MOVEMENT AND FATE OF AGRICULTURAL CHEMICALS IN THE SURFACE AND SUBSURFACE ENVIRONMENTS NEAR PLAINS, SOUTHWESTERN GEORGIA--INTEGRATED WORK PLAN

By David W. Hicks, James B. McConnell, Loris E. Asmussen, Ralph A. Leonard, and Charles N. Smith

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CONVERSION FACTORS

For use of readers who prefer to use metric (International System) units, conversion factors for terms used in this report are listed below:

Multiply inch-pound units	By	To obtain metric units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare
	Volume	
gallon (gal)	3.785	liter (L)
	Mass	
pound (lb)	4.536	kilograms (kg)
ounce (oz)	28.35	gram (g)
	28.35×10^3	milligram (mg)
	28.35×10^6	microgram (µg)
	Temperatures	
degree Fahrenheit (F)	C = 5/9 x (F-32)	degree Celsius (C)

Sea level

In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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David W. Hicks[1/], James B. McConnell[1/], Loris E. Asmussen[2/], Ralph A. Leonard[2/], and Charles N. Smith[3/]

ABSTRACT

The vulnerability of aquifers to contamination by agrichemicals is relatively high in many regions of the United States, particularly in the "corn belt" region of the midwest and the Coastal Plain of the southeast. Heavy use of chemicals on farmlands in these regions increases the potential for nonpoint-source contamination of the water resources.

Existing mathematical models may be used to simulate the transport and fate of agrichemicals in the soil-root, unsaturated, or saturated zones. Because these models are not integrated and are limited, they may not be effective in evaluating the potential for contamination of ground-water resources from agrichemicals. Therefore, a model is needed that will simulate the transport and fate of these chemicals throughout the entire continuum from land surface into the ground-water-flow system. Such a model could be mathematically linked whereby the model results, or output, from one zone may be incorporated as a boundary condition, or input, for the simulation of the next zone. An understanding of the complex processes controlling these factors is needed to develop a linked mathematical model that accurately describes the transport and fate of agrichemicals.

The U.S. Geological Survey and the U.S. Department of Agriculture, Agricultural Research Service initiated a cooperative, multidisciplinary research investigation in 1986 to develop an effective model(s), as well as design and instrument a field research site to provide data necessary for the validation of the model(s). In 1987, the U.S. Environmental Protection Agency joined the research investigation. The major objectives of this investigation are to (1) describe the processes that affect the transport and fate of agrichemicals in the soil-root, unsaturated, and saturated zones; (2) develop and validate a linked model(s) that mathematically describes the process-oriented findings; and (3) use the model(s) as a tool to evaluate the affect of agricultural management practices on the chemical quality of ground water in the southeast as well as in other regions of the United States.

A research site near Plains, Georgia, includes two, 16.7-acre fields and approximately 40 acres of adjacent woodlands. The instrumentation design on the test plot(s) at the site will address the transport and fate of atrazine, alachlor, carbofuran, and nitrogen fertilizer, as well as a conservative tracer, potassium bromide. The development and validation of model(s) and data bases at the Plains, Georgia, site will parallel, and be supportive of, ongoing research efforts in other areas.

[1/]U.S. Geological Survey
[2/]U.S. Department of Agriculture
[3/]U.S. Environmental Protection Agency

INTRODUCTION

The vulnerability of aquifers to contamination by surface-applied chemicals such as agrichemicals is relatively high in many regions of the United States, particularly in the "corn belt" regions of the midwest and the Coastal Plain of the Southeast. Heavy use of these chemicals on farmlands increases the potential for nonpoint-source contamination of water resources.

Mathematical models that can be used to simulate transport and fate of surface-applied chemicals (agrichemicals) in various phases of the soil-root, unsaturated, or saturated zones, currently exist. However, these models are not effective in evaluating the potential for contamination of ground-water resources from agrichemicals. Therefore, a model(s) is needed that will simulate the transport and fate of these chemicals through entire continuum from land surface through the ground-water-flow system. This model(s) would describe the transport and fate of agrichemicals through the soil-root, unsaturated, and saturated zones, and mathematically link the output of one zone as a boundary condition, or input, for the simulation of the next zone. To develop a linked mathematical model(s) that accurately describes the transport and fate of agrichemicals, an understanding of the complex processes controlling these factors is needed.

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Agriculture, Agricultural Research Service (ARS), initiated a cooperative, interdisciplinary research investigation in 1986 to develop this model(s), as well as a field-research site to provide data necessary for the validation of the model(s). In 1987, scientists from the University of Georgia became aware of ongoing research and showed interest in developing faculty/student participation in peripheral research activities. Later in 1987, copies of a comprehensive work plan, drafted by the USGS and ARS, were provided to the U.S. Environmental Agency (USEPA), for their review. Subsequent to their review, scientists from the USEPA, Athens Environmental Research Laboratory (AERL), Athens, Ga., became interested in participating in the cooperative research project. As a result of increased participation and a subsequent broadening of objectives, the original work plan has been significantly altered, and incorporated into this report. Research at the Plains site is projected to continue through 1993, and may be extended.

OBJECTIVES

The major objectives of this project are to (1) describe the processes that affect the movement and fate of nitrogen fertilizers and selected pesticides in the soil-root, the unsaturated, and the saturated zones; (2) develop linked mathematical models that describe the process-oriented findings; and (3) use these mathematical models to evaluate the affect of agricultural management practices on the chemical quality of ground water. It is anticipated that during the course of this project, secondary objectives may be developed as a result of ongoing research.

The cooperating research agencies (USGS, ARS, and USEPA) are in general agreement with the major objectives of the project. However, each of the cooperating agencies has developed secondary research objectives. For example, the secondary objectives of the USEPA are to develop a data base for use in calibration and testing of the components VADOFT and SAFTMOD of the Risk of Unsaturated-Saturated Transport and Transformation Interactions for Chemical Concentrations (RUSTIC) model in the unsaturated and saturated zones, and to investigate sampling techniques and strategies for the unsaturated and saturated zones (Charles N. Smith, U.S. Environmental Protection Agency, oral commun.). These objectives may differ slightly from, but are closely tied to, those of the USGS and ARS. The data bases developed to focus on the objectives of one research group can be shared and will be applicable to the development, validation, and testing of various models.

HYDROGEOLOGIC SETTING

Location and General Site Description

The study area selected in 1986 by the USGS and the ARS included the upper Ty Ty Creek tributary watershed near Plains in Sumter County, Georgia. The area covers an area of 1.03 mi^2 and is typical of watersheds in the Fall Line Hills district of the Coastal Plain physiographic province of southwestern Georgia (figs. 1 and 2). Monitor wells were installed at 85 sites in, and adjacent to, the Ty Ty Creek tributary watershed to define the hydrogeology and to develop an understanding of the ground-water and surface-water relations.

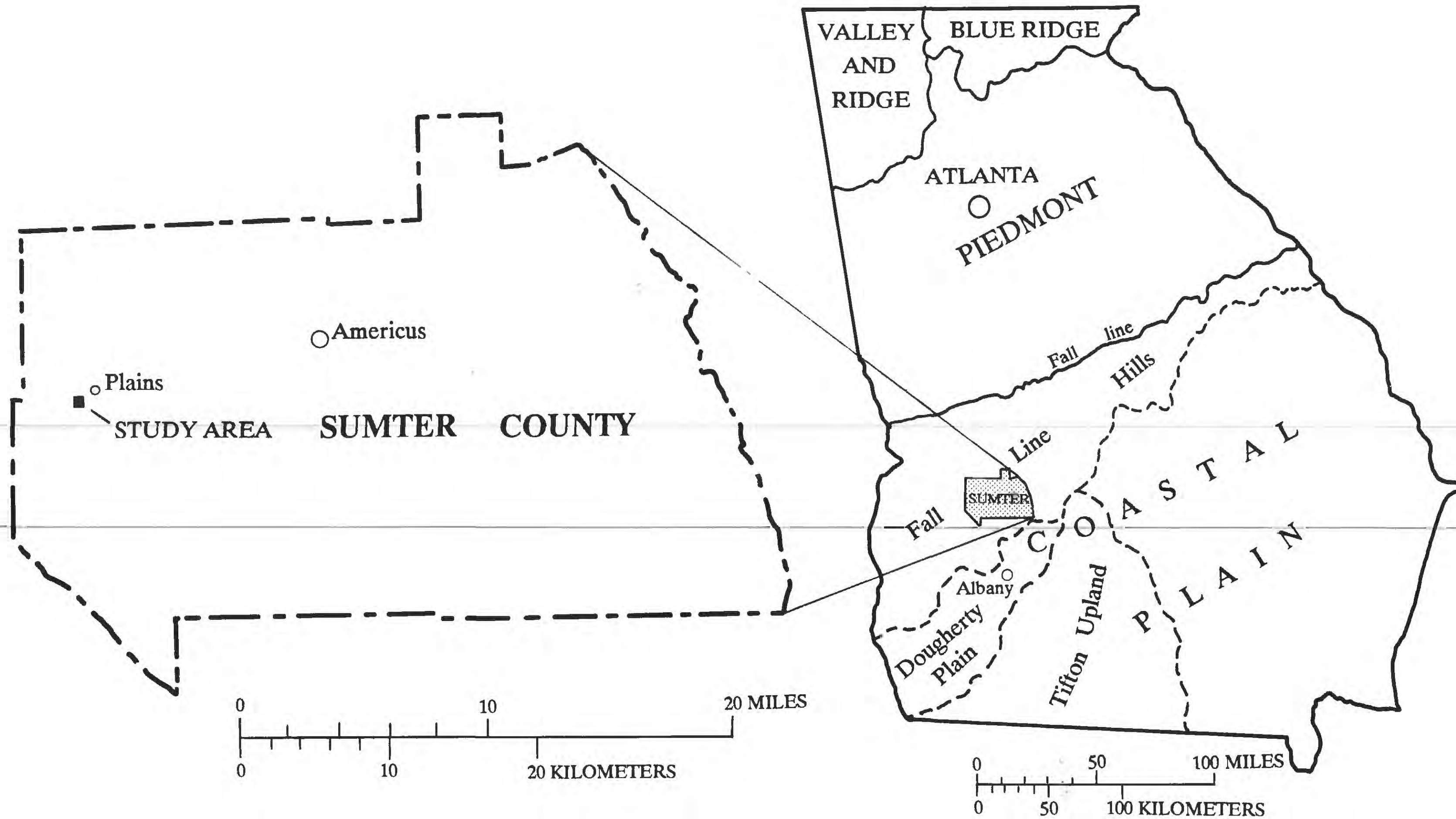
Hydrogeologic data collected since 1986 indicate that the Claiborne aquifer, which is the uppermost saturated zone, is rapidly recharged by rainfall in parts of the watershed. After periods of heavy rainfall, the rate and volume of ground water that is discharged to the intercepting surface-water system may increase. The general direction of ground-water flow in the Claiborne aquifer is toward the south through the watershed. The configuration of the water table generally reflects the topography in the area.

The size, location, and hydrogeology of the watershed are ideal for conducting field-scale studies. However, a preliminary site evaluation revealed that the areal extent of the watershed and the spatial variability of the hydraulic properties, were not conducive to model validation and testing. For this reason, adjacent farmland, within the Ty Ty Creek watershed, was leased by the USGS in late 1988 for the purpose of establishing several plot-sized areas in which research could be conducted and the data necessary for model validation and testing could be collected (fig. 2).

The leased area consists of two 16.7-acre fields and approximately 40 acres of adjacent woodland (figs. 2 and 3). The fields are in an interstream area that separates Ty Ty Creek and Ty Ty Creek tributary. The area is characterized by relatively level farmland with wooded midslope and toe-slope areas extending to the adjacent streams. Land-surface altitudes range from about 390 to 470 ft above sea level. A field reconnaisance of the research sites identified two soil series. The soil in field "A" is Eustis sand (a Psammentic Paleudult) and the soil in field "B" is Eustis sand in the upper part and Troup sand (a Grossarenic Paleudult) in the lower part. Interior drainage is typical of the area, as a result of the sandy, highly permeable, surface soils.

Geologic and Hydrologic Conditions

Data collected from 37 monitor wells installed in and adjacent to the leased land, indicate that the geologic units important to this study are, in ascending order, the Tuscahoma Formation (Paleocene), the Tallahatta Formation (Eocene), and the undifferentiated residuum and alluvium (fig. 4). The Tuscahoma Formation consists of homogeneous, well sorted, glauconitic, very fine-to-fine, argillaceous, quartz sand, and the Tallahatta Formation is composed of fine-to-coarse, quartz sand. The undifferentiated residuum and alluvium consist of alternating and intermittent layers of sand, clayey sand, and clay. The unsaturated zone includes the undifferentiated residuum and alluvium and the upper part of the Tallahatta Formation, and ranges in thickness from a few feet in the toe-slope areas to about 40 ft in parts of the interfluve areas. The saturated zone, or Claiborne aquifer (named for the Claiborne Group, which includes the Tallahatta Formation), is restricted to the lower part of the Tallahatta Formation and ranges in thickness from about 8 to 45 ft. The aquifer is underlain by the less permeable Tuscahoma Formation and generally is unconfined.



Physiography from Clarke and Zisa (1976)

Figure 1.--Location of study area and physiographic provinces of Georgia.

Figure 2.--Location of original study area (1986) and leased farmland. Aerial photograph from U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service.

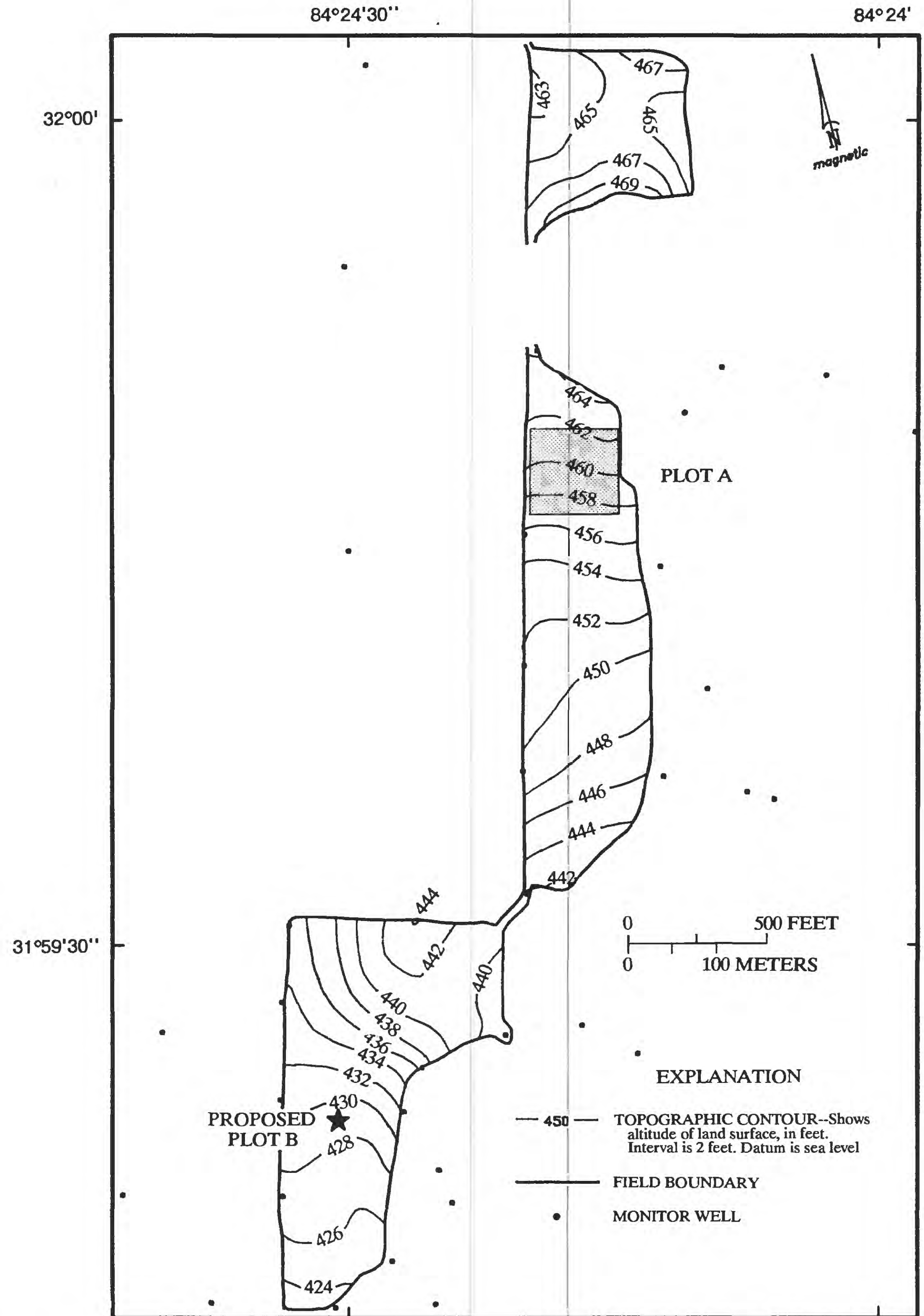


Figure 3.--Location of research plots A and B, monitor wells tapping the Clairborne aquifer, and land-surface topography of leased farmland near Plains, Ga.

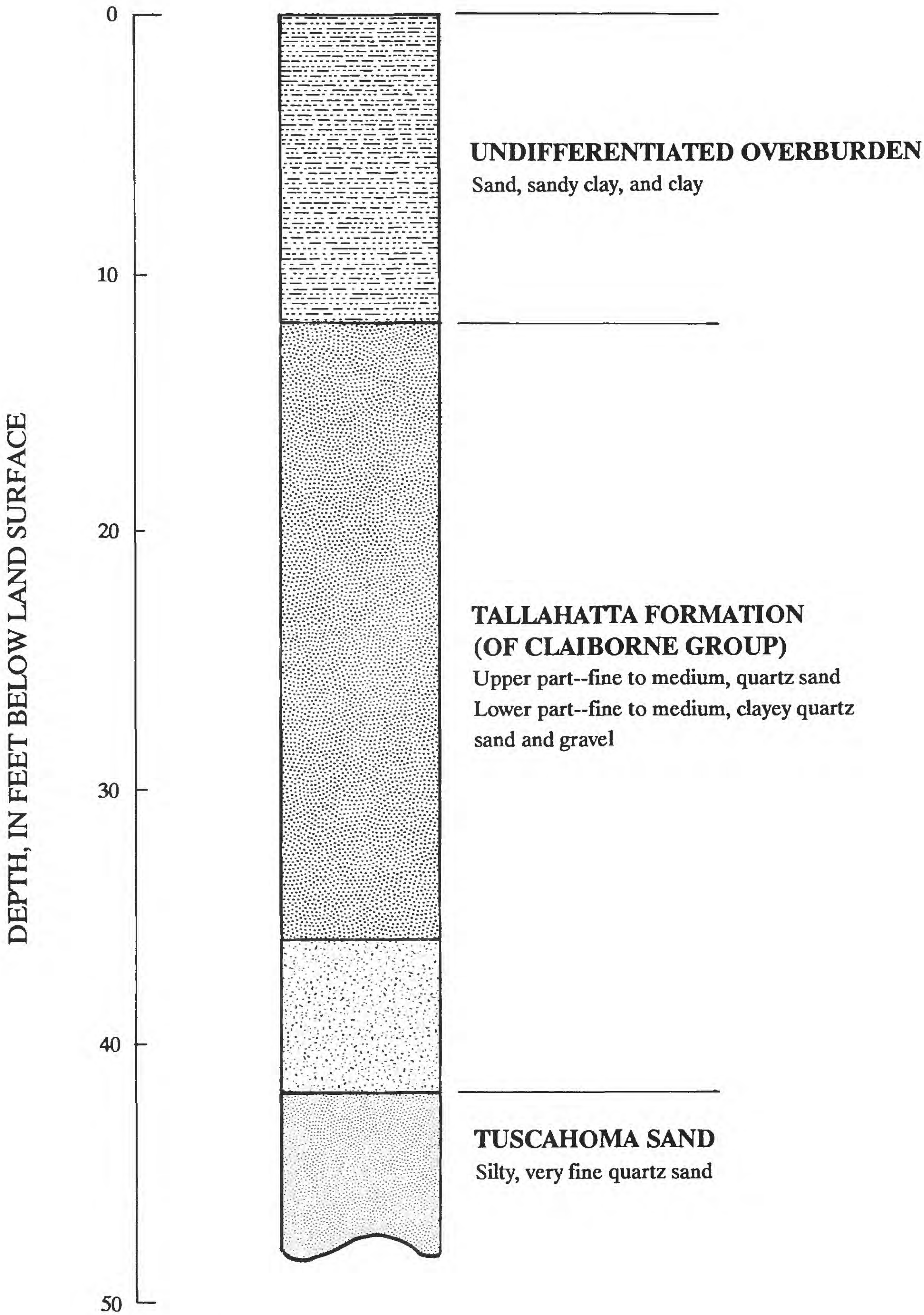


Figure 4.--Generalized geologic section, near Plains, Ga.

STUDY APPROACH

The USGS, ARS, and USEPA are designing the data collection programs for the test plots to provide data bases that will meet the research objectives of the project. Two 2-acre test plots have been tentatively located on the leased farmland (one plot in each of the two fields, "A" and "B"), each in a unique hydrogeologic setting. The proposed instrumentation at each test plot will permit the collection of data pertinent to the transport and fate of test compounds. The study will ensure that pertinent data are collected to adequately define the spatial variability of the factors controlling the transport and fate of agrichemicals and provide an understanding of the physical and chemical processes that are important to the validation and testing of models.

During the first year of the multiagency study, efforts will be focused on designing and instrumenting a 2-acre test plot (300 ft by 290.4 ft) located in field "A". Subsequently, a second 2-acre test plot may be instrumented in field "B" (fig. 3). The second plot could provide an area for comparative research under different hydrogeologic conditions within the same climatic environment. Plans for study in the test plot in field "B" have not been finalized and are not discussed in this report.

An irrigation well tapping a deep aquifer, vertically isolated from the Claiborne aquifer, will be installed by a water-well contractor in an area convenient to the two proposed test plots. The well will provide a water supply to an irrigation system that will facilitate infiltration research activities and provide supplemental water for sustained crop growth.

EXPERIMENTAL DESIGN AND INSTRUMENTATION OF TEST PLOT A

The test plot will be divided into 100 rows, each row 3 ft wide and 290.4 ft long, extending from east to west across the field. The field will be further subdivided into quadrants for monitoring and sampling.

Permanent monitoring stations will be randomly located at 12 sites in the test plot (fig. 5). The monitoring equipment will consist of (1) 2-inch diameter wells cased with threaded-joint plastic pipe installed at three depth intervals at each of the 12 sites (four of these wells will fully penetrate the aquifer); (2) stainless steel, vacuum lysimeters (soil-moisture samplers) installed at seven depth intervals in the unsaturated zone (at eight sites); (3) soil-moisture sensors (Water Mark[4/] sensors) installed at 12 depths, seven of which correspond to the lysimeter depths, and soil-temperature detectors (thermocouples) at four depths all connected to centrally located data loggers (at 12 sites); and (4) soil-moisture probe access tubes installed to a depth of 20 ft (at four sites) (fig. 6). All instrumentation at the 12 sites will be permanently installed within the planted rows to eliminate disturbance in the soil-root zone created by burying and retrieving the monitoring equipment during the farming operations. The area proximate to the monitoring sites will be farmed by hand if it cannot be farmed with mechanized equipment. Spray application of the agrichemicals will not be impeded by the monitoring equipment. Installation of the monitoring equipment will be a joint effort of the USGS, ARS, and USEPA.

[4/]Use of brand and trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey, the U.S. Department of Agriculture, or the U.S. Environmental Protection Agency.

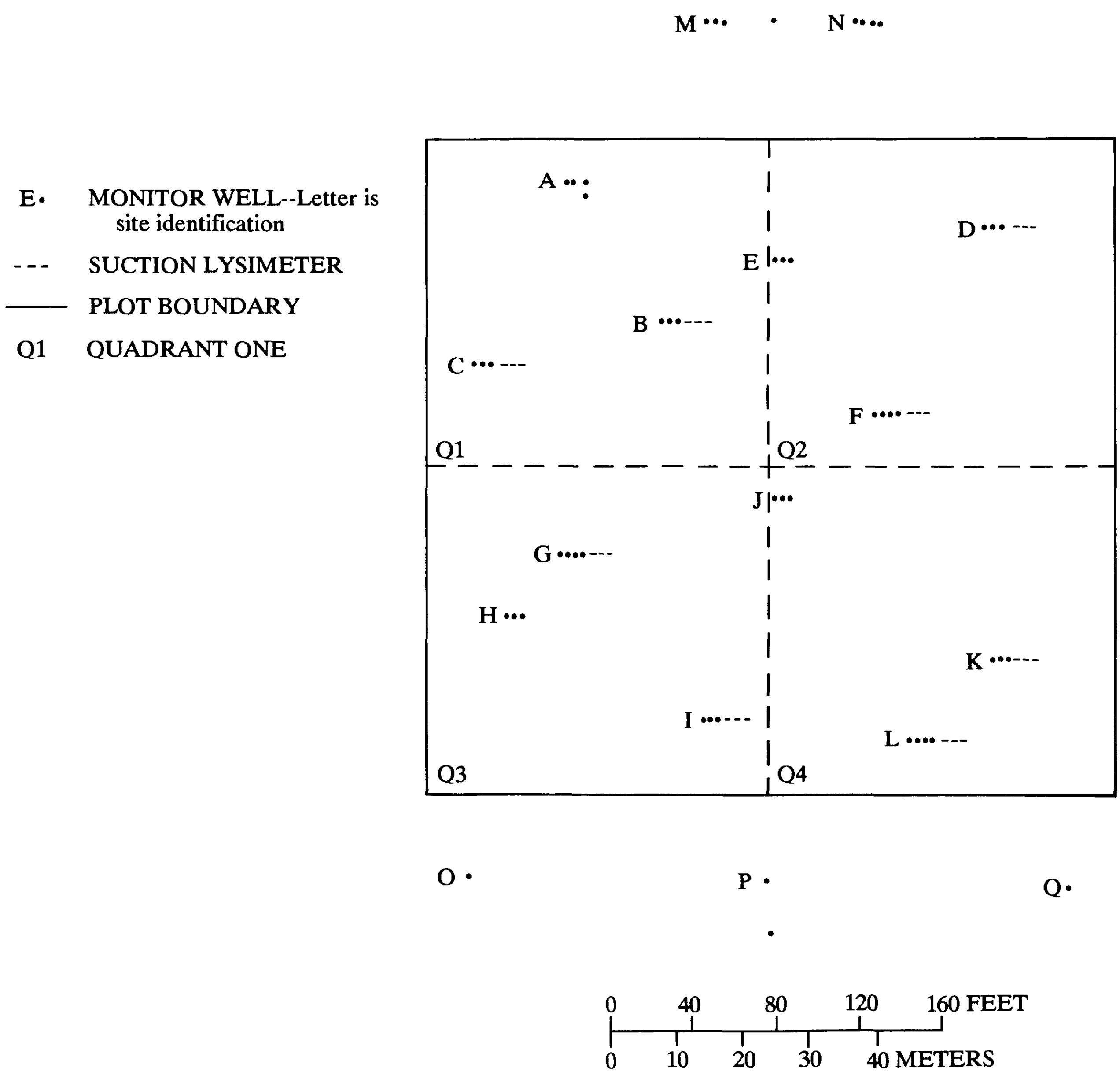


Figure 5.--Location of permanent monitor sites at research plot A.

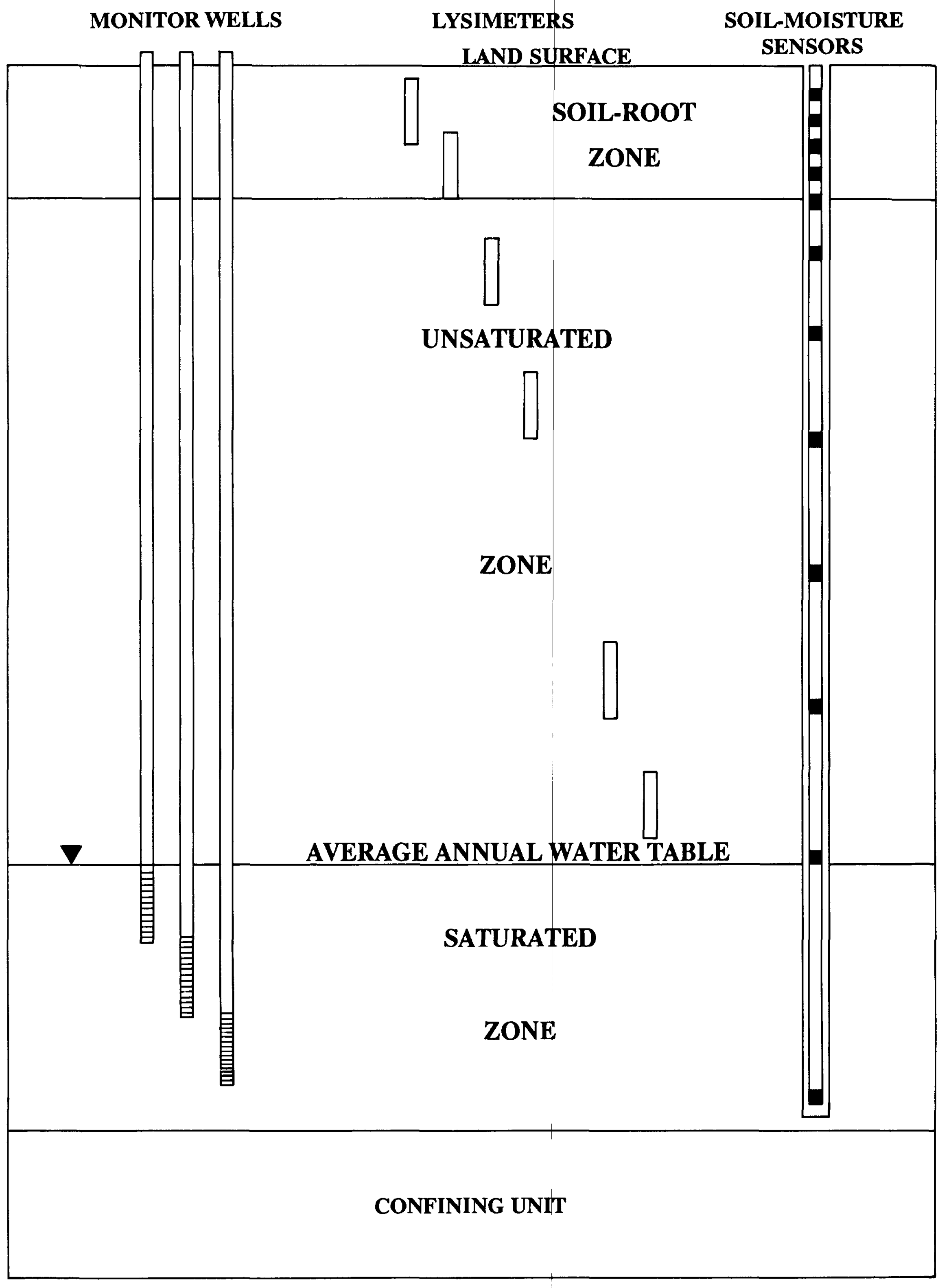


Figure 6.--Generalized monitor-site installation. Placement of observation wells, lysimeters, and soil-moisture sensors at monitor sites.

Climatic Data Collection

The ARS has operated rainfall recorders at four sites in the watershed since 1987. Additional rainfall recorders will be installed at two sites near the research plot to evaluate the effect of rainfall rate on field saturation, runoff, and ground-water recharge.

Since 1947, the University of Georgia has operated a weather station at the Southwest Georgia Experiment Station (SGES), Plains, Ga., (about 2.0 mi from the study area). Pan evaporation, wind speed and direction, ambient air temperature, and rainfall data have been collected at the SGES.. It is anticipated that areal variations in these climatic parameters (other than rainfall) will be negligible and data collected at the SGES may be incorporated into the data bases generated at the study area. However, a weather station will be instrumented at the research plot to evaluate the applicability of the data collected at the SGES. If the data correlate within experimental limits, the weather station at the research plot will be discontinued.

Runoff

A 12-in. soil berm will be built around the perimeter of the plot to prevent the runon and control the runoff of rainfall. A flume will be installed by the ARS at the topographic low of the 2-acre test plot to measure runoff and losses of sediment and agrichemicals transported in the water and sediment. The runoff-monitoring installation will consist of a stage recorder and an automated sample-collection device. Initiation of sample collection will be stage dependent and time-integrated samples will be collected for the duration of the runoff event. Substantial runoff is not expected because of the highly permeable surface soils.

Chemical Application

During the study, standard agricultural management practices will be used. Tilling, fertilizing, planting, and chemical application will be conducted in accordance with procedures outlined by the SGES and the chemical manufacturers for the production of corn.

Liquid atrazine, carbofuran, and alachlor will be applied annually to the cropped area in a manner and a volume specified by each respective chemical manufacturer for the production of corn. A potasium bromide salt, also in a liquid form, will be applied as a conservative tracer immediately following the pesticide application during the first and third year of the study. Chemical spray equipment will be calibrated prior to each application and will be thoroughly washed following the application of each chemical. Subsequent to the application, the rate, and the chemical mass of each organic compound applied will be determined. The mass of the formulations will be determined by obtaining the total weight of the application and by soil sampling. About 60 random soil samples will be collected immediately following application of the chemicals and analyzed. For liquid applications (including the tracer), the application rate will be monitored by randomly installing approximately 100 filter discs in the field prior to each chemical application. Immediately following application, the discs will be removed for analyses of pesticides or bromide. Pesticide analysis will be conducted at the USEPA laboratory, Athens, Ga., and bromide analyses will be conducted at the ARS laboratory in Tifton, Ga.

Soil-Zone Properties

The soil properties will be determined in the test-plot area. A grid system will be developed and soil cores will be collected to a depth of approximately 3 ft and described by the USDA, Soil Conservation Service (SCS), State Soil Correlator. From these descriptions, the soil series, number of soil horizons, and the thickness of each horizon will be determined.

Two pits will be excavated by the ARS to a depth of approximately 10 ft adjacent to the plot. Appropriate depth-integrated samples will be collected from each pit for the determination of bulk density, pH, organic carbon content, porosity, particle-size distribution, mineralogy, hydraulic conductivity (laboratory permeability), and moisture content, and moisture-release curves will be developed. Samples will be analyzed at the ARS laboratory, Tifton, Ga., and the USDA, SCS laboratory, Lincoln, Nebr.

The USGS and ARS will conduct permeability tests on undisturbed soil using a Guelph permeameter to evaluate the infiltration rate of each soil horizon in the upper part of the unsaturated zone. Data collected during the permeameter tests can be used to calculate the saturated hydraulic conductivity. Data obtained from borehole geophysical logs will be used to estimate relative formation permeability, and will be compared to on-site and laboratory developed estimates of hydraulic properties.

Unsaturated-Zone Properties

The USGS, ARS, and USEPA will collect vertically continuous soil cores at each of the 12 monitoring sites and at five sites randomly located in each quadrant. A continuous-coring device, such as a Shelby-tube sampler, will be used to collect "undisturbed" soil cores from selected depths extending from land surface to the top of the saturated zone.

A falling-head, controlled-gradient permeability test will be performed on selected soil core to determine the saturated hydraulic conductivity. Soil core subsamples, approximately 4 in. in length, will be cut from the undisturbed core. The subsamples will be installed in a flexible-wall permeameter cell for the determination of saturated permeability. Tests will be conducted at the ARS laboratory at Tifton, Ga. These values of permeability will be compared to those developed on site using the Guelph permeameter.

Minerology, bulk density, pH, organic carbon content, porosity, moisture content, and particle-size distribution also will be determined from the soil cores. Analytical responsibility for these determinations will be divided between the ARS Laboratory, Tifton, Ga., and the SCS Laboratory, Lincoln, Nebr. Soil cores will be collected annually and analyzed to evaluate changes in the physical and chemical properties as a result of research activities.

Saturated-Zone Properties

Rising-head and falling-head aquifer tests (slug tests) will be conducted by the USGS in the test-plot area. Results from these tests will be used to estimate the transmissivity, hydraulic conductivity, diffusivity, and specific yield of the Claiborne aquifer.

Undisturbed cores will be collected by the USGS, ARS, and USEPA from the Claiborne aquifer and from the underlying confining unit to determine laboratory values of vertical hydraulic conductivity. Soil core will be analyzed at the ARS Laboratory, Tifton, Ga.

Chemical Compounds in the Unsaturated Zone

During the installation of the monitor wells, the ARS and USEPA will collect soil core from selected depths within the unsaturated zone. Intervals of core will be sealed in metal containers, chilled and transported to the USEPA Laboratory, Athens, Ga., to be analyzed for pesticide residual. The USEPA will determine the areal distribution, sample depth, and volume of sample needed to evaluate the ambient soil-water quality. The ARS also will collect samples to be analyzed at the ARS Laboratory, Tifton, Ga., for inorganic constituents.

Soil will be collected from land surface to the saturated zone at three randomly located sites in each quadrant during three scheduled sampling events each year. Samples will be collected using a hollow-stem auger sampling device. A maximum of 12 soil samples collected during each of the three sampling events will be analyzed for pesticide residues. The 12 sampling sites will be randomly selected prior to each sampling event.

Sampling events also will be "keyed" to the occurrence of significant rainfall. Immediately following periods of heavy rainfall, lysimeters will be purged and sampled prior to a proposed soil-sampling event. The samples will be analyzed by the USEPA Laboratory, Athens, Ga., or the ARS Laboratory, Tifton, Ga. The analytical results of these samples will be used as a guide to determine the optimum depth interval for the collection of soil samples. The soil samples will be collected to depths of 10 ft or less using a hand auger.

Samples will be collected in the unsaturated zone at depths and over time intervals adequate to attain breakthrough curves at all sites. These curves will define the time scale at which mathematical representation of transport processes will be developed for incorporation into the models. Because it is perceived that some transport processes in the unsaturated zone occur at time scales that are much smaller than for saturated transport, some of the unsaturated-zone processes may not be represented by an equation developed for the saturated zone. It may be necessary to transform the effects of these processes in the unsaturated zone into boundary conditions to the transport equation in the saturated ground-water system.

In addition to the 12 random soil-sampling sites, eight sites proximate to the lysimeter installations will be sampled by the USGS. During each sampling event, soil samples will be collected at intervals that correspond to the lysimeter depths, as well as intermediate depths. These samples will be used to determine the gravimetric soil-moisture content at the approximate time that each of the lysimeter samples was collected. From these data, the relation between soil moisture and saturated hydraulic conductivity will be developed.

Subsequent to the moisture content determinations, the soil samples will be pulverized and a 150 mL volume of deionized water will be added. The samples will be agitated for a period of 24 hrs. A representative sample volume will be extracted for bromide analysis using a Ion Chromatograph. The soil moisture and bromide analyses will be conducted at the USGS Laboratory, Doraville, Ga.

Chemical Compounds in the Saturated Zone

Subsequent to the collection of soil and water samples from the unsaturated zone, each monitor well in the test plot will be purged and sampled. A minimum of five sampling events per year is planned. The sampling of downgradient wells will be contingent on the detection of certian chemical compounds in the wells located within the test plot. When chemicals are detected in the test-plot wells, samples will be collected from the downgradient wells during the next scheduled sampling event.

Water samples will be analyzed at the USEPA Laboratory, Athens, Ga., or the ARS Laboratory, Tifton, Ga. All analyses for total organic compounds will be performed by the USEPA. The ARS Laboratory, Tifton, Ga., will analyze water samples for nitrate, chloride, and bromide.

The USGS, Branch of Analytical Services, Arvada, Co., will provide analytical support for pesticide residue determinations on selected water samples. The USGS will provide pesticide residue determinations for atrazine, de-alkylated atrazines, and hydroxyatrazine from selected ground-water samples. In addition, samples will be analyzed for alachlor, alachlor carbinol, ortho-diethylaniline, carbofuran, carbofuran phenol, 3-hydroxycarbofuran, and 3-ketocarbofuran.

Ground-Water Monitoring

Monitoring wells, constructed identical to those within the test plot, will be installed by the USGS, ARS, and USEPA upgradient and downgradient from the test plot. Two groups of wells will be installed upgradient of the test site. These monitoring wells will provide control for the test site and will be sampled to establish ambient ground-water quality. During the first year of the study, one line of three wells will be installed downgradient from the test plot. The spacing of these wells will be dependent upon the horizontal hydraulic properties of the aquifer. Additional lines of wells will be installed as the movement of the chemical compounds is detected in the downgradient monitoring wells.

Two, fully penetrating, monitoring wells will be installed adjacent to the test plot: one upgradient, and one downgradient. Each of these wells will be equipped with a continuous water-level recorder. Continuous water-level data will be collected so that, together with other data, a rainfall/recharge relation may be developed for the plot area. The USGS will maintain these monitoring sites.

Long term, seasonal, and instantaneous water-level changes will be monitored. The water level in the Claiborne aquifer will be monitored continuously at five sites in the watershed and at two sites proximate to the test plot. Ground-water levels will be measured monthly in approximately 145 wells completed in the Claiborne aquifer in the watershed. The water levels obtained from wells completed at various depths at a site (clustered wells) within this network will be compared to evaluate vertical head gradients within the saturated zone.

ASSESSMENT OF SAMPLING AND ANALYLTICAL QUALITY

A quality-assurance (QA) plan will be implemented as a basic set of field and laboratory quality-control procedures to minimize errors in the data. Procedures for the collection of soil and water samples and for field measurements will be established to reduce sampling variability and error, and to identify and correct measurement problems in the field.

Laboratory quality control will be part of the QA program. Participating laboratories will follow documented quality-control procedures and provide data on the reliability of their analytical performance.

RELATED RESEARCH

Nitrogen Cycle Studies

Various forms of nitrogen, originating from fertilizer application, have been detected in ground water in agricultural areas. Moreover, it is hypothesized that nitrogen cycling may be an important factor in pesticide transport. Organic compounds may be coupled with the nitrogen cycle through microbial processes. For example, denitrifying bacteria could utilize the pesticide as a carbon source and nitrate as an electron acceptor.

Studies are proposed to (1) establish a 3-year nitrogen budget for the study area (a number of physical-transport mechanisms, microbial reactions, and harvesting would be considered); (2) address the denitrification part of the cycle in detail by quantifying the rates of denitrification in undisturbed cores of aquifer material and the effects of nitrate and pesticide in aquifer microcosms; (3) quantify denitrification on a field scale; and (4) field test the hypothesis that denitrification and other nitrogen cycling reactions result in significant changes in the composition of ground water.

Microbial Studies

It is likely that microbial processes have a significant effect on the transport and degradation of organic compounds. Field and laboratory experiments are proposed to evaluate the role of microbial processes. Undisturbed soil cores will be collected from the soil-root zone, the unsaturated zone, the saturated zone, and the confining unit that underlies the aquifer. Samples from the interior of each soil core will be analyzed for microbial activity. Microbial colonies will be exposed to labeled atrazine, alachlor, and carbofuran to evaluate the effect on the microbes as well as the microbial degradation of the compounds.

Methods Development

Monitoring the movement of pesticides in the unsaturated and the saturated zones is an important aspect of the research program. To evaluate the processes controlling the transport, degradation, and fate of agrichemicals, it is necessary to detect extremely low chemical concentrations in both soil-water and ground-water samples. For the interpretation of analytical results to be meaningful, bias introduced by the method of sampling and preservation should be evaluated and the accuracy, precision, and detection limits of the analytical methodology should be determined.

The chemical analysis of the pore water extracted from soil core is not routine for the determination of pesticide analytes. Currently, there is no published technique that addresses the residue analysis of soil for a combination of specific analytes. A soil-core residue analysis will be developed for the specific analytes of atrazine, carbofuran, and alachlor by the USGS as a part of the research initiative.

MODEL EVALUATION, DEVELOPMENT, AND TESTING

The USGS and the ARS propose to evaluate, develop, and test mathematical models in two phases. Phase I will focus on the development of a one-dimensional, soil-root/unsaturated zone flow and transport predictor. In phase II, a linked model will be developed capable of simulating the multi-dimensional transport and fate of land-applied agrichemicals from the point of application through the ground-water-flow system.

Phase I

The model developed in phase I will be used to design laboratory and field experiments, as well as approximate the transport and fate of nutrients and pesticides on a soil series, field, or regional scale. The Ground Water Loading Effects of Agricultural Management Systems (GLEAMS) model (Leonard and others, 1987), or a root-zone model similar in approach, will be coupled with a one-dimensional transport model. The root-zone model will define the upper boundary condition for the unsaturated-zone model. The one-dimensional model will be based on partial differential equations derived from the conservation of mass principle, and will simulate transport in variably saturated porous media.

Phase II

In phase II, the USGS will review the equation development and numerical methods inherent to existing root-zone, unsaturated-zone, saturated zone, and linked models for their applicability to this study, as well as to other studies. Suitable models will be tested using data bases developed through this research effort. This work will identify models that accurately simulate transport of atrazine and other selected agrichemicals through the soil-root, unsaturated and saturated zones.

It has been theorized that nonvertical flow in the variably saturated media may control the dispersion of chemical residues in the unsaturated zone. Phase II modeling will attempt to quantify the chemical dispersion by using numerical simulation. An existing two-dimensional, unsaturated-zone model, VS2D (Lappala and others, 1987), may be coupled with a saturated-zone, solute transport model. The linkage of unsaturated- and saturated-zone models will provide the contamination source input to a saturated-zone, solute-transport model of the ground-water-flow system. The output from the unsaturated-zone model may be used as an upper boundary condition for the saturated-zone model.

The USGS will develop a saturated-zone transport model that is compatible with the MODular Finite Element Flow model (MODFE) (Torak and Cooley, in press), based on a modified method of characteristics. This saturated-zone transport model will provide researchers and field personnel with a versatile tool for evaluating the saturated transport of agrichemicals and other solutes in the ground-water-flow system. The model will accept the solute flux from the unsaturated zone, thereby completing the process of simulating solute transport from the point of application through the ground-water-flow system. An unsaturated/saturated-zone solute-transport model, linked by a boundary condition, could provide a means for making predictions over regional scale and simulations accurate at the plot scale. Thus, this model will be applicable to the research site at Plains, Ga., and may have a significant transfer value for evaluating the transport and fate of agrichemicals in other areas.

In addition to the transport and fate modeling described herein, the USGS will simulate the saturated flow system with the MODFE model. Results of the MODFE model will be used to evaluate the direction and magnitude of ground-water flow within and near the Plains, Ga., test plots to determine the effects of lateral ground-water movement on agrichemical transport in the saturated zone.

PROJECT MATRIX

A summary of project activities was prepared to ensure that all objectives are accomplished in a timely manner (table 1, at end of this report). The summary of project activities defines each data collection activity, identifies the agency responsible for the activity, and suggests a time table for completing the task. The scope, frequency, and type of data are described by system compartment or process. Each system compartment contains data elements essential to the testing and validation of agriculturally-related models. These elements and their relation to the overall model testing and validation activity are defined in figures 7 and 8.

Each agency is responsible for the computer entry, file maintenance, and transfer sharing of data collected or analyzed by that agency. A designated individual or group within each respective agency would be responsible for these tasks.

OVERVIEW OF THE RESEARCH PERSPECTIVE

The USGS, ARS, and USEPA are sharing technical expertise and resources in a research project of mutual interest that involves complex, interdisciplinary investigations by scientists from each agency. The success of this research project will require careful planning and implementation of research activities, as well as frequent communication among the various scientists from each participating agency.

Conceptually, each research participant will concentrate on testing a hypothesis that relates to specific physical, chemical, or biological processes that affect the transport and fate of nitrogen species or pesticides. The data sets assembled as a result of these research activities will be used to test and validate modeling efforts in each component of the hydrologic system. As the studies proceed, data and technical expertise will be exchanged among the cooperating scientists. Information exchange is an essential element of the research project.

LINKED ONE-DIMENSIONAL TRANSPORT MODEL

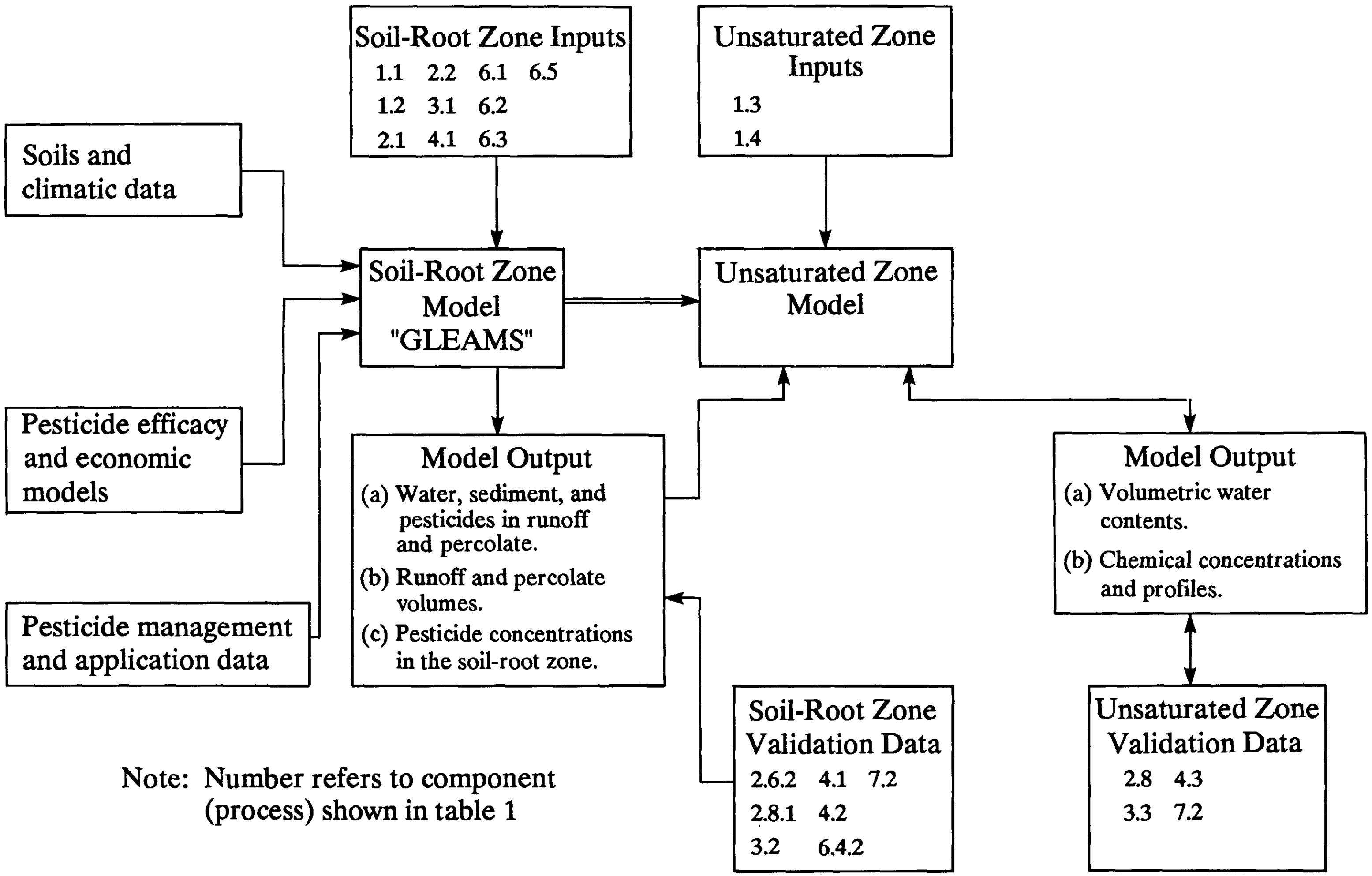
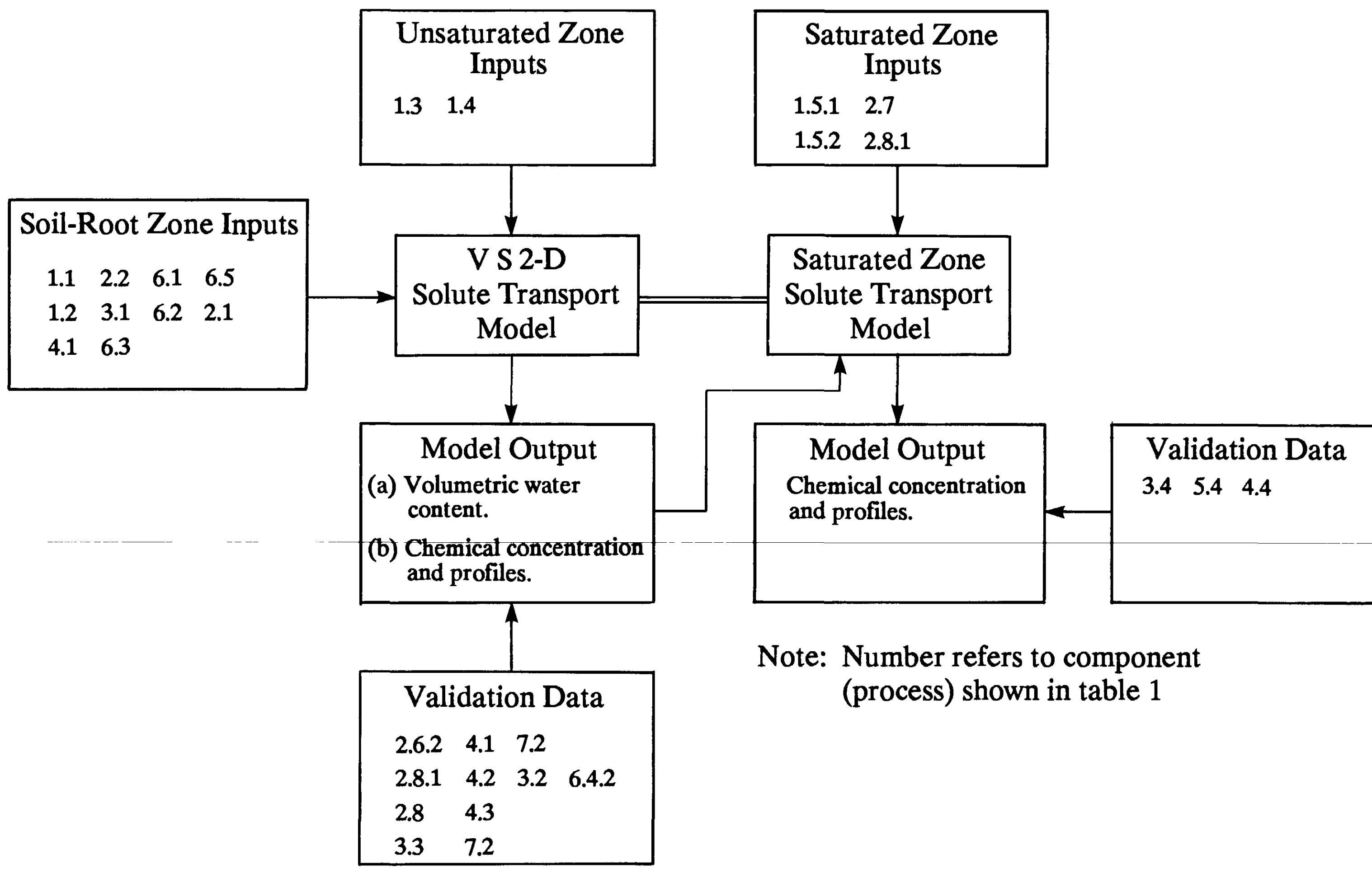


Figure 7.--One-dimensional modeling approach.

LINKED TWO-DIMENSIONAL TRANSPORT MODEL



Note: Number refers to component (process) shown in table 1

Figure 8.--Two-dimensional modeling approach.

Each research scientist has a vital interest in the project and in collecting data to test specific hypotheses related to processes of interest. In normal pursuit of his or her professional responsibility, each scientist is expected to author relevant publications. Most publications will involve joint authorship by researchers from various combinations of the three Federal agencies and other researchers, such as scientists from the University of Georgia.

During the course of the investigation, data sets will be assembled to test models that are in various stages of development and application by the respective agencies. It will be incumbent on each researcher and agency to share data and information in a timely manner and use such information respecting agency protocols and the individual scientist's contributions. Data sets developed are expected to have wide applicability and be in demand by groups not directly involved with the investigation. At the conclusion of the project, a final report will be prepared that will serve as the primary vehicle for data release to individuals and agencies outside the project team. In the interim, any data released to those other than on the initial project team, should be with mutual knowledge and consent by all parties. This is not to exclude widening of the project with additional cooperators covering topics not currently addressed. Such activities will be jointly planned and revised by team members representing the three primary Federal agencies. Currently (1991), the representatives from the three agencies are David W. Hicks, USGS, Georgia District, Doraville, Ga.; Charles N. Smith, USEPA, AERL, Athens, Ga.; and Ralph A. Leonard, USDA, ARS, Tifton, Ga.

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Table 1.--*Summary of project activities*

[ARS, Agricultural Research Service; SCS, Soil Conservation Service; UGA, University of Georgia; USGS, U.S. Geological Survey; EPA, U.S. Environmental Protection Agency; GIS, Geographic Information System]

	Component (process)	Scope or product	Frequency of activity	Types of reports and their due dates	Responsible agency
1.0	**PHYSICAL SYSTEM CHARACTERIZATION:**				
1.1	Topography	maps, elevations, benchmarks	initial, and as needed	after initial survey, and as requested	ARS
1.2	Soil Properties:				
1.2.1	Classification and morphology	soil maps, pedon descriptions	initial	after initial survey	SCS, UGA
1.2.2	Soil pedon characteristics	chemical and physical data by soil horizon	initial	after initial survey	SCS, ARS
1.2.3	Infiltration characteristics	infiltration rates by Guelph permeameter for each horizon, 12 sites	initial, and periodic for management effects	initial and annual	USGS, ARS
1.3	Stratigraphy:				
1.3.1	Monitor wells	well installation logs, visual description, 12 plot sites, 20 down-gradient sites	initial installation	upon completion	USGS, ARS
1.3.2	Neutron and natural gamma logs	continuous charts with depth, 12 plot sites, 20 downgradient sites	initial	upon completion	ARS, USGS
1.3.3	Ground-penetrating radar	spatially continuous; charts; 50-foot grid. Plot and immediate vicinity	initial	upon completion	ARS
1.4	Unsaturated Zone Properties:				
1.4.1	Permeability	saturated and unsaturated conductivities on core sections. 12 depths; 12 to 20 sites	initial on cores from well installation	upon completion	ARS, USGS
1.4.2	Composition	particle-size distribution on selected core sections as above, carbon and pH	initial on cores from well installation	upon completion	UGA, ARS
1.4.3	Mineralogy	selected core sections, 12 depths, 5 sites	initial on cores from well installation	upon completion	UGA

Table 1.--*Summary of project activities--Continued*

[ARS, Agricultural Research Service; SCS, Soil Conservation Service; UGA, University of Georgia; USGS, U.S. Geological Survey; EPA, U.S. Environmental Protection Agency; GIS, Geographic Information System]

	Component (process)	Scope or product	Frequency of activity	Types of reports and their due dates	Responsible agency
1.5	Saturated Zone Properties:				
1.5.1	Aquifer tests	transmissivity by pumping and slug tests	initial	upon completion	USGS
1.5.2	Laboratory tests	saturated hydraulic conductivity undisturbed cores	inital	upon completion	ARS
2.0	**HYDROLOGIC AND METEORLOGIC OBSERVATIONS;**				
2.1	Precipitation	digital-weighing gages; 4 offsite; 1 plot, 0.1 inch resolution; 1 standard gage on plot	5-minute continuous and daily	quarterly	ARS
2.2	Radiation	net radiation	daily	monthly	UGA
2.3	Evaporation	pan evaporation	daily	monthly	UGA
2.4	Temperature:				
2.4.1	Ambient	maximum and minimum	daily	monthly	UGA
2.4.2	Soil	thermocouples, 12 plot sites, 4 depths	hourly, daily	quarterly	ARS
2.5	Wind	wind, miles	daily	monthly	UGA
2.6	Surface Runoff:				
2.6.1	Watershed	3 sites in 1.0 mile of Ty Ty Creek trubutary watershed. Wier, stream, pond, and flume	5-minute digital	quarterly	ARS, USGS
2.6.2	Plot	continuous-recording-flume stage gage	event oriented	quarterly	ARS
2.7	Ground-water levels:				
2.7.1	Instantaneous	continuous-record period. 5 per watershed, 2 per plot	continuous	quarterly	USGS
2.7.2	Seasonal and long-term	145 Claiborne aquifer wells	monthly	quarterly	USGS

Table 1.--*Summary of project activities--Continued*

[ARS, Agricultural Research Service; SCS, Soil Conservation Service; UGA, University of Georgia; USGS, U.S. Geological Survey; EPA, U.S. Environmental Protection Agency; GIS, Geographic Information System]

	Component (process)	Scope or product	Frequency of activity	Types of reports and their due dates	Responsible agency
2.8	Soil and Unsaturated Zone Water:				
2.8.1	Instantaneous	resistance sensors, 12 plot sites, 12 depths	hourly, daily	quarterly	ARS
2.8.2	Neutron probe	soil-water contents or relative changes with depth and time	periodic	annual	ARS
2.8.3	Gravimetric	water contents for calibration purposes	periodic	annual	ARS, USGS
2.8.4	Ground-penetrating radar	relative changes in dielectric properties on selected transects	periodic	annual	ARS
3.0	PESTICIDE FATE AND TRANSPORT:				
3.1	Field application rate	actual amounts applied and spatial variability by filter	seasonal	annual	EPA
3.2	Soil and root zone	pesticide concentrations in root zone with depth and time; 10 depth intervals, 20 random sites	5 years following application	annual	EPA
3.3	Unsaturated Zone:				
3.3.1	Soil solution	pesticide in soil solution from lysimeters. 7 depths	periodic after infiltration events	annual	EPA, ARS, USGS
3.3.2	Continuous soil cores	pesticide concentration in select core sections collected from land surface to saturated zone, 20 sites	3 years; before application, summer and late fall	annual	EPA, ARS, USGS
3.4	Saturated zone	pesticide concentrations in ground water. 12 well sites per plot, 3 depths of well screen, 3 down-gradient well transects, 2 upgradient well sites	5 samplings per year	annual	EPA, USGS
3.5	Methodology and Quality Assurance:				
3.5.1	Laboratory	comparison of pesticide recoveries between laboratories and methods	periodic	annual	ARS, EPA

Table 1.--*Summary of project activities--Continued*

[ARS, Agricultural Research Service; SCS, Soil Conservation Service; UGA, University of Georgia; USGS, U.S. Geological Survey; EPA, U.S. Environmental Protection Agency; GIS, Geographic Information System]

	Component (process)	Scope or product	Frequency of activity	Types of reports and their due dates	Responsible agency
3.5.2	Sampling methods	tests for possible cores--contamination and adsorption by equipment	periodic	annual	ARS, USGS
4.0	**BROMIDE TRACER TRANSPORT:**				
4.1	Field application rate	actual amounts applied and spatial variability by filter disc interception	seasonal	annual	ARS
4.2	Soil and root zone	bromide concentrations in root zone with depth and time; 20 depth intervals, 20 random sites	5 years following	annual	ARS, USGS
4.3	Unsaturated Zone:				
4.3.1	Soil solution	bromide in soil solution from lysimeters, 7 depths	periodic after infiltration events	annual	ARS, USGS
4.3.2	Continuous soil cores	bromide concentrations in selected core sections collected from land surface to the saturated zone, 20 sites	3 years; before application, summer and late fall	annual	ARS, USGS
4.4	Saturated zone	bromide concentrations in ground water; 12 well sites on plot; 3 depths of well screen; 3 down-gradient; well transects; 2 up gradient wells	5 years	annual	ARS, EPA, USGS
4.5	Methodology and quality assurance	comparison of recoveries on knowns and spikes, and between flow injections and ion chromatography	perodic	annual	ARS, EPA, USGS
5.0	**NITROGEN TRANSPORT:**				
5.1	Precipitation inputs	estimates of nitrogen in rainfall by interpolation	event rainfall volumes and weekly chemistry	annual	ARS
5.2	Soil and root zone	nitrogen species in root zone with depth and time; 10 depth intervals, 20 random sites	5 years following application	annual	ARS

Table 1.--*Summary of project activities--Continued*

[ARS, Agricultural Research Service; SCS, Soil Conservation Service; UGA, University of Georgia; USGS, U.S. Geological Survey; EPA, U.S. Environmental Protection Agency; GIS, Geographic Information System]

	Component (process)	Scope or product	Frequency of activity	Types of reports and their due dates	Responsible agency
5.3	Unsaturated Zone:				
5.3.1	Soil solution	nitrogen species in soil solution from lysimeters, 7 depths	periodic after infiltration events	annual	ARS
5.3.2	Continuous soil cores	nitrogen species in selected core sections in 2.5 feet intervals to 32 feet	3 years; before planting, summer and late fall	annual	ARS, USGS
5.4	Saturated zone	nitrogen species in ground water, 12 well sites on plot; 3 depths of well screen; 3 downgradient transects	5 years	annual	ARS, USGS
5.5	Quality assurance	participate in USGS Quality Assurance Program, field blanks spikes, replicates	periodic	annual	ARS, USGS
6.0	**AGRONOMICS**:				
6.1	Cultural practices				
6.1.1	Tillage, planting, harvest	dates and methods	periodic	annual	UGA
6.1.2	Chemical application	dates, rates, methods of application	periodic	annual	UGA
6.2	Crop development	plant height, appearance, and maturity dates	periodic	annual	ARS
6.3	Crop yields	grain yields by random sampling	seasonal	annual	ARS
6.4	Chemical Uptake and Removal:				
6.4.1	Nitrogen	nitrogen contents of crop by sampling and analysis	seasonal	annual	ARS
6.4.2	Bromide	bromide contents of crop by sampling and analysis	seasonal	annual	ARS
6.5	Irrigation	irrigation schedules, amounts, and dates of application	periodic	annual	ARS, UGA

Table 1.--*Summary of project activities--Continued*

[ARS, Agricultural Research Service; SCS, Soil Conservation Service; UGA, University of Georgia; USGS, U.S. Geological Survey; EPA, U.S. Environmental Protection Agency; GIS, Geographic Information System]

	Component (process)	Scope or product	Frequency of activity	Types of reports and their due dates	Responsible agency
7.0	**RELATED PROCESS STUDIES:**				
7.1	Nitrogen transformation	nitrification and denitrification rates and potentials in soil, unsaturated and saturated zones	periodic	annual	ARS
7.2	Pesticide transformation	pesticide degradation and transformation processes and rates in soil, unsaturated and saturated zones	periodic	annual	ARS, EPA
7.3	Short- and long-term affects of Clayton-Cretaceous ground water (irrigation) on chemistry of Claiborne ground water	comparison of ground water, pH, alkalinity and ion content before and during study period	periodic	end of project	UGA, USGS
8.0	**RELATED REGIONAL STUDIES:**				
8.1	Soil and pesticide grouping	grouping of soils overlying Claiborne and other aquifers of the Coastal Plain for pesticide leaching potential	simulation analysis	as completed	ARS, UGA
8.2	Aquifer vulnerability	maps using GIS and available data	as data are available	as completed	ARS, UGA, USGS
9.0	**MODELS:**				
9.1	Development:				
9.1.1	1-Dimensional	linked 1-Dimensional soil-root and unsaturated zone model	ongoing	as completed	ARS, EPA, USGS
9.1.2	2-Dimensional	linked 2-Dimensional unsaturated and saturated solute transport model	ongoing	as completed	ARS, EPA, USGS, UGA
9.2	Validation:				
9.2.1	1-Dimensional	validate 1-Dimensional linked model to observed field results	ongoing	as completed	ARS, EPA USGS, UGA
9.2.2	2-Dimensional	validate 2-Dimensional linked model to observed field results	ongoing	as completed	ARS, USGS, UGA

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