STREAMFLOW AND WATER-QUALITY SAMPLING NETWORK FOR THE MISSISSIPPI DELTA MANAGEMENT SYSTEMS EVALUATION AREAS (MSEA) PROJECT

R.A. Rebich
U.S. Geological Survey, WRD
Pearl, Mississippi

INTRODUCTION

Agricultural activities are a major source of nonpoint source pollution in the Nation. Surface and subsurface waters draining agricultural fields transport nutrients, pesticides, and suspended sediments to streams, thereby contaminating them and sometimes making them unsuitable for designated uses. One of the most intensively farmed areas of the United States is the Mississippi River Alluvial Plain in northwestern Mississippi, a 7,000-square-mile area locally referred to as the "Delta." Agricultural activities in the Delta differ significantly from those in other regions such as the Midwestern United States. The humid sub-tropical climate in the Delta increases dependence of farmers on pesticides, and the crops and cultural practices dictate a different array of pesticides be used than those used in other areas of the Nation. For example, one of the primary crops produced in the Mississippi Delta is cotton. Little ground cover remains after cotton is harvested in the late fall leaving the soil unprotected during the winter rainy season, thus increasing runoff and erosion potential. These factors, in combination with high regional rainfall, increase the chances for chemical movement within soils and water in this area. A research and demonstration project, entitled the Mississippi Delta Management Systems Evaluation Areas (MDMSEA) project, was begun in 1994 with the purpose of assessing the effects of agricultural activities on water quality in the Mississippi Delta and evaluating Best Management Practices (BMPs) as components to Delta farming systems (Rebich et al., 1995). The U.S. Geological Survey (USGS) began operating a streamflow and water-quality sampling network in the fall of 1995 as part of the MDMSEA project. The USGS part of the MDMSEA project is funded cooperatively with the Mississippi Department of Environmental Quality, Office of Pollution Control. The primary objective of the network is to sample and measure storm runoff from agricultural fields that contain BMPs and from fields that do not contain BMPs. Data from the various sites will be analyzed to assess how agricultural practices affect water quality and to evaluate the effectiveness of the BMPs. The purpose of this paper is to describe the streamflow and water-quality sampling network operated by the USGS for the MDMSEA project and to present selected preliminary nitrogen data, March through December 1996.

SITE LOCATIONS

The MDMSEA project is focused on oxbow lake watersheds. These watersheds are considered closed systems because all of the runoff from the agricultural fields drains into the oxbow lakes. These lakes are, therefore, biological endpoints for upstream improvements. The three MDMSEA oxbow lake watersheds are located in Sunflower and Leflore Counties, Mississippi (Figure 1).

BMPs used in the MDMSEA project were distributed among the three watersheds using a hierarchy approach. The Thighman Lake watershed was selected as the control and would not contain BMPs. The Beasley Lake watershed was selected to have nominal BMPs using low-cost structural practices such as filter strips, slotted-board risers, and slotted-inlet pipes. The Deep Hollow Lake watershed was selected to have the same structural BMPs as the Beasley Lake watershed, but would also include cultural BMPs such as conservation tillage, winter cover crops, and precision farming.

The streamflow and water-quality sampling network of the USGS was established to characterize the runoff in each of the three watersheds and to evaluate as many BMPs or BMP combinations as possible. The sites are distributed among the three watersheds as follows:

A. Thighman Lake watershed (Figure 1)

- Site 1 is an edge-of-field site located on the east side of Thighman Lake downstream of a conventional tillage cotton field, which has no BMPs. Runoff data collected at this site will be compared to data collected from sites that have BMPs.
- Site 2 is located on an inlet tributary of Thighman Lake at a gas line bridge approximately 1,000 feet upstream from a gravel road crossing. Data collected from this site will provide information concerning chemical or sediment loads that may be entering the lake during runoff events from a large area north of the lake.

B. Beasley Lake watershed (Figure 1)

- Site 3 is an edge-of-field site that will be used to evaluate the combination of filter strips and slotted-board risers as BMPs. Site 3 is located in the south-central section of the Beasley Lake watershed at an open-channel drainage ditch. A bridge over the channel has been constructed with an instrument shelter to minimize interference with farming operations such as pivot crossings. The ditch at this site drains a large area of conventional tillage cotton.

- Site 4 is an edge-of-field site that will be used to evaluate the performance of a slotted-board riser pipe, by itself, as a BMP. This site is located in the north-central section of the Beasley Lake watershed, and the riser pipe drains a well-defined area of conventional tillage cotton.
- Sites 5, 6, and 7 will be used to assess the performance of a natural riparian zone to improve the quality of surface-water runoff. Sites 5 and 6 are located at the entrance of the riparian zone, which is in the east-central part of the watershed. Most of the eastern part of the watershed, which will be planted in conventional cotton, eventually drains through Sites 5 and 6. Site 7 is located at the outlet end of the riparian zone upstream of the lake entrance.

C. Deep Hollow Lake watershed (Figure 1)

- Site 8 is an edge-of-field site located in the southeastern part of the watershed near the lake. Fields upstream of Site 8 are planted in both soybean and cotton and will have a combination of conservation tillage and winter cover crops as BMPs.
- Site 9 is located in the northeastern part of the watershed near the lake. The ditch at this site also drains both soybean and cotton fields that will have the combination of conservation tillage and winter cover crops. Site 9 is different from site 8 because the culvert entrance will have a slotted-board riser.

METHODS AND MATERIALS

Streamflow (or total runoff volume) and water-quality samples are collected at each site in the network. Concentration distributions and loads can be calculated at each site for every runoff event; data can then be compared between the two BMP watersheds and the control watershed. The following sections describe the structures and instrumentation used to measure streamflow and the strategy used to collect water-quality samples.

Streamflow Measurement

The agricultural setting of the MDMSEA project presents a number of hydraulic problems that cause difficulty in accurately measuring streamflow. For example, ditches and row alignments are designed to drain fields very quickly to prevent ponding of water on the fields after heavy rainfall. Ponded water prevents farming operations and can also cause crops to rot if ponded for long periods of time. Because of the small drainage basins and the small travel times for flow, instrumentation must account for rapidly rising and falling stages during heavy rainfall. Structures such as flumes or weirs are also used to provide permanent channel geometry to facilitate streamflow computations. A hydraulic problem at two of the sites is backwater caused by flat channel slopes and site locations in close proximity to the lakes. Additional instrumentation may be necessary to compute streamflow at sites with backwater conditions. The following paragraphs describe the structures and instrumentation that are used at each site to measure streamflow.

Sites 1 and 9 use 2.5-foot H-flumes constructed of sheet metal as the primary method to measure streamflow (Kilpatrick 1965). The H-flumes have laboratory-developed stage-flow (stage-discharge) relations; however, streamflow measurements have been made to verify those relations (Rantz et al. 1982). The laboratory-developed stage-flow relation for a 2.5-foot H-flume is shown in Figures 2a and 2b along with the streamflow measurements made at Sites 1 and 9, respectively. Staff gages have been installed in the flumes for a supplemental outside reference for stage. Stages are recorded at these two sites using bubbler-type instrumentation. A bubbler instrument discharges a bubble of air through tubing that has an outlet at the bottom of the flume. The bubbles of air pass through the tubing at a rate of about 1 bubble per second. The pressure required to force the bubble of air through the tubing increases with stage, and this information is recorded by the data logger. Rain gages are installed at these sites to measure the total amount of rainfall during storms.

Site 4 was scheduled to have a 2-foot H-flume attached to the culvert outlet to measure streamflow. However, during most storms, the culvert outlet was observed to be affected by backwater due to the flat slope and close proximity of the site to Beasley Lake, thus nullifying the stage-flow relation associated with an H-flume. As previously stated, this site will be used to evaluate the effectiveness of a slotted-board riser as a BMP. A slotted-board riser acts as a weir to reduce energy and associated velocities of the runoff, thus causing the suspended-sediment particles to settle before flowing through the culvert and into the lake. Because the riser acts as a weir, it was determined that the best alternative to an H-flume would be to rate the site as a rectangular sharp-crested weir (Rantz et al. 1982). Channel and weir geometry will be surveyed to compute a stage-flow relation based on a weir equation. Streamflow measurements will be made to verify the weir equation. A staff gage has been installed about 15 feet upstream of the riser and will be used as the supplemental reference for stage. Stage is measured using a bubbler, and a rain gage has been installed at the site.

Site 8 presented a difficult challenge to measure streamflow. Runoff from the fields drains though a culvert that has a 10 percent slope in 40 feet. A large scour hole is located at the outlet of the culvert due to the high velocities associated with the large culvert slope. From the scour hole, runoff flows about 100 yards to Deep Hollow Lake. During the rainy winter months, the area between the outlet of the culvert and the lake is completely ponded. Due to high velocities in the culvert and the ponding downstream of the culvert, it was impractical to develop an accurate stage-flow relation using culvert computations. It was determined that the best alternative was to measure streamflow upstream of the culvert. Several flume designs were considered but were not selected because they could not be adapted to the conditions upstream of the culvert nor could they be attached easily to the culvert invert. An approach channel made of sheet metal was designed and attached to the culvert invert. The approach channel is rectangular with a height of 20 inches and width of 24 inches. A staff gage has been installed upstream of the entrance of the approach channel and will be used as the supplemental reference for stage. Critical depth and a hydraulic jump occur in the approach channel slightly upstream of the culvert invert during runoff events. A bubbler was installed at the same location as the staff gage to measure stage, and a rain gage was installed. Streamflow measurements have been made near the entrance of the approach upstream of critical depth and the hydraulic jump. Figure 2c shows the stage-flow relation for Site 8 that was established using the streamflow measurements.

Sites 2 and 3 are affected by backwater conditions. Both sites are located upstream of culverts and upstream of the lakes. Streamflow is determined at these two sites by multiplying the cross-sectional area of flow by instantaneous values of velocity. Instantaneous values of cross-sectional area can be converted to instantaneous values of stage using a stage-area relation. The channel geometry must be stable, but not necessarily uniform, to establish the stage-area relation. The channel at Site 2 is about 5 to 10 feet deep and 40 to 70 feet wide and is considered stable. No channel stabilization improvements were necessary at this site. The channel at Site 3 is trapezoidal with a 20-foot bottom width, a 25-foot top width, and is 8 to 10 feet deep. The channel cross section is not stable and is periodically "cleaned" with a backhoe by the landowner. For these reasons, a concrete trapezoidal weir was constructed in the channel at Site 3 to provide a stable cross section. Cross-sectional channel geometry was surveyed at the two sites. Step-backwater computer models were used to compute the stage-area relations at both sites by calculating values of cross-sectional area for incremental values of stage. Staff gages have been installed to provide a supplemental reference for stage, and rain gages have been installed at both sites.

Instantaneous velocity at Sites 2 and 3 is measured by area-velocity meters. These devices use the Doppler technology, in which a pair of transducers mounted in a sensor transmits and receives ultrasonic wave signals in the flow path of the drainage ditch. After one of the transducers sends the wave signal into the flow path, particles such as sediment or even water bubbles reflect the wave signal to the receiving transducer. The difference in the frequency of the wave signals after being transmitted and received is proportional to the velocity of flow. Because the transducers detect both increases and decreases in wave frequencies, the sensor can then detect the velocities of both forward (toward the sensor) and reverse (away from the sensor) flows. These velocities are considered an instantaneous velocity for that particular location in the channel. Velocity gradients within the entire cross-section of a channel vary laterally and with depth. Streamflow measurements are made to determine average velocities for the entire cross section, and an average velocity-instantaneous velocity relation can be established. By using the stage-area relation and the average velocity-instantaneous velocity relation, incremental values of streamflow can be computed using the continuity equation (Chow 1959).

Sites 5, 6, and 7 are located in the riparian zone area of Beasley Lake watershed. All three sites have unstable channel banks, indeterminate drainage boundaries, and intermingling flow. Reliable streamflow measurements at these sites are virtually impossible to determine. Therefore, stage is the only data recorded at these sites. Sites 5 and 6 use an ultrasonic instrument that sends a signal to the surface of the water and receives the reflected signal. The signal is related to stage and is recorded by the data logger. Stage is measured at Site 7 with a bubbler. Staff gages are installed at the three sites as a supplemental reference for stage.

Water-Quality Sampling Strategy

Traditional scientific approaches emphasize sampling strategies to quantify pollutant loads to assess the effects of agricultural activities on water quality and the effectiveness of BMPs. However, such approaches are limited in that the quantified pollutant load may be the only data product of that study. Issues such as the determination of the chemical speciation of a pollutant cannot be addressed when pollutant loads are the only data product. In addition, most regulatory criteria for public water supplies are specified in terms of pollutant concentrations rather than loads (for example, Maximum Contaminant Levels, MCLs). A scientific approach that emphasizes a sampling strategy to quantify pollutant concentration distributions as well as loads with time would provide a more comprehensive data base to address such issues.

Research by Roman-Mas and Klaine (1994) conducted in the Beaver Creek watershed in West Tennessee emphasized a sampling strategy in which multiple discrete samples were collected during storms by automated samplers. Discrete sampling provides an accurate characterization of the temporal patterns in the concentration of chemicals and sediment in agricultural runoff. The research included a strategy to determine an optimal frequency of collecting discrete samples during storms. Discrete samples were collected about every 5 minutes during storms. Therefore, for a 2-hour storm duration, about 24 samples were collected, processed, and analyzed. One of the results of the research was that significant differences in the data occurred as a result of increasing the sampling frequency from 5 to 60 minutes. Segregating the data into growing seasons or segregating the data on the basis of position on the storm hydrograph (rising limb, falling limb, and so forth) did not alter the results. The conclusion drawn by Roman-Mas and Klaine was that an optimal sampling strategy for small drainage basins was one in which samples are collected about every 5 percent of the total runoff volume.

Results from the Beaver Creek research were incorporated into the sampling strategy of the MDMSEA project. However, due to budget limitations, discrete sampling was not feasible for all of the MDMSEA sites. A combination of flow-weighted composite and discrete sampling will be used instead. All of the sites will have at least one sampler to collect a flow-weighted composite sample. During runoff events, small portions, or aliquots, of runoff water will be collected and deposited into a series of glass bottles. The water that is collected in each container is combined into one container and then divided into samples that are shipped for analyses. Therefore, only one sample is analyzed to determine an average concentration for a particular constituent for the runoff event. The water will be analyzed for suspended-sediment concentration; nutrients, such as dissolved nitrate, dissolved nitrite, dissolved ammonia, dissolved ortho-phosphorus, total nitrogen, and total phosphorus; total organic carbon (TOC); and selected cotton herbicides such as fluometuron and norflurazon. Composite samples will be collected and analyzed for almost every runoff event throughout the year.

Sites 1, 4, and 8 will have two additional automated samplers for the purposes of discrete sampling. Individual samples are collected on the basis of incremental amounts of runoff volume based on the Beaver Creek research. These samples are placed in polypropylene containers and analyzed individually. One sampler will collect samples that are analyzed for suspended-sediment concentration for almost every storm event at these three sites. The other sampler will collect samples that are analyzed for nutrient and herbicide concentrations similar to the composite samples mentioned previously with the exception of TOC. These discrete samples will only be collected for runoff events during the growing season, mid-March through August, each year.

The strategy for collecting runoff samples would not be complete without an adequate quality assurance/quality control (QA/QC) program. In 1994, the USGS began a new QA/QC program for all water-quality related projects throughout the Nation. This program was developed to provided researchers with means to detect and eliminate potential sources of sample contamination and to assess the quality of data that were analyzed at trace levels. The new program has been nicknamed the "parts-per-billion protocols" and includes cleaning procedures, QA/QC sample collection such as field and equipment blank samples, and statistical methods of QA/QC data interpretation. A complete description of the new program is provided in Horowitz et al. 1994. The new program has been incorporated into the sampling strategy of the USGS for the MDMSEA project. Specific items of the new program that were adopted for the MDMSEA project are as follows:

- All sampler tubing used for sampler intake lines are made of Teflon.
- The sample bottles are either glass or fluorinated polypropylene. Fluorinating the polypropylene bottles causes them to be more inert than non-fluorinated bottles. The tubing used for filtration is Teflon.
- Glass and polypropylene bottles are cleaned in the lab prior to field use as follows: De-ionized (DI) water rinse, non-phosphorus detergent rinse, DI water rinse, methanol rinse. The tubing used for filtration is cleaned similarly.
- All sampler lines in the field will be rinsed with DI water at least three times between each storm event.
- Field blanks will be taken at least four times per year (or more if time allows): winter, early spring, late spring, and summer. Both organic and nutrient blanks will be collected and analyzed.
- If significant "hits" are observed in the field blanks, then appropriate action will be taken to identify and eliminate the source of contamination.
- Equipment blanks for the filtration system will be collected and analyzed with each set of environmental samples (per storm event).
- Split samples from the composite samplers will be taken about 1 in every 20 samples.
- Laboratories will provide additional QA/QC as samples are received, processed, and analyzed.

PRELIMINARY RESULTS

Several storms were sampled in fiscal year 1996. Most of the automatic samplers were not operational until about June of 1996, effectively after the "spring flush" of pre-emergence chemicals. Samples were collected manually in the spring of 1996. All of the composite samplers are currently operational, and composite samples have been collected at most of the sites since July 1996. Discrete sampling for suspended-sediment concentrations began in the summer of 1996 and is ongoing. Discrete sampling for chemical constituents will not begin until the spring of 1997.

Nitrogen will be studied extensively in the MDMSEA because it is an important component in the balance of the ecosystem that receives the runoff from the fields. Nitrogen must be available to aquatic systems to nurture plants that are a food source to fish and other wildlife. However, too much nitrogen in the system can cause problems such as algal blooms that reduce dissolved oxygen or are toxic to organisms in the lakes.

Nitrogen can exist in the runoff water basically in two ways - dissolved in the water or adsorbed onto particulate matter that is transported in the water. By analyzing the runoff water for dissolved nitrogen, researchers can estimate the fate of nitrogen that is applied to a field. Dissolved nitrate, nitrite, and ammonia concentrations for six of the nine runoff sites are summarized in Figure 3. The riparian zone sites in the Beasley Lake watershed have not been sampled as of the date of this paper.

As expected, the highest concentrations of nitrate in samples among all of the sites were at Site 1 in the Thighman Lake watershed, which is the control watershed. These concentrations occurred during the spring flush period of April and May of 1996 and were all above 10 milligrams per liter (mg/L) as N. Nitrite and ammonia concentrations were also high during this period. Nitrate, nitrite, and ammonia concentrations decreased in the summer and fall months. Nitrate, nitrite, and ammonia concentrations were low at Site 2 in the Thighman Lake watershed during the spring flush, however.

Higher concentrations of nitrate were observed in the spring months than in the fall months at Sites 3 and 4 of the Beasley Lake watershed and Sites 8 and 9 in the Deep Hollow Lake watershed. Ammonia concentrations appear to follow similar temporal patterns as nitrate levels at Sites 8 and 9. Other than samples collected at Site 1, samples collected in March of 1996 at Sites 8 and 9 have the only other nitrate concentrations above 10 mg/L.

SUMMARY

The USGS began installation and operation of a streamflow and water-quality sampling network in the fall of 1995 as part of the MDMSEA project. The primary objective of the network is to sample storm runoff from agricultural fields that contain BMPs and from fields that do not contain BMPs. Data from the various sites will analyzed to assess how agricultural practices affect water quality and to evaluate the effectiveness of BMPs.

The streamflow and water-quality sampling network of the USGS was organized to characterize the runoff in each of the three MDMSEA watersheds and to evaluate as many BMPs or BMP combinations as possible. Two principal types of information are collected at each site in the network: streamflow (or total runoff volume) and water-quality data.

The agricultural setting of the MDMSEA project presents a number of hydraulic problems that cause difficulty in measuring streamflow accurately. Streamflow instrumentation must overcome the difficulty of measuring rapidly rising and falling stages during storms at some sites and severe backwater problems at other sites. Structures such as flumes or weirs are used to provide permanent channel geometry to facilitate streamflow determinations.

Traditional scientific approaches emphasize sampling strategies that quantify pollutant loads. A scientific approach that emphasizes a sampling strategy to quantify pollutant concentration distributions as well as loads with time would provide a more comprehensive data base. Thus, a combination of flow-weighted composite and discrete sampling is being used for sampling the runoff for the MDMSEA project. The runoff water is being analyzed for suspended-sediment concentration; nutrients, such as dissolved nitrate, dissolved nitrite, dissolved ammonia, dissolved ortho-phosphorus, total nitrogen, and total phosphorus; total organic carbon; and selected cotton herbicides such as fluometuron and norflurazon. Quality assurance/quality control of the sampling process has been adopted from the latest national USGS program.

Several storms were sampled in fiscal year 1996. Most of the automatic samplers were not operational until about May 1996, effectively after the "spring flush" of pre-emergence chemicals. Samples were collected manually in the spring of 1996, however. All of the composite samplers are currently operational, and composite samples have been collected at most of the sites since June 1996. Discrete sampling for suspended-sediment concentrations was begun in the summer of 1996 and is ongoing. Discrete sampling for chemical constituents will not begin until the spring of 1997.

Nitrogen will be studied extensively in the MDMSEA project. Nitrogen can exist in the runoff water basically in two ways - dissolved in the water or adsorbed onto particulate matter that are transported in the water. By analyzing the runoff water for dissolved nitrogen, researchers can estimate the fate of nitrogen that is applied to a field. The highest concentrations of dissolved nitrate among all of the sites were observed at the edge-of-field site in the Thighman Lake watershed, which is the control watershed. These samples were collected during the spring flush period of April and May 1996 and were all above 10 mg/L.

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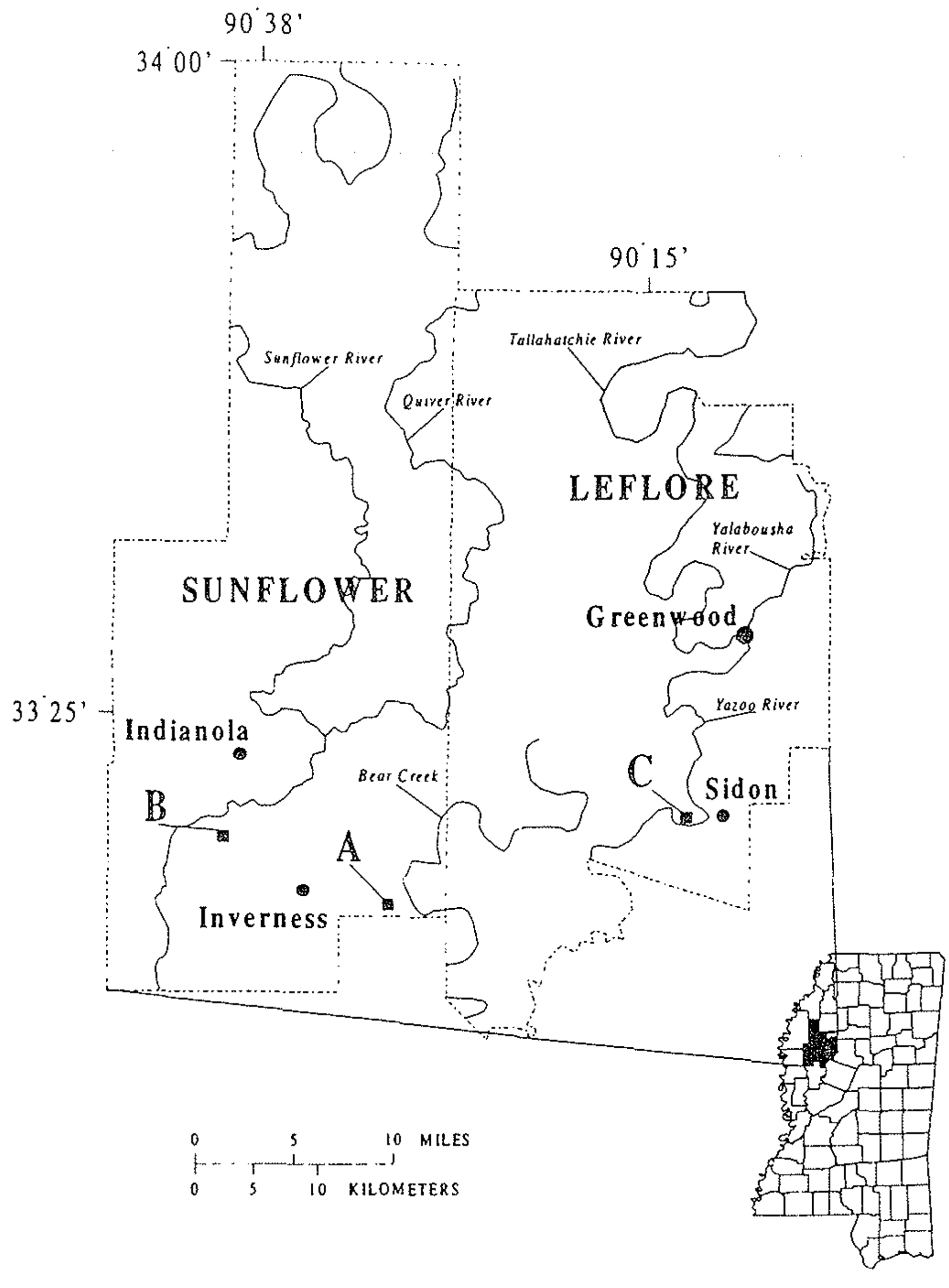


Figure 1. Mississippi Delta MSEA study watersheds and runoff monitoring site locations: A) Thighman Lake watershed (Sites 1 and 2); B) Beasley Lake watershed (Sites 3 - 7); C) Deep Hollow Lake watershed (Sites 8 and 9).

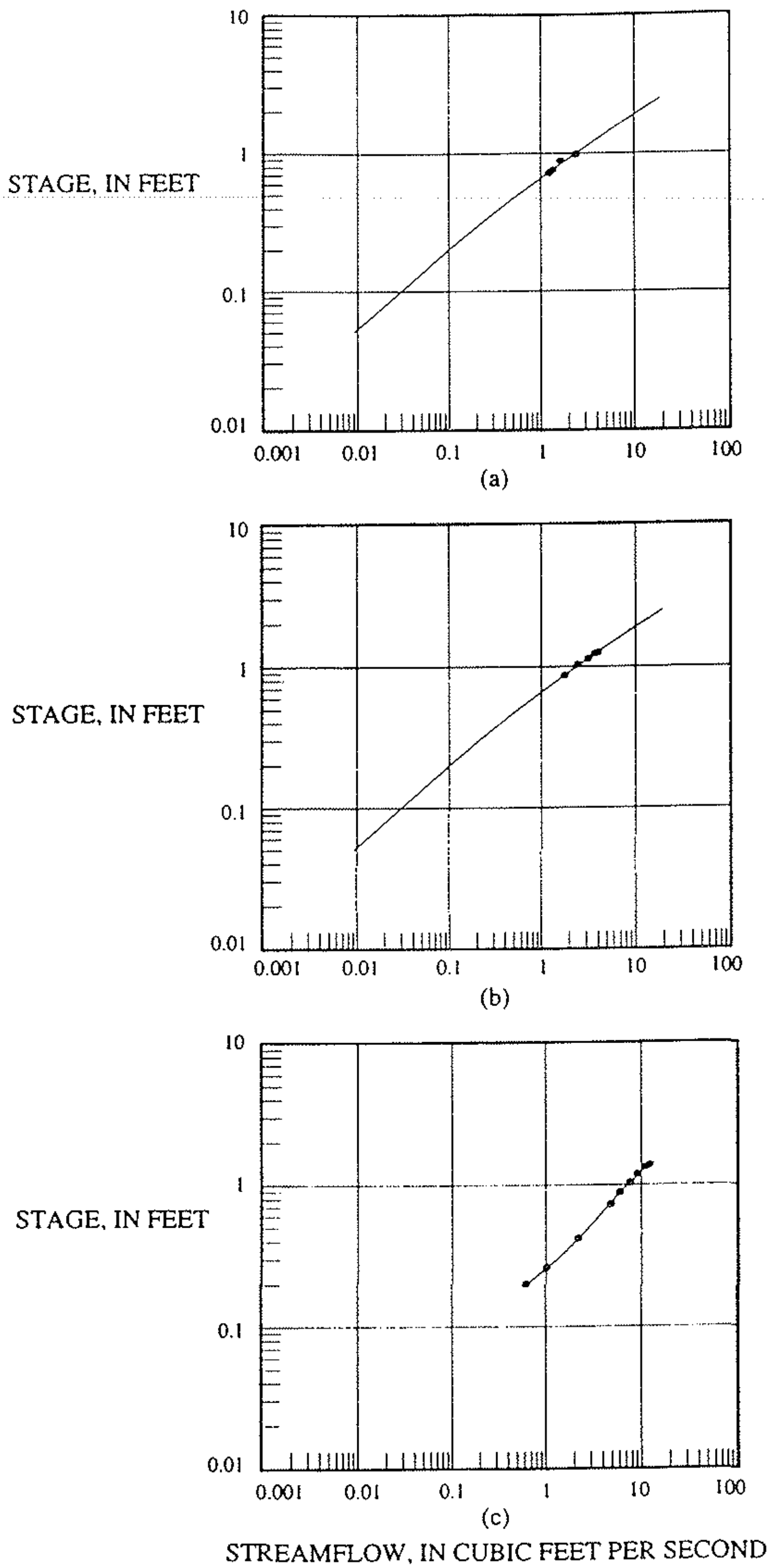


Figure 2. Stage-flow relations for flumes and associated streamflow measurements for: a) Site 1, b) Site 9, and c) Site 8.

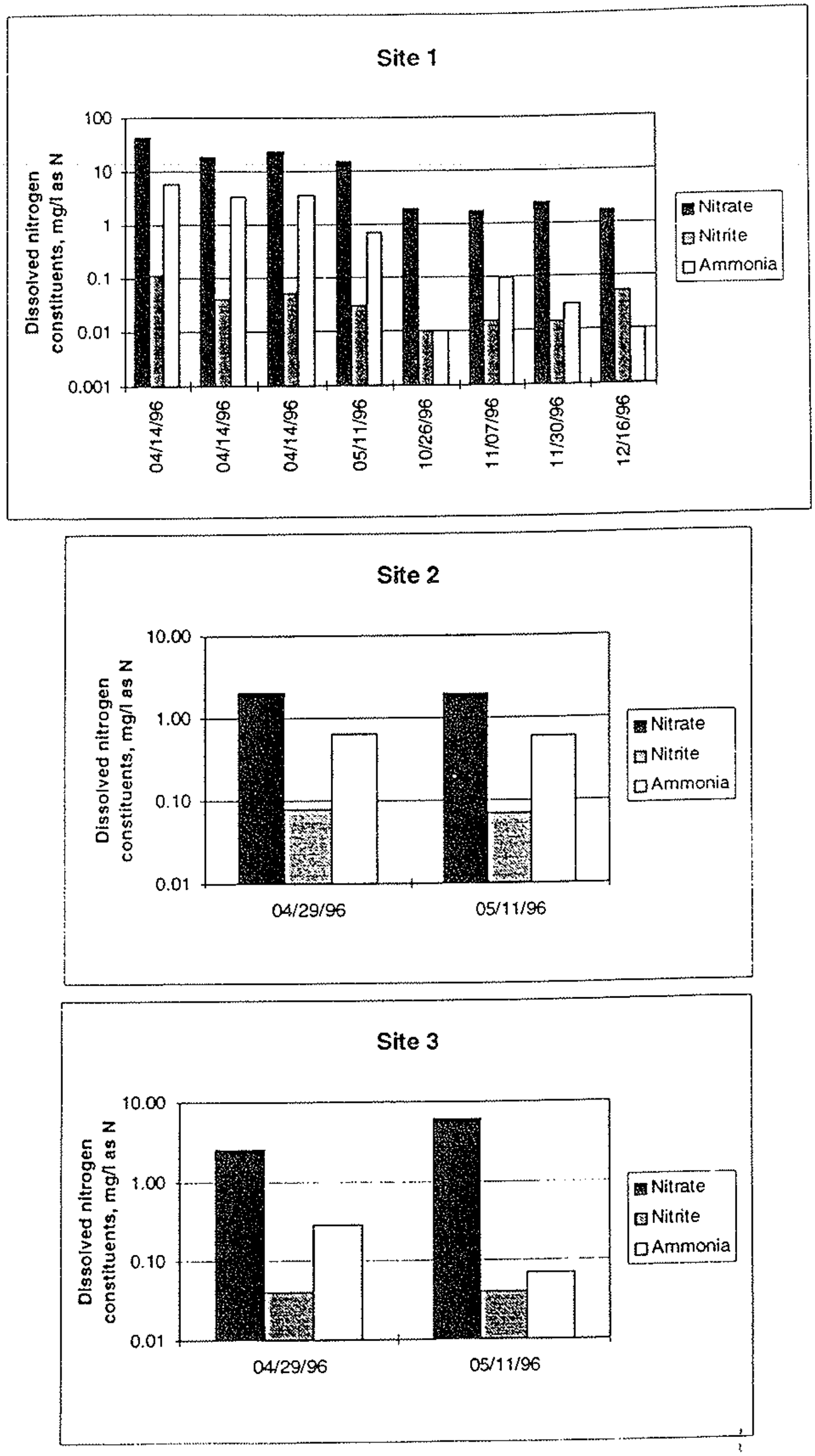
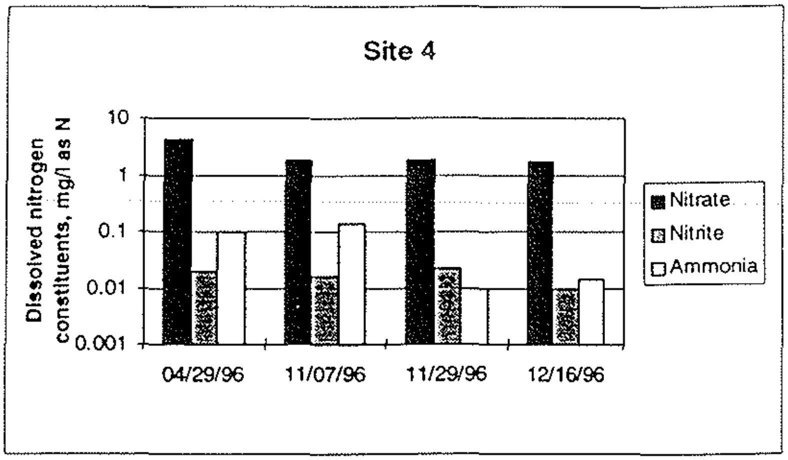
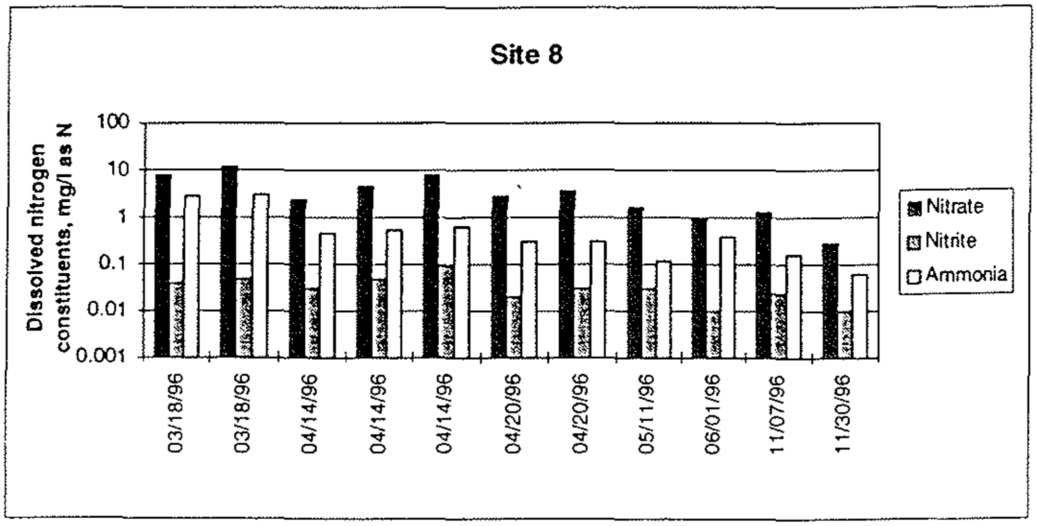


Figure 3. Dissolved nitrate, nitrite, and ammonia concentrations for samples collected at selected MDMSEA sites.





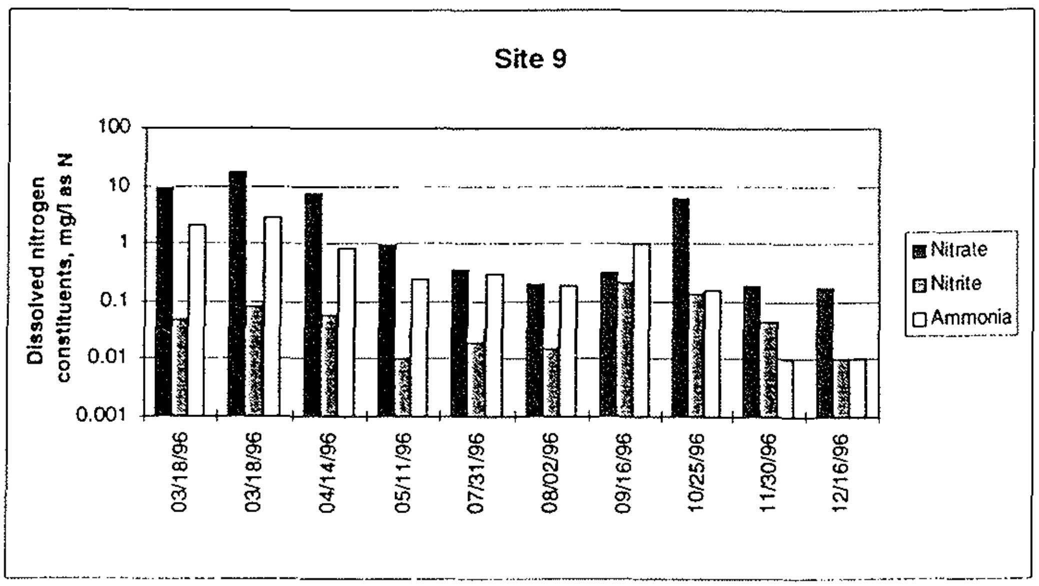


Figure 3...*continued*. Dissolved nitrate, nitrite, and ammonia concentrations for samples collected at selected MDMSEA sites.