + u) - \delta_\rho(\underline{s};t)), \tag{4}$$

which is assumed to be a function only of the "lags" $\underline{h}$ and u, and where the lag "interval" $\underline{h}$ is the displacement between sampling sites measured along the streams and u is the time between samples. The "stationarity" assumption in (4) allows $2\gamma_\rho$ to be estimated. Define

$$N(\underline{h};u) \equiv \{(\underline{s}_i;t_i), (\underline{s}_j;t_j): \underline{s}_i - \underline{s}_j = \underline{h} \text{ and } t_i - t_j = u)\}, \tag{5}$$

where $\{(\underline{s}_i;t_i): i = 1,\ldots,n\}$ are the locations of the monitoring sites and the times that samples were taken. The estimator is $2\hat{\gamma}_\rho$ with

$$2\hat{\gamma}_\rho(\underline{h};u) \equiv \sum_{N(\underline{h};u)} \{\hat{\delta}_\rho(\underline{s}_i;t_i) - \hat{\delta}_\rho(\underline{s}_j;t_j)\}^2/|N(\underline{h};u)| \;;\; \rho = 1, 2, \tag{6}$$

where $|N(\underline{h};u)|$ denotes the number of pairs in $N(\underline{h};u)$.

The variogram (4) *has* to be conditionally negative-definite; however, the estimator (6) typically is not. Various *valid* variogram models will be fit to the estimator (6) and the best one chosen. Denote the fitted variograms as

$$2\gamma_\rho^*(\underline{h};u); \; \rho = 1, 2. \tag{7}$$

In summary, the spatio-temporal model will look like:

$$Z_\rho(\underline{s};t) = \underline{x}(\underline{s};t)'\underline{\beta}_\rho + \delta_\rho(\underline{s};t);\ \rho = 1,\ 2.$$

The spatial dependence in the error δ_ρ will be characterized by the (fitted) variogram

$$2\gamma_\rho^*;\ \rho = 1,\ 2.$$

Spatio-Temporal Prediction

Using the theory of best linear unbiased prediction (sometimes referred to as *kriging*), we shall be able to predict $Z_\rho(\underline{s}_0;t_0)$ (or some aggregation of it) at *any* surface water location $\underline{s}_0$ and at any time t_0. Call the optimal predictor

$$\hat{Z}_\rho(\underline{s}_0;t_0);\quad \rho = 1,\ 2. \tag{8}$$

The precision of the prediction can be quantified by the mean squared prediction error (MSPE),

$$M_\rho(\underline{s}_0;t_0) \equiv E\{Z_\rho(\underline{s}_0;t_0) - \hat{Z}_\rho(\underline{s}_0;t_0)\}^2;\ \ \rho = l,\ 2. \tag{9}$$

Geographic Information Systems

Consider the spatial statistical model proposed by the spatial statistical models section of this appendix:

$$Z_\rho(\underline{s};t) = \mu_\rho(\underline{s};t) + \delta_\rho(\underline{s};t);\quad \rho = 1\ 2.$$

This model decomposes the concentration of a pollutant into large-scale and small-scale variation. The GIS will be used to create a database essential for the modeling of both sources of variation.

In the spatial statistical model, large-scale variation is expressed in terms of k regressors whose values correspond to physical characteristics that influence the concentration of the pollutant under consideration. Measuring these physical characteristics (e.g., soil properties, precipitation, basin area, and basin slope) has traditionally been a difficult and tedious job. The use of a GIS greatly reduces the work involved and, potentially, allows more of the variation to be accounted for by important *explanatory variables*. Variables that may be important include the sampling site drainage area, the amount of precipitation that fell in the drainage area in the preceding 48-hour period, the average slope of the drainage area, and the number of dairies in the drainage area with distances to each dairy measured along the path of flow. Studies have been conducted to investigate the influence of basin characteristics on discharge and water quality. These studies will be reviewed to determine which physical characteristics may be the most influential and the GIS will be used to store, manage, and retrieve the necessary information.

The small-scale variation and spatial dependence will be modeled using the variogram as described above. The spatial lag $\underline{h}$ will be defined to be the displacement between sampling sites measured along the streams. This will be done because the surface water processes being modeled are occurring within the streams. The topological data structure of the GIS allows these distances to be calculated easily.

The strategy of spatial statistical modeling is relatively straight forward and, once implemented, allows predictions to be made in space and time, with known confidence. The use of a GIS greatly enhances the statistical modeling by providing the ability to conduct dynamic exploratory data analyses and to summarize, in space and time, physical characteristics such as soil type, precipitation, and basin characteristics, that might help to explain the variability in the pollutant concentration. The result of the efforts will be the ability to predict the pollutant concentration at any point along the surface water system, and to produce pollutant concentration maps that can be seen to evolve dynamically in time.

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