# The Environmental Component of the National Pilot Project Integrated Modeling System

*Livestock Series Report 8*

Philip W. Gassman and Larry Hauck

***Staff Report 96-SR 84***
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# ABSTRACT

This paper briefly describes the environmental component of an integrated modeling system that has been developed for simulating the movement of nutrients (nitrogen and phosphorus) from dairy waste disposal fields through the Upper North Bosque River Watershed (UNBRW) stream network in Erath and Hamilton Counties, Texas, as part of the "Livestock and the Environment: A National Pilot Project" (NPP). The environmental component consists of the Agricultural Policy/Environmental eXtender (APEX) model and the Soil Water Assessment Tool (SWAT). The APEX model is designed to simulate the edge-of-field nutrient runoff and leaching loadings from the application of solid and liquid manure on dairy waste disposal fields that are subsequently routed through the UNBRW stream system in SWAT to the watershed outlet near Hico, Texas. The basis for selecting APEX and SWAT, and the linkages between the two models, are emphasized within the context of the UNBRW modeling system configuration. A brief overview of the watershed characteristics and the in-stream water quality monitoring system installed on the UNBRW stream network is also presented. This monitoring system provides a key data set that has been used to calibrate the environmental modeling component for current conditions in the watershed.

# THE ENVIRONMENTAL COMPONENT OF THE NPP INTEGRATED MODELING SYSTEM

The "Livestock and the Environment: A National Pilot Project" (NPP) was initiated in the Upper North Bosque River Watershed (UNBRW) in Erath County, Texas, to help solve real and perceived environmental problems associated with the local dairy industry. Also, the project was designed to create a transferable methodology that can be used to solve pollution problems in other intensive livestock production regions. In the UNBRW, the major environmental problems have been identified as nonpoint source runoff of nitrogen (N) and phosphorous (P) from manure application fields, and odor from feedlots, waste storage ponds, and manure application fields.

A key task of the NPP is to evaluate the economic and environmental impacts of different policies that could be applied to the dairy production sector in the UNBRW in order to mitigate manure disposal pollution problems. From the outset, it was recognized that this task could only be accomplished within an integrated economic-environmental modeling framework. Important criteria for the integrated system included: (1) flexibility in evaluating a variety of technologies and management systems, (2) the ease of inputting data into the system for different scenarios, (3) the ability to provide "directionally correct" output, and (4) feasibility of transferring the system to other watersheds.

This report describes the environmental component of the integrated modeling system, focusing on the assumptions used in configuring the models for the UNBRW and the linkages between them. We first overview the characteristics of the UNBRW and the monitoring system that has been installed to provide in-stream water quality assessments. This monitoring system was a key source of calibration data used to gauge model performance for an environmental baseline simulation (CARD 1996; Rosenthal 1996).

## Watershed Description and Overview of the In-Stream Monitoring System

The UNBRW (Figure 1) is defined for the NPP as the contributing drainage area above the U.S. Geological Survey streamflow site (Gauge Number 08094800; North Bosque River at Hico, Texas; U.S. Highway 281 river crossing). The majority of the 230,000 acre watershed lies within Erath County, though the southern extremity is in Hamilton County. It is also located within the Central Oklahoma—

Texas Plains Ecoregion, a region characterized by irregular plains and potential natural vegetation of oaks and bluestem grasses. Climatologically the watershed is a Subtropical Subhumid area with hot summers and dry winters (Larkin and Bomar 1983). Average annual precipitation is approximately 30 inches, and average gross lake surface evaporation is nearly 70 inches. Rainfall generally follows a bimodal pattern with peaks in the spring and fall. Average wind speed is about 13 miles per hour and the prevailing direction is from the southeast.

Figure 1 shows the dairy and monitoring site locations, application fields, and stream network within the watershed. Erath County contains approximately 200 dairies with an estimated cumulative herd size of 65,000 cows, of which 95 dairies and an estimated 34,000 cows are in the UNBRW. The actual numbers for operating dairies and herd size are not static but change in response to market demands and other factors. The estimated herd size is based on a compilation of the most recently available information from Texas Natural Resource Conservation Commisstion (TNRCC) and Texas Institute for Applied Environmental Research (TIAER) surveys on milking herd size. Therefore, the estimated herd size includes only milking cows and does not include dry herd and replacement heifers.

### The Monitoring System

The monitoring program is designed to characterize the water quality at several different scales of the UNBRW, for the entire watershed, for the primary or major tributary subwatersheds, and for smaller tributary micro-watersheds (less than 6,400 acres or 10 square miles). A summary of each site is provided in Table 1. A unique, five-digit alphanumeric code identifies each site. The first two digits specify the tributary; for example, IC for Indian Creek and SF for South Fork. The last three digits give relative location, with the lowest numeric value nearer the headwater and the largest numeric value at the farthest downstream sample point. BO040 is the North Bosque River below Stephenville, and BO070 is the North Bosque River at Hico. A more detailed description of the monitoring system and in-stream monitoring results is presented in McFarland and Hauck (1995).

### Land Use

A geographic information system (GIS) database comprising individual land uses, topography, and soil layers has been developed for the UNBRW using the Geographic Resources Analysis Support System (GRASS). Characteristics of the entire watershed and the subwatersheds of each sampling site were determined through manipulation of these data within GRASS. As shown in Figure 1, the dairy locations are not evenly distributed throughout the watershed, but are concentrated in the northern region. The distribution of dairies and dairy cows in the watershed above each monitoring site is highly variable (Table 2) and include a 995-head calf raising operation. The drainage basins of sites NF005, NF020, NF030, NF035, SF075, DB040, IC020, IC030 and IC035 have the highest herd densities, and SF020, SF030, SF035, SP020, SP030, and SP035 have the lowest herd densities.

Integrated into the sample site locations is variation in the level of agricultural and urban land use practices. Some sites may be characterized as least impacted, with rangeland and woodland covering most of the drainage area, while other watersheds represent various degrees of impact due to the level of agricultural and urban land uses. The land uses of the watershed were determined from Landsat TM imagery classification. Ground truth was provided to assist in the imagery classification and to validate the final results. Rangeland, improved pasture (or coastal bermudagrass), woodland (trees and heavy brush), wheat and sudan (double cropping), orchards and groves, peanuts, urban, barren, and water were the nine land-use categories specified.

The drainage area and land-use characteristics for each monitoring site are provided in Table 3. The land-use characteristics of the UNBRW, as represented by the values for site BO070 at Hico, are 68 percent woodland plus rangeland, 29 percent improved pasture, wheat/sudan, peanuts plus orchards and less than 2 percent urban. As designed, much greater than average urban land use is found above sites MB040 and IB040. Relatively more intensive agricultural practices are found above sites NF005, NF010, NF020, NF030, NF035, NF050, SF075, and DB040. In contrast, SF020, SF030, SF035, SP020, SP030, and SP035 have less intensive agricultural practices and more rangeland and woodland than the watershed average.

Table 4 shows the percentage of land used for improved pasture or wheat/sudan that is utilized for either dairy waste application fields or nondairy (forage) production. The size and location of the animal waste application fields were obtained from the TNRCC dairy permits and available waste management plans. These sources of waste application field data are public information from the TNRCC Austin, Texas, office. For six of the unpermitted dairies, i.e., dairies with less than 250 cows in confinement, estimates of application fields were necessary. In these cases, the standard guidance found in TNRCC permit applications was used to determine application field sizes. While the size and location of application fields is not static, the information from TNRCC was largely collaborated by the GIS land-use layer. This assessment of dairy waste application field sizes and locations in the UNBRW uses the best available information and is sufficiently current to categorize this land use.

## Model Review

The design of the integrated modeling system was driven by the need to obtain in-stream water quality indicators of nutrient movement for the UNBRW stream network, depicted in Figure 1, for a variety of policy scenarios that could not be evaluated with the water quality monitoring system. Ideally, the integrated modeling system would have also incorporated the ability to simulate nutrient movement to and through groundwater, and odor movement. However, the limited resources of the NPP precluded linking groundwater and odor models into the integrated system. An application of an odor dispersion model a dairy in Erath County is described by McFarland (1995); a review of odor dispersion model limitations and applications is given in Gassman (1995). Reviews of groundwater models that could potentially be applied to aquifers underlying the UNBRW are given in Duffy et al. (1990) and van der Heijde and Prickett (1990). The remainder of this discussion focuses on models appropriate for simulating surface water runoff and/or stream routing of nutrients from dairy manure application fields.

Literally dozens of physical process models have been developed over the past three decades at various scales to simulate the effects of agricultural nonpoint source pollution. These models can be roughly categorized as: (1) field-scale models that simulate edge-of-field agricultural chemical runoff (in both the solution phase and on eroded sediment) and leaching loadings, (2) watershed-scale models that route sediment and chemicals to watershed outlets (but do not simulate routing of pollutants in streams and rivers), or (3) river basin models that route agricultural pollutants through stream systems. Some models can be applied at more than one of these scales, such as the Hydrological Simulation Program—FORTRAN (Johanson et al. 1984) that can be used at both the watershed and river basin scales. Model reviews that fall into one or more of these categories can be found in Crowder (1987), DeCoursey (1985), Devries and Hromadka (1993), Ghadiri and Rose (1992), Henderson-Sellers et al. (1990), and Rose et al. (1990).

The choice of models for the NPP was dependent on the ability to simulate relatively detailed management practices for the dairy manure application fields and the subsequent routing of the edge-of-field nutrient runoff loadings through the UNBRW to the outlet near Hico, as shown in Figure 1. It was also important that the selected models have the ability to simulate the long-term impacts of different management systems, such as the total loadings of N and P at the UNBRW outlet over 30 years. A model review process was conducted to determine the most appropriate models that would meet these criteria. Some of the models considered are listed in Table 5.

The model review process was initiated by TIAER (1990), before the start of the NPP. They reviewed seven models discussed by Crowder (1987), including the AGNPS, GLEAMS, and EPIC models listed in Table 5, to assess their ability for simulating cropping systems and management practices relevant to the application of manure on dairy waste disposal fields. Of the seven models, it was determined that EPIC was the most flexible model for the task. Key reasons for the selection of EPIC include the ability to simulate: (1) irrigation and manure applications, (2) nutrient (N and P) transformation and transport processes, (3) multi-crop rotations within a generic crop growth submodel, (4) weather generation, and (5) long-term simulation periods. None of the other models reviewed was capable of all these functions.

Further model review performed for the NPP revealed that, while EPIC was the best available model for simulating field-scale manure management, it still had shortcomings that needed to be overcome in order to satisfy the goals for the integrated modeling system. Key enhancements required are the ability to simulate the effects of filter strips on reducing nutrient loads from application fields and a comprehensive waste storage pond/irrigation submodel that would provide greater accuracy in simulating nutrient applications in the effluent from waste storage ponds. These improvements were built into the Agricultural Environmental Policy eXtender (APEX) model (Willams et al. 1995), which is essentially a multi-field version of EPIC that includes waste storage pond dynamics[1].

The remaining model review effort focused on the selection of an appropriate model that could simulate the routing of the edge-of-field nutrient runoff loadings from APEX through the UNBRW stream network. Many of the available watershed models, such as the AGNPS, ANSWERS, and SWRRB models listed in Table 5, are not capable of routing nutrient runoff through a stream system the size of the UNBRW and were eliminated from further consideration. Attention then focused on models such as HSPF and SWAT that could be classified as River Basin models (Table 5).

The main advantage of HSPF is that it is a comprehensive water quality model that can simulate in-stream transformation kinetics (degradation, etc.) of nutrients; in SWAT, only simple in-stream nutrient routing can be performed[2]. However, SWAT has major advantages over HSPF in ease of data inputs through the use of a GIS interface and the linking of APEX output from more than 300 manure application fields. Also, it was assumed that during periods of overland flow that contribute a major portion of the nutrient loadings in the UNBRW, the nutrient travel time from most points in the watershed will be hours rather than days to the outlet near Hico. Thus, it would be expected that in-stream nutrient transformations would be relatively minor (modifications were made to SWAT in order to account for the removal of N and especially P that occurs within the reservoirs in the watershed). For these reasons, coupled with direct support from the model developers, the decision was made to use SWAT.

## The Integrated Modeling System

Figure 2 is a schematic of the integrated modeling system for the NPP. The system is initiated by describing a set of policy scenarios that cover a range of economic instruments and best management practices that could potentially be applied to the dairy industry in the UNBRW. Once the policy scenarios have been defined, they are executed individually within the representative dairy farm economic model. The economic model is executed in a static, short-term (one-year) mode for three classes of dairies: (1) small (0-249 head), (2) medium (250-599 head), and (3) large (600 + head). Representative herd sizes of 225, 400, and 1200 head are assumed for each of these three size classes in the economic model. Output from the representative dairy model includes production costs, net returns, technology choice, cropping rotation, and the amount of N and P in the manure. A more detailed explanation of the representative dairy farm model can be found in CARD (1995).

The environmental component consists of APEX and SWAT. The APEX model is designed to simulated the edge-of-field nutrient runoff and leaching loadings from the application of solid and liquid manure on dairy waste disposal fields. The linkage between the economic model and the environmental component is accomplished by passing data generated for each policy scenario in the economic model directly to APEX. The APEX field-level simulations are then performed for 30 years, providing daily, annual, and long-term average edge-of-field output. The daily output is routed through the simulated UNBRW stream network for 30 years in SWAT. Estimates of in-stream nutrient levels can be obtained from SWAT at the outlet of the entire UNBRW located near Hico (Figure 1), or at other points farther upstream within the watershed.

Comparisons of economic and environmental results are performed once a scenario has been executed within the complete integrated system (Figure 2). These results may lead to a modification of the initial scenario, reflecting a desire to see an improvement in the economic and environmental indicators. This link is not automatic; each policy scenario must be configured manually as input into the economic model before the integrated system can be executed and analyzed for the given policy scenario. An array of economic and environmental indicators can be compared across several policy scenarios, after each scenario has been executed individually within the integrated system.

The monitoring system installed for the UNBRW provides in-stream water quality background information that was used in the calibration and testing of APEX and SWAT for an environmental baseline. Results of the environmental baseline are described for APEX in CARD (1996) and for SWAT in Rosenthal (1996). The calibrated models were then used to assess the environmental impacts of different policies that are discussed in Pratt et al. (1996).

## Environmental Component Linkages

The environmental component is executed in three stages for each policy scenario. First, the individual APEX input files are constructed and run within run_apex. Second, individual daily output files (termed swatout.out files) generated from each APEX simulation within a given micro-watershed are aggregated into one file and input into SWAT at the micro-watershed outlet. Last, SWAT is run for the entire UNBRW by splitting the simulated watershed into four separate quadrants. Last, the complete UNBRW is simulated by dividing the watershed into four quadrants and performing successive SWAT runs for each quadrant until the final nutrient loadings are output at the outlet at Hico (Figure 1). The remainder of this section describes these steps in greater detail.

### Construction and Execution of APEX Input Files

The 30-year APEX simulations were performed using run_apex, a program that automatically reads the required data, creates the input files, and executes APEX (Figure 3). Total N and P produced per cow, cropping system, and nutrient fractions that define the amount of N and P in the dairy manure are passed from the economic model to APEX as a function of policy, dairy size, and manure type (solid or irrigated). These data are mapped to the specific dairies in the UNBRW. Each dairy is classified as small, medium, or large according to milking herd size. Determination of the specific permitted fields to be executed in APEX is made with a field selection process described in CARD (1996). Input files for the selected fields are constructed by linking in the appropriate soil, weather generator, management, and other miscellaneous data. Each input file, along with other standard APEX input files and the daily weather data, are then read into APEX and executed for 30 years. Detailed explanations of the majority of underlying assumptions used in building the soil, weather, and management data are given in CARD (1996).

Two types of output files are generated for each APEX simulation: (1) the standard output file and (2) swatout.out files that contain flow, sediment, and nutrient loading output required to link APEX to SWAT. Table 6 lists the selected annual values and 30-year averages that are scanned from the standard output files within run_apex to allow the evaluation of the tradeoff between the edge-of-field environmental indicators and the economic performance of the representative dairy farms. Output for the eight variables listed in Table 7 are passed from APEX to SWAT on a daily basis, allowing SWAT to estimate the in-stream water quality impacts of N and P loadings to the stream system for different temporal periods and spatial locations.

### Swat Configuration and Input of APEX Output

The input layers to the SWAT model were constructed using an interface program that is executed within the GRASS GIS. These data include soil layer and map, land use, topographic, stream system, subsurface geologic, reservoir and pond, and weather data. Execution of SWAT for the UNBRW stream system required splitting the simulated watershed into four quadrants, as shown in Figure 4. Each quadrant was run as a separate SWAT simulation for a given policy scenario. The SWAT runs are performed in a sequence that captures the flow of water, sediment, and nutrients from the north to the east quadrant, and from the west and east to the south quadrant.

The characteristics of each quadrant are listed in Table 8 as total area, number of micro-watersheds, dairies, and waste application fields. The configuration of the UNBRW in SWAT was further subdivided into 156 micro-watersheds to facilitate the linkage between APEX and SWAT. The micro-watersheds for the four quadrants are shown superimposed on the stream system in Figures 5 through 8. The APEX output was input to these SWAT micro-watersheds in a two-step procedure. First, all of the individual swatout.out files created for waste application fields located within a given micro-watershed were aggregated into one basin.dat file, using a post-processing routine following the completion of run_apex for an entire quadrant. Imbedded in this step was the conversion of the APEX output units into units that were more suitable for input to SWAT (Table 7). Second, the aggregated basin.dat files were input into SWAT at the outlet of the respective micro-watersheds where the original application fields were located.

This aggregation procedure ignores the direct runoff loadings from each individual application field and the initial routing that would occur through the stream segments within the micro-watershed where the fields are located. Therefore, some error would be expected to be introduced by this methodology. However, the micro-watersheds were constructed on a small enough scale so that much of the potential error would be minimized. Also, once the loadings were entered at a micro-watershed outlet, the nutrients were routed through the remaining stream segments in other micro-watersheds that lie below the respective outlet. Results reported by Rosenthal (1996) show that the SWAT output matched measured loads well for most indicators of interest at the UNBRW outlet near Hico, confirming the validity of the aggregation technique.

Table 9 lists the micro-watersheds for each UNBRW quadrant that contain dairy waste application fields. Whether or not aggregated APEX output was input into each of the micro-watersheds listed in Table 9 was dependent on the field selection process for a specific policy scenario. For example, no fields were selected for micro-watersheds 14 and 30, 7, and 15 in the north, west, and east quadrants, respectively, for the environmental and policy baseline runs. Thus, no aggregated APEX output was entered into SWAT for these four micro-watersheds. The APEX-SWAT linkage could also be expanded to handle new fields that might be created (either virtual or actual) in micro-watersheds not listed in Table 9. This flexibility may be useful for future scenarios that incorporate additional dairies and waste application fields in areas of the UNBRW that currently have no or limited dairy concentrations.

The sediment and nutrient variables listed in Table 8 as inputs from APEX into SWAT are also the in-stream indicators that are available as outputs from SWAT. As previously mentioned, these indicators can be obtained as long-term averages or as time series plots for the UNBRW outlet at Hico or at selected outlets of upstream micro-watersheds. The time series plots and averages can be made for the entire 30-year duration of the simulation runs or for just a portion of the simulated time period.

## Summary

An integrated modeling system has been constructed for the UNBRW located in Erath and Hamilton Counties, Texas, as part of the NPP. The integrated system is designed to simulate both the economic and environmental impacts of proposed policies for the local dairy industry. The environmental component of the integrated system consists of the APEX field-scale and SWAT watershed models. Applications of dairy manure to waste disposal fields are simulated in APEX as a function of cropping system, application rate, and manure type within an automatic input file builder and execution program called run_apex. Runoff loadings of N and P in both solution phase and on eroded sediment are passed from APEX to SWAT on a micro-watershed basis. The nutrient loads are routed through the simulated stream network to the UNBRW outlet at Hico, Texas. Environmental outputs are provided at both edge-of-field from APEX and at the UNBRW and individual micro-watershed outlets in SWAT. These environmental indicators are compared with economic output from the representative dairy farm model for different policy scenarios.

Table 1. Monitoring sites historical summary

| Sample Site Number | Watershed | Site Type[a] | Automatic Sampler Installation Date | iological Site | Monthly Grab Sample | Date of First Water Sample |
|---|---|---|---|---|---|---|
| AL030 | Alarm Creek | R | | X | X | 04/03/91 |
| AL040 | Alarm Creek | TB | 4/1/91 | X | X | 04/18/91 |
| BO040 | Bosque River | MS | 8/13/93 | X | X | 04/04/91 |
| BO060 | Bosque River | MS | | X | X | 04/04/91 |
| BO070 | Bosque River | MS | 4/1/91 | X | X | 04/04/91 |
| CC030[b] | Colony Creek | TBr | | X | | 01/04/94 |
| DB040 | Dry Branch | TB | 7/28/93 | | | 07/28/93 |
| GC020 | Green Creek | R | | X | X | 04/03/91 |
| GC100 | Green Creek | TB | 8/1/92 | X | X | 09/01/92 |
| IB040 | Industrial Branch | TB | 7/20/93 | | | 09/13/93 |
| IC020 | Indian Creek | TB | 9/24/93 | | | 10/18/93 |
| IC030 | Indian Creek | R | | X | X | 08/04/93 |
| IC035 | Indian Creek | S | 9/22/93 | | | no sample[c] |
| MB040 | Methodist Branch | TB | 7/28/93 | | | 08/02/93 |
| NF005 | North Fork North Bosque | TB | 6/11/92 | | | 06/25/92 |
| NF010 | North Fork North Bosque | TB | 4/1/92 | | | 04/18/91 |
| NF020 | North Fork North Bosque | TB | 4/1/92 | | | 05/19/92 |
| NF030 | North Fork North Bosque | R | | X | X | 04/22/91 |
| NF035 | North Fork North Bosque | S | 8/20/92 | | | 11/19/92 |
| NF050 | North Fork North Bosque | TB | 4/1/91 | X | X | 04/04/91 |
| SB030[b] | South Bear Creek | TBr | | X | | 01/07/93 |
| SC030 | Simms Creek | R | | X | X | 08/04/93 |
| SF020 | South Fork North Bosque | TB | 4/1/92 | | | 05/16/92 |
| SF030 | South Fork North Bosque | R | | X | X | 04/30/91 |
| SF035 | South Fork North Bosque | S | 8/1/92 | | | 02/15/93 |
| SF060 | South Fork North Bosque | R | | X | X | 04/30/91 |
| SF075 | South Fork North Bosque | TB | 8/6/92 | X | X | 11/19/92 |
| SP020 | Spring Creek | TB | 9/23/93 | | | 10/20/93 |
| SP030 | Spring Creek | R | | X | X | 08/04/93 |
| SP035 | Spring Creek | S | 9/9/93 | | | no sample[c] |

[a] Site type codes: TB-Tributary of Bosque River; TBr - Tributary of Brazos River; MS - Mainstem of Bosque River;R - Mainbody of PL-566 Reservoir; S - Spillway of PL-566 Reservoir

[b] Denotes biological reference sites, which are not located in the Upper North Bosque River Watershed,

[c] No releases occurred from reservoirs during study period

SOURCE: McFarland and Hauck 1995.

Table 2. Dairy operations and herd size characteristics by sampling site drainage basin

| Sampling Site | Number of Dairies | Herd Size by Permit or Waste Management Plan | Estimated Milking Herd Size | Herd Density[a] (Cows/Acres) |
|---|---|---|---|---|
| NF005 | 2 | 1450 | 756 | 0.68 |
| NF010 | 0 | 0 | 0 | 0.00 |
| NF020 | 3 | 2050 | 1256 | 0.64 |
| NF030/NF035 | 3 | 2050 | 1256 | 0.33 |
| NF050 | 11 | 4090 | 2698 | 0.13 |
| SF020 | 0 | 0 | 0 | 0.00 |
| SF030/SF035 | 0 | 0 | 0 | 0.00 |
| SF060 | 6 | 2540 | 1440 | 0.17 |
| SF075 | 21 | 11474 | 8620 | 0.38 |
| DB040 | 8 | 2159 | 1612 | 0.25 |
| MB040 | 0 | 0 | 0 | 0.00 |
| IB040 | 0 | 0 | 0 | 0.00 |
| BO040 | 41 | 17873 | 12995 | 0.25 |
| IC020 | 7 | 2750 | 1442 | 0.32 |
| IC030/IC035 | 7 | 2750 | 1442 | 0.30 |
| AL030 | 8 | 4248 (+ 995 calves) | 2868 (+ 995 calves) | 0.25 |
| AL040 | 8 | 4248 (+ 995 calves) | 2868 (+ 995 calves) | 0.25 |
| SC030 | 4 | 847 | 787 | 0.14 |
| BO060 | 62 | 26948 (+ 995 calves) | 19172 (+ 995 calves) | 0.19 |
| GC020 | 0 | 0 | 0 | 0.00 |
| GC100 | 24 | 13701 | 11116 | 0.17 |
| SP020 | 0 | 0 | 0 | 0.00 |
| SP030/SP035 | 0 | 0 | 0 | 0.00 |
| BO070 | 94 | 45497 (+ 995 calves) | 33748 (+ 995 calves) | 0.16 |

[a] Herd densities based on estimated milking herd size (milking herd + (0.5 x calves)) and actual drainage area.

SOURCE: McFarland and Hauck 1995.

Table 3. Land use identification for drainage basins above sampling sites.

| Sampling Site | Woodland (%) | Range (%) | Improved Pasture (%) | Wheat-Sudan (%) | Peanuts (%) | Orchards (%) | Water (%) | Urban (%) | Barren) (%) | Total Acres |
|---|---|---|---|---|---|---|---|---|---|---|
| NF005 | 11.0 | 34.3 | 52.5 | 1.7 | | | 0.2 | | 0.3 | 1106 |
| NF010 | 17.7 | 40.6 | 30.7 | 10.8 | | | | | 0.3 | 1278 |
| NF020 | 13.6 | 28.6 | 49.3 | 8.0 | | | 0.3 | | 0.2 | 1953 |
| NF030/NF035 | 15.4 | 32.8 | 40.7 | 9.5 | | | 1.3 | | 0.2 | 3858 |
| NF050 | 20.2 | 29.7 | 40.2 | 8.2 | 0.5 | 0.2 | 0.7 | | 0.4 | 20606 |
| SF020 | 35.6 | 60.5 | 2.6 | 1.0 | | | 0.2 | | 0.1 | 2095 |
| SF030/SF035 | 37.4 | 56.6 | 4.2 | 0.9 | | | 0.9 | | 0.1 | 2293 |
| SF060 | 31.7 | 40.8 | 23.9 | 2.8 | | | 0.7 | | 0.1 | 8581 |
| SF075 | 28.3 | 28.9 | 34.1 | 6.1 | 1.5 | 0.1 | 0.8 | | 0.3 | 30302 |
| DB040 | 22.0 | 24.5 | 33.2 | 8.3 | 7.1 | 1.2 | 0.9 | 0.1 | 2.6 | 6355 |
| MB040 | | | | | | | | 100.0 | | 421 |
| IB040 | 18.1 | 18.0 | 20.6 | 8.8 | 0.6 | 1.9 | 0.4 | 30.8 | 0.8 | 3209 |
| BO040 | 23.7 | 27.7 | 34.9 | 6.7 | 1.6 | 0.3 | 0.7 | 3.7 | 0.7 | 63868 |
| IC020 | 16.1 | 50.2 | 25.4 | 7.4 | 0.4 | | 0.0 | | 0.5 | 4494 |
| IC030/IC035 | 15.8 | 51.7 | 24.1 | 7.1 | 0.4 | | 0.6 | | 0.4 | 4771 |
| AL030 | 19.3 | 45.1 | 26.9 | 4.2 | 2.5 | 1.1 | 0.3 | | 0.8 | 13392 |
| AL040 | 19.3 | 45.0 | 27.0 | 4.2 | 2.4 | 1.0 | 0.3 | | 0.7 | 13423 |
| SC030 | 21.8 | 58.5 | 16.4 | 2.2 | | 0.1 | 0.8 | | 0.2 | 5594 |
| BO060 | 21.0 | 39.8 | 27.9 | 5.6 | 1.3 | 0.5 | 0.6 | 2.8 | 0.6 | 120936 |
| GC020 | 31.6 | 43.1 | 11.1 | 12.9 | | | 1.3 | | | 2180 |
| GC100 | 22.4 | 49.2 | 20.1 | 4.8 | 2.2 | 0.3 | 0.5 | 0.4 | 0.2 | 64308 |
| SP020 | 30.6 | 53.6 | 10.9 | 4.5 | | 0.3 | 0.1 | | 0.1 | 3924 |
| SP030/SP035 | 29.2 | 55.9 | 9.8 | 4.0 | | 0.2 | 0.8 | | 0.1 | 4377 |
| BO070 | 23.3 | 45.2 | 22.4 | 4.8 | 1.4 | 0.4 | 0.5 | 1.7 | 0.4 | 230243 |

SOURCE: McFarland and Hauck 1995.

Table 4. Intensive agricultural practices land separated into dairy and non-dairy categories by percentages of drainage basin

| Sampling Site | Dairy Waste Application Fields (%) | Nondairy Forage Fields (%) |
|---|---|---|
| NF005 | 41.7 | 12.4 |
| NF010 | 3.4 | 38.0 |
| NF020 | 45.4[a] | 11.9 |
| NF030/NF035 | 24.2 | 26.1 |
| NF050 | 10.1 | 38.4 |
| SF020 | 0.7 | 2.9 |
| SF030/SF035 | 1.0 | 4.1 |
| SF060 | 8.2 | 18.5 |
| SF075 | 14.6 | 25.6 |
| DB040 | 13.5 | 28.0 |
| MB040 | 0.0 | 0.0 |
| IB040 | 0.1 | 29.3 |
| BO040 | 11.8 | 29.8 |
| IC020 | 17.3 | 15.5 |
| IC030/IC035 | 16.4 | 14.8 |
| AL030 | 10.2 | 20.9 |
| AL040 | 10.1 | 21.1 |
| SC030 | 5.2 | 13.4 |
| BO060 | 9.2 | 24.3 |
| GC020 | 2.5 | 21.5 |
| GC100 | 6.9 | 17.9 |
| SP020 | 0.0 | 15.4 |
| SP030/SP035 | 0.0 | 13.8 |
| BO070 | 7.2 | 19.9 |

[a] A 20-acre field permitted for land application of septage is located immediately above site NF020, but is not included in the percentage for dairy waste application fields. This field was not simulated for either the environmental baseline or the policy scenarios (the area of the septage field is less than 0.01 percent of the total area of the application fields simulated for the environmental baseline).

SOURCE: McFarland and Hauck 1995.

Table 5. Selected water quality models available for application to the North Bosque watershed for the NPP

| Model | Scale | Source |
|---|---|---|
| Agricultural Nonpoint Source Pollution Model (AGNPS) | Watershed | Young et al. 1989 |
| Agricultural Policy/Environmental eXtender (APEX) | Farm (multi-field) | Williams 1995 |
| Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) | Watershed | Beasley et al. 1980 |
| Erosion Productivity Impact Calculator (EPIC) | Field | Williams 1990 |
| Groundwater Loading effects of Agricultural Management Systems (GLEAMS) | Field | Leonard et al. 1987 |
| Hydrologic Simulation Program - FORTRAN (HSPF) | Watershed/River Basin | Johanson et al. 1984 |
| Leaching Estimation and Chemistry Model (LEACHM) | Field | Wagenet and Huston 1989 |
| Simulator for Water Resources in Rural Basins (SWRRB) | Watershed | Arnold et al. 1990 |
| Soil and Water Assessment Tool (SWAT) | Watershed/River Basin | Srinivasan and Arnold 1993 |

Note: The models listed are some of the most widely used models available; however, this is not intended to be an exhaustive list of extensively used models.

Table 6. Variables scanned from APEX output for edge-of-field analyses

| Variable | Units | Output Type[a] | Description |
|---|---|---|---|
| YLD | t/ha | average/annual | Crop yield |
| PRCP | mm | average/annual | Precipitation |
| Q | mm | average/annual | Surface runoff |
| PRK | mm | average/annual | Percolation below soil profile |
| SSF | mm | average/annual | Lateral subsurface flow |
| ET | mm | average | Evapotranspiration |
| IRGA | mm | annual | Irrigation |
| MUSS | t/ha | average/annual | Eroded sediment from water erosion (using small watershed musle option) |
| FNO3 | kg/ha | average | $NO_3$ applied |
| FNH3 | kg/ha | average | $NH_3$ applied |
| FNO | kg/ha | average | Organic N applied |
| FPO | kg/ha | average | Organic P applied |
| FPL | kg/ha | average | Labile P applied |
| YON | kg/ha | average/annual | Organic N loss in sediment |
| YNO3 | kg/ha | average/annual | $NO_3$ loss in surface runoff |
| SSFN | kg/ha | average/annual | $NO_3$ loss in subsurface flow |
| PRKN | kg/ha | average/annual | $NO_3$ loss in percolation below soil profile |
| MNN | kg/ha | average/annual | Mineralization of N |
| DN | kg/ha | average/annual | Denitrification of N |
| TNO3 | kg/ha | annual | Total $NO_3$ in soil profile |
| NITR | kg/ha | average/annual | Nitrification |
| AVOL | kg/ha | average/annual | Volatilization |
| YLN | kg/ha | average/annual | N in crop yield |
| YP | kg/ha | average/annual | Organic P loss in sediment |
| YAP | kg/ha | average/annual | Labile P loss in surface runoff |
| MNP | kg/ha | average/annual | Mineralization of P |
| PLAB | kg/ha | annual | Labile P in soil profile |
| YLP | kg/ha | average/annual | P in crop yield |
| YPO | kg/ha | average/annual | Routing of organic P on sediment |
| QNO | kg/ha | average/annual | Routing of $NO_3$ in surface flow |
| QPO | kg/ha | average/annual | Routing of labile P in surface runoff |

[a] APEX indicators output every year are denoted as "annual" while those listed in the 30-year summaries at the end of the APEX output files are denoted as "average"; the determination of whether a variable is annual, average, or both is a function of user choice, APEX output flexibility, and characteristics of the specific indicator.

Table 7. Aggregated APEX output that is input to SWAT at the micro-watershed level

| Variable | APEX Output Units | SWAT Input Units | Definition |
|---|---|---|---|
| Q | mm | $m^3$ | Surface runoff |
| SSF | mm | $m^3$ | Lateral subsurface flow |
| MUSL | t/ha | t | Soil loss from water erosion (MUSLE) |
| YON | kg/ha | kg | Organic N loss with sediment |
| $YNO_3$ | kg/ha | kg | $NO_3$ loss in surface runoff |
| SSFN | kg/ha | kg | Mineral N loss in subsurface flow |
| YP | kg/ha | kg | P loss with sediment |
| YAP | kg/ha | kg | Soluble P loss in runoff |

Table 8. Characteristics of the four UNBRW quadrants configured in SWAT

| Quadrant | Total aarea ton$^2$ | Total Micro-watershed | Total dairies | Total application fields |
|---|---|---|---|---|
| North | 240 | 34 | 41 | |
| West | 260 | 43 | 21 | 69 |
| East | 260 | 52 | 27 | 94 |
| South | 150 | 27 | 6 | 17 |
| Total | 910 | 156 | 95 | 320 |

Table 9. Micro-watersheds in each quandrant that contain dairy waste application fields

| Quadrant | Micro-watersheds |
|---|---|
| North | 2, 3, 5, 6, 8, 9, 11, 12, 13, 14, 15, 16, 21, 22, 23, 24, 25, 27, 28, 29, 30, 31, 32, 33, 34 |
| West | 4, 6, 7, 9, 10, 11, 16, 18, 19, 20, 23, 24, 25, 26, 27, 29, 31, 33, 35, 36, 37 |
| East | 2, 4, 15, 16, 17, 18, 19, 21, 22, 23, 26, 27, 42, 43, 44, 45, 47, 51 |
| South | 14, 20, 26, 27 |

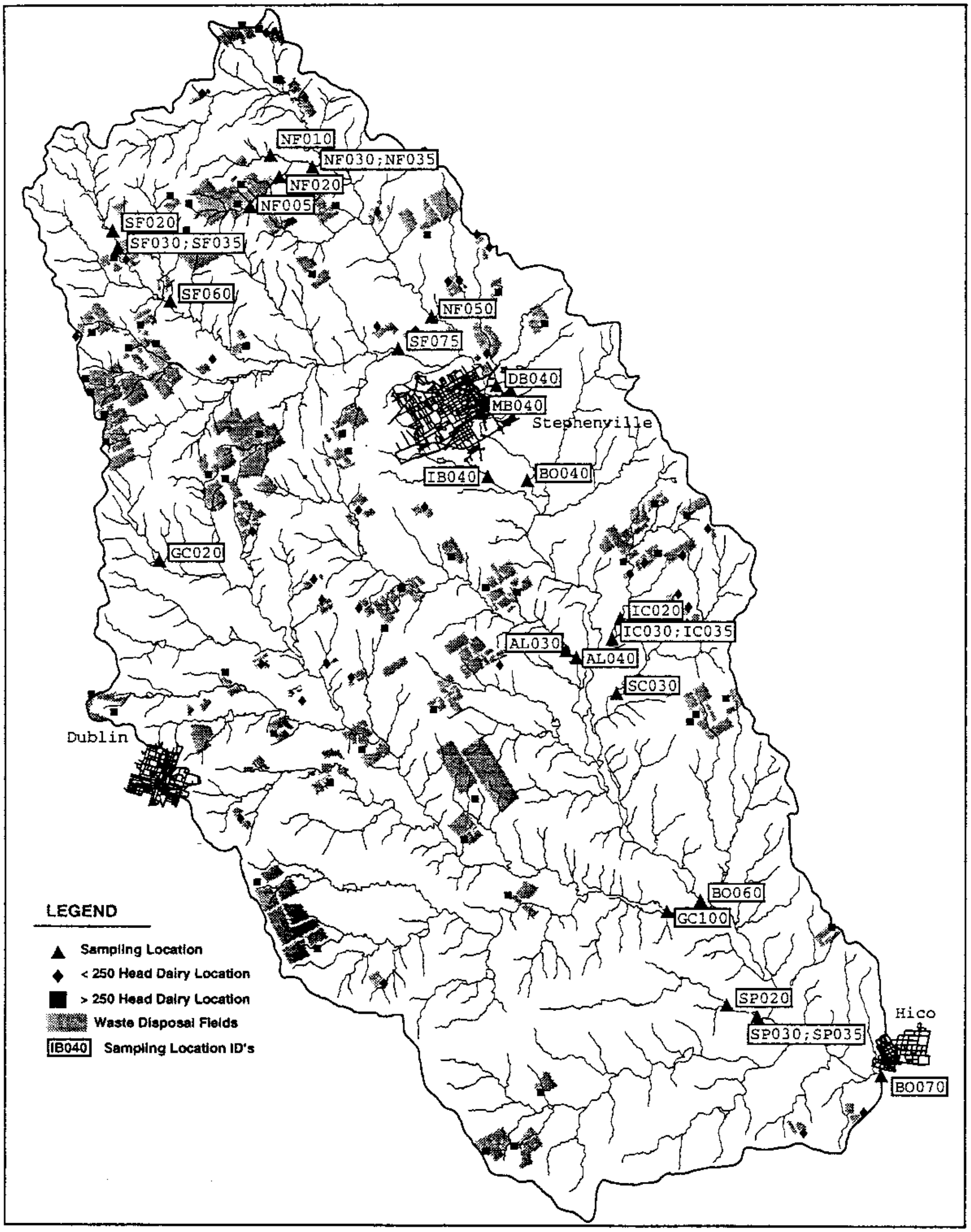

Figure 1. Location of dairies, waste disposal fields, and sampling devices overlaid on the stream network within the Upper North Bosque River Watershed in Erath and Hamilton Counties, Texas

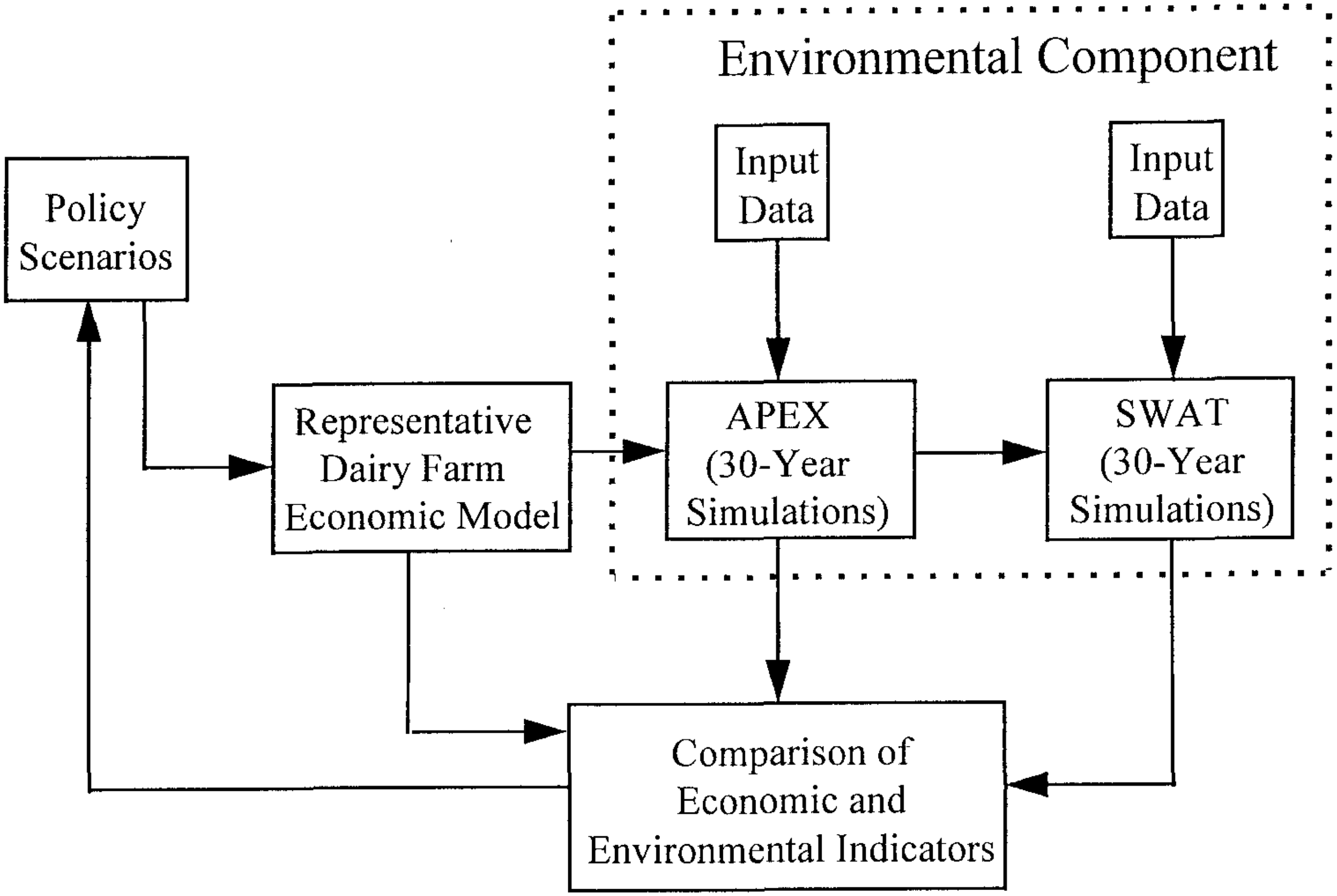

Figure 2. Schematic of the integrated modeling system for the NPP

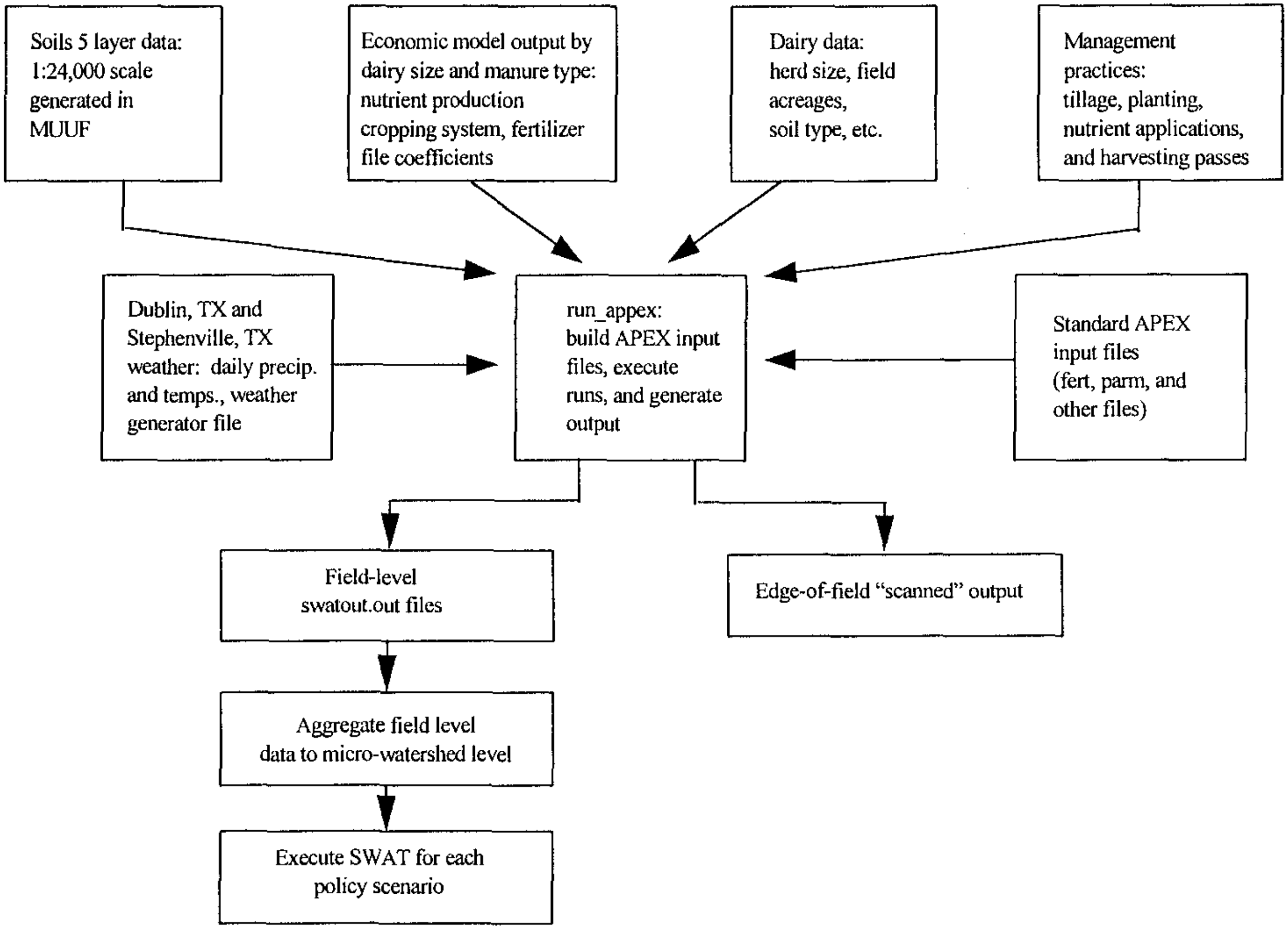

Figure 3. Schematic of the automatic APEX input file building and execution program (run APEX), and required steps to link APEX with SWAT

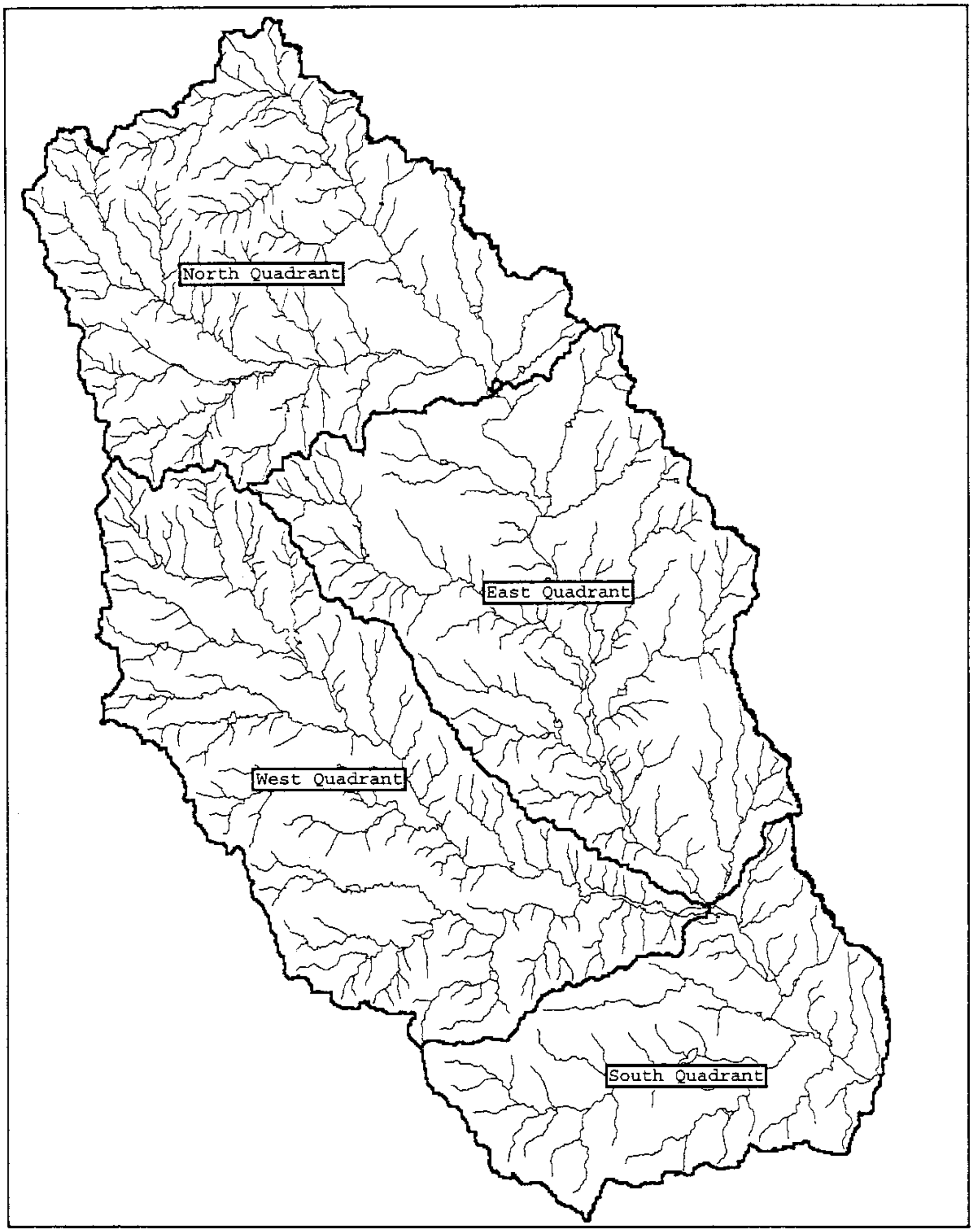

Figure 4. The four quadrants for the SWAT analysis overlaid on the Upper North Bosque River Watershed stream network

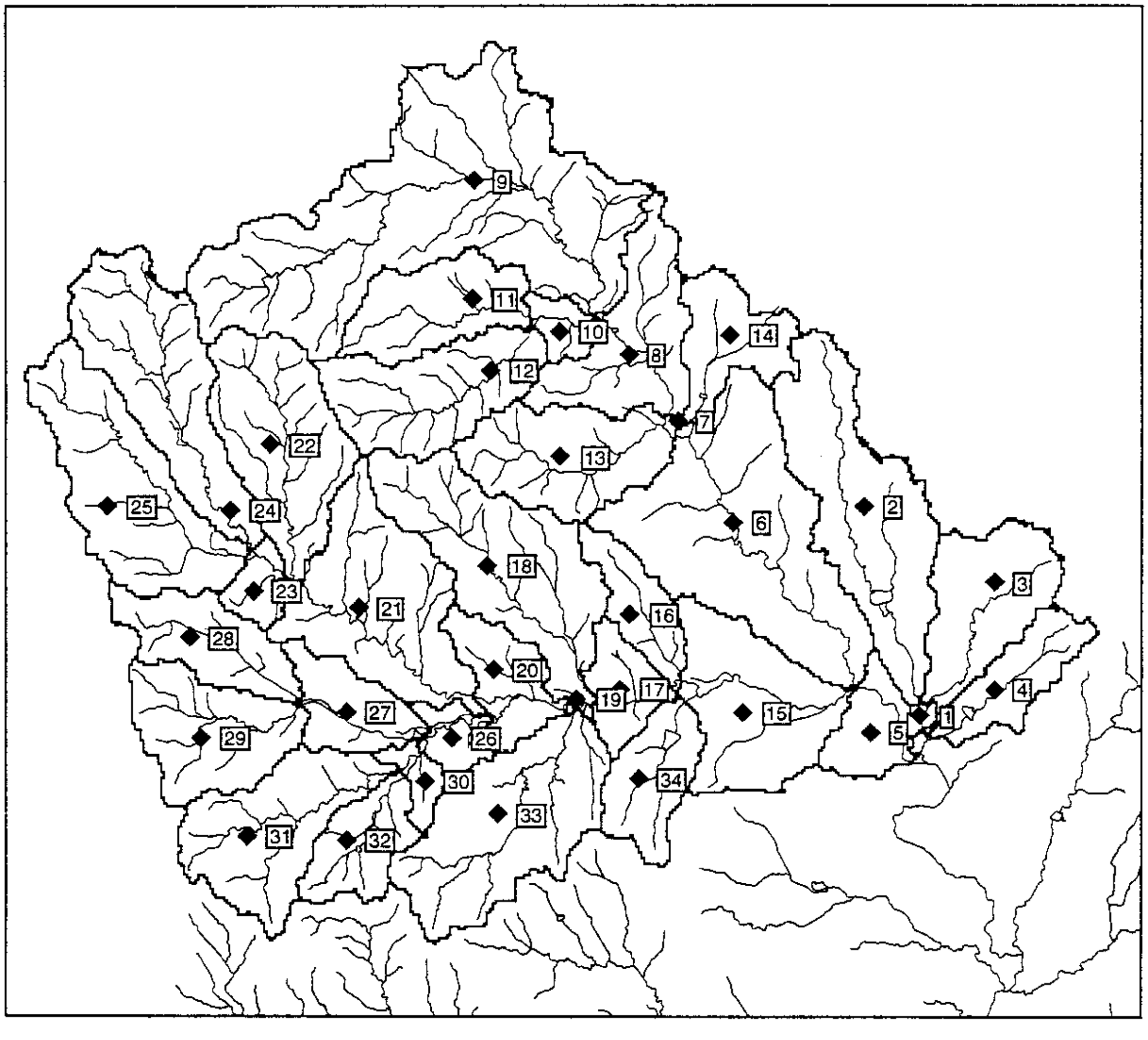

Figure 5. The micro-watersheds for the north quadrant overlaid on the Upper North Bosque River Watershed stream network

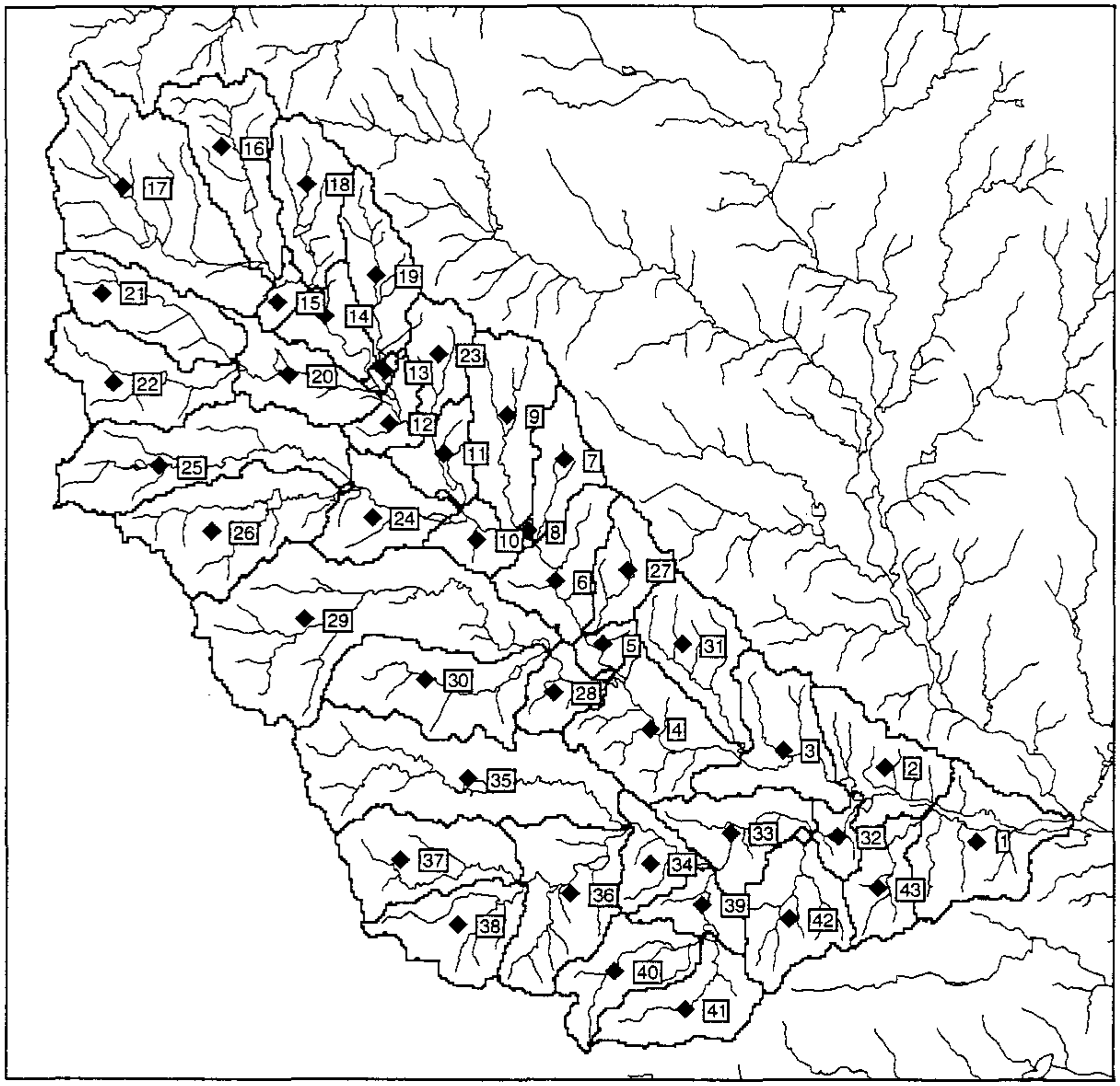

Figure 6. The mircro-watersheds for the west quadrant overlaid on the Upper North Bosque River Watershed stream network

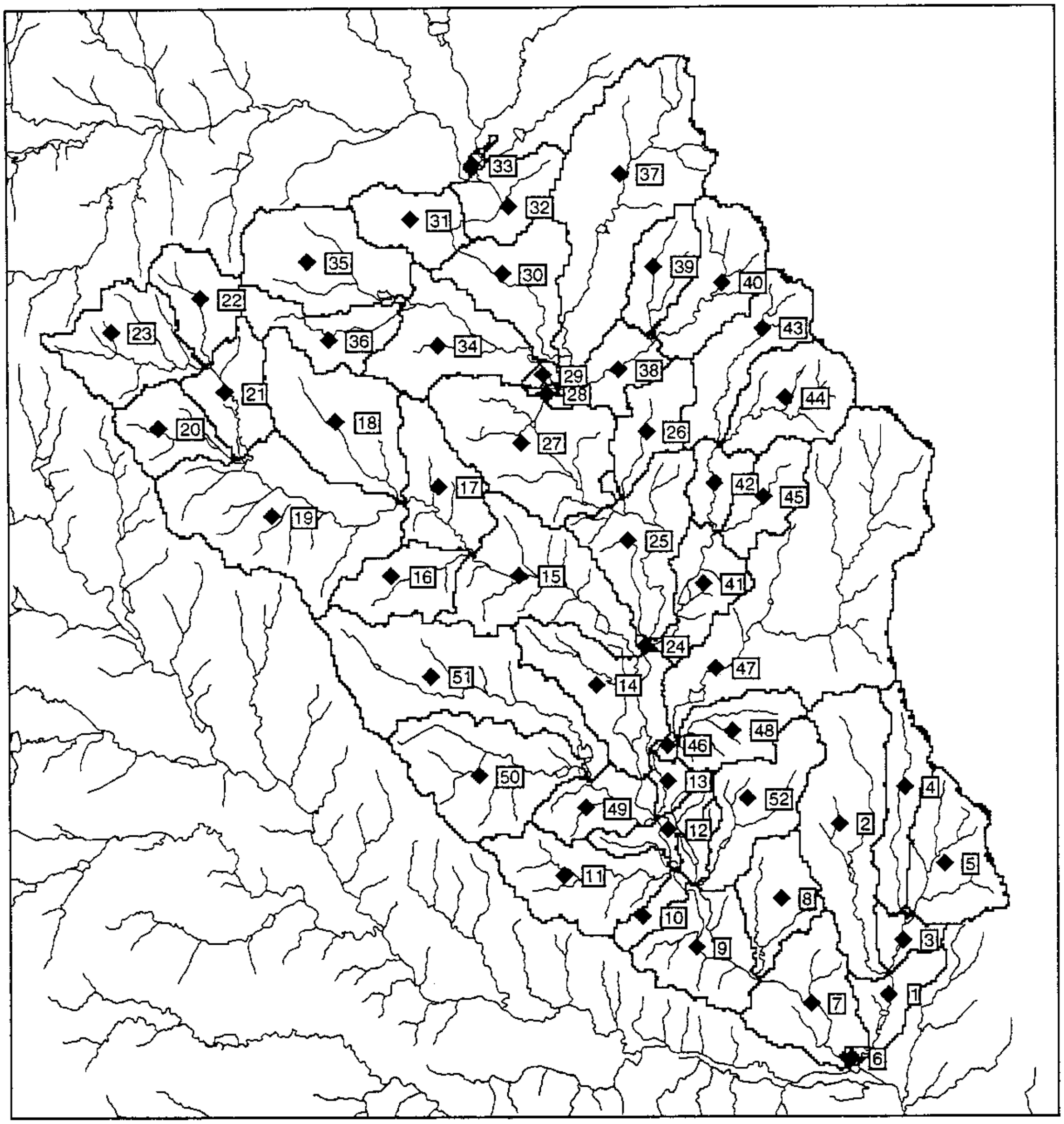

Figure 7. The micro-watersheds for the east quadrant overlaid on the Upper North Bosque River Watershed stream network

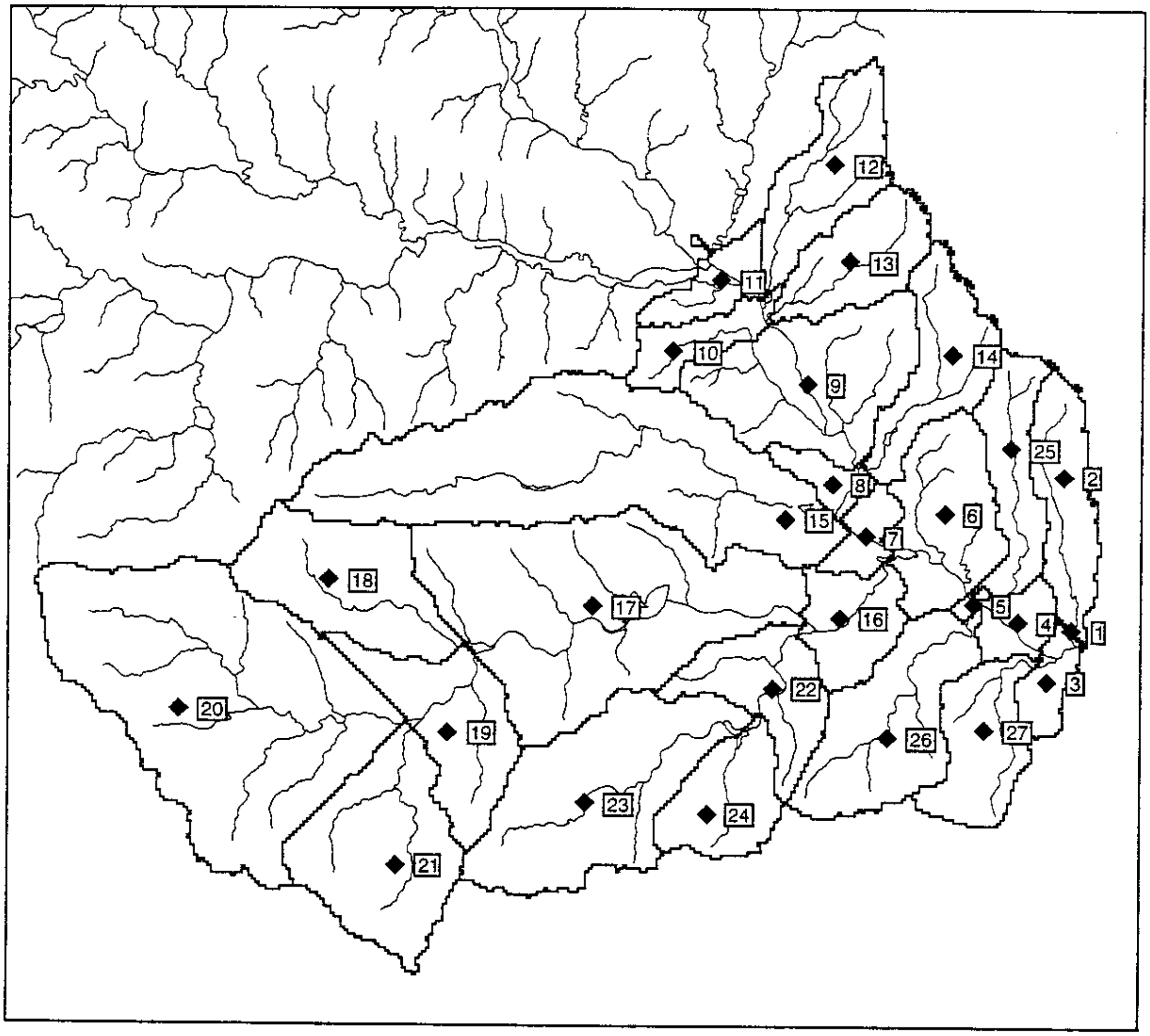

Figure 8. The micro-watersheds for the south quadrant overlaid on the Upper North Bosque River Watershed stream network

## ENDNOTES

[1] Current versions of the EPIC model, such as EPIC5125 and EPIC5300, also have the capability of simulating waste storage pond dynamics.

[2] The SWAT model is being upgraded by inserting in-stream transformation routines into it from USEPA QUALII model. This version of SWAT should be operational sometime in 1996.

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