Two Approaches to Identify Storm Water Runoff Loads

W. Harry Doyle, Jr.
Hydrologist
U.S. Geological Survey
Marshall E. Jennings
Hydrologist
U.S. Geological Survey
Gulf Coast Hydroscience Center

INTRODUCTION

By the early 1970's it was becoming apparent that man's land-use activities were seriously affecting the water quality of the nation's streams. Even though pollutants, that is, high concentrations of certain water-quality constituents, from "point" sources such as industrial and municipal locations in urban areas were substantially reduced, serious levels of pollution remained and were attributed to "nonpoint" sources including storm-water runoff from urban areas. To aid in urban storm-water planning, the U.S. Geological Survey (USGS) is developing methods of identifying non-point pollution based on data collection and modeling concepts. After outlining storm-water quality planning approaches, this paper describes two studies recently completed in Houston, Texas and Miami, Florida. The studies are representative of pilot USGS activities in urban storm-water hydrology.

APPROACHES TO STORM-WATER QUALITY PLANNING

Urban storm-water quality problems arise from man's land-use and other activities within and adjacent to urban areas. Pollutants accumulate on urban surfaces, especially impervious areas which are subject to washoff by storm events. Automobile emissions, fertilizers applied to lawns, industrial effluents and many other pollutant sources are washed from the atmosphere and the urban landscape into storm-drainage systems and eventually into receiving waters. Because pollutant loads often enter streams during summer storms while streams are at low flow, they frequently cause a shock to the stream's ecosystem.

Storm-water quality planning has two main phases: identification of sources of pollutants and approaches to pollutant level reduction. The USGS is active in the identification phase of urban storm-water planning. Due to a lack of basic data, the identification of urban pollutant sources has not been accomplished—at least in the comprehensive sense required for metropolitan planning. A recently initiated national study of urban storm-water runoff sponsored by the U.S. Geological Survey and the U.S. Environmental Protection Agency should aid in identifying urban storm-water problems and to test management practices. Once the sources of urban pollutants have been adequately identified, studies of alternative approaches to pollutant level reduction such as street sweeping, litter control, detention ponds, storm-water treatment and so forth can proceed. The effectiveness of the various pollutant level reduction strategies can be tested using data collection and modeling techniques.

Two recently completed USGS studies in the Houston, Texas, and Miami, Florida, areas provide examples of urban storm-water studies approached at widely differing scales of data collection and modeling approaches. The Houston urban study reflects the use of sparse data from large watersheds and employment of a "coarse" modeling technique. The Miami, Florida, urban study involved intense data collection and a more refined modeling approach applied to relatively small catchments. These studies, discussed below, illustrate the identification phase of urban storm-water quality planning.

HOUSTON, TEXAS, URBAN STORM-WATER STUDY

The Texas Department of Water Resources developed a water-quality model of the Galveston Bay estuarine system. A significant part of the inflow to Galveston Bay is runoff from the Houston metropolitan area; therefore refinement and verification of the estuarine model required order-of-magnitude definition of the quality of runoff from the Houston area. The study has been reported in Waddell, Massey and Jennings (1979).

The Houston study area (figure 1) is the rapidly urbanizing Buffalo Bayou basin encompassing 975 square miles in and near metropolitan Houston, Texas. Gaged watersheds in the study varied in size from 16 to 293 square miles. Land use in the study area was 55 percent rural, 32 percent residential, and 13 percent industrial-commercial. Although streamflow records have been continuously collected at some of the sites since about 1940, water-quality record collection began in 1969. However, most samples were collected during non-storm conditions.

Because of the limitations of funding and available data and the large areas to be studied, a broad-scale modeling approach was selected as the best approach to satisfy study objectives. The model selected for use was the "STORM" (storage, treatment, overflow, and runoff) model developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (1976). The model was calibrated independently for each of eight watersheds and combinations of five land-use characteristics using measured evaporation, runoff, and water-quality data. Although STORM operates on an hourly time step, the flow from each basin was calibrated to best fit the measured annual runoff volume with some emphasis on monthly volumes. Continuous daily discharge values were available for each site. All available sample analyses were used to estimate daily and annual loads (or concentrations) of biochemical oxygen demand, dissolved solids, total phosphorus, total organic carbon, and total nitrogen, and also the densities of fecal-coliform bacteria. Regression equations were developed which expressed the relationship between constituent concentrations and discharge. The equations provided a means of estimating daily and therefore annual water-quality loads.

For modeling purposes it was necessary to calibrate the accumulation of constituents in pounds per day by land use. A series of linear equations of the form:

$$C_1 \cdot O_j + C_2 \cdot S_j + C_3 \cdot M_j + C_4 \cdot I_j + C_5 \cdot Cu_j = R_{ij}$$

where $C_1, C_2 \ldots C_5$ are unknown constituent accumulation rates for each of the five land uses. O_j, S_j, M_j, I_j, and Cu_j are respectively the areas in acres for the open land, single-family residential, multiple-family residential, industrial and commercial land-use types, and R_{ij} is the observed basin accumulation rate in pounds per day for constituent i and basin j. The values of R_{ij} were averaged over a year to provide daily estimates. The solution of the linear equations for a subset of five basins provided estimates of $C_1, C_2 \ldots C_5$. The technique assumes uniform constituent accumulation rates for a given land-use throughout the study area.

The water quality calibration for each basin was accomplished by adjusting washoff parameters until the modeling results were in near agreement with the regression estimated values of annual runoff loads. A long term (20-year) simulation was made for each of the eight basins in the Houston area using hourly precipitation data as input to the calibrated STORM model. A flow chart of the computations is shown in figure 2.

The results of the Houston study indicated that annual storm-runoff loads ranged from 43 to 97 percent of total basin load (includes both storm and non-storm runoff loads) depending on

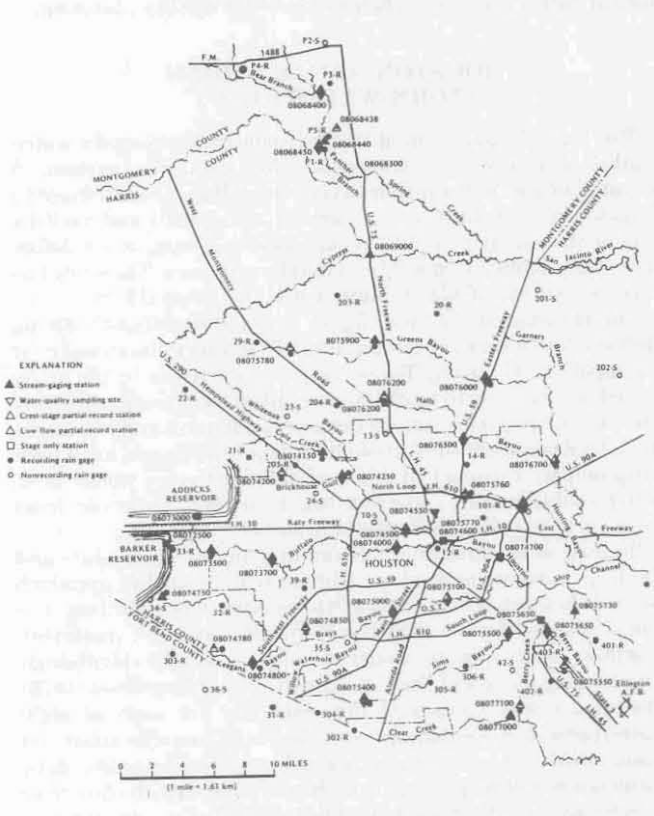

Figure 1. Houston Study Area

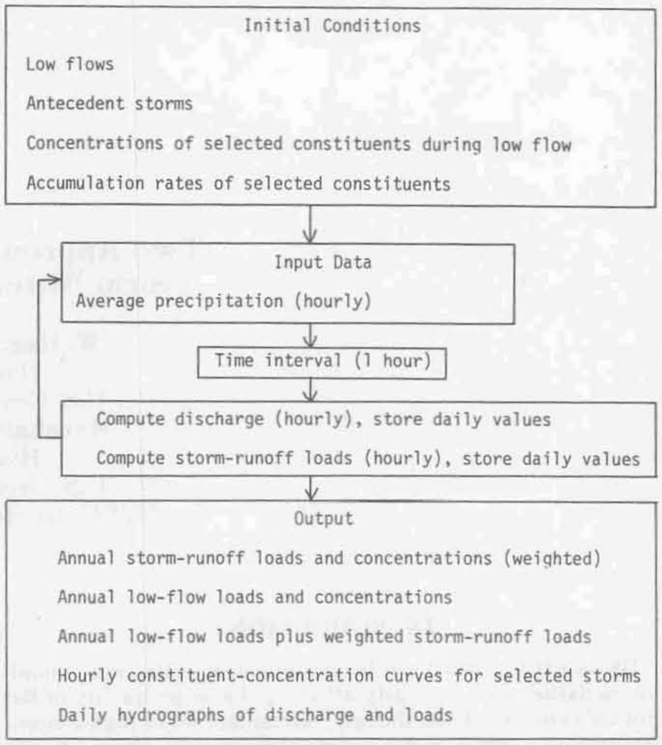

Figure 2. Flow chart of STORM calculations for Houston Study

the basin and the constituent. Calibration errors for simulated annual data for the eight basins using 1975 water-year data ranged from -9 to +5 percent for discharge to -33 to +140 percent for fecal-coliform bacteria. Annual, and with some restrictions, monthly water-quality loads resulting from the study were recommended for use in the estuarine studies. Thus, as a broad-scale identification approach, the Houston STORM application successfully obtained the required estimates of storm-water loading into Galveston Bay.

MIAMI, FLORIDA, URBAN STORM-WATER STUDY

In contrast to the Houston study, the Miami, Florida, study involved a comprehensive data collection network that was established to identify urban pollutant sources by gaging and sampling runoff from small catchments of homogeneous land use. Figure 3 shows the location of the catchments which included a single-family residential area of 40.8 acres, a highway area of 58.3 acres, a commercial area of 20.4 acres, and a multiple-family residential area of 14.7 acres. Essentially, this study constituted a research effort to test the utility of identifying pollution quantities from small catchments having a specific land use. The gaging of such small catchments also required the development of special instrumentation and data handling procedures.

The instrumentation developed for the study was an automated monitoring system (Hardee, 1979) designed especially for measurement of storm-water quantity and quality in urban storm sewers. The instrumentation system recorded rainfall and stage data and activated the water-sampling equipment. All functions of the system, shown in figure 4, were simultaneously recorded on a six channel analog recorder allowing records to be filed in a computerized data base at 1-minute time intervals.

Rainfall was recorded by as many as three tipping-bucket rain gages, each with a resolution of 0.01 inch of rainfall. Rain gages were connected to the recorder at the central gaging point by commercial telephone lines. Flow in the storm sewers was

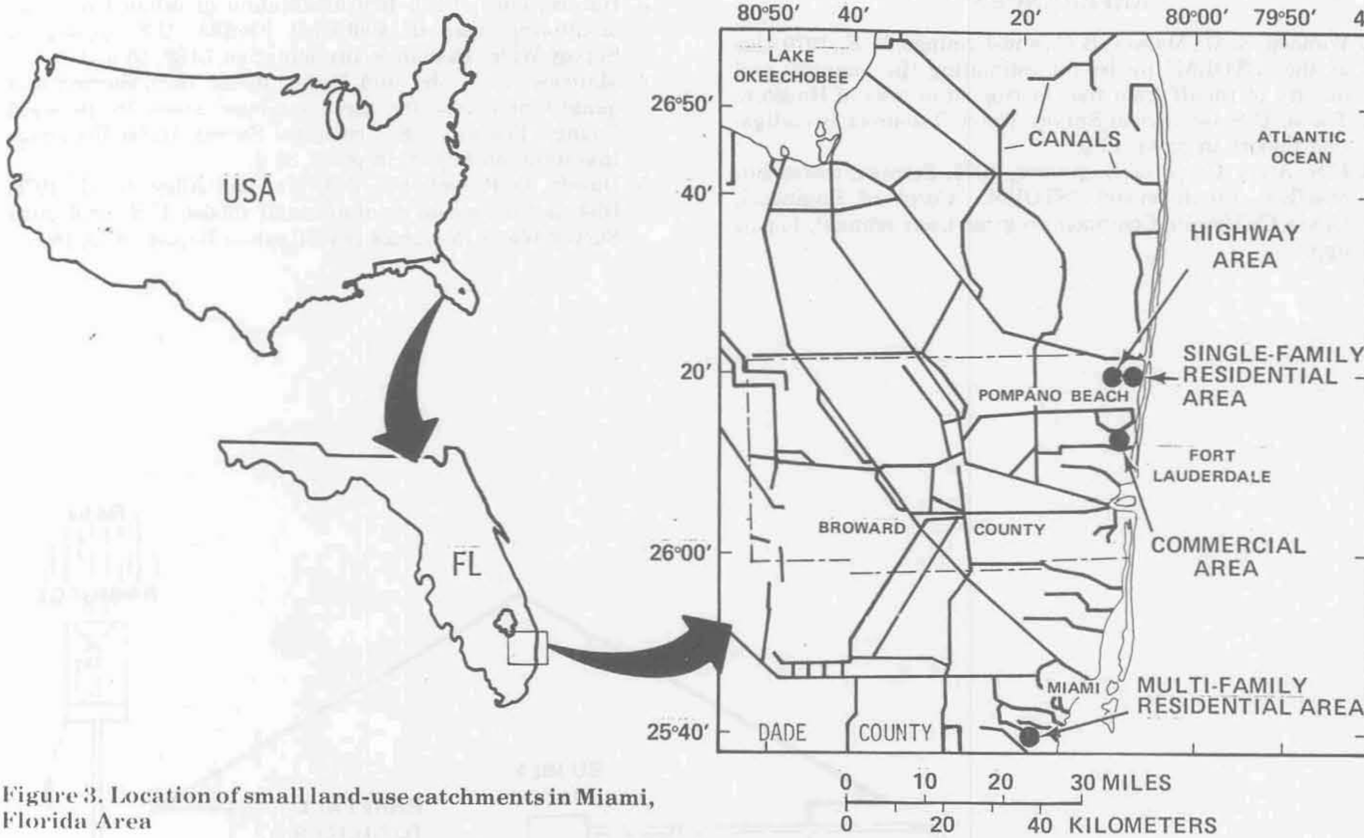

Figure 3. Location of small land-use catchments in Miami, Florida Area

computed from the continuous record of water pressure at two peizometers in a U-shaped Venturi-type construction. A continuous flow water-quality sampling system collected 24 (2-liter) at a preset time interval ranging from 2 to 7 minutes depending on the site. Sampling was initiated by a pre-selected water stage in the sewer. Storm-water was continuously pumped through a distribution system filling a 2-liter sample bottle in 10 seconds. In addition to runoff water-quality samples, chemical analyses were also made of bulk precipitation (dry fallout plus wetfall).

The automatic instrumentation facilitated collection of intensive data describing urban storm-water processes. The mass of data made it necessary to develop a data management system as shown in figure 5. The system provided report generation capability and, in addition, interfaced storm data to statistical and mathematical models.

One of the objectives of the Miami studies was to determine storm and annual constituent loads generated from representative land uses in South Florida. Thus, constituent loads were calculated using measured discharge and water-quality data for about 30 storms at each site during the gaging period. Utilizing multiple-regression techniques relating storm load to various hydrologic and meterologic parameters, it was possible to estimate loadings for unsampled storm events. Average annual basin loadings in pounds per day per acre for various land uses are shown in figure 6. A report by Mattraw and Miller (1979) describes interpretive results for three land-use areas in the Miami Area.

Another objective of the Miami studies was to test the utility of rainfall/runoff models for small catchments with short-time interval rainfall-runoff data. The distributed watershed model selected for simulation of the rainfall-runoff process was developed by Dawdy, Schaake, and Alley (1978). This model required detailed basin characteristics information as shown for the highway site in figure 7. Some of the better flow modeling results for this particular site are shown in figure 8.

The availability of instrumentation, data handling, and modeling capability for collecting and analyzing urban storm-water data on small homogeneous land-use catchments provides a basis for defining urban storm-water quality processes. Assuming catchment information can be transferred to ungaged areas, simulation modeling of larger urban watersheds becomes possible in order to test alternatives for pollutant level reduction.

CONCLUSIONS

Two different approaches to identification of urban pollutants for urban storm-water quality planning have been used by the U.S. Geological Survey in two recently completed studies. A broad-scale identification approach was used to determine the amount of urban pollutants that enter Galveston Bay from the Houston, Texas, metropolitan area. Results of the Houston study indicated that annual storm-runoff loads ranged from 43 to 97 percent of individual total basin loads (includes both storm and non-storm runoff loads). In contrast to the broad-scale approach that is useful for quick, order-of-magnitude answer, an intensive approach that involved a comprehensive data collection network was used in a Miami, Florida, study to identify urban pollutant sources from four small catchments of homogeneous land use. If monies and manpower are available, the intensive approach can be used to identify pollutants by land-use type. Once the sources of urban storm-water pollutant generation are identified, the second phase of planning the reduction of stormwater pollutants can begin.

REFERENCES

1. Waddell, K. M., Massey, B. C., and Jennings, M. E., 1979, Use of the "STORM" model for estimating the quantity and quality of runoff from the metropolitan area of Houston, Texas, U.S. Geological Survey Water Resources Investigation Report, in press, 49 p.
2. U.S. Army Corps of Engineers, 1976, Storage, treatment, overflow, runoff model "STORM", Corps of Engineers, Davis, California, Computer program users manual, 45 p., 4 app.
3. Hardee, Jack, 1979, Instrumentation of urban hydrology monitoring sites in southeast Florida, U.S. Geological Survey Water Resources Investigation 79-37, 56 p.
4. Mattraw, H. C. Jr., and Miller, R. A., 1979, Storm-water quality processes for three land-use areas in Broward County, Florida, U.S. Geological Survey Water Resources Investigation Report, in press, 84 p.
5. Dawdy, D. R., Schaake, J. C. Jr., and Alley, W. M., 1978, Distributed routing rainfall-runoff model; U.S. Geological Survey Water Resources Investigation Report 78-90, 146 p.

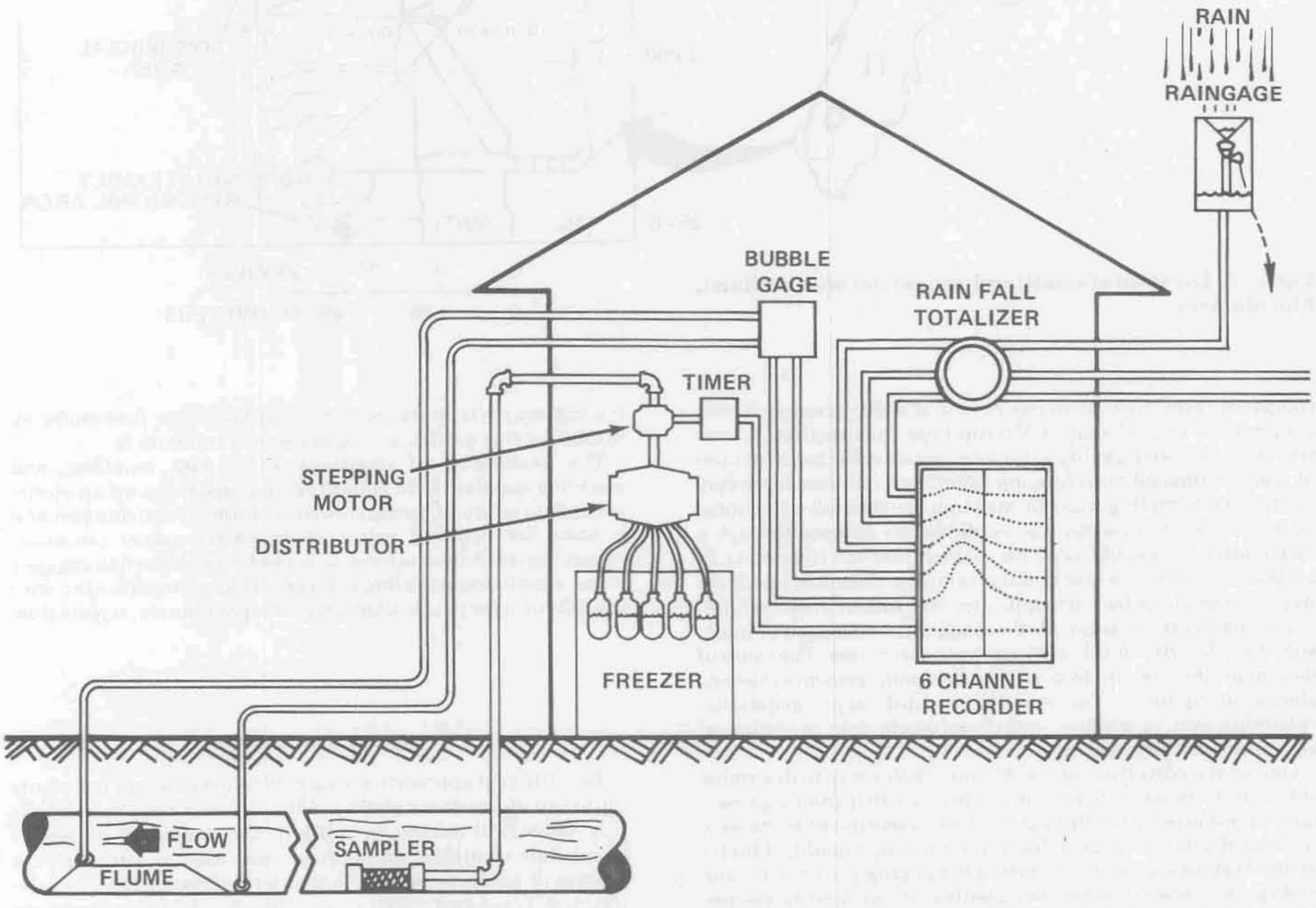

Figure 4. Schematic of Miami Urban Instrumentation System

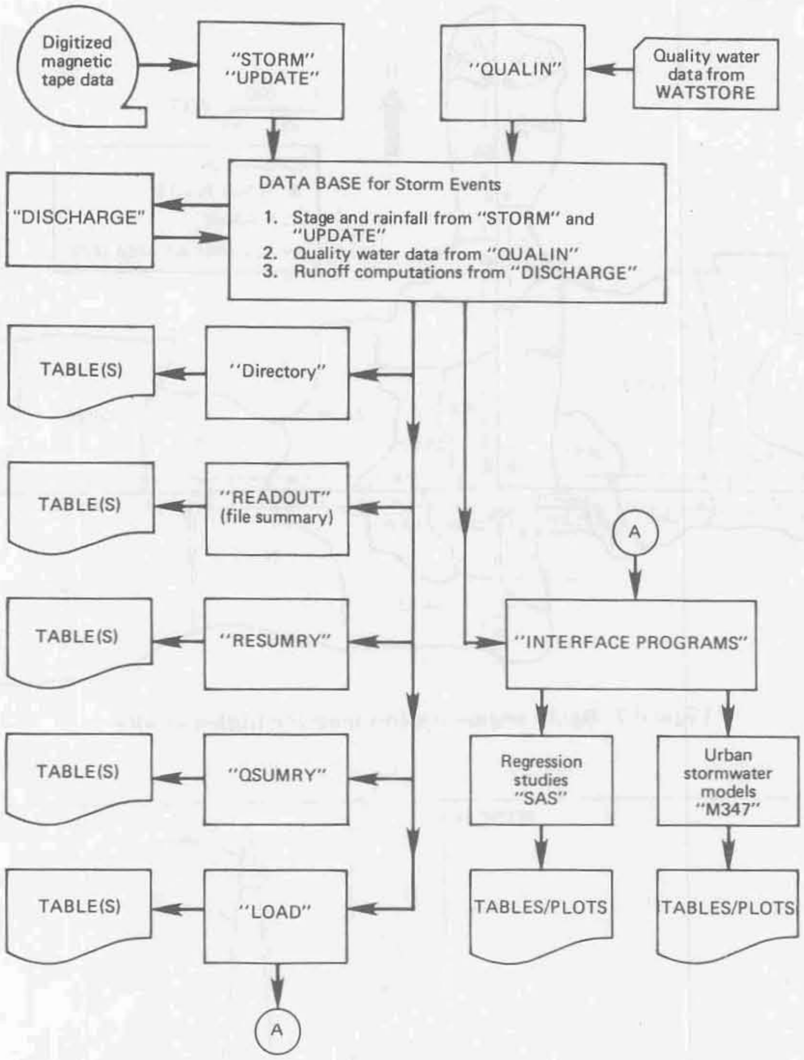

Figure 5. Data Management System for Miami Urban Storm-Water Study

AVERAGE ANNUAL BASIN LOADINGS IN POUNDS PER DAY PER ACRE

	Single-family Residential	Highway	Commercial
H.E.I.A.*	2.4	10.5	20.0
Total nitrogen	0.046	0.016	0.023
Total phosphorus	0.0090	0.0016	0.0017
Total Carbon	0.42	0.41	0.40
Chemical oxygen demand	0.70	0.94	1.8
Total residue	3.9	2.0	3.6
Total lead	0.0025	0.0073	0.0099
Total zinc	0.0026	0.0017	0.0031

*Hydraulically Effective Impervious Area (in acres)

Figure 6. Daily loadings for three land-use areas

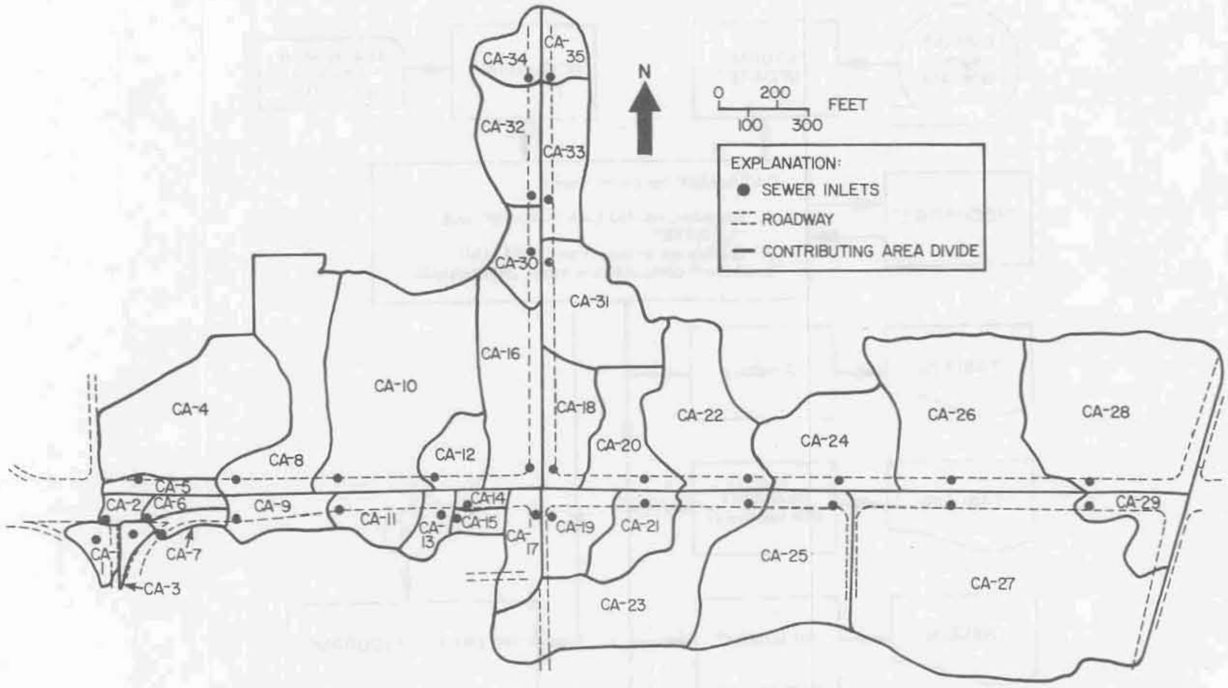

Figure 7. Basin segmentation map for highway site

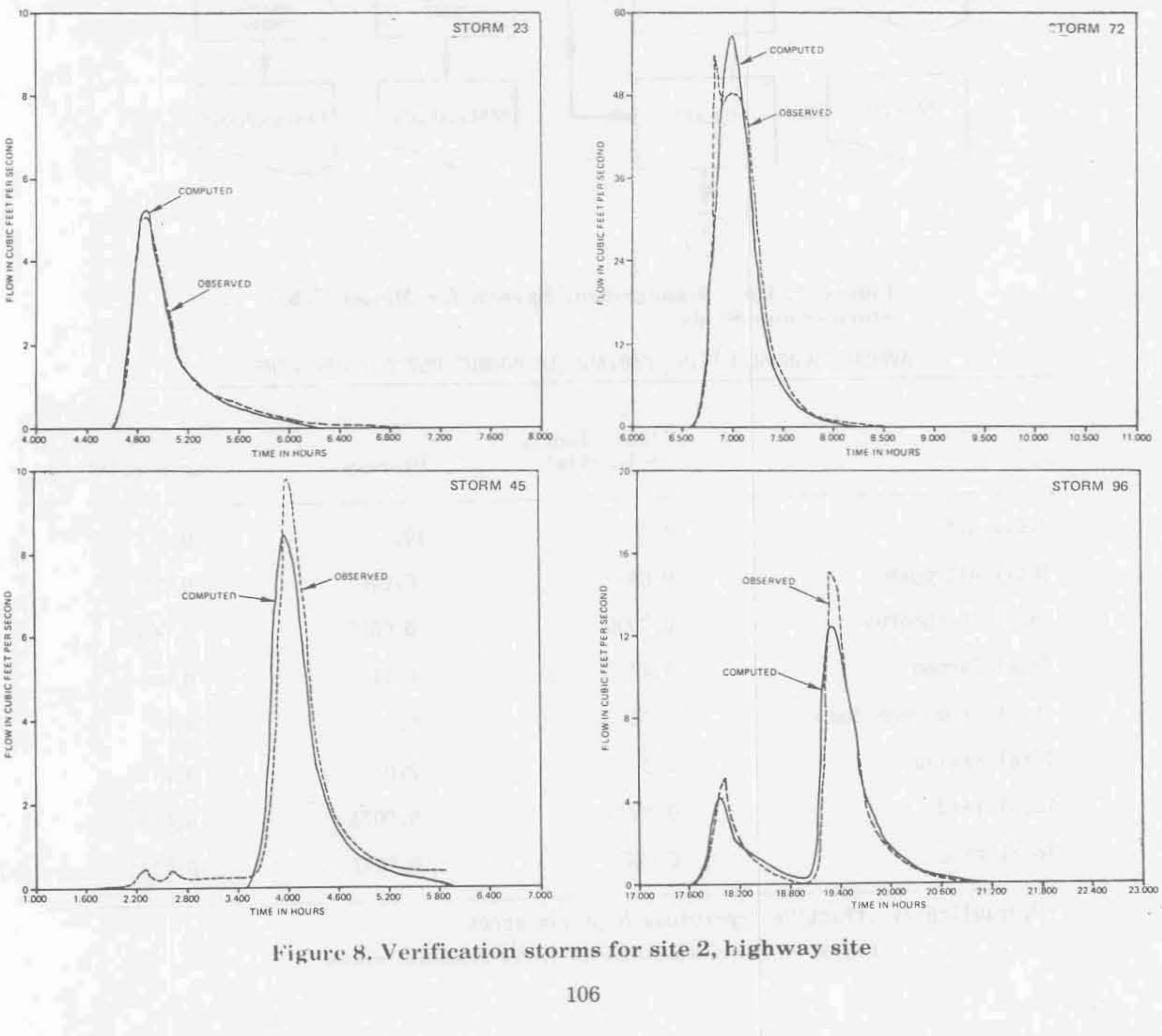

Figure 8. Verification storms for site 2, highway site

CONFERENCE ATTENDANCE

Bennett, Allen	Corps of Engineers - Vicksburg District	Vicksburg
Bernard, Jerry M.	Soil Conservation Service	Jackson
Bond, Marvin	Water Resources Research Institute	MSU
Bowie, Andrew J.	USDA Sedimentation Laboratory	Oxford
Campbell, John T.	Office of Water Research & Technology	Washington, DC
Carlson, Karl W.	Electrical Engineering Department	MSU
Carroon, Lamar	U.S. Geological Survey	Jackson
Cribbs, M.E.	Soil Conservation Service	Jackson
Currie, Floyd L.	Corps of Engineers - Mobile District	Mobile, AL
Dana, Caleb	Bureau of Pollution Control	Jackson
Dedeaux, Edwin K.	Allen & Hoshall, Inc.	Jackson
Dendy, Farris E.	USDA Sedimentation Laboratory	Oxford
Doyle, Harry W.	U.S. Geological Survey	NSTL Station
Eatherly, Billy J.	Economics Department	MSU
Eleuterius, Charles	Gulf Coast Research Laboratory	Ocean Springs
Engdahl, Thomas L.	Waterways Experiment Station	Vicksburg
Fulton, William A.	Soil Conservation Service	New Albany
Galdis, Alan V.	Corps of Engineers - Mobile District	Mobile, AL
Goodman, Max R.	Soil Conservation Service	New Albany
Guest, George P.	Spencer Associates, Inc.	Jackson
Hart, Dale	Corps of Engineers - Vicksburg District	Vicksburg
Herring, John W.	Electrical Engineering Department	MSU
Hill, Jr., Thomas	Corps of Engineers - Vicksburg District	Vicksburg
Hines, James V.	Corps of Engineers - Vicksburg District	Vicksburg
Hobgood, William B.	Corps of Engineers - Vicksburg District	Vicksburg
Holman, David	Miss. Research & Development Center	Jackson
Hollman, Kenneth W.	Bureau of Business & Economic Research	UM
Jaynes, Samuel L.	Continental Engineering	Aberdeen
Jennings, Marshall E.	U.S. Geological Survey	NSTL Station
Keeter, Frederick E.	USDA Soil Conservation Service	Clinton
Key, Russell	Pat Harrison Waterway District	Hattiesburg
King, Hub	Smith & Sanders, Inc.	Jackson
Ladner, Cornell	Miss. Bureau of Marine Research	Long Beach
Langston, John C.	Soil Conservation Service	Jackson
Long, Fred W.	Soil Conservation Service	Greenwood.
May, Jonathan	USDA Sedimentation Laboratory	Oxford
McCleave, Barry W.	Waterways Experiment Station	Vicksburg
McHenry, J. R.	USDA Sedimentation Laboratory	Oxford
Melton, Gary L.	Corps of Engineers - Mobile District	Mobile AL
Mitchell, Gayle F.	Civil Engineering Department	MSU
Montgomery, Raymond L.	Waterways Experiment Station	Jackson
Mowry, Bruce A.	Civil Engineering Department	MSU
O'Dell, Robert	Jackson County Planning Commission	Pascagoula
O'Neal, Ferris B.	Pat Harrison Waterway District	Wiggins
Pepper, Jack W.	Bureau of Land & Water Resources	Jackson
Peterson, John H.	Anthropology Department	MSU
Rentschler, Robert	Corps of Engineers - Vicksburg District	Vicksburg
Roberts, Vernon A.	Pat Harrison Waterway District	Quitman
Römkens, M. J. M.	USDA Sedimentation Laboratory	Oxford
Rowe, Lawrence A.	USDA Soil Conservation Service	Jackson
Seyfarth, Robert H.	Bureau of Pollution Control	Jackson
Simmons, H. B.	Waterways Experiment Station	Vicksburg
Smith, Mark O.	DNR - Bureau of Pollution Control	Jackson
Stampley, Norris L.	Miss. Power and Light Co.	Jackson

Stennis, Earl A.	MAFES	MSU
Sullivan, Michael J.	Biological Sciences Department	MSU
Tate, Jr., Charles H.	Waterways Experiment Station	Vicksburg
Thompson, Frederick G.	Corps of Engineers - Mobile District	Mobile, AL
Ulmer, Ross L.	USDA - Soil Conservation Service	Clinton
Unger, Robert W.	Michael Baker, Jr., Inc.	Jackson
Whisler, Frank D.	Agronomy Department	MSU
Wilhelms, Steven	Waterways Experiment Station	Vicksburg
Wiygul, Julius S.	Mississippi State Highway Department	Jackson
Young, Judy K.	Agronomy Department	MSU
Zitta, Victor L.	Civil Engineering Department	MSU