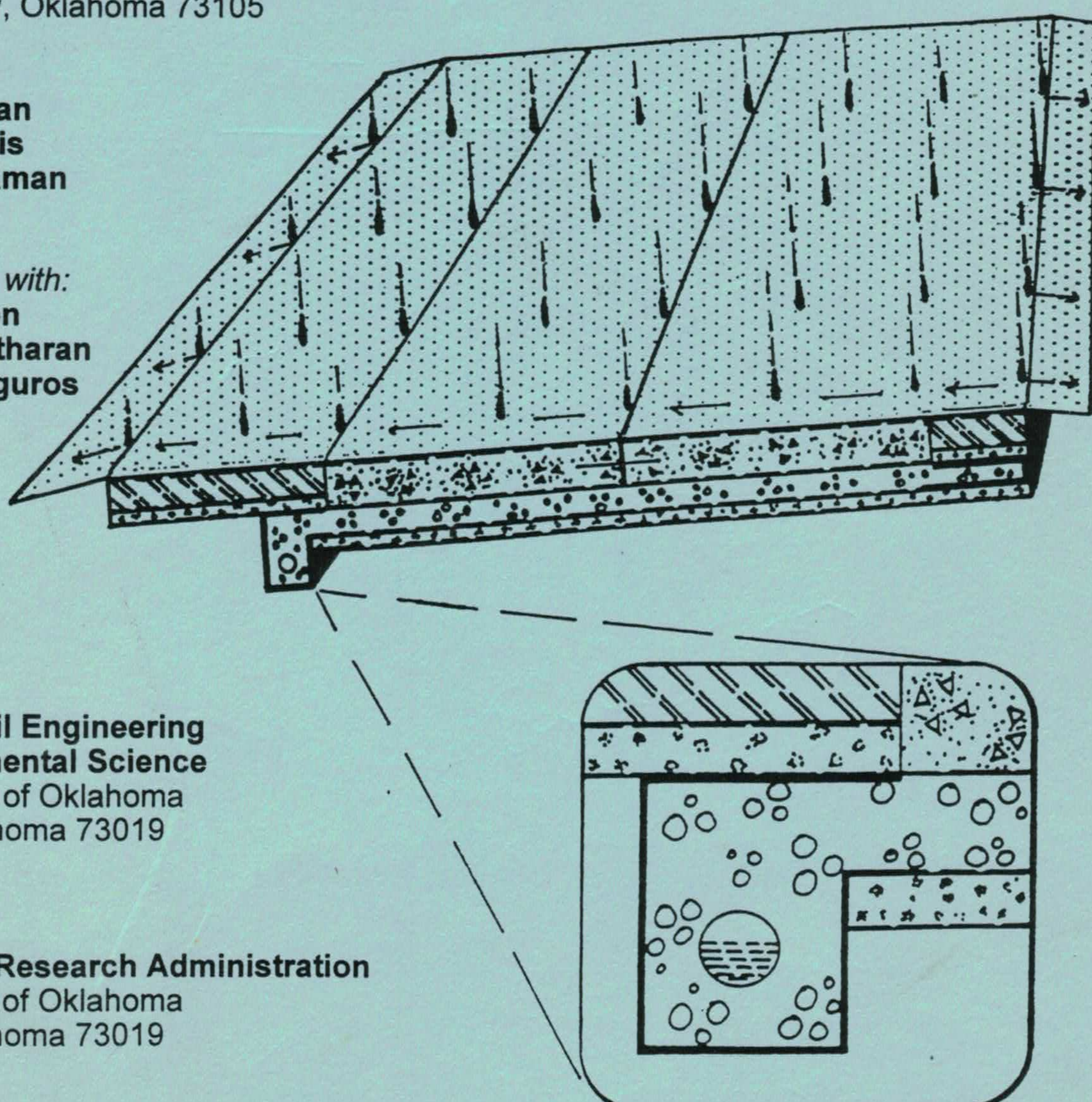
FIELD EVALUATION OF DRAINABLE BASES IN OKLAHOMA

FINAL REPORT
(Item 2181; ORA 125-4299)

Submitted to:
Lawrence J. Senkowski
Assistant Division Engineer
Research and Development
Oklahoma Department of Transportation
200 N. E. 21st Street
Oklahoma City, Oklahoma 73105

Prepared by:
Motiar Rahman
Thomas Curtis
Musharraf Zaman

In cooperation with:
David A. Ooten
K. K. Muraleetharan
Joakim G. Laguros



School of Civil Engineering
and Environmental Science
The University of Oklahoma
Norman, Oklahoma 73019

From:
The Office of Research Administration
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16 . ABSTRACT

The Oklahoma Department of Transportation (ODOT) Research and Development Division (R&D) installed field data acquisition systems in 1992 on five test pavement sections with a view to evaluate the performance of the drainable base and edge drain systems in Oklahoma. Rainfall, outflow and other data have been collected continuously since that time. The University of Oklahoma (OU), in association with ODOT, analyzed the field data, developed appropriate computer programs (written in SAS 6.08 language) to analyze the data, developed a simple, quick and efficient field test scheme to evaluate the drainage efficiency of the existing pavement sections, and conducted a number of field tests for this purpose. This report presents the results of these studies.

The useful data, containing rainfall values and the corresponding outflow values reflecting the drainage characteristics of the pavement drainage system, were identified and grouped into a number of "events." The events were studied to establish any relationship between outflow and rainfall magnitudes, flow rates, time required to initiate flow in different types of pavements, and time required for drainage. This information was combined to determine the drainage efficiency of the corresponding drainable base and edge drain system. Finally, the time for 50% drainage was computed and compared with the AASHTO guidelines to determine the drainage quality of the pavements under investigation. This report presents the steps involved in grouping, analyzing and interpreting the field data, and explains the findings with appropriate textual and graphical illustrations.

A field test procedure was developed to facilitate a quick examination of the quality of a pavement drainage system. The procedure for this field test, results of the field tests performed, and a comparison with regular rainfall and outflow data are also presented in this report.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

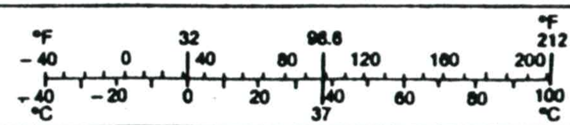
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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EXECUTIVE SUMMARY

With the objective of draining out the water entrapped in a pavement section in a quick and efficient manner, and thereby, providing the pavement the opportunity to perform under design conditions, some form of drainage systems are installed presently in most new pavement construction projects, as well as, pavement rehabilitation projects. The performance and efficiency of these drainage systems in a real field situation, as compared to the design and theory, is largely unknown. This report deals with this particular issue.

The Oklahoma Department of Transportation (ODOT) Research and Development Division (R&D) installed field data acquisition systems in 1992 on five test pavement sections with a view to evaluate the performance of the drainable base and edge drain systems in Oklahoma. Rainfall, outflow and other data have been collected continuously since that time. The University of Oklahoma (OU) School of Civil Engineering and Environmental Science (CEES), in association with ODOT R&D, analyzed the field data, developed appropriate user-friendly computer programs (written in SAS 6.08 language) to analyze the data, developed a simple and time efficient field test scheme to evaluate the drainage efficiency of in-situ test sections, and conducted a number of field tests for this purpose. This report presents the results of these studies.

The useful data, containing rainfall values and corresponding outflow values and reflecting the drainage characteristics of the pavement drainage system, were identified and grouped into a number of "events." The events were studied to find out any relationship between outflow and rainfall magnitudes, flow rates, time required to initiate flow in different types

of pavements, and time required for drainage. This information was combined to determine the drainage efficiency of the corresponding drainable base and edge drain system. Finally, the time for 50% drainage was computed and compared with AASHTO guidelines to determine the drainage quality of the pavements under investigation.

It was found that a pavement section with edge drain, in absence of any open graded base, did not experience any outflow. Another pavement section with edge drain and broken and seated concrete base experienced very little outflow at a very slow rate. None of these two systems were deemed acceptable from pavement drainage considerations. The other three pavement sections with edge drains and open graded bases, experienced frequent outflow and performed more efficiently as compared to the other two sections. This report presents the steps involved in grouping, analyzing and interpreting the field data, and explains the findings with appropriate textual and graphical illustrations.

A field test procedure was developed to facilitate quick examination of the quality of a pavement drainage system. The procedure for this field test, results of the field tests performed, and comparison with regular rainfall and outflow data are also presented in this report.

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Inadequate drainage continues to be a major source of problems associated with the performance of roadway pavements. It not only makes a roadway surface hazardous to traffic due to increased skid potential but also threatens particularly the long term structural integrity of the pavement itself. To reduce the impact of drainage related problems, efforts have been made in the past to prevent water from entering the roadbed and to enhance the drainage capability of the base for water that inevitably finds its way into the roadbed. In an attempt to evaluate the drainage characteristics of pavements, AASHTO has proposed a technique, but its implementation in a field situation is unclear. During the past few decades, the traffic volumes and loads have increased tremendously, making the need to understand the drainage behavior of pavements particularly critical. This report presents the findings of a study "Field Evaluation of Drainable Bases in Oklahoma" conducted by the University of Oklahoma in collaboration with the Oklahoma Department of Transportation.

1.2 BACKGROUND

Drainage of water was an important consideration in road construction practices in ancient Rome, Greece and Egypt. In the 18th and early 19th centuries, French and English engineers addressed this problem. P.M.J. Tresaguet, the introducer of "French drains" in France, and Thomas Telford and John L. McAdam in England made significant contributions in this regard (Ref. 1). In the early 20th century, the mechanization of handling, processing and placing of materials resulted in major changes in roadway design and construction methods.

Usually these roads were not designed for drainage of internal water. But during the past few decades, the traffic volumes and loads increased so much that these kind of roads are no longer successful. As a result, drainage has drawn the attention of the pavement designers once again.

Reports regarding the removal of water from pavement sections were published in 1944 by Izzard (Ref. 2), in 1952 by Casagrande and Shannon (Ref. 3) and by Barber and Sawyer (Ref. 4). Since these studies, a general attention to internal water removal in road designs started gaining momentum. Since about 1970, various agencies have shown considerable interest toward pavement subsurface drainage. Publications by Cedergreen (Ref. 5), Cedergreen et al. (Ref. 6, 7), Moulton (Ref. 8), and Dempsey et al. (Ref. 9) are some of the important works in this field. New types of materials like geotextiles and prefabricated geocomposite edge drains have also helped paying increased attention to the drainage of internal water from pavements.

1.3 THE CASE FOR OKLAHOMA

Rainfall is considered the main source of water that enters into the pavements in Oklahoma. The annual rainfall in the State is between 380 to 1420 mm (15 to 56 inches). With a landscape nearly level to gently rolling in 80% of the State, surface runoff is not always so dominant and much of the rainfall water can infiltrate into the pavement base.

Modern pavement drainage facilities in Oklahoma started in 1986 with the installation of edge drain systems on highway US-69 in the eastern part of the State. Oklahoma has used different types of bases such as open graded bituminous base (OGBB), open graded concrete base (OGCB), and "broken and seated" concrete base. Although the primary objective of using the broken and seated base is not to address drainage, this base is still able to drain out some of the water entrapped in the pavement system.

Two major types of edge drains have been used: prefabricated geocomposite edge drains and perforated pipe edge drains. Often in pavement rehabilitation projects, edge drains have been installed within the existing pavement structures (which in many instances do not have a drainable type base). Such operations have been called "retrofit installation of edge drains."

1.4 OBJECTIVES OF THE PROJECT

With the frequent installation of drainable base and edge drain systems on different pavement structures some issues arose. How efficiently do these systems perform, what kind of system (say, prefabricated geocomposite edge drains or perforated pipe type edge drains) is the best, do these systems experience any degradation with time, if so then how soon after installation such questions needed to be answered. Consequently, the Oklahoma Department of Transportation (ODOT) Research and Development Division (R&D) started its research project No. 2181 in 1990. By 1992, five edge drain sites were instrumented with sensors and data loggers and continuous collection of associated drainage data began.

Staff limitations did not allow R&D to effectively and efficiently study the technical issues related to the problem. Therefore, R&D signed a contract with the University of Oklahoma (OU) School of Civil Engineering and Environmental Science (CEES) in January 1995 to pursue a study with the following objectives:

(i) to review and analyze project data in order to characterize the performance of drainable bases and edge drains, and to compare these characteristics to Federal Highway Administration (FHWA) design standards,

(ii) to inspect field installations and modify data collection for increased efficiency and optimum data, and

(iii) to develop and implement a strategy for determining drainage characteristics of in-place test sections.

Since January 1995 this project has been a joint effort between ODOT R&D and OU CEES. The results of this joint study are presented in this report.

1.5 WORK AGREEMENT

A stipulation of the contract mentioned in the preceding section was for OU CEES to provide a Research Assistant (RA) who would use the offices of R&D to perform the research tasks. This was requested for the following reasons:

(i) to better facilitate project understanding,

(ii) to work with the data on ODOT's system, and

(iii) to provide the results on ODOT's computer system.

R&D determined that this project would be best completed without having to convert all data and programming files as all data had been processed using the SAS system, which is not commonly used by the OU CEES. Also, due to the history and complexity of the research project and objectives, face-to-face interaction was deemed the optimum working situation. R&D provided office space, support staff, and a dedicated mainframe graphics terminal for this purpose.

A working agreement was established such that the RA was at the R&D office four days (Monday through Thursday) of the work week, and at OU on Friday (and any other times as necessary). Both data reduction, and review and analysis tasks were performed using this schedule. During the reporting phase of this project, the RA spent more time at OU (as immediate access to data was not as critical) using a PC word processing software package which was compatible with R&D's computer system.

1.6 ORGANIZATION OF THE REPORT

There are nine chapters in this report. Description of the test sites are provided in chapter 2. Various features of data collection and storage efforts are discussed in chapter 3. Some important terms used in this report are defined and explained in chapter 4. Phase-I of data analysis and Phase-II of data analysis are presented in chapters 5 and 6, respectively. The field test developed to evaluate the drainage efficiency of the drainable base system is elaborated in chapter 7. The results of the study are presented in chapter 8, while conclusions and recommendations are outlined in chapter 9.

There are five appendices in this report. The county maps showing the test sites are presented in Appendix A. Various aspects of site instrumentation are discussed in Appendix B. The data acquisition system and procedures related to data retrieval are dealt with in Appendices C and D, respectively. Computer programs used for data analysis are discussed briefly in Appendix E.

CHAPTER 2
DESCRIPTION OF TEST SITES

2.1 GENERAL

ODOT R&D selected five test sites for continuous monitoring of different parameters pertaining to pavement drainage. These five sites are located in different parts of Oklahoma (Fig. 2.1). Table 2.1 provides the location and project information of the test sites. The county maps showing the locations of the test sites are provided in Appendix A (Figs. A-1-A-5). Selected features regarding the geometry and structure of the test sites are discussed in the following sections and are summarized in Table 2.5.

2.2 ROADWAY SLOPES

The test sections are located on roadways having different grade line (longitudinal) slopes, as shown in Figs. 2.2-2.5. The cross slope of all the test sites are same (4.23 mm per m or ¼ inches per foot). However, due to different longitudinal slopes, they have different resulting slopes. The resulting slope is computed by:

$$S_R = [(S_L)^2 + (S_C)^2]^{1/2} \quad (2.1)$$

where, S_R = Resulting slope,

S_L = Longitudinal slope, and

S_C = Cross slope.

The resulting slopes for various sites are provided in Table 2.5. The resulting slopes for the various sites are very close. The maximum resulting slope is found at the Logan county site (0.02149), while the minimum resulting slope is found at the Noble county site (0.02093).

2.3 PAVEMENT MATERIALS AND CROSS SECTIONS

Some of the pavements (Atoka, Noble, and Nowata) are constructed of asphalt concrete while others (Logan and Pittsburg) are constructed of Portland cement concrete. These pavement sections are composed of different layers of varying thickness (Figs. 2.6-2.10). As a result, the crack patterns, joints and permeability of the surface vary from site to site. Therefore the drainage characteristics of one site also vary from that of another site.

2.4 TYPES OF BASE MATERIALS

The test sections have a variety of bases from a drainage standpoint (see Figs. 2.6-2.10 for pavement cross-sections and Figs. 2.11-2.15 for pavement construction drawings). Atoka and Noble county sites have a 102 mm (4 in) open graded bituminous base (OGBB), whereas the site at Pittsburg county has a 102 mm (4 in) open graded concrete base (OGCB). The 102 mm (4 in) drainable bases at Atoka and Pittsburg county sites are underlain by 305 mm (12 in) stabilized aggregate base. The 102 mm (4 in) drainable base at Noble county site is underlain by 152 mm (6 in) fly ash treated subgrade. Both OGBB and OGCB were designed to provide good drainage characteristics.

The site at Nowata county does not have one of these conventional bases. Before the construction of the existing pavement at this site there was a 203 mm (8 in) thick concrete pavement surface (Fig. 2.13). This 203 mm (8 in) concrete pavement was broken and then used as the base material. This is known as the *broken and seated* base.

No drainable base is used at the Logan county site.

The gradation requirements for the OGBB and OGCB, as used in the above sites, are provided in Table 2.2 (Ref. 10, pp. 24-27 and Ref. 11, p. 369). The gradation of the broken and seated concrete base, as used in the Nowata county site, is given in Table 2.3 (Ref. 12, p. 10).

ODOT requires for the OGBB that "the asphalt binder to be mixed with the aggregate shall be AC-20. The amount of binder used shall be 2.5±0.3% by weight of the mix. The amount of asphalt binder may be adjusted if the effective specific gravity of the combined aggregate is greater than 2.833 or less than 2.495" (Ref. 10, pp. 24-25). ODOT requires for the OGCB that "the Portland cement content shall not be less than 282 pounds per cubic yard (167.3 kg/m^3) of the open graded Portland cement base. The water-cement ratio (W/C = lbs. of water / lbs. of cement) shall be a maximum of 0.45" (Ref. 10, pp. 26-27).

2.5 TYPES OF EDGE DRAINS

Prefabricated geocomposite edge drains ("Hydraway Drain®" edge drains, produced by Monsanto Company) were placed at all test sites except the Atoka county site. The flexible, rectangular-shaped edge drains have a cross section of 17⅝ in x $1^{1}/_{16}$ in or 448 mm x 27 mm (nominal 18 in or 457 mm size). A filter fabric is bonded permanently to the internal supporting core. The unobstructed inflow area on the wall adjacent to the pavement (catchment) is 75%, and 5% on the opposing wall. Therefore, almost all water carried by these edge drains should come from the pavements, provided they have a drainable base. The water flow rate through these nominal 18 in (457 mm) edge drains on a slope of 1-2% is 850-1050 GPH (3218-3975 LPH). The filter fabric has an equivalent opening size of 70 maximum sieve size. The coefficient of permeability of the fabric is 0.2 cm/sec (0.0065 ft/sec) (Ref. 13, p. 21).

The Atoka county site has a perforated pipe edge drain placed at the bottom of a 305 mm x

305 mm (12 in x 12 in) trench and covered by coarse aggregate (gravel or crushed stone). The gradation requirements for this aggregate are described in Table 2.4 (after Ref. 11, p. 385). The perforated pipe is of "Corrugated Polyethylene Drainage Tubing" type and conforms to AASHTO M 252 Standards (Ref. 11, p. 456).

2.6 CATCHMENT AREA : LOCATIONS OF THE EDGE DRAINS AND THE OUTLET PIPES

The catchment area for a particular outlet is determined by the locations of the edge drain and the outlet pipes. Theoretically, the catchment area is the roadway area between the two lines of resulting slope that intersect the outlet pipe in question and the upgrade outlet next to it, respectively. This is illustrated in Figs. 2.16 and 2.17. Two dark arrows in these figures indicate the directions of the longitudinal and the transverse slopes. The resulting slope line B′A intersects outlet 1 while the resulting slope line C′D intersects outlet 2. Thus, the rectangle AB′C′D in Figs. 2.16 and 2.17 represents the theoretical catchment area corresponding to outlet 1. However, the area of the rectangle ABCD in these figures is the same as the area of the rectangle AB′C′D; therefore, the catchment area can be taken as the area of the rectangle ABCD (shaded in Figs. 2.16 and 2.17). Depending on whether the edge drain is located at the outer edge of the outside shoulder (case A : Fig. 2.16) or between the driving lane and the shoulder (case B : Fig. 2.17), the area under the outside shoulder may or may not be considered to be a part of the catchment area. Since the edge drains are continuous at all the test sites described in this report, the outlet pipes can often receive water from other catchment areas. For example, outlet 1 in Figs. 2.16 and 2.17 can receive water from the catchment area DCEF if outlet 2 is clogged.

The edge drains are placed between the 3.05 m (10 ft) wide outside shoulder and the right driving lane in the Logan, Nowata, and Pittsburg sites (Figs. 2.12, 2.14 and 2.15). Therefore, the catchment area for these three sites does not include the shoulder area. The edge drain is placed 305 mm (12 in) outside the outside shoulder at the Atoka county site (note that Fig. 2.11 does not show the exact location of the edge drain). At the Noble county site, the edge drain is placed in the outside shoulder at a distance of 483 mm (19 in) measured from the outer edge of the shoulder (note that Fig. 2.13 does not show the exact location of the edge drain).

The outlet pipes are placed at 90-150 m (300-500 ft) intervals.

2.7 PAVEMENTS WITH FABRIC

Some of the sites have a fabric placed above or beneath the drainable base. The drainage characteristics of the fabric affects the flow of water to or from the bases and, consequently, influences the drainage characteristics of the respective sites. Only the Pittsburg county site has a separator fabric beneath the permeable base. There is no separator fabric between the permeable base and the fly ash treated subgrade in the Noble county site. The Atoka county site has a fabric covering a limited area (see Fig. 2.11). There is a pavement reinforcing fabric in the Nowata county site between the 76 mm (3 in) asphalt concrete Type A surface course and the 51 mm (2 in) leveling course Type B layers. Detailed information about the separator fabrics can be found in Ref. 10, pp. 28-29, while information about the reinforcing fabric can be found in Ref. 11, pp. 425-426.

Table 2.1 Pavement drainage test sites

County	Highway	Location	Year constructed	Project No.
Atoka	US-69 Northbound	304.8 m (1000 ft) south of Tushka	1991	F-219 (112)
Logan	I-35 Northbound	mile post 148	1989	IR-35-4 (115)
Noble	US-64 Westbound	4.83 km (3 miles) east of Garfield county line	1990	MAF-396 (86)
Nowata	US-169 Northbound	12.87 km (8 miles) north of SH-28	1990	MAF-193 (45)
Pittsburg	US-69 Northbound	16.09 km (10 miles) north of US-270	1989	F-186 (183)

Table 2.2 Gradation requirements of the materials used for OGBB and OGCB (after Ref. 10, pp. 24-27 and Ref. 11, p. 369)

Size	% passing by weight	
	OGBB	OGCB
1½"	100	100
1"	95-100	95-100
½"	25-60	25-60
No. 4	0-10	0-10
No. 8	-	0-5
No. 10	0-5	-
No. 200	0-3	0-1.5

Table 2.3 Gradation of the broken and seated concrete base placed at the Nowata county site (after Ref. 12, p. 10)

Size	**Weight (Lbs.)**	**% of weight**
16" x 14"	49.1	17.9
8" x 6" to 5" x 3"	102.9	37.6
4" x 3½" to 1½" x 1½"	51.5	18.8
1½" to ½"	36.6	13.4
½" to No. 200 sieve size	33.6	12.3
Total	273.7	100

Table 2.4 Gradation requirements for coarse aggregate cover (after Ref. 11, p. 385)

Description of sieve	**% passing**
½"	100
⅜"	90-100
No. 4	20-55
No. 16	5-30
No. 50	0-10
No. 100	0-5

Table 2.5 Summary of the site geometry

	Atoka	Logan	Noble	Nowata	Pittsburg
Pavement Surface	Asphalt	Concrete	Asphalt	Asphalt	Concrete
Edgedrain Type	102 mm (4 in) diameter perforated pipe	prefabricated geocomposite	prefabricated geocomposite	prefabricated geocomposite	prefabricated geocomposite
Drainable Base	OGBB	-	OGBB	broken and seated	OGCB
Station, 100'	2353+00	1139+13	1416+18	280+16	689+18
Cross Slope, mm/m (in/ft)	4.23 (¼)	4.23 (¼)	4.23 (¼)	4.23 (¼)	4.23 (¼)
Grade, m/m	0.0053	0.0054	0.0024	0.0048	0.0042
Base Width, m (ft)	11.58 (38)	8.53 (28)	11.58 (38)	3.66 (12)	9.75 (32)
Outlet Spacing, m (ft)	91.4 (300)	125.9 (413)	103.6 (340)	152.4 (500)	97.5 (320)
Resulting Slope, m/m	0.021465	0.02149	0.020938	0.021347	0.02122
Resulting Angle (°)	14.295°	14.554°	6.582°	12.995°	11.416°
Resulting Length, m (ft)	11.95 (39.21)	8.82 (28.93)	11.66 (38.25)	3.76 (12.32)	9.95 (32.65)
Catchment Area, sq. m (sq ft)	1059 (11400)	1074 (11564)	1200 (12920)	557 (6000)	951 (10240)

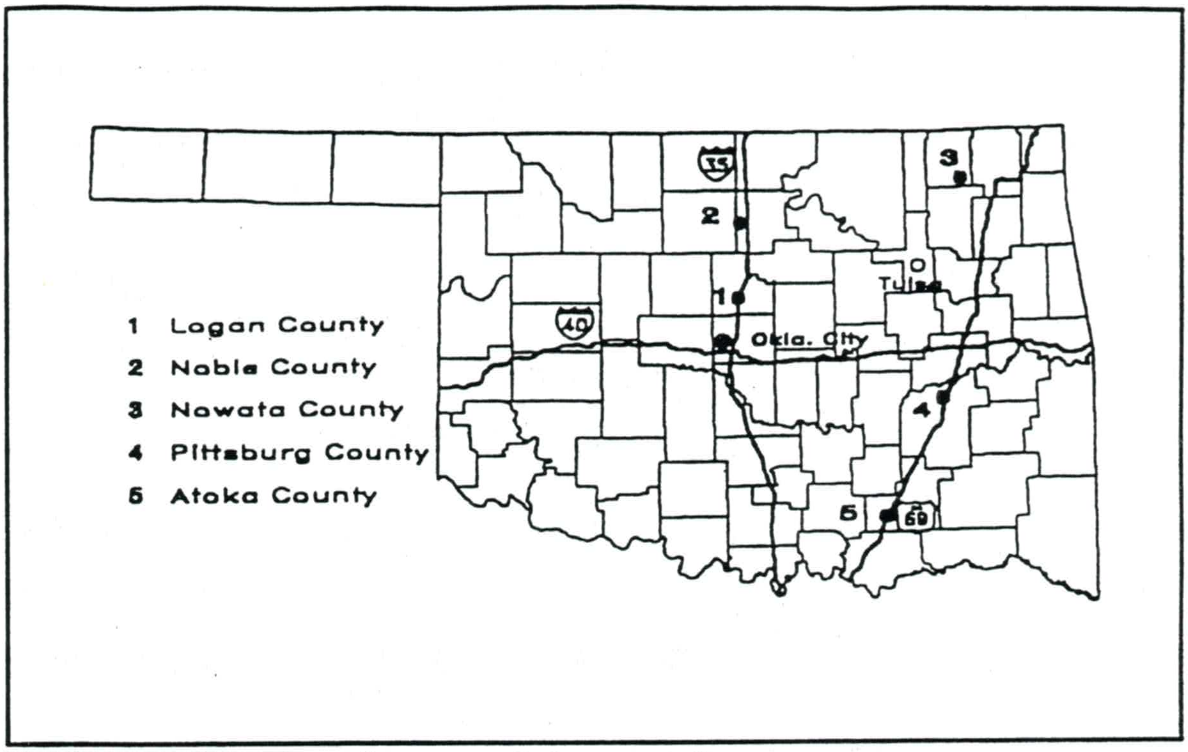

Fig. 2.1 Locations of pavement drainage test sites

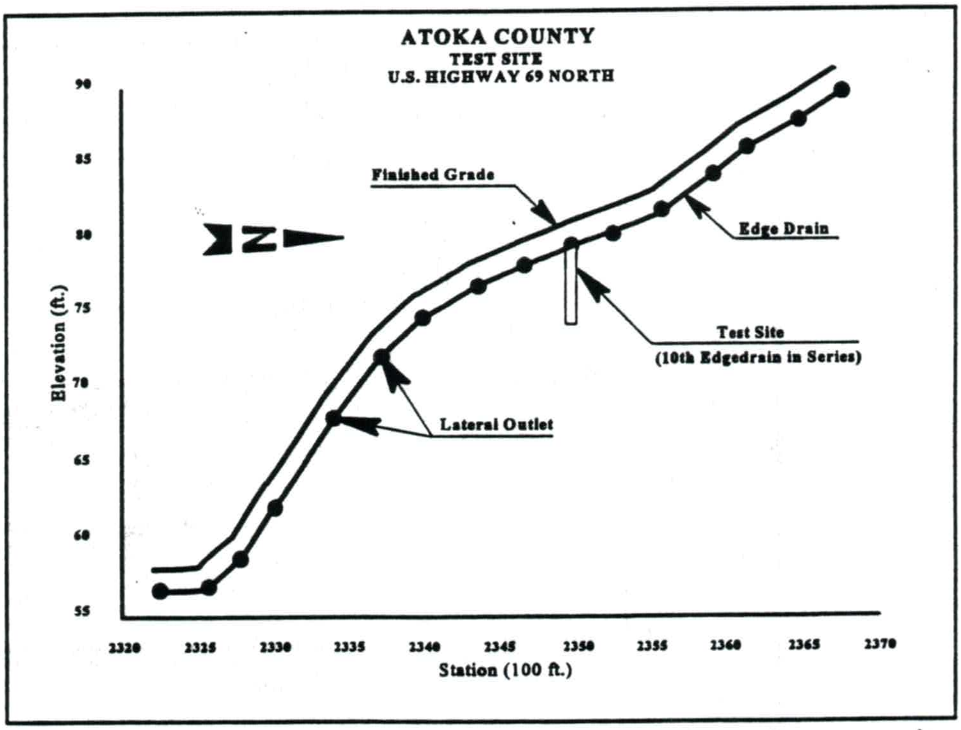

Fig. 2.2 Longitudinal slope of the roadway at the Atoka county site

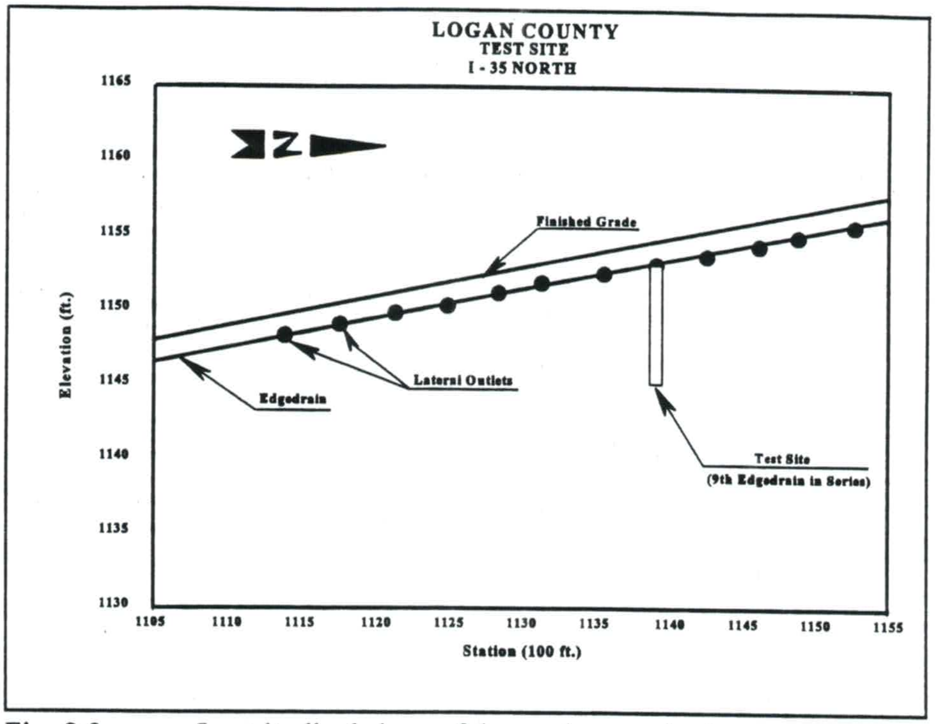

Fig. 2.3 Longitudinal slope of the roadway at the Logan county site

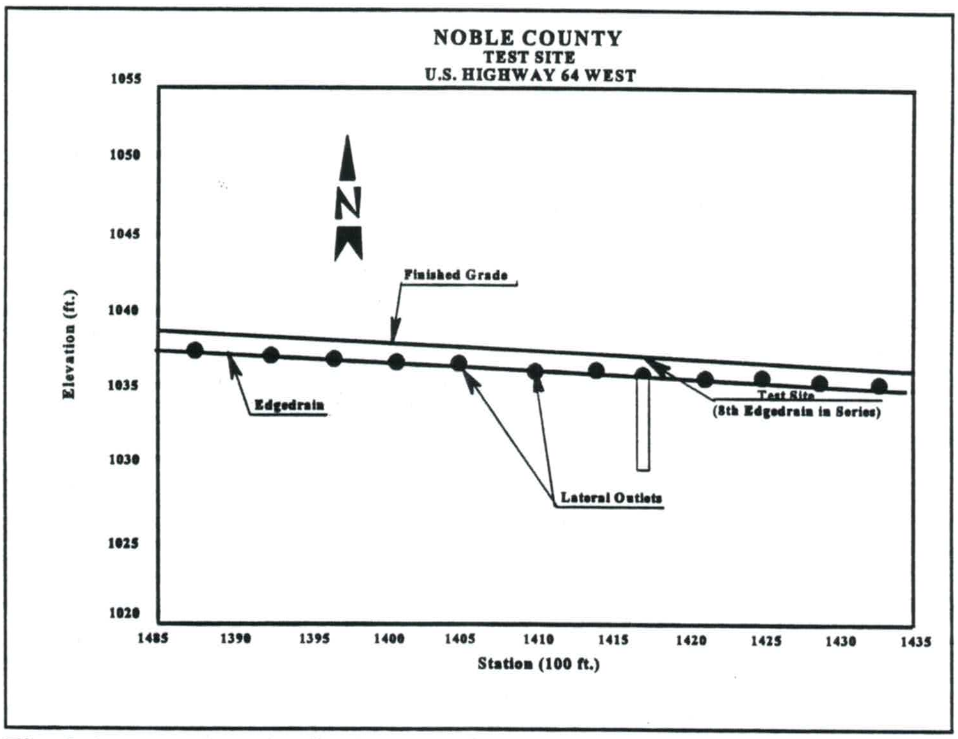

Fig. 2.4 Longitudinal slope of the roadway at the Noble county site

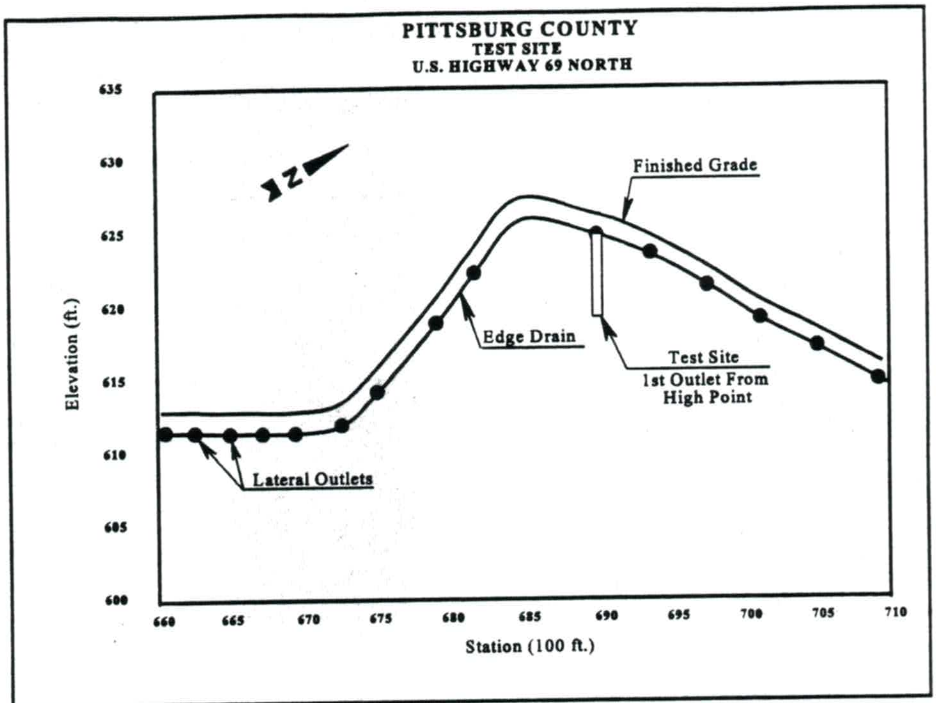

Fig. 2.5 Longitudinal slope of the roadway at the Pittsburg county site

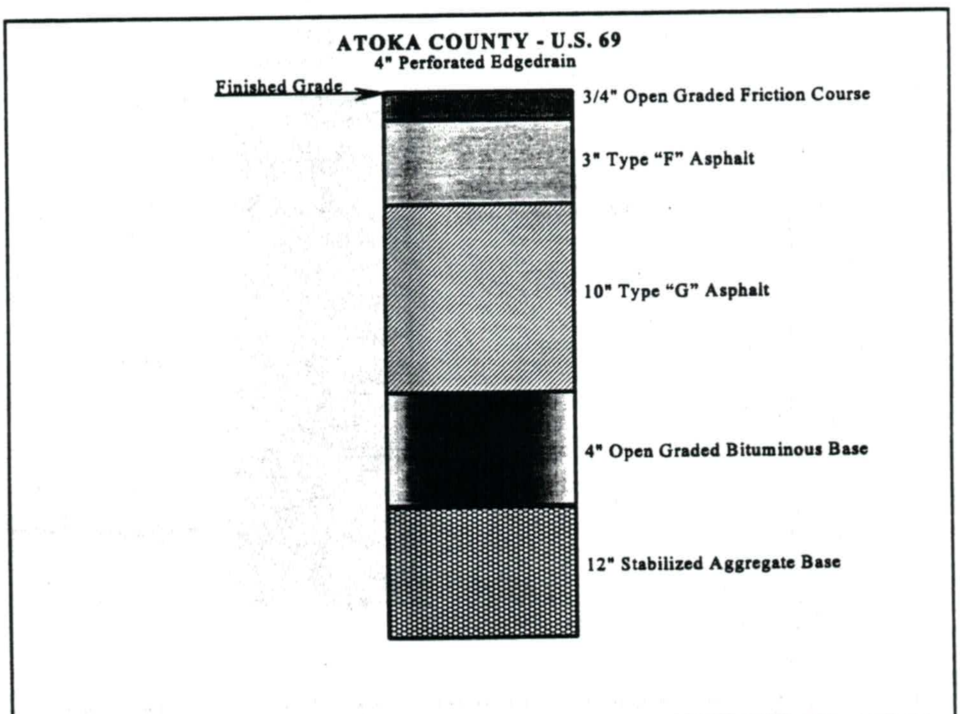

Fig. 2.6 Pavement cross-section (Atoka county)

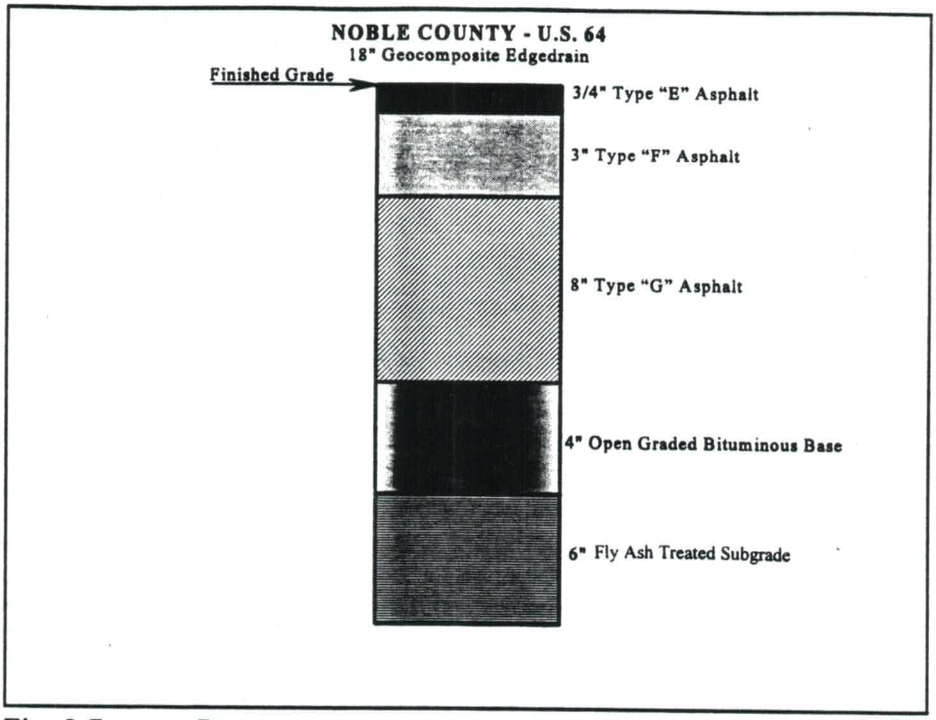

Fig. 2.7 Pavement cross-section (Noble county)

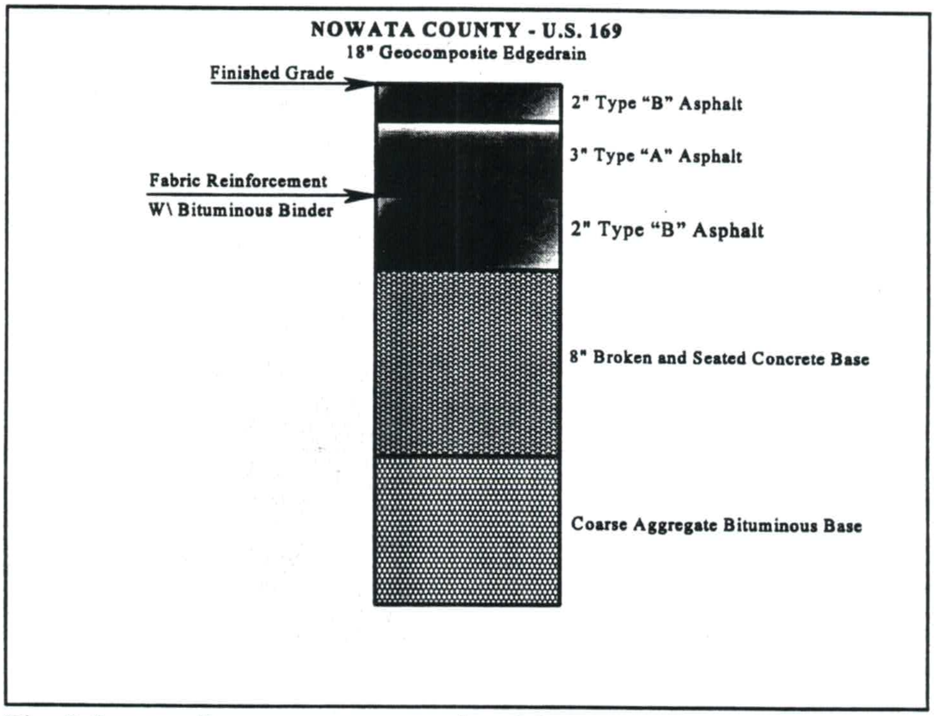

Fig. 2.8 Pavement cross-section (Nowata county)

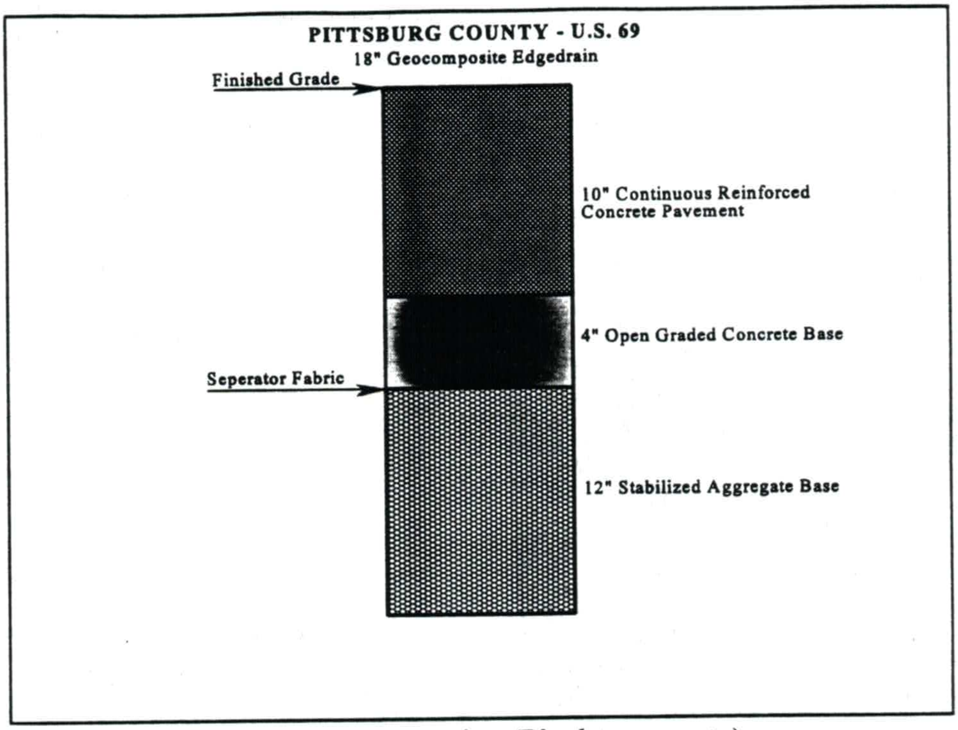

Fig. 2.9 Pavement cross-section (Pittsburg county)

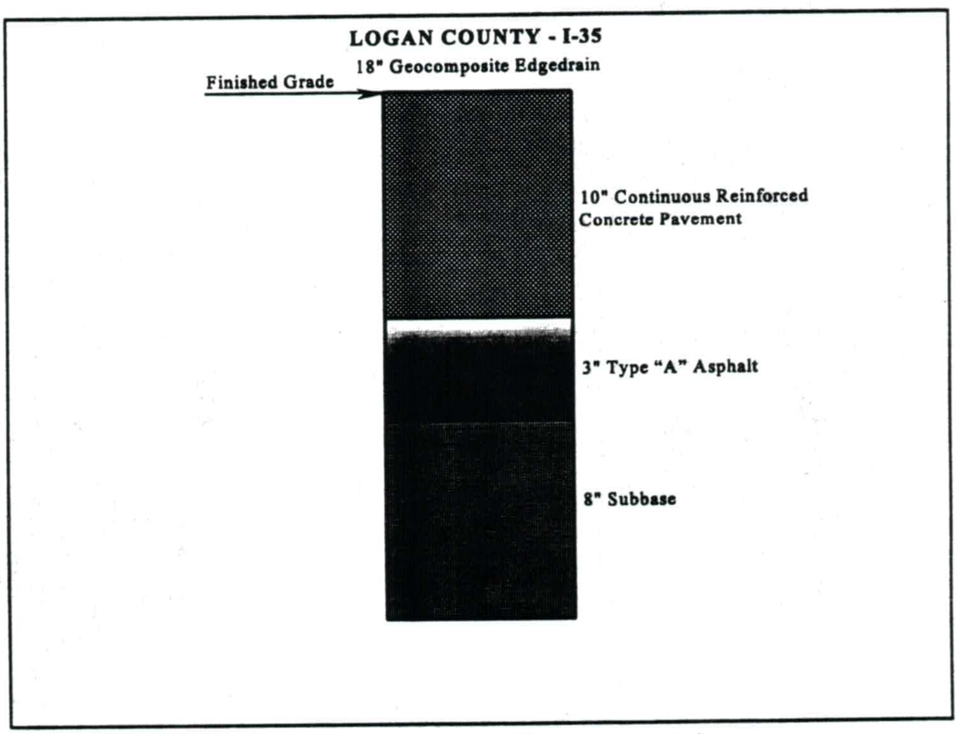

Fig. 2.10 Pavement cross-section (Logan county)

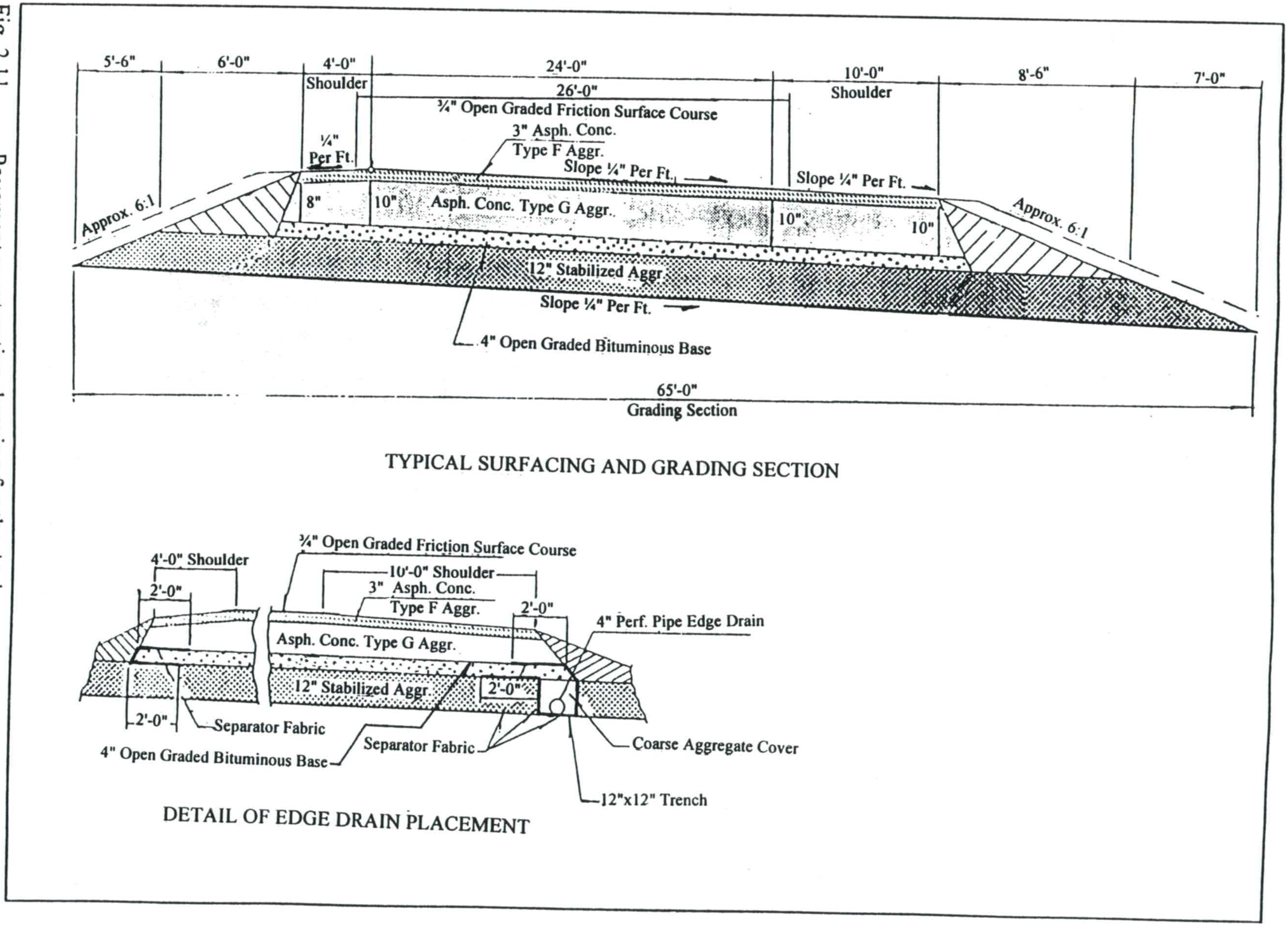

Fig. 2.11 Pavement construction drawing for the Atoka county site

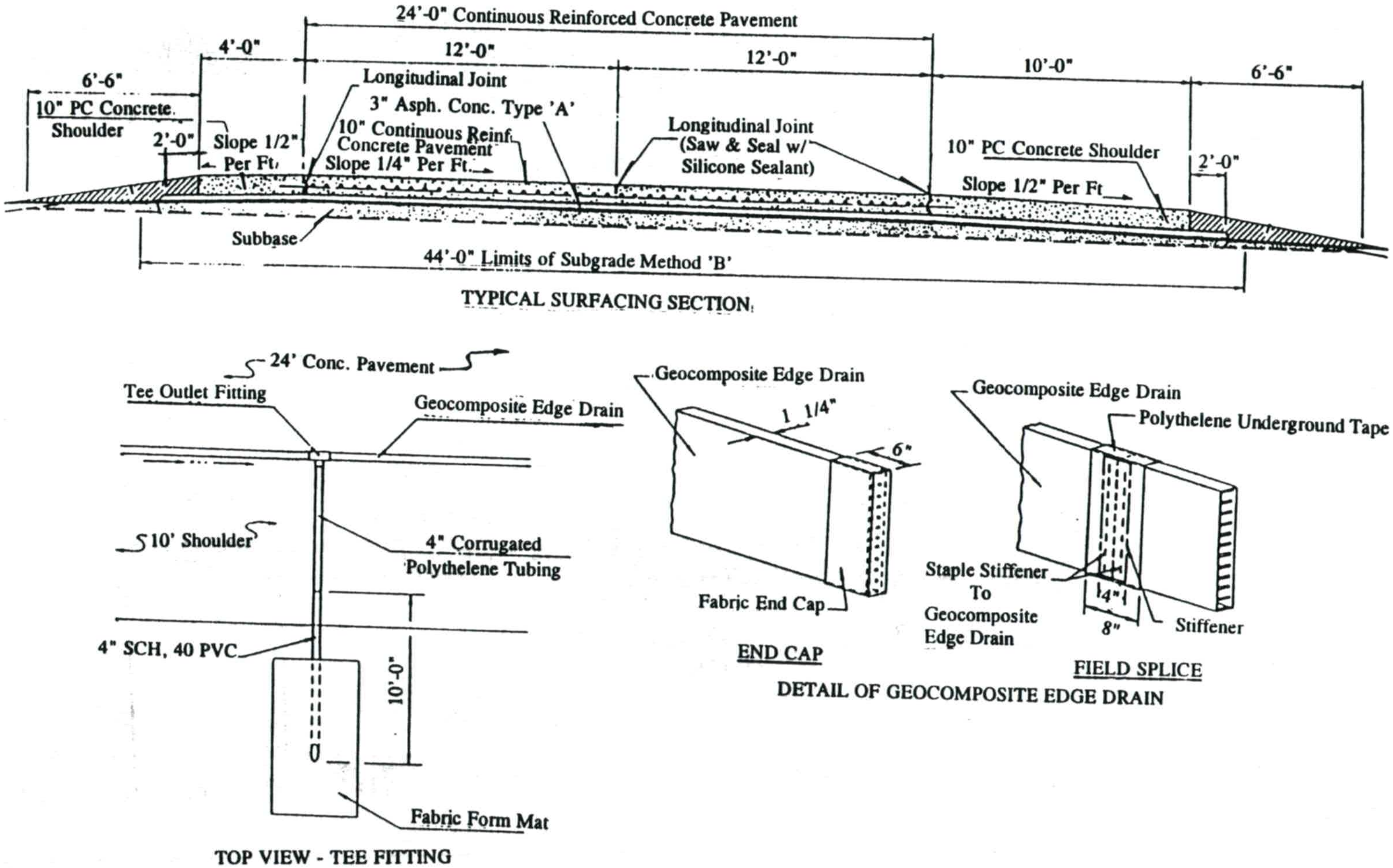

Fig. 2.12 Pavement construction drawing for the Logan county site

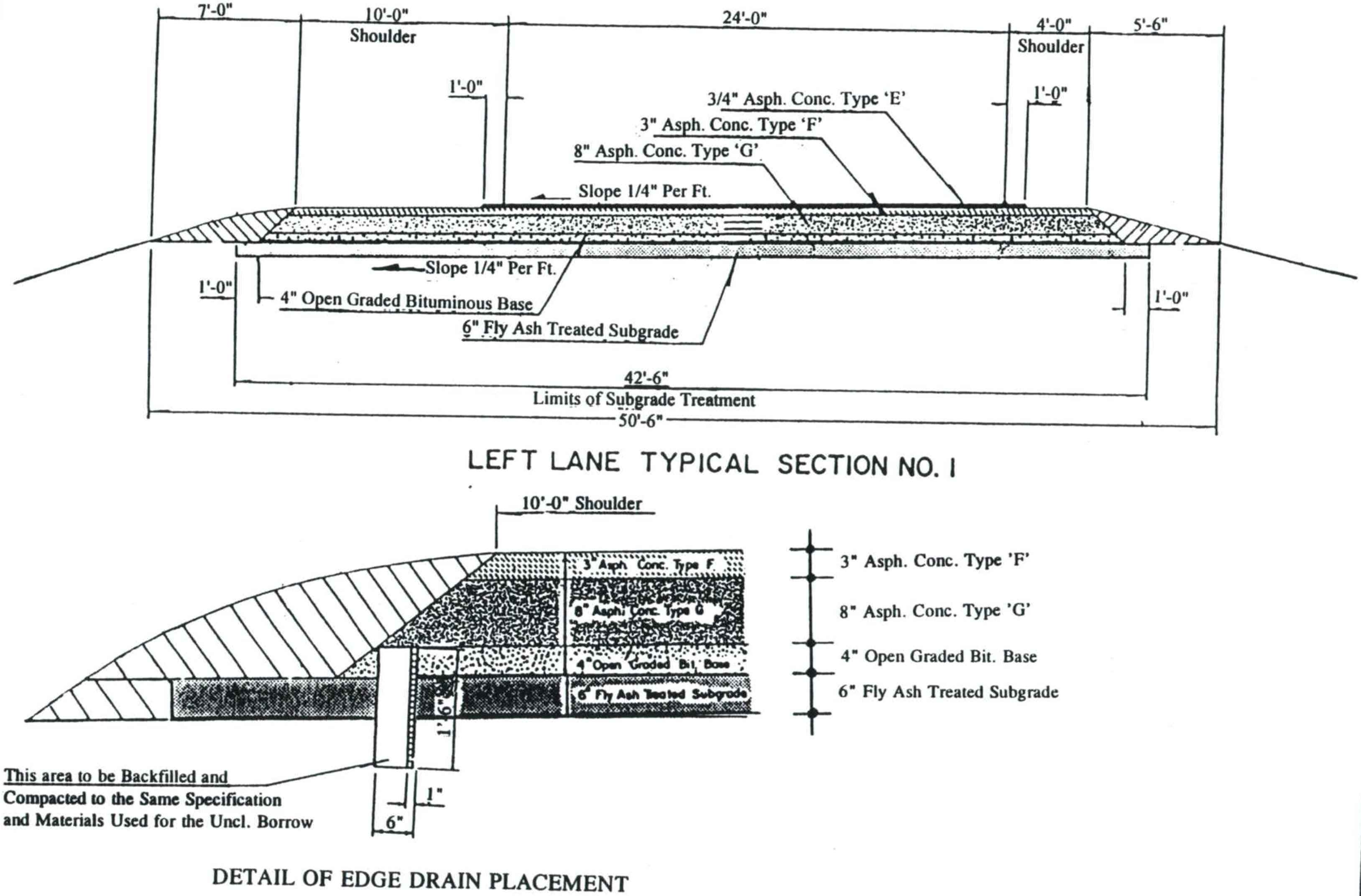

Fig. 2.13 Pavement construction drawing for the Noble county site

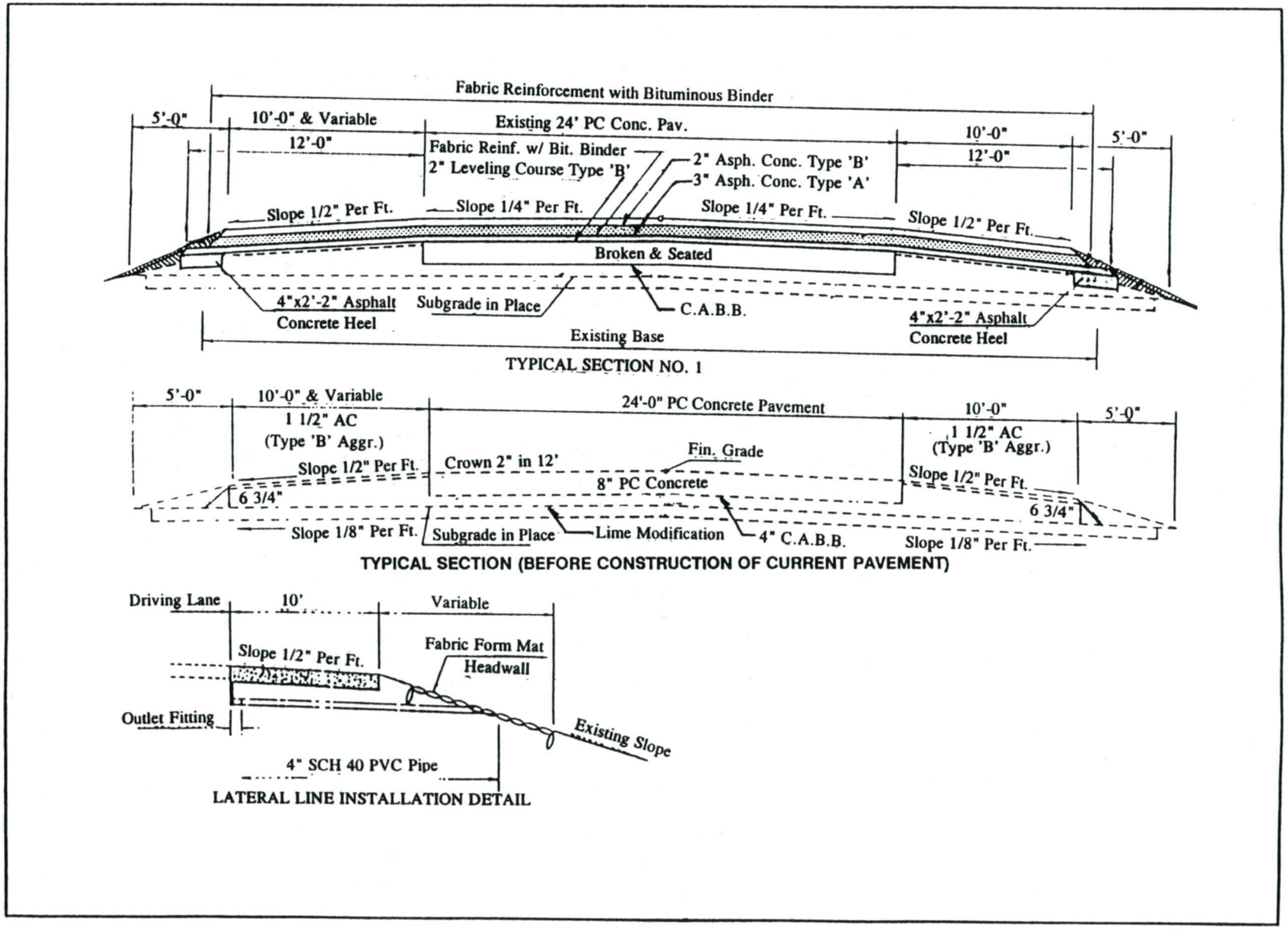

Fig. 2.14 Pavement construction drawing for the Nowata county site

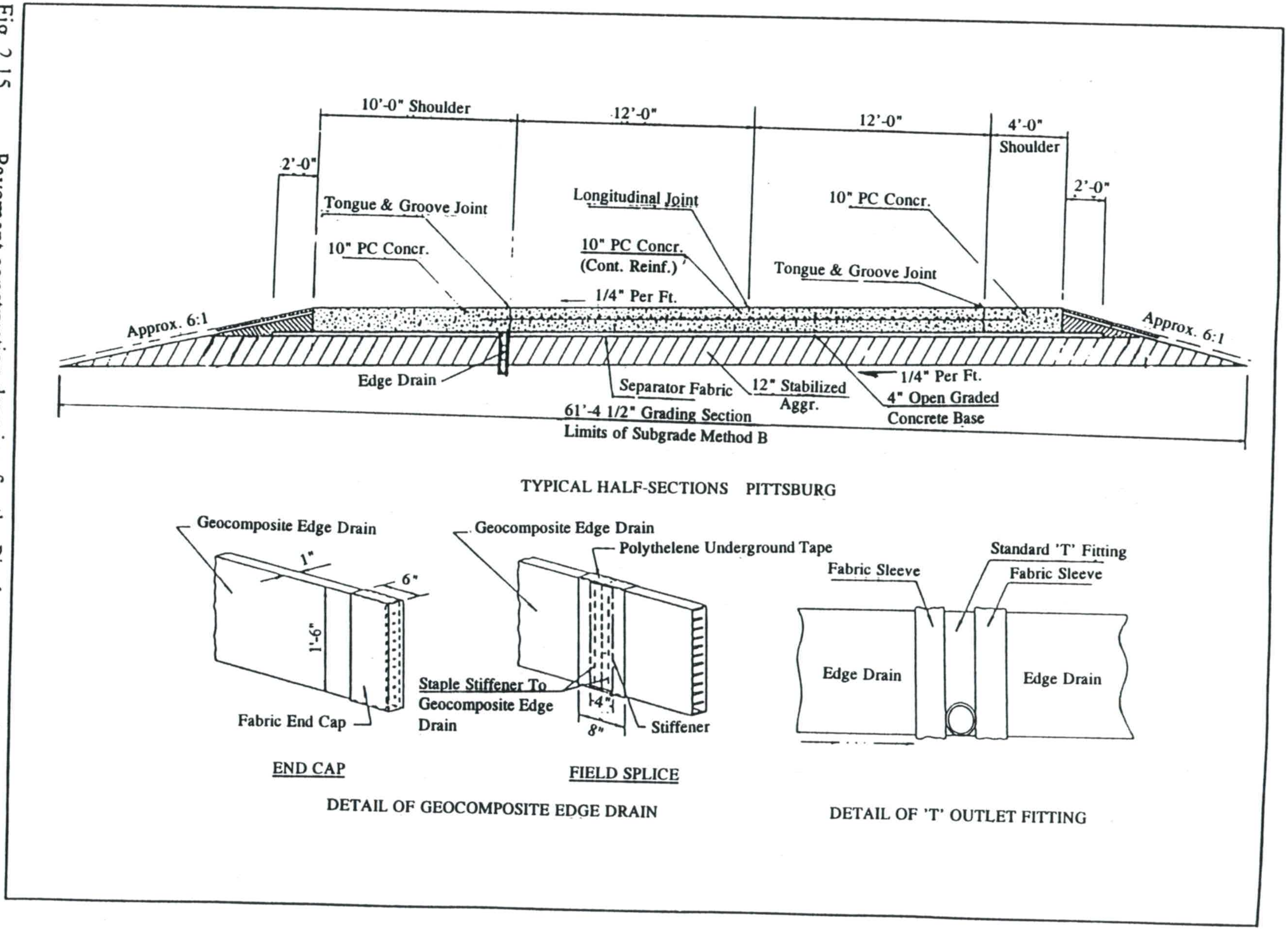

Fig. 2.15 Pavement construction drawing for the Pittsburg county site

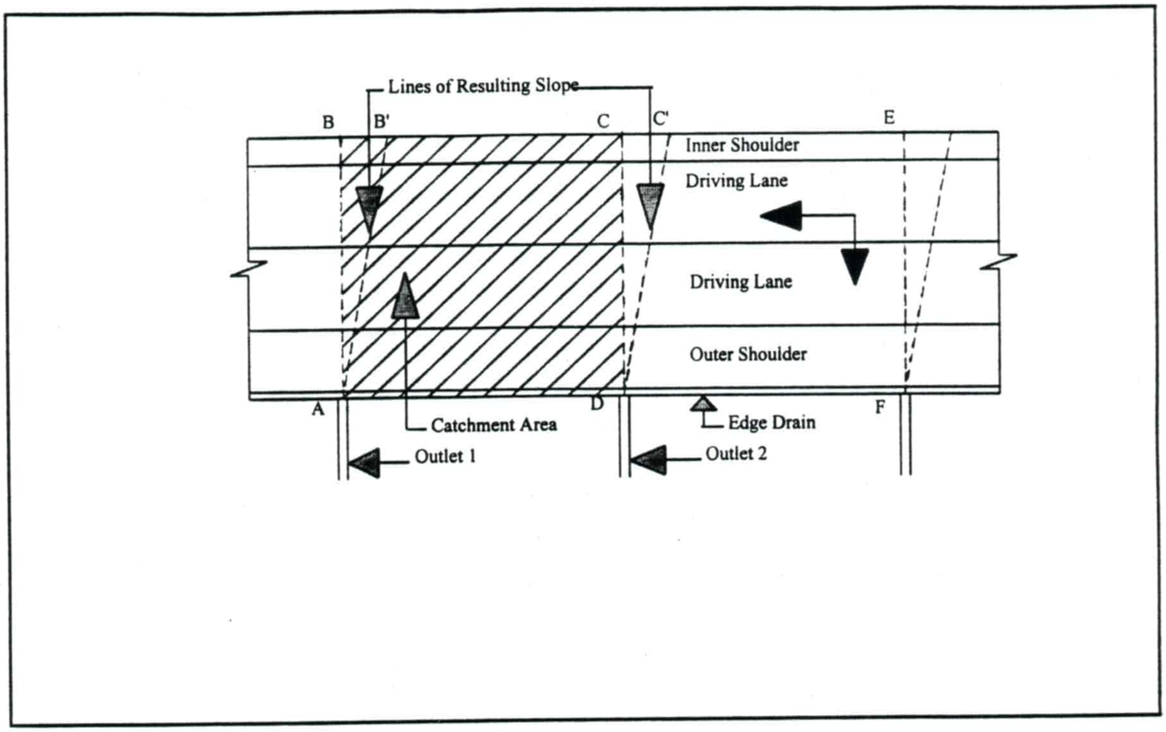

Fig. 2.16 Catchment area - case A

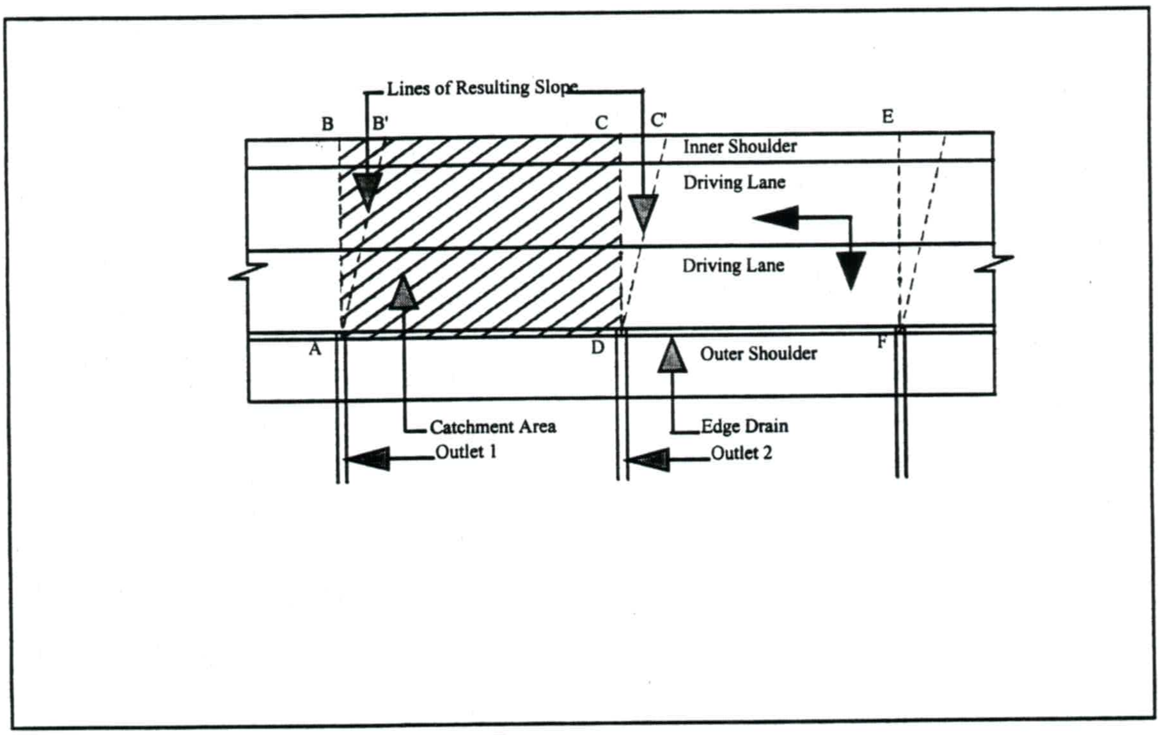

Fig. 2.17 Catchment area - case B

CHAPTER 3
DATA COLLECTION AND STORAGE

3.1 GENERAL

The amount of water that enters into the pavement section and the time taken to drain out that water are two basic parameters involved in the design and construction of drainable bases. The amount of water depends primarily on the following: the rainfall intensity and duration, size of the catchment area, number and width of cracks in the pavement, pavement material, and pavement slope. The drainage time depends, among other factors, on the effective porosity and permeability of the drainable base, the resulting slope of the base, and the permeability of the filter fabric wrapped around the edge drain. Temperature and antecedent moisture conditions are also believed to affect the drainage of water from the base. The degree of drainage or drainage efficiency can be estimated if the height of water level in the saturated base and in the edge drain are known at different times. The height of water level may be computed by measuring the water pressure at these two locations. ODOT decided to measure a number of parameters noted above (Table 3.1). Due to various practical problems, some of the parameters could not be measured and some measured parameters indicate equipment malfunctioning.

3.2 EQUIPMENT AND SETUP

Each of the sites are instrumented with five pieces of equipment as shown in Table 3.1. The outflow tipping bucket is placed at the end of the lateral outflow pipe, close to it are the rain gauge and the ambient temperature probe. One pressure transducer is placed in the base and another in the edge drain. All the equipment is connected to a data logger. The equipment collect data and send electrical signals to the data logger which keeps the data in its memory for a specified period of time and then writes the data to a permanent storage. The specified time period is ten minutes for most of the cases, for example, for the data presented in Fig. 3.1 (this time period is discussed elaborately in section 4.2.1 in chapter 4). The data logger adds up the amount of rainfall and outflow during that time and records the sum at the end of that time. An elaborate description of the instruments and their setup is provided in Appendix B.

3.3 DATA LOGGER PROGRAMS

The data logger receives, recognizes and interprets the signals sent by the different sensors, converts those signals to ASCII recognizable data, and then stores the data in the storage module. The data logger performs these steps according to a set of instructions provided through a control program. This program must be loaded into the data logger before starting data collection. The logic and flow of this program greatly affects the efficiency of the data logger in terms of memory and usable data. The program originally used by ODOT R&D for data collection stores the data at a certain interval, for example, every ten minutes for most of the cases (or thirty minutes in few cases). Even if there is no rainfall and/or outflow in the field, the data logger still keeps recording zero values for the corresponding parameter(s). Thus, often the memory of the storage module is used up rather quickly with a series of 0 values which bear little practical significance.

As a part of this project, a new program was written to use the data storage capacity in a more efficient manner. This program checks for any rainfall or outflow activity in the field and stores the value (which is greater than zero, obviously) of the appropriate parameter every two minutes, only if it finds an activity (rainfall or outflow) occurring in the field. When there is no rainfall and/or outflow in the field, the corresponding parameter(s) is (are) not recorded. Temperature and pressure values are always recorded every thirty minutes irrespective of the rainfall/outflow event.

The following example illustrates the improvement in memory use efficiency with the new program. Let a whole day (24 hours) without any rainfall or outflow be considered. The old program would record 2,016 values [24x6x(4+5x2)] in 864 lines (24x6x6) while the new program records only 244 values (24x2x5+4) in 49 (1+24x2) lines (these numbers are based on the data format which is discussed in section 3.6). The corresponding memory used for these two cases (old and new) are 9,422 bytes and 1,325 bytes, respectively. The new program, thus, saves 86% memory usage when there is no rainfall and outflow. When there is rainfall and outflow, the new program provides more continuous data (every two minutes compared to ten or thirty minutes, as was the case with the older program). An elaborate discussion of the data logger programs is presented in Appendix C.

3.4 DATA COLLECTION

Usually data are collected or transferred from the storage module connected to the data logger to a laptop personal computer once each month. The laptop is connected to the data logger using a transmission cable. The data logger support software which facilitates the transfer of the data from the data logger to the laptop must be installed in the laptop. The procedure of transferring the field data from the data logger to the laptop is known as "downloading the data." Once the data are transferred to the laptop, the data logger memory needs to be cleared so that it is ready again to store data for the next month.

After downloading the data from all the sites, the laptop is brought back to ODOT R&D office and a copy of all the data is loaded on a 3½" floppy disk. The data files are then uploaded to ODOT's mainframe computer through a base PC.

3.5 CONVENTION FOR NAMING THE DATA FILES

The file names usually consist of six alpha-numeric characters. The first two characters (letters) represent the site, the second two characters (numbers) represent the calendar year and the last two characters (numbers) represent the month of the year. The year and month correspond to the date on which data is downloaded. The following site name abbreviations have been used: 'AT' (also 'AK' was used at the beginning of the project) for the Atoka county site, 'LG' for Logan, 'NB' for Noble, 'NW' for Nowata and 'PT' for Pittsburg. Examples of the file names are: 'AT9204' (data collected from Atoka county site in the month of April, 1992), 'LG9308' etc. When data is collected from a site more than once in a month, usually a suffix is added at the end of the regular file name. Examples of such files are: 'AK9206A', 'NB9502MA' etc. More information concerning the naming of the data files is discussed in sections 5.4 and 5.7 in chapter 5.

3.6 DATA STRUCTURE

The data are arranged in different lines with line identifiers. Each line starts with an identifier (an integer number) which identifies the numbers stored on that line. These identifiers are provided by and dependent on the data logger program. Based on the different data logger programs used so far, the data have been stored in different formats as discussed in the following subsections.

3.6.1 First version of data format

All the data collected before July, 1995, have the same format as shown in Fig. 3.1. Table 3.2 explains the meaning of different variables in this data format. For purposes of this report, this format will be called the "first version of the data format". In this format data are recorded at the end of a preset interval. For example, the data have been recorded every ten minutes for the data shown in Fig. 3.1. As a result, many unnecessary data (with zero rainfall and zero outflow values) have been recorded.

3.6.2 Second version of data format

In June, 1995, an early version of the program presented in Appendix C was installed in the Noble county site. The data collected in the following month (July, 1995) from that site corresponds to the format set by this program. For the purposes of this report, this format will be called the "second version of the data format" (see Fig. 3.2). Explanations of the data items with this format are provided in Table 3.3.

With this version, the temperature and pressure data are recorded every thirty minutes while rainfall and outflow data are recorded every two minutes, provided that they have some non-zero values. It is seen from Fig. 3.2 that, due to some programming error, some outflow data are recorded even though the outflow was actually zero at that time.

3.6.3 Third version of data format

In the next month (July, 1995), the current version of the program presented in Appendix C was installed in the Noble county site. The data collected from that site during July-October, 1995 corresponds to the format set by this program. For the purposes of this report, this format will be called the "third version of the data format" (Fig. 3.3). In this format, the year and day values are recorded at midnight. The temperature and pressure data are recorded every half hour and rainfall and outflow data are recorded every two minutes, provided they contain some non-zero values. Explanations of the different data items with this version of data format are provided in Table 3.4.

3.6.4 Fourth version of data format

In October 1995, a slightly modified version of the program presented in Appendix C was installed in the Noble county site. The data collected since the month of November from that site corresponds to the format set by this program. For purposes of this report, this format will be called the "fourth version of the data format" (see Fig. 3.4). The data format in the fourth version differs slightly from the data format in the third version. With the fourth version, the first data record must be the year, day and time. Also, the year, day and time are written twice - once at midnight and then one minute after midnight. All other features are essentially same as the third version of data format. Explanations of the data items with this version of data format are provided in Table 3.5.

3.7 IMPACT OF DATA COLLECTION TIME INTERVAL

As explained in the preceding section, different versions of the data acquisition program record data at a certain interval; in most cases it is either ten minutes or thirty minutes. Therefore, it is not possible to exactly say when a particular rainfall event started or stopped in the field by examining the data. For example, if the data recorded at time 11:10 show no rainfall and the data recorded at time 11:20 do show some rainfall, it is not possible to say whether the rainfall started at time 11:12 or at 11:17. The same argument is also true for the outflow. As a result, the exact duration and intensity of rainfall remain unknown. The exact value of the retention time (time gap between the start of rainfall and the start of outflow) also remains an unknown. In other words, values of these parameters, computed in accord with data collected every ten minutes, are somewhat approximate because these values are known only to the nearest ten minutes. This limitation is overcome by a certain extent by the new data logger program (presented in Appendix C) which records the data at a much shorter time interval (two minutes).

3.8 PROBLEMS ASSOCIATED WITH FIELD DATA COLLECTION

A large amount of data have been gathered so far from the field. But the quality of data greatly affects its use. One of the objectives of the current study is to compare the amount of outflow with the corresponding amount of rainfall. This goal may not always be achieved because of a number of field problems that affects/affected the data collection process. This limitation should be kept in mind while interpreting the data. These problems are discussed in the following sub-sections.

3.8.1 Clogged and/or scaled outlet pipes

The lateral outlet pipes at the test sites are not always well maintained. Usually the personnel collecting data maintain the test outlet at the time of data collection. If any obstruction blocking the outflow is found at the time of inspection, appropriate actions are taken by the individual(s) involved. But other upgrade and downgrade outlets often remain unnoticed. In a number of cases these outlets at different sites were found clogged heavily with soils. Fig. 3.5 shows one such clogged outlet.

In some situations, a scaling formation on the inner walls of the outlet pipe was evident. It can, thus, be argued that if the upgrade outlet pipes are clogged, then some of the water that was supposed to flow through those outlets would exit through the test outlet. In other words, the catchment area for the test outlet is changed. Thus, the amount of outflow caused by a certain rainfall may be found to be quite different from the amount of outflow caused by a similar rainfall at a different time due to clogged/scaled outlets. As the upgrade and downgrade outlet pipes were not examined and maintained regularly, it is difficult to determine how much data was corrupted in this manner.

3.8.2 Equipment malfunctioning

A number of reasons have caused either the rain gage or the outflow tipping bucket to stop functioning from time to time. Field personnel who visit the sites have serviced the equipment when a problem was found. As a result, the data are not continuous and some of the data may not be used in any systematic analysis for this reason. For example, if the outflow tipping bucket stops working at a time when there is some outflow in the field, then the actual amount of outflow corresponding to the previous rainfall would remain unknown. This type of discontinuous data were not used in this study when comparing the amount of outflow with the corresponding amount of rainfall. Some reasons for unrecorded data are sensor failure and tipping bucket creep (where the tipping bucket is moved away from the outlet).

3.8.3 Problems caused by human error

At least two problems were caused by human errors. The first one is the failure to enter the correct date and time into the data logger. The date and time needs to be entered after the data logger is powered up. If the field personnel (who usually replace the batteries in the field every month) forget to do so, then the data logger, by default, assumes the date to be

0'th day of the year 2000 and the time to be 0000 hour. However, data showing such faulty date and time can be used by examining the previous and next file (this is discussed further in section 5.3.2 of chapter 5).

The other problem caused by human error involves giving a wrong name, an error which causes two data files to possess identical contents. This error causes the loss of some data.

3.8.4 Presence of living organisms

Occasionally, ants established colonies and/or spiders lived in the rain gage. Also, rodents sometimes infiltrated both equipment and the lateral outlet pipes. The effects of all these living organisms on the quality of data remain unknown.

Table 3.1 Parameters measured at the sites

No.	Parameter	Equipment
1	Rainfall	Qualimetrics Model 6018A tipping bucket type rain gauge
2	Outflow	Wisconsin DOT type tipping bucket
3	Temperature	Campbell Scientific Model 107 temperature probe
4	Pressure at base	Druck Model PCDR-940 pressure transducer
5	Pressure at edge drain	
6	Sub-grade moisture content	One Trace Time Domain Reflectometry (TDR) soil moisture device with two TDR wave guide probes [Soil Moisture Corp. Models 6050X1 and 6005]

Table 3.2 Description of data items in data format version #1

Line no.	Description of data items
101	Year, Day of the year, Military Time
103	Temperature (°Celsius)
106	Rainfall amount (inches)
109	Outflow amount (gallons)
112	Pressure at base (psi)
115	Pressure at edge drain (psi)

Table 3.3 Description of data items in data format version #2

Line no.	Description of data items
106	Year, Day, Time, Rainfall amount (inches)
111	Year, Day, Time, Outflow amount (gallons)
115	Year, Day, Time, Pressure at Base (psi), Pressure at Edge Drain (psi), Temperature (° Celsius)

Table 3.4 Description of data items in data format version #3

Line no.	Description of data items
101	Year, Day, Time (= 2400)
108	Time, Rainfall amount (inches)
113	Time, Outflow amount (gallons)
117	Time, Pressure at Base (psi), Pressure at Edge Drain (psi), Temperature (° Celsius)

Table 3.5 Description of data items in data format version #4

Line no.	Description of data items
101	Year, Day, Time (= 2400)
108	Time, Rainfall amount (inches)
113	Time, Outflow amount (gallons)
117	Time, Pressure at Base (psi), Pressure at Edge Drain (psi), Temperature (° Celsius)
125	Year, Day, Time, Battery Voltage (volts)

```
101 1992 110 400
103 19.61
106 0.03
109 3.5
112 .019
115 .005
101 1992 110 410
103 19.62
106 0
109 5
................
................
```

Fig. 3.1 Data format version #1

```
... ...  ... ....  ....
... ...  ... ....  ....
111 1995 159 2116 .5
111 1995 159 2128 .5
115 1995 159 2130 -.004 -6999 23.91
111 1995 159 2142 .5
111 1995 159 2154 .5
111 1995 159 2156 0
115 1995 159 2200 -.004 -6999 22.46
111 1995 159 2210 .5
106 1995 159 2214 .01
106 1995 159 2216 .03
106 1995 159 2218 .07
106 1995 159 2220 .09
106 1995 159 2222 .12
111 1995 159 2222 .5
106 1995 159 2224 .16
111 1995 159 2224 0
106 1995 159 2226 .15
... ...  ... ....  ....
... ...  ... ....  ....
```

Fig. 3.2 Data format version #2

```
... .... ... ....
... .... ... ....
108 2358 .03
101 1995 254 2400
117 2400 -.102 -6999 16.64
108 0 .06
108 2 .07
108 4 .02
108 6 .02
108 8 .03
108 24 .01
108 30 .01
117 30 -.101 -6999 16.63
108 34 .01
117 100 -.1 -6999 16.81
113 114 .5
113 122 .5
113 128 .5
113 130 .5
117 130 -.097 -6999 17.08
113 132 .5
... .... ... ....
... .... ... ....
113 158 .5
108 200 .01
113 200 1
117 200 -.093 -6999 17.24
113 202 1
... .... ... ....
... .... ... ....
```

Fig. 3.3 Data format version #3

```
125 1995 278 1133 12.13
117 1200 -.049 -6999 19.85
113 1202 .5
117 1230 -.049 -6999 19.84
113 1236 .5
... .... ..... ..... .....
... .... ..... ..... .....
117 2230 -.048 -6999 12.54
117 2300 -.048 -6999 12.34
113 2330 .5
117 2330 -.049 -6999 11.88
101 1995 278 2400
117 0 -.049 -6999 12.56
125 1995 279 1 11.76
113 18 .5
117 30 -.049 -6999 12.53
... .... ..... ..... .....
... .... ..... ..... .....
```

Fig. 3.4 Data format version #4

Fig. 3.5 Clogged outlet pipe (Atoka county)

CHAPTER 4

DATA ANALYSIS PRELIMINARIES

4.1 GENERAL

Before reporting the data analysis task undertaken in this project, a number of terms need to be defined and explained. Also, some assumptions and clarifications need to be stated at this stage to avoid any confusion during the data analysis reporting.

4.2 DEFINITIONS

A number of terms are defined and explained with examples in the following sub-sections.

4.2.1 Data collection interval or data interval

Data collection interval (or *data interval* in short) refers to the time interval in which data have been recorded in the storage module connected to the data logger. The data interval for the data shown in Fig. 3.1 in chapter 3 and in Table 4.1 in the current chapter is ten minutes. Only data files with the first version of data format have a fixed data interval of either ten or thirty minutes. In all other versions, the data interval is two minutes for rainfall and outflow, if any corresponding activity occurs at that time.

4.2.2 Continuous Rainfall Event (CoRE)

If all the recorded values of rainfall during a certain period of time are greater than zero, and if the recorded values of rainfall just before and after that period of time are zero, then such an incidence is termed *Continuous Rainfall Event* (or, in short, *CoRE)*. The time length of a CoRE, then, indicates the duration of rainfall corresponding to that CoRE - this is called *CoRE duration* in this study. One can recognize five CoREs in the data in Table 4.1 and three CoREs in Fig. 4.1 which shows a part of the data in Table 4.1.

4.2.3 Event

If the outflow during a certain period of time is only a result of the rainfall during the same period of time, and any rainfall occurring before that period of time does not influence the outflow under consideration, and if that outflow completely stops at the end of that time period, then the occurrence of the rainfall and outflow during such a period of time is called an *event* (see Fig. 4.2).

By definition, an event then should have the following properties:

a) The rate of outflow just before the event starts must be zero.

b) The rate of outflow just after the event stops must be zero.

c) The first record in an event must have a rainfall value greater than zero.

d) An event may contain one or more CoREs.

The rate of outflow may be zero for some time in the beginning of an event, but it increases gradually, reaches a peak, and then decreases gradually to zero. As soon as the outflow rate becomes zero, the event is said to have ended. The time gap between the first record of an event and the occurrence of outflow rate greater than zero should be short enough so that the outflow can be taken to be influenced by the rainfall in question. This time gap is determined by examining a considerable amount of data for different sites.

4.2.4 Retention time for events and sites

Retention time for an event is the time gap between the first rainfall of a event and the first outflow for that particular event. This indicates the amount of time required to initiate flow at a particular site. For example, rainfall starts at time 0.833 hour and outflow starts at time 1.833 hour in the data in Table 4.1, therefore, the retention time for this event is 1.0 hr (1.833

- 0.833). This is shown in Fig. 4.3.

Depending on the intensity and duration of the rainfall, the time gap between the first rainfall and first outflow differs for different events. The *retention time for a site* is indicated by the *75% expectation* of the retention time for the individual events. For example, the expression "the retention time for site X is fifty minutes" implies that out of every one hundred events, at least seventy-five events have a retention time less than or equal to fifty minutes.

A large value of the retention time may indicate theoretically that the pavement is so good that it allows water to infiltrate at a very slow rate; however, it may also indicate that the pavement has poor drainage characteristics and it takes long time to initiate the flow (the broken and seated concrete base at Nowata county is an example of the second proposition). As such, this term should be considered with care, possibly with a knowledge of the drainability of the site from other terms such as maximum outflow rates, drainage time, etc.

4.2.5 Rainfall and outflow rates

The *rainfall and outflow rates* over a certain period of time can be found by dividing the total amount by the time period. Hence, the rate is dependent on the time period under consideration. For example, a 90-minute duration rainfall rate indicates that the rate is found by considering the rainfall amount over a 90 minute time period. In this report, if the time duration associated with the rate is not specified, then that indicates that the time duration is the same as the data collection interval for that case.

4.2.6 Ratio of water drained or outflow proportion

The ratio of water drained or *outflow proportion* (always expressed as per cent in this report) is the ratio between the outflow and corresponding rainfall. Sometimes it is simply called *the ratio* or *proportion*. The amount of rainfall can be found by multiplying the depth of water (rain gage reading) by the catchment area (see Table 2.5 in chapter 2). For the data in Table 4.1, one can find the ratio as 33.4% (12861.73 ÷ 38461.58 x 100%).

If the conditions of a number of pavements are such that same amount of water enters those pavement systems, then this ratio can be used to get an idea about the comparative efficiency of drainable base and edge drain systems of these sites. The higher the ratio, more efficient the system is, in such case.

This ratio can also be used to obtain the comparative drainage property of the pavement surface for sites with efficient drainable base systems. In such cases, rainfall water that enters into the base is drained out rather quickly and, therefore, the amount of water that percolates to the subgrade can be neglected. So, the amount of water drained through the edge drain in such systems can be assumed to be the same as the water that entered the base. A small ratio in these cases indicates better drainage property of the pavement surface, since the pavement surface allows less water to enter the roadbed. However, this proposition is not valid for sites with poor and inefficient drainable base systems because rainfall water that enters into the base is drained out rather slowly and therefore, the amount of water that percolates to the subgrade can not be neglected.

4.2.7 Time for drainage and other related parameters

All the water that is drained out of the pavement system during the time period beginning from the last of all of the occurrences of rainfall in an event till the end of the corresponding event is called the *100% drainage amount* for that particular event. The time required to drain out this water is called the *100% drainage time* or *time for 100% drainage,* and the time required to drain out n% of this water is called the *n% drainage time* or *time for n% drainage* for that event.

The data presented in Table 4.1 shows that no rainfall occurs after 5.833 hours. So, the time for drainage starts after 5.833 hours. As such, the drainage amount for this event is 3,978.33 liters (12,861.73 - 8,883.4) or 1,051 gallons. The time for 100% drainage for this event is 10.167 hours (16 - 5.833). Time for 50% drainage for this event corresponds to the time when the cumulative outflow is 10,872.6 liters (8,883.4 + 3,978.33 x 50%) or 2,872.5 gallons. A cumulative outflow of 10,874.31 liters (2,873 gallons) is found to occur at time 7 hours. Hence, the time for 50% drainage for this particular event can be taken as 1.167 hours (7 - 5.833). Drainage times for different degrees of drainage for this event are shown in Table 4.2 and Fig. 4.4.

Depending on the intensity and duration of rainfall, the time gap among the individual CoREs, and the outflow rate, the drainage time differs for different events. The *n% drainage time for a site* is indicated by the *75% expectation* of that n% drainage time for the individual events. For example, the expression "50% drainage time for site X is one hour" implies that out of every one hundred events, at least seventy-five events have a 50% drainage time less than or equal to one hour.

Table 4.1 Rainfall and outflow data for a selected event from the Atoka county site

Record No.	Time Passed (hr)	Rainfall (mm)	Outflow (l)	Rainfall Rate (mm/hr)	Outflow Rate (l/hr)	Cum. Rainfall (l)	Cum. Outflow (l)	Comments
1	0.167	0	0	0	0	0	0	
2	0.333	0	0	0	0	0	0	
3	0.5	0	0	0	0	0	0	
4	0.667	0	0	0	0	0	0	
5	0.833	0.25	0	1.52	0	268.96	0	CoRE #1
6	1	0	0	0	0	268.96	0	
7	1.167	0.25	0	1.52	0	537.92	0	CoRE #2
8	1.333	0.25	0	1.52	0	806.89	0	
9	1.5	0	0	0	0	806.89	0	
10	1.667	0.25	0	1.52	0	1075.85	0	CoRE #3
11	1.833	2.29	3.8	13.72	22.71	3496.51	3.79	
12	2	4.06	242.2	24.38	1453.44	7799.9	246.03	
13	2.167	3.81	469.3	22.86	2816.04	11834.33	715.37	
14	2.333	6.6	518.5	39.62	3111.27	18827.35	1233.91	
15	2.5	3.05	545	18.29	3270.24	22054.89	1778.95	
16	2.667	0.25	537.5	1.52	3224.82	22323.85	2316.42	
17	2.833	0	590.5	0	3542.76	22323.85	2906.88	
18	3	0	571.5	0	3429.21	22323.85	3478.42	
19	3.167	0	423.9	0	2543.52	22323.85	3902.34	
20	3.333	0	317.9	0	1907.64	22323.85	4220.27	
21	3.5	0	238.5	0	1430.73	22323.85	4458.73	
22	3.667	0	185.5	0	1112.79	22323.85	4644.19	
23	3.833	0	143.8	0	862.98	22323.85	4788.02	
24	4	0	117.3	0	704.01	22323.85	4905.36	
25	4.167	0.25	102.2	1.52	613.17	22592.82	5007.55	CoRE #4
26	4.333	0	83.3	0	499.62	22592.82	5090.82	
27	4.5	3.56	102.2	21.34	613.17	26358.29	5193.02	CoRE #5
28	4.667	5.59	359.6	33.53	2157.45	32275.45	5552.59	
29	4.833	1.52	446.6	9.14	2679.78	33889.22	5999.22	
30	5	0.76	348.2	4.57	2089.32	34696.11	6347.44	
31	5.167	1.02	435.3	6.1	2611.65	35771.96	6782.72	
32	5.333	0.76	575.3	4.57	3451.92	36578.85	7358.04	
33	5.5	0.51	548.8	3.05	3292.95	37116.77	7906.86	
34	5.667	0.76	511	4.57	3065.85	37923.66	8417.84	
35	5.833	0.51	465.6	3.05	2793.33	38461.58	8883.4	
36	6	0	412.6	0	2475.39	38461.58	9295.96	
37	6.167	0	352	0	2112.03	38461.58	9647.97	
38	6.333	0	306.6	0	1839.51	38461.58	9954.55	

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Table 4.1 Rainfall and outflow data for a selected event (continued)

Record No.	Time Passed (hr)	Rainfall (mm)	Outflow (l)	Rainfall Rate (mm/hr)	Outflow Rate (l/hr)	Cum. Rainfall (l)	Cum. Outflow (l)	Comments
39	6.5	0	268.7	0	1612.41	38461.58	10223.29	
40	6.667	0	242.2	0	1453.44	38461.58	10465.53	
41	6.833	0	212	0	1271.76	38461.58	10677.49	
42	7	0	196.8	0	1180.92	38461.58	10874.31	
43	7.167	0	166.5	0	999.24	38461.58	11040.85	
44	7.333	0	143.8	0	862.98	38461.58	11184.68	
45	7.5	0	124.9	0	749.43	38461.58	11309.58	
46	7.667	0	113.6	0	681.3	38461.58	11423.13	
47	7.833	0	98.4	0	590.46	38461.58	11521.54	
48	8	0	98.4	0	590.46	38461.58	11619.95	
49	8.167	0	98.4	0	590.46	38461.58	11718.36	
50	8.333	0	90.8	0	545.04	38461.58	11809.2	
51	8.5	0	79.5	0	476.91	38461.58	11888.69	
52	8.667	0	71.9	0	431.49	38461.58	11960.6	
53	8.833	0	60.6	0	363.36	38461.58	12021.16	
54	9	0	56.8	0	340.65	38461.58	12077.94	
55	9.167	0	49.2	0	295.23	38461.58	12127.14	
56	9.333	0	41.6	0	249.81	38461.58	12168.78	
57	9.5	0	41.6	0	249.81	38461.58	12210.41	
58	9.667	0	37.9	0	227.1	38461.58	12248.26	
59	9.833	0	34.1	0	204.39	38461.58	12282.33	
60	10	0	30.3	0	181.68	38461.58	12312.61	
61	10.167	0	30.3	0	181.68	38461.58	12342.89	
62	10.333	0	26.5	0	158.97	38461.58	12369.38	
63	10.5	0	30.3	0	181.68	38461.58	12399.66	
64	10.667	0	22.7	0	136.26	38461.58	12422.37	
65	10.833	0	26.5	0	158.97	38461.58	12448.87	
66	11	0	22.7	0	136.26	38461.58	12471.58	
67	11.167	0	18.9	0	113.55	38461.58	12490.5	
68	11.333	0	22.7	0	136.26	38461.58	12513.21	
69	11.5	0	18.9	0	113.55	38461.58	12532.14	
70	11.667	0	18.9	0	113.55	38461.58	12551.06	
71	11.833	0	18.9	0	113.55	38461.58	12569.99	
72	12	0	18.9	0	113.55	38461.58	12588.91	
73	12.167	0	18.9	0	113.55	38461.58	12607.84	
74	12.333	0	15.1	0	90.84	38461.58	12622.98	
75	12.5	0	15.1	0	90.84	38461.58	12638.12	
76	12.667	0	18.9	0	113.55	38461.58	12657.04	

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Table 4.1 Rainfall and outflow data for a selected event (continued)

Record No.	Time Passed (hr)	Rainfall (mm)	Outflow (l)	Rainfall Rate (mm/hr)	Outflow Rate (l/hr)	Cum. Rainfall (l)	Cum. Outflow (l)	Comments
77	12.833	0	15.1	0	90.84	38461.58	12672.18	
78	13	0	15.1	0	90.84	38461.58	12687.32	
79	13.167	0	15.1	0	90.84	38461.58	12702.46	
80	13.333	0	11.4	0	68.13	38461.58	12713.82	
81	13.5	0	15.1	0	90.84	38461.58	12728.96	
82	13.667	0	15.1	0	90.84	38461.58	12744.1	
83	13.833	0	15.1	0	90.84	38461.58	12759.24	
84	14	0	11.4	0	68.13	38461.58	12770.59	
85	14.167	0	15.1	0	90.84	38461.58	12785.73	
86	14.333	0	11.4	0	68.4	38461.58	12797.13	
87	14.5	0	11.4	0	68.4	38461.58	12808.53	
88	14.667	0	9.5	0	57	38461.58	12818.03	
89	14.833	0	11.4	0	68.4	38461.58	12829.43	
90	15	0	9.5	0	57	38461.58	12838.93	
91	15.167	0	7.6	0	45.6	38461.58	12846.53	
92	15.333	0	7.6	0	45.6	38461.58	12854.13	
93	15.5	0	3.8	0	22.8	38461.58	12857.93	
94	15.667	0	1.9	0	11.4	38461.58	12859.83	
95	15.833	0	1.9	0	11.4	38461.58	12861.73	
96	16	0	0	0	0	38461.58	12861.73	

Table 4.2 Outflow and drainage data

Record No.	Time Passed (hr)	Cum. Outflow (l)	Drainage Time (hr)	Drainage Amount (l)	Drainage Percent (%)
35	5.833	8883.4	0.00	0	0.00
36	6	9295.96	0.17	412.56	10.37
37	6.167	9647.97	0.33	764.57	19.22
38	6.333	9954.55	0.50	1071.15	26.92
39	6.5	10223.29	0.67	1339.89	33.68
40	6.667	10465.53	0.83	1582.13	39.77
41	6.833	10677.49	1.00	1794.09	45.10
42	7	10874.31	1.17	1990.91	50.04
43	7.167	11040.85	1.33	2157.45	54.23
44	7.333	11184.68	1.50	2301.28	57.85
45	7.5	11309.58	1.67	2426.18	60.98
46	7.667	11423.13	1.83	2539.73	63.84
47	7.833	11521.54	2.00	2638.14	66.31
48	8	11619.95	2.17	2736.55	68.79
49	8.167	11718.36	2.33	2834.96	71.26
50	8.333	11809.2	2.50	2925.8	73.54
51	8.5	11888.69	2.67	3005.29	75.54
52	8.667	11960.6	2.83	3077.2	77.35
53	8.833	12021.16	3.00	3137.76	78.87
54	9	12077.94	3.17	3194.54	80.30
55	9.167	12127.14	3.33	3243.74	81.54
56	9.333	12168.78	3.50	3285.38	82.58
57	9.5	12210.41	3.67	3327.01	83.63
58	9.667	12248.26	3.83	3364.86	84.58
59	9.833	12282.33	4.00	3398.93	85.44
60	10	12312.61	4.17	3429.21	86.20
61	10.167	12342.89	4.33	3459.49	86.96
62	10.333	12369.38	4.50	3485.98	87.62
63	10.5	12399.66	4.67	3516.26	88.39
64	10.667	12422.37	4.83	3538.97	88.96
65	10.833	12448.87	5.00	3565.47	89.62

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Table 4.2 Outflow and drainage data (continued)

Record No.	Time Passed (hr)	Cum. Outflow (l)	Drainage Time (hr)	Drainage Amount (l)	Drainage Percent (%)
66	11	12471.58	5.17	3588.18	90.19
67	11.167	12490.5	5.33	3607.1	90.67
68	11.333	12513.21	5.50	3629.81	91.24
69	11.5	12532.14	5.67	3648.74	91.72
70	11.667	12551.06	5.83	3667.66	92.19
71	11.833	12569.99	6.00	3686.59	92.67
72	12	12588.91	6.17	3705.51	93.14
73	12.167	12607.84	6.33	3724.44	93.62
74	12.333	12622.98	6.50	3739.58	94.00
75	12.5	12638.12	6.67	3754.72	94.38
76	12.667	12657.04	6.83	3773.64	94.85
77	12.833	12672.18	7.00	3788.78	95.24
78	13	12687.32	7.17	3803.92	95.62
79	13.167	12702.46	7.33	3819.06	96.00
80	13.333	12713.82	7.50	3830.42	96.28
81	13.5	12728.96	7.67	3845.56	96.66
82	13.667	12744.1	7.83	3860.7	97.04
83	13.833	12759.24	8.00	3875.84	97.42
84	14	12770.59	8.17	3887.19	97.71
85	14.167	12785.73	8.33	3902.33	98.09
86	14.333	12797.13	8.50	3913.73	98.38
87	14.5	12808.53	8.67	3925.13	98.66
88	14.667	12818.03	8.83	3934.63	98.90
89	14.833	12829.43	9.00	3946.03	99.19
90	15	12838.93	9.17	3955.53	99.43
91	15.167	12846.53	9.33	3963.13	99.62
92	15.333	12854.13	9.50	3970.73	99.81
93	15.5	12857.93	9.67	3974.53	99.90
94	15.667	12859.83	9.83	3976.43	99.95
95	15.833	12861.73	10.00	3978.33	100.00
96	16	12861.73	10.17	3978.33	100.00

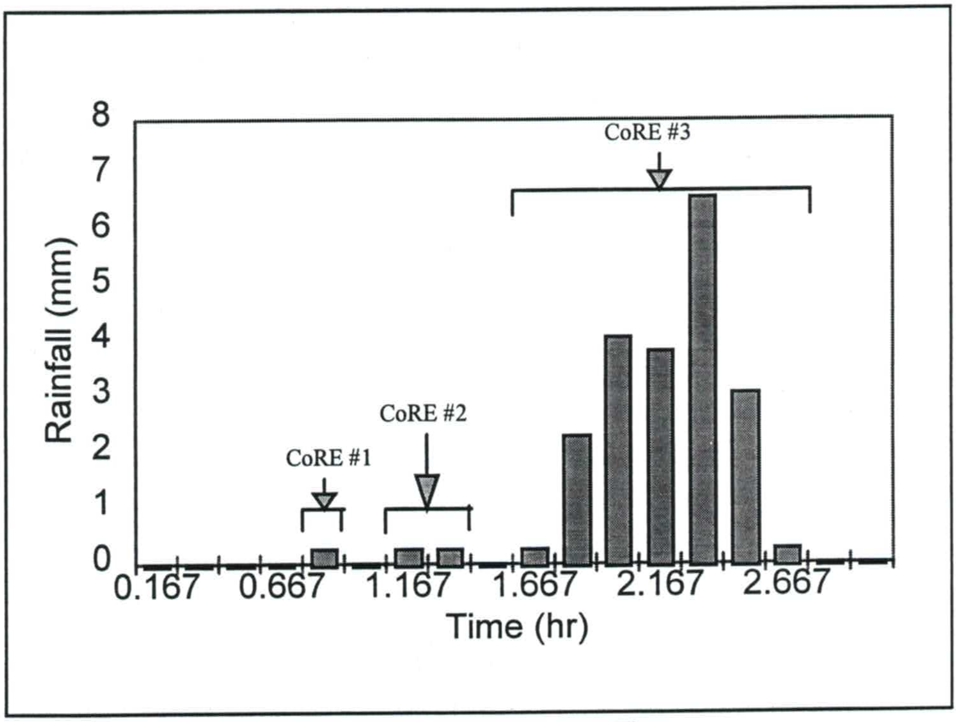

Fig. 4.1 Continuous rainfall events (CoRE)

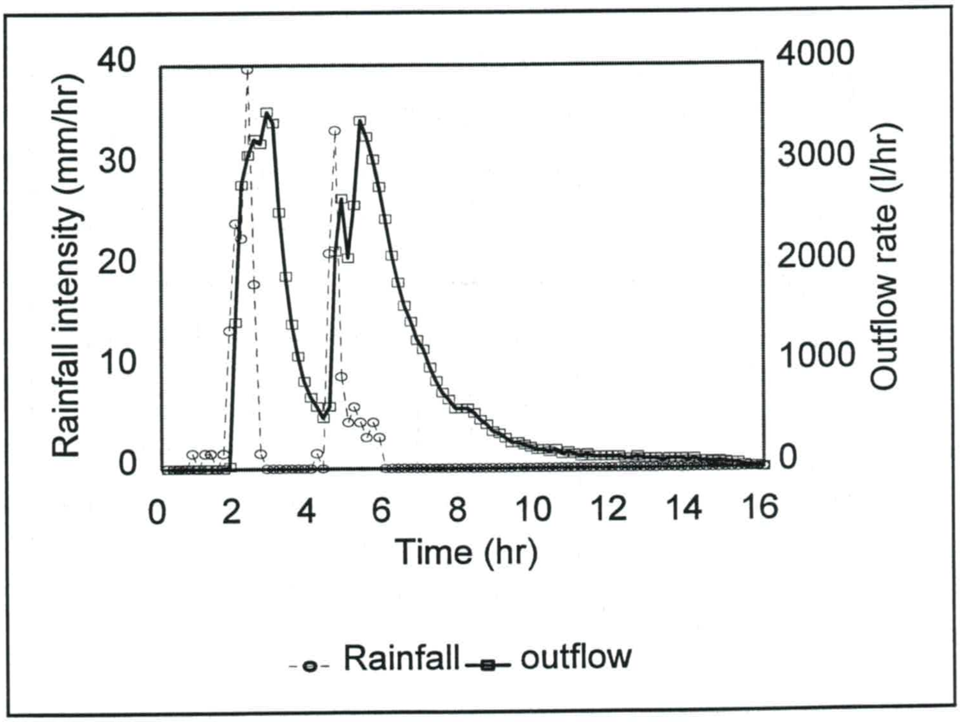

Fig. 4.2 Event

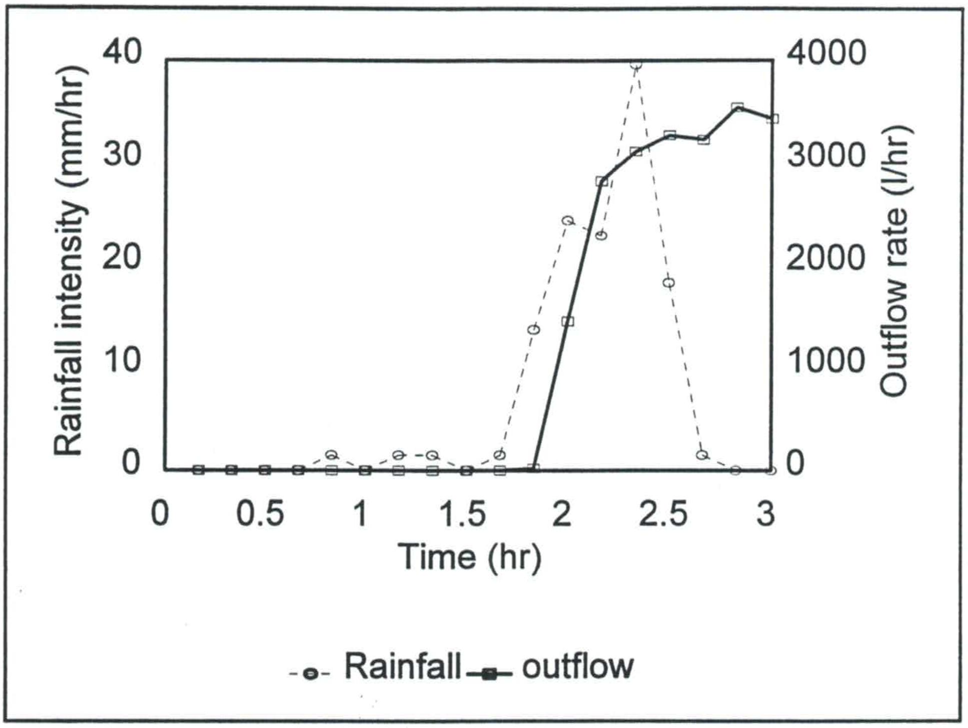

Fig. 4.3 Retention time for an event

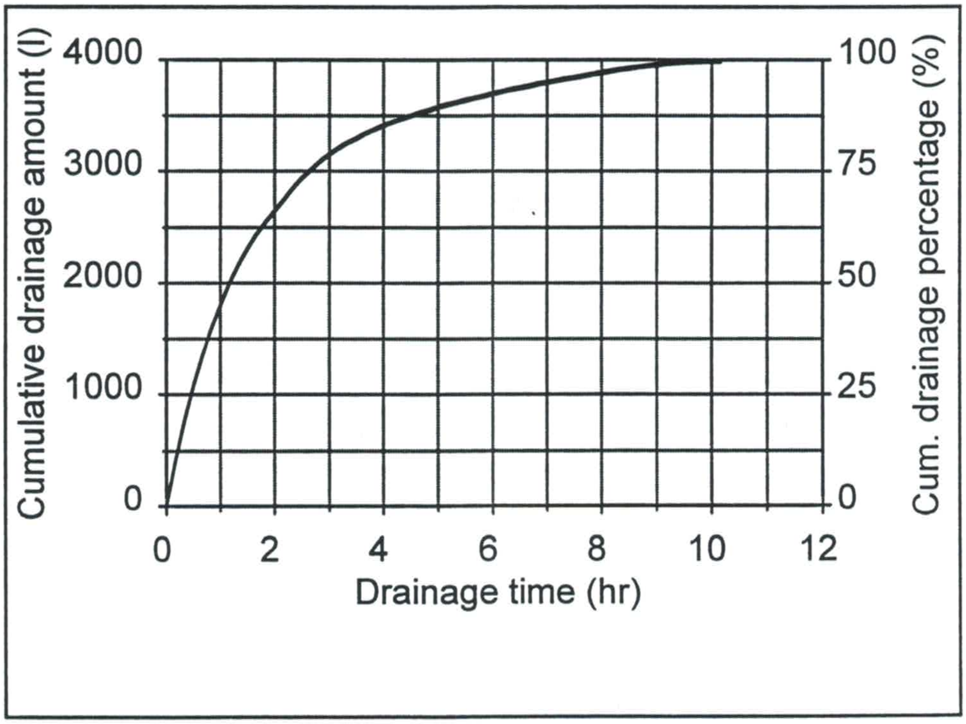

Fig. 4.4 Drainage time for an event

CHAPTER 5
DATA ANALYSIS PHASE-I

5.1 GENERAL

The data gathered from the field were examined (or analyzed) in two phases. In phase-I, a general approach was adopted to obtain a general overview of the data. Phase-I aimed at summarizing different information regarding rainfall, outflow, etc. and determining any inconsistency or incompatibility in data that may have resulted from equipment malfunctioning and/or from other errors. This is required because the field personnel usually visit the sites only once a month and, if equipment malfunctions any time prior to this visit, then resulting data would contain some erroneous, unusable data. The only way to separate the usable data from the unusable data is by examining the data (probably using a computer program). In phase-II of data analysis, details of the drainage characteristics of the sites were examined. Phase-I of data analysis is discussed in this chapter while phase-II of data analysis is discussed in the next chapter.

5.2 HARDWARE AND SOFTWARE

As mentioned earlier, the data is uploaded into the main frame computer at ODOT. The same main frame computer is used for all the data analysis. Special purpose programs, such as, P2000, VERSION2, etc. as mentioned in the subsequent sections, were written as a part of this project to perform data analysis. These programs utilized SAS Version 6.08 which is part of ODOT's main frame system (details of the programs are presented in Appendix E).

5.3 SOME PROBLEMATIC DATA FILES

Before starting the data analysis using the computer programs, a brief visual examination of the data files is necessary to check the data format because computer programs cannot read data from files with incorrect format. Out of the 168 data files in the database, it was found that some of the files had certain problems which presented an obstruction for their use in the analysis. Some of the files had to be totally discarded, while some other files could be used with proper modifications. Such files are discussed briefly in the following sub-sections.

5.3.1 Files with incorrect format

Due to incorrect format three files could not be read by the programs used to analyze the data. These three files are: (1) NB9208, (2) NW9207 and (3) NW9208. File NB9208 starts with part of line 101 of the first version of data format (see Fig. 5.1). All three files contain twelve records per minute (this means that data were recorded every five seconds, but the recorded time values contain only hour and minute parts, they do not contain the second part of the time values). The programs used in this study are unable to read such data and therefore, these files are never used in any phase of the analysis. It is most likely that these data were obtained from some testing done in the laboratory in 1992.

5.3.2 Files with faulty date and time values

Five files contain faulty date and time values. Whenever the data logger is powered on, the date and time need to be entered. If the data logger is set to start collecting data without specifying the date and time, then, by default, the data logger starts from year 2000, day 0 (outside the correct calendar day range of 1 to 366). As such, these data files need to be preprocessed by using program P2000 which rectifies the year, day and time values. An example of such faulty data file is given in Fig. 5.2. A listing of all such files is given in

Table 5.1.

When a data file with faulty date and time values was obtained, the date and time corresponding to the last data record in the file collected from the same site just before the collection of the faulty file was to be noted. Then the date and time when the faulty data were downloaded were to be noted. This date and time can be obtained from the output of the DOS command DIR (assuming that the laptop's clock is set properly). Alternatively, this date and time can be obtained from the notebook of the field personnel who downloaded the data. If the time interval between these two incidents and the length of time period over which data had been recorded in the faulty file are about the same, as has always been the case so far, then the last date and time value in the faulty file should be changed accordingly to reflect the actual date and time when this faulty data were downloaded.

For example, the file NB9311 started at time 100 on day 0 of the year 2000 and stopped at time 2330 on day 55 of year 2000. Thus, the length of data recorded in that file is 55 days and 22.5 hours. The file collected from the same (Noble county) site in the previous month is NB9310. The last record in the file NB9310 corresponds to time 1020 on day 280 of the year 1993. The exact date and approximate time when file NB9311 was downloaded can be found by looking at the file NB9401 which was collected from the same site in the next month. The first record in the file NB9401 corresponds to time 1030 on day 336 of the year 1993. Thus, the time gap between time 1020 on day 280 of the year 1993 and time 1030 on day 336 of the same year is 56 days and 10 minutes which is close to the length (55 days and 22.5 hours) of data recorded in file NB9311. The small difference in time occurs because two consecutive data files usually have a time gap of about half an hour to one hour. This amount of time is usually required to download the data, test the equipment and correct any problems associated with the equipment. As such, the file NB9311 can safely be assumed to have started at time 1130 on day 280 of year 1993 and stopped at time 1000 on day 336 of the same year.

5.3.3 Files with the second, third and fourth versions of data format

Data recorded with second, third and fourth versions of data format also need to be modified to make these files compatible with the data analysis programs. When these modifications are performed, the same data analysis programs can be used to read data from files with either the first version or higher versions of data format. The program VERSION2 modifies the line identifiers of the file NB9507B by increasing the line identifiers by 100 so that the data format version can be understood readily from the first digit of the line identifiers (see Fig. 5.3 for example and compare this figure with Fig. 3.2).

The program VERSION3 modifies the files with the third and fourth versions of data format such that the modified files have the same format as the modified files with the second version of data format (see Fig. 5.4, for example, and compare this figure with Figs. 3.3 and 5.3).

5.4 FIRST EXAMINATION OF DATA

After all the pre-processing discussed in section 5.3 is complete, the files are ready to be processed by the program FILENFO1. A total of 165 files (168 minus 3 files mentioned in section 5.3.1) were processed by this program. These files constitute the "Level One" files. Any file that is readable to the data analysis programs is placed in the Level One files. The program FILENFO1 then prepares a summary of the data in two different output files. The first output summarizes the basic information about the input files used (see Fig. 5.5, for illustration). The second output summarizes the information about monthly rainfall, outflow, etc. Results of the first examination of the data are discussed in the following sub-sections.

5.4.1 Data files with inconsistent names

Looking at the date and time when a file starts and when it stops (Fig. 5.5), one can find that the file named AT9212 actually fits between files AT9209 and AT9211. As such, the file AT9212 will be renamed MAT9210 to reflect the month corresponding to the data contained in that file, and to ensure consistency with the file naming convention discussed in section 3.5 in chapter 3. This was the only occurrence of this situation (that is, only this file was found to be given an inconsistent name).

5.4.2 Repetitive data files

From an examination of the information presented in Fig. 5.5, this is observed that the data contained in some of the files are repeated in some other files. For example, the data in the following pairs of files are exactly the same: (1) AT9208 and AT9210, (2) NB9307 and NB9308, (3) NW9307 and NW9308, and (4) NW9311 and NW9312. This is probably due to human error; the person downloading or uploading the data may have entered a wrong file name. File NB9212 covers all the data also contained in file NB9211. In this case, the storage module memory was not cleared after the file NB9211 was downloaded. To avoid confusion, all the repetitive data files must be discarded from further analysis. The total number of such discarded files is five and they are: (1) AT9210, (2) NB9308, (3) NW9308, (4) NW9312 and (5) NB9211.

5.4.3 Data records repeated in two consecutive files

In some cases, some data from the end of a file is repeated at the beginning of the next file. For example, file AT9502 ends at 1050 on day 46 while file AT9503 starts at 1010 on the same day (see Fig. 5.5). This indicates that the data corresponding to time interval from 1010 to 1050 have been repeated in the later file. The portion of data that was repeated in the second file was deleted. After deletion, the data were saved in a new file. The new file was named by adding a prefix 'M' at the beginning of the original file name. The total number of files that required such modification is seven and they are: (1) AT9211, (2) AT9302, (3) AT9503, (4) LG9209, (5) NB9212, (6) NW9211 and (7) NW9412.

5.5 SECOND EXAMINATION OF DATA

After the first examination of the data, the input files were modified appropriately to address the different problems as discussed in the preceding section. Also, files AK9206A and AT9206 were combined to produce a single file (MAT9206). These files then represented the actual net extent of data collected from the field. These files are called "Level Two" files in this report. There are 159 files (165 minus 5 files mentioned in section 5.4.2 minus 1 to account for file AK9206A) in Level Two. There are 39 files for the Atoka county site, 32 files for the Noble county site, 35 files for the Nowata county site, 40 files for the Pittsburg county site, and 13 files for the Logan county site. The Level Two files are processed again by using the program FILENFO1 to obtain a summary of the data collected from all these sites since the beginning of data collection (1992) until September, 1995. The results of this analysis are discussed in the following sub-sections.

5.5.1 Raw TSO datasets and basic information about them

The term *TSO dataset* or *TSO file* as used in this report refers to such a file that can be created or edited using the TSO option. A *raw TSO dataset* is a TSO file that contains the data collected from the field (the TSO file may have undergone some modifications as discussed in the preceding sections).

The basic information about the raw TSO datasets in Level Two are provided in Figs. 5.6 through 5.10. All these figures are actually a summary of the first output of the data analysis program FILENFO1 and this output prints the extent of data contained in a file. This output also provides the data interval (if the data is recorded at a fixed interval), the duration of rainfall, and outflow during the time period corresponding to the file.

The total rainfall and outflow is also found from this output. These two quantities are very important in obtaining an idea about the quality of data. For example, the amount of outflow in file AT9303 is 48,584 liters (12,836 gallons) corresponding to 106.9 mm (4.21 in) of rainfall, whereas the amount of outflow in file AT9305 is 6,057 liters (1,600 gallons) corresponding to 186.4 mm (7.34 in) of rainfall. The difference in outflow is sufficient enough to cause some doubt about the quality of data in file AT9305. It is probable that the outflow tipping bucket was malfunctioning for the whole or part of the data collection time period corresponding to file AT9305. Also, as another example, note that the amount of outflow in file AT9209 is 2,715 liters (717 gallons) even though there was no rainfall. This is not surprising, because the outflow might have been initiated by a rainfall even before the beginning of this file (10:00 am of day 247). For most of the files, the data record interval is ten minutes. Only for a few files in 1993 and 1994, the data record interval is thirty minutes.

5.5.2 Information about monthly rainfall, outflow and other related quantities

The graphical representation of the second output of the program FILENFO1 is presented in Figs. 5.11 through 5.26. The actual output is shown in a slightly modified, tabular form in Tables 5.2 through 5.6. Parameters listed in these tables are the duration of data collection, rainfall duration, rates of peak rainfall (mm/hr), peak outflow (l/hr), total amount of rainfall (mm) and outflow (l) for every month. The last column of the table presents the ratio between the outflow amount and the rainfall amount. This is an important information because it gives a crude idea about the drainability of a site. The rainfall amount (which has unit of depth in the aforementioned tables) needs to be converted to volumetric units before finding the ratio. This is done by multiplying the depth of rainfall by the appropriate catchment area (the term catchment area is explained earlier in section 2.6 in chapter 2).

The percentile distribution of different parameters contained in the output mentioned above is processed by the program FILENFO9 and the output is presented in Table 5.7 in a slightly modified form. A graphical representation of the same output is presented in Fig. 5.27.

All the parameters discussed in this section are based on the data collection interval. The values of these parameters are closer to the actual rainfall condition if the data collection interval is smaller.

Monthly data collection duration: The time period over which data have been collected from a site in a month is not the same for all the months. The obvious reason for this is equipment malfunctioning or other errors. This information should be kept in mind while comparing the data for one month with that of another.

Monthly rainfall duration: The monthly rainfall duration is usually less than fifty hours. However, the value of this parameter is found to be as high as 322.5 hours (April, 1994 at the Nowata county site) in the extreme case. Information about this parameter is provided in Figs. 5.15 through 5.18 and in Tables 5.2 through 5.6. The percentile distribution of this parameter is provided in Table 5.7.

Monthly rainfall and outflow magnitudes and monthly outflow proportions: These quantities are computed on the basis of the rainfall and outflow in a calendar month. Since the outflow in a calendar month may have been caused by a rainfall that occurred in the previous month(s), these quantities do not always reflect the true drainage characteristics of the site. For example, the monthly outflow at Nowata county site is almost always less than 6% except for June 1994, when the monthly outflow is 80%. Obviously the huge amount of outflow was caused by the large amount of rainfall in the previous month. Information about the monthly rainfall and outflow magnitudes is provided in Figs. 5.19 through 5.22, and information about monthly outflow proportions (as percentage of monthly rainfall) is provided in Figs. 5.23 through 5.26. This information can also be found in Tables 5.2 through 5.6. This is clear from Table 5.6 and Fig. 5.10 that there was no significant flow through the edge drain system at the Logan county site. Therefore, this site is omitted in this report from both the detailed analysis and corresponding plots.

The percentile distribution of these parameters is provided in Table 5.7 and Fig. 5.27. The magnitude of total monthly rainfall usually does not exceed the range of 200-300 mm (8-12 in), while the magnitude of total monthly outflow does not exceed the range of 40,000-60,000 liters (10,500-16,000 gallons).

Maximum rainfall and outflow rates: The maximum rainfall and outflow rates based on the data collection interval are presented in Tables 5.2 through 5.6. The percentile distribution of these two parameters are shown in Table 5.7 and in Fig. 5.27. These parameters can be used to obtain a preliminary and indirect measurement of the drainability of a site. However, due to the difference in the data collection interval for different data segments, the values of these parameters as presented in the aforementioned tables and figures should be used cautiously. The maximum outflow rate for the Nowata county site in the months of February, March and April, 1994 is unusually high (see Table 5.4). In fact, the data recorded during that time period (files NW9403, NW9404 and NW9405) should be discarded because of equipment malfunctioning.

The maximum rainfall and outflow rates based on 30, 60, ..., 150 and 180 minute duration rainfall and outflow are provided in Fig. 5.28. Textual versions of the same are provided in Figs. 5.29 and 5.30. This is observed that the values of the maximum rainfall rates for different sites are of the same order of magnitude. Based on the highest value of the maximum rate of outflow, the sites can be ranked in the following order: Atoka, Pittsburg, Noble, Nowata and Logan (the most efficient site mentioned first).

5.6 ANNUAL RAINFALL AND OUTFLOW

The annual amount of rainfall and outflow is computed and plotted by using program FILENFO7 (see Fig. 5.31, for a typical plot). This information again can be used to obtain a crude estimate of the comparative drainability of the sites. Incomplete datasets due to equipment malfunctioning and other reasons make this information of limited use. The percentile distribution of these two parameters are shown in Figs. 5.32 and 5.33. Table 5.8

summarizes the corresponding information in a tabular form.

5.7 DAILY RAINFALL AND OUTFLOW

The daily rainfall and outflow for the data in a file are computed by program FILENFO4. The results are plotted by using program FILENFO5 (see Fig. 5.34). If the rainfall and outflow in this figure increase consistently, then the data in the corresponding file can be taken as acceptable (free from field problems). But if the increase in rainfall and that in outflow are not consistent, then the data in the corresponding file cannot be taken as acceptable (reflects field problems). For example, for file NB9307 (Fig. 5.34), the outflow increases with an increase in rainfall as expected. But, for file AT9207 (Fig. 5.35), the outflow does not increase at all, though the plot shows a significant amount of rainfall. The opposite situation is encountered for data in file AT9209 (Fig. 5.35), where the rain gage recorded 0 rainfall but the outflow tipping bucket recorded a significant amount of outflow. It is thus evident that equipment malfunctioning has caused such error in these files. For purposes of comparing the outflow with rainfall, this kind of data are unusable and therefore, such files were discarded from further analysis.

In some cases, only a part of a file is found to contain such inconsistent rainfall and outflow data; these data should be deleted prior to the next phase of analysis. For example, the part of data in file PT9502 after day 20 does not show any increase of outflow with rainfall. Thus this portion of data reflects malfunctioning of the outflow tipping bucket, and these data should be deleted.

In some other situations, although the data in a file may be free from any inconsistency, part or all of the data may be useless in analyses for comparing the outflow with rainfall. This can be best understood by the following example. The plot for file PT9502 in Fig. 5.35 indicates malfunctioning of the outflow tipping bucket after day 20. The next file PT9503 (Fig. 5.35) seems to be free from any inconsistency. But the amount of outflow from day 45 to day 52 as recorded in these two files can not be compared to the rainfall that caused this outflow because the complete outflow amount is not known (due to the malfunctioning of the outflow tipping bucket for data in file PT9502) and the outflow pattern is inconsistent compared to other situations from the same site. In such cases also, part of the data file is unusable and should be deleted when comparing the outflow with rainfall.

All files with problems discussed in this section are listed in Tables 5.9 through 5.11. If a file is modified at this stage (by deleting the assumed bad/unusable data) then a prefix 'N' is added before the original name of the data file. Files finally selected for next phase of data analysis are called "Level Three" files in this report, and they are listed in Fig. 5.36 through 5.39.

Table 5.1 List of data files with faulty date and time values.

No.	File names	Data set names	File starts (faulty values)			File starts (correct values)			Modified file names
			Year	Day	Time	Year	Day	Time	
1	AT9507b	Urad348.DrainAt.Data	2000	0	20	1951	164	140	MAT9507B
2	AT9508	Urad348.DrainAt.Data	2000	29	950	1995	193	1050	MAT9508
3	NB9311	Urad013.DrainNb.Data	2000	0	100	1993	280	1130	MNB9311
4	NB9506	Urad348.DrainNb.Data	2000	0	20	1995	131	1030	MNB9506
5	NW9209	Urad013.DrainNw.Data	2000	0	20	1992	245	1220	MNW9209

Table 5.2 Monthly information about the raw data for the Atoka county site

No.	Month	Data collection time (days)	Rainfall duration (hours)	Peak rainfall (mm/hr)	Peak outflow (l/hr)	Total rainfall (mm)	Total outflow (l)	Outflow as % of rainfall
1	(1992) 4	8.5625	5.6667	77.724	1090.08	46.736	3588.18	7.2505
2	5	24.0347	39.5	77.724	851.63	173.99	36508.22	19.8157
3	6	29.9861	29	71.628	11.36	174.244	11.36	0.006
4	7	30.9931	21	76.2	0	129.286	0	0
5	8	30.9792	2.3333	152.4	431.49	62.23	140.05	0.2125
6	9	29.9792	0.1667	44.196	1339.89	7.366	2730.88	35.0117
7	10	30.9931	2.6667	44.196	1850.87	10.668	2216.12	19.6179
8	11	24.4236	24.6667	70.104	726.72	138.684	4706.65	3.205
9	(1993) 1	25.4444	13.5	15.24	181.68	45.466	5136.24	10.6685
10	2	27.9861	36.1667	16.764	987.89	104.394	43873.83	39.6892
11	3	30.9861	25.8333	15.24	1158.21	80.518	41209.19	48.333
12	4	29.9861	24	27.432	1669.19	103.886	25558.21	23.2336
13	5	29.8472	23.8333	57.912	1203.63	205.486	7007.93	3.2207
14	6	29.9931	19	62.484	4632.84	147.066	11949.25	7.6731
15	7	30.9861	0	1.524	22.71	0	15.14	.
16	8	30.9931	12	56.388	3133.98	78.994	14006.39	16.7446
17	9	29.9931	25.6667	53.34	3542.76	213.36	56896.12	25.1833
18	10	30.9514	40	33.02	3410.29	129.286	58695.89	42.8745
19	11	29.9792	35	46.736	0	110.998	0	0
20	12	30.9792	23.5	34.544	0	96.774	0	0
21	(1994) 1	30.9583	25	9.652	635.88	46.736	12906.85	26.0802
22	2	27.9792	32.5	27.94	3819.07	124.968	57831.02	43.7023
23	3	30.9583	34	31.496	3444.35	72.898	61790.13	80.0472
24	4	29.9375	24.5	33.02	2596.51	124.968	38786.79	29.3108
25	5	30.9375	42	50.8	1782.74	190.5	48022.19	23.8062
26	6	29.9583	10.5	39.624	1559.42	43.434	8926.92	19.4095
27	7	30.9792	43	26.924	2127.17	132.334	32081.66	22.8943
28	8	30.9375	20	67.564	1903.86	137.668	22689.18	15.5643
29	9	29.9861	19.1667	21.336	1313.4	54.864	17795.18	30.6307
30	10	30.9653	25.3333	91.44	2327.78	115.824	32832.98	26.7704
31	11	28.1389	39.1667	33.528	2361.84	149.352	64254.16	40.6287
32	12	25.3889	22.3333	19.812	1442.09	76.2	25225.13	31.2623
33	(1995) 1	30.9792	28	15.24	976.53	67.056	26197.88	36.8953
34	2	27.9931	2.3333	4.572	22.71	4.318	1534.82	33.5673
35	3	30.9792	25.3333	35.052	2202.87	133.604	36705.04	25.9447
36	4	29.8611	21.5	83.82	2282.36	177.038	38158.48	20.3548
37	5	30.9722	32.6667	80.772	2588.94	210.058	50796.59	22.8369
38	6	13	14.3333	42.672	3133.98	70.358	21076.77	28.29
39	7	30.9861	12	85.344	3099.92	99.568	18730.07	17.7649
40	8	30.9583	2.3333	48.768	2271	24.13	4585.53	17.9463
41	9	29.9792	24	123.444	3508.7	189.738	34475.67	17.1594

Table 5.3 Monthly information about the raw data for the Noble county site

No.	Month	Data collection time (days)	Rainfall duration (hours)	Peak rainfall (mm/hr)	Peak outflow (l/hr)	Total rainfall (mm)	Total outflow (l)	Outflow as % of rainfall
1	(1992) 8	4.5486	0.1667	1.524	0	0.254	0	0
2	9	29.9722	6.6667	6.096	352.005	11.684	1894.39	13.51
3	10	30.9931	4.1667	62.484	590.46	38.354	6190.37	13.449
4	11	29.9931	48.8333	35.052	261.165	143.51	10927.3	6.3448
5	12	21.5833	10.3333	4.572	215.745	20.32	8202.1	33.635
6	(1993) 1	30.9861	8.5	7.62	272.52	17.78	25230.8	118.25
7	2	27.9931	12.6667	4.572	193.035	23.114	18308.1	66.001
8	3	30.9861	9.5	7.62	181.68	21.336	21674.8	84.65
9	4	29.9861	23.6667	68.58	397.425	86.868	26811.1	25.718
10	5	30.9792	40.3333	85.344	352.005	220.726	46432.5	17.529
11	6	29.9931	15.1667	123.444	249.81	137.16	22918.2	13.923
12	7	14.5139	12	27.432	204.39	54.61	11203.6	17.095
13	8	20.3958	6.6667	25.908	851.625	34.798	11360.7	27.204
14	9	29.9931	14.8333	54.864	397.425	114.3	30705.8	22.385
15	10	30.9514	6	5.588	105.98	8.128	1495.08	15.327
16	11	29.9792	23	9.652	401.21	45.974	15876.2	28.775
17	12	30.9792	0	0.508	352.005	0	11877.3	.
18	(1994) 1	17.3958	0.5	0.508	3.785	0.254	17.03	5.5877
19	3	8.5625	5	6.096	185.465	8.89	3926.94	36.808
20	4	29.9167	51	37.084	480.695	266.192	44454.8	13.916
21	5	30.9583	25.5	34.544	370.93	95.504	24672.5	21.527
22	6	29.9792	8	5.588	268.735	18.034	4313.01	19.928
23	7	30.9583	21	18.796	719.15	65.278	17528.3	22.375
24	8	30.9375	20	24.892	772.14	81.534	14693.4	15.017
25	9	29.9583	14	7.62	261.165	17.526	8137.75	38.691
26	10	30.9722	9.3333	22.86	249.81	26.67	10647.2	33.266
27	11	30	27.3333	30.48	556.395	117.856	26201.7	18.525
28	12	30.9792	8	15.24	170.325	20.574	5819.44	23.569
29	(1995) 1	30.9792	7	7.62	113.55	12.954	8913.68	57.337
30	2	27.9722	2	7.62	102.195	5.08	3586.29	58.826
31	3	30.9792	24.6667	30.48	170.325	87.63	12848.2	12.217
32	4	13.3542	2.5	10.668	113.55	6.858	2344.81	28.49
33	5	20.5625	20	28.956	215.745	78.74	14710.4	15.567
34	6	29.9736	24.6667	121.92	624.525	205.232	25906.4	10.518
35	7	30.9819	3.9333	60.96	397.425	58.928	999.24	1.413
36	8	30.9514	3.83333	106.68	113.55	64.77	974.64	1.2539
37	9	29.9736	7.23333	53.34	454.2	68.58	17577.5	21.357

Table 5.4 Monthly information about the raw data for the Nowata county site

No.	Month	Data collection time (days)	Rainfall duration (hours)	Peak rainfall (mm/hr)	Peak outflow (l/hr)	Total rainfall (mm)	Total outflow (l)	Outflow as % of rainfall
1	(1992) 9	29.4583	0.5	13.716	11.355	2.794	35.958	2.30919
2	10	30.9931	12.3333	19.812	11.355	43.18	3.785	0.0157
3	11	29.9653	42.6667	27.432	11.355	130.302	404.995	0.55769
4	12	30.9861	38.3333	15.24	34.065	124.968	866.765	1.24451
5	(1993) 1	30.9861	25.3333	27.432	11.355	58.42	484.48	1.48803
6	2	27.9861	13.6667	15.24	22.71	27.432	246.025	1.60923
7	3	30.9792	29.6667	39.624	11.355	89.662	404.995	0.81047
8	4	29.9861	38.5	25.908	11.355	102.362	393.64	0.69001
9	5	30.9861	46.1667	65.532	22.71	286.512	925.433	0.57956
10	6	29.9861	12.8333	51.816	11.355	88.646	194.928	0.39456
11	7	12.3611	14.5	33.528	22.71	82.296	191.143	0.41675
12	8	20.5694	5	51.816	11.355	26.924	20.818	0.13873
13	9	29.9861	34.1667	77.724	22.71	265.938	325.51	0.21962
14	10	30.9722	13.5	9.144	11.355	23.622	1.893	0.0144
15	11	29.9792	29	25.908	0	62.23	0	0
16	12	30.8958	19	18.288	3.785	44.45	1.893	0.008
17	(1994) 1	30.9792	10	4.064	0	11.43	0	0
18	2	27.9792	27.5	18.288	136.26	57.658	422.03	1.3133
19	3	30.9375	317.5	10.668	79.485	239.268	1782.74	1.3369
20	4	29.8958	322.5	32.004	238.455	395.478	2946.62	1.3369
21	5	30.9583	53	99.568	26.495	134.62	1160.1	1.5463
22	6	29.9722	0.833	1.524	11.355	0.762	340.65	80.2139
23	7	30.9931	20.333	71.628	11.355	114.808	374.72	0.5856
24	8	29.7153	22	23.876	7.57	74.422	75.7	0.1825
25	9	29.9722	26.5	45.72	11.355	75.692	85.16	0.2019
26	10	30.8889	22.333	131.064	22.71	137.668	166.54	0.2171
27	11	29.9931	21.333	32.004	11.355	91.694	405	0.7925
28	12	30.9792	13.167	16.764	11.355	32.766	15.14	0.0829
29	(1995) 1	30.9722	10.6667	10.668	11.355	22.098	90.84	0.7376
30	2	27.9722	5.6667	6.096	11.355	14.224	115.44	1.45626
31	3	30.9792	12.3333	13.716	11.355	28.194	787.28	5.01036
32	4	29.9167	36.6667	45.72	11.355	147.066	418.24	0.51028
33	5	30.8194	24	50.292	11.355	122.936	1146.86	1.67389
34	6	29.9583	39.6667	135.636	11.355	262.128	2032.55	1.39131
35	7	30.9444	6.5	21.336	11.355	15.494	333.08	3.85728
36	8	30.9792	2.8333	73.152	11.355	22.098	170.325	1.383
37	9	29.9792	14	36.576	11.355	65.024	22.71	0.0627

Table 5.5 Monthly information about the raw data for the Pittsburg county site

No.	Month	Data collection time (days)	Rainfall duration (hours)	Peak rainfall (mm/hr)	Peak outflow (l/hr)	Total rainfall (mm)	Total outflow (l)	Outflow as % of rainfall
1	(1992) 4	15.5903	16	25.908	1442.09	67.564	13665.74	21.265
2	5	30.9861	48.3333	30.48	1146.86	202.946	25257.31	13.0844
3	6	29.9861	32.5	83.82	658.59	225.298	16213.05	7.5658
4	7	30.9792	24.3333	42.672	669.95	91.186	12492.39	14.4034
5	8	30.9931	14	118.872	647.24	135.636	6487.49	5.0286
6	9	29.9792	23.5	112.776	783.5	248.666	12513.21	5.2905
7	10	30.9861	5.8333	64.008	488.27	26.416	2236.94	8.9029
8	11	29.9931	40.1667	27.432	431.49	139.446	12634.33	9.5256
9	12	30.9792	50.8333	27.432	567.75	185.928	17467.78	9.8773
10	(1993) 1	30.9792	18.3333	15.24	386.07	53.848	5079.47	9.9174
11	2	27.9861	33.6667	13.716	476.91	101.346	9471.96	9.8261
12	3	30.9861	20	33.528	295.23	57.912	5123	9.3004
13	4	29.9861	31.1667	47.244	556.4	151.638	12412.91	8.6062
14	5	30.9861	2.6667	38.1	635.88	19.812	15051.05	79.8704
15	6	29.9861	15.6667	59.436	1408.02	88.138	10622.6	12.6711
16	7	30.9931	0.1667	1.524	68.13	0.254	136.26	56.4004
17	8	30.9931	15.1667	45.72	749.43	77.978	11038.95	14.8834
18	9	29.9444	32.1667	160.02	1544.28	313.69	35849.63	12.0152
19	10	30.9583	28.3333	38.1	1033.31	70.612	18122.58	26.9829
20	11	14.8542	20.5	27.432	1127.93	67.564	11873.55	18.4762
21	12	30.9792	30	25.4	1710.82	79.502	20719.09	27.3993
22	(1994) 1	30.9375	21	29.972	1180.92	59.944	8578.7	15.0461
23	2	27.9792	25	29.972	37.85	98.806	62.45	0.0665
24	3	29.0625	41	17.78	1324.75	96.012	2619.22	2.8681
25	4	29.8958	21	22.86	1154.43	87.63	13414.04	16.0936
26	5	30.9375	28	32.512	1059.8	129.032	17940.9	14.6182
27	6	29.9583	19	56.388	919.76	91.186	3911.8	4.5102
28	7	30.9792	33	49.276	582.89	117.602	7104.44	6.3513
29	8	30.9375	29.5	63.5	310.37	141.478	2100.68	1.5611
30	9	29.9583	8.8333	7.62	386.07	18.034	1926.57	11.2315
31	10	30.9583	19.6667	32.004	908.4	70.866	8342.14	12.3762
32	11	29.9792	42.5	108.204	669.95	227.076	3686.59	1.7069
33	12	30.9722	22.6667	30.48	658.59	81.534	7647.59	9.8613
34	(1995) 1	30.9792	9.5	7.62	647.235	24.892	11196.03	47.2881
35	2	27.9792	2.33333	3.048	34.065	4.064	465.56	12.0438
36	3	30.9792	21.6667	16.764	1476.15	80.772	5255.47	6.84067
37	4	29.9167	22.3333	67.056	1078.73	150.368	11124.11	7.77781
38	5	30.9583	26.3333	70.104	862.98	176.022	5480.68	3.27352
39	6	29.9792	16	48.768	601.82	116.078	7002.25	6.34213
40	7	30.9722	10.6667	89.916	1725.96	90.932	8319.43	9.61888
41	8	30.9792	2.6667	47.244	862.98	23.114	781.6	3.55515
42	9	29.9792	23	50.292	1850.87	145.034	5124.89	3.71503

Table 5.6 Monthly information about the raw data for the Logan county site

No.	Month	Data collection time (days)	Rainfall duration (hours)	Peak rainfall (mm/hr)	Peak outflow (l/hr)	Total rainfall (mm)	Total outflow (l)	Outflow as % of rainfall
1	(1992) 8	8.8472	4.6667	4.572	0	7.874	0	0
2	9	29.9861	9.1667	62.484	56.775	101.346	9.4625	0.01
3	10	30.9861	1.8333	24.384	0	17.272	13.2475	0.071
4	11	29.9861	41.8333	30.48	0	137.668	0	0
5	12	30.9722	27	13.716	0	74.676	0	0
6	(1993) 1	30.9931	4.8333	3.048	0	8.382	0	0
7	2	27.9931	20.3333	15.24	0	44.196	0	0
8	3	30.9861	0	1.524	22.71	0	3.785	.
9	4	29.9792	1	51.816	0	19.812	0	0
10	5	30.9861	6.1667	51.816	0	43.942	0	0
11	6	13.375	4.8333	16.764	0	20.828	0	0
12	7	19.5694	3.8333	28.956	0	13.97	0	0
13	8	10.6458	2.8333	12.192	0	9.906	0	0

Table 5.7 Percentile distribution of monthly rainfall, outflow and some other related parameters

No.	**Description**	**Unit**	**90% value**	**98% value**	**100% value**
1	Rainfall duration	hr	40	51	323
2	Maximum rainfall rate	mm/hr	83	131	160
3	Maximum outflow rate	l/hr	1904	3508	4633
4	Total monthly rainfall	mm	190	266	396
5	Total monthly outflow	l	32833	57831	64254
6	Monthly outflow as % of monthly rainfall	%	37	80	118

Note: the n% value in the above table indicates that the value of the parameter is less than or equal to the listed value in n% of the cases. For example, the value of total monthly rainfall is less than or equal to 266 mm in 98% of the cases.

Table 5.8 Percentile distribution of annual rainfall and outflow

No.	Description	Unit	90% value	98% value	100% value
1	Total annual rainfall	mm	1318	1351	1366
2	Total annual outflow	liters	247985	365976	423142

Note: the n% value in the above table indicates that the value of the parameter is less than or equal to the listed value in n% of the cases. For example, the value of total annual rainfall is less than or equal to 1351 mm in 98% of the cases.

Table 5.9 List of files that are not accepted in Level III

No.	Site	File Name	Equipment with Problem
1	Atoka	AT9206	outflow tipping bucket (otb)
2		AT9207	otb
3		AT9208	otb and rain gage (rg)
4		AT9209	rg
5		AT9301	otb
6		AT9401	otb
7	Noble	NB9401	rg
8		NB9507b	
9	Nowata	NW9210	otb
10		NW9311	otb
11		NW9401	otb
12		NW9404	otb, rg
13		NW9405	otb, rg
14		NW9501	otb
15		NW9506	
16		NW9507a	
17		NW9507b	
18		NW9508	
19	Pittsburg	PT9403	otb
20		PT9404	otb
21		PT9509	
22		PT9510	
23-35	Logan	All 13 files	(insignificant drainage)

Table 5.10 List of files that are partially accepted in Level III

No.	Site	File Name	Equipment with Problem
1	Atoka	AT9204	outflow tipping bucket (otb)
2		AT9205	otb
3		MAT9210	Problem from previous file (ppf)
4		MAT9211	otb
5		MAT9302	ppf
6		AT9305	otb
7		AT9306	ppf
8		AT9311	otb
9		AT9509	otb
10	Noble	NB9209	otb
11		NB9301	Rain gage (rg)
12	Nowata	MNW9211	otb
13		NW9304	otb
14		NW9403	otb, rg
15		NW9505	rg
16	Pittsburg	PT9409	otb
17		PT9411	otb
18		PT9502	otb
19		PT9503	ppf

Table 5.11 List of files with some bad data but accepted in Level III

No.	Site	File Name	Equipment with Problem
1	Atoka	AT9505	outflow tipping bucket (otb)
2	Noble	NB9411	Rain gage (rg)
3	Nowata	NW9305	otb
4		NW9306	Problem from previous file (ppf)
5		NW9408	otb, rg
6		NW9411	rg
7		NW9502	rg

```
218 53
103 21.83
106 0
109 0
112 .015
115 .058
101 1992 218 53
103 21.83
106 0
109 0
... .... ... ...
... .... ... ...
101 1992 218 53
103 21.82
106 0
109 0
112 .015
115 .059
101 1992 218 54
103 21.82
106 0
109 0
112 .015
115 .058
... .... ... ...
... .... ... ...
```

Fig. 5.1 Faulty TSO data file (NB9208)

```
101 2000 0 20
103 33.59
106 0
109 0
112 -.003
115 -.069
... .... ... ...
... .... ... ...
101 2000 26 2340
103 27.94
106 .09
109 .5
112 -.015
115 -.08
```

Fig. 5.2 Faulty date and time (NW9209)

```
... ...  ... ....  ....
... ...  ... ....  ....
211 1995 159 2116 0.5
211 1995 159 2128 0.5
215 1995 159 2130 -0.004 -6999 23.91
211 1995 159 2142 0.5
211 1995 159 2154 0.5
211 1995 159 2156 0
215 1995 159 2200 -0.004 -6999 22.46
211 1995 159 2210 0.5
206 1995 159 2214 0.01
206 1995 159 2216 0.03
206 1995 159 2218 0.07
206 1995 159 2220 0.09
206 1995 159 2222 0.12
211 1995 159 2222 0.5
206 1995 159 2224 0.16
211 1995 159 2224 0
206 1995 159 2226 0.15
... ...  ... ....  ....
... ...  ... ....  ....
```

Fig. 5.3 Second version of data format after modification

```
... ...  ... ....  ....
... ...  ... ....  ....
206 1995 254 2358 0.03
215 1995 255 2400 -0.102 -6999 16.64
206 1995 255 0 0.06
... ...  ... ....  ....
... ...  ... ....  ....
206 1995 255 30 0.01
215 1995 255 30 -0.101 -6999 16.63
206 1995 255 34 0.01
215 1995 255 100 -0.1 -6999 16.81
211 1995 255 106 0.5
... ...  ... ....  ....
... ...  ... ....  ....
```

Fig. 5.4 Third version of data format after modification

FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
At9208	216	1210	247	940	10	0.10	0.01	62.230	140.045
At9209	247	1000	274	1120	10	0.00	1.47	0.000	2715.737
At9210	216	1210	247	940	10	0.10	0.01	62.230	140.045
At9212	274	1140	302	1030	10	0.05	0.16	14.224	895.152
At9211	302	950	330	1010	10	1.10	0.99	142.494	6042.752
At9301	6	1320	21	910	10	0.56	0.10	45.466	79.485
At9302	21	910	49	1330	10	1.02	22.10	77.978	34036.612
At9502	11	1020	46	1050	10	1.10	22.08	64.262	26142.995
At9503	46	1010	74	1040	10	0.87	9.71	88.646	21071.095
Lg9208b	240	910	244	1550	10	0.01	0.00	0.508	0.000
Lg9209	244	1550	273	1030	10	0.39	0.01	101.600	9.463
Nb9210	273	930	300	1200	10	0.05	1.24	9.398	350.112
Nb9211	300	1120	328	1040	10	1.65	4.85	145.034	8111.255
Nb9212	300	1120	348	330	10	2.58	16.68	193.802	24816.352
Nb9307	165	1020	196	1220	10	0.97	19.05	156.210	29030.950
Nb9308	165	1020	196	1220	10	0.97	19.05	156.210	29030.950
Nw9210	272	1230	301	940	10	0.20	0.01	22.606	1.893
Nw9211	301	910	329	840	10	1.79	0.88	131.318	238.455
Nw9307	166	930	194	840	10	0.86	1.23	128.778	340.650
Nw9308	166	930	194	840	10	0.86	1.23	128.778	340.650
Nw9311	277	1230	335	1130	30	1.77	0.00	85.852	0.000
Nw9312	277	1230	335	1130	30	1.77	0.00	85.852	0.000
Nw9411	284	1150	319	1200	10	0.63	0.90	97.282	246.025
Nw9412	319	1150	339	1440	10	0.74	0.76	76.200	208.175

Fig. 5.5 A brief, partial and slightly modified output of the program FILENFO1 corresponding to the Level One input files

Note: The interpretation of the different columns in the above figure are: (1) input file name, (2) file start day, (3) file start time, (4) file stop day, (5) file stop time, (6) data interval, (7) total duration of rainfall (days), (8) total duration of outflow (days), (9) total amount of rainfall (mm) and (10) total amount of outflow (liters).

Site=Atoka * Start Year=1992

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
1	At9204	105	1340	114	300	10	0.24	3.50	46.736	3588.180
2	At9205	128	2310	162	1010	10	2.14	16.93	243.840	36508.217
3	mAt9206	162	1030	191	1200	10	0.80	0.04	112.522	11.355
4	At9207	191	1210	216	1140	10	0.79	0.00	121.158	0.000
5	At9208	216	1210	247	940	10	0.10	0.01	62.230	140.045
6	At9209	247	1000	274	1120	10	0.00	1.47	0.000	2715.737
7	mAt9210	274	1140	302	1030	10	0.05	0.16	14.224	895.152
8	mAt9211	302	1040	330	1010	10	1.10	0.99	142.494	6042.752

Site=Atoka * Start Year=1993

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
9	At9301	6	1320	21	910	10	0.56	0.10	45.466	79.485
10	mAt9302	21	920	49	1330	10	1.02	22.10	77.978	34006.332
11	At9303	49	1350	81	1440	10	1.56	29.20	106.934	48584.260
12	At9304	81	1500	104	1150	10	0.61	20.07	76.962	27289.850
13	At9305	104	1210	133	940	10	1.10	6.86	186.436	6057.892
14	At9306	134	1320	167	1000	10	0.96	18.90	157.480	10633.957
15	At9307	167	1010	195	840	10	0.12	7.58	35.560	8098.007
16	At9308	195	900	222	1040	10	0.35	1.34	48.768	12806.547
17	At9309	222	1050	252	1130	10	0.51	1.37	71.882	10471.202
18	At9310	252	1140	278	1150	10	0.71	8.60	171.704	47624.762
19	At9311	278	1300	334	1300	30	3.13	7.52	240.284	58695.887
20	At9401	334	1330	19	1400	30	1.48	0.00	127.254	0.000

Site=Atoka * Start Year=1994

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
21	At9403	19	1500	62	1300	30	2.56	32.58	160.274	89655.295
22	At9404	62	1400	98	730	30	0.79	25.56	54.356	42872.695
23	At9405	98	900	124	1330	30	1.65	7.96	170.688	59676.202
24	At9406	124	1500	180	1200	30	1.50	31.44	187.452	36059.695
25	At9408	180	1300	229	1030	30	2.13	22.94	213.360	43313.647
26	At9409	229	1200	251	1030	30	0.94	9.25	88.900	21110.837
27	At9410	251	1050	285	1020	10	0.66	6.12	88.900	17776.252
28	At9412	285	1110	333	320	10	2.41	40.17	199.136	87452.425
29	At9501	340	1440	11	950	10	1.03	17.77	80.010	26782.660

Site=Atoka * Start Year=1995

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
30	At9502	11	1020	46	1050	10	1.10	22.08	64.262	26142.995
31	mAt9503	46	1100	74	1040	10	0.87	9.71	88.646	21071.095
32	At9504	74	1110	102	910	10	0.76	22.22	146.050	37613.437
33	At9505	102	1230	128	1320	10	1.15	20.83	232.664	45728.477
34	At9506	128	1400	158	930	10	0.68	16.33	68.326	24734.975
35	At9507a	158	1020	164	100	10	0.43	2.79	38.862	12140.387
36	mAt9507b	164	140	193	1030	10	0.23	4.75	66.548	12112.000
37	mAt9508	193	1050	215	1000	10	0.45	4.21	76.454	16536.665
38	At9509	215	1100	249	1230	10	0.01	0.55	0.508	149.507
39	At9510	249	1300	277	1110	10	1.09	10.01	204.724	37806.472

Fig. 5.6 Basic information about the raw TSO datasets for the Atoka county site

-------------------- Site=Noble * Start Year=1992 --------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
1	Nb9209	240	1050	273	850	10	0.28	0.36	11.938	1894.392
2	Nb9210	273	930	300	1200	10	0.05	1.24	9.398	350.112
3	mNb9212	300	1210	348	330	10	2.57	16.67	192.024	24812.567
4	Nb9301	357	1330	19	1140	10	0.21	14.05	10.922	17846.275

-------------------- Site=Noble * Start Year=1993 --------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
5	Nb9302	19	1200	47	1050	10	0.48	17.15	20.066	20175.942
6	Nb9303	47	1100	74	1000	10	0.40	20.16	18.796	14803.135
7	Nb9304	74	1020	102	1020	10	0.37	19.05	19.812	19708.495
8	Nb9305	102	1040	131	810	10	2.10	19.37	254.254	46818.557
9	Nb9306	131	840	165	1010	10	0.58	17.48	82.296	24352.690
10	Nb9307	165	1020	196	1220	10	0.97	19.05	156.210	29030.950
11	Nb9309	223	1430	250	1100	10	0.42	6.17	49.022	22007.882
12	Nb9310	250	1110	280	1020	10	0.47	9.19	100.076	20058.607
13	mNb9311	280	1130	336	1000	30	1.21	12.48	54.102	17371.257
14	Nb9401	336	1030	18	930	30	0.02	12.90	0.254	11894.362

-------------------- Site=Noble * Start Year=1994 --------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
15	Nb9404	82	1030	96	1130	30	0.31	7.29	11.938	4858.047
16	Nb9405	96	1330	123	1000	30	2.25	19.23	269.240	47562.310
17	mNb9407	123	1100	193	1000	30	1.17	26.56	107.442	24952.612
18	mNb9408	193	1100	227	1100	30	0.94	9.73	69.850	17596.465
19	Nb9409	227	1230	249	1100	30	1.29	9.21	90.170	22051.410
20	mNb9410	249	1200	283	1150	10	0.17	7.72	8.382	6046.537
21	Nb9411	283	1230	322	1210	10	0.74	16.52	63.754	17208.502
22	Nb9412	322	1210	339	1010	10	0.68	4.28	76.708	14299.730
23	Nb9501	339	1040	12	1250	10	0.35	10.13	21.082	7702.475

-------------------- Site=Noble * Start Year=1995 --------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
24	Nb9502ma	12	1320	47	1050	10	0.34	11.52	15.240	9706.632
25	Nb9503	47	1130	75	910	10	0.90	13.10	79.756	10961.360
26	Nb9504	75	940	104	830	10	0.26	11.60	17.018	5141.922
27	mNb9506	131	1030	159	1030	10	1.62	18.55	166.116	27159.267
28	mNb9507a	159	1100	186	930	.	0.24	3.52	117.856	13578.687
29	mNb9507b	186	1000	194	904	.	0.00	0.00	0.254	5.678
30	mNb9508	194	930	216	900	.	0.28	0.38	107.950	1222.555
31	mNb9509	216	942	255	1016	.	0.08	0.83	27.940	2019.297
32	mNb9510	255	1026	278	1100	.	0.33	6.91	67.564	19738.775

Fig. 5.7 Basic information about the raw TSO datasets for the Noble county site

------------------- Site=Nowata * Start Year=1992 -------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
1	mNw9209	245	1220	272	1140	10	0.02	0.13	2.794	35.957
2	Nw9210	272	1230	301	940	10	0.20	0.01	22.606	1.893
3	mNw9211	301	950	329	840	10	1.79	0.88	131.318	238.455
4	Nw9212	329	930	357	840	10	1.89	3.27	144.272	1029.520
5	Nw9301	357	900	20	930	10	0.97	1.17	53.594	319.832

------------------- Site=Nowata * Start Year=1993 -------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
6	Nw9302	20	950	48	1320	10	0.50	0.77	25.146	211.960
7	Nw9303	48	1340	75	830	10	0.31	1.44	12.954	416.350
8	Nw9304	75	900	103	740	10	1.88	0.71	113.792	193.035
9	Nw9305	103	800	132	1000	10	2.10	1.45	249.936	395.532
10	Nw9306	132	1020	166	910	10	0.90	3.44	151.384	968.960
11	Nw9307	166	930	194	840	10	0.86	1.23	128.778	340.650
12	Nw9309	223	1020	251	910	10	0.39	0.09	67.056	24.602
13	Nw9310	251	930	277	1150	10	1.24	1.04	225.806	323.617
14	Nw9311	277	1230	335	1130	30	1.77	0.00	85.852	0.000
15	Nw9401	335	1400	21	1030	30	1.00	0.02	48.006	1.893

------------------- Site=Nowata * Start Year=1994 -------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
16	Nw9403	21	1100	61	930	30	1.85	1.58	77.978	514.760
17	Nw9404	61	1100	97	830	30	14.42	14.42	269.748	2009.835
18	Nw9405	97	1100	123	1530	30	13.06	13.06	370.332	2759.265
19	Nw9406	123	1630	179	1130	30	0.92	13.71	117.094	1356.922
20	Nw9408	179	1210	227	410	10	0.86	1.42	115.316	386.070
21	Nw9409	228	1100	250	930	30	1.75	1.19	96.012	111.657
22	Nw9410	250	1010	284	910	10	0.72	0.60	110.236	170.325
23	Nw9411	284	1150	319	1200	10	0.63	0.90	97.282	246.025
24	mNw9412	319	1210	339	1440	10	0.74	0.76	76.200	208.175
25	Nw9501	339	1510	9	1230	10	0.67	0.06	37.084	15.140

------------------- Site=Nowata * Start Year=1995 -------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
26	Nw9502	9	1310	45	950	10	0.34	0.44	18.288	121.120
27	Nw9503	45	1030	73	1000	10	0.67	1.02	34.798	278.197
28	Nw9504	73	1030	101	820	10	0.51	2.84	46.228	774.032
29	Nw9505	101	1020	130	850	10	1.08	1.16	107.696	316.047
30	Nw9506	130	1310	156	1210	10	1.42	5.35	175.768	1457.225
31	Nw9507a	156	1310	192	940	10	1.47	7.12	218.440	1939.812
32	Nw9507b	192	1050	194	1200	10	0.01	0.02	0.762	5.678
33	Nw9508	194	1220	214	930	10	0.08	0.47	20.574	128.690
34	Nw9509	214	1000	248	1240	10	0.07	0.27	7.112	73.807
35	Nw9510	248	1310	276	940	10	0.58	0.09	65.024	24.602

Fig. 5.8 Basic Information about the Raw TSO Datasets for the Nowata county site

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
Site=Pittsburg * Start Year=1992										
1	Pt9204	106	950	133	1050	10	1.10	8.93	161.798	22621.052
2	Pt9205	133	1110	161	1030	10	2.22	17.88	178.562	22766.775
3	Pt9206	161	1050	192	810	10	0.74	12.54	155.956	10104.057
4	Pt9207	192	840	217	750	10	1.03	7.23	91.694	12409.122
5	Pt9208	217	800	247	1310	10	0.56	4.03	134.620	6250.927
6	Pt9209	247	1330	274	850	10	0.97	8.58	246.126	12460.220
7	Pt9210	274	910	303	920	10	0.23	1.02	16.510	2077.965
8	Pt9211	303	940	330	820	10	1.68	5.35	150.876	12795.192
9	Pt9212	330	830	356	1310	10	2.07	4.66	183.896	17411.000
10	Pt9301	356	1340	20	1320	10	0.83	3.68	56.896	5122.997
Site=Pittsburg * Start Year=1993										
11	Pt9302	20	1350	49	1050	10	0.90	2.89	70.358	6093.850
12	Pt9303	49	1110	76	1040	10	0.87	2.53	50.038	5611.262
13	Pt9304	76	1100	105	750	10	1.42	4.65	150.368	12745.987
14	Pt9305	105	810	133	800	10	0.47	7.36	59.944	12823.580
15	Pt9306	133	820	166	1400	10	0.50	5.38	67.056	12793.300
16	Pt9307	166	1420	194	1240	10	0.16	3.60	21.336	2778.190
17	Pt9308	194	1250	222	1220	10	0.29	2.22	31.750	4706.647
18	Pt9309	222	1230	252	820	10	0.85	5.78	114.046	18273.980
19	Pt9310	252	940	278	830	10	0.90	8.20	267.208	25395.457
20	Pt9311	278	930	319	1200	30	1.96	11.27	116.840	28506.727
21	Pt9401	334	1530	20	1030	30	1.94	11.63	106.680	27649.425
Site=Pittsburg * Start Year=1994										
22	Pt9403	20	1200	61	1430	30	1.90	1.27	152.146	1712.712
23	Pt9404	63	1300	97	1300	30	1.13	2.65	81.026	2619.220
24	Pt9405	97	1530	124	1030	30	1.27	7.33	116.840	22405.307
25	Pt9406	124	1200	180	930	30	1.48	23.46	185.420	12861.430
26	Pt9408	180	1030	229	800	30	1.71	17.81	192.024	7653.270
27	Pt9409	229	930	250	1530	30	1.06	1.40	72.898	1621.872
28	Pt9410	250	1630	285	800	10	0.59	2.92	56.896	8752.812
29	Pt9411	285	900	320	1020	10	1.86	1.33	230.632	1464.795
30	Pt9412	320	1050	340	1050	10	0.34	3.41	22.606	3667.665
31	Pt9501	340	1130	10	1000	10	0.99	7.34	83.312	8279.687
Site=Pittsburg * Start Year=1995										
32	Pt9502	10	1030	46	1310	10	0.42	4.74	26.162	10571.505
33	Pt9503	46	1340	74	1220	10	0.69	2.40	52.324	821.345
34	Pt9504	74	1250	102	720	10	0.57	6.94	79.502	10119.197
35	Pt9505	102	920	129	830	10	1.29	5.95	210.058	5955.697
36	Pt9506a	129	930	157	1300	10	0.69	10.32	134.874	7834.950
37	Pt9507	157	1330	193	820	10	0.46	6.02	62.738	7261.522
38	Pt9508	193	900	215	830	10	0.47	1.78	98.552	6426.930
39	Pt9509	215	900	249	1030	10	0.02	0.01	1.016	5.678
40	Pt9510	249	1100	277	830	10	1.06	0.19	170.942	5121.105

Fig. 5.9 Basic Information about the Raw TSO Datasets for the Pittsburg county site

------------------- Site=Logan * Start Year=1992 -------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
1	Lg9208a	227	940	231	1500	10	0.17	0.00	7.112	0.000
2	Lg9208b	240	910	244	1550	10	0.01	0.00	0.508	0.000
3	mLg9209	244	1600	273	1030	10	0.39	0.01	101.600	9.463
4	Lg9210	273	1050	300	1050	10	0.02	0.00	6.350	0.000
5	Lg9211	300	1110	328	930	10	1.44	0.01	131.826	13.248
6	Lg9212	328	950	358	820	10	1.49	0.00	91.440	0.000
7	Lg9301	358	900	19	1040	10	0.20	0.00	8.382	0.000

------------------- Site=Logan * Start Year=1993 -------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
8	Lg9302	19	1050	47	930	10	0.46	0.00	18.796	0.000
9	Lg9303	47	940	74	900	10	0.39	0.01	25.400	3.785
10	Lg9304	74	920	102	910	10	0.00	0.00	0.000	0.000
11	Lg9305	102	940	133	1400	10	0.04	0.00	19.812	0.000
12	Lg9306	133	1420	165	900	10	0.46	0.00	64.770	0.000
13	Lg9308	193	1020	223	1530	10	0.28	0.00	23.876	0.000

Fig. 5.10 Basic Information about the Raw TSO Datasets for the Logan county site

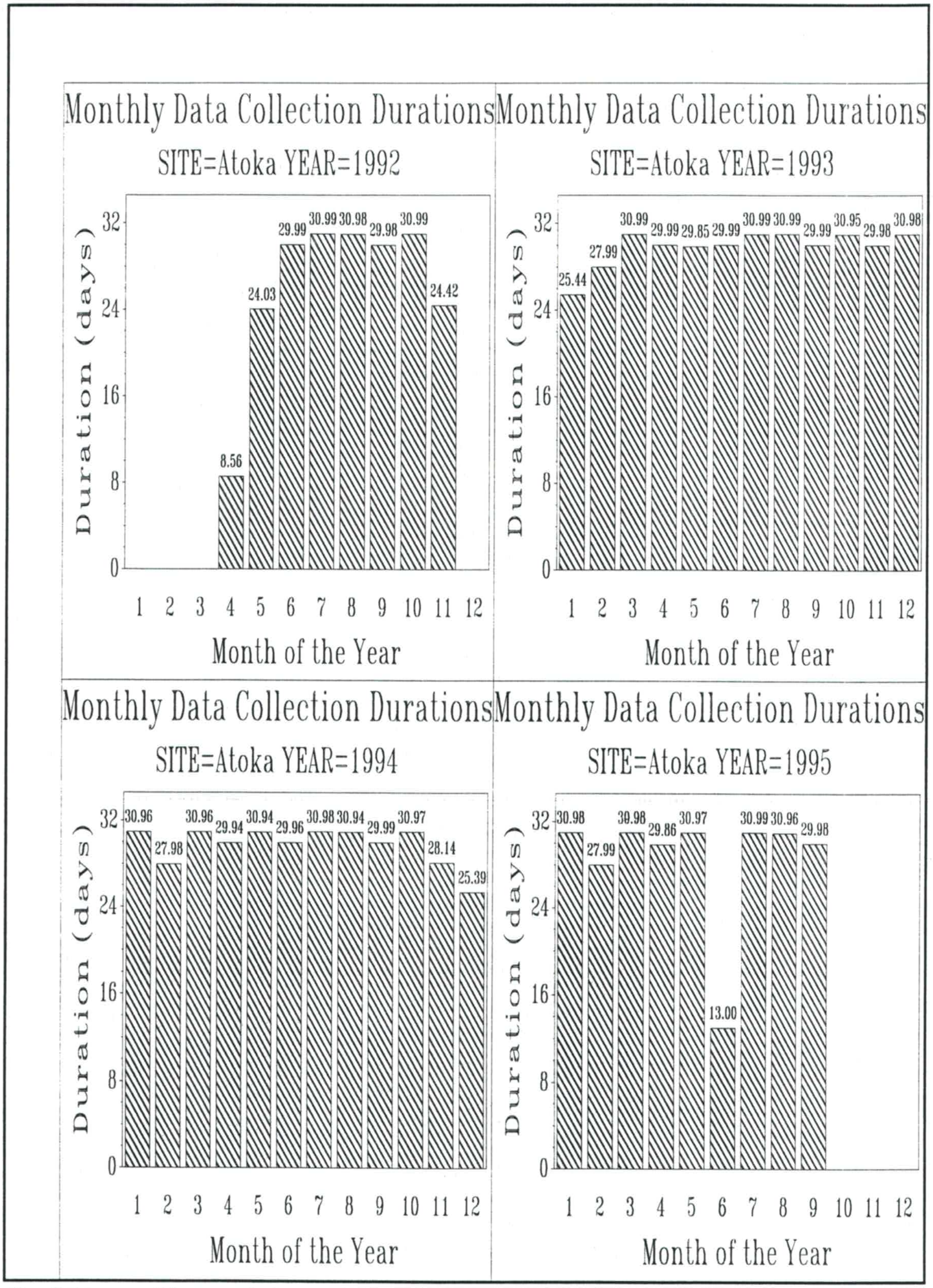

Fig. 5.11 Time period over which data were collected from the Atoka county site

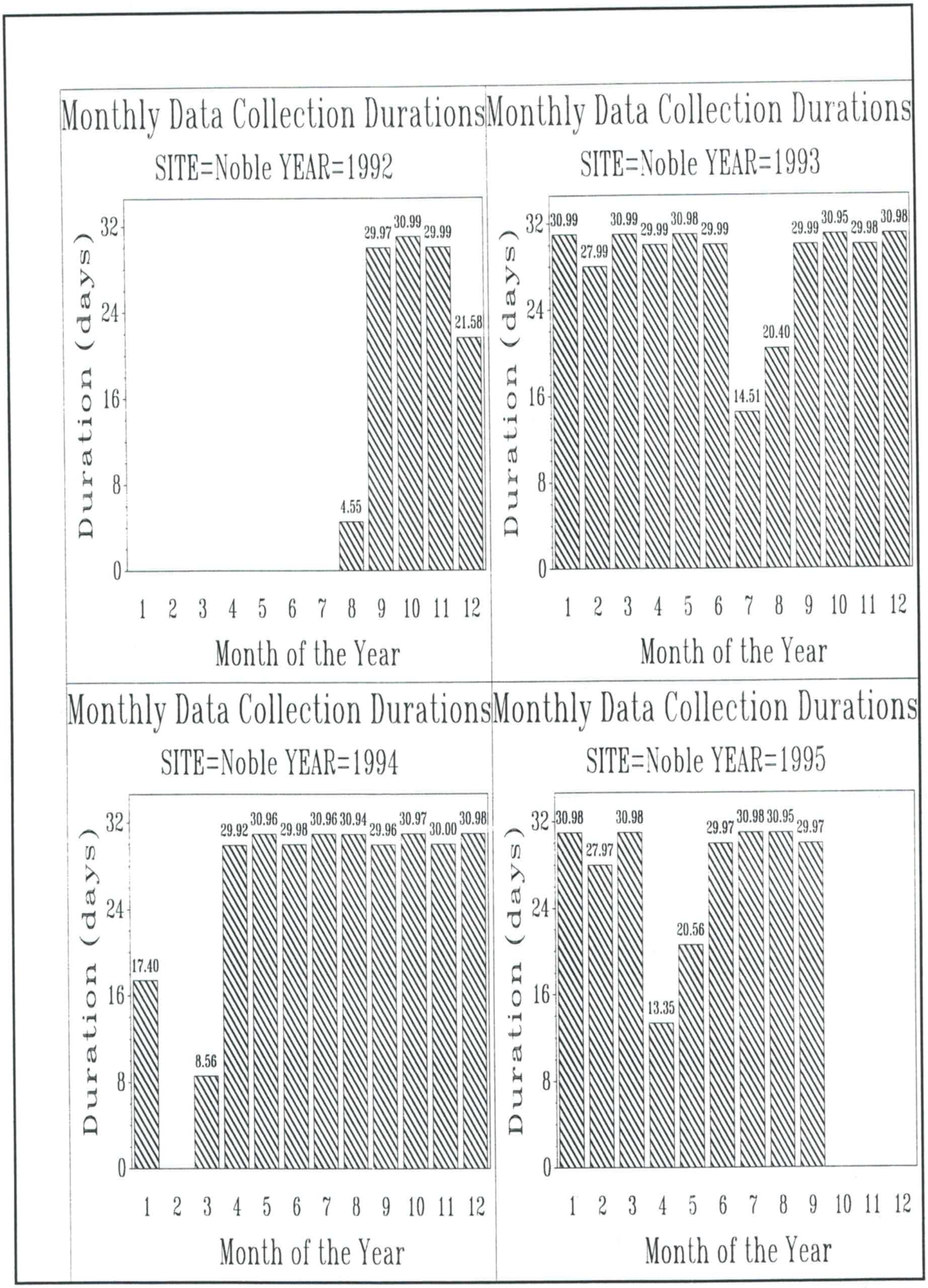

Fig. 5.12 Time period over which data were collected from the Noble county site

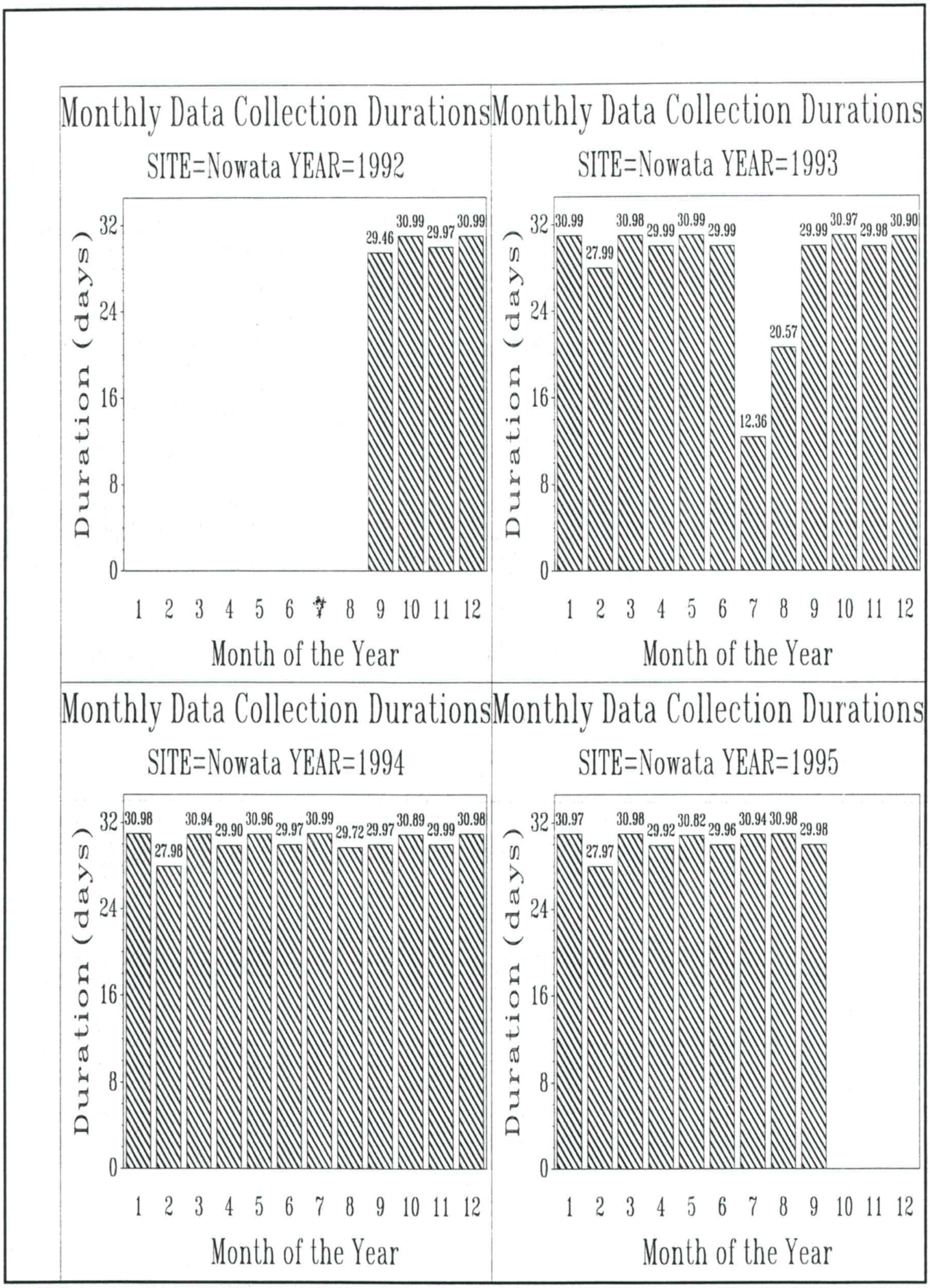

Fig. 5.13 Time period over which data were collected from the Nowata county site

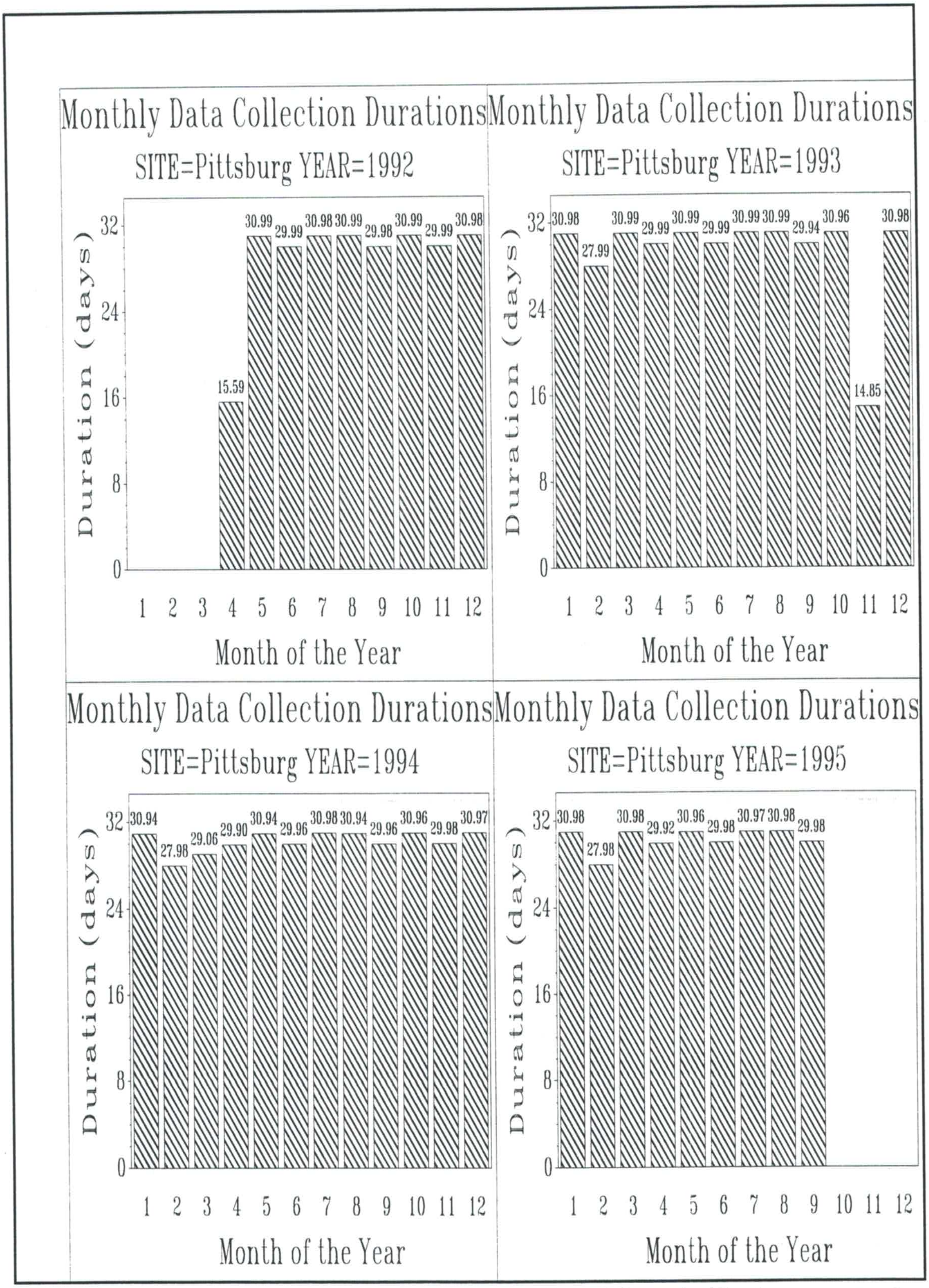

Fig. 5.14 Time period over which data were collected from the Pittsburg county site

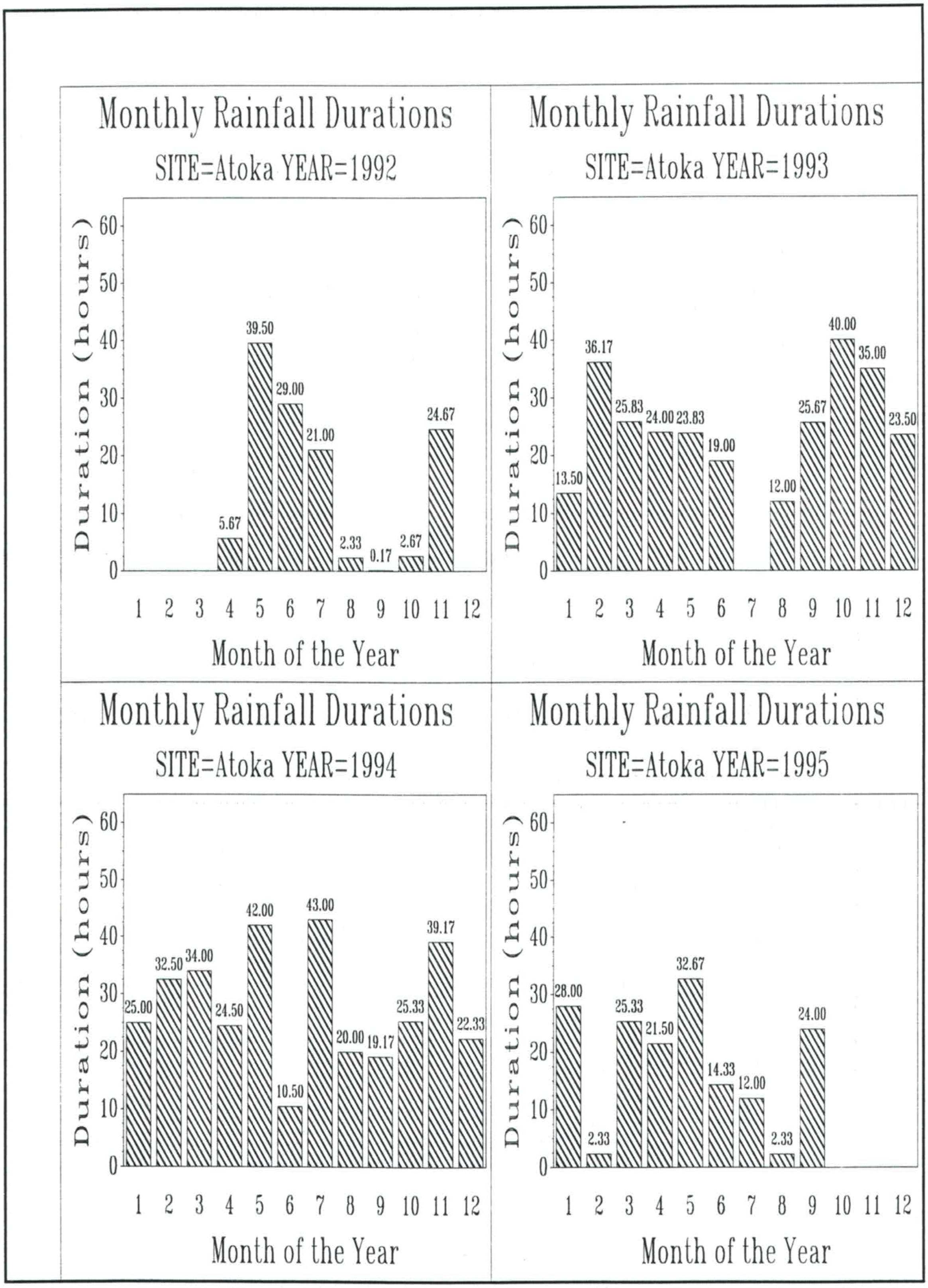

Fig. 5.15 Total duration of measured rainfall at the Atoka county site

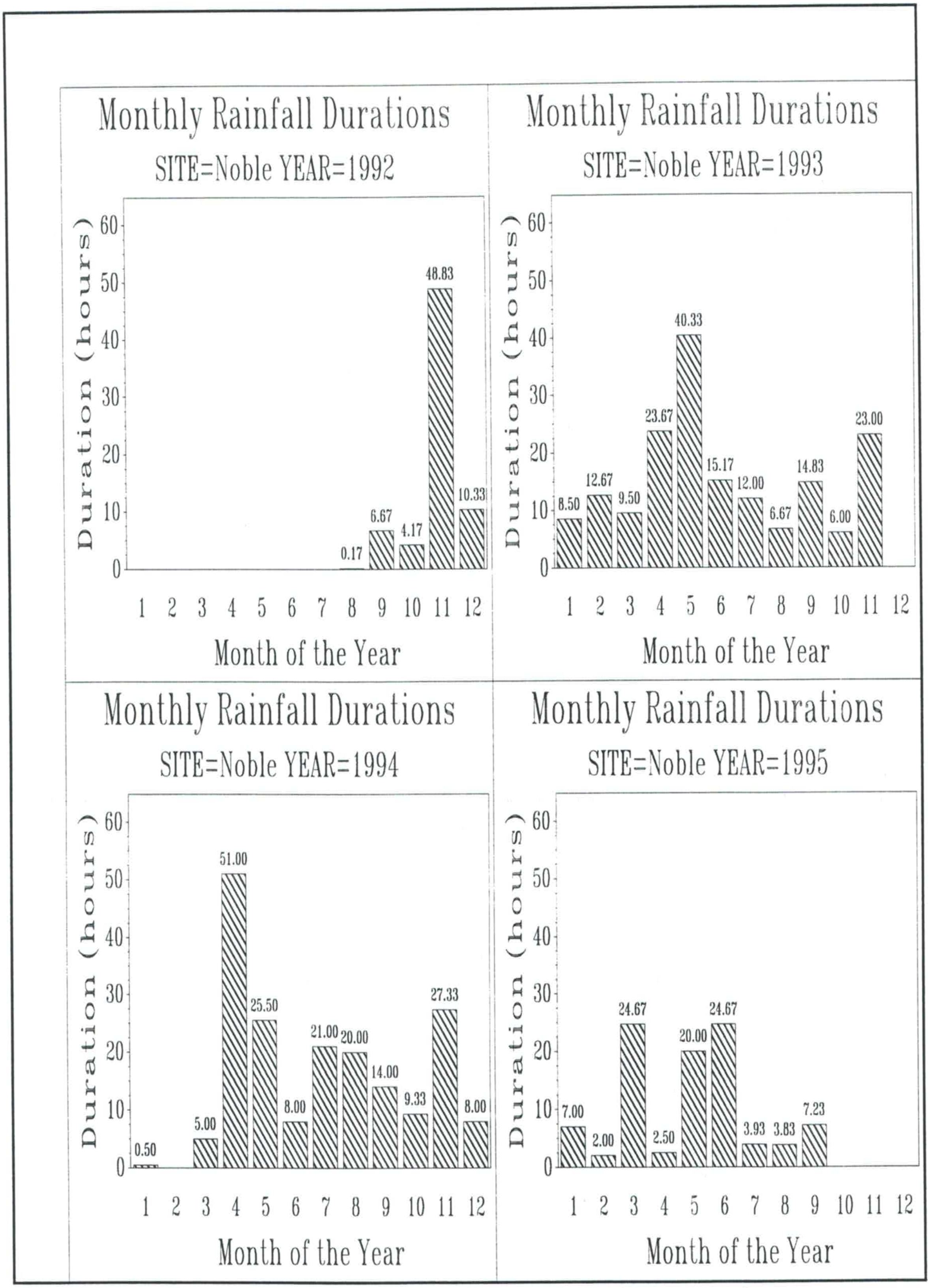

Fig. 5.16 Total duration of measured rainfall at the Noble county site

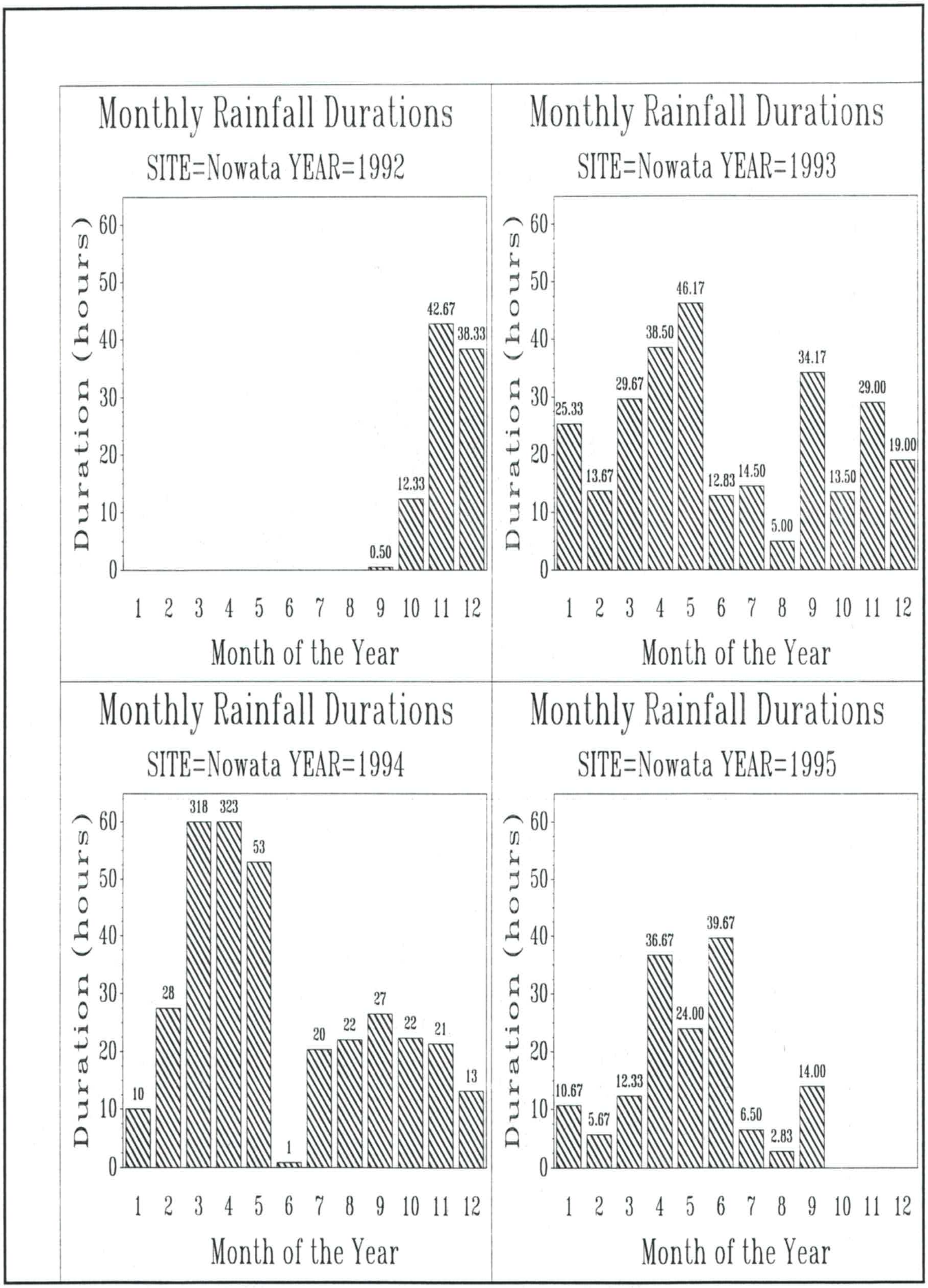

Fig. 5.17 Total duration of measured rainfall at the Nowata county site

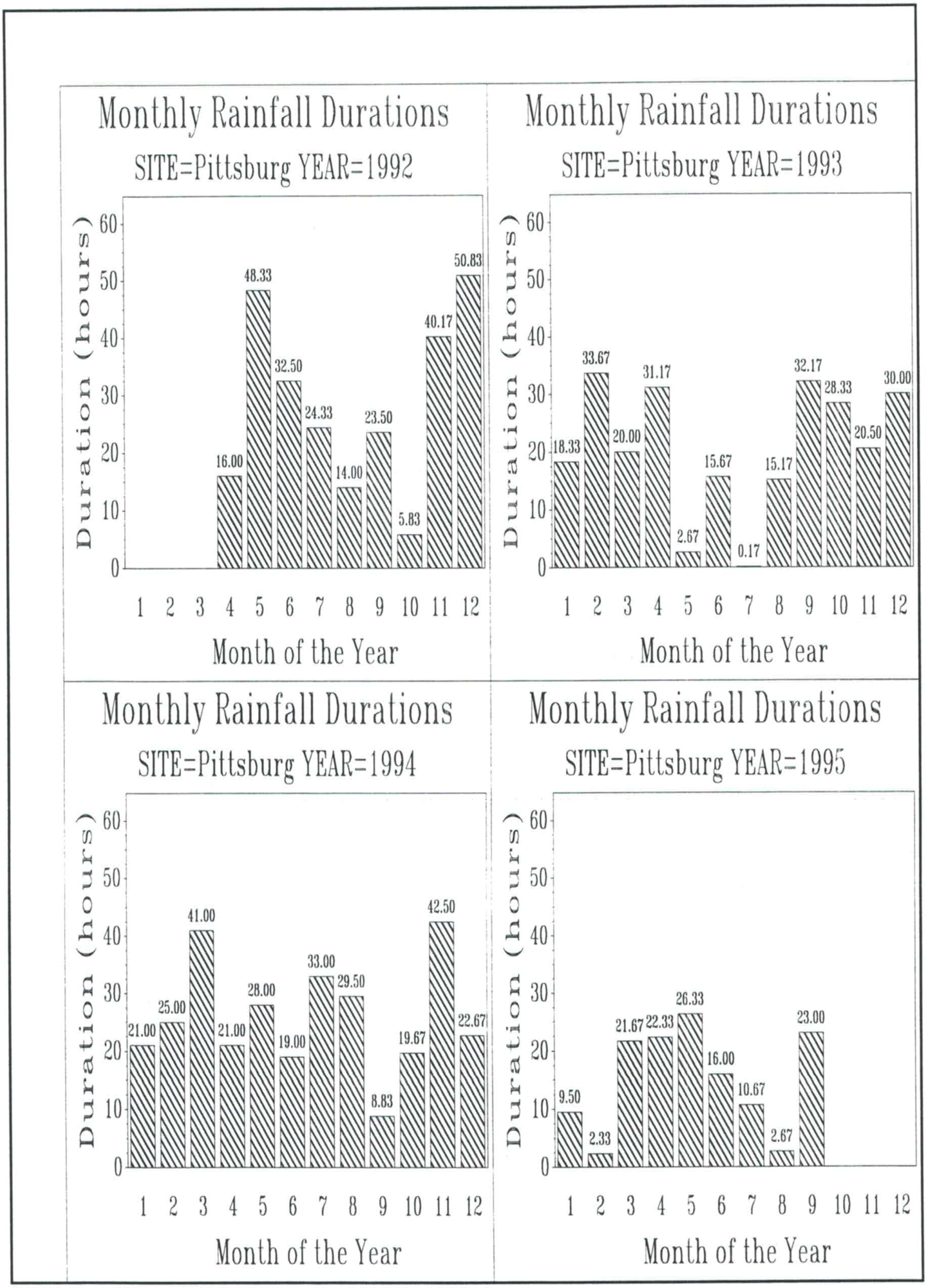

Fig. 5.18 **Total duration of measured rainfall at the Pittsburg county site**

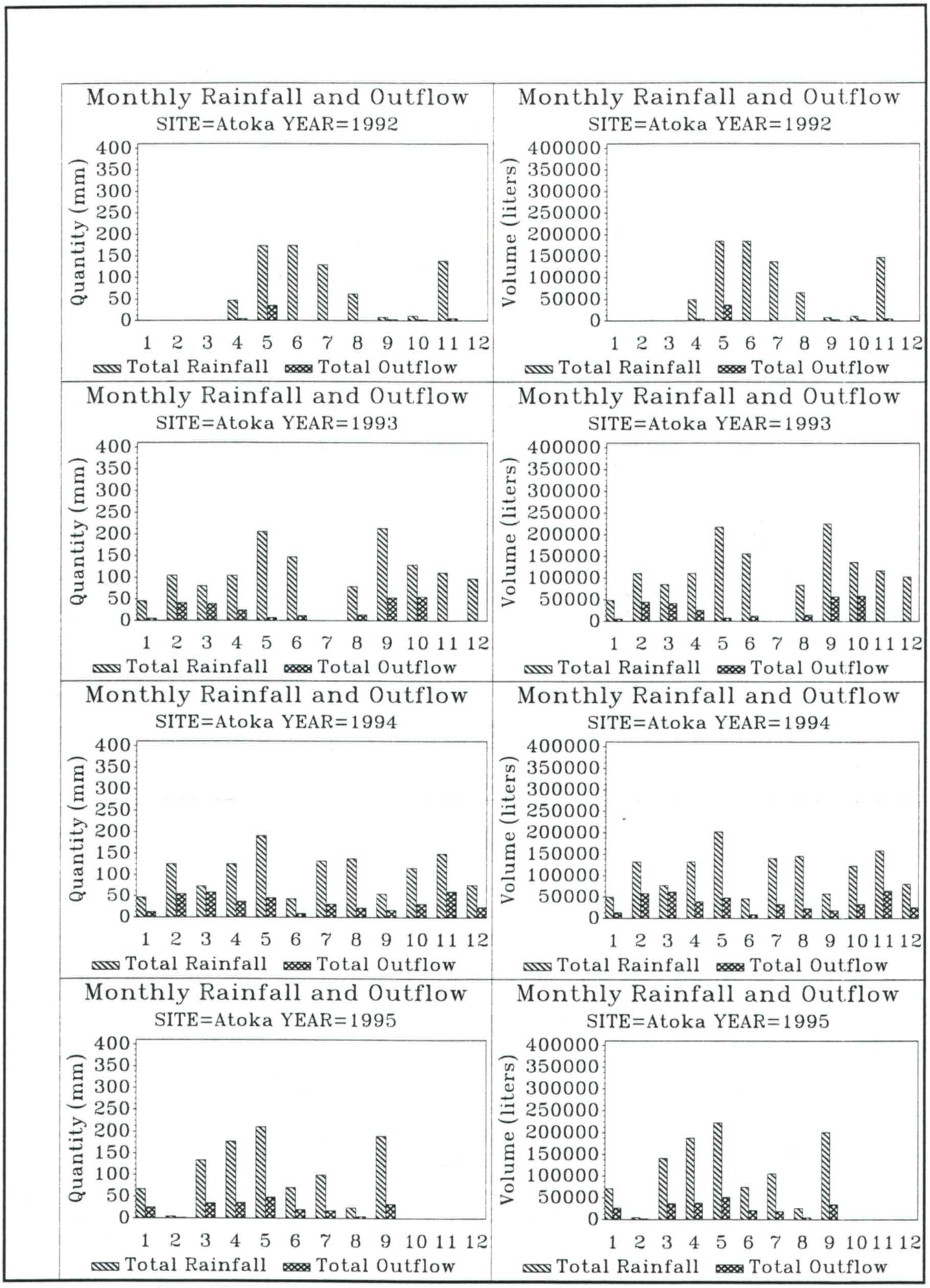

Fig. 5.19 Monthly rainfall and outflow for the Atoka county site

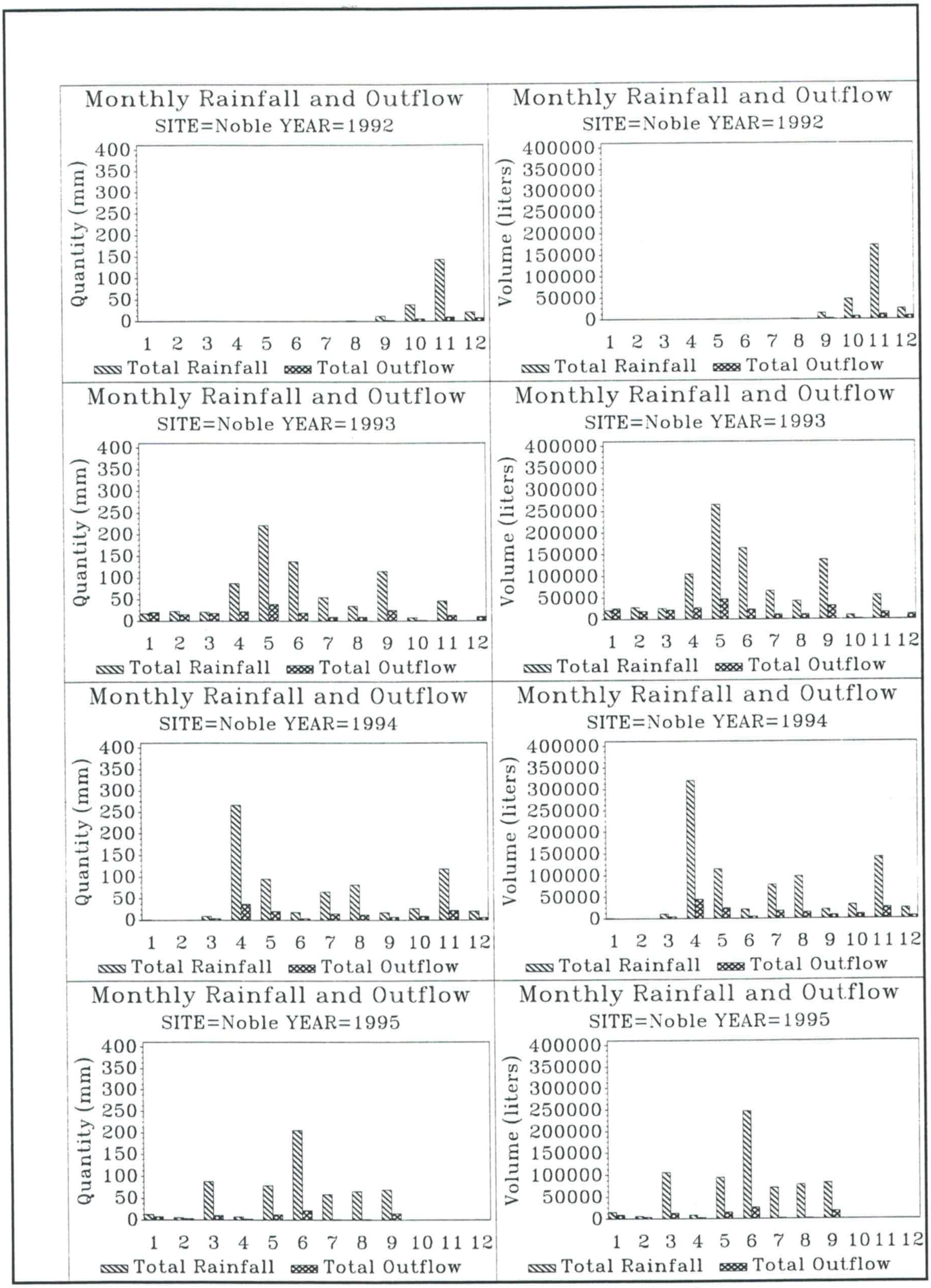

Fig. 5.20 Monthly rainfall and outflow for the Noble county site

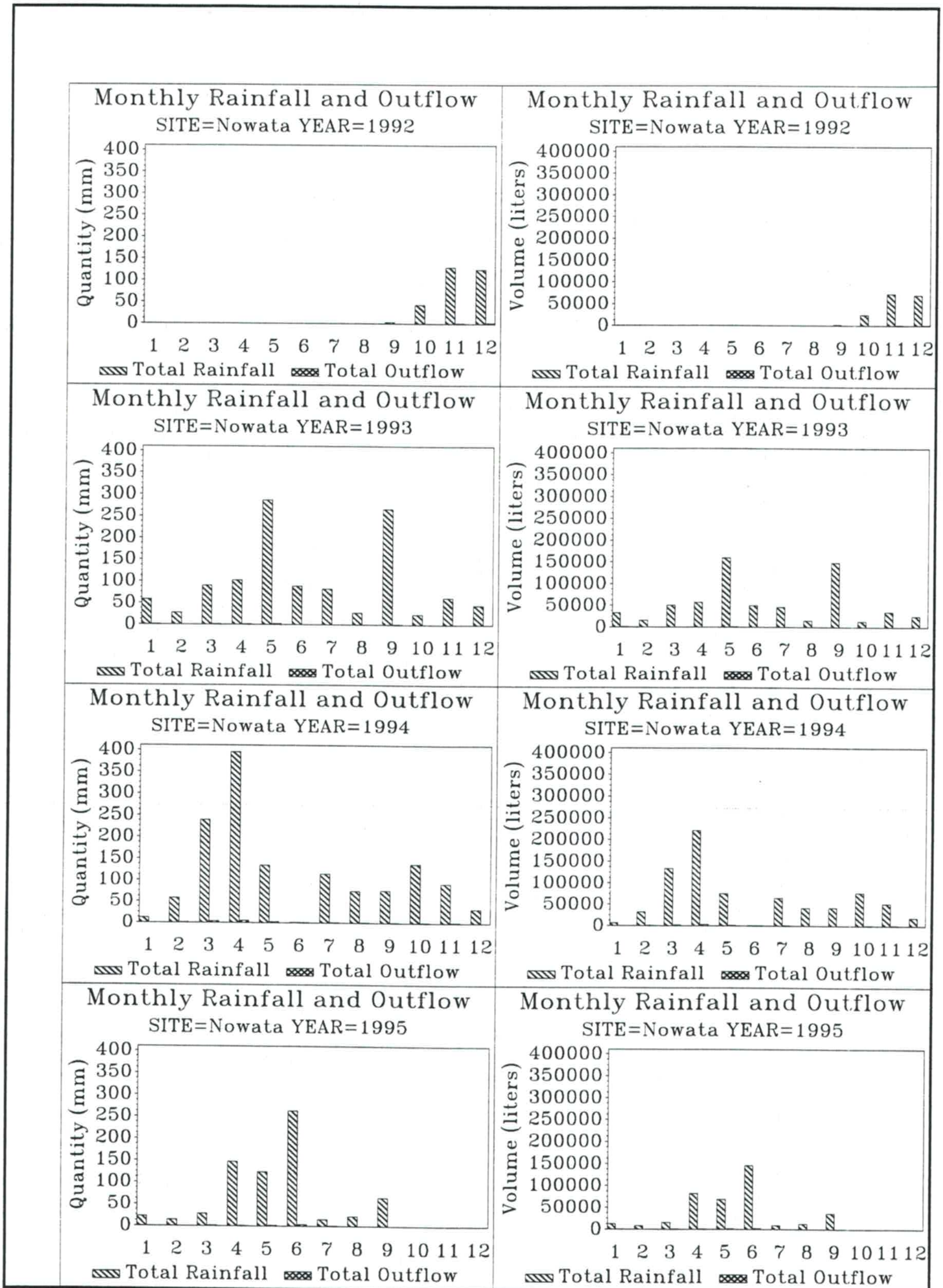

Fig. 5.21 Monthly rainfall and outflow for the Nowata county site

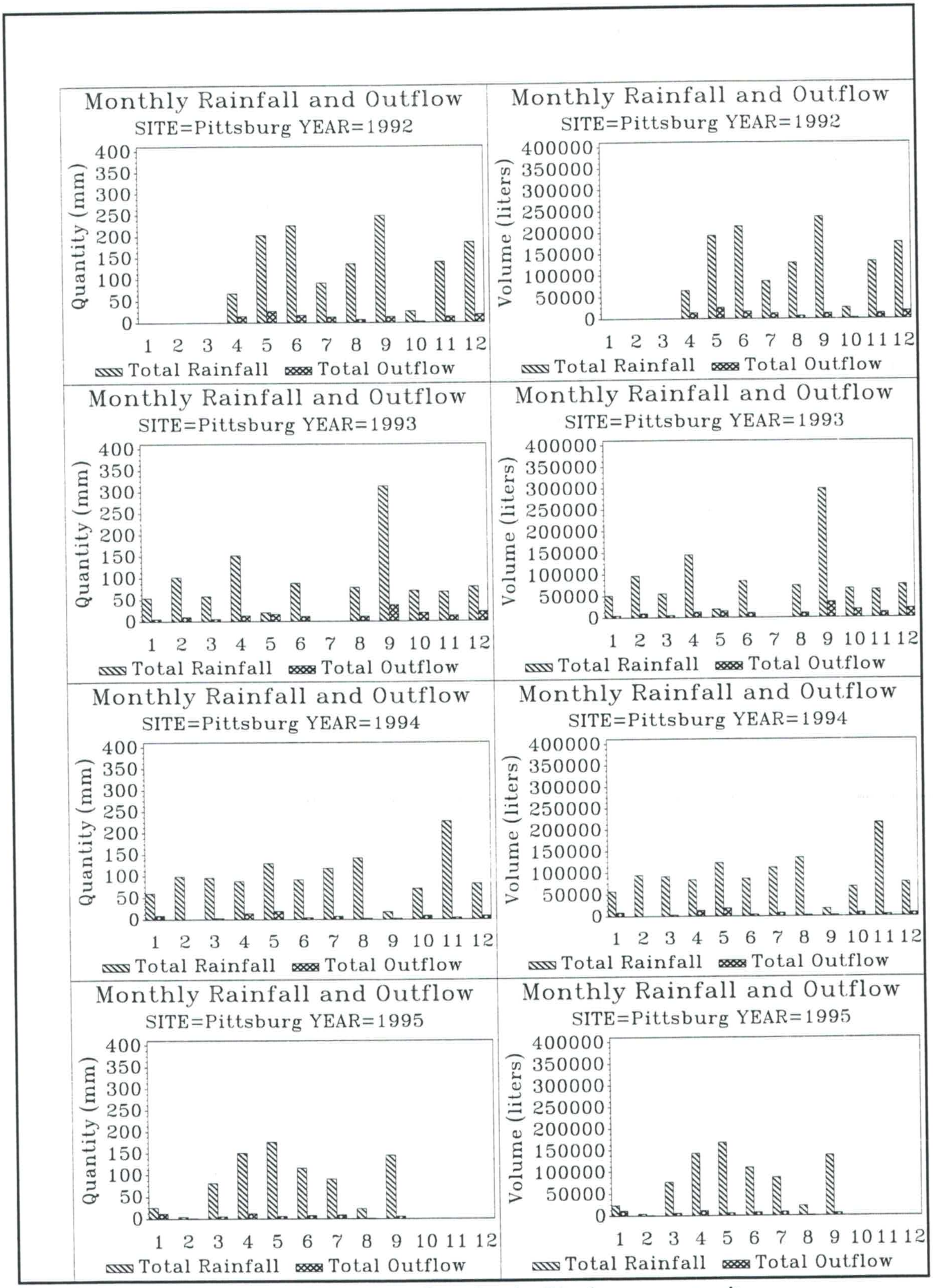

Fig. 5.22 Monthly rainfall and outflow for the Pittsburg county site

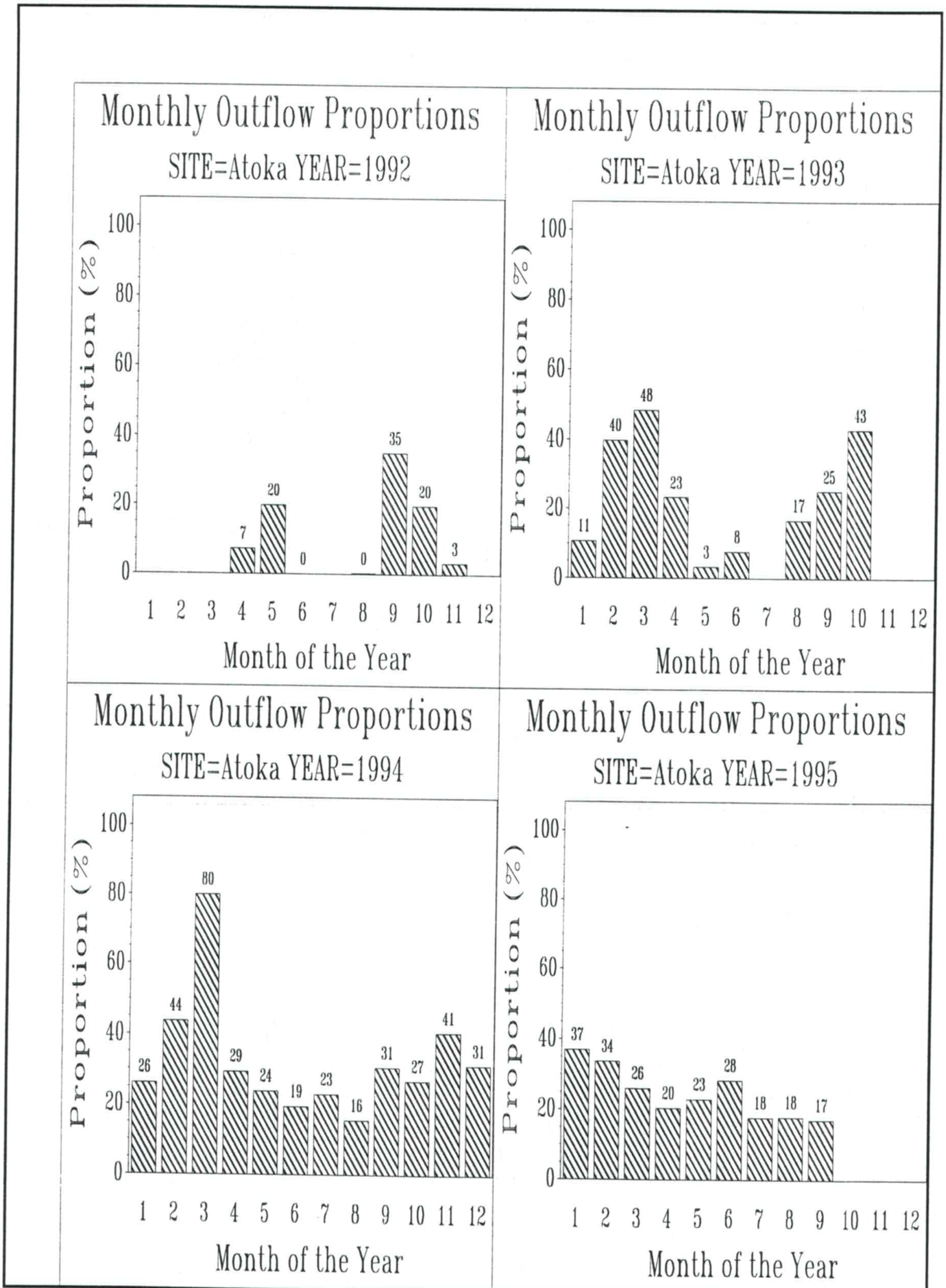

Fig. 5.23 Monthly outflow expressed as % of monthly rainfall for the Atoka county site

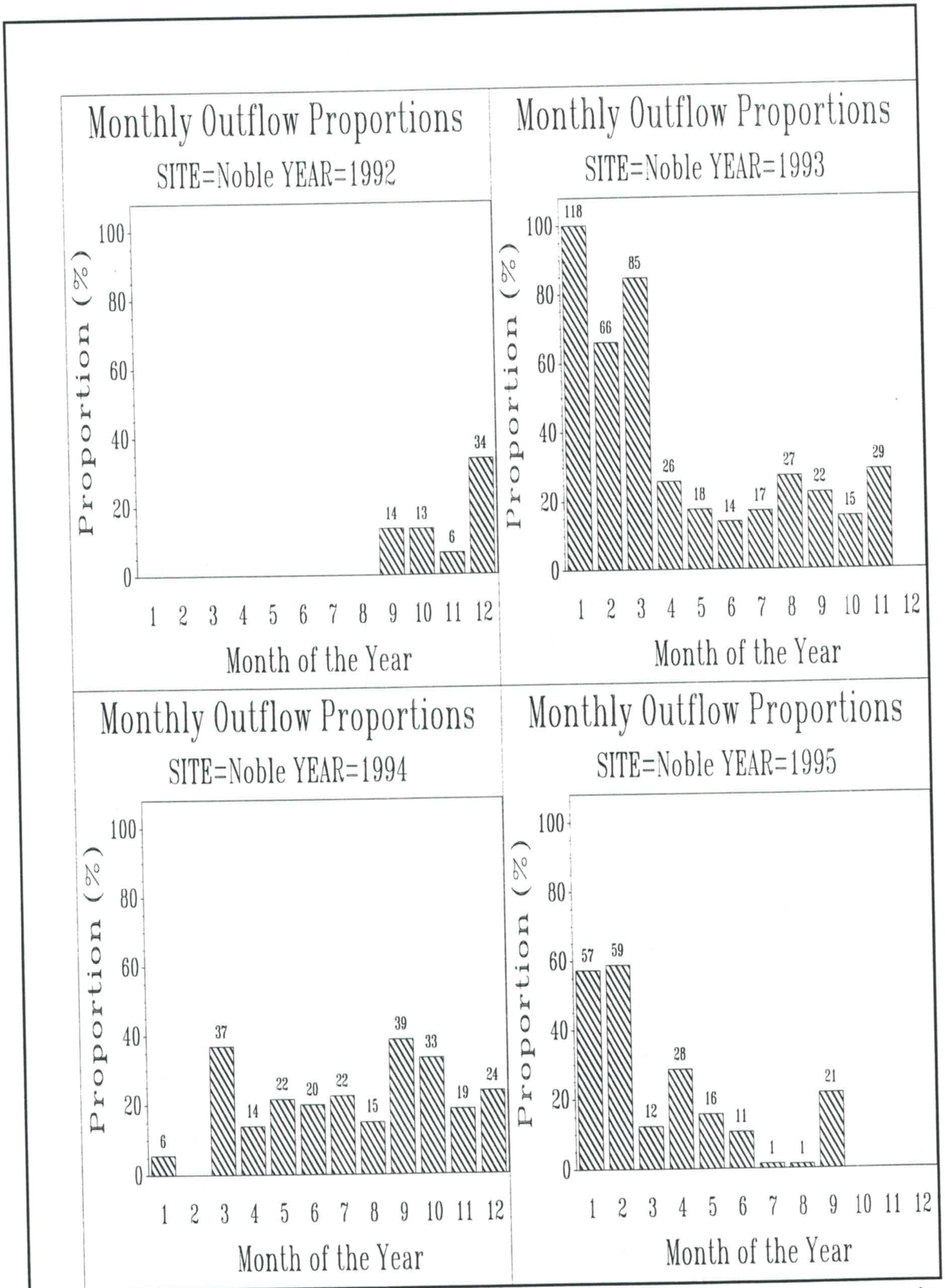

Fig. 5.24 Monthly outflow expressed as % of monthly rainfall for the Noble county site

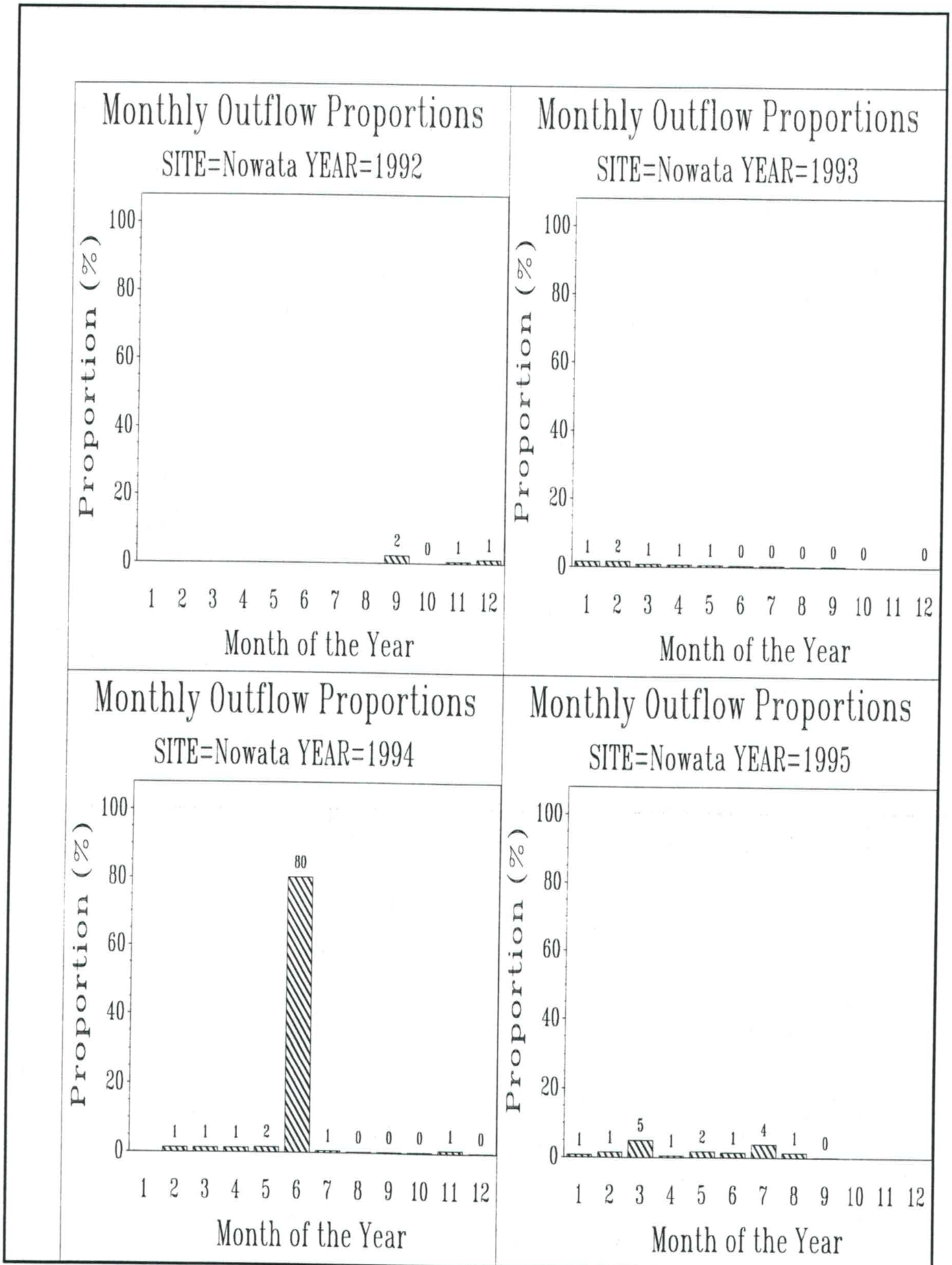

Fig. 5.25 Monthly outflow expressed as % of monthly rainfall for the Nowata county site

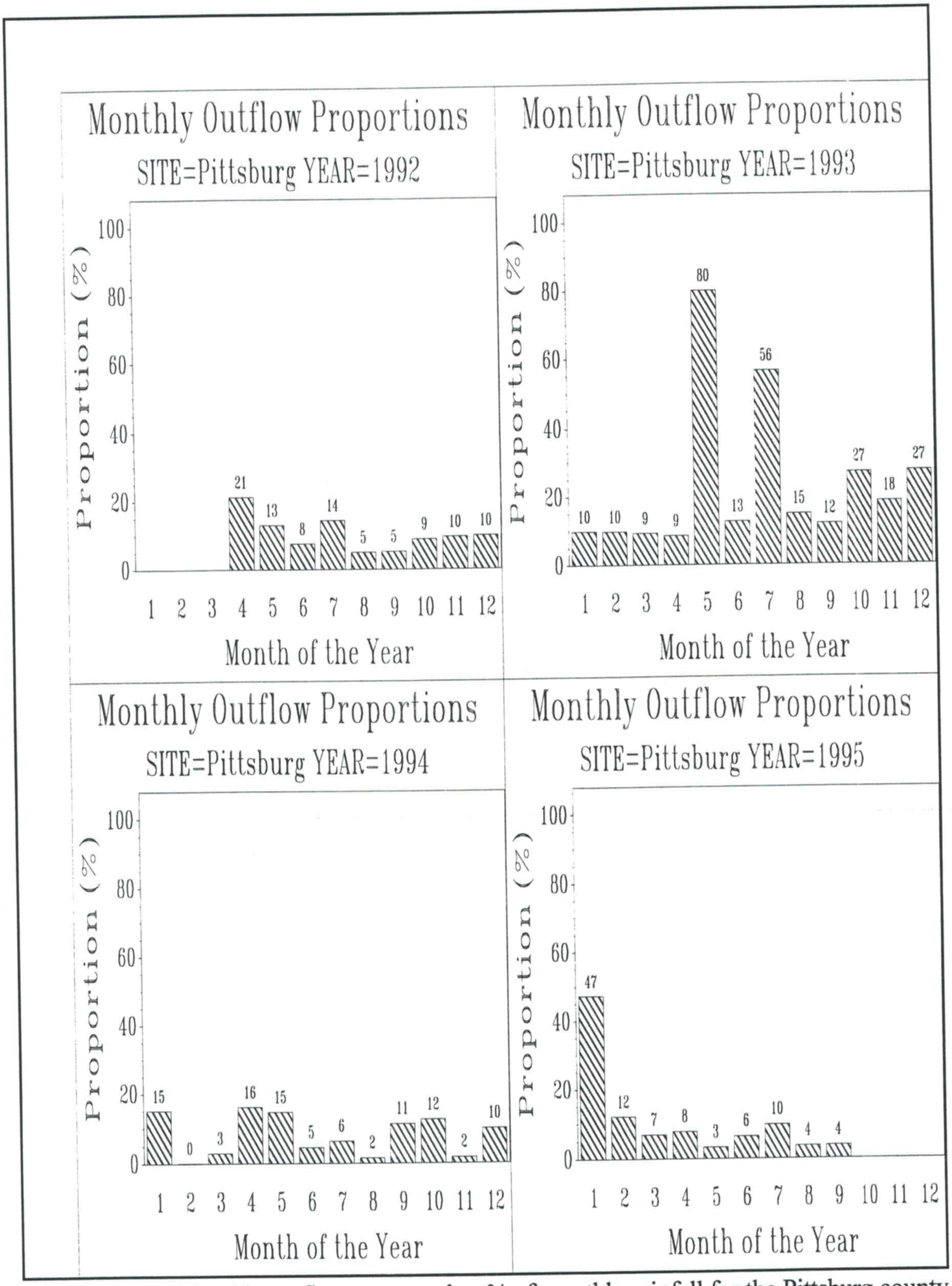

Fig. 5.26 Monthly outflow expressed as % of monthly rainfall for the Pittsburg county site

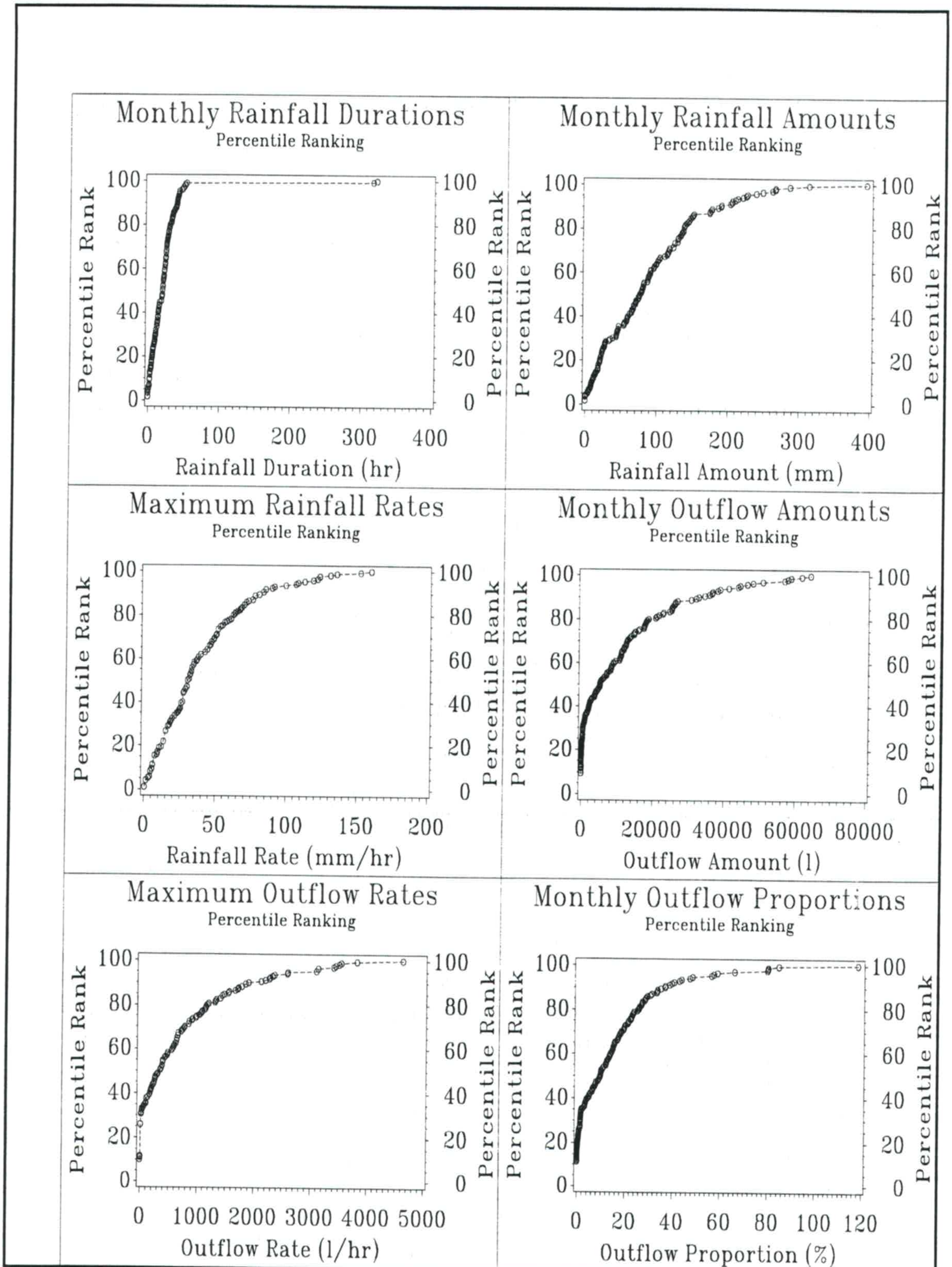

Fig. 5.27 Percentile ranking for some parameters corresponding to monthly rainfall and outflow

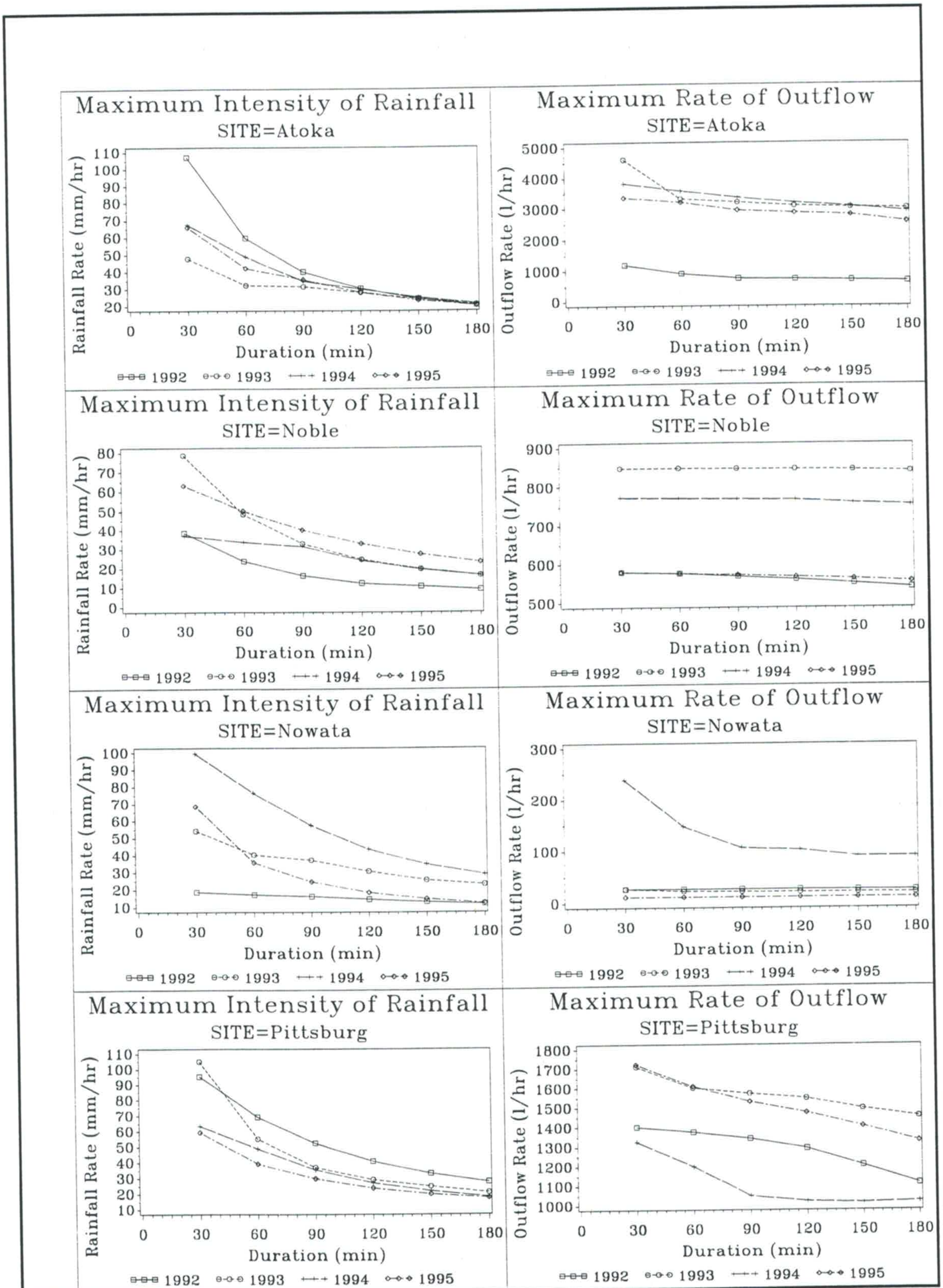

Fig. 5.28 Maximum rates of rainfall and outflow based on different time durations

Year	t=30	t=60	t=90	t=120	t=150	t=180
			Site=Atoka			
1992	107.188	59.690	40.1320	30.480	24.3840	20.4047
1993	47.752	32.258	31.4960	28.067	24.2824	20.9127
1994	67.564	48.768	34.7133	30.099	25.0952	21.4207
1995	66.040	42.164	35.5600	28.067	23.4696	20.4047
			Site=Logan			
1992	54.864	34.290	23.876	18.161	14.5288	12.1073
1993	32.004	16.764	11.176	8.382	6.7056	5.5880
			Site=Noble			
1992	38.608	23.876	16.4253	12.446	10.8712	9.2287
1993	78.740	48.514	33.0200	24.765	19.8120	16.5100
1994	37.084	33.782	31.4960	24.257	19.7104	16.5100
1995	62.992	50.292	40.1320	33.020	27.5336	23.3680
			Site=Nowata			
1992	18.796	17.272	16.2560	14.605	13.2080	12.0227
1993	54.356	40.386	37.2533	30.861	25.7048	23.1987
1994	99.568	76.454	57.5733	43.561	34.8488	29.0407
1995	68.580	35.814	24.7227	18.542	14.8336	12.3613
			Site=Pittsburg			
1992	95.504	69.342	52.4933	41.021	33.3248	27.9400
1993	105.156	55.372	37.0840	29.337	24.9936	21.2513
1994	63.500	49.022	35.5600	27.305	22.1488	18.4573
1995	59.436	39.370	29.9720	23.876	20.2184	17.8647

Fig. 5.29 Maximum rainfall rates (mm/hr) based on different time durations, t (min)

Year	t=30	t=60	t=90	t=120	t=150	t=180
			Site=Atoka			
1992	1180.92	904.62	743.12	723.88	691.90	654.17
1993	4602.56	3306.20	3190.76	3076.26	3027.24	2993.30
1994	3819.07	3574.93	3352.25	3174.67	3054.50	2901.20
1995	3345.94	3190.76	2937.16	2858.62	2789.55	2566.86
			Site=Logan			
1992	26.495	13.2475	8.83167	6.62375	5.299	4.41583
1993	7.570	3.7850	2.52333	1.89250	1.514	1.26167
			Site=Noble			
1992	579.105	575.320	567.750	560.180	550.339	539.993
1993	847.840	847.840	846.578	845.948	844.055	840.270
1994	772.140	770.248	768.355	766.463	759.271	753.846
1995	579.105	575.320	571.535	566.804	561.694	555.133
			Site=Nowata			
1992	26.495	26.495	26.495	26.495	25.738	25.2333
1993	26.495	22.710	21.448	20.818	20.439	20.1867
1994	238.455	147.615	105.980	102.195	90.083	90.2092
1995	11.355	11.355	11.355	11.355	11.355	11.3550
			Site=Pittsburg			
1992	1400.45	1375.85	1342.41	1292.58	1206.66	1114.05
1993	1710.82	1601.06	1572.04	1547.12	1495.08	1454.70
1994	1324.75	1199.85	1049.71	1021.95	1015.89	1021.95
1995	1722.18	1608.63	1530.40	1474.26	1404.99	1329.17

Fig. 5.30 Maximum outflow rates (l/hr) based on different time durations, t (min)

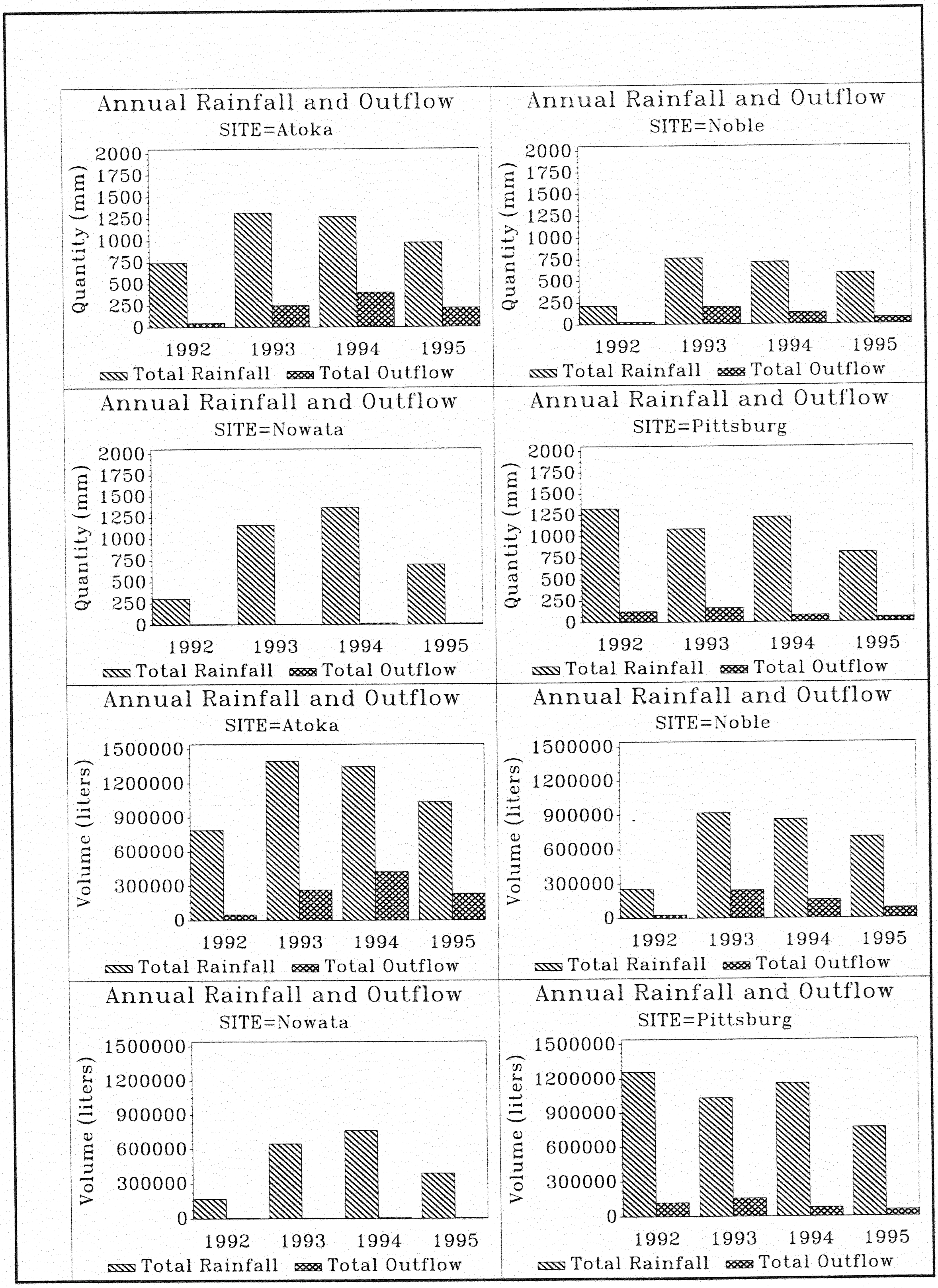

Fig. 5.31 Annual rainfall and outflow amounts

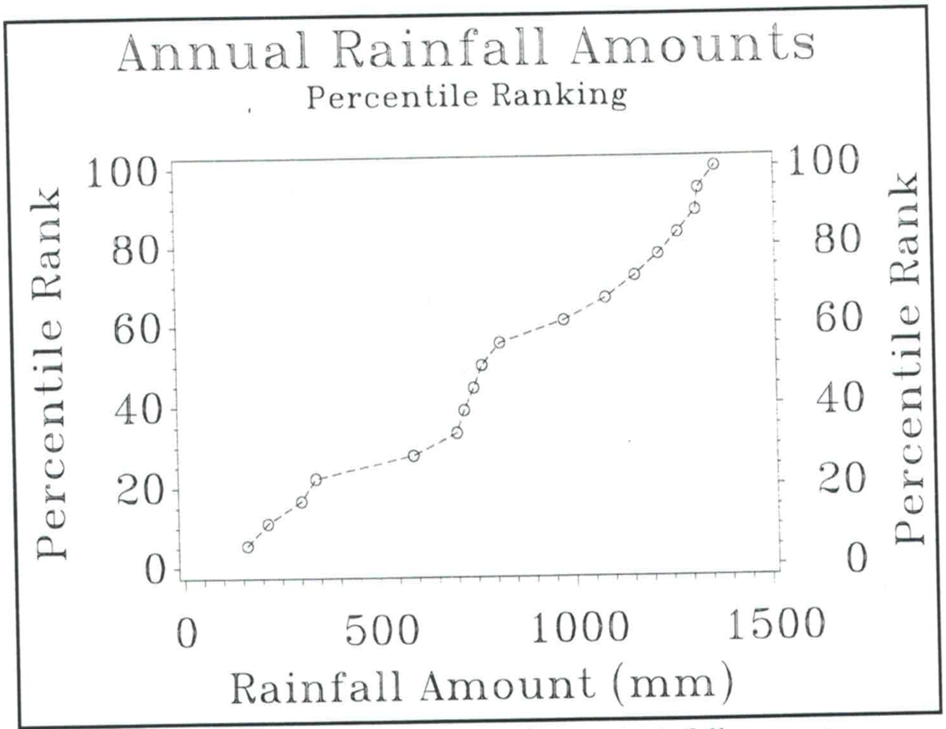

Fig. 5.32 Percentile distribution of annual rainfall amounts

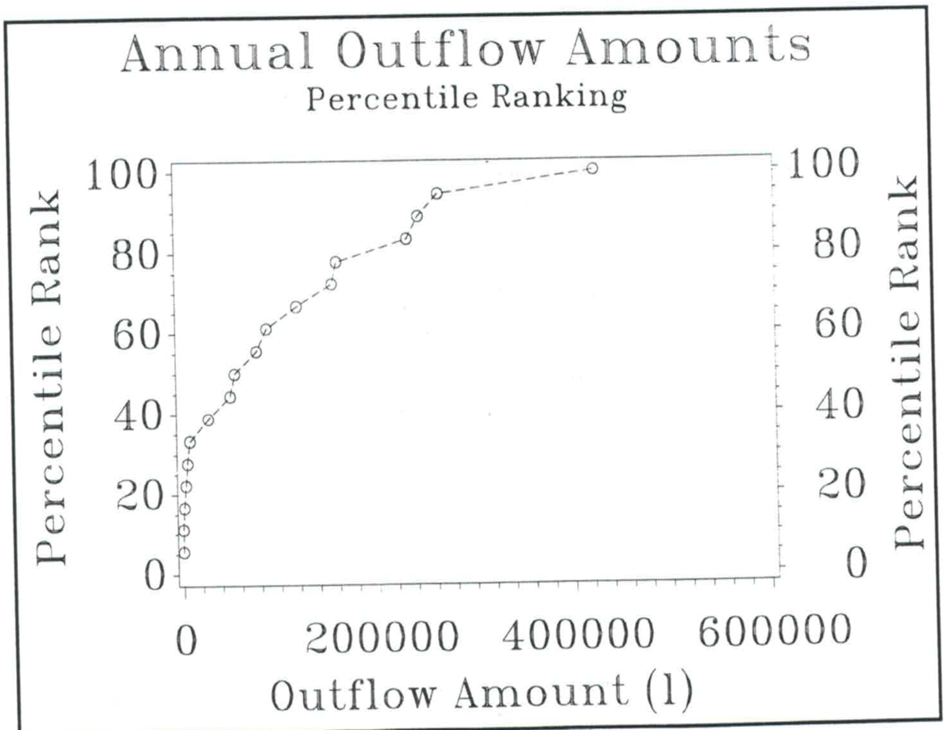

Fig. 5.33 Percentile distribution of annual outflow amounts

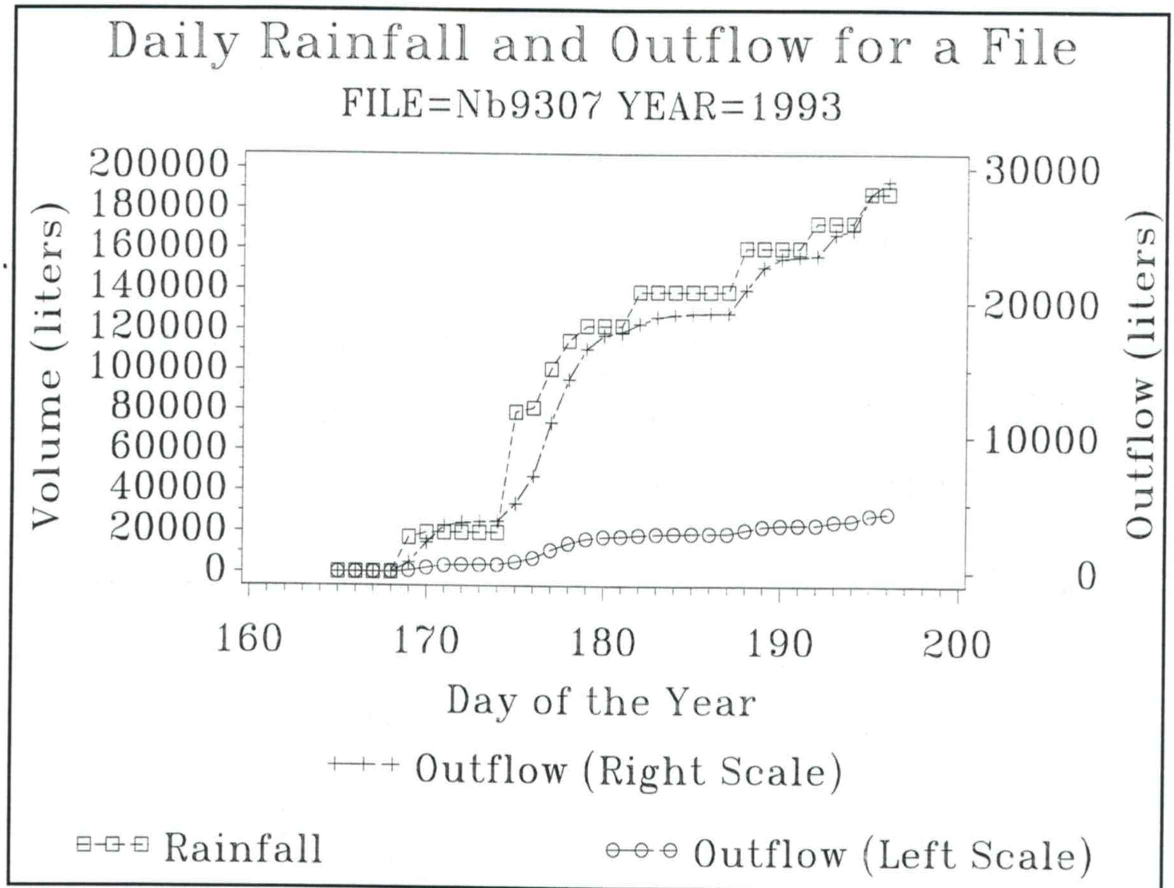

Fig. 5.34 Daily rainfall and outflow for the data in a file

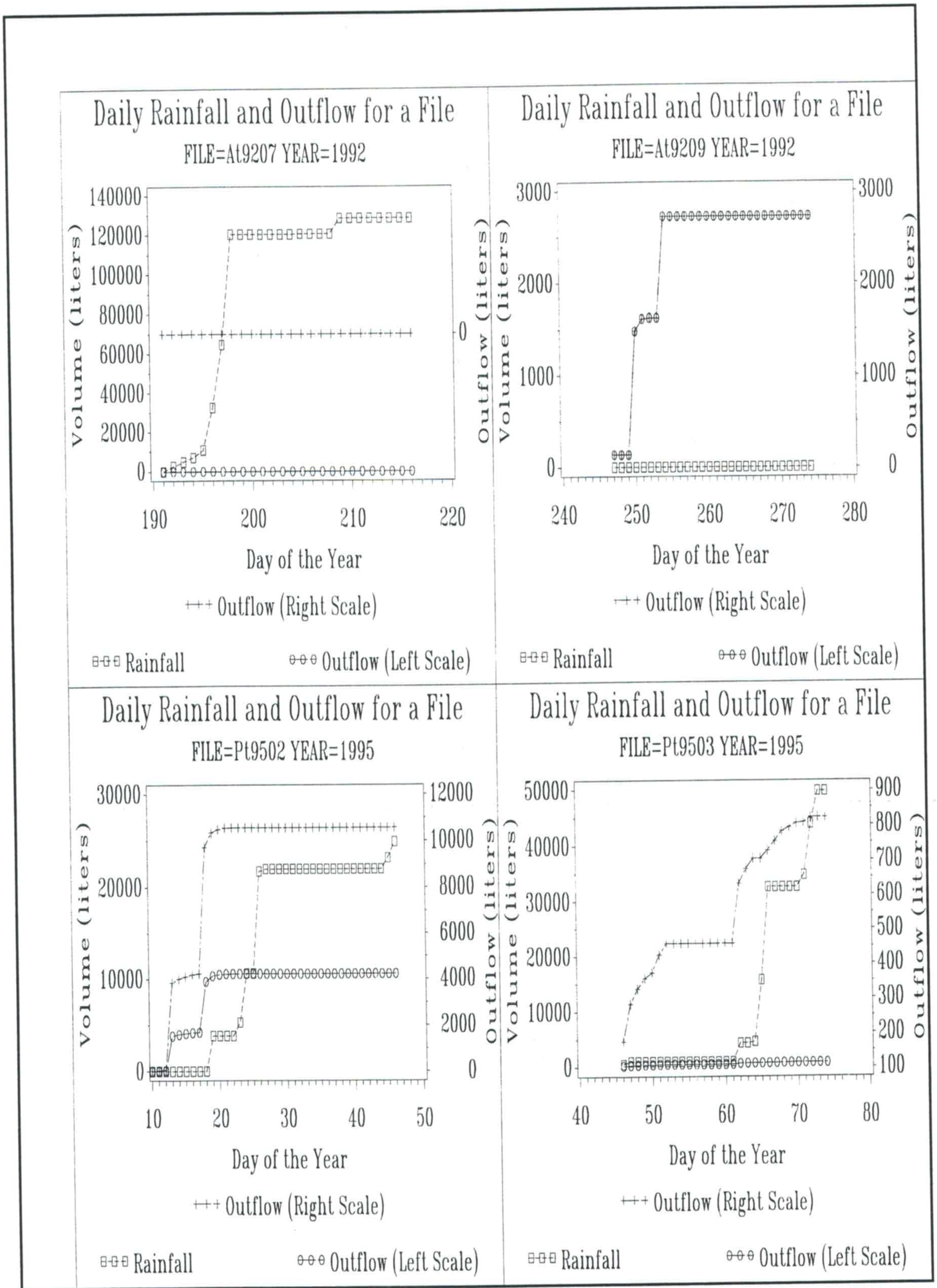

Fig. 5.35 Some files with inconsistent values of daily rainfall and outflow

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
Site=Atoka * Start Year=1992										
1	nAt9204	110	400	110	1600	10	0.15	0.32	40.640	1907.640
2	nAt9205	131	1400	147	2350	10	1.10	15.53	136.398	36127.825
3	nAt9210	298	10	302	1030	10	0.03	0.13	6.604	755.107
4	nAt9211	302	1040	303	2350	10	0.07	0.28	3.810	1336.105
Site=Atoka * Start Year=1993										
5	nAt9302	33	10	49	1330	10	1.02	15.26	77.978	28906.045
6	At9303	49	1350	81	1440	10	1.56	29.20	106.934	48584.260
7	At9304	81	1500	104	1150	10	0.61	20.07	76.962	27289.850
8	nAt9305	104	1210	112	2350	10	0.10	6.81	3.810	5817.545
9	nAt9306	158	10	167	1000	10	0.67	3.70	111.506	3559.792
10	At9307	167	1010	195	840	10	0.12	7.58	35.560	8098.007
11	At9308	195	900	222	1040	10	0.35	1.34	48.768	12806.547
12	At9309	222	1050	252	1130	10	0.51	1.37	71.882	10471.202
13	At9310	252	1140	278	1150	10	0.71	8.60	171.704	47624.762
14	nAt9311	278	1300	295	2330	30	1.50	7.52	126.746	58695.887
Site=Atoka * Start Year=1994										
15	At9403	19	1500	62	1300	30	2.56	32.58	160.274	89655.295
16	At9404	62	1400	98	730	30	0.79	25.56	54.356	42872.695
17	At9405	98	900	124	1330	30	1.65	7.96	170.688	59676.202
18	At9406	124	1500	180	1200	30	1.50	31.44	187.452	36059.695
19	At9408	180	1300	229	1030	30	2.13	22.94	213.360	43313.647
20	At9409	229	1200	251	1030	30	0.94	9.25	88.900	21110.837
21	At9410	251	1050	285	1020	10	0.66	6.12	88.900	17776.252
22	At9412	285	1110	333	320	10	2.41	40.17	199.136	87452.425
23	At9501	340	1440	11	950	10	1.03	17.77	80.010	26782.660
Site=Atoka * Start Year=1995										
24	At9502	11	1020	46	1050	10	1.10	22.08	64.262	26142.995
25	mAt9503	46	1100	74	1040	10	0.87	9.71	88.646	21071.095
26	At9504	74	1110	102	910	10	0.76	22.22	146.050	37613.437
27	At9505	102	1230	128	1320	10	1.15	20.83	232.664	45728.477
28	At9506	128	1400	158	930	10	0.68	16.33	68.326	24734.975
29	At9507a	158	1020	164	100	10	0.43	2.79	38.862	12140.387
30	mAt9507b	164	140	193	1030	10	0.23	4.75	66.548	12112.000
31	mAt9508	193	1050	215	1000	10	0.45	4.21	76.454	16536.665
32	nAt9509	215	1100	218	10	10	0.00	0.55	0.000	149.507
33	At9510	249	1300	277	1110	10	1.09	10.01	204.724	37806.472

Fig. 5.36 Basic information about the TSO datasets from the Atoka county site accepted for detailed analysis

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
Site=Noble * Start Year=1992										
34	nNb9209	240	1050	247	2350	10	0.13	0.35	5.842	1871.682
35	Nb9210	273	930	300	1200	10	0.05	1.24	9.398	350.112
36	mNb9212	300	1210	348	330	10	2.57	16.67	192.024	24812.567
Site=Noble * Start Year=1993										
37	nNb9301	1	10	19	1140	10	0.19	13.47	10.160	17689.197
38	Nb9302	19	1200	47	1050	10	0.48	17.15	20.066	20175.942
39	Nb9303	47	1100	74	1000	10	0.40	20.16	18.796	14803.135
40	Nb9304	74	1020	102	1020	10	0.37	19.05	19.812	19708.495
41	Nb9305	102	1040	131	810	10	2.10	19.37	254.254	46818.557
42	Nb9306	131	840	165	1010	10	0.58	17.48	82.296	24352.690
43	Nb9307	165	1020	196	1220	10	0.97	19.05	156.210	29030.950
44	Nb9309	223	1430	250	1100	10	0.42	6.17	49.022	22007.882
45	Nb9310	250	1110	280	1020	10	0.47	9.19	100.076	20058.607
46	mNb9311	280	1130	336	1000	30	1.21	12.48	54.102	17371.257
Site=Noble * Start Year=1994										
47	Nb9404	82	1030	96	1130	30	0.31	7.29	11.938	4858.047
48	Nb9405	96	1330	123	1000	30	2.25	19.23	269.240	47562.310
49	mNb9407	123	1100	193	1000	30	1.17	26.56	107.442	24952.612
50	mNb9408	193	1100	227	1100	30	0.94	9.73	69.850	17596.465
51	Nb9409	227	1230	249	1100	30	1.29	9.21	90.170	22051.410
52	mNb9410	249	1200	283	1150	10	0.17	7.72	8.382	6046.537
53	Nb9411	283	1230	322	1210	10	0.74	16.52	63.754	17208.502
54	Nb9412	322	1210	339	1010	10	0.68	4.28	76.708	14299.730
55	Nb9501	339	1040	12	1250	10	0.35	10.13	21.082	7702.475
Site=Noble * Start Year=1995										
56	Nb9502ma	12	1320	47	1050	10	0.34	11.52	15.240	9706.632
57	Nb9503	47	1130	75	910	10	0.90	13.10	79.756	10961.360
58	Nb9504	75	940	104	830	10	0.26	11.60	17.018	5141.922
59	mNb9506	131	1030	159	1030	10	1.62	18.55	166.116	27159.267
60	mNb9507a	159	1100	186	930	.	0.24	3.52	117.856	13578.687
61	mNb9508	194	930	216	900	.	0.28	0.38	107.950	1222.555
62	mNb9509	216	942	255	1016	.	0.08	0.83	27.940	2019.297
63	mNb9510	255	1026	278	1100	.	0.33	6.91	67.564	19738.775

Fig. 5.37 Basic information about the TSO datasets from the Noble county site accepted for detailed analysis

------------------ Site=Nowata * Start Year=1992 -------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
64	mNw9209	245	1220	272	1140	10	0.02	0.13	2.794	35.957
65	nNw9211	313	10	329	840	10	1.34	0.86	104.902	234.670
66	Nw9212	329	930	357	840	10	1.89	3.27	144.272	1029.520
67	Nw9301	357	900	20	930	10	0.97	1.17	53.594	319.832

------------------ Site=Nowata * Start Year=1993 -------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
68	Nw9302	20	950	48	1320	10	0.50	0.77	25.146	211.960
69	Nw9303	48	1340	75	830	10	0.31	1.44	12.954	416.350
70	nNw9304	75	900	90	2350	10	1.08	0.71	84.074	193.035
71	Nw9305	103	800	132	1000	10	2.10	1.45	249.936	395.532
72	Nw9306	132	1020	166	910	10	0.90	3.44	151.384	968.960
73	Nw9307	166	930	194	840	10	0.86	1.23	128.778	340.650
74	Nw9309	223	1020	251	910	10	0.39	0.09	67.056	24.602
75	Nw9310	251	930	277	1150	10	1.24	1.04	225.806	323.617

------------------ Site=Nowata * Start Year=1994 -------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
76	nNw9403	21	1100	37	2330	30	0.27	0.00	8.890	0.000
77	Nw9406	123	1630	179	1130	30	0.92	13.71	117.094	1356.922
78	Nw9408	179	1210	227	410	10	0.86	1.42	115.316	386.070
79	Nw9409	228	1100	250	930	30	1.75	1.19	96.012	111.657
80	Nw9410	250	1010	284	910	10	0.72	0.60	110.236	170.325
81	Nw9411	284	1150	319	1200	10	0.63	0.90	97.282	246.025
82	mNw9412	319	1210	339	1440	10	0.74	0.76	76.200	208.175

------------------ Site=Nowata * Start Year=1995 -------------------

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
83	Nw9502	9	1310	45	950	10	0.34	0.44	18.288	121.120
84	Nw9503	45	1030	73	1000	10	0.67	1.02	34.798	278.197
85	Nw9504	73	1030	101	820	10	0.51	2.84	46.228	774.032
86	nNw9505	101	1020	115	2350	10	1.07	0.58	107.188	158.970
87	Nw9509	214	1000	248	1240	10	0.07	0.27	7.112	73.807
88	Nw9510	248	1310	276	940	10	0.58	0.09	65.024	24.602

Fig. 5.38 Basic information about the TSO datasets from the Nowata county site accepted for detailed analysis

OBS	FINPUT	STARTDAY	STARTIME	STOPDAY	STOPTIME	INTERVAL	DUR_RAIN	DUR_OUT	TOT_RAIN	TOT_OUT
---------- Site=Pittsburg * Start Year=1992 ----------										
89	Pt9204	106	950	133	1050	10	1.10	8.93	161.798	22621.052
90	Pt9205	133	1110	161	1030	10	2.22	17.88	178.562	22766.775
91	Pt9206	161	1050	192	810	10	0.74	12.54	155.956	10104.057
92	Pt9207	192	840	217	750	10	1.03	7.23	91.694	12409.122
93	Pt9208	217	800	247	1310	10	0.56	4.03	134.620	6250.927
94	Pt9209	247	1330	274	850	10	0.97	8.58	246.126	12460.220
95	Pt9210	274	910	303	920	10	0.23	1.02	16.510	2077.965
96	Pt9211	303	940	330	820	10	1.68	5.35	150.876	12795.192
97	Pt9212	330	830	356	1310	10	2.07	4.66	183.896	17411.000
98	Pt9301	356	1340	20	1320	10	0.83	3.68	56.896	5122.997
---------- Site=Pittsburg * Start Year=1993 ----------										
99	Pt9302	20	1350	49	1050	10	0.90	2.89	70.358	6093.850
100	Pt9303	49	1110	76	1040	10	0.87	2.53	50.038	5611.262
101	Pt9304	76	1100	105	750	10	1.42	4.65	150.368	12745.987
102	Pt9305	105	810	133	800	10	0.47	7.36	59.944	12823.580
103	Pt9306	133	820	166	1400	10	0.50	5.38	67.056	12793.300
104	Pt9307	166	1420	194	1240	10	0.16	3.60	21.336	2778.190
105	Pt9308	194	1250	222	1220	10	0.29	2.22	31.750	4706.647
106	Pt9309	222	1230	252	820	10	0.85	5.78	114.046	18273.980
107	Pt9310	252	940	278	830	10	0.90	8.20	267.208	25395.457
108	Pt9311	278	930	319	1200	30	1.96	11.27	116.840	28506.727
109	Pt9401	334	1530	20	1030	30	1.94	11.63	106.680	27649.425
---------- Site=Pittsburg * Start Year=1994 ----------										
110	Pt9405	97	1530	124	1030	30	1.27	7.33	116.840	22405.307
111	Pt9406	124	1200	180	930	30	1.48	23.46	185.420	12861.430
112	Pt9408	180	1030	229	800	30	1.71	17.81	192.024	7653.270
113	nPt9409	229	930	233	2330	30	0.42	0.77	26.924	1506.430
114	Pt9410	250	1630	285	800	10	0.59	2.92	56.896	8752.812
115	nPt9411	285	900	291	2330	10	0.18	1.15	8.128	1398.557
116	Pt9412	320	1050	340	1050	10	0.34	3.41	22.606	3667.665
117	Pt9501	340	1130	10	1000	10	0.99	7.34	83.312	8279.687
---------- Site=Pittsburg * Start Year=1995 ----------										
118	nPt9502	10	1030	22	2350	10	0.09	4.71	4.064	10563.935
119	nPt9503	60	10	74	1220	10	0.66	0.96	51.308	363.360
120	Pt9504	74	1250	102	720	10	0.57	6.94	79.502	10119.197
121	Pt9505	102	920	129	830	10	1.29	5.95	210.058	5955.697
122	Pt9506a	129	930	157	1300	10	0.69	10.32	134.874	7834.950
123	Pt9507	157	1330	193	820	10	0.46	6.02	62.738	7261.522
124	Pt9508	193	900	215	830	10	0.47	1.78	98.552	6426.930

Fig. 5.39 Basic information about the TSO datasets from the Pittsburg county site accepted for detailed analysis

CHAPTER 6
DATA ANALYSIS PHASE-II

6.1 GENERAL

In phase-II of data analysis, details about each rainfall and outflow incidents have been studied. Such incidents are idealized as "events" (see chapter 4 for elaborate definition of the term). Events are studied in terms of outflow proportions, retention times and drainage times. Details are presented in the following sections.

6.2 EVENTS

The data is first examined by using the program CORE1 to identify each of the "continuous rainfall events" (abbreviated as "CoRE"). Then the program EVENT1 uses the information generated by the program CORE1 to identify the events and to prepare preliminary information about the events. As the initial and final conditions for all the events are same, they provide a reasonable time frame for analysis of the data. Once the events are identified, analysis of some of the interesting features of the drainable bases can be performed. Figures 6.1 through 6.4 show statistics of some parameters related to the events. Two major parameters from these figures are discussed in the following subsections.

6.2.1 Event durations

The time durations of different events may greatly differ because of frequent rainfalls, continued (and probably slow) outflow, etc. The maximum values of the event durations found are: 616 hours (Atoka, 1994), 310 hours (Noble, 1993), 68 hours (Nowata, 1995) and 138 hours (Pittsburg, 1992). The event durations indicate indirectly the drainage pattern of the sites because longer event durations often result from slow outflow rates. The large value as clogging of one or more of the uphill and/or downhill outlets. It may also indicate movement of underground water from nearby irrigation fields, although no decisive or convincing evidence exists in this regard.

6.4 RETENTION TIME

Retention time is another indirect measurement of the drainability of a pavement system because longer retention time, as it appears, indicates a poor drainage capacity. Distribution of the retention times for the Atoka, Noble and Pittsburg county sites are shown in Figs. 6.14-6.16. Table 6.2 lists the retention times for different sites. It is found from these figures and table that the Pittsburg county site has the least retention time (0.67 hours), and the Noble county site has the largest retention time (2.83 hours). The retention time for the Nowata county site was not studied due to the very slow and uncertain flow behavior.

6.5 TIME FOR DRAINAGE

Time for drainage is probably the most important feature that should be investigated when investigating drainable bases. This is the property upon which AASHTO defines the drainability of different types of pavements (such as, excellent, good or poor). A longer duration for drainage is an indication of poor drainage conditions.

Time for 50% drainage for different events at different sites are shown in Figs. 6.17-6.22 and the time for complete drainage are shown in Figs. 6.23-6.28. Table 6.3 lists the 50% and 100% drainage time for different sites. From this table, it is clear that the Pittsburg county site requires the least amount of time to drain out 50% of water accumulated in the system after all rainfall stopped. The relationship between the Atoka and Noble county sites are quite close in this regard.

Due to very small amounts of outflow and uncertain flow behavior under such conditions, the drainage time for the Nowata county site was not studied.

Table 6.1a* Relationship between outflow and rainfall for the Atoka county site

	1992	1993	1994	1995	1992-1995
Constant	0	0	0	0	0
Std Err of Y Est	3.9218633	5.4459586	11.367577	3.2867331	8.9012742
R Squared	0.8825113	0.8942734	0.7745081	0.8365964	**0.7544831**
No. of Observations	5	14	27	21	67
Degrees of Freedom	4	13	26	20	66
X Coefficient(s)†	0.2245995	0.3765149	0.3687188	0.2113659	**0.3273898**
Std Err of Coef.	0.032205	0.024739	0.031753	0.014272	0.018002

Table 6.1b* Relationship between outflow and rainfall for the Noble county site

	1993	1994	1995	1992-1995
Constant	0	0	0	0
Std Err of Y Est	4.3139222	1.9487337	1.8248421	3.3572543
R Squared	0.7559095	0.9158148	0.7388433	**0.7675262**
No. of Observations	26	21	12	65
Degrees of Freedom	25	20	11	64
X Coefficient(s)†	0.1776936	0.1627502	0.1095014	**0.1616849**
Std Err of Coef.	0.014468	0.00778	0.01113	0.00787

Table 6.1c* Relationship between outflow and rainfall for the Pittsburg county site

	1992	1993	1994	1992-1995
Constant	0	0	0	0
Std Err of Y Est	1.9686214	2.4544795	2.0082915	2.261023
R Squared	0.5888809	0.6405292	0.4379664	**0.4925776**
No. of Observations	44	46	39	155
Degrees of Freedom	43	45	38	154
X Coefficient(s)†	0.076671	0.1310592	0.1067922	**0.093136**
Std Err of Coef.	0.00635	0.010389	0.013464	0.00519

* Note: The values presented in Tables 6.1a-6.1c are obtained by performing linear regression analysis using "Quattro Pro Version 6.0 for Windows" software.

† Note: This parameter is same as the slope of the straight lines in Figs. 6.5, 6.6, 6.9, 6.10, 6.12 and 6.13 and indicates the proportion between outflow and rainfall.

Note: Due to lack of enough data points, regression analysis is not performed for Noble'92 and Pittsburg'95 data.

Table 6.2 Retention times for different sites

Site	Retention time (hour)
Atoka	1.17
Noble	2.83
Pittsburg	0.67

Table 6.3 50% and 100% Drainage time (hours) for different sites

Site	50% drainage					100% drainage
	1992	1993	1994	1995	1992-1995	1992-1995
Atoka	11	25	17	13	17	71
Noble	10.5	19	11.5	16	16.5	83
Pittsburg	3.9	3.0	3.0	3.8	3.5	24.5

Type	Event Duration (hr)	Average Rainfall (in/hr)	Maximum Rainfall (in/hr)	Maximum Flow Rate (gal/hr)	Amount of Rainfall (in)	Amount of Outflow (gal)	Ratio (%)
Site=Atoka Year=1992							
Freq	8.000	8.000	8.000	8.000	8.00	8.0	8.00
Min	3.167	0.060	0.060	3.000	0.03	67.5	5.99
Max	221.333	0.480	3.060	489.000	4.41	7726.5	44.56
Mean	65.479	0.229	1.207	202.125	0.95	1381.6	23.27
S.D.	78.736	0.145	1.255	178.572	1.52	2629.6	13.05
Site=Atoka Year=1993							
Freq	24.000	24.000	24.000	24.000	24.00	24.0	23.00
Min	1.500	0.000	0.060	0.000	0.00	0.0	0.00
Max	537.333	0.870	2.460	1224.000	3.92	12603.5	94.66
Mean	67.958	0.254	0.969	437.094	1.07	1996.3	28.59
S.D.	117.609	0.253	0.722	373.413	1.02	3108.6	26.24
Site=Atoka Year=1994							
Freq	27.000	27.000	27.000	27.000	27.00	27.0	27.00
Min	7.500	0.013	0.060	36.000	0.06	53.0	6.78
Max	616.833	0.980	3.600	1009.000	5.86	16925.0	102.01
Mean	140.432	0.206	0.947	411.111	1.33	2785.2	31.99
S.D.	166.490	0.203	0.833	237.623	1.46	3531.3	22.86
Site=Atoka Year=1995							
Freq	21.000	21.000	21.000	21.000	21.00	21.0	19.00
Min	9.333	0.000	0.060	15.000	0.00	80.5	11.35
Max	436.333	0.792	3.360	828.000	6.34	7879.5	67.10
Mean	105.008	0.264	1.243	419.857	1.12	1818.6	25.38
S.D.	98.702	0.233	1.028	254.630	1.53	2166.1	13.32

Fig. 6.1 Statistics of some event parameters (Atoka county)

Type	Event Duration (hr)	Average Rainfall (in/hr)	Maximum Rainfall (in/hr)	Maximum Flow Rate (gal/hr)	Amount of Rainfall (in)	Amount of Outflow (gal)	Ratio (%)
---------------------- Site=Noble Year=1992 ----------------------							
Freq	8.000	8.000	8.000	8.000	8.00	8.0	8.00
Min	2.000	0.078	0.120	0.000	0.20	0.0	0.00
Max	156.000	0.471	2.460	156.000	1.55	2103.0	36.27
Mean	45.104	0.195	0.803	57.375	0.68	833.3	15.00
S.D.	54.081	0.149	0.840	52.977	0.53	905.3	13.58
---------------------- Site=Noble Year=1993 ----------------------							
Freq	26.000	26.000	26.000	26.000	26.00	26.0	24.00
Min	33.333	0.000	0.120	9.000	0.00	57.0	8.62
Max	310.500	0.728	4.860	225.000	3.91	5787.5	176.79
Mean	133.551	0.164	0.921	59.500	0.79	1811.1	45.87
S.D.	78.038	0.162	1.234	44.169	0.93	1586.2	46.32
---------------------- Site=Noble Year=1994 ----------------------							
Freq	22.000	22.000	22.000	22.000	22.00	22.0	21.00
Min	1.000	0.000	0.060	0.000	0.00	0.0	0.00
Max	276.000	0.281	1.460	204.000	4.50	4488.0	134.36
Mean	104.652	0.126	0.655	72.591	0.94	1506.0	27.90
S.D.	60.214	0.077	0.447	56.187	1.10	1277.4	25.79
---------------------- Site=Noble Year=1995 ----------------------							
Freq	10.000	10.000	10.000	10.000	10.00	10.0	8.00
Min	35.500	0.000	0.120	9.000	0.00	125.0	11.36
Max	219.667	0.179	1.560	57.000	4.05	3976.0	51.59
Mean	103.167	0.103	0.588	30.600	0.77	1025.4	22.88
S.D.	55.547	0.065	0.514	15.414	1.30	1263.3	14.58

Fig. 6.2 Statistics of some event parameters (Noble county)

Type	Event Duration (hr)	Average Rainfall (in/hr)	Maximum Rainfall (in/hr)	Maximum Flow Rate (gal/hr)	Amount of Rainfall (in)	Amount of Outflow (gal)	Ratio (%)
Site=Nowata Year=1992							
Freq	15.000	15.000	15.000	15.000	15.00	15.0	15.00
Min	1.500	0.060	0.060	0.000	0.01	0.0	0.00
Max	54.667	0.309	1.080	9.000	2.01	169.0	49.47
Mean	15.467	0.116	0.316	1.645	0.60	17.2	4.20
S.D.	16.460	0.076	0.284	2.317	0.74	42.8	12.59
Site=Nowata Year=1993							
Freq	63.000	63.000	63.000	63.000	63.00	63.0	63.00
Min	0.333	0.031	0.060	0.000	0.01	0.0	0.00
Max	36.500	0.588	3.060	6.000	4.55	55.0	48.13
Mean	6.966	0.190	0.713	1.338	0.57	7.3	2.63
S.D.	7.666	0.146	0.785	1.750	0.82	13.2	7.69
Site=Nowata Year=1994							
Freq	38.000	38.000	38.000	38.000	38.00	38.0	38.00
Min	0.500	0.027	0.040	0.000	0.01	0.0	0.00
Max	28.000	1.715	5.160	6.000	3.43	52.5	6.82
Mean	6.377	0.244	0.733	0.787	0.61	3.9	0.60
S.D.	6.386	0.335	1.094	1.328	0.78	9.8	1.27
Site=Nowata Year=1995							
Freq	59.000	59.000	59.000	59.000	59.00	59.0	58.00
Min	0.333	0.000	0.060	0.000	0.00	0.0	0.00
Max	68.500	1.080	5.340	3.000	1.84	115.5	9.36
Mean	6.523	0.189	0.589	1.136	0.39	6.5	1.01
S.D.	9.640	0.204	0.886	1.019	0.47	15.8	1.68

Fig. 6.3 Statistics of some event parameters (Nowata county)

Type	Event Duration (hr)	Average Rainfall (in/hr)	Maximum Rainfall (in/hr)	Maximum Flow Rate (gal/hr)	Amount of Rainfall (in)	Amount of Outflow (gal)	Ratio (%)
Site=Pittsburg Year=1992							
Freq	44.000	44.000	44.000	44.000	44.00	44.0	42.00
Min	0.333	0.000	0.060	0.025	0.00	4.5	0.36
Max	138.000	2.760	4.680	381.000	5.90	3577.0	133.17
Mean	38.830	0.298	1.148	112.228	1.07	623.3	14.98
S.D.	30.818	0.440	1.100	77.234	1.41	741.0	21.79
Site=Pittsburg Year=1993							
Freq	46.000	46.000	46.000	46.000	46.00	46.0	43.00
Min	1.333	0.000	0.020	3.000	0.00	2.0	0.71
Max	96.000	1.620	6.300	452.000	5.23	4088.5	79.70
Mean	25.315	0.204	0.839	125.304	0.81	720.8	15.61
S.D.	21.434	0.282	1.101	110.089	1.05	1025.4	12.96
Site=Pittsburg Year=1994							
Freq	39.000	39.000	39.000	39.000	39.00	39.0	38.00
Min	3.500	0.000	0.040	0.000	0.00	0.0	0.00
Max	58.500	0.634	2.500	312.000	2.65	3318.5	29.36
Mean	25.184	0.184	0.634	100.744	0.67	406.2	10.75
S.D.	16.194	0.157	0.645	87.630	0.63	599.9	6.75
Site=Pittsburg Year=1995							
Freq	19.000	19.000	19.000	19.000	19.00	19.0	19.00
Min	2.667	0.072	0.120	0.000	0.05	0.0	0.00
Max	64.167	0.454	2.760	390.000	2.99	1124.5	22.34
Mean	20.667	0.271	1.083	117.632	0.78	267.3	7.90
S.D.	18.374	0.118	0.819	113.568	0.67	297.1	6.94

Fig. 6.4 Statistics of some event parameters (Pittsburg county)

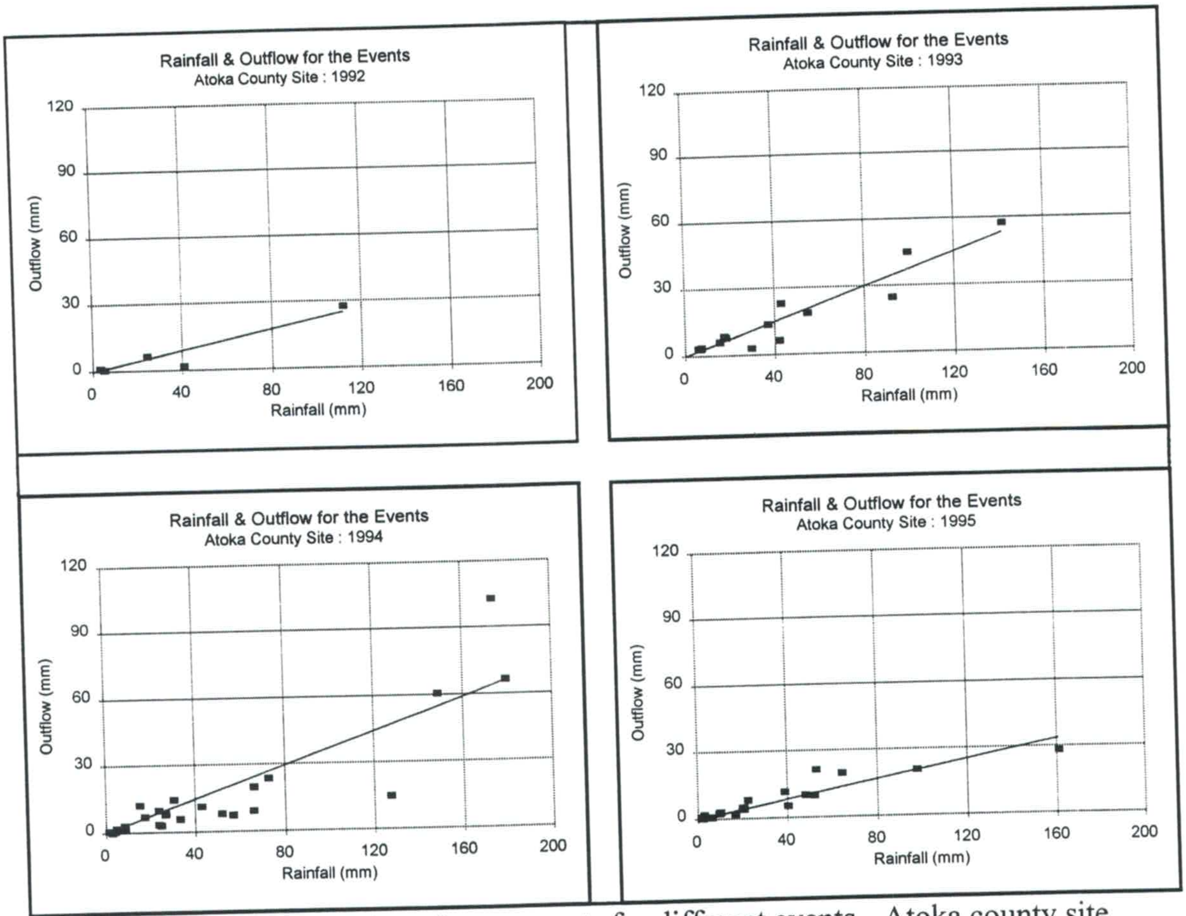

Fig. 6.5 Rainfall and outflow amounts for different events - Atoka county site

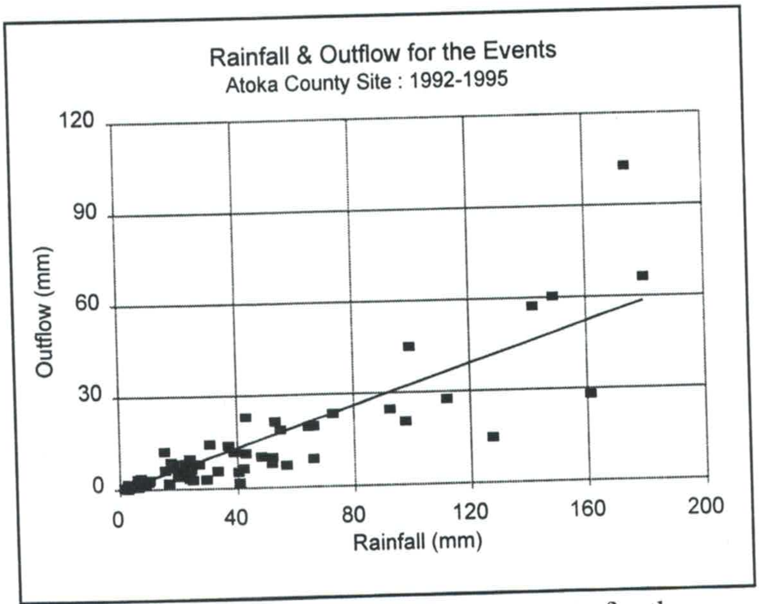

Fig. 6.6 Rainfall and outflow amounts for the Atoka county site, 1992-1995

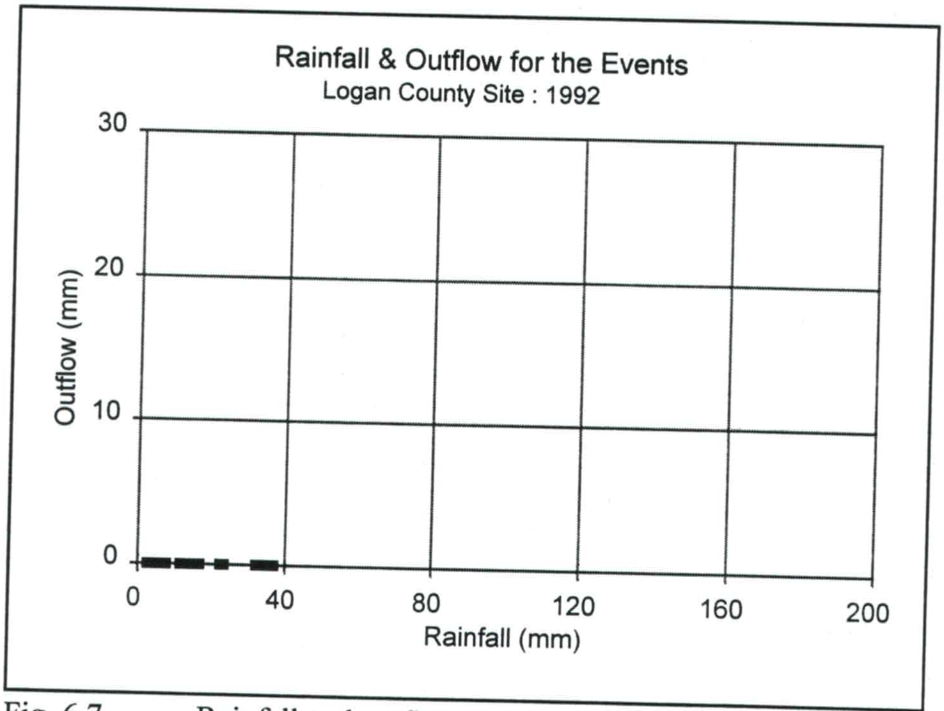

Fig. 6.7 Rainfall and outflow amounts for different events - Logan county site, 1992

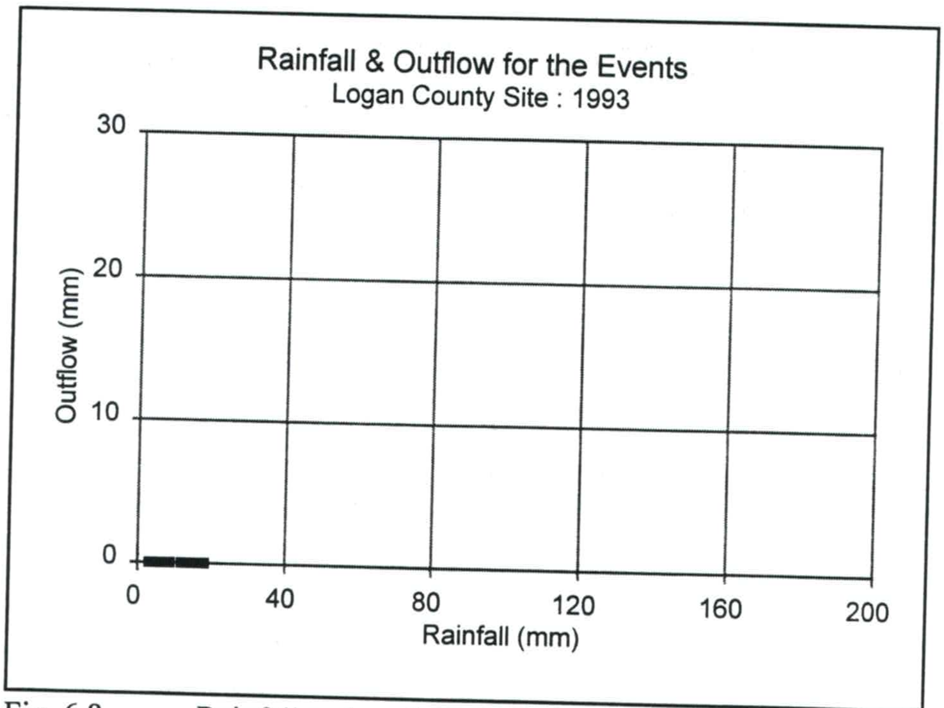

Fig. 6.8 Rainfall and outflow amounts for different events - Logan county site, 1993

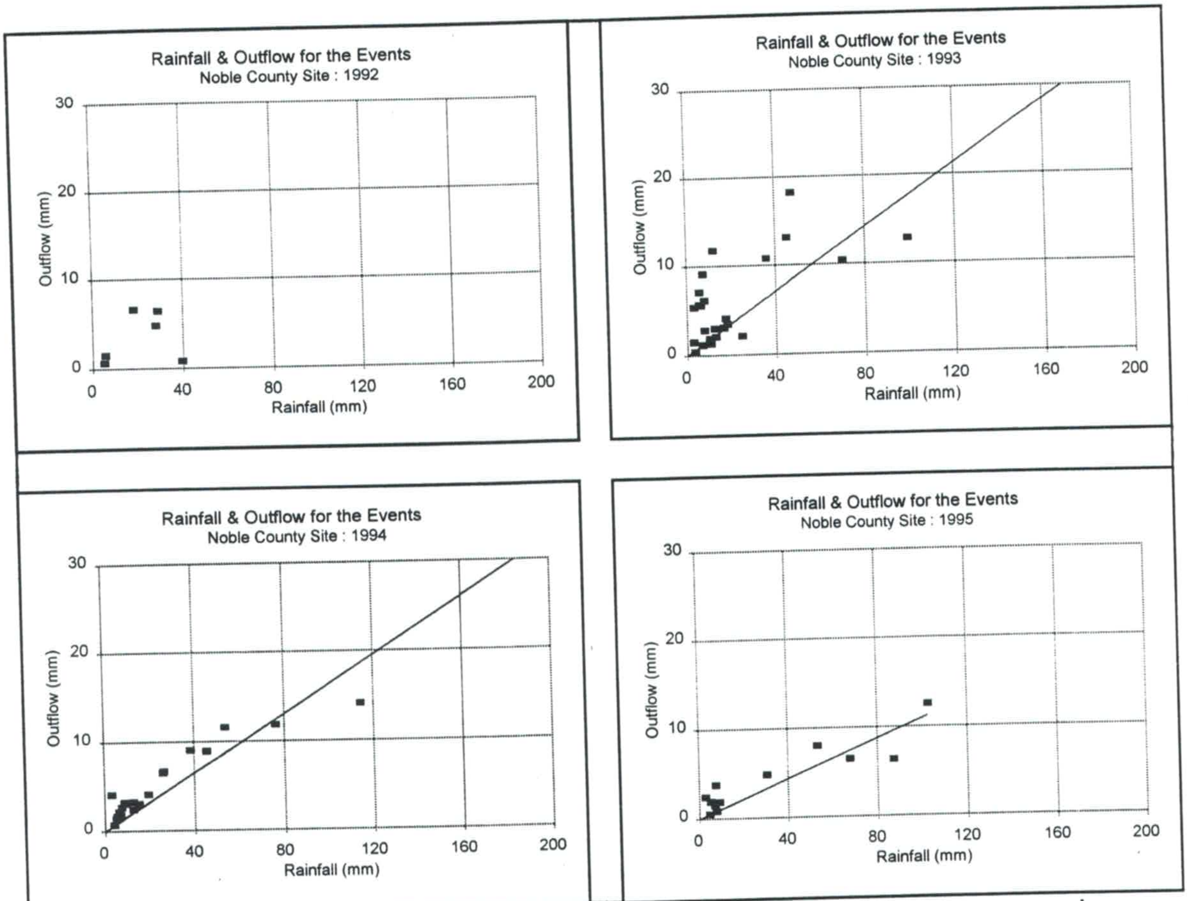

Fig. 6.9 Rainfall and outflow amounts for different events - Noble county site

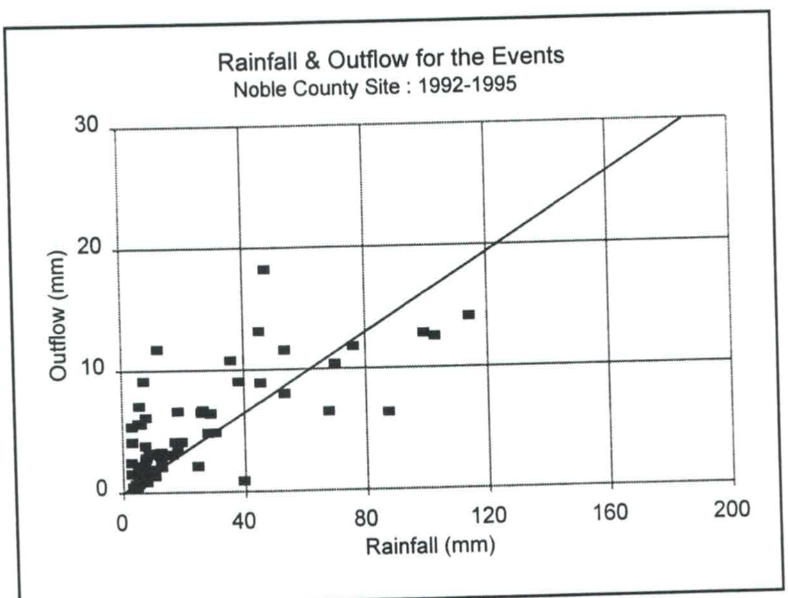

Fig. 6.10 Rainfall and outflow amounts for the Noble county site, 1992-1995

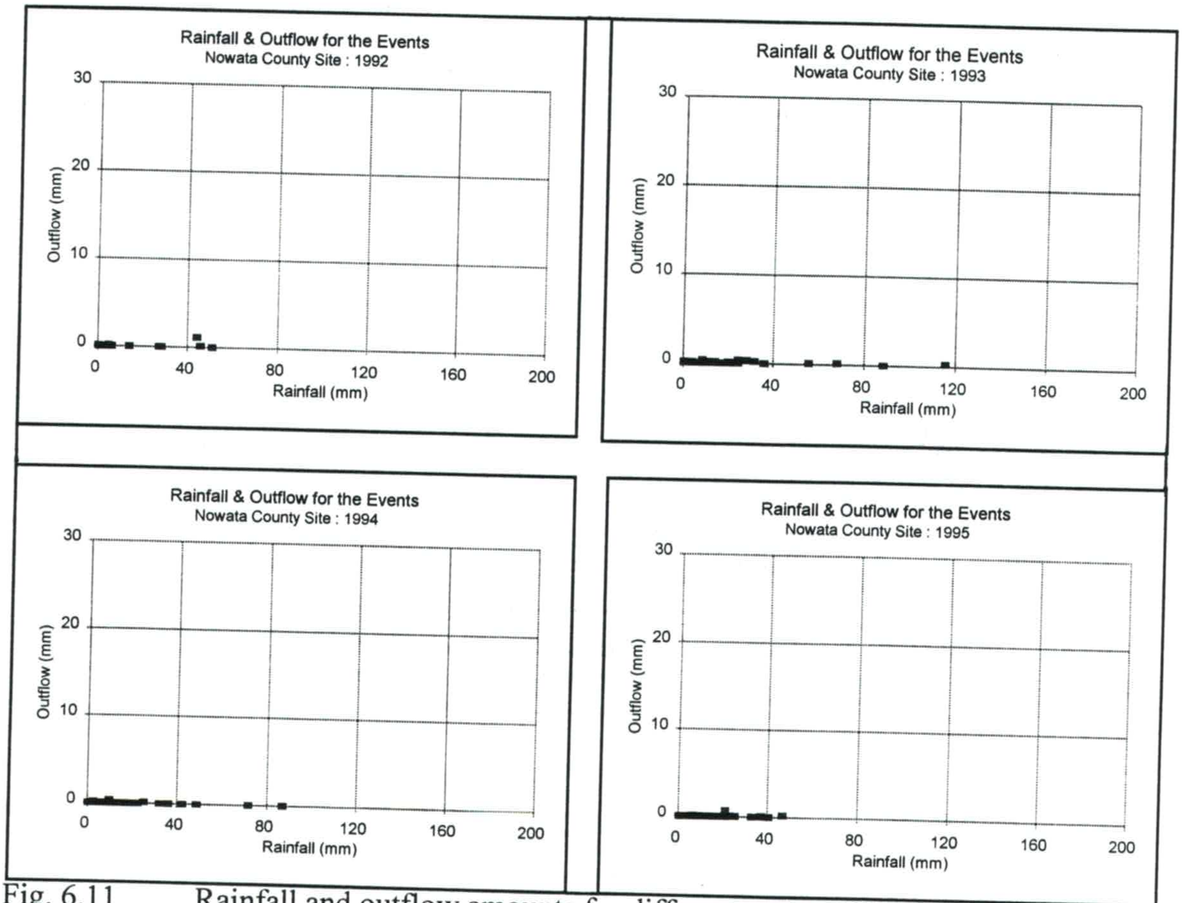

Fig. 6.11 Rainfall and outflow amounts for different events - Nowata county site

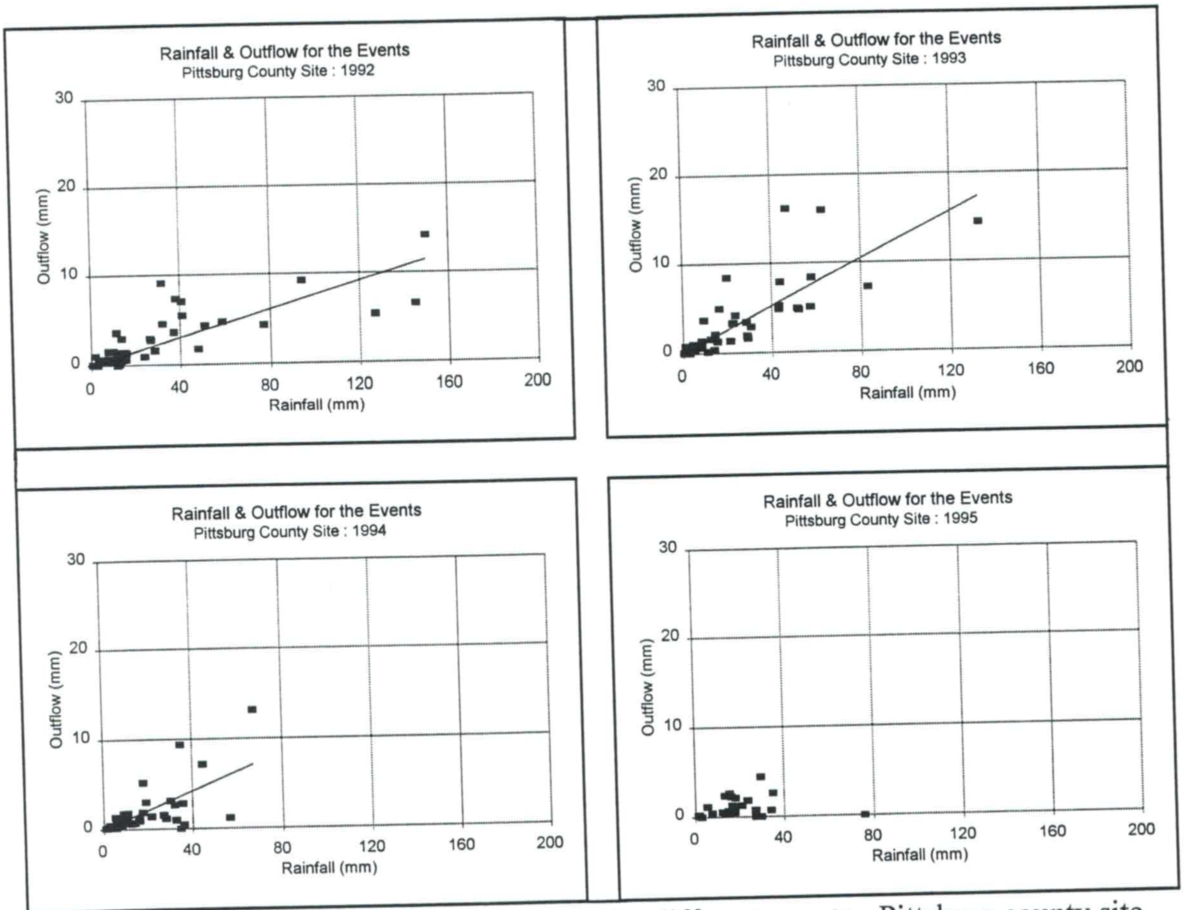

Fig. 6.12 Rainfall and outflow amounts for different events - Pittsburg county site

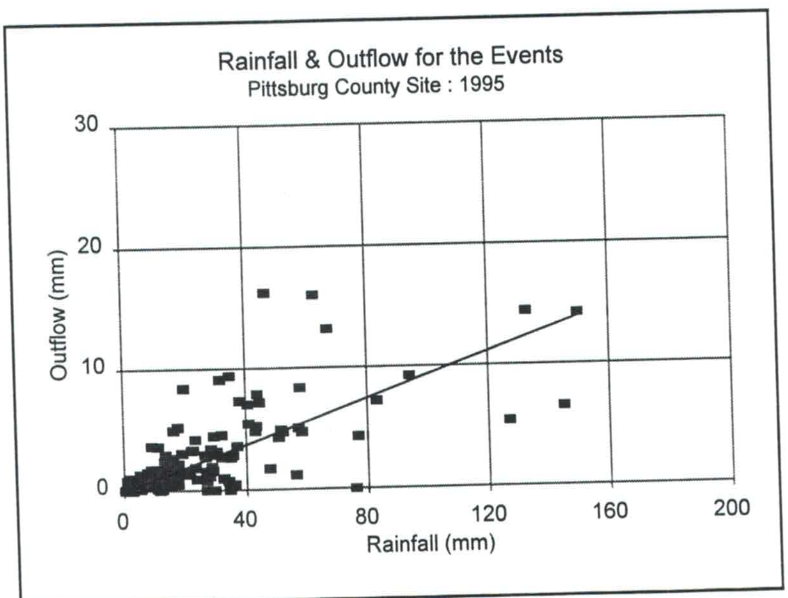

Fig. 6.13 Rainfall and outflow amounts for the Pittsburg county site, 1992-1995

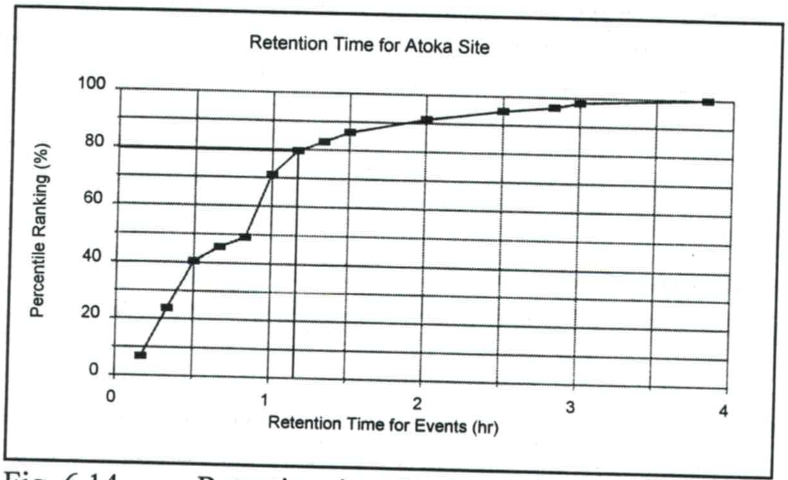

Fig. 6.14 Retention time for the Atoka county site

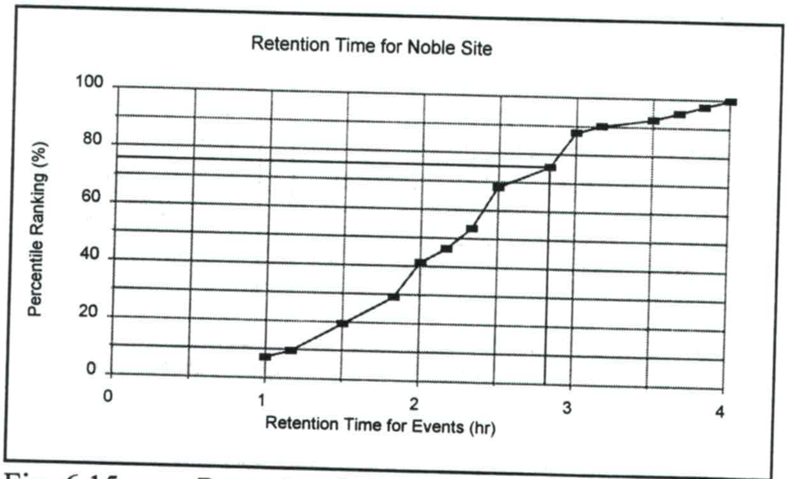

Fig. 6.15 Retention time for the Noble county site

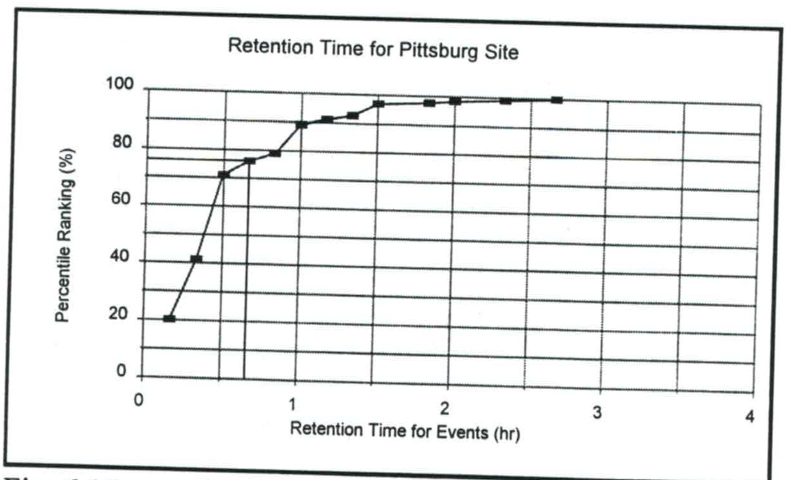

Fig. 6.16 Retention time for the Pittsburg county site

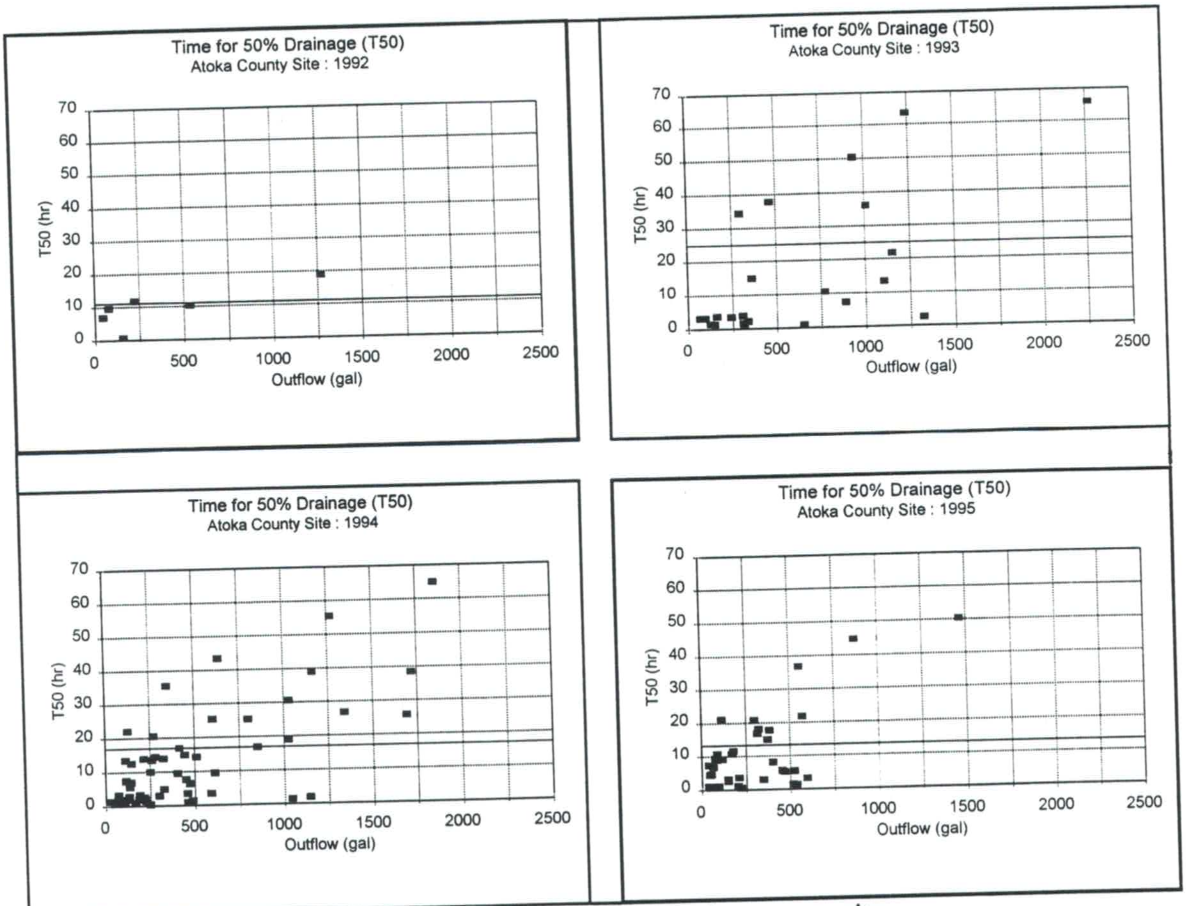

Fig. 6.17 Time required for 50% drainage - Atoka county site

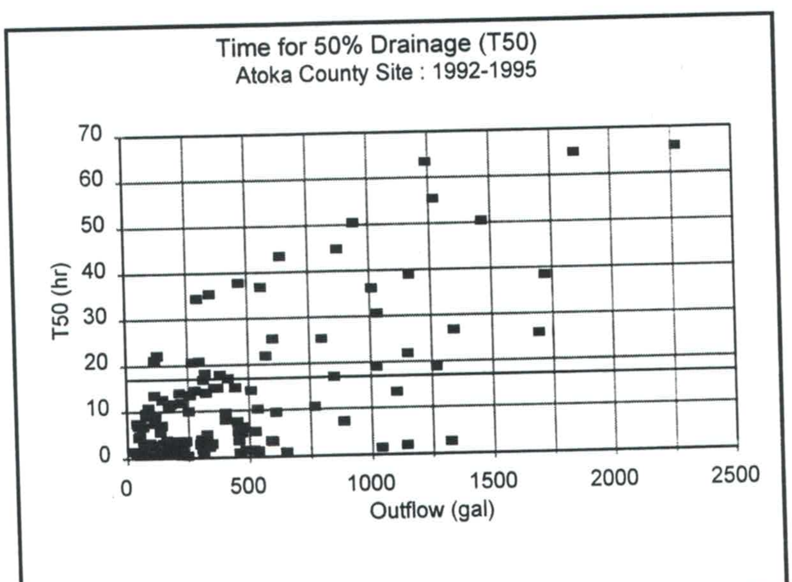

Fig. 6.18 Time required for 50% drainage - Atoka county site, 1992-1995

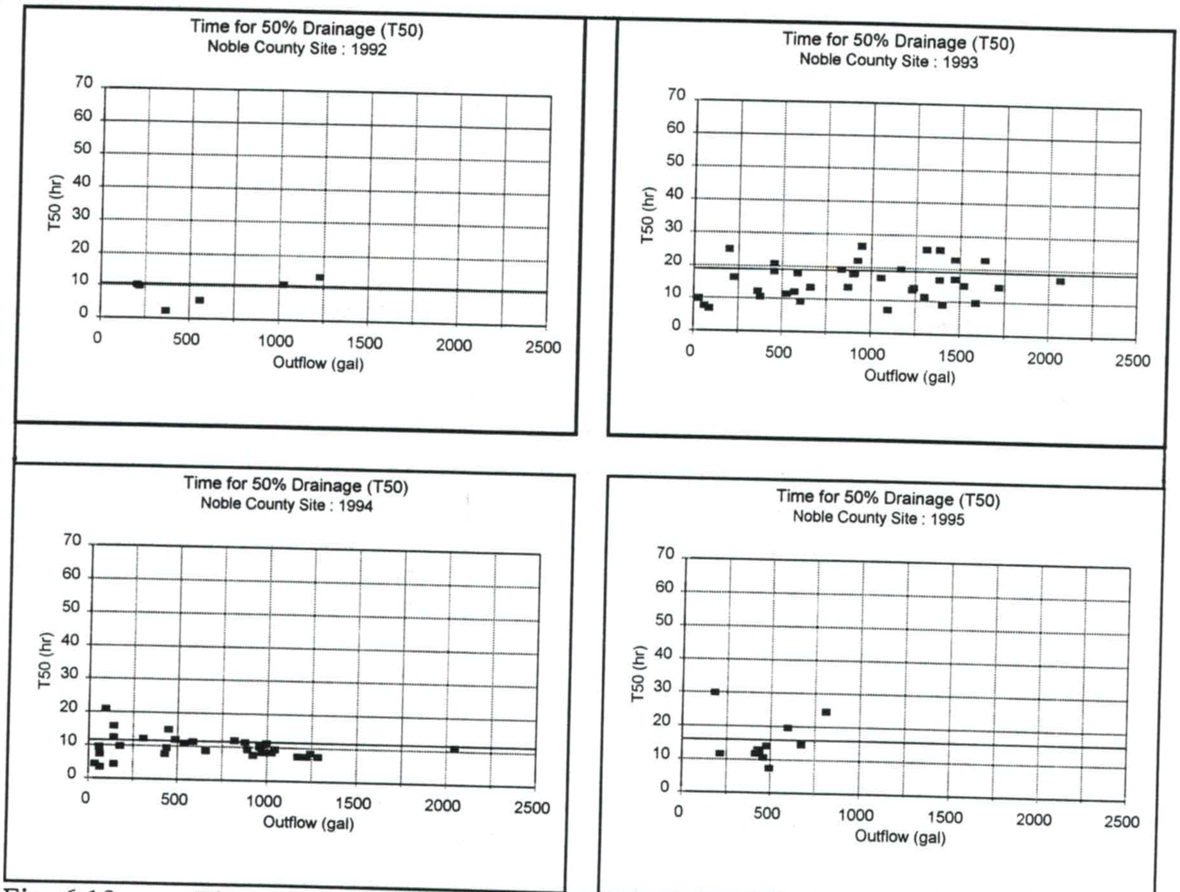

Fig. 6.19 Time required for 50% drainage - Noble county site

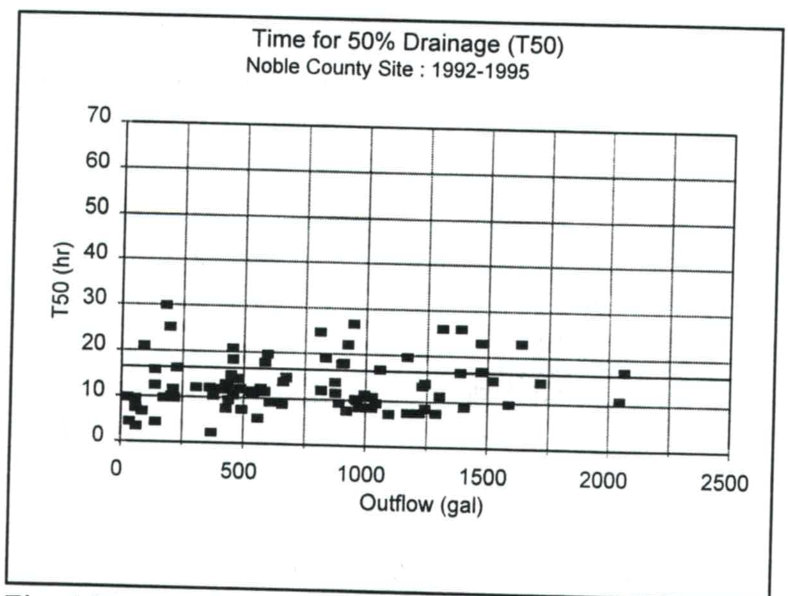

Fig. 6.20 Time required for 50% drainage - Noble county site, 1992-1995

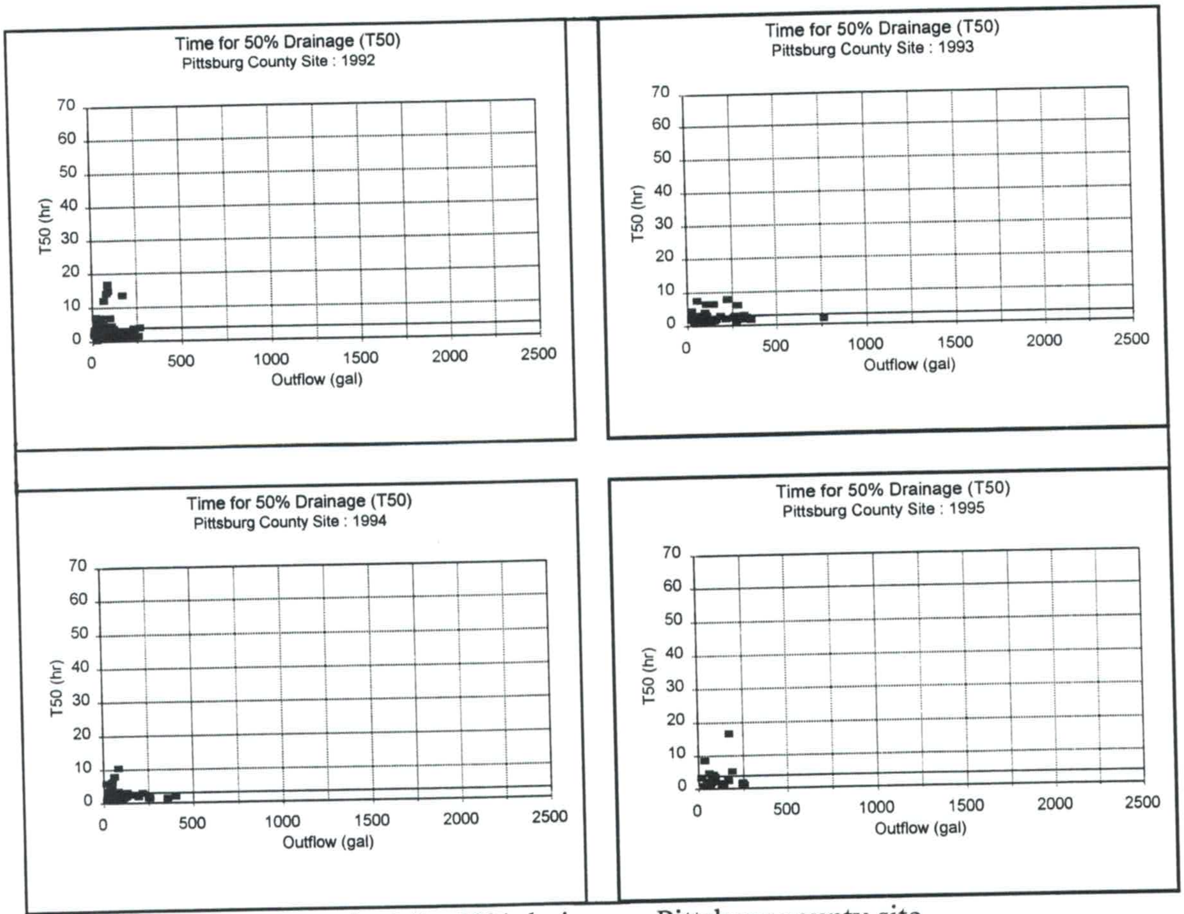

Fig. 6.21 Time required for 50% drainage - Pittsburg county site

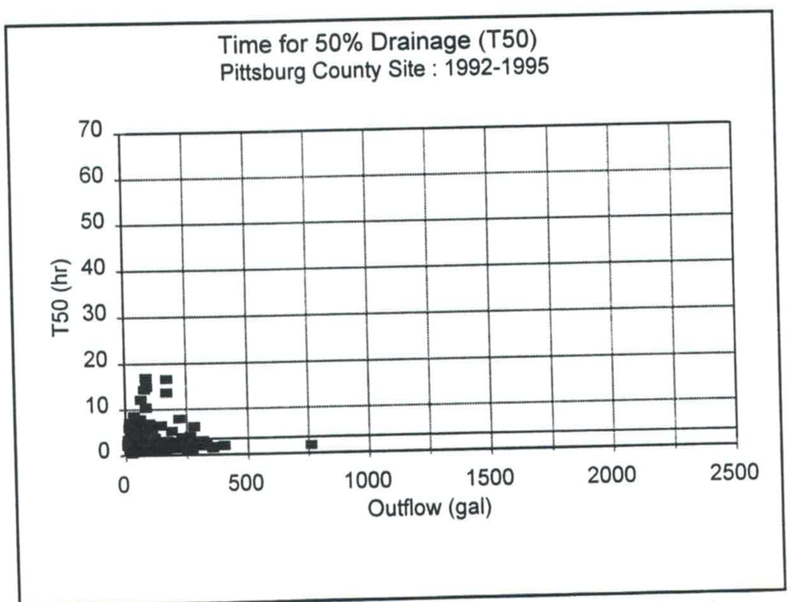

Fig. 6.22 Time required for 50% drainage - Pittsburg county site, 1992-1995

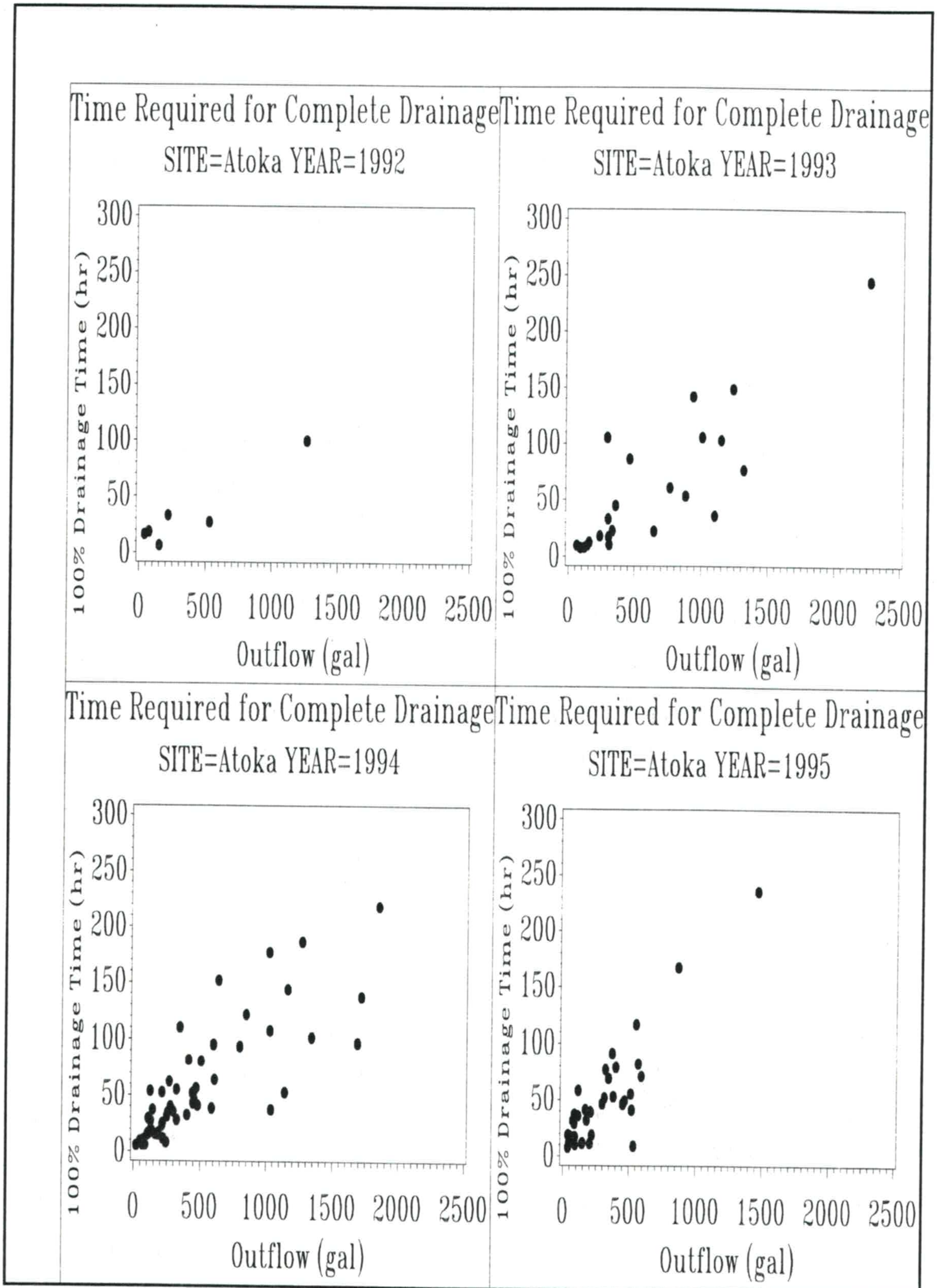

Fig. 6.23 Time required for 100% drainage - Atoka county site

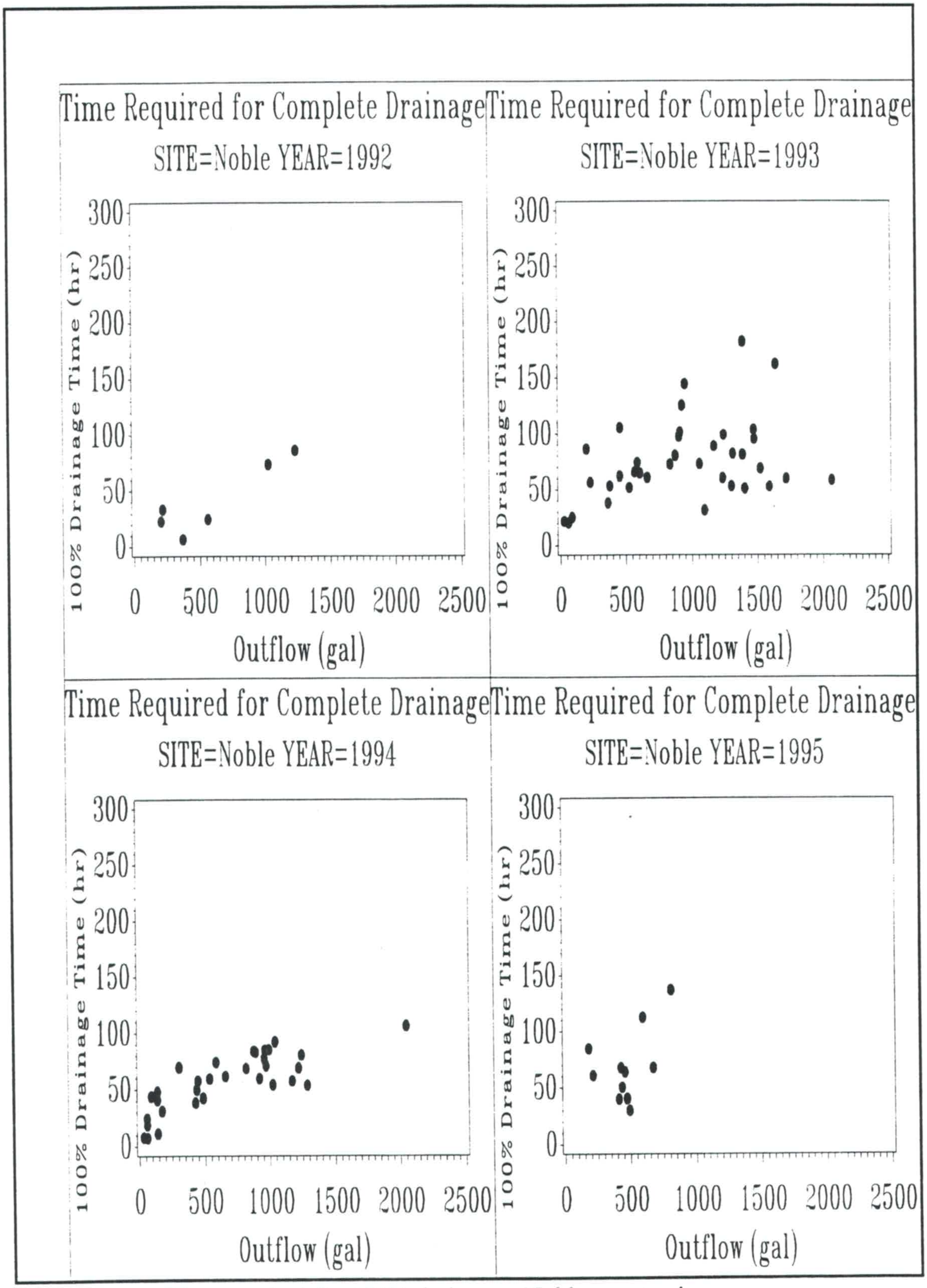

Fig. 6.24 Time required for 100% drainage - Noble county site

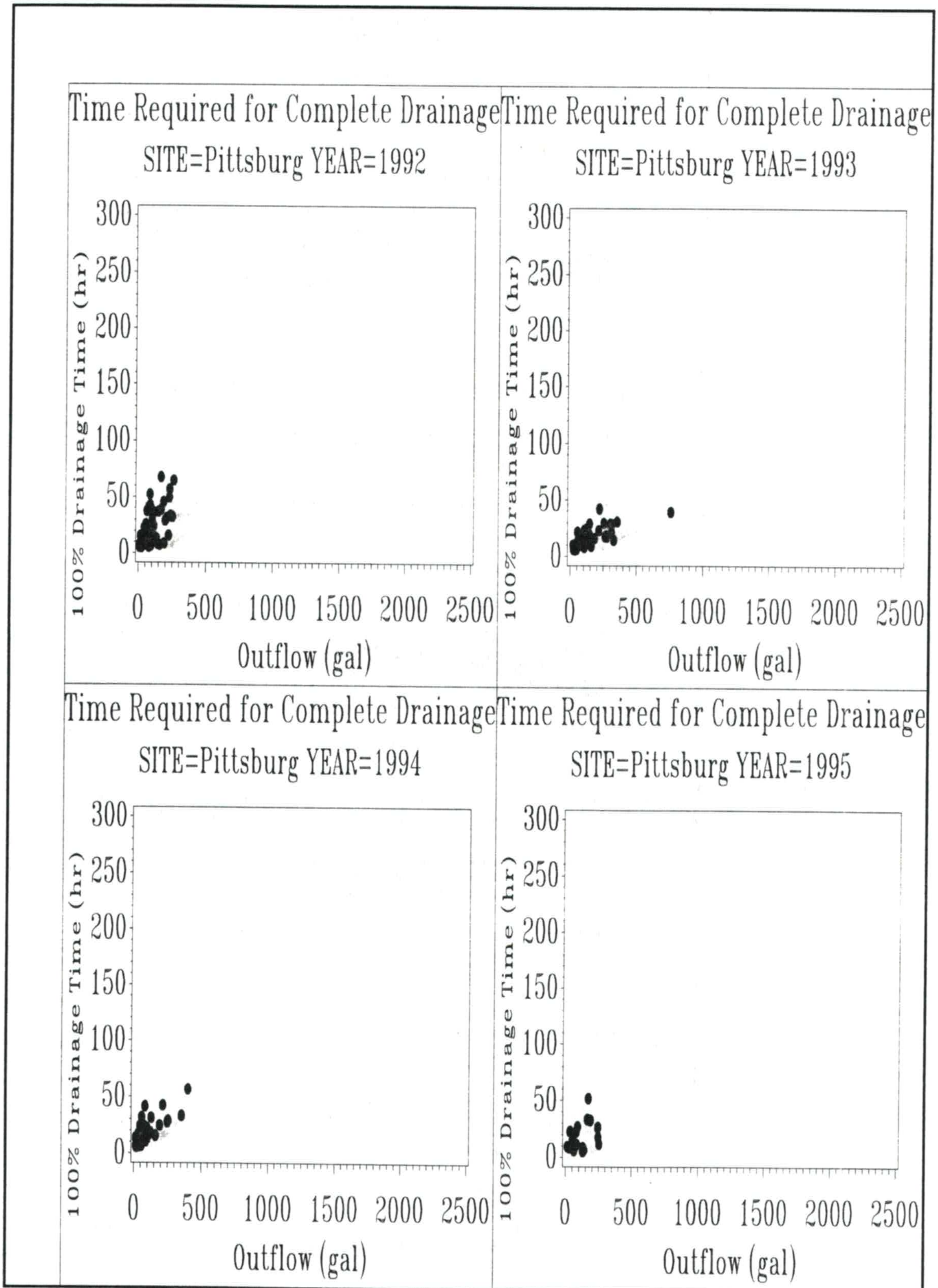

Fig. 6.25 Time required for 100% drainage - Pittsburg county site

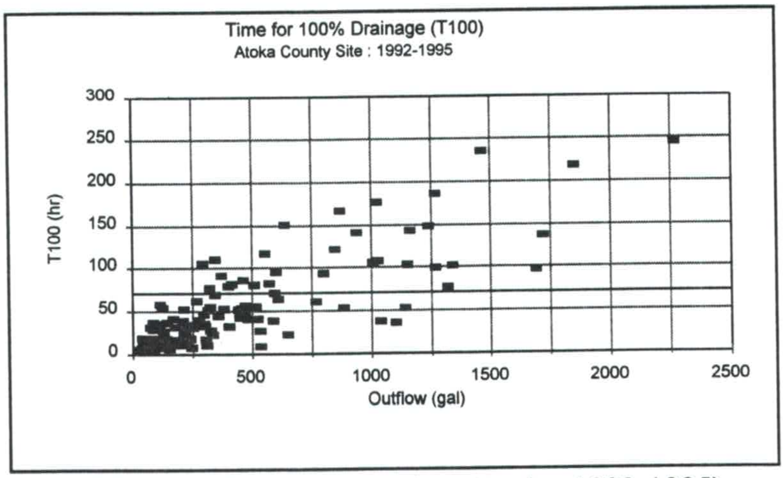

Fig. 6.26 100% drainage time (Atoka, 1992-1995)

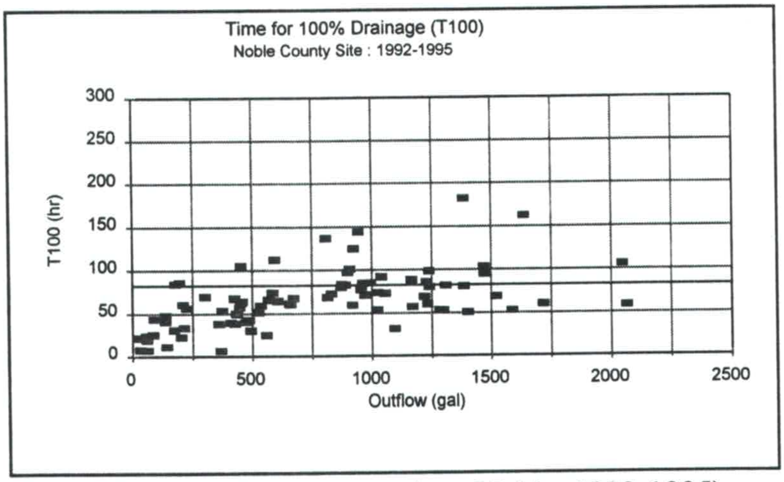

Fig. 6.27 100% drainage time (Noble, 1992-1995)

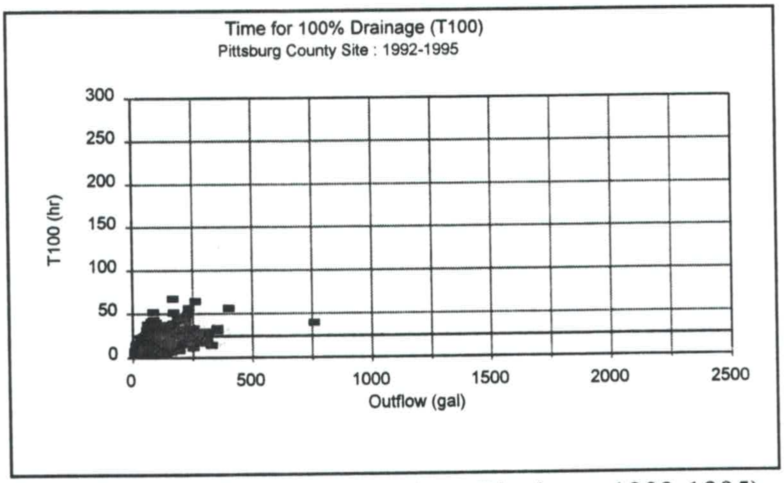

Fig. 6.28 100% drainage time (Pittsburg, 1992-1995)

CHAPTER 7
FIELD TEST

7.1 GENERAL

A field test was deemed necessary in order to evaluate the drainability of different sites based on common infiltration. The purpose of the test was to develop some quantitative means to express the drainability of any pavement with drainable base and edge drain system. The test was intended to be quick and simple, able to be performed at a number of state highways within a reasonable amount of time and resource. Also, a desirable test would be able to compare the drainability of one site to that of another. In the month of August 1995, a preliminary plan for such a test was developed in collaboration with ODOT R&D and the site at Noble county was tested using this plan. Later, based on the experience at this site, this preliminary plan was modified and a final test scheme was adopted. The sites at Pittsburg county and Atoka county were tested using this test scheme. The test scheme and the actual tests are discussed in the subsequent sections.

7.2 EQUIPMENT AND SUPPLIES

The equipment and the supplies are listed and described in Table 7.1.

7.3 TEST PROCEDURE

The test must be performed in a dry system. The “test outlet” (the first downgrade outlet pipe - also called “outlet 1" in this report) is equipped with an outflow tipping bucket. A rain gage is also installed within 1.0 m (3.28 ft) of the tipping bucket. A data logger is connected with the rain gage and the outflow tipping bucket. At least twelve hours after installation of the data logger, a portable laptop computer is connected with the data logger. Then the data collected thus far are downloaded and checked for any outflow at the test outlet. This information is used to record Items 1 and 2 of the *Field Data Sheet* (see Fig. 7.1). If any outflow is observed, then further testing is abandoned. The test must be delayed until a dry system is achieved.

The test is performed by introducing 1,022 liters (270 gallons) of water into the drainage system through a core hole drilled into the pavement. A drum is used to measure the supply of the required water into the system. The drum has a gross capacity of 208 liters (55 gallons) of which 204.4 liters (54 gallons) can be emptied through the drum outlet. Due to the construction of the drum, about 3.785 l (1 gal) cannot be emptied. The drums are emptied as quickly as the drainable base permits. The time gap provided between emptying two consecutive drums should be just sufficient to fill up the drum with water from a nearby water truck. A dye is used to help differentiate between water supplied during the test and the water retained in or flowing from the system at the beginning of the test. The test is said to have started as soon as water from the drum starts flowing into the core hole for the first time. The test is said to have stopped as soon as the outflow from the test outlet completely stops or after thirty hours. Tests are concluded after thirty hours due to time limitations.

The *Field Data Sheet* (Fig. 7.1) shows the different parameters the crew members need to observe in the field. All the parameters, excluding Items 1 and 2 in the *Field Data Sheet,* are to be observed manually. After all five barrels of water are emptied into the system and all the Items in the *Field Data Sheet* are recorded, the crew can leave for another site while the data logger remains at the site to record the outflow for a period of at least thirty hours from the beginning of the test. The data logger also records any rainfall to insure that the test is performed on a dry system. If any rainfall occurs during the test, the data obtained from the test should be discarded and the test should be repeated.

7.4 SITE PREPARATION

The field crew needs to prepare the site the day before the actual testing. This preparation process includes installing the tipping bucket, rain gage and data logger. Using the as-built plans, the edge drain is located and marked with spray paint.

7.4.1 Locating the core hole

The location of the core hole is determined as follows:

Longitudinal distance: 61 m (200 ft) upslope of the test outlet, not to exceed ⅔ of the total distance between outlets. If the outlet spacing is ≥ 91 m (300 ft), then the hole is placed 61 m (200 ft) from the test outlet (case A) (see Fig. 7.2). If the outlet spacing is < 91 m (300 ft), then the hole is placed at a distance of ⅔ of the outlet spacing (case B) (see Fig. 7.3).

Transverse distance: 1.22 m (4 ft) from the edge drain (see Fig. 7.4).

7.4.2 Drilling the core hole

On the day of testing, one 152 mm (6 in) diameter core extending to the top of the drainable base layer of the pavement is taken at the premarked location. At least 51 mm (2 in) of base material is also removed, bagged and marked (if any laboratory testing of the removed material is intended). The condition of the base material is noted on the Field Data Sheet.

7.5 WATER APPLICATION

Five drums of water are emptied into the core hole as quickly as possible. To obtain colored water, die is mixed with water in all five drums. The time required to empty each of the drums is recorded on the *Field Data Sheet.* The hole is patched after all the five rounds of water application is complete.

7.6 FIELD TEST PERFORMED AT THE NOBLE COUNTY SITE

The Noble county site is one of the five original sites selected for and equipped with the field data acquisition system. In order to obtain a clear idea about the drainage characteristics of the open graded base, a rudimentary form of field test described in the foregoing sections was performed at this site on August 23-24, 1995. This is the first of all the field tests conducted so far. Major differences in terms of test procedures performed at the Noble county site with the procedure described in sections 7.3 through 7.5 are:

(1) **Number and location of core holes:** There were four core holes drilled at different locations of the pavement as shown in Fig. 7.5. Also the view port (at location C) was used to put one barrel of water directly into the system.

(2) **Number of outlets observed:** Because some of the core holes were close to the test outlet, it was necessary to observe the flow at the next downhill outlet (called "in-situ outlet" or "outlet 2" in this report).

(3) **Amount of water supplied:** Different amount of water was supplied in different core holes (see Table 7.2).

(4) **Rate of water supply:** Rate of water supply varied for different core holes (see Table 7.2).

The base material removed from the core hole was found to be contaminated with a significant amount of fines. This may be due to the absence of any separator fabric underneath the drainable base at this site. The summary of the testing information for this site is provided in Table 7.2. It can be observed from this Table that some of the data were recorded manually by one or more members of the field personnel. The drainage information for the test is provided in Table 7.3. It is observed that only about 31-41% of the supplied water was drained out by the system. It is also observed that at the time of closing the test, the in-situ outlet (ie, outlet 2) still had some outflow. The flow rates as recorded by the data loggers are shown in Figs. 7.6 and 7.7. The corresponding cumulative outflows are shown in Figs. 7.8 and 7.9.

7.7 FIELD TEST PERFORMED AT THE ATOKA COUNTY SITE

A field test similar to the one described in sections 7.3 through 7.5 was performed at the Atoka county site on October 18, 1995. Five drums of water were emptied into the drainable base through a single core hole as discussed in Section 7.4. The testing and drainage information for this site are provided in Table 7.4. It is observed that about 76% of the supplied water was drained out by the system, and the outflow stopped within a very short time after the test started. The flow rates as recorded by the data logger are shown in Fig. 7.10, and the corresponding cumulative outflows are shown in Fig. 7.11.

7.8 FIELD TEST PERFORMED AT THE PITTSBURG COUNTY SITE

A field test was performed at the Pittsburg county site on October 17, 1995. The test procedure followed was similar to the procedure described in sections 7.3 through 7.5 except that the transverse location of the core hole was at a distance of 3.05 m (10 ft) from the edge of the outside shoulder. Five drums of water were emptied into the drainable base through a single core hole as before. Here also, the core hole was located in the shoulder area. The base was found to have a thickness somewhat less than four inches. The testing and drainage information for this site is provided in Table 7.5. It is observed that about 74% of the supplied water was drained out by the system, and the outflow stopped before the time of closing the test. The flow rates as recorded by the data logger are shown in Fig. 7.12 and the corresponding cumulative outflows are shown in Fig. 7.13.

Table 7.1 Description of the equipment and supplies required for field test

No.	Name	Function/description
1	Tipping bucket	Measures the amount of outflow
2	Rain gage	Measures the rainfall (if any) during the test
3	Data logger	Acquires and stores the rainfall and outflow data
4	Portable laptop computer (the PC208 datalogger support software must be installed in it)	Downloads data from the datalogger to the computer
5	Stopwatch	Shows time
6	208 l (55 gal) drum with 51 mm (2 in) side bung and faucet	Used to measure the supply water and to maintain the same head during the tests in an average sense
7	Water hose	Connects the water supply (water truck, for example) with the
8	Insitu coupling and pipes	Used for installation of the outflow tipping bucket on the test
9	Dye	Used to color the supply water
10	A complete set of "as built" plans	Required to locate the edge drain beneath the pavement
11	Patching material	Required to seal the core hole after the water supply ends
12	Drill truck	Required to drill the core hole
13	1155 l (300 gal) water supply	Provides the supply water for the test and it may be obtained from a water truck

Table 7.2 Summary of the testing information for the Noble county site

No.	Description	Unit	Hole A	Hole B	Hole C	Hole D	Hole E
1	Longitudinal distance from outlet 1	m	12.2	12.2		45.7	91.1
2	Distance from outlet 2	m	103.6	103.6		137.2	182.6
3	Transverse distance from the edge	m	1.2	6.0	0	6.0	1.2
4	Day on which test was done	-	1	1	2	2	2
5	No. of drums of water supplied	-	3	5	1	4	4
6	Amount of water supplied	l	625	1041	208	833	833
7	Average time gap between consecutive drums of water supply	min	25	9	NA	6.7	6.2
8	Average time for drum to empty	min	5.2	5		6.1	7.9
9	Average water intake rate	l/hr	2419	2506		2051	1578

Table 7.3 Drainage information for the test conducted at the Noble county site

No.	Description	Unit	Day one		Day Two	
			outlet 1	outlet 2	outlet 1	outlet 2
1	Time for flow to start	hr.	0.6	13.7	< 2	18
2	Time for completion of	hr.	13.3	17.8	24.9	8+
3	Flow rate at start of test	l/hr	0	0	0	0
4	Flow rate at end of test	l/hr	0	0	0	11
5	Peak flow rate	l/hr	28.4	56.8	56.8	13.2
6	Amount of outflow	l	125	566	598	68+
7	Share of total outflow	%	18	82	90	10
8	Total water supplied	l	1665		1874 (1665)*	
9	Total outflow	l	691		666 (522)*	
10	Ratio (outflow ÷ supply)	%	41		35 (31)*	

* Note: Amounts enclosed within parentheses indicate amount excluding the water supplied at hole C and corresponding outflow.

Table 7.4 Testing and drainage information - Atoka county site

No.	Description	Unit	Amount
1	Time for flow to start	hr.	0.26
2	Time for completion of flow	hr.	2.55
3	Flow rate at start of test	l/hr	0
4	Flow rate at end of test	l/hr	0
5	Peak flow rate	l/hr	1022
6	Average time gap between consecutive	min	5.63
7	Average time for drum to empty	min	13.88
8	Average water intake rate	l/hr	884
8	Total water supplied	l	1022
9	Total outflow	l	781.6
10	Ratio (outflow ÷ supply)	%	76.5

Table 7.5 Testing and drainage information - Pittsburg county site

No.	Description	Unit	Amount
1	Time for flow to start	hr.	1.65
2	Time for completion of flow	hr.	59.88
3	Flow rate at start of test	l/hr	0
4	Flow rate at end of test	l/hr	0
5	Peak flow rate	l/hr	227
6	Average time gap between consecutive drums of water supply	min	4.83
7	Average time for drum to empty	min	51.17
8	Average water intake rate	l/hr	240
8	Total water supplied	l	1022
9	Total outflow	l	747.5
10	Ratio (outflow ÷ supply)	%	73.1

FIELD DATA SHEET
DRAINABLE BASE TESTING

- LOCATION: ______________________________
- WEATHER: ______________________________
- DATE: ______________________________
- WORK PARTY: ______________________________

INFORMATION FROM THE DATA LOGGER:

1. Rate of Flow Present at the Time of First Arrival at Site: ____________

2. Rate of Flow Present at the Time of Starting the Test: ____________

MANUAL OBSERVATIONS:

3. Longitudinal Distance Between Core Hole and Lateral Outlet Pipe: ____________

4. Transverse Distance Between Core Hole and Edgedrain: ____________

5. Testing Information

Water Barrel No.	Real Time Test Starts (Hr:Min:Sec)	Elapsed Time Test Starts (Hr:Min:Sec)	Real Time Test Stops (Hr:Min:Sec)	Elapsed Time Test Stops (Hr:Min:Sec)	Time Taken for Test (Hr:Min:Sec)
1					
2					
3					
4					
5					

No.	Description	Real Time (Hr:Min:Sec)	Elapsed Time (Hr:Min:Sec)
6.	First Flow From Test Outlet		
7.	First Tip of the Outflow Tipping Bucket		
8.	First Appearance of Dye in Discharged Water		

9. Comments: ______________________________

____

____

Fig. 7.1 Field data sheet

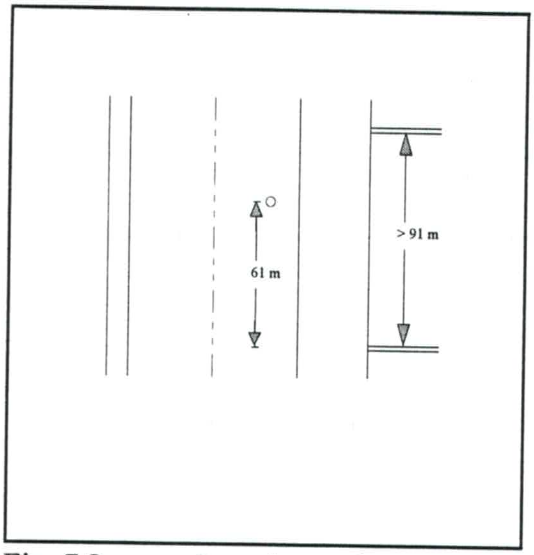

Fig. 7.2 Location of core hole (case A)

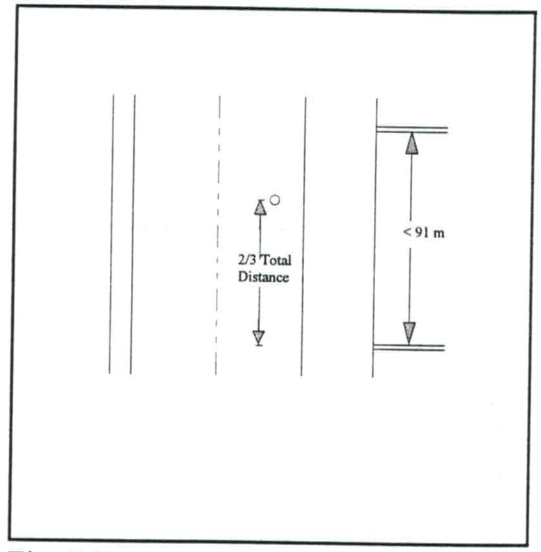

Fig. 7.3 Location of core hole (case B)

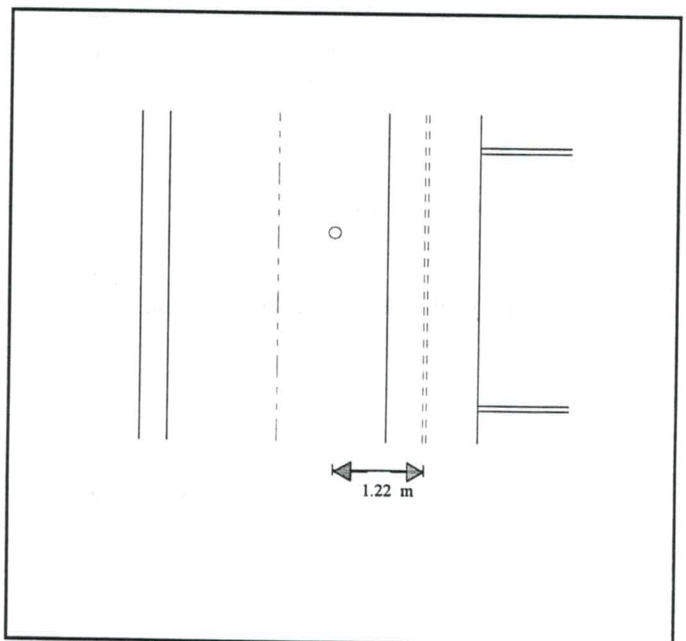

Fig. 7.4 Location of core hole - transverse distance

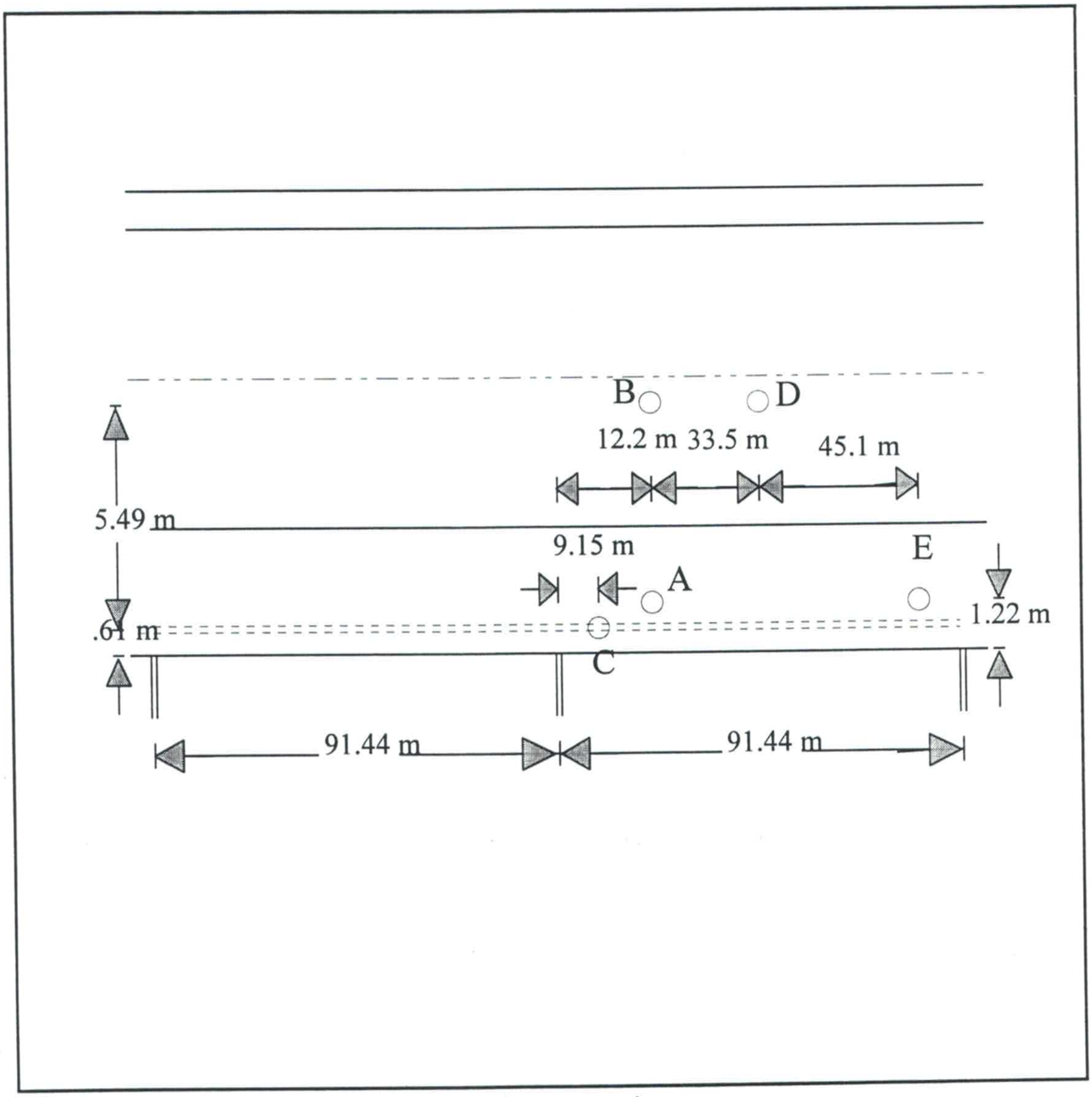

Fig. 7.5 Layout map for the Noble county site

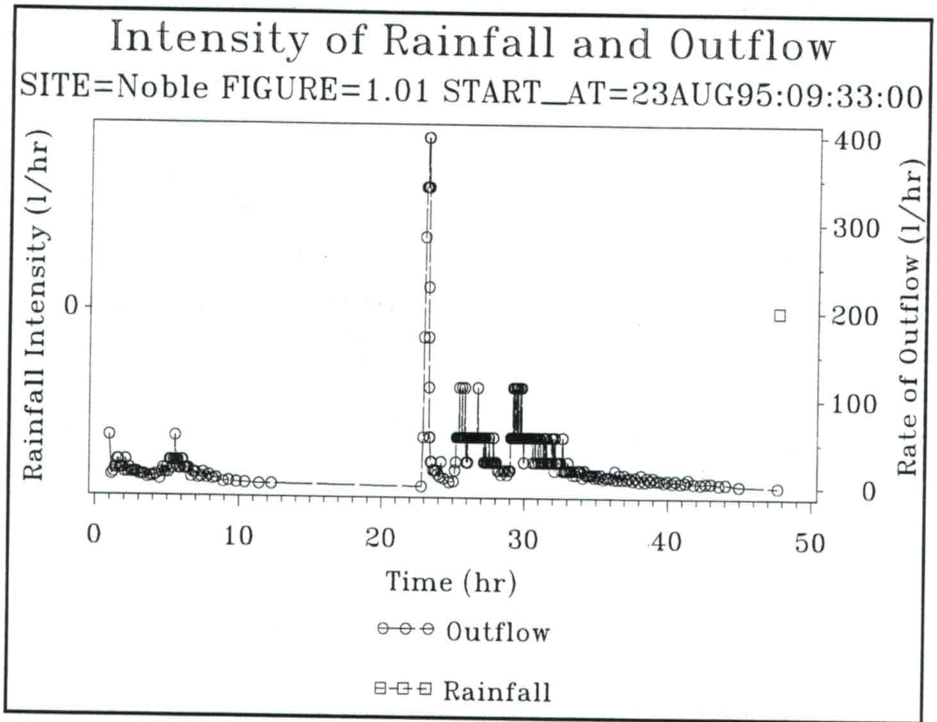

Fig. 7.6 Intensity of outflow at the primary outlet (Noble county)

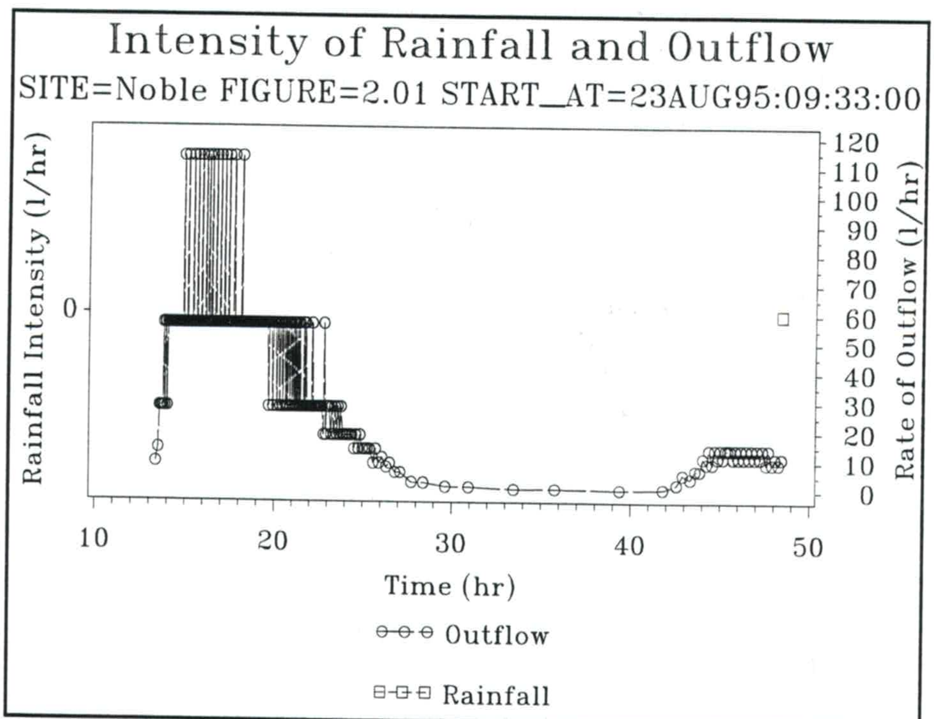

Fig. 7.7 Intensity of outflow at the in-situ outlet (Noble county)

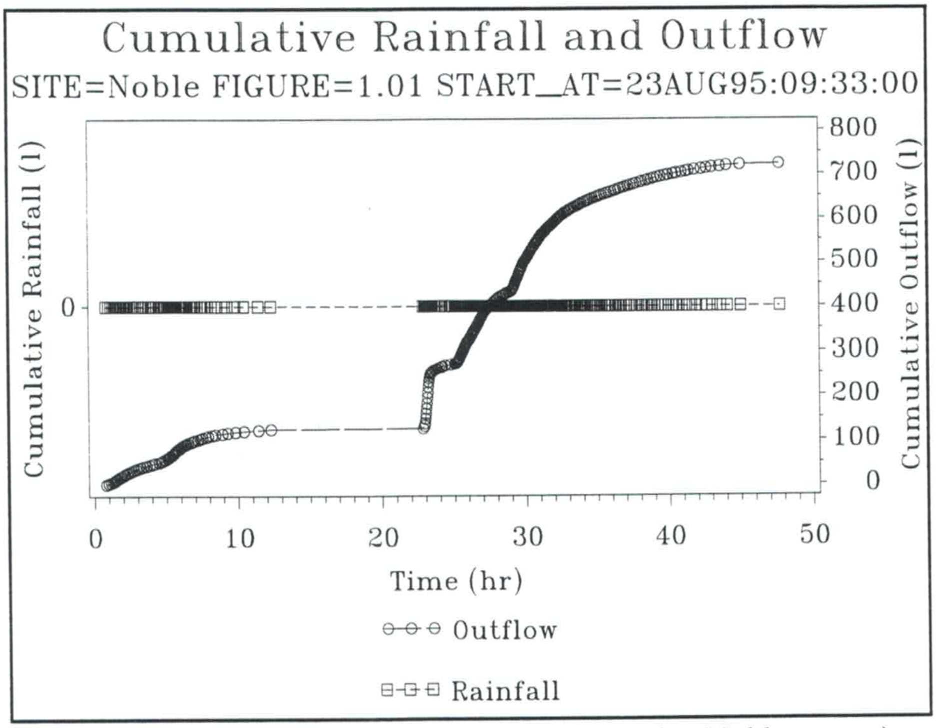

Fig. 7.8 Cumulative flow at the primary outlet (Noble county)

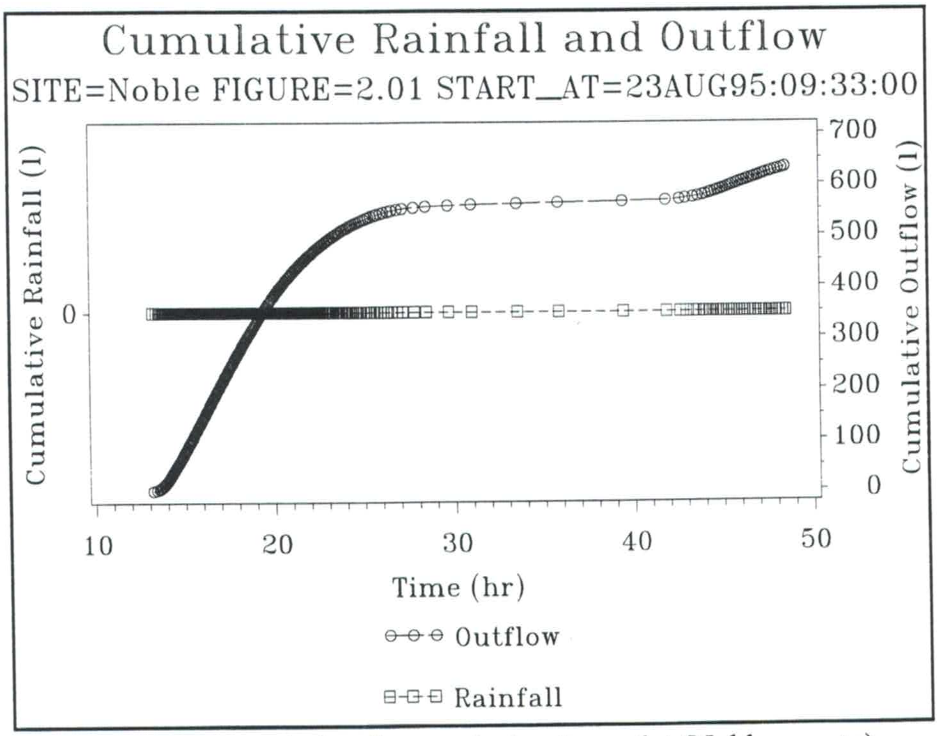

Fig. 7.9 Cumulative flow at the in-situ outlet (Noble county)

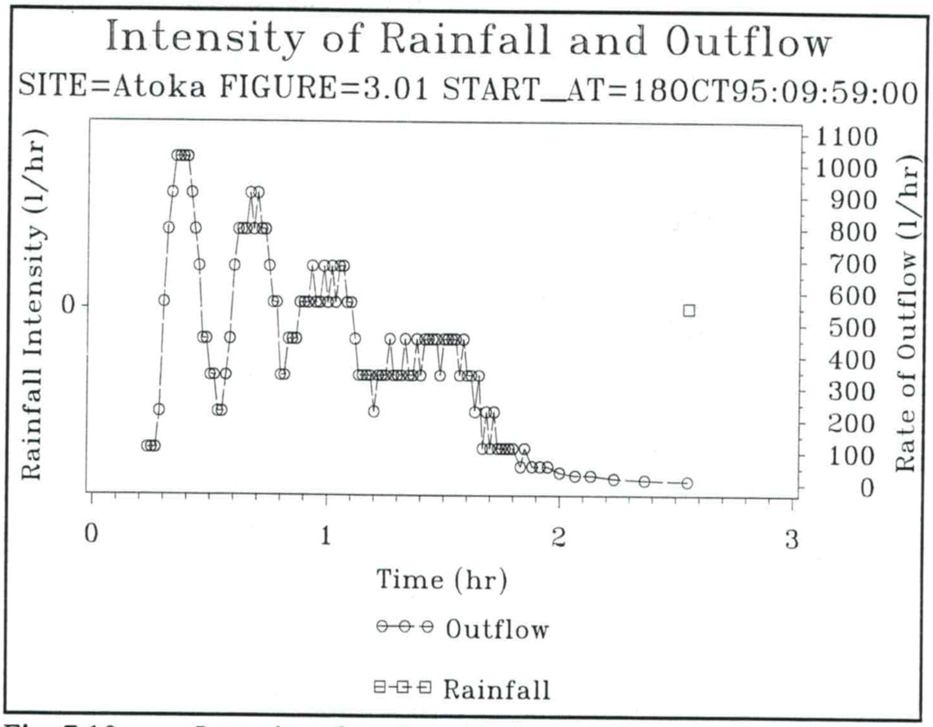

Fig. 7.10 Intensity of outflow (Atoka county)

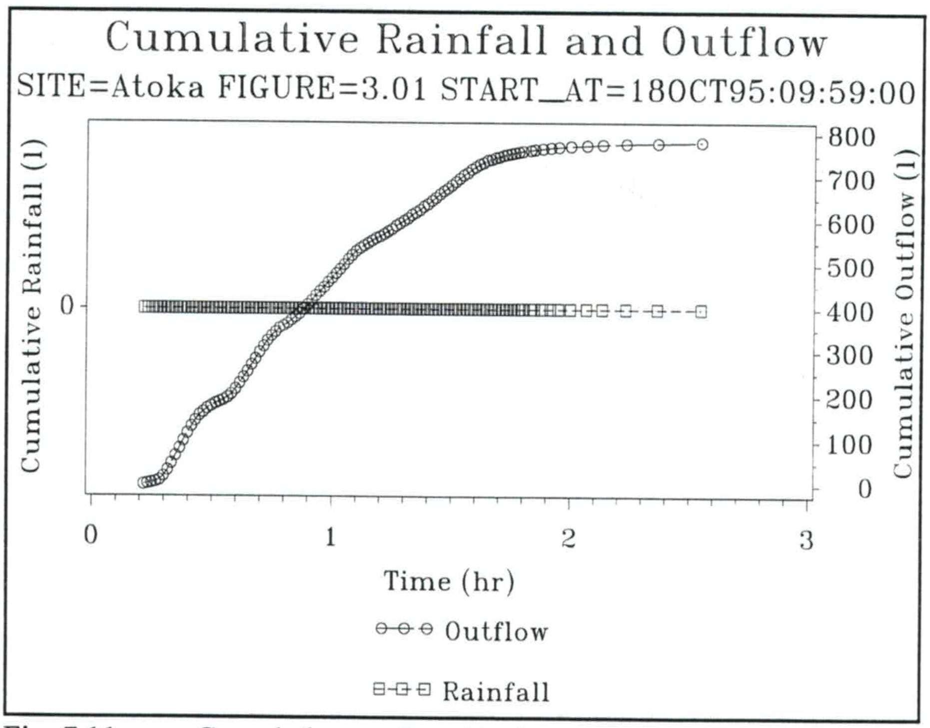

Fig. 7.11 Cumulative outflow (Atoka county)

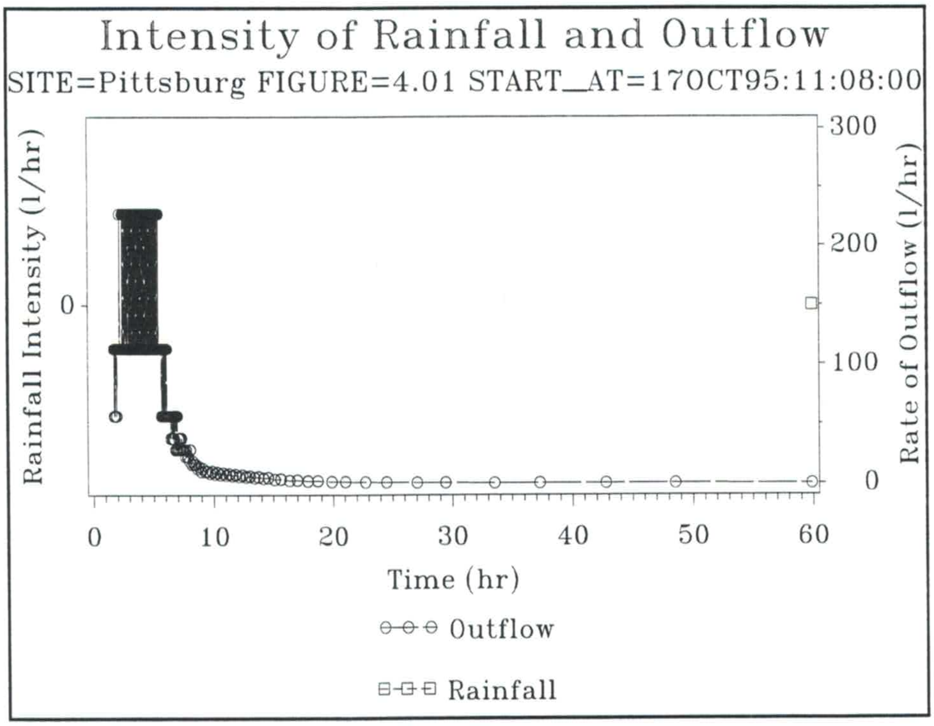

Fig. 7.12 Intensity of outflow (Pittsburg county)

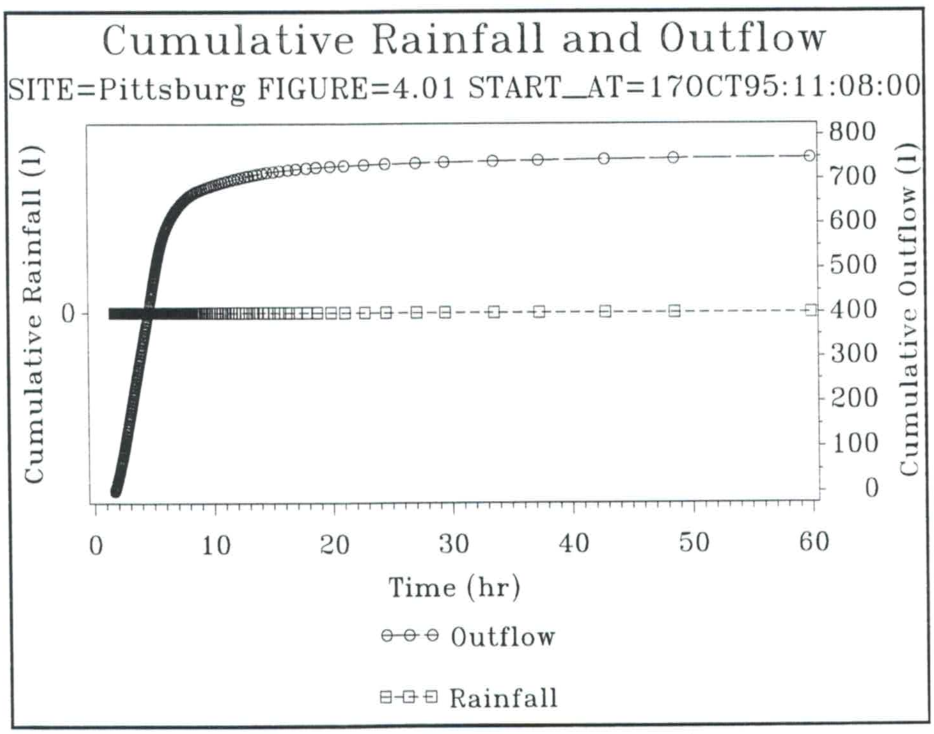

Fig. 7.13 Cumulative outflow (Pittsburg county)

CHAPTER 8
DISCUSSION OF RESULTS

8.1 GENERAL

After the rainfall and outflow data gathered from the field since 1992 and the inflow and outflow data obtained from the field tests were processed, a comparison analysis of the results was performed. A discussion of the results is presented in this chapter.

8.2 EDGE DRAINS WITHOUT OPEN GRADED BASE

The data gathered from the Logan county site shows clearly that this site did not experience any outflow (Table 5.6 and Fig. 5.10 in chapter 5, and Figs. 6.7 and 6.8 in chapter 6). The absence of any outflow can be attributed to the absence of any open graded base at this site.

8.3 BROKEN AND SEATED CONCRETE BASE

It is found that the amount of water drained through this kind of base at the Nowata county site is as little as 2% of rainfall or less. The maximum flow rate observed at this site is also the lowest: 34 l/hr (9 gal/hr), or only 4% of the second lowest value of 852 l/hr (225 gal/hr) from the Noble county site. Taking the amount of water drained equal to the amount of water infiltrated through the pavement into the base, one might argue that very little water infiltrates through the pavement into the base at this site which, in turn, produces a very slow outflow rate. But considering the high retention and drainage times, this seems very unlikely. In fact, all the information gathered so far indicates a poor drainage condition at this site. As quoted in Table 2.3, 74.3% of the material used as base contains concrete chunks of size larger than 38 mm x 13 mm (1½ in x ½ in) with a considerable amount of fines. The fines are possibly carried away with the drainage water, gathering on the wall of the geocomposite edge drain. A segment of the edge drain collected from this site showed a severe clogging of the wall. It is understandable that a clogged edge drain will prevent or at least slow down the draining of water. Considering these facts, one can conclude that the type of broken and seated concrete used as base at the Nowata county site did not provide enough drainability and this kind of material does not appear to be suitable to address the current pavement drainage design considerations.

8.4 COMPARISON OF FIELD TEST RESULTS WITH THE REGULAR DATA

The time for completion of flow for the field tests was found to be much less than the 100% drainage time for the regular data from both the Noble and Atoka county sites. The time for completion of flow (13 to 25 hours) for the field test performed at the Noble county site was less than the 100% drainage time (83 hours [see Fig. 6.27 in Chapter 6]) for the regular data obtained from this site. The time for completion of flow (2.55 hours) for the field test performed at the Atoka county site was also less than the 100% drainage time (71 hours [see Fig. 6.26 in Chapter 6]) for the regular data obtained from this site. Though the time for completion of flow (59.88 hours) for the field test performed at the Pittsburg county site was large compared to the 100% drainage time (24.5 hours [see Fig. 6.28 in Chapter 6]) for the regular data obtained from this site, 92% of the total outflow occurred within the first ten hours of drainage for the field test performed at this site (see Fig. 7.13 in Chapter 7).

The large values of the 100% drainage time for the regular data might have been caused by the existence of many clogged outlet pipes both upgrade and downgrade the test outlets. As mentioned in Chapter 3, these outlets are not regularly maintained. The test outlet, therefore, has to often drain out a share of water for the clogged upgrade and downgrade outlets as well. Field personnel have frequently reported the clogging of the lateral outlet pipes. Maintenance of the outlets has, thus, been found to be an important issue for pavement drainage.

8.5 COMPARISON OF ATOKA COUNTY SITE WITH NOBLE COUNTY SITE

The Atoka county site drains out about 33% of the rainfall water (Table 6.1a in chapter 6) while the Noble county site drains out about 16% of the rainfall water (Table 6.1b in chapter 6). The retention time from the Atoka county site (1.17 hours) is much less (indicates better drainage) compared to the retention time from the Noble county site (2.83 hours). Though these two sites have similar pavement structures (AC) but the thickness of the pavements are different (349 mm, or 13¾ in, at the Atoka county site, and 298 mm, or 11¾ in, at the Noble county site). There is no separator fabric under the drainable base at the Noble county site. There are also differences in edge drains: the Atoka county site has a perforated pipe type edge drain, while the Noble county site has geocomposite edge drain.

Field test results also indicate better drainage characteristics (Tables 7.2-7.4) for the Atoka county site compared to the Noble county site. The amount of water drained at the Noble county site was less than that at the Atoka county site. The flow rate from both field tests and regular monthly data is less at the Noble county site compared to the Atoka county site. The drainage time is about the same for these two sites for the regular monthly data, while the drainage time for the field test data was very large for the Noble county site when compared to the Atoka county site. Considering these facts, one can consider the Atoka county site better than the Noble county site from a pavement drainage point of view.

8.6 COMPARISON OF PITTSBURG COUNTY SITE WITH ATOKA AND NOBLE COUNTY SITES

The flow rate at the Pittsburg county site, as obtained from both the field test data and regular monthly data, is higher than that at the Noble county site and less than that at the Atoka county site. The retention time and drainage time for the Pittsburg county site, as obtained from regular monthly data, are far less or shorter (indicates better drainage) than the same quantities for the Atoka and Noble county sites. It appears that the outflow rate for the Pittsburg county site, as observed during the field test, is somewhat slow compared to the outflow rate as observed during the regular data collection period. Consequently, the drainage time for the field test performed at this site is somewhat high, particularly, when compared with the drainage time for the field test performed at the Atoka county site. This may be due to the particular location of the core hole drilled during the field test. Few core holes had been drilled in the past at the close vicinity of the current test core hole. It appears from this observation that more field tests need to be performed at different locations at these two sites to understand their drainage characteristics properly. However, one can observe better drainage properties at the Pittsburg site when compared to the Atoka and Noble county sites.

8.7 COMPARISON WITH AASHTO GUIDELINES

AASHTO has provided guidance for characterizing the drainability of different kind of bases depending on the time taken by these bases to drain out 50% of the free water (see Table 8.1). The underlying assumptions are: (a) the base is saturated at the time when drainage starts, and (b) there is no more inflow once the drainage starts.

Both assumptions depend on weather. The rainfall intensity and durations must be enough to saturate the base while it must not rain again once the drainage begins until the outflow completely stops. From this study, no indications of the base being saturated were present. If a constant value of the maximum flow rate could be found for more than one incident, then such incidents could be taken as an indication of saturation of the base. This was not at all evident from the analysis of data. However, one can still use the current drainage amounts and remain on the conservative side because these flow amounts are obtained from unsaturated systems and because unsaturated flow usually takes more time than saturated flow. Keeping this in mind, the current drainage amounts were related to the AASHTO guidelines and the drainage quality of the corresponding pavements were determined as shown in Table 8.2.

Table 8.2 indicates that the drainage characteristics of pavements having both open graded bases and edge drains compare favorably to the AASHTO guidelines. The sites in Atoka, Noble and Pittsburg counties fall in this category.

The Nowata county site has a broken and seated concrete base and, consequently, the comparison with AASHTO guidelines is somewhat surprising. According to the AASHTO guidelines, this site can be considered to possess *fair* drainage characteristics. The term *fair* usually indicates acceptable. But this is already discussed in section 8.3 that the drainage characteristics of the broken and seated concrete base does not appear to be acceptable. It appears that the term *fair* used in the AASHTO guidelines possibly needs re-examination.

The Logan county site, according to the AASHTO guidelines, possess *very poor* drainage quality. This is not surprising because this site has no open graded base and has never experienced any outflow.

Table 8.1 AASHTO recommendations for quality of pavement drainage (Ref. 14)

Time to drain out 50% of the free water from a base that was saturated at the time drainage started	**Quality of drainage**
2 hours	Excellent
1 day	Good
7 days	Fair
1 month	Poor
Does not drain at all	Very poor

Table 8.2 Tentative quality of drainage for the drainable bases under investigation

Site	**Time taken to drain out 50% of the free water from base**	**Tentative quality of drainage**
Atoka	17 hours	Good
Noble	16.5 hours	Good
Pittsburg	3.5 hours	Good
Nowata	> 1 day, ≤ 7 days	Fair
Logan	Does not drain at all	Very poor

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

The field behavior of five different pavement drainage systems composed of edge drains and/or drainable bases were investigated in this project. The data have been collected by ODOT R&D with field installed electronic sensors and data loggers since 1992. Out of five different types of data collected (rainfall, outflow, air temperature, and pressures at base and edge drain), two types of data (rainfall and outflow) were found to be of more practical use than the other types. It was determined that better drainage quality is achieved by using open type bases such as OGBB and OGCB. Although the broken and seated base, as used at the Nowata county site, was found to drain out some water, it cannot be regarded as a drainable base. The outflow rate is too slow at this site, and both the retention time and 50% drainage time are too large. The installation of a geocomposite edge drain on a newly constructed pavement without an open graded base at the Logan county site was found to produce no drainage. The OGCB, along with geocomposite edge drain at the Pittsburg county site, was found to drain out infiltrated water more rapidly than other types of bases. The OGBB, along with perforated pipe edge drain at the Atoka county site, was found to possess far better drainage qualities (for example, much higher outflow rate) compared to the OGBB along with geocomposite edge drain at the Noble county site.

Maintenance of the outlets was found to be an important issue for pavement drainage. If the upgrade outlets are clogged, then the test outlet has to drain out a share of water for the clogged upgrade outlets.

The field test results were found to indicate better drainage characteristics for the Atoka county site when compared to the Noble county site. The pavement structure for these two sites is approximately the same. The base is also the same (102 mm or 4 in OGBB) for both the sites. However, the Atoka county site has a perforated pipe edge drain, while the Noble county site has a prefabricated geocomposite edge drain. More investigation is needed, however, to determine if the difference in drainage characteristics for these two sites is due to the difference in type of the edge drains.

The 50% drainage times for the sites were computed and compared with the AASHTO guidelines. The sites with open type bases (Atoka, Noble and Pittsburg) were found to possess *good* drainage quality, as expected. The Nowata county site (with broken and seated concrete base) was surprisingly found to have *fair* drainage quality. The use of the term *fair,* in connection with the drainage behavior of the Nowata county site, needs re-examination; because this site experienced very little outflow at a very slow rate. The Logan county site was found to have *very poor* drainage quality because no drainage occurred at this site. No indication of any of the bases ever being saturated was found. However, it is not possible to conclude whether or not the thickness of the bases is too large; more investigation is needed to settle this issue.

9.2 RECOMMENDATIONS

1. As all the sites with open graded bases with edge drains are found to exhibit *good* drainage characteristics, the use of either OGBB or OGCB is recommended for all newly constructed pavements to address the pavement drainage concerns. The edge drain can be either perforated pipe or prefabricated geocomposite.

2. Based on the results of the Logan county site, using edge drain with a new construction of pavement is not recommended if no open graded base is used.

3. Based on the experience at the Nowata county site, using edge drain with broken and seated concrete base is not recommended.

4. Regular data collection efforts should be continued for at least several years (assuming no serious, long term equipment malfunctioning occurs). During this time period , at least three upgrade outlets and three downgrade outlets, as well as the test outlet, should be inspected regularly when downloading the data. Also, any material obstructing the free outflow of water from these outlet pipes should be removed. The field personnel should document any problems observed at the sites.

5. More than one field test needs to be performed at these sites, ideally at places located at different catchment areas. All these data should be compared to the regular data to determine the relationship between field test results and the in-situ drainage behavior. One of the goals of this field testing program should be to develop a standardized field test method that can be used to evaluate pavement drainage characteristics. Presently no such test methods exist in Oklahoma or other states.

6. At its final form, the field test should be performed at different sites on a yearly basis to study any temporal changes in the drainage quality.

7. It is recommended that the field testing program be conducted in conjunction with a numerical study (involving the physics of the pavement drainage conditions) to identify the influence of important drainage parameters. The goal of this study should be to improve pavement drainage design and maintenance.

COUNTY MAPS SHOWING THE SITES

A-1 GENERAL

The county maps showing the regular data collection sites are presented in the following figures (see Fig. A-1 to A-5). These maps are obtained from reference Ref. 15.

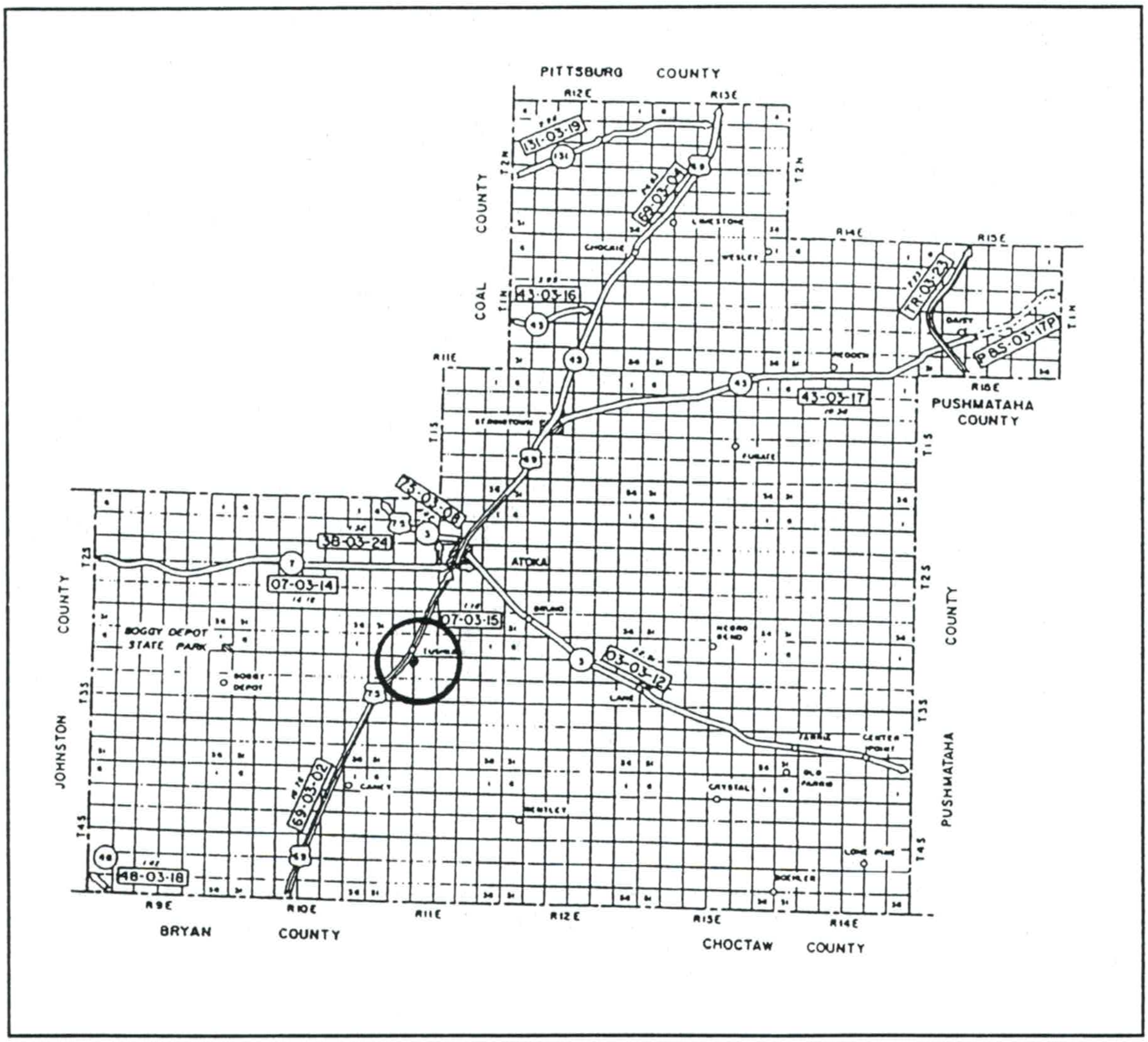

Fig. A-1 Atoka county site on northbound US-69: 304.8 m (1000 ft.) south of Tushka

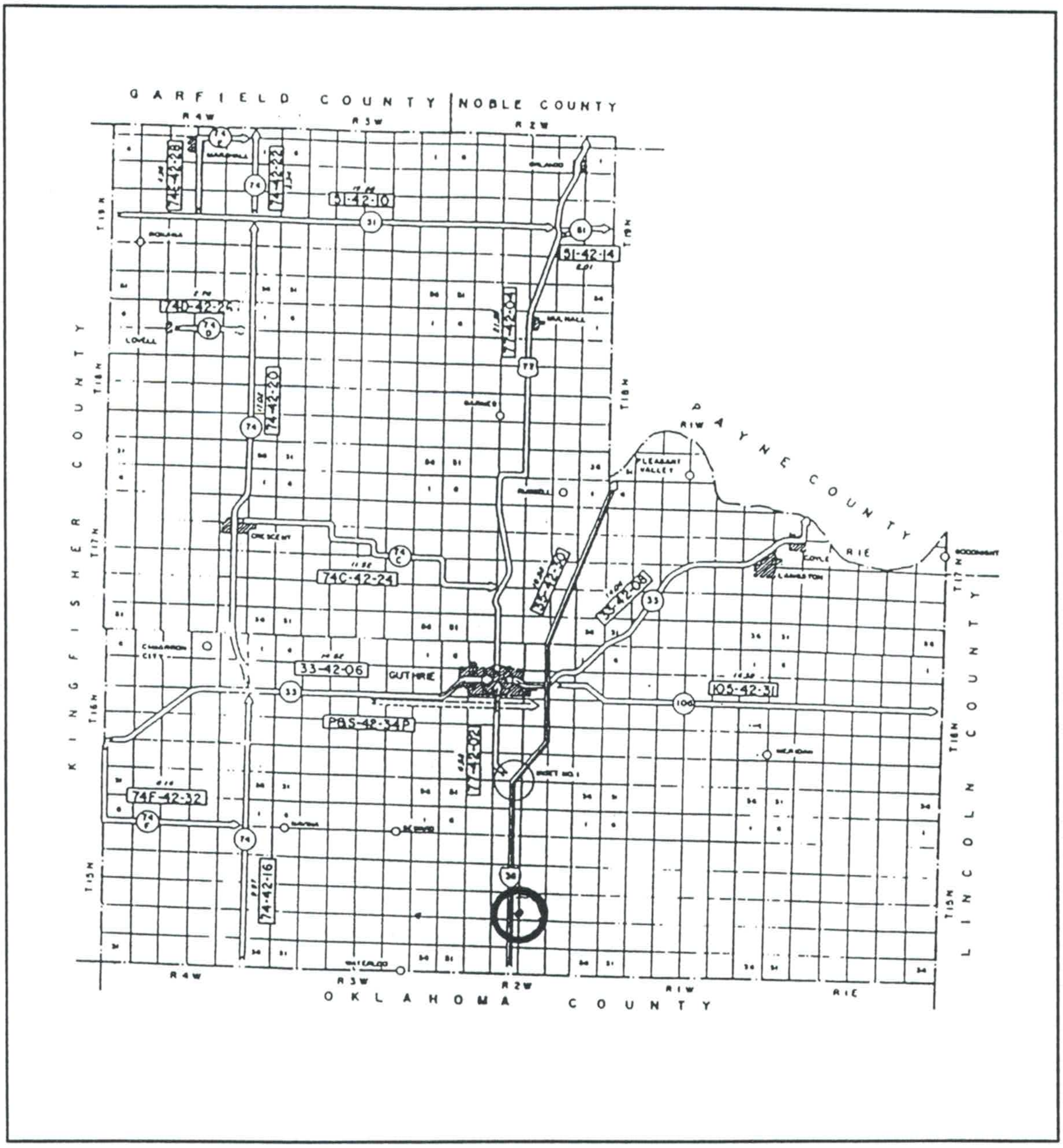

Fig. A-2 Logan county site on northbound I-35: mile post 148

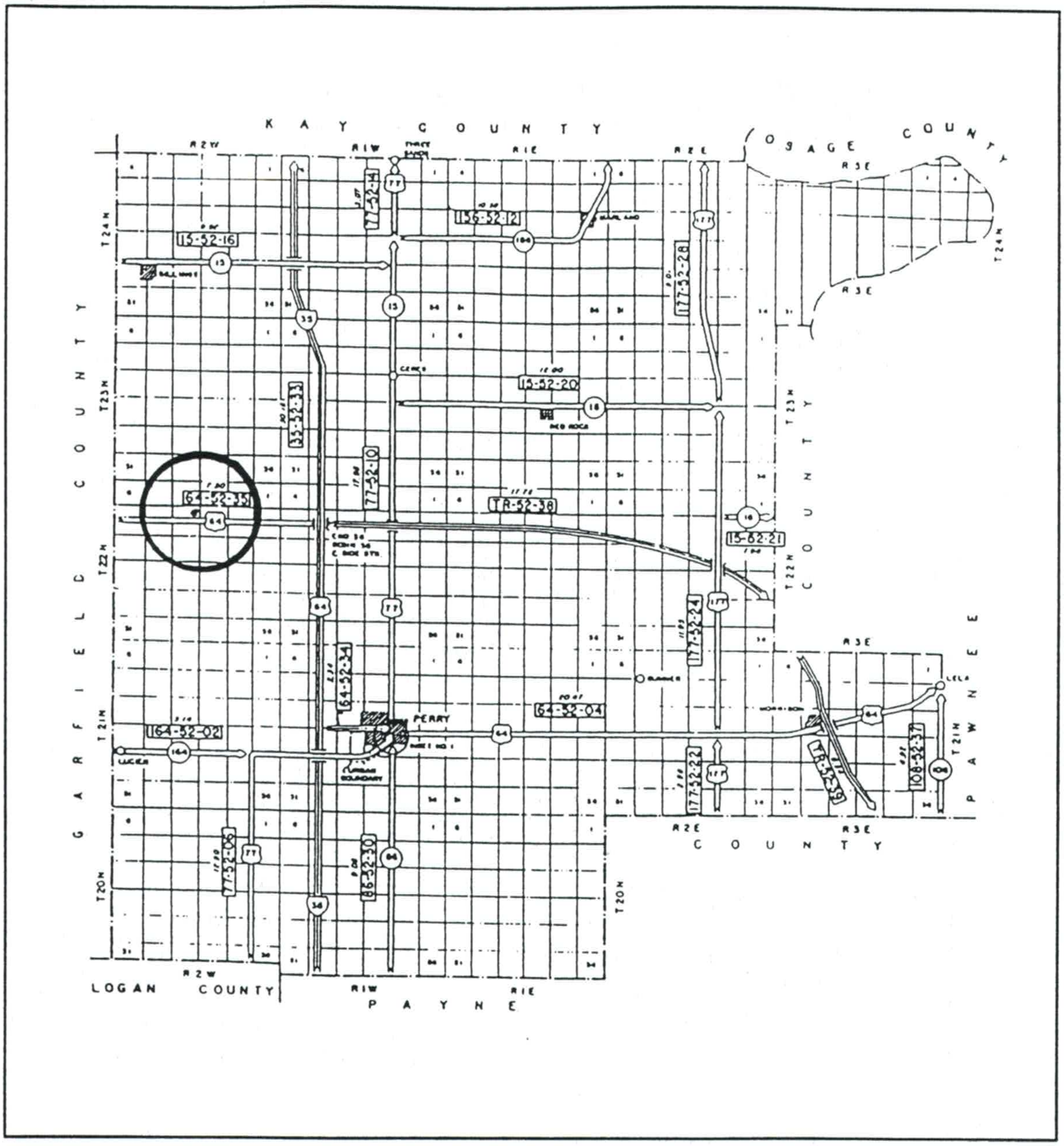

Fig. A-3 Noble county site on northbound US-64: 4.83 Km (3 miles) east of Garfield county line

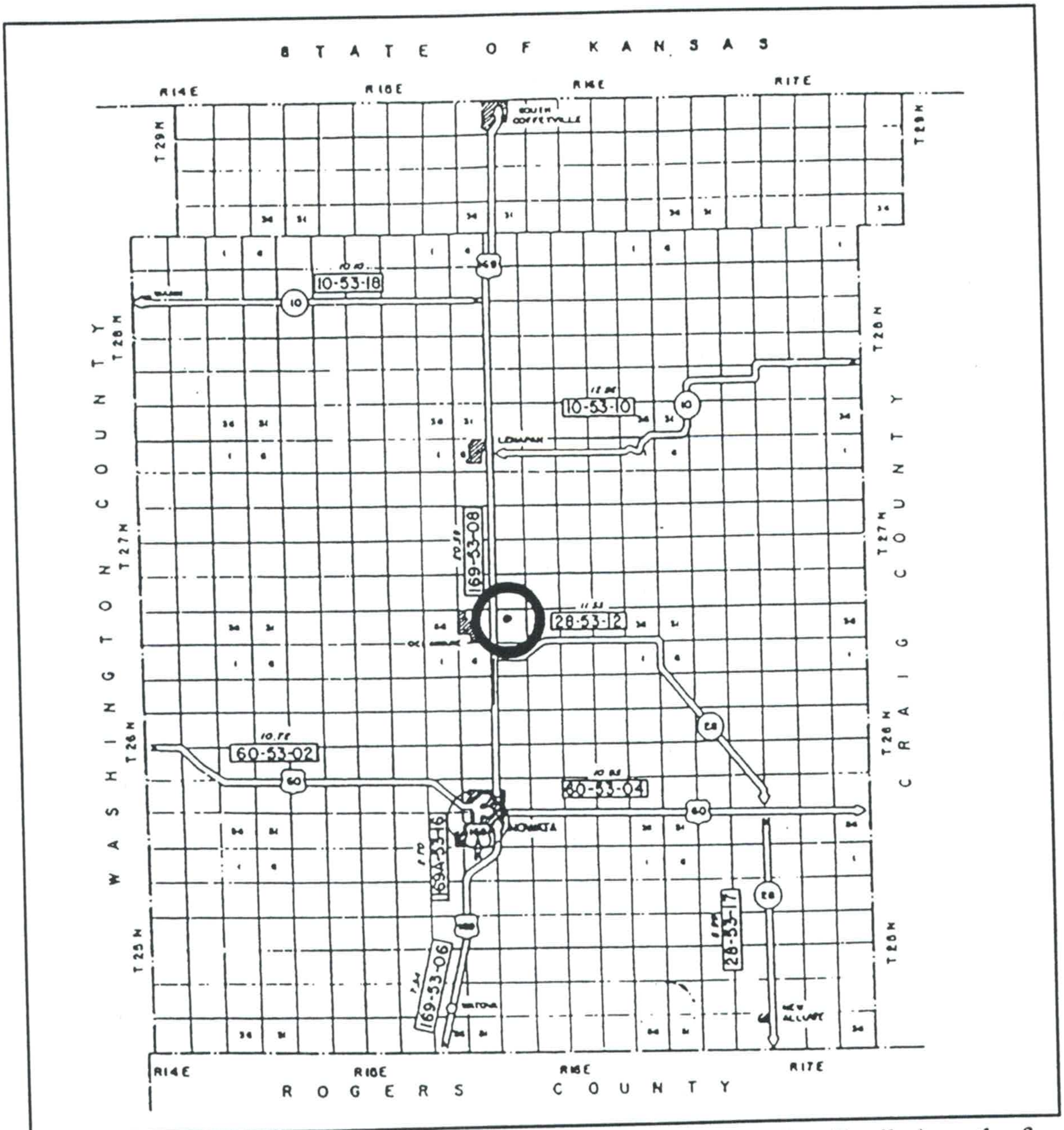

Fig. A-4 Nowata county site on northbound US-169: 12.87 Km (8 miles) north of SH-128

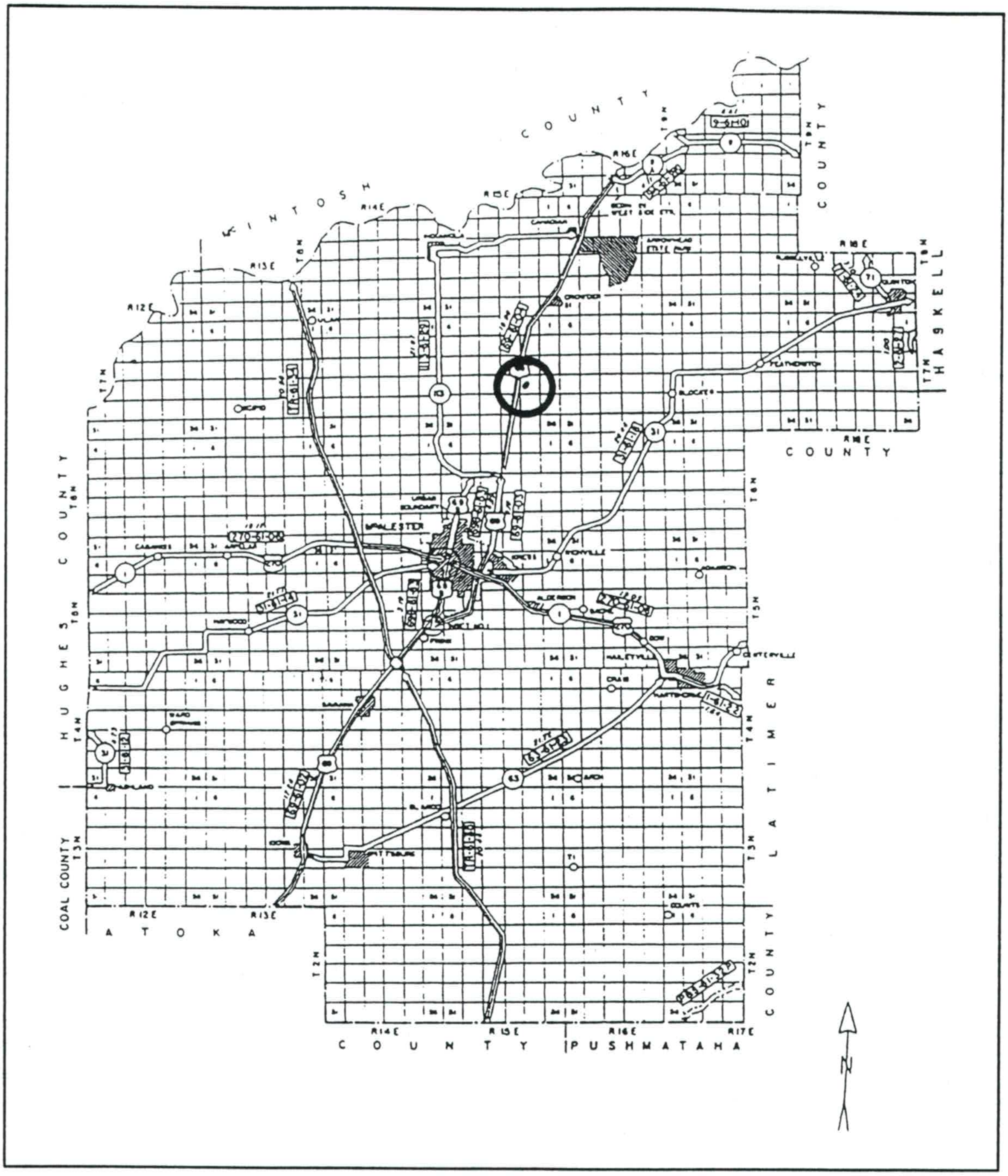

Fig. A-5 Pittsburg county site on northbound US-69: 16.09 Km (10 miles) north of US-270

APPENDIX B

SITE INSTRUMENTATION

B-1 GENERAL

A number of instruments were used in the sites during different phases of the project (see Table B-1). Some of these instruments were installed at the sites while some others (such as the fiberscope) were taken out to the site to perform some special tasks. The instruments are outlined in section B-2, and the installation procedure is described in section B-3 (duplicated with ODOT R&D permission from Ref. 16, pp. 10-20, with slight modification).

B-2 DESCRIPTION OF THE INSTRUMENTS

A brief description of the instruments used is provided in the following sub-sections.

B-2.1 Description of the outflow tipping bucket

In this study, the Wisconsin DOT tipping bucket design was used to measure the outflow of the lateral outlets. Water from the edge drain flows through the outlet into the tipping bucket (see Fig. B-1). Water fills one side of the bucket until the weight of water causes the bucket to tip. Then the other side is filled with water as the first side is emptied. Each tip is equivalent to 1.8925 liters (0.5 gallons) of water and is recorded electronically to a data logger connected to the tipping bucket via electric cables.

B-2.2 Description of the rain gage

One tipping bucket rain gage, Qualimetrics model 6018-A, is used to measure the rainfall amount (see Fig. B-2). The rain gage measures the precipitation at the site by letting rainfall flow through a 304.8 mm (12 in) opening into a tipping bucket. Each tip is recorded electronically to a data logger and is equivalent to 0.254 mm (0.01 inches) of rainfall. The gage has a protective housing and screen to protect the tipping bucket from grass and bugs. The rain gage has an accuracy of 0.5% at 12.7 mm/hr (0.5 in/hr of rainfall).

B-2.3 Description of the temperature probe

Temperature is measured with a Campbell Scientific model 107 temperature probe (see Fig. B-3). The probe is a small thermocouple which measures the ambient temperature at each site in units of °C (degrees Celsius). The probe has an accuracy of ±0.2 °C.

B-2.4 Description of the pressure transducers

Two pressure transducers, Druck model PCDR-940, are used to measure the pore water pressure in the edge drain and the drainable base (see Fig. B-5). These pressure transducers record measurements in pounds per square inch which can be converted to depth of water. The probes measure 76 mm (3 inches) long and have an accuracy of ±0.04% static pressure.

B-2.5 Description of the soil moisture device

A Trace Time Domain Reflectometry (TDR) soil moisture device and two TDR wave guide probes, Soil Moisture Corporation Models 6050X1 and 6005, are used to determine the percent moisture content of the soil beneath the pavement (see Fig. B-4). The portable soil moisture device was intended to be used at all the sites. The probes, installed permanently at the sites, measure 76 mm (3 inches) wide and 152 mm (6 inches) long.

B-2.6 Description of the data logger

One data logger, Campbell Scientific model CR-10, is used to record readings from the rain gage, pressure transducers, temperature probe and the outflow tipping bucket (see Fig. B-6). The data logger is installed permanently at the site. The data logger is battery operated and it can be programmed to record the data at any suitable interval or condition.

B-2.7 Description of the fiberscope

An Olympus fiberscope, Model IF1104-15, is used to inspect and record conditions inside the edge drains (see Fig. B-7). The fiberscope can be used with a .35 mm camera for obtaining photographs.

B-3 INSTALLATION

The installation process for the instruments is described briefly in the following sub-sections. Fig. B-8 shows the typical site layout.

B-3.1 Installation of the outflow tipping bucket

The first step in instrumenting each site was to build a 1.524 m X 1.524 m (5 ft X 5 ft) concrete block structure around the lateral outlet pipe. One tipping bucket was placed inside the structure and connected to the data logger. The outflow tipping bucket was manufactured locally.

B-3.2 Installation of the rain gage

The rain gage was mounted on a 0.304 m X 0.304 m (12 in X 12 in) concrete pad placed about 1.0 m (3.28 ft) away from the tipping bucket structure. This was done so that the tipping bucket structure would not interfere with the operations of the rain gage. The rain gage was then connected to the data logger through cables buried underground.

B-3.3 Installation of the temperature probe

A temperature probe was placed on the post of the data logger. A cable linked the probe and the data logger.

B-3.4 Installation of the pressure transducers

Two pressure transducers were installed at each site, one in the outside wheel path of the outside lane and one next to the edge drain (see Fig. B-9). In the wheel path, a 203 mm (8 in) core hole was cut to a depth of 102 mm (4 in) below the base. A 51 mm (2 in) thick layer of bentonite was placed at the bottom of the hole, and a 102 mm (4 in) long piece of 203 mm (8 in) diameter PVC pipe was set in the core hole on top of the bentonite. The first pressure transducer was placed in the hole with the tip of the transducer extending down 51 mm (2 in) below the permeable base. The hole was backfilled with river gravel to the top of the permeable base, where a 51 mm (2 in) bentonite plug was placed and the remainder of the core was filled with Duracal (quick set concrete).

The second pressure transducer was placed in another 203 mm (8 in) core hole, cut next to the geocomposite edge drain which extended to the bottom of the edge drain. A 51 mm (2 in) thick layer of bentonite was placed at the bottom of the hole as before. A full depth piece of 203 mm (8 in) diameter PVC pipe was cut lengthways and placed into the core hole with the open end facing the edge drain. The filter fabric around the edge drain was cut so that the water could fill around the pressure transducer. Next, the pressure transducer was placed in the core hole with the tip extending to the bottom of the edge drain. The core hole was backfilled with gravel and a PVC cap was placed on the PVC pipe.

At the Atoka county site (the only site with a perforated pipe instead of a geocomposite edge drain), the second pressure transducer was placed through the center of the 102 mm (4 in) diameter corrugated pipe edge drain. A 102 mm (4 in) core hole was cut through the pavement into the top of the pipe edge drain. The pressure transducer was placed inside the pipe with the transducer lying at the bottom of the pipe. The sensor cable was buried underground to the data logger from the edge of the pavement.

B-3.5 Installation of the soil moisture device

Two 102 mm (4 in) diameter holes were drilled through the pavement down 152 mm (6 in) into the subgrade. Both holes were located in the outer most wheel path at 3.05 m (10 ft) spacing. One TDR moisture probe was placed vertically in each hole and backfilled with sand to the top of the subgrade (see Fig. B-10). A 51 mm (2 in) layer of bentonite was placed on the top of the sand to minimize surface infiltration. The remainder was filled with Duracal to the top of the pavement. Next, a saw cut was made from each core hole out to the shoulder where the cables were placed and covered with joint sealer.

B-3.6 Installation of the data logger

The data logger, along with a storage module and power supply module, was placed inside a housing case made of steel. The housing case is mounted on two steel posts and rests about 150 mm to 300 mm (6 inches to 12 inches) above ground.

B-4 VIEWPORTS

A number of bore holes were drilled into the edge drain at each site uphill from the outlet. A 51 mm (2 in) PVC pipe was then connected and sealed to the edge drain. The fiberscope is used through the view port to inspect the conditions in the edge drain.

Table B-1 List of instruments used

No.	Name	Installed at the sites?
1	Outflow tipping bucket	Yes
2	Rain gage	Yes
3	Temperature probe	Yes
4	Pressure transducers	Yes
5	Soil moisture device	Yes
6	Data loggers	Yes
7	Fiberscope	No

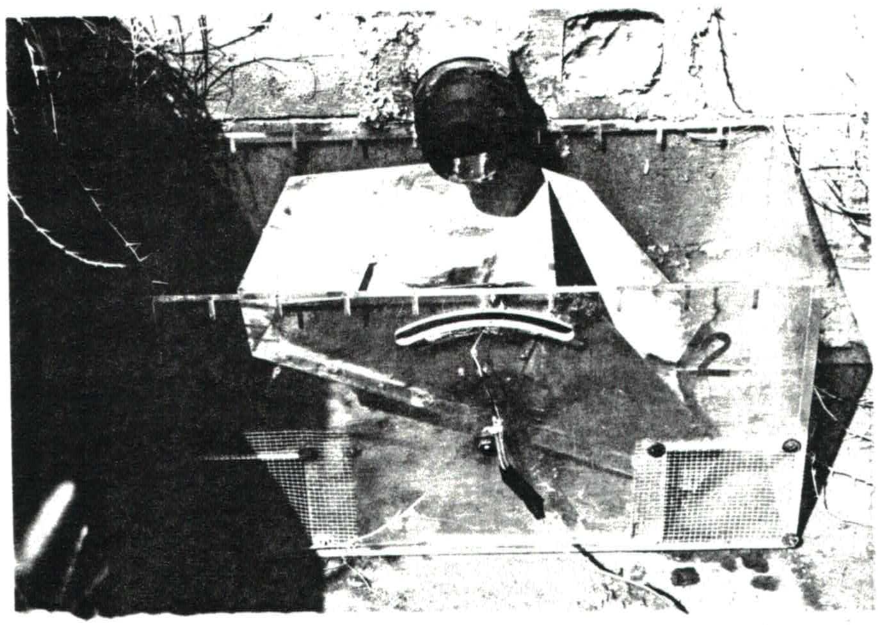

Fig. B-1 Outflow tipping bucket

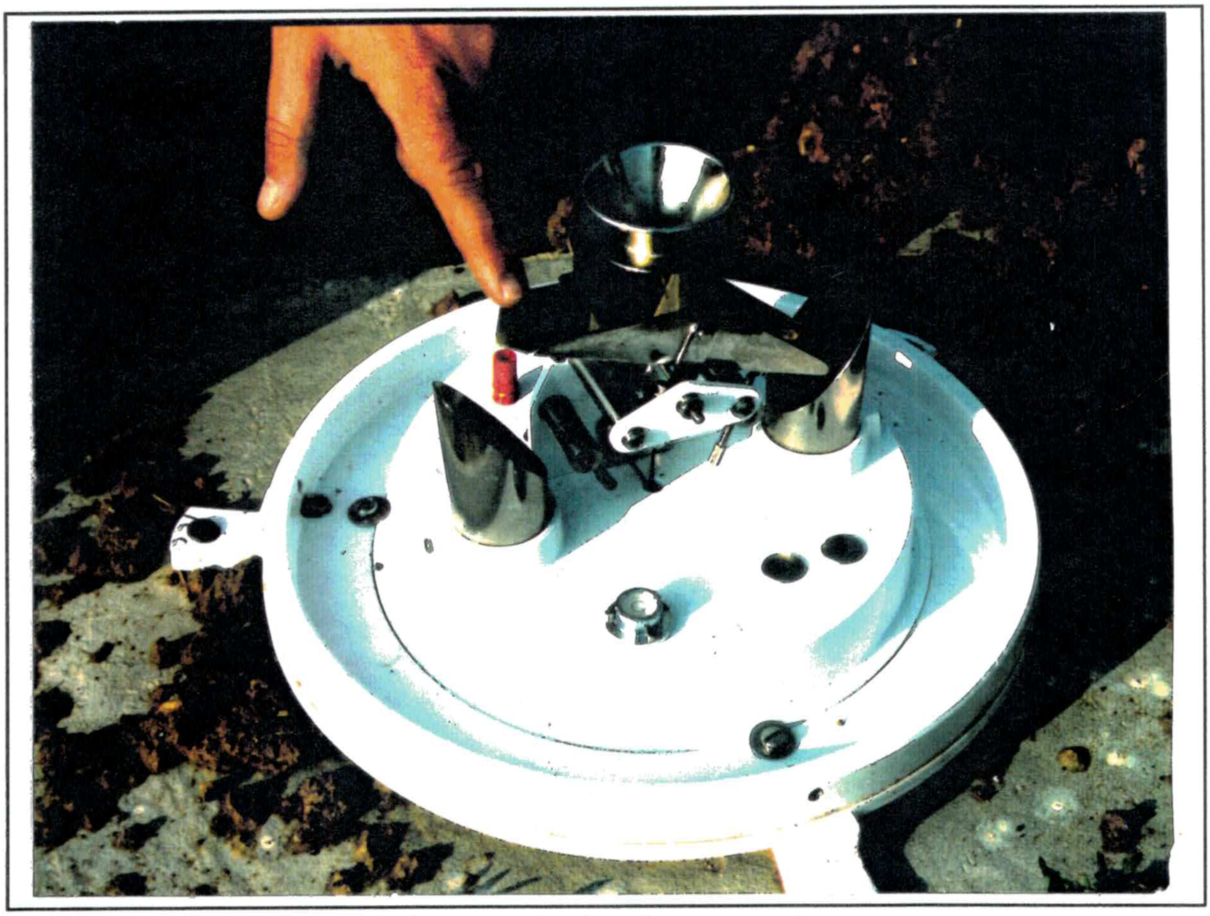

Fig. B-2 Rain gage with the protective housing removed

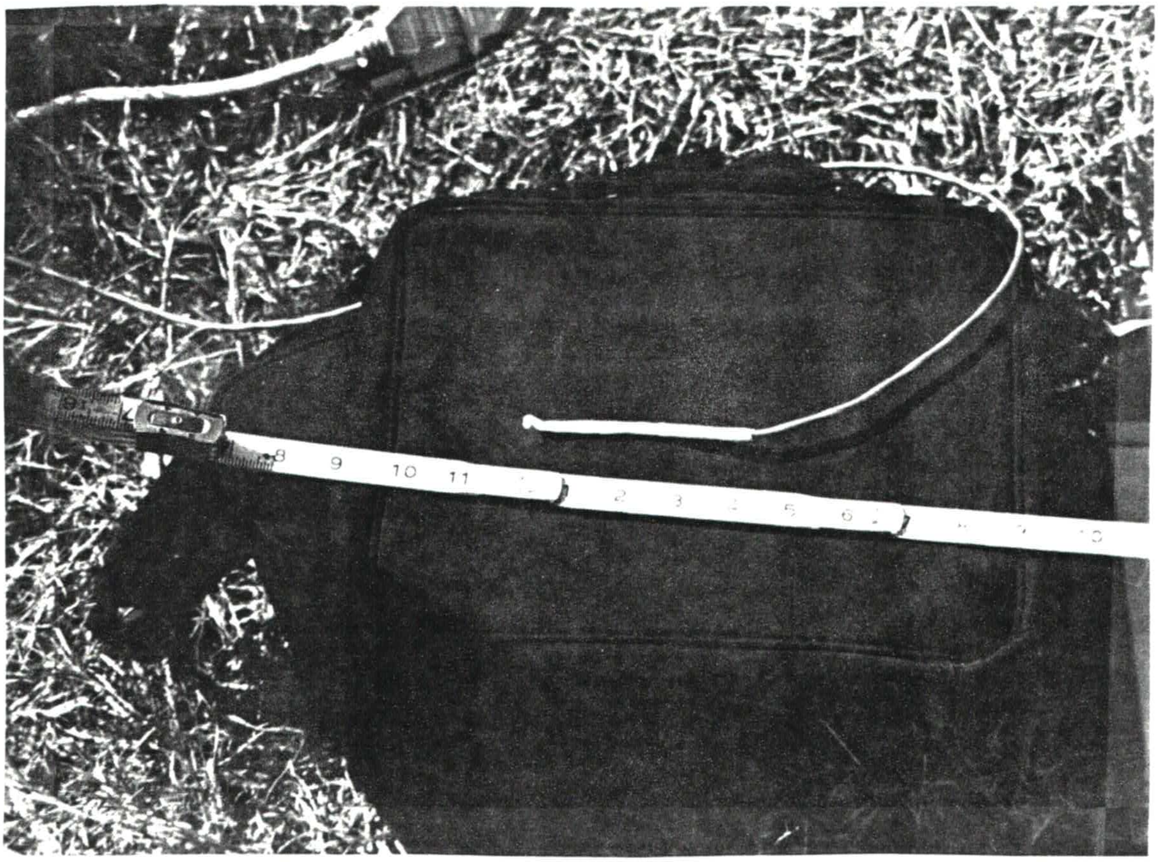

Fig. B-3 Temperature probe

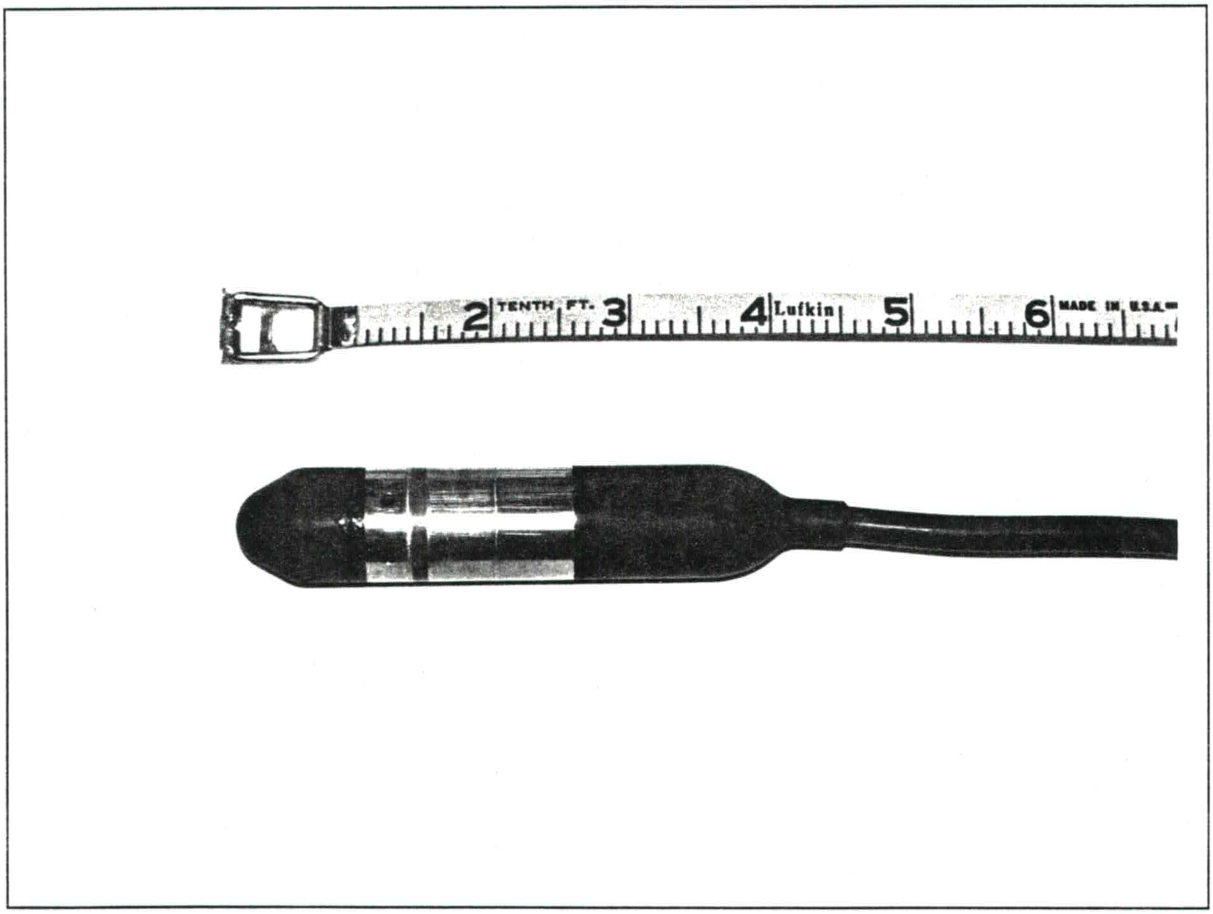

Fig. B-4 Pressure transducers

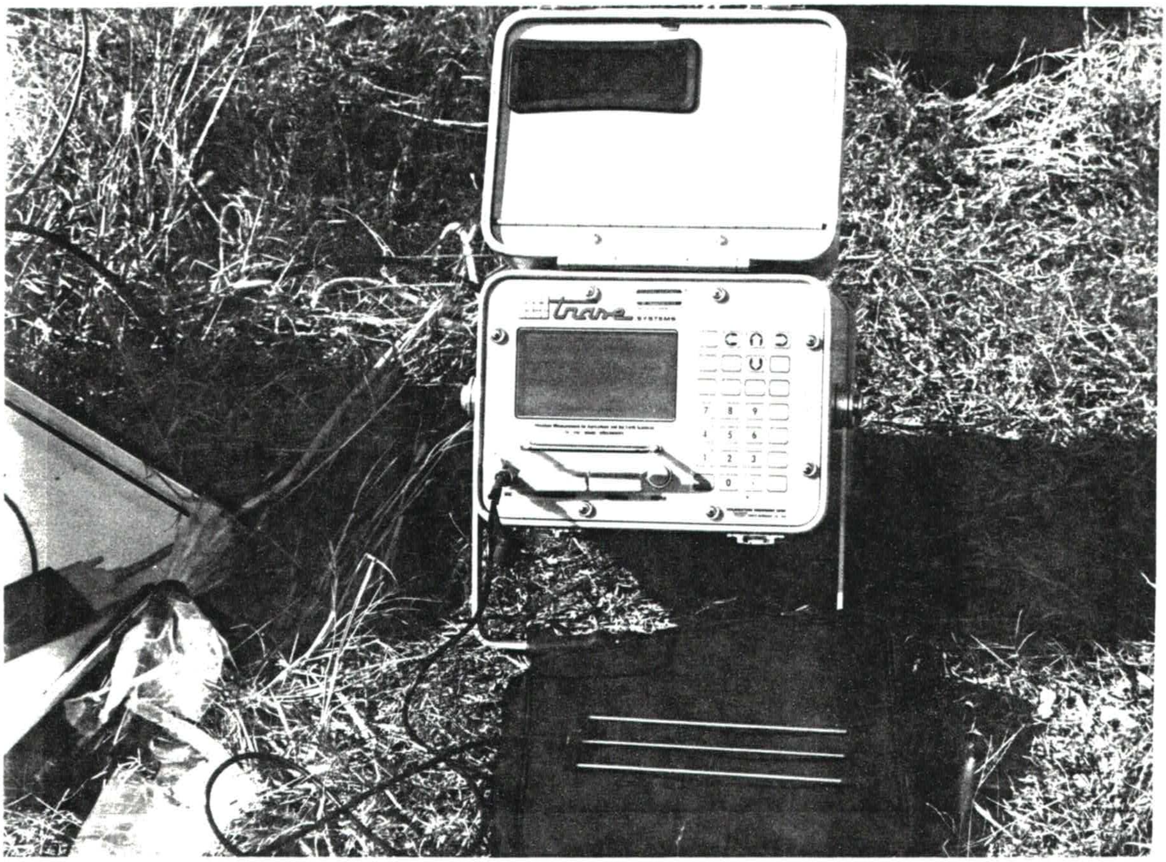

Fig. B-5 TDR moisture device and wave guide

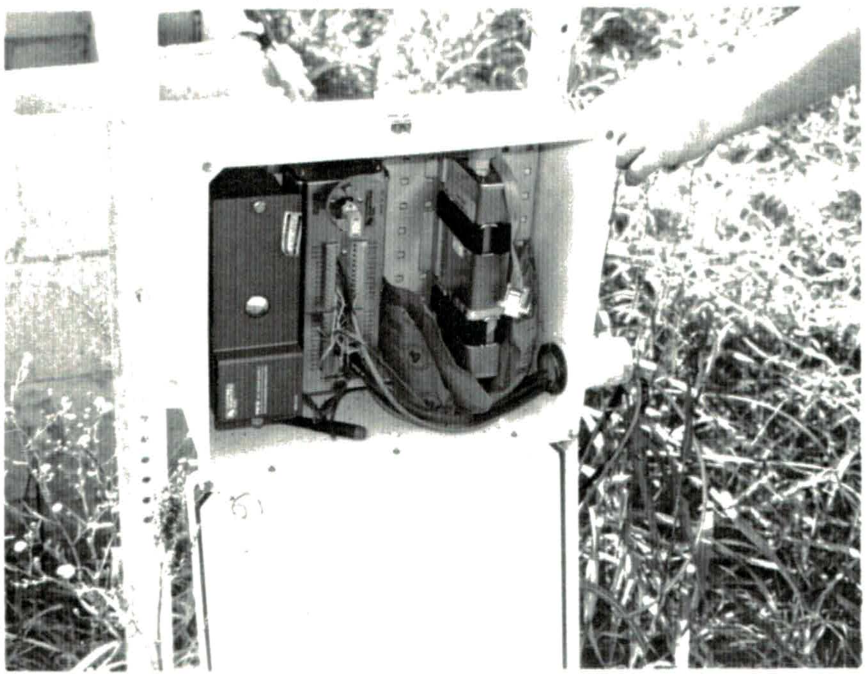

Fig. B-6 Data logger

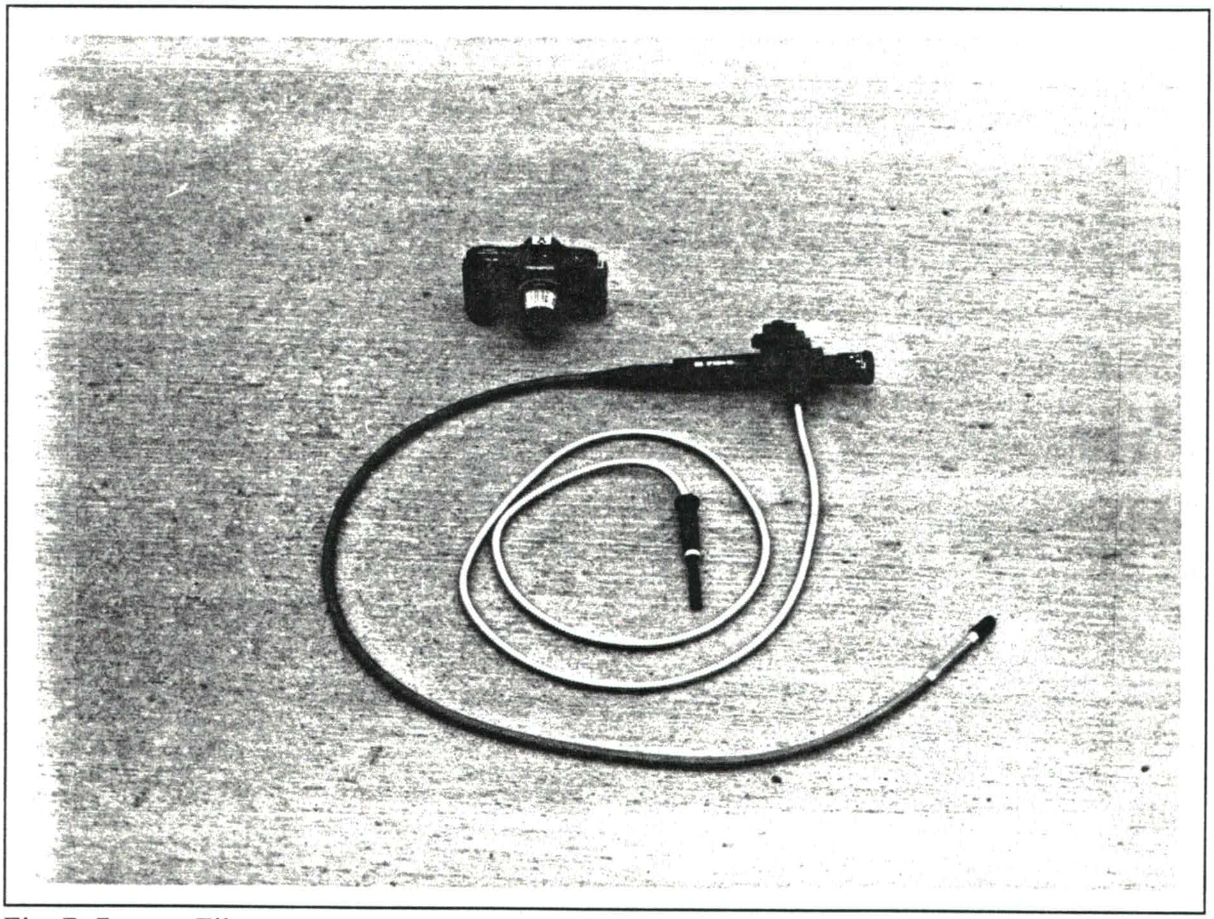

Fig. B-7 Fiberscope

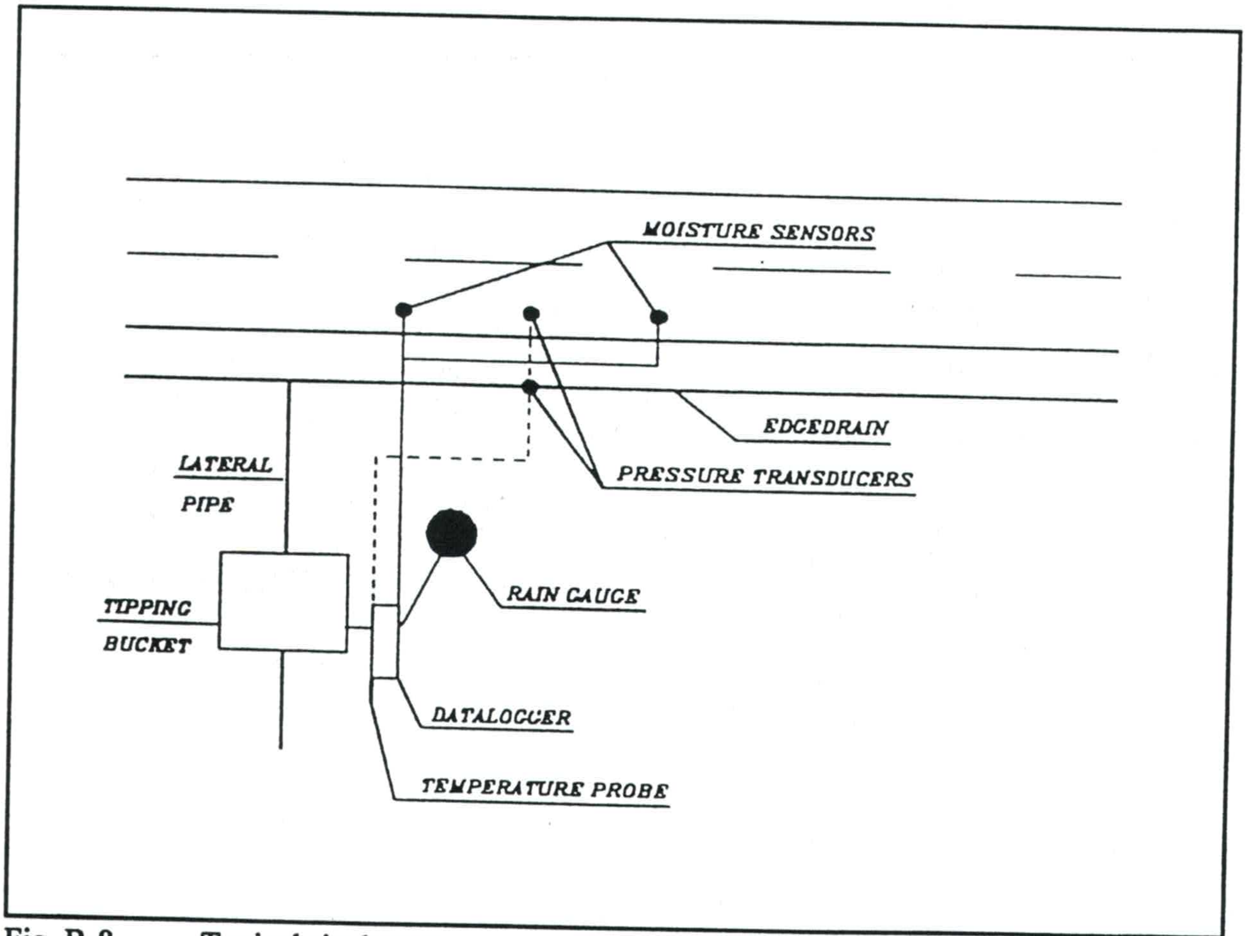

Fig. B-8 Typical site layout

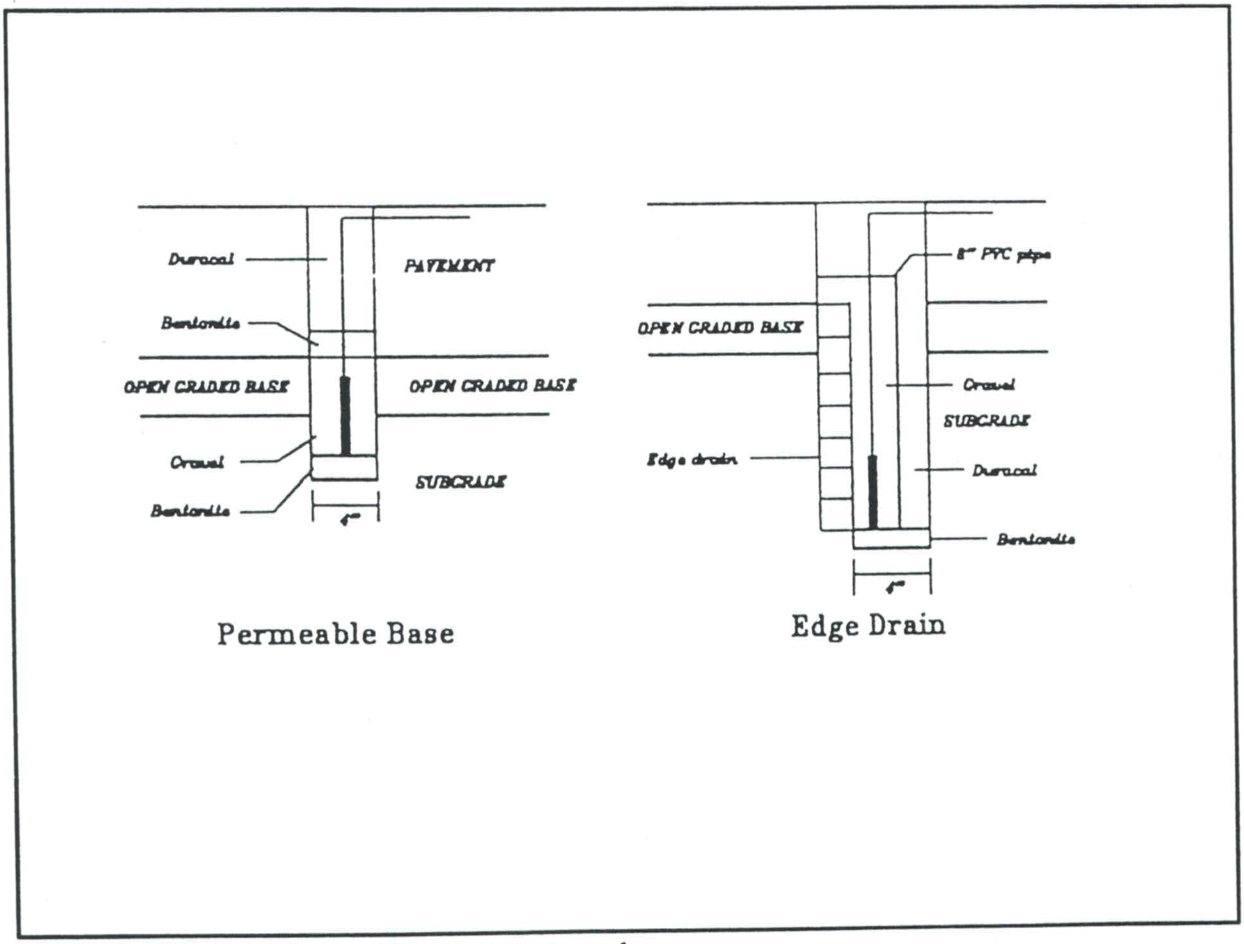

Fig. B-9 Locations of the pressure transducers

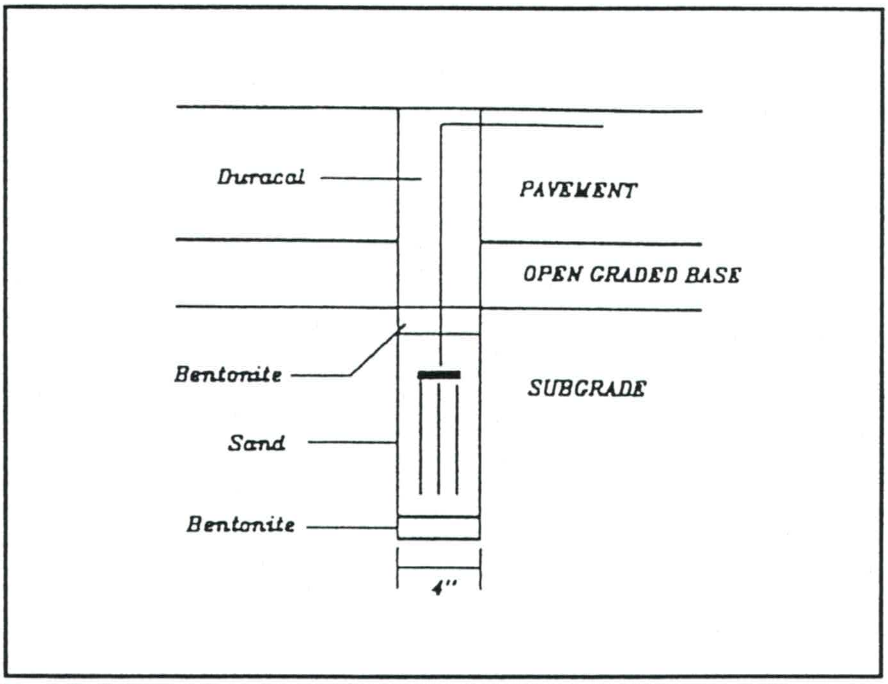

Fig. B-10 Location of TDR soil moisture probe

APPENDIX C

DATA ACQUISITION SYSTEM

C-1 GENERAL

This appendix is designed to enable a person to obtain an introductory understanding of the data acquisition system used by ODOT R & D to acquire information on field performance of drainable bases in Oklahoma. The data acquisition system measures, processes and stores data obtained from different sensors in a suitable format for easy understanding and interpretation. In addition to the sensors, the data acquisition system consists of three basic components: (1) the data logger, (2) the storage module, and (3) PC208 data logger support software. These three items are discussed in this appendix in sections C-2 through C-4. The data logger programming features are discussed in section C-5. A sample program is included in section C-7. Details of the sensors are not discussed in this appendix. It should be noted that this appendix only provides an introductory understanding of the data acquisition system and, therefore, is not a replacement for the Operator's Manual (Ref. 17). Also, it should be noted that this report is a synopsis of information provided by Campbell Scientific, Inc. (CSI) in different manuals, prompt sheets, pamphlets, etc. (Refs. 17 through 22).

C-2 DATA LOGGER

Campbell Scientific, Inc. (CSI) produces different models of data loggers, such as, CR7, CR10, 21X, etc. The CR10 data loggers are used in this project. The CR10 is a fully programmable data logger/controller in a small, rugged, sealed module (Ref. 17, p. OV-1) [see Fig. C-1 (Ref. 22, p. 10)]. The user can access the CR10 with a portable CR10KD

Keyboard Display or with a computer or terminal (Ref. 17, p. OV-7). The user must program the data logger to properly recognize, process and store the output signals sent to it from different sensors connected to it (see section C-4.3 for details) (Ref. 17, p. OV-4).

C-2.1 Powering up the data logger

The CR10 data logger is powered by an external power source (Ref. 17, p. OV-1). It can be powered by any 12 VDC power source. To avoid shorting, the 12 volt lead should be connected first, and then the ground lead should be connected (Ref. 17, p. OV-4). Below 9.6 or above 16 volts the CR10 does not operate properly (Ref. 17, p. OV-20).

C-2.2 Input and output terminals or ports of the data logger

As discussed in the following paragraphs, the data logger electrical configuration is composed of a number of ports or terminals (see Fig. C-2) (Ref. 17, pp. OV-1 to OV-3).

Analog Inputs: Terminals labeled 1H to 6L are analog inputs. These numbers refer to the high and low inputs to the differential channels 1 through 6. In a differential measurement, the voltage H input is measured with respect to the voltage on the L input.

Excitation Outputs: Terminals labeled E1, E2, and E3 are precision, switched excitation outputs used to supply excitation voltages for resistive bridge measurements. The DC or AC excitation voltages measure between -2500 mV and +2500 mV. See section 19 (pressure transducer #1) and section 21 (pressure transducer #2) of the sample program in section C-7 for examples of excitation outputs.

Pulse Inputs: Terminals labeled P1 and P2 are the pulse counter inputs. They are programmable for switch closure, high frequency pulse or low level AC. See section 3 (rain gauge) and section 5 (outflow) of the sample program in section C-7 for examples of pulse inputs.

Analog Ground: Terminals labeled AG are analog grounds used for single-ended measurements and excitation return.

12V and Power Ground : Terminals labeled G are used to supply the 12 VDC power to the data logger.

In the current project, the data loggers are connected to five sensors through the different kinds of terminals discussed above. Names of the different sensors and corresponding setup of the terminals are shown in Table C-1.

C-2.3 Memory allocation of CR10 data logger

The CR10 data logger has 64K RAM divided into five areas (Ref. 17, p. OV-4 and p. 1-5):

Input Storage: Holds the results of measurements or calculations.

Intermediate Storage: Processes operational instructions and processing instructions. The user does not have direct access to this storage area. This is the data logger's "scratch-pad" area for performing intermediate calculations prior to output.

Final Storage: Holds final values here for future transfer to a printer or storage module, or for retrieval via telecommunications links. Values are stored in Final Storage only by the Output Processing Instructions, and only when the Output Flag is set high (a relative term, see sections 1, 4, 6, 13 etc. in the sample program in section C-7 of this appendix for illustration) in the program. There are 29,900 data locations allocated to Final Storage (Ref. 17, p. OV-4).

System Memory: Used for overhead tasks such as compiling programs or transferring data. The user cannot access this memory.

Program Memory: Used for programs entered in program tables.

C-2.4 Data retrieval options

Three general approaches can be used to retrieve data from a data logger (Ref. 17, p. OV-18):

1) Send Final Storage data on-line to a peripheral storage device. On a regular schedule, the data in the storage device is either downloaded on site or the data logger is brought back to the office/laboratory where the data is transferred to the computer.

2) Bring a storage device to the data logger and download all the data that has accumulated in the Final Storage since the last visit.

3) Retrieve the data over some form of telecommunication link, such as telephone, RF, short haul modem, satellite, etc.

C-2.5 Applications of CR10 data loggers

Any sensors with a suitable analog or pulse output can be interfaced to CR10 Data loggers (Ref. 20, p. 4). Some of the sensors offered by CSI measure:

- Barometric pressure
- Leaf wetness
- Net radiation
- Precipitation
- Relative humidity
- Snow depth
- Soil heat flux, moisture, and temperature
- Solar irradiance and quantum flux density
- Water level and quality
- Wind speed and direction

CSI customers have measured many different parameters using their own sensors, including:

• Engine speed	• Weight	• Pressure, load, strain
• Rock stress	• Vibration	• Mechanical displacement
• Rate of corrosion	• Flow	• concentrations of CO, CO_2 etc.

The number of sensors that can be measured by a data logger can be increased by using suitable peripheral devices like Multiplexers (for analog sensors) and SDMs (to expand digital control ports, analog outputs, and data logger measurement capabilities) (for details, see Ref. 20, p. 4).

C-3 STORAGE MODULE

The storage module by CSI provides battery-backed, solid-state, RAM data storage to supplement the storage capacity in a data logger (Ref. 18, p. 1-1). The SM192 model storage module is used in this project. The storage modules can store data from all CSI Data loggers and from other devices which properly enable them (Ref. 18, p. 2-1). The storage module is powered by a 5 VDC received from the data logger or from data retrieval interfaces (Ref. 18, p. 2-6). Memory backup power is provided by an internal 3.5 VDC battery when the storage module is disconnected from a primary power source (Ref. 18, p. 2-7). The storage module has a dimension of 195 mm. x 91 mm. x 37 mm. (7.684 in. x 3.575 in. x 1.450 in.) and weight of 0.70 kg. (1.54 lbs). It uses a Hitachi 6303 processor. The operating temperature range is -35°C to 65°C (-31°F to 95°F) (Ref. 18, p. 2-7).

C-3.1 Memory configurations of the storage module

The SM192 has a CPU card with six 32K RAM chips, providing 192,896 bytes of storage in total. Data is stored in binary format in the storage module. Binary storage for low resolution data [-6999 to +6999 (Ref. 22, p. 14)] uses 2 bytes of memory per data point (Ref. 17, p. 1-5). Therefore, there are 96,000 low resolution data points available in the storage module. High resolution data (-99999 to +99999) requires twice as much space (Ref. 22, p. 14). The storage module's memory can be configured as either "Fill and Stop" (the storage module stops accepting data when its memory is full) or "Ring" (new data continues to be stored [written over oldest data] even after the memory is full, this is the default setting) style memory (Ref. 18, p. 2-4). Depending on the programming strategy, storage of values of one parameter in the storage module can be dependent on or independent of other parameters measured and stored by the same data logger.

C-3.2 Transferring data to and from the storage module

The data logger is programmed to send all or part of data from its Final Storage to a connected storage module. If no storage module is connected then the data will be "queued up" in the data logger's Final Storage until the storage module is connected (Ref. 22, p. 13). Up to eight storage modules can be connected to a single CR10 data logger and data can be sent from the data logger to any one or more than one of them at the same time (Ref. 18, p. 3-1). A storage module can be connected to a computer or a terminal directly or via a data logger to facilitate transfer of data from the storage module to the computer. The simplest method of retrieving data from the storage module is to use the SMCOM program supplied by CSI with the PC208 data logger support software.

C-4 PC208 DATA LOGGER SUPPORT SOFTWARE

The PC208 software is provided by CSI in three 5¼ in. floppy diskettes (Ref. 19, p. 1-1). It is useful in using and customizing the CSI Data loggers to meet specific individual needs.

C-4.1 Hardware and software requirements

The following computer resources are necessary to implement the PC208 software (Ref. 19, p. 1-1):

1) IBM PC, XT, AT, Portable or hardware compatible PC.
2) Minimum 256 K bytes of RAM.
3) PC-DOS version 2.0 or greater (or equivalent).

The software will also run on a Macintosh computer under Insignia Solutions SoftPC (Version 1.3).

C-4.2 Installation

The software needs to be installed before it can be used. The user needs to insert diskette 1 into an appropriate floppy disk drive, type "INSTALL" and press the *enter* key (Ref. 19, p. 1-2). The installation should start. The user can install the program in any drive or path, provided an appropriate directory is created first. For example, to install the software in C:\PC208 directory, the directory named PC208 must be created prior to installation.

C-4.3 PC208 programs

The software package consists of six separate programs. They are described below [after reference (Ref. 19, p. 1-2)]:

1) **Editor (EDLOG):** Used to develop and document programs for the CR10 and other Data loggers.

2) **Terminal Emulator (TERM):** Establishes communication between external computer and data logger for real time display of data and downloading/uploading of data logger programs or data.

3) **Data Split (SPLIT):** Processes selected data from a data file or several files and combines the data into a report file.

4) **Telecommunications (TELCOM):** Retrieves data from data logger over the phone and hardware interfaces.

5) **Storage module Communications (SMCOM):** Provides communication link between storage module and data logger.

6) **Wake up Time (WAKETIME):** It is used to set the date and time for the PC201 card to wake up the computer to run TELCOM and collect data.

Default extension names are assigned to files generated by the PC208 software. Table C-2 summarizes these extensions [after reference (Ref. 19, p. 1-1 {2nd})].

C-5 PROGRAMMING THE DATA LOGGER

The users need to write their own programs to customize the data logger for intended, specific applications (Ref. 17, p. OV-4). These programs then need to be loaded on to the data logger before starting the data collection operation. Without these user-written programs, the data logger is like a PC without DOS installed in it.

C-5.1 Terminology

1) **Program Table:** It consists of a group of instruction codes which are to be executed. Programs are entered in Tables 1 and 2. Subroutines called from either of those two Tables are entered in subroutine Table 3 (Ref. 17, p. OV-6). See attached program in section C-7 for example.

2) **Execution Interval:** Determines how frequently the Program is executed (Ref. 17, p. OV-6). The time interval at which the table is executed determines how often data

is to be collected. It does not indicate how often the data is stored permanently in the storage module. See attached program in section C-7, for example.

3) **Output Interval:** Time interval at which data is permanently stored in the storage module (Ref. 17, p. OV-7). Its occurrence is independent of the execution interval. It must occur when the table is executed. A single program table can have many different output intervals and conditions, each with a unique output array. For example, rainfall and outflow values are recorded every two minutes at certain conditions whereas the temperature and pressure values are always recorded every thirty minutes by the sample program presented at the end of this appendix. See program sections 1, 8, 13, 17, 26, 27 of attached program in section C-7 of this appendix for illustration.

C-5.2 Instruction codes (programming tips)

The data logger programs consist of a series of instructions which perform measurement, data processing, data storage, and logical control functions (Ref. 22, p. 8). Instructions are identified by an instruction number. Each instruction has a number of parameters that give the CR10 the information it needs to execute the instruction (Ref. 17, p. OV-10). There are a variety of instruction codes available. For example: (1) input/output instructions, (2) processing instructions (such as: z=sqrt(x) and so on), (3) output instructions (such as: standard deviation, histogram, etc.) (4) program control instructions (IF, DO etc.). A complete list of the instruction codes can be found in reference (Ref. 17, "prompt sheet"). Some of the instruction codes used in the attached program are discussed below [after reference (Ref. 17, "prompt sheet")].

P92: Sets Output Processing Time.

P77: Sets real time format.

P3: Activates pulse.

P89: Defines numerical range for data storage in storage module.

P91: Do statement: if flag is set high, the instructions following this statement will be executed.

P6: Activates a full wheatstone bridge for measurement of electrical potential.

P71: Takes average of corresponding data.

P11: Activates temperature probe.

P70: Reads data.

P96: Designates type of data storage module.

C-5.3 Creating a new program or editing an existing program

A program is created by entering it directly into the data logger or on a computer using the PC208 data logger support software program EDLOG (Ref. 17, p. OV-9). The procedure is discussed below in a stepwise manner.

Step 1: Start EDLOG. Starting any of the PC208 programs needs a little discussion and clarification here. ODOT R&D uses a Compaq laptop PC for creating, modifying and installing the data logger programs. This PC has a menu driven environment created by a software called FDO. One can start EDLOG (or any other PC208 program) by using these menus or from DOS, as discussed below.

Starting EDLOG in ODOT R&D Compaq Laptop Computer:

1) First switch on the computer. Enter/confirm date and time. The user will see the "main menu" of the computer (Fig. C-3).

2) Press 5 to enter PC208 data logger support software environment. The user will see the "PC208 data logger menu" (Fig. C-4).

3) The user can start any of the PC208 data logger support system programs by pressing the number corresponding to that program. The user must press 1 to start EDLOG program.

Starting EDLOG from DOS Command Prompt:

This section assumes that the user has preliminary knowledge on MS-DOS. The user can start any of the PC208 data logger support system programs by typing in the program name at the command prompt and then pressing the *enter* key. The user may need to define the appropriate path for the location (directory) of the PC208 programs in the PC. Alternatively, the user may change the directory to the appropriate directory and then issue the command. For example, if the PC208 programs in the PC are installed in the directory named 'PC208', then the following sequence of commands can be used:

C:\> cd PC208 (press *enter* key)

C:\pc208> EDLOG (press *enter* key)

Step 2: The user will see a screen like the one shown in Fig. C-5. Type in the .DOC file name and press *enter* key.

Step 3: The user will see a screen like the one shown in Fig. C-6. Type in the data logger type (CR10 for this project) and press *enter* key.

Step 4: The user will see a screen like as that shown in Fig. C-7. The user can write the program in this file. The environment is quite user-friendly with helpful menus.

Step 5: When the user is done and wants to save and quit the program, press the *F2* key to start the *'File'* menu.

Step 6: At this stage, the user will see a screen like the one shown in Fig. C-8. The user can save the program now by pressing the letter 'S' and giving the file name (see Fig. C-9). After saving the program, the user can quit the program by pressing the letter 'Q.'

C-5.4 Loading a program on to the data logger and testing it

Programs can be entered into the CR10 in one of three ways (Ref. 17, p. OV-11). The simplest one within the ODOT's current resources is by storing the program in a disk and sending it to the CR10 from a computer (using PC208 programs EDLOG and TERM). The procedure is discussed below. As the steps are quite straight forward and the process for selecting options from the menus is very similar to that discussed in section C-4.3 above, no additional figures of the screens are shown in this appendix.

Step 1: Start PC208 data logger support software program TERM. For tips on how to start TERM, see step 1 of section C-4.3.

Step 2: Type in the station (county) name and press the *enter* key.

Step 3: Press 'D' to download program to data logger.

Step 4: Type the program name (such as FIELD) and press the *enter* key.

Step 5: When the program is completely downloaded press the *esc* key to return to

TERM menu. Error codes will appear at this point if there is a problem with syntax or logic. See back of CR10 Prompt Sheet in Ref. 17 for error codes.

Step 6: Press 'M' for monitor screen (to view data as it is recorded).

Step 7: Tip rain gauge and outflow tipping bucket (monitor should show readings). In order to test the program in the office, the user does not actually need a rain gauge or a outflow tipping bucket. The user can simulate the tips by pressing a toggle switch properly connected to the appropriate terminal. To connect the toggle switches correctly, see section C-2.2 of this appendix.

Step 8: Run test (1) by tipping the rain gage and/or outflow tipping bucket or (2) by clicking the toggle switches 'X' amount of times over a given time period. After the test is done, retrieve the data (section C-6.1) and check (section C-6.2) if the data is recorded correctly as it was entered.

C-6 DATA RETRIEVAL

After the data logger collects the data for a desirable time period, it is necessary to transfer the data from the data logger to a computer. Usually, it is a good idea to verify that the data is transferred properly to check against any data loss. At the same time, the storage module memory should also be cleared to prevent exhausting the memory which would lead to data overwriting of data in the storage module. The procedure is discussed in detail in the following sub-sections.

C-6.1 Downloading data from the storage module to computer

Step 1: Connect the SC32A interface to the data logger (see Fig. C-10).

Step 2: Connect interface to coaxial cable (female with 25 pins).

Step 3: Connect coaxial cable to computer (female with 25 pins).

Step 4: Start the PC208 data logger support software program SMCOM. For tips on how to start SMCOM, see step 1 of section C-4.3 of this appendix.

Step 5: Press '1' to select COM1.

Step 6: Press 'N' for SMCOM menu.

Step 7: Press 'A' to collect all data files.

Step 8: Specify a file name and press the *Enter* key.

Step 9: Press 'C' to save data in comma delineated ASCII arrays. This is necessary for office maintenance of the data.

Step 10: Press 'Q' to quit.

C-6.2 Confirming and viewing data

Step 1: (Start the laptop computer. Exit to DOS. If the user is unable to do so, someone familiar with DOS and the menus of the operating environment of the laptop computer should be reported to.)

Step 2: Type 'cd pc208' and press the *enter* key.

Step 3: Type 'dir/w' and press the *enter* key.

Step 4: Confirm file name. If the file name does not appear, the problem should be reported to someone knowledgeable in DOS.

Step 5: Type 'type *filename.dat*' or 'type *filename.dat* | more' and press the *enter* key.

Step 6: View data.

C-6.3 Clearing the storage module memory

Step 1: Start the PC208 data logger support software program SMCOM. For tips on how to start SMCOM, see step 1 of section C-4.3 of this appendix.

Step 2: Press '1' to select COM1.

Step 3: Press 'N' for SMCOM menu.

Step 4: Press 'C' to clear data.

Step 5: Press 'Y' to confirm.

Step 6: Press 'Q' to quit.

C-7 SAMPLE PROGRAM

A program is written to customize the CR10 data logger being used by ODOT R&D for the field evaluation of drainable bases of pavements in Oklahoma. The data logger is installed at the Noble county site. It is connected with a rain gauge, an outflow tipping bucket that measures the amount of water that is discharged through the particular outlet pipe, a temperature probe, and two pressure transducers. This program is written with a view to collect and store data in the most efficient manner possible. For example, it stores the rainfall and outflow values every two minutes only if there was a rainfall or outflow during the two minutes immediately before the time when the data logger checks for them. It records temperature and pressure values every thirty minutes. It records the year and day at midnight.

The program is composed of twenty-eight sections. Each section starts with the section number followed by the characters ": Pn", where n is an integer and "Pn" indicates the instruction code for that section. For example, section two of this program starts with the following: "02: P77". The program is explained in the following pages.

```
Program:NOBLE TEST9
Flag Usage:
Input Channel Usage:
Excitation Channel Usage:
Control Port Usage:
Pulse Input Channel Usage:
Output Array Definitions:
```

```
*      1         Table 1 Programs
  01: 60         Sec. Execution Interval
```

Time interval to execute program.

```
01:  P92         If time is
  01: 0          minutes into a
  02: 1440       minute interval
  03: 10         Set high Flag 0 (output)
```

Section One: Sets time interval to 24 hours for next instruction code P77.

```
02:  P77         Real Time
  01: 1120       Year,Day,Hour-Minute
```

Section Two: Records real time every 24 hours in storage device.

```
03:  P3          Pulse
  01: 1          Rep
  02: 1          Pulse Input Chan
  03: 2          Switch closure
  04: 2          Loc [:rain gage]
  05: .01        Mult
  06: 0          Offset
```

Section Three: Activates rain gauge and defines appropriate channel, switch closure input location, multiplying factor, etc.

```
04:  P89         If X<=>F
  01: 2          X Loc rain gage
  02: 3          >=
  03: .01        F
  04: 11         Set high Flag 1
```

Section Four: Logic statement which allows rainfall data values only ≥0.01 in. to be recorded in storage device by setting high Flag 1.

```
05:  P3          Pulse
  01: 1          Rep
  02: 2          Pulse Input Chan
  03: 2          Switch closure
  04: 3          Loc [:outflow  ]
  05: .5         Mult
  06: 0          Offset
```

Section Five: Activates outflow tipping bucket sensor and defines appropriate channel, switch closure input location, multiplying factor, etc.

```
06:  P89         If X<=>F
  01: 3          X Loc outflow
  02: 3          >=
  03: .5         F
  04: 12         Set high Flag 2
```

Section Six: Logic statement which allows outflow data values only ≥0.50 gal. to be recorded in storage device by setting high Flag 1.

```
07:  P91         If Flag/Port
  01: 11         Do if flag 1 is high
  02: 30         Then Do
```

Section Seven: Logic statement which checks if Flag 1 is high. If so, then the subroutine defined by next three instruction codes (P92, P77, and P95) will be executed.

```
08:  P92         If time is
  01: 0          minutes into a
  02: 2          minute interval
  03: 10         Set high Flag 0 (output)
```

Section Eight: Sets time interval to 2 minutes for P72 instruction code. The amount recorded in this 2 minutes will be totalized and stored in storage device.

09: P77 01: 0010	Real Time Hour-Minute	**Section Nine:** Records the time (hour and minute) when the data values were totalized.
10: P72 01: 1 02: 2	Totalize Rep Loc rain gage	**Section Ten:** Totalizes the amount of rain recorded every two minutes if Flag 0 is high.
11: P95	End	**Section Eleven:** Ends the subroutine.
12: P91 01: 12 02: 30	If Flag/Port Do if flag 2 is high Then Do	**Section Twelve:** Logic statement which checks if Flag 2 is high. If so, then the subroutine defined by next three instruction codes (P92, P77, and P95) will be executed.
13: P92 01: 0 02: 2 03: 10	If time is minutes into a minute interval Set high Flag 0 (output)	**Section Thirteen:** Sets time interval to 2 minutes for P72 instruction code. The amount recorded in this 2 minutes will be totalized and stored in storage device.
14: P77 01: 0010	Real Time Hour-Minute	**Section Fourteen:** Records the time (hour and minute) when the data values were totalized.
15: P72 01: 1 02: 3	Totalize Rep Loc outflow	**Section Fifteen:** Totalizes the amount of Outflow recorded every two minutes if Flag 0 is high.
16: P95	End	**Section Sixteen:** Ends the subroutine.
17: P92 01: 0 02: 30 03: 10	If time is minutes into a minute interval Set high Flag 0 (output)	**Section Seventeen:** Sets time interval to 30 minutes for P72 instruction code. Temperature, P1 and P2 will be recorded every thirty minutes.
18: P77 01: 0010	Real Time Hour-Minute	**Section Eighteen:** Records the time (hour and minute) of the data values.
19: P6 01: 1 02: 3 03: 2 04: 2 05: 2500 06: 4 07: 0.997 08: .017	Full Bridge Rep 25 mV slow Range IN Chan Excite all reps w/EXchan 2 mV Excitation Loc [:PSIg #1] Mult Offset	**Section Nineteen:** Activates full Wheatstone Bridge for pressure transducer #1. Defines range of voltage, channel, amount of potential applied, input location, multiplying factor, and other required parameters.
20: P71 01: 1 02: 4	Average Rep Loc PSIg #1	**Section Twenty:** Calculates average of data values. These average values are stored every thirty minutes.

21: P6 Full Bridge 01: 1 Rep 02: 3 25 mV slow Range 03: 3 IN Chan 04: 3 Excite all reps w/EXchan 3 05: 2500 mV Excitation 06: 5 Loc [:PSIg #2] 07: 1.002 Mult 08: .019 Offset	**Section Twenty-one:** Activates full Wheatstone Bridge for pressure transducer #2. Defines range of voltage, channel, amount of potential applied, input location, multiplying factor, and other required parameters.
22: P71 Average 01: 1 Rep 02: 5 Loc PSIg #2	**Section Twenty-two:** Calculates average of data values. These average values are stored every thirty minutes.
23: P11 Temp 107 Probe 01: 1 Rep 02: 1 IN Chan 03: 1 Excite all reps w/EXchan 1 04: 1 Loc [:Temp] 05: 1 Mult 06: 0.0000 Offset	**Section Twenty-three:** Activates temperature probe sensor and defines appropriate channel, excitation, number of repetitions, etc.
24: P70 Sample 01: 1 Reps 02: 1 Loc Temp	**Section Twenty-four:** Activates temperature probe.
25: P96 Serial Output 01: 71 SM192/SM716	**Section Twenty-five:** Indicates type of storage module.
26: P92 If time is 01: 0 minutes into a 02: 2 minute interval 03: 21 Set low Flag 1	**Section Twenty-six:** Sets Flag 1 low every two minutes to prevent continuous storage of rainfall data in the storage module.
27: P92 If time is 01: 0 minutes into a 02: 2 minute interval 03: 22 Set low Flag 2	**Section Twenty-seven:** Sets Flag 2 low every two minutes to prevent continuous storage of outflow data in the storage module.
28: P End Table 1	**Section Twenty-eight:** Ends Table 1.
* 2 Table 2 Programs 01: 0.0000 Sec. Execution Interval	Mode 2 - indicates program table - 2. It Can have separate execution blocks with separate execution interval (different from that in Table -1).
01: P End Table 2	Ends Table 2.
* 3 Table 3 Subroutines	Mode 3 - indicates program table - 3. Used for the subroutines (if any).
01: P End Table 3	Ends Table 3.

```
*       A          Mode 10 Memory Allocation
  01: 28           Input Locations
  02: 64           Intermediate Locations
  03: 0.0000       Final Storage Area 2
```

Functional mode A - defines storage allocations for the CR10 data logger.

```
Page 4    Mode C

*     C          Mode 12 Security
  01: 0000         LOCK 1
  02: 0000         LOCK 2
  03: 0000         LOCK 3
```

Functional mode C provides a four digit security code to lock or unlock the respective functional modes of the program. This program has no codes, ie, all zeros indicates all functional modes are unlocked.

```
Page 5     Input Location Assignments (with comments):

  Key:
  T=Table Number
  E=Entry Number
  L=Location Number

  T:  E:  L:
  1: 23:  1:  Loc [:Temp      ]
  1:  3:  2:  Loc [:rain gage]
  1:  5:  3:  Loc [:outflow   ]
  1: 19:  4:  Loc [:PSIg #1   ]
  1: 21:  5:  Loc [:PSIg #2   ]
```

Input location assignments are necessary for programming reference. This program includes five data variable each of which has an independent location assignment for storage purposes.

```
Page 6     Input Location Labels:

 1:Temp          3:outflow     5:PSIg #2     7:________
 2:rain gage     4:PSIg #1     6:________    8:________
```

Input location tables are a reference for programming purposes

C-8 CONCLUDING REMARKS

The data acquisition system used by ODOT R&D for the measurement of on-site data in Project 2181 is described briefly in the preceding sections. A preliminary introduction to the CSI equipment used for the data acquisition system is provided in a concise form. Efforts have been made to give the reader an idea about different components of the system, functions performed by them, and how they perform and interact. The reader needs to consult the actual manuals and other materials provided by CSI to obtain detailed, technical information on the subject.

Table C-1 Current setup of terminals

Sensor Name	**Color of wire**	**Terminal Identification**
Temperature Probe	Black	E1
	Purple	AG
	Clear	G
	Red	1H
Rain Gauge	Red	P1
	Black	G
Outflow Tipping Bucket	Red	P2
	Black	G
Pressure Transducer (Edge Drain)	Red	E2
	White	G
	Yellow	2H
	Blue	2L
Pressure Transducer (Base)	Red	E3
	White	G
	Yellow	3H
	Blue	3L

Table C-2 File types used with PC208 software

Extension Type	Mnemonic of Extension	Software that Generated File	Description / Uses
.DAT	raw DATa	TELCOM, SMCOM	Data as received from data logger. Format can be ASCII, or Final Storage Format.
.STN	STatioN parameter	TELCOM, TERM	Parameters necessary to call data logger.
.ERR	ERRor log file	TELCOM	Record of communication errors. ASCII file.
.CQR	Communication Quality Report	TELCOM	Record of communication quality from RF Modem shut down blocks. ASCII file.
.DOC	data logger program DOCumentation	EDLOG	Documentation of data logger program.
.DLD	DownLoaD program to data logger	EDLOG, TERM	EDLOG generates this down-loadable file. TERM also uses extension when saving program from data logger. Can also be fed into EDLOG to develop .DOC file.
.LIB	LIBrary file	EDLOG	Contains group of program instructions.
.PDF	Printable Document File	EDLOG	Produced by EDLOG for subsequent printing or use in a standard text editor.
.RPT	data RePorT file	SPLIT	Produced by SPLIT for subsequent printing or use in a standard text editor.
.PRN	PRiNtable data file	SPLIT	Produced by SPLIT for subsequent use by LOTUS or other spreadsheet programs.
.PAR	PARameter file	SPLIT	Contains parameters used by SPLIT for data selection and processing.
.OBJ	OBJect file	TERM	Code for PROM from TERM create Power-up option.

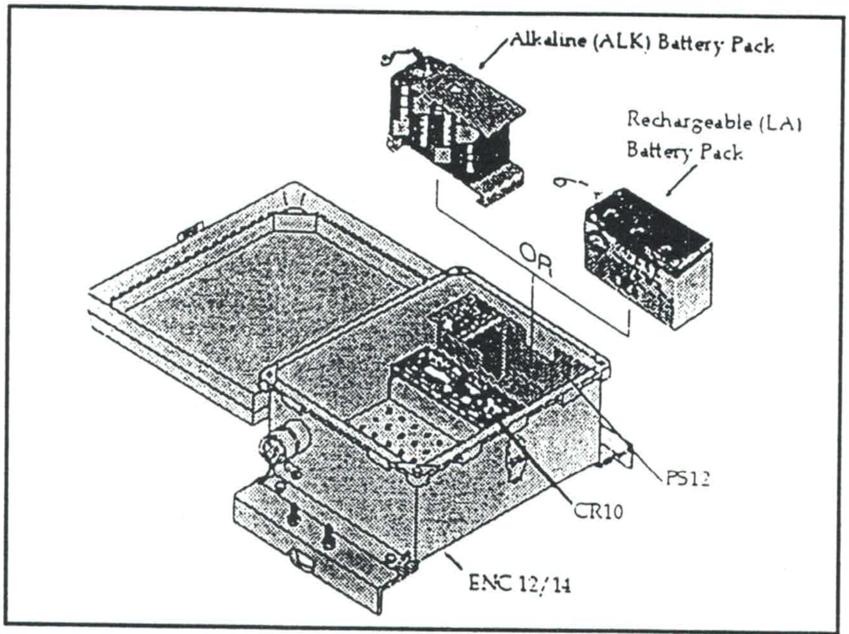

Fig. C-1 The data logger

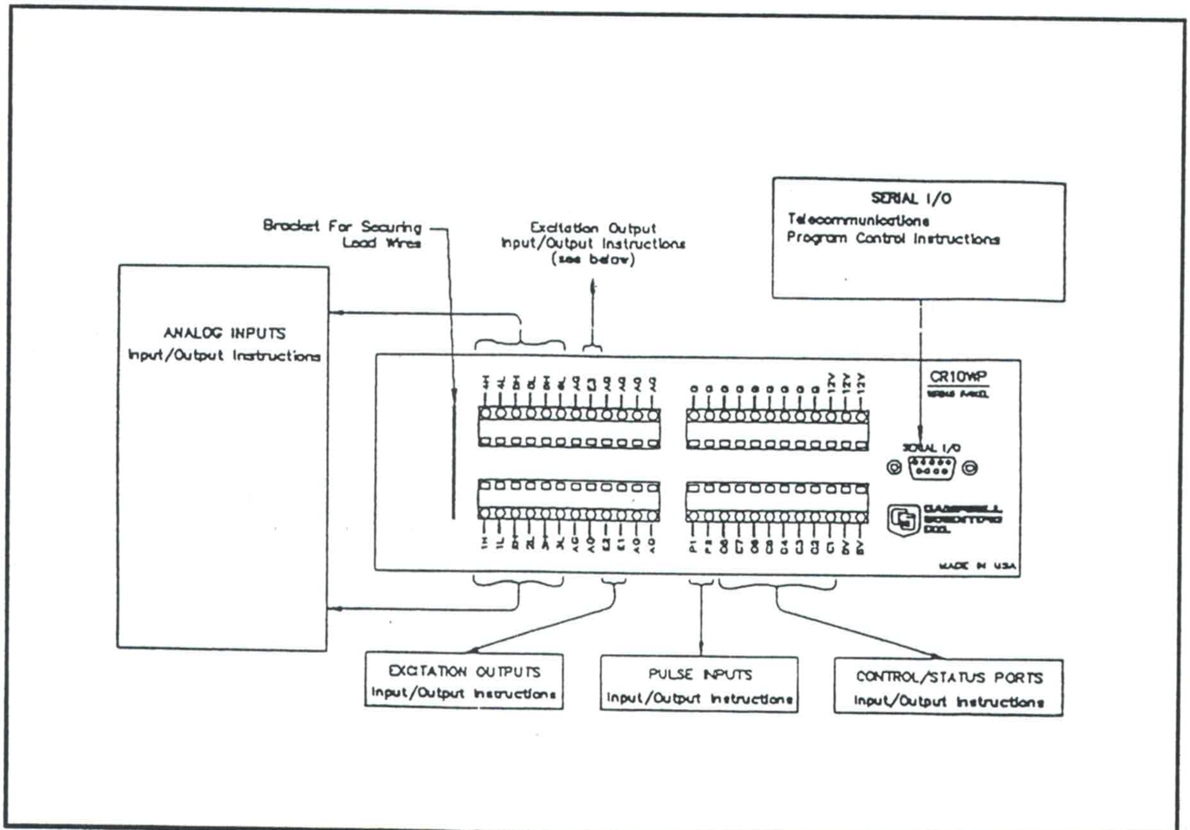

Fig. C-2 CR10 wiring panel / instruction access

ODOT RESEARCH DIVISION

Date: 09-15-1995
Time: 08:42:30

Page 1 of 2
Version 1.00

1. Lotus 1-2-3 R. 3.1
2. ProComm
3. DOS Commands
4. Exit to DOS
5. PC208 Datalogger
6. dBASE IV

↑or↓ point to option ENTER select option	F1 Help F7 Quit F9 Menu Maintenance PgDn Next page

Fig. C-3 Main menu of the Compaq laptop computer at ODOT R&D

PC208 Datalogger

Date: 09-15-1995
Time: 08:45:09

Page 1 of 2
Version 1.00

1. EDLOG
2. TERM
3. SPLIT
4. TELCOM
5. SMCOM

↑or↓ point to option ENTER select option	F1 Help Esc Previous menu F7 Quit F9 Menu Maintenance PgDn Next page

Fig. C-4 PC208 data logger menu

```
.DOC file name:_
──────────EDLOG  Ver 5.1────────────────────────────────────
```

Fig. C-5 EDLOG prompt for .DOC file name

```
Enter Datalogger Type (CR10, 21X, CR7):
──────────EDLOG  Ver 5.1───────MIAMI.DOC────────────────────
```

Fig. C-6 EDLOG prompt for data logger type

```
F1=Help F2=File Commands F3=Edit Functions F4=GoTo
23 lines.
══════════EDLOG CR10 Ver 5.1═══MIAMI.DOC══════════════════
>Program:
>Flag Usage:
>Input Channel Usage:
>Excitation Channel Usage:
>Control Port Usage:
>Pulse Input Channel Usage:
>Output Array Definitions:

*      1        Table 1 Programs
  01: 0.0000    Sec. Execution Interval

01:   P         End Table 1

*      2        Table 2 Programs
  01: 0.0000    Sec. Execution Interval

01:   P         End Table 2

*      3        Table 3 Subroutines
```

Fig. C-7 View of file newly created and opened with EDLOG

```
Quit    Edit    Save    Print    Load new .DOC file    Document .DLD file

============EDLOG CR10 Ver 5.1=====MIAMI.DOC================================
>Program:
>Flag Usage:
>Input Channel Usage:
>Excitation Channel Usage:
>Control Port Usage:
>Pulse Input Channel Usage:
>Output Array Definitions:

 *      1        Table 1 Programs
   01: 0.0000    Sec. Execution Interval

 01:   P         End Table 1

 *      2        Table 2 Programs
   01: 0.0000    Sec. Execution Interval

 01:   P         End Table 2

 *      3        Table 3 Subroutines
```

Fig. C-8 View of file opened with EDLOG after *F2* key has been pressed

```
Quit    Edit    Save    Print    Load new .DOC file    Document .DLD file
Name of file to save : _
============EDLOG CR10 Ver 5.1=====MIAMI.DOC================================
>Program:
>Flag Usage:
>Input Channel Usage:
>Excitation Channel Usage:
>Control Port Usage:
>Pulse Input Channel Usage:
>Output Array Definitions:

 *      1        Table 1 Programs
   01: 0.0000    Sec. Execution Interval

 01:   P         End Table 1

 *      2        Table 2 Programs
   01: 0.0000    Sec. Execution Interval

 01:   P         End Table 2

 *      3        Table 3 Subroutines
```

Fig. C-9 View of file opened with EDLOG : prompt for name of file to be saved

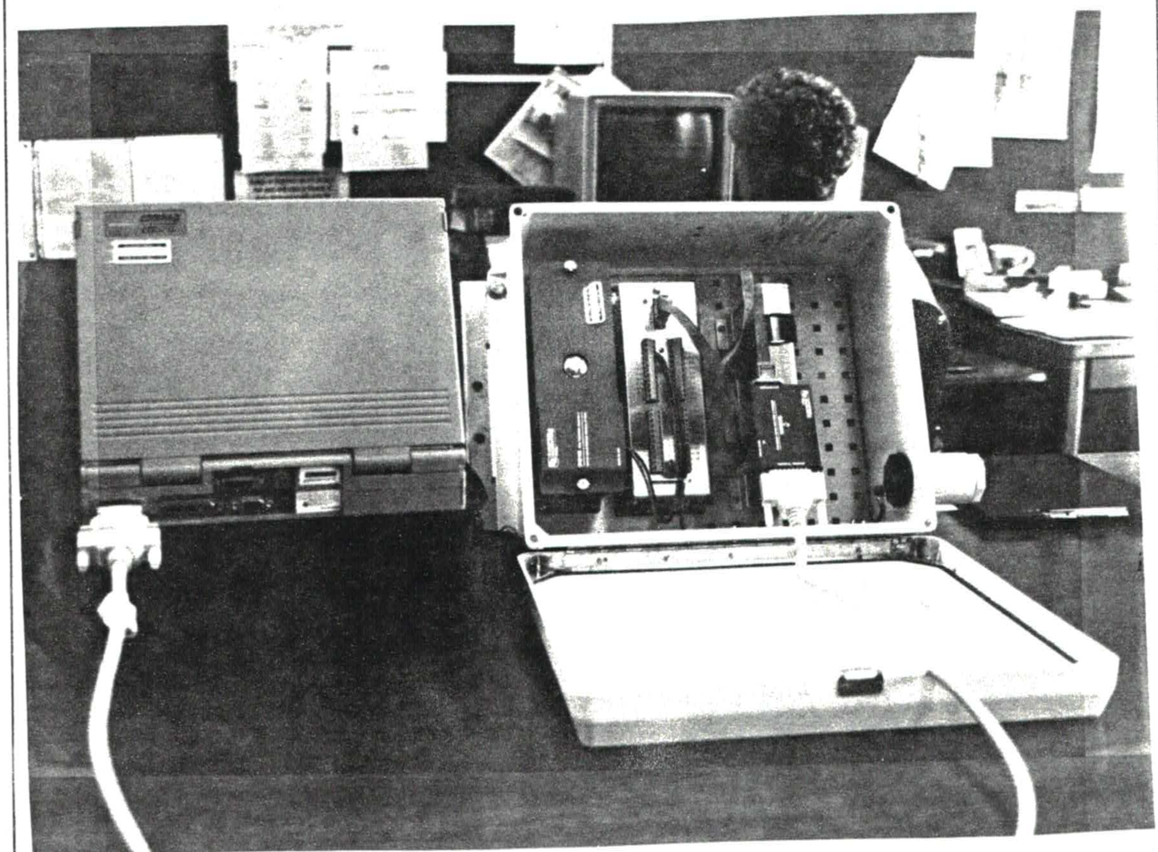

Fig. C-10 Connection between the data logger and the laptop computer

PROCEDURES RELATED TO DATA RETRIEVAL

D-1 GENERAL

The procedures for writing a data collection program, installing such programs on the data logger and testing the same, etc. are discussed in Appendix C. The procedures related to data retrieval from the data loggers in the field are discussed in this appendix. The following three steps have already been discussed in Appendix C are same as that discussed in Appendix C (sections C-6.1, C-6.2 and C-6.3): (1) downloading data from the Storage Module to computer, (2) confirming and viewing data and (3) clearing the storage module memory. Other steps are discussed in the following sections.

D-2 TESTING EQUIPMENT

Once the data have been downloaded to the portable computer (section C-6.1) and confirmed (section C-6.2), it is necessary to test the different sensors and equipment to ensure that they are working properly. A program named FIELD is used for this purpose. This program records data every 10 seconds to facilitate a rapid testing of any equipment problems. The steps of this procedure are discussed below (after Ref. 15).

<u>Steps 1-6:</u> These steps are the same as the Steps 1-6 of section C-5.4 in Appendix C.

<u>Step 7:</u> Tip the rain gage and the outflow tipping bucket manually. The monitor should show the corresponding data if all the equipment function properly. If the data corresponding to a particular sensor is not appropriately shown on the monitor then that equipment probably needs servicing. Perform the servicing needed and repeat steps 1-7.

Step 8: After the testing is done, press the *esc* key.

Step 9: Type the station or county name (e.g., Noble) and press the *enter* key to load the regular data collection program on the data logger again.

Step 10: After the program is loaded on the data logger, press the *esc* key and then type 'Q' to quit.

D-3 BATTERY REPLACEMENT

The batteries are replaced once every month (right after downloading the data) to prevent any power failure. The procedure is discussed below (after Ref. 15).

Step 1: Remove the battery cover plate and turn the power switch off (see Fig. D-1).

Step 2: Unplug the battery holder and remove. Replace old batteries with new ones and reinstall the holder. Make sure that the springs are in the center of the battery, otherwise the batteries may fall out.

Step 3: Turn the data logger power switch on. Connect computer to data logger (see Fig. C-10. In Appendix C).

Step 4: Turn the computer on. After the computer completes internal booting, confirm or enter the date and time.

Step 5: Select 2 (TERM). Type in the station or county name and press *enter*. Press 'K', then 'Y.' Press 'M' and verify the data logger time. If the time is not correct, repeat step 4.

Step 6: Press *esc* key and then press 'Q' to quit.

D-4 ROUTINE CHECK-UPS

After data have been downloaded to the portable computer, the vicinity of the test outlet should be observed for any kind of abnormality. A few examples are cited below:

(1) At least three uphill outlet pipes and three downhill outlet pipes should be checked for any clogging, scaling or any other kind of obstructions. All such obstructions should be removed properly.

(2) Check all exposed cables for any kind of damages (cables have been found in conditions supposedly chewed by rodents).

(3) Check for any abnormal objects (such as ant colonies, tarantula habitats) in the rain gage. If such objects are found to obstruct normal operations of the equipment, they should be destroyed.

D-5 TRANSFERRING THE DATA TO A FLOPPY DISK

In order to upload the data on to the IBM main frame computer, it is first necessary to transfer the data to a floppy disk from the hard disk of the laptop computer. The procedure is discussed below (after Ref. 15).

<u>Step 1:</u> Turn on the laptop computer and exit to DOS.

<u>Step 2:</u> Type 'DIR/P' and press the *enter* key. Find out the desired file and note the total number of bytes.

<u>Step 3:</u> Insert a formatted 3.5" floppy disk with enough unused memory in the disk drive.

<u>Step 4:</u> Type 'COPY *filename.dat* A:' and press the *enter* key.

<u>Step 5:</u> Type 'DIR A:' and press the *enter* key. Find out the copied file and note the total number of bytes. Make sure that this number is the same as the one noted in step 3 above.

Any problems should be reported to a person familiar with DOS and the menu system of the operating environment of the laptop computer.

D-6 UPLOADING DATA TO THE IBM MAIN FRAME COMPUTER

Data is uploaded to the IBM main frame computer using a personal computer (PC) linked with the main frame. The procedure is discussed below (after Ref. 15).

<u>Step 1:</u> Power up the PC. Start the main frame session. Refer to the R&D Computer Liaison.

<u>Step 2:</u> At the "READY" prompt in the TSO environment of the main frame session, type '\ft' and press the *enter* key.

<u>Step 3:</u> Switch to the C: command prompt of the PC (consult the R&D Computer Liaison with any problem).

<u>Step 4:</u> Type "SEND *pcfile tsofile* ASCII CRLF" and press the *enter* key. Here, the term *pcfile* indicates the name of the file in PC environment (i.e., the file stored in the floppy, in this case) including the appropriate path name. The term *tsofile* indicates the name of the file in the TSO environment of the main frame.

For example, if a file named MYFILE is stored in the disk in the A: drive of the PC and it is intended to make a copy of this file under the name NEWFILE in the location SAMPLE.DATA in the TSO environment of the main frame computer then one should type in "SEND A:MYFILE A:SAMPLE.DATA(NEWFILE) ASCII CRLF" and then press the *enter* key. Note that the mainframe dataset (SAMPLE.DATA in this example) must be created before performing step 4.

D-7 DATA VERIFICATION

Once the data have been uploaded on to the mainframe computer, it should be checked for any unusual recordings which might have been caused by equipment malfunctioning, human error or other unknown situations. The data should be checked by the two methods discussed below.

D-7.1 Manual examination of the data

Edit the data manually either on the computer screen or on a hard copy. (1) Check if the data format is consistent with the expected output of the data collection program. (2) Check if the recorded year, day and time values are consistent with the calendar (a number of data files have been found to record the year as the default year 2000 - in such case the data file needs special pre-processing [see chapter 3 of this report]). (3) Check if the year, day and time changed appropriately (same data not recorded again and again). (4) Check for any discontinuity of data.

D-7.2 Computerized check-ups

Computer program RAWDATA is used to plot different raw data (see Fig. D-2 through Fig. D-6). These plots indicate if the corresponding sensor was working properly. These plots, however, do not show the total amount of any parameter. It shows only one point corresponding to a particular value on a calendar day. For example, if more than one data records on day 'n' shows 2.5 gallons of outflow, the corresponding plot would show only one point at coordinate (day=n, outflow=2.5 gallons).

These plots are very helpful in identifying consistent data and, hence, any equipment malfunctioning. The outflow shown in Fig. D-3 is consistent with the rainfall shown in Fig. D-2, but the outflow shown in Fig. D-8 is not consistent with the rainfall shown in Fig. D-7. Looking at the series of zero outflow shown in Fig. D-8, one can conclude that malfunctioning of the outflow tipping bucket is indicated in this case. Both temperature and pressure records seem to be reasonable (see Fig. D-4 through Fig. D-6).

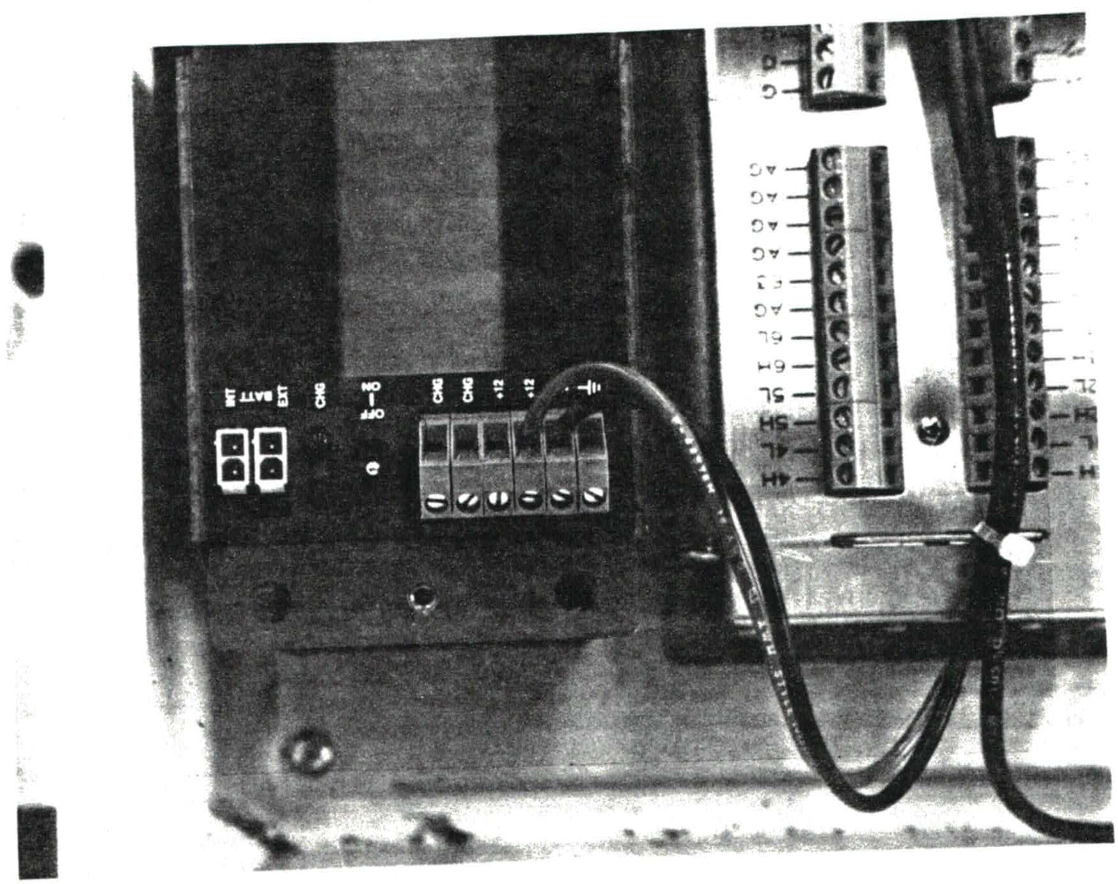

Fig. D-1 Data logger power switch

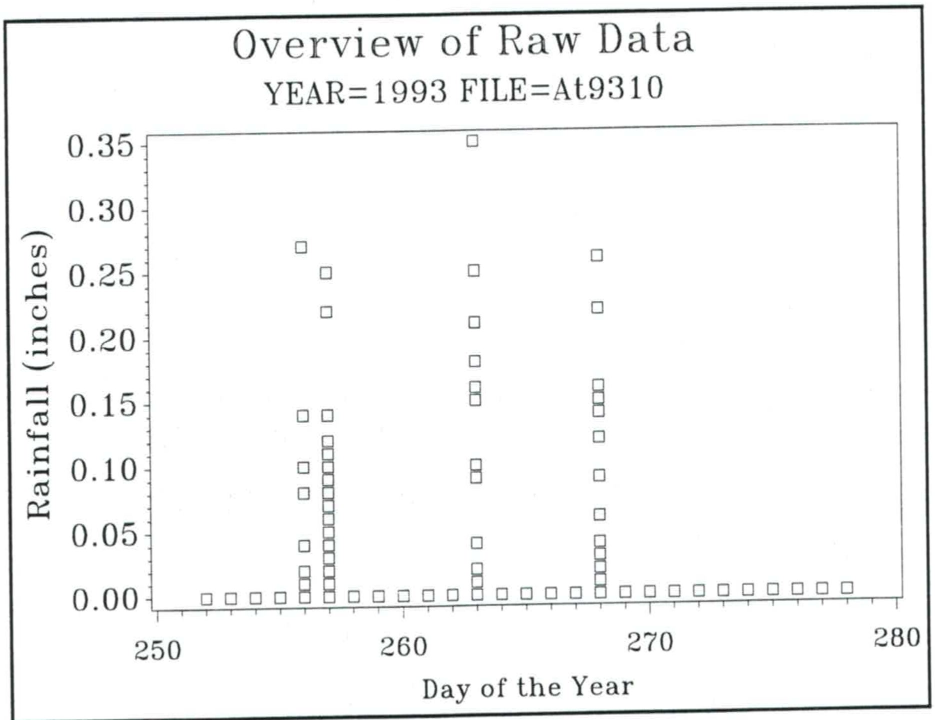

Fig. D-2 Overview of raw data (rainfall)

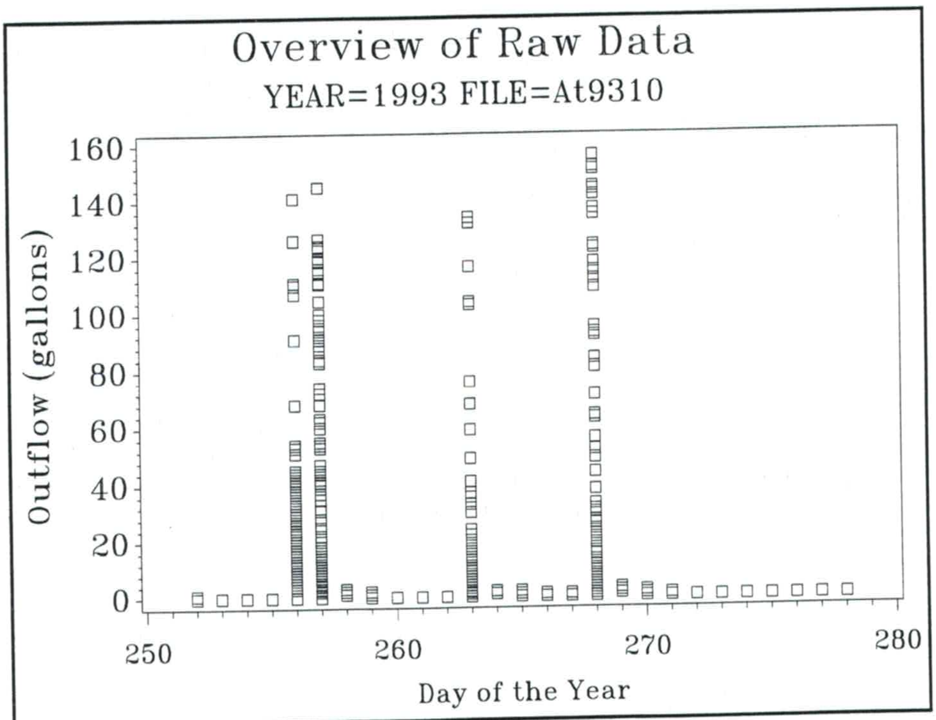

Fig. D-3 Overview of raw data (outflow)

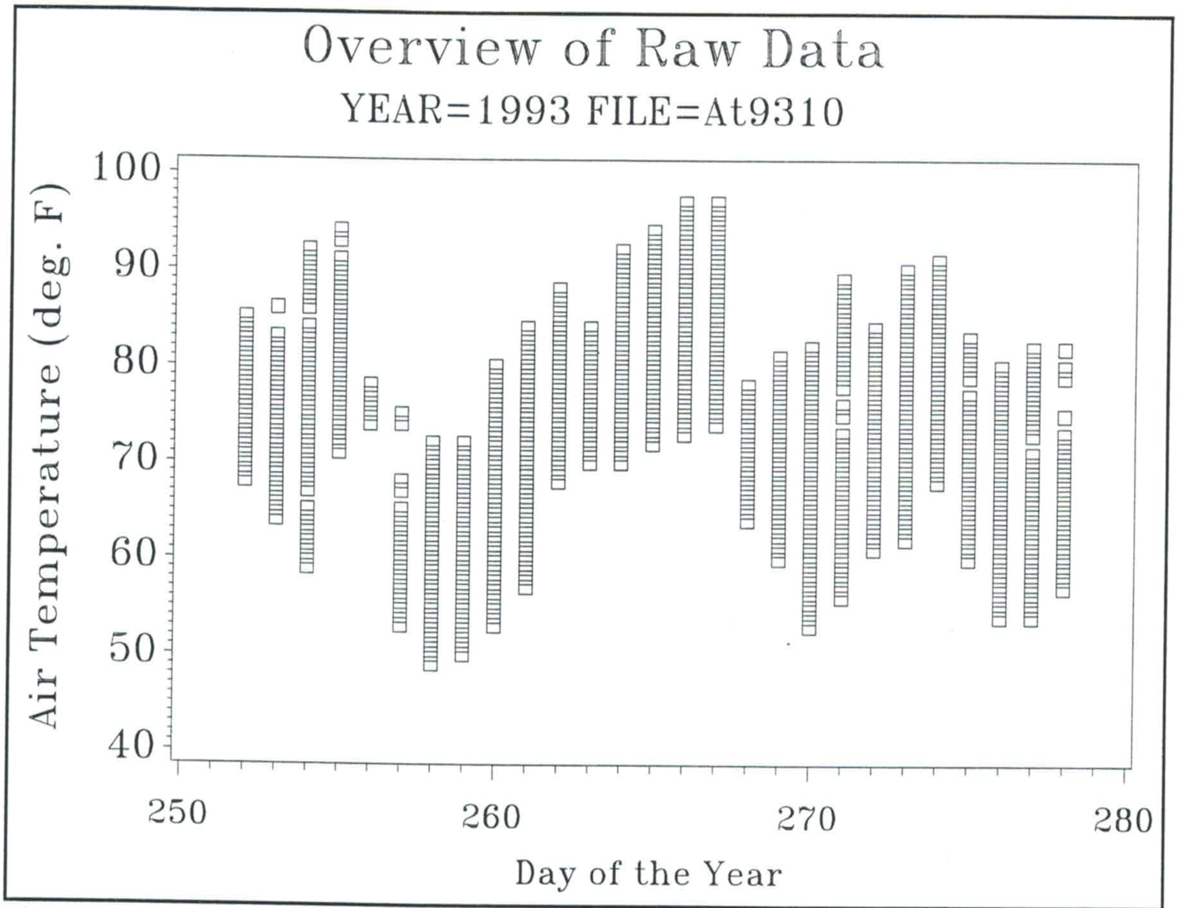

Fig. D-4 Overview of raw data (temperature)

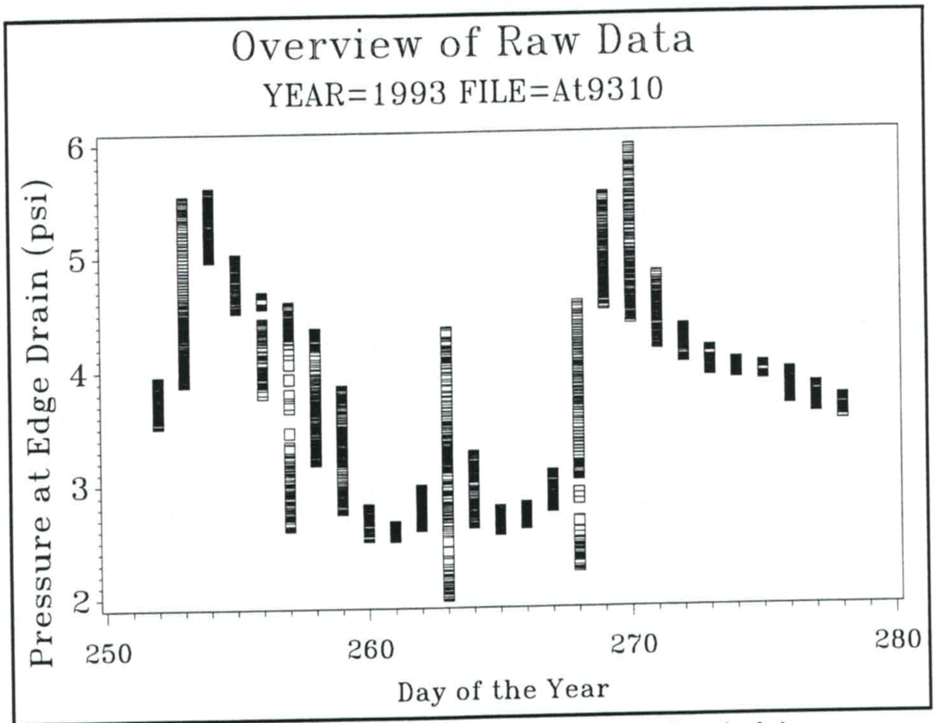

Fig. D-5 Overview of raw data (pressure at edge drain)

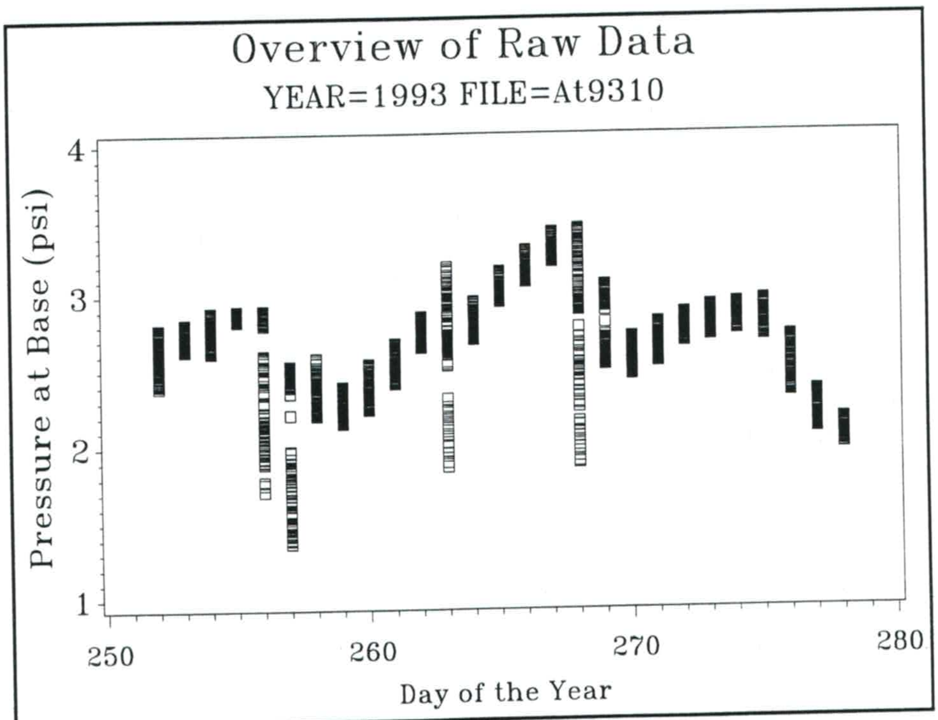

Fig. D-6 Overview of raw data (pressure at base)

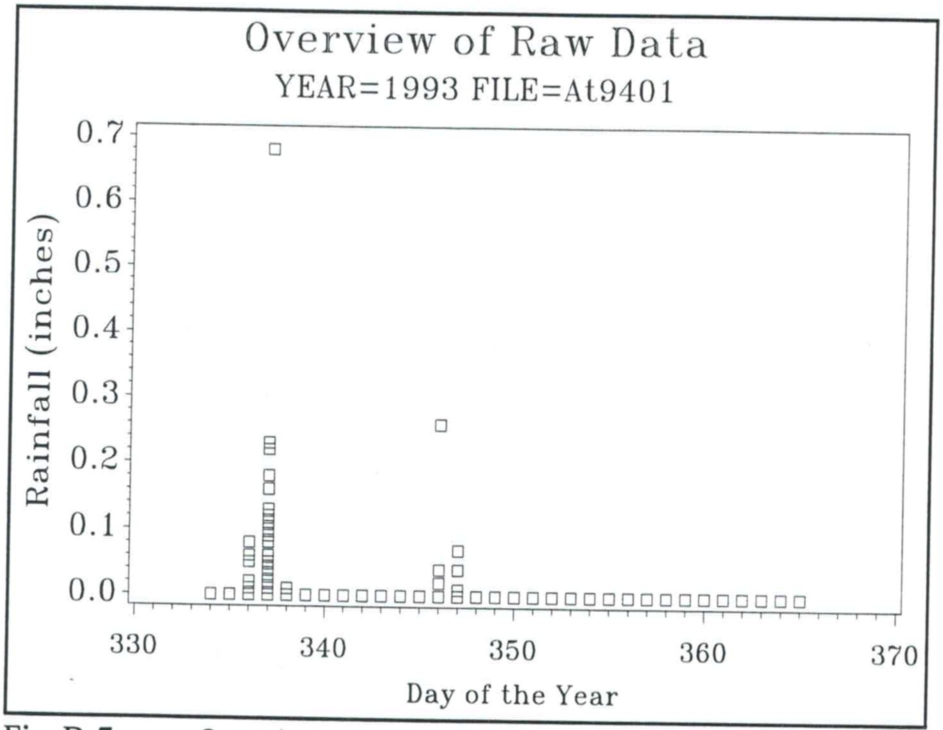

Fig. D-7 Overview of raw data (rainfall) for file AT9401

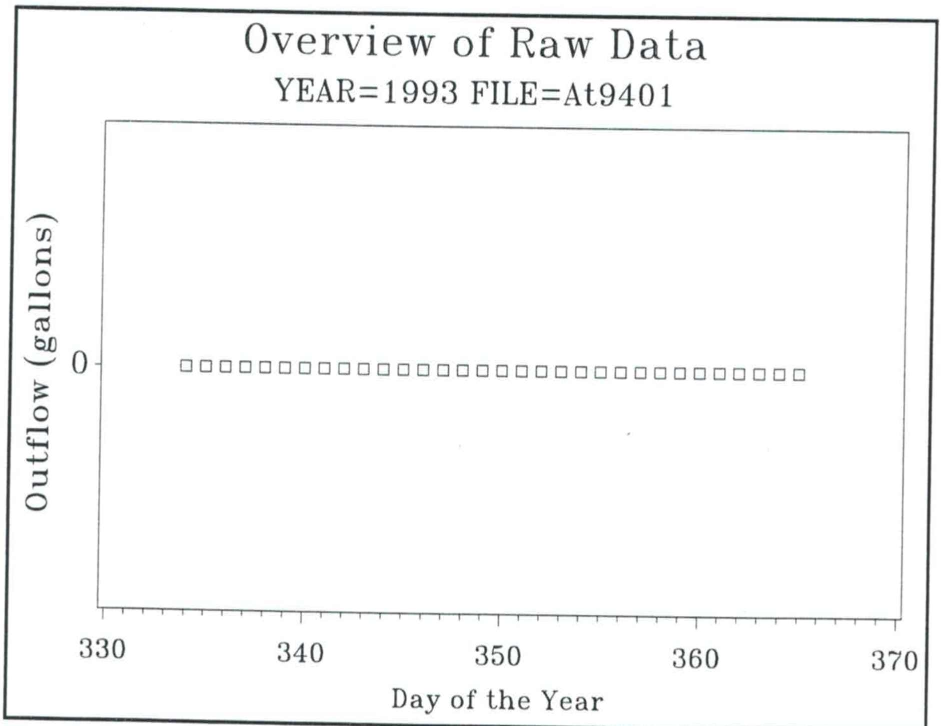

Fig. D-8 Overview of raw data (outflow) for file AT9401

COMPUTER PROGRAMS USED FOR DATA ANALYSIS

E-1 GENERAL

A number of computer programs were used to analyze the data gathered from the field. The programs are written in SAS programming language. The programs are intended to be used on the IBM mainframe computer at ODOT. They may need some modifications if they are to be used on other systems. Depending on the general purposes of the programs they are divided into six groups, as listed in Table E-1. A brief description of the individual programs is provided in Tables E-2a through E-2f. Some basic facts about the programs are discussed in the sections E-2 through E-6. The general procedure to run a program is presented in section E-7. Programs that require special notes are discussed in sections E-8 through E-21.

E-2 ASSUMPTIONS AND LIMITATIONS

All the programs that read data from the raw TSO data files assume that the recorded data are in fps system of units. All such programs can prepare the output in either fps or metric system of units depending on the user's request. In present form, all the programs assume that the valid site names are: Atoka, Logan, Noble, Nowata and Pittsburg. Some of the programs require the site geometry which are included in the programs; therefore, the programs would need some modifications before they can be used for new sites.

If the user wants to analyze more than one site with the same county name then the user would also face a problem because the sites are currently identified by the county names and there is only one site per county. This problem may be overcome by adding a suffix at the end of the site names (for example: Atoka1, Atoka2 etc.).

E-3 PROGRAMMING ENVIRONMENT

The programs are created and stored using the Time Sharing Option (TSO) in the MVS environment of the IBM mainframe computer used to perform the analysis. The location of a file is divided in three parts: (1) *project* (for example: Urad013), (2) *group* (for example: DrainAt) and (3) *type* (for example: Data). Any reference to a file should include all these three parts separated by periods. For example, a file named PREPNAME stored in location: project=Urad013, group=Sample2 and type=Data should be referenced as Urad013.Sample2.Data(PREPNAME). All the data analysis programs are currently stored in location: Urad013.Sample2.Data.

E-4 TSO FILES AND SAS FILES

Files created and stored using TSO (utilizing the ISPF program development facility [ISPF/PDF]) are called TSO files in this report. All SAS programs and raw data files collected from the fields are examples of such files. Files created by SAS programming language which are readable to SAS system only are called SAS files in this report. Such files can be recognized, viewed, edited and/or modified by using only SAS programs. It should be mentioned here that the SAS programs can also be used to prepare a file in the TSO environment (such files can then be edited by using ISPF/PDF). The data analysis programs discussed in this chapter often prepare an output (called TSO output file in this report) for the TSO environment. Also a SAS program can use input data from a TSO file (called TSO input file in this report).

E-5 RESERVED FILES

The data analysis programs reserve the use of some TSO and SAS files and, therefore, the user should not use those files to store any kind of data. These files are normally used as temporary files. All such TSO files are stored in locations Urad013.Sample.Data and Urad013.Sample2.Data. The data analysis programs are examples of such TSO files in location Urad013.Sample2.Data. The following ten TSO files in location Urad013.Sample.Data are also reserved: TMPORARY, TMPORAR1, TMPORAR2, ..., TMPORAR9. The following eleven SAS files in SAS dataset location Urad013.SAS.Sample are also reserved: PREPDATA, TMPORARY, TMPORAR1, TMPORAR2, ..., TMPORAR9. In most cases (especially when an output is generated by a program), the original SAS program prepares a temporary program in the TSO file TMPORARY in location "URAD013.SAMPLE.DATA" and then uses that program. Users who want to make some changes in the output of a program can do so by first running the original program, editing and modifying the program TMPORARY, and then running this program.

E-6 HOW TO RUN A PROGRAM

The programs are executed by using a "clist" file which contains necessary instructions to run the program. Program RUN95.CLIST presented at the end of this appendix can be used to run a program. The user needs to have an idea about the output the program would generate because the "clist" program needs to identify appropriate output based on whether the print-out contains text or graphic data, whether the orientation of a text print-out is portrait or landscape, etc. During the execution of the program, the "clist" file makes inquiries about those parameters and the user needs to feed in appropriate answers.

E-7 GENERAL STEPS IN RUNNING A PROGRAM

<u>Step 1:</u> Submit a program for execution by using an appropriate "clist" file.

Step 2: Carefully read the set of instructions on the computer monitor. The user is requested to edit a SAS dataset (the program makes necessary arrangements in a couple of moments) where the user needs to confirm or modify some options required to run the program (see Fig. E-1). Usually, the names and locations of input and output files, destinations for output (computer screen, printer or a file), etc. are some of the information the user is asked about. The instructions printed on the computer screen contain helpful hints about any input files, orientation of text print-outs and other items the user may be asked about.

Step 3: After reading and understanding the instructions discussed in step 2 above, hit the *Enter* key on the computer key board.

Step 4: The computer screen changes to a SAS edit screen. The SAS dataset PREPDATA is edited by SAS system procedure FSEDIT, known as PROC FSEDIT. The user finds a number of options described in the left side of the screen while the default values for all the options are shown on the right side of the screen (see Fig. E-2). The user may confirm a value by pressing the *enter* key or may modify a value by typing in the appropriate value. Any item shown on this screen whose description begins with the pound (#) symbol is intended to provide some extra assistance to the user, and the value of such an option does not need to be changed. The maximum length of a dataset location is 40 alpha-numeric characters, that of a file (member) is 8 alpha-numeric characters, and that of a site name is 12 alpha-numeric characters.

Step 5: When the user completes making all the modifications in the SAS dataset PREPDATA, stop the SAS edit session by choosing *File* and then *End* from the menu.

Step 6: Most of the programs start execution at this stage and continue for a while depending on the size of the tasks to be performed by the program and the size of the data to be processed. In some cases, the user is required to edit one or more of the output SAS datasets. In some cases, the user may be shown a screen print-out. In some cases, the program may need more feed-back from the user and as such the SAS dataset (described in step 4 above) is edited more than once. After all the processing is done, the program stops. The options available in the *clist* file used to run the program affect the hard copy (if any) of the text/graphic outputs of the program.

E-8 PROGRAM *PREPNAME*

This program prepares a SAS dataset that contains the names and locations of the files that contain the raw data. After the program *PREPNAME* prepares the database of the TSO files that contain the data to be analyzed, other programs can be used to analyze these data. This program reads the required information from a TSO input file prepared by the user (see Fig. E-1). The TSO file contains the following information in each line:

(1) site number (site numbers are 1 for Atoka, 2 for Noble, 3 for Nowata and 4 for Pittsburg),

(2) site name (the first letter of the site name must be capital and all other letters

must be small) - not more than 12 alpha-numeric characters,

(3) location of raw dataset in the TSO environment (either capital or small letters can be specified) - not more than 40 alpha-numeric characters,

(4) name of raw dataset in the TSO environment (either capital or small letters can be specified) - not more than 40 alpha-numeric characters.

E-8.1 Steps in executing the program *PREPNAME*

Step 1: As soon as the execution starts, the user will find some instructions on the computer monitor which asks the user to edit the SAS dataset *PREPDATA* and confirm/modify the names and locations of the TSO input and SAS output of this program. The user needs to press the *enter* key.

Step 2: The user finds that the SAS editor FSEDIT shows the dataset *PREPDATA* on the computer screen. The user can make any modifications in this dataset. If the actual TSO input data file has a different name or location then the user needs to make appropriate modifications to specify these names. The default TSO input data file is named *PREPDATA* and the default location for this file is *URAD013.SAMPLE.DATA*. *PREPNAME* looks at file *PREPDATA* in location *URAD013.SAMPLE.DATA* to find the necessary input parameters. The default SAS output has the name *PREPNAME* in location Urad013.SAS.Sample. After all the necessary modifications have been made, the user can terminate the edit session by choosing

"End" from the "File" option in the menu.

Step 3: The user will see a screen print-out of the "list of sites, datasets and files." The user can confirm by looking at this list if the program has properly read all the input parameters from the TSO input file specified by the user in Step 2 above.

Step 4: The user is taken to edit the SAS output file of this program. The user finds one additional observation in the beginning of this dataset - this is done by the program. As soon as the user terminates the edit session, the program comes to an end.

E-9 PROGRAM *DPREP1*

This program sets up the time frame of an event the user wants to analyze in greater details. The output of this program describes which part of the data is to be analyzed. For example, if the user wants to analyze the data for the Atoka county site for the time period: time 2310 on day 45 to time 1430 on day 46 in the year 1993. The program DPREP1 sets up this time reference for this event. It also sets up the name and location of the raw data file, etc. The input for this program is to be provided by the user via an SAS input file that may be created during the execution of this program or the user may even use an SAS input file which was created earlier. The output of this program is also another SAS file.

E-10 PROGRAM *DPREP2*

This program is similar to the program DPREP1. The only difference is in the time frame. The program DPREP1 is used when the user wants to study any arbitrary event which may start or stop at any arbitrary time while the program DPREP2 is used when the user wants to study the whole data in a raw file on a day by day basis. The whole data in a raw file is divided in a number of segments - each segment representing a different calendar day. The start and stop time should be same for each day (except the two days when the file starts and when the file ends). For example, for the data file AT9308 which starts at time 900 on day 195 and stops at time 1040 on day 222, the first segment starts at time 900 on day 195 and stops at the midnight on the same day, the segment starts 1 minute after midnight on day 196 and stops at the midnight on the same day. The last segment stops at time 1040 on day 222. This program gets the required input from the SAS output of the program FILENFO1.

E-11 PROGRAM *P2000*

Some of the raw TSO data files have been found to record faulty year, day and time values as described in section 5.3.2 in chapter 5. The user needs to know the actual year, day and time corresponding to the last record in the raw TSO data file. The user can guess this by looking at the year, day and time corresponding to the first record in the next raw TSO data file or by knowing the actual time of data collection. The output of this program is another raw TSO data file in the same version as the input raw TSO data file but containing true year, day and time values.

E-12 PROGRAM *VERSION2*

This program makes some modifications in the format of the raw TSO data file mNb9507a. The data recorded in this file is in the second version of data format. After the program VERSION2 makes the necessary modifications and generates a new raw TSO data file with this modified format, then any data analysis program can use/read the data from this new file. See section 3.6.2 in chapter 3 for more details.

E-13 PROGRAM *VERSION3*

This program makes some modifications in the format of the raw TSO data files which contain data recorded in the third or fourth versions of data format. After the program VERSION3 makes the necessary modifications and generates a new raw TSO data file with this modified format then any data analysis program can use/read the data from this new file. See section 3.6.3 in chapter 3 for more details.

E-14 PROGRAMS *FILENFO1, FILENFO2 AND FILENFO3*

The program FILENFO1 generates two reports. The first report contains information about raw TSO data files (the names of these TSO data files are to be passed to this program by using the SAS output of the program *PREPNAME*) (see Fig. 5-6 in chapter 5). The second report contains information about monthly rainfall, outflow, etc. (see Table 5-2 in chapter 5). This program can prepare the outputs in either the FPS or Metric system of units. The outputs of this program can be appended at the end of existing outputs. For example, one can run this program for all the raw TSO data files and save the outputs. In the next month, when some more data are collected from the field, this program can be executed for only these new files and the output can be appended at the end of the output generated in the earlier analysis. Program FILENFO2 prints the first output of the program FILENFO1, while program FILENFO3 prints the second output.

E-15 PROGRAM *CORE3*

The program *CORE3* prepares the rainfall and outflow data to be used by the program *CORE4*. The program *CORE3* has options to prepare the output in either FPS or Metric system of units. It also has a delete option which is helpful in situations when the user is not sure about the data values. This may be the case when the user tries to process all the data in a single file (see section E-8). There may be a number of situations when there is no rainfall or outflow; therefore it may be desirable to delete such events. If the user sets the delete option to 1 then all such events will be discarded for the purpose of plotting by the program *CORE4*. Any event with only one record of non-zero rainfall and/or outflow value(s) will also be discarded in such case. The start time option is to indicate the exact time since when an event starts. Consider an event defined to start at time 1724. Any data record found in the data file on or after time 1724 (on that specific day) is considered part of the event. Assume that the first such record found in the data file is at time 1730. If the start time is exact, then this record indicates six minutes have passed since the event started; however, if the start time is not exact, then this record indicates that the time passed since the event has started is equal to the time gap between the current record and the previous record in the data file. If the previous data was recorded at time 1720, then this would be ten minutes.

E-16 PROGRAMS *FILENFO6* AND *FILENFO7*

The program FILENFO6 generates the charts of monthly rainfall and outflow amounts against the months of the year, while the program FILENFO7 generates the charts of annual rainfall and outflow amounts against the years. The unit for both rainfall and outflow must be the same. Either volumetric (such as gallons or liters) or linear units (such as inches or millimeters) can be used to measure the rainfall and outflow. One can process for a particular site or year using any of these two programs.

E-17 PROGRAM *FILENFO9*

This program prepares the percentile ranking of a number of items as described in Table E-2c. The user can consider a particular site or year or all the data for finding out the percentile rankings. The user needs to specify the number of data points or observations corresponding to the year or site or the whole database according to user's choice. For example, if the user wants to find out the percentile distribution of the monthly rainfall amounts based on the data obtained from the Atoka county site in the year 1993, then it is necessary to specify the number of data points as 11 (see Fig. 5.19 in chapter 5).

E-18 PROGRAM *MAXRATE1*

This program computes the maximum rates of rainfall and outflow. It has options for units of measurements and appending outputs similar to the program FILENFO1 (see section E-12 for details). The user needs to specify the time basis for computation of the rates. For example one can compute the rates based on 30-minute duration rainfall and outflow.

E-19 PROGRAMS *MAXRATE2* AND *MAXRATE3*

If the user runs the program *MAXRATE1* six times to compute the rates for data based on 30, 60, 90, 120, 150 and 180 minute duration rainfall and outflow and combines all the outputs (by using the append option in program *MAXRATE1*), then the PROGRAMS *MAXRATE2* AND *MAXRATE3* can be used. The first program prints the text output, while the second one plots the graphic output.

E-20 PROGRAM *RETEN1*

The program *RETEN1* is divided into two parts. The first part of the program *RETEN1* prints the rainfall and outflow data, as prepared by the program CORE2 (see Fig. E-1). The user needs to specify the amount of data to be printed by means of a maximum time limit. If the maximum time limit is specified as 2 hours, then the printed data will contain information for about the first 2 hours of an event. The user needs to look at this printed data to identify the observation (data record) when the outflow starts.

In the second part of the program, the user is taken to edit the dataset where the user needs to mark the observation by changing the value of a variable named GOOD from 0 to 1. For example, in the above figure, the outflow seems to start 0.5 hours after the rainfall starts. The program then prepares different information about the retention time, amount of rainfall before the flow starts (called "initiative rainfall" in this report), rainfall intensity before rainfall starts, etc.

E-21 PROGRAM *RETEN2A*

This program analyzes the percentile distribution of the retention time and initiative rainfall. It can generate either text or graphic output depending on the user's request. The output contains information on either retention time or initiative rainfall depending on the user's choice. The analysis may be based on all data in the database or on a specific year or specific site at a time. Fig. 6.11 through Fig. 6.13 are prepared by running this program three separate times, each time for a single site. The user needs to mention the number of data points or observations in the database that correspond to the specific case (like a particular site or year) being analyzed.

E-22 EXECUTION PROGRAM *RUN95.CLIST*

As mentioned in seciton E-6, the"clist" file listed below can be used to execute different data analysis programs discussed in this report.

```
00010006PROC 0 SASDD(USER)    +
00010106       FORMAT(FORMATS.LOAD)
00011000CLRSCR
00011124CONTROL NOMSG NOLIST
00049504
00049608WRITE
00049609WRITE   Enter program name. Example: sample2.Data(PrepName)
00049610WRITE
00049611WRITENR          ==>
00049612READ    INPUT
00049613
00049614WRITE
00049615WRITE   Enter SAS dataset name. Example: Sas.Sample
00049616WRITE
00049617WRITENR          ==>
00049618READ    SASDS
00049620
00049630WRITE
00049640WRITE   If you have a graphic output and you want to send it to the
00049650WRITE      printer then type Y and press enter.
00049660WRITE
00049670WRITENR          ==>
00049680READ    MQZVM
00049690
00049700/* WRITE ***
00049800/* READ
00049900CLRSCR
00050000
00050716SET STATE = &SYSDSN(&SASDS.)
00050817IF &STATE = OK THEN DO
00050916     ALLOC F(&SASDD.) DA(&SASDS.) OLD
00051017  END
00051116ELSE
00051216 IF &STATE = DATASET NOT FOUND THEN DO
00051316     WRITE
00051317     WRITE
00051318     WRITE !! WARNING: &SASDS. FILE DOES NOT EXIST
00051416     WRITE             YOU MUST CREATE THIS NEW FILE THROUGH SASBATCH
00051516     WRITE
00051517     WRITE ***
00051518     READ
00051519     GOTO ENDIT
00051616  END
00052116
00052117
00052119IF &MQZVM = &STR(Y) THEN WRITE mqzvm = &MQZVM
00052120   IF &MQZVM = &STR(Y) THEN GOTO JZQWV
00052121
00052130
00052206/**********************************************************************
00052306/*
00052406/*   HERE IS WHERE YOU WILL NEED TO PUT SPECIFIC FILE ALLOCATIONS
00052506/*   FOR EACH DIVISION.
00052606/*
00052607/**********************************************************************
00052608
00052706FREE F©
00052806ALLOC F© DA('RDP.SAS6.DATA')
00052914FREE F(LIBRARY FT06F001)
00053006ALLOC F(LIBRARY) DA(&FORMAT.)
00053122 FREE DA(XEROX.REPORT)
00053222 DELETE XEROX.REPORT
00053223
00053323/*IF SYSDSN(XEROX.REPORT) NE 'OK' THEN + */
00053423/*DO */
```

```
00053424
00053522 FREE AT(XXRO)
00053622 ATTR XXRO LRECL(137) RECFM(V B A) BLKSIZE(1374)
00053722 ALLOC F(FT06F001) DA(XEROX.REPORT) NEW USING(XXRO) -
00053811    SPACE(20,50) TRACKS RELEASE
00053812
00053824
00053923 /*END */
00054023 /*ELSE DO  */
00054123 /*  FREE DA(XEROX.REPORT)*/
00054223 /*  ALLOC F(FT06F001) DA(XEROX.REPORT) OLD */
00054323 /*END*/
00054406/*
00054506/*****************************************************************
00054604
00054712STP1: SAS607  +
00054818INPUT(&INPUT.)
00054919/*PRINT(FT06F001)*/
00055019/* DDPRINT(FT06F001) PRINT(XEROX.REPORT) */
00055119/* DDPRINT(FT06F001)    MAKE SURE ALLOC AS DISP=OLD */
00055219/* PRINT(FT06F001)       AS ABOVE */
00055318/* DDSYSIN(SYSIN) INPUT(&INPUT.) + */
00055418/* OPTIONS('INITSTMT="%INCLUDE SYSIN;"') + */
00055421WRITE
00055422WRITE ***
00055423READ
00055430CLRSCR
00055510WRITE
00055600WRITE   If you want to print, type Y and press ENTER, my Lord.
00055700WRITE
00055800WRITENR           ==>
00055900READ    PRT
00055910
00056000IF &PRT = &STR(Y) THEN GOTO PRINTIT
00056100GOTO ENDIT
00056110
00056200PRINTIT: +
00056203WRITE
00056204WRITE
00056210WRITE   What is the output orientation ?
00056220WRITE
00056230WRITE        1 - PORTRAIT  (8.5" X 11")
00056240WRITE        2 - LANDSCAPE (11" X 8.5")
00056250WRITE
00056260WRITENR           ==>
00056270READ    ORIENT
00056271
00056274WRITE
00056276WRITE   PRINTER IDENTIFICATIONS: U18 = RESEARCH; U2 = RURAL DESIGN
00056277WRITE
00056278WRITE   ENTER PRINTER NAME (U18 OR U2 ?)
00056279WRITE
00056280WRITE   << NOTE: HIT ENTER TO CANCEL PRINT PROCESS.>>
00056281WRITE
00056282WRITENR           =======>
00056283READ    DEST
00056284
00056285IF &ORIENT = &STR(1) THEN GOTO PORTRAIT
00056286IF &ORIENT = &STR(2) THEN GOTO LANDSCAPE
00056290GOTO ENDIT
00056291
00056292PORTRAIT: +
00056293PRINTO XEROX.REPORT DEST(&DEST) FCB(BAMQ) UCS(CE12)
00056294GOTO ENDIT
00056295
```

```
00056296LANDSCAPE: +
00056298PRINTO XEROX.REPORT DEST(&DEST) FCB(STDZ) UCS(GT15) NOHEADING
00056300GOTO ENDIT
00056301
00056306/*                              */
00056310/*IBMPRINT DSN(XEROX.REPORT) + */
00056400/*  COPIES(1) + */
00056500/*  ORIENT(X)    */
00056600
00060200/* JZQWV: +
00060201
00060210FREE F©
00060220ALLOC F© DA('RDP.SAS6.DATA')
00060230FREE F(LIBRARY FT06F001)
00060240ALLOC F(LIBRARY) DA(&FORMAT.)
00060250 FREE DA(XEROX.REPORT)
00060260 DELETE XEROX.REPORT
00060270
00060280/*IF SYSDSN(XEROX.REPORT) NE 'OK' THEN + */
00060290/*DO */
00060291
00060292 FREE AT(XXRO)
00060293 ATTR XXRO LRECL(137) RECFM(V B A) BLKSIZE(1374)
00060294 ALLOC F(FT06F001) DA(XEROX.REPORT) NEW USING(XXRO) -
00060295    SPACE(20,50) TRACKS RELEASE
00060300
00060400Alloc F(AdmSymbl) DA ('Sys1.GddmSym') SHR
00060410Alloc F(AdmPc)    DA ('Sys1.GddmSym') SHR
00060420Alloc F(AdmDefs)  DA ('Rdp.SAS.Source(sasPage)') SHR
00060430Alloc F(AdmImage) DA ('Rdp.OutLib(Plot)') SHR
00060500
00060600Stp2: SAS607 Options('BufNo=2 Center Date LineeSize=120 Macro -
00060700      Number Skip=2 NoSpool') +
00060800      Input(&Input.) +
00060900      Print(Ft06F001)
00061000
00061001Write
00061002Write ***
00061003Read
00061004
00061005ClrScr
00061006
00061009Write
00061010Write Enter the Printer Id : U18 or U2 ?
00061011Write   << Note: Hit Enter to cancel print process >>
00061012Write
00061013WriteNr              ========>
00061015Read Dest
00061016
00061017IF &DEST = &STR(Y) THEN GOTO PRINTOUT
00061018
00061019PR DSN('RDP.OutLib(Plot)') Dest(&Dest)
00061020GoTo EndIt2
00061021
00061022/* PRINTOUT: +
00061023
00061024Set &Dest=U18
00061025Pr DSN('RDP.OutLib(Plot)') Dest(&Dest)
00061029
00061030/* ENDIT2: +
00061100
00061101Free F(C AdmDefs AdmImage AdmSymbl AdmPC FT06F001)
00061102Free  DA('Rdp.SAS.Source(SasPage)', 'RDP.OutLib(Plot)', 'Xerox.Report', &Input.,
&SasDs.)                                                                  Input.,
00061103Free DA('Rdp.SAS6.Data')
```

```
&SasDs.)
00061104Go To ENDIT3
00061106
00061107ENDIT: +
00061108FREE DA(&INPUT,&SASDS,XEROX.REPORT,'RDP.SAS6.DATA')
00061109FREE FI(C LIBRARY FT06F001)
00061111
00061112ENDIT3: +
00061120END
00061200
00061300
```

Table E-1 Different groups of data analysis programs

Group #	General purpose of the Programs in this Group
1	Preprocessing of data before any analysis starts and making some initial setup as may be necessary in some cases.
2	• Obtaining preliminary information about the data. • Obtaining an overview of the field activities and identifying equipment malfunctioning (if any), etc.
3	Obtaining summarized plots of the monthly and/or annual activities.
4	Analyzing rainfall events in greater details.
5	Obtaining information about the retention time.
6	Obtaining information about the ratio between outflow and rainfall magnitudes.
7	Obtaining information about time required for drainage.

Table E-2a Description of different programs in group 1

No.	Program	Function
1	PREPNAME	Prepares a SAS database that contains the names and locations of all raw TSO datasets that are to be analyzed.
2	DPREP1	Sets up the time frame of the raw data (corresponding to one or more events) for detailed analysis. The time frame is specified by the user.
3	DPREP2	Divides the raw data in one or more whole files in a number of segments and sets up the time frame of the raw data (corresponding to those segments) for detailed analysis. Each segment equals a calendar day.
4	P2000	Corrects the faulty date and time values in a raw data file (see section 5.3.2 in chapter 5).
5	VERSION2	Modifies the format of the raw TSO data files that contain data with the second version of the data format (see section 3.6.2 in chapter 3).
6	VERSION3	Modifies the format of the raw TSO data files that contain data with the third and fourth version of the data format (see sections 3.6.3-3.6.4 in chapter 3).

Table E-2b Description of different programs in group 2

No.	Program	Function
1	RAWDATA	Plots an overview of the raw data (see Fig. D-2 through Fig. D-6 in Appendix D for illustration).
2	FILENFO1	Prepares summary reports about the rainfall and outflow data based on (1) the raw TSO data files and (2) the months of the years. Program PREPNAME must be executed before running this program.
3	FILENFO2	Prints the first report prepared by program FILENFO1.
4	FILENFO3	Prints the second report prepared by program FILENFO1.
5	FILENFO4	Prepares the data for program FILENFO5. Program PREPNAME must be executed before running this program.
6	FILENFO5	Plots the cumulative amounts of the daily rainfall and outflow for a file (see Fig. 5-34 in chapter 5). This program uses the data prepared by program FILENFO4.
7	CORE3	Prepares the detailed rainfall and outflow data for programs CORE4 and CORE5. Any of the programs DPREP1 or DPREP2 must be executed before running this program.
8	CORE4	Plots any of the following (using the data prepared by CORE3): • Intensity of rainfall and outflow for the events • Cumulative amounts of rainfall and outflow for the events.
9	CORE5	Prints the rainfall and outflow data generated by program CORE3.

Table E-2c Description of different programs in group 3

No.	Program	Function
1	FILENFO6	Charts monthly rainfall and outflow amounts using the data prepared by program FILENFO1 (see Fig. 5.19 in chapter 5 for example).
2	FILENFO7	Charts annual rainfall and outflow amounts using the data prepared by program FILENFO1 (see Fig. 5.31 in chapter 5 for example).
3	FILENFO8	Charts any of the following (using the data prepared by program FILENFO1): • monthly data collection durations (see Fig. 5.11 in chapter 5 for example) • monthly rainfall durations (see Fig. 5.15 in chapter 5 for example) • monthly outflow proportions (see Fig. 5.23 in chapter 5 for example).
4	FILENFO9	Plots percentile ranking of any of the eight items listed in below (using the data prepared by program FILENFO1): • monthly rainfall durations • maximum rainfall rates (based on data collection intervals) • maximum outflow rates (based on data collection intervals) • amounts of monthly rainfall • amounts of monthly outflow • proportions between monthly outflow and monthly rainfall • amounts of annual rainfall • amounts of annual outflow (see Fig. 5.27 and Fig. 5.32 in chapter 5 for examples).
5	MAXRATE1	Computes the maximum rainfall and outflow rates based on a user specified time duration. The program PREPNAME must be executed before running this program.
6	MAXRATE2	Prints the maximum rainfall and outflow rates based on 30, 60, ..., and 180 minutes time durations as computed by the program MAXRATE1 (see Figs. 5.29-5.30 in chapter 5 for examples).
7	MAXRATE3	Plots the maximum rainfall and outflow rates based on 30, 60, ..., and 180 minutes time durations as computed by the program MAXRATE1 (see Fig. 5.28 in chapter 5 for example).

Table E-2d Description of different programs in group 4

No.	Program	Function
1	CORE1	Finds out the continuous rainfall events and gathers information about them. Program PREPNAME must be executed before running this program.
2	CORE2A	Prints the first output of the program CORE1
3	CORE2B	Prints the second output of the program CORE1
4	EVENT1	Finds out the events and gathers information about them. Program CORE1A must be executed before running this program.
5	EVENT2	Program EVENT1 must be executed before running this program. Plots any of the following: • Outflow amounts against the rainfall amounts • Outflow proportions against the rainfall amounts • Outflow proportions against the outflow amounts
6	EVENT3	Program CORE3 must be executed before running this program. It computes and prints general statistics about different features of the events. It can also print percentile ranking of the outflow proportions.
7	CORE3	Prepares the detailed rainfall and outflow data for program CORE4 and CORE5. The program DPREP1 or DPREP2 must be executed before running this program.
8	CORE4	Plots any of the following (using the data prepared by the program CORE3) • Intensity of rainfall and outflow for the events • Cumulative amounts of rainfall and outflow for the events.
9	CORE5	Prints the rainfall and outflow data generated by program CORE3

Table E-2e Description of different programs in group 5

No.	Program	Function
1	RETEN1	Prepares the information about the retention times. The program CORE2 must be executed before running this program.
2	RETEN2A	Computes and plots the percentile information about the retention time as prepared by the program RETEN1 (these plots are similar to Fig. 6.14 in chapter 6).
3	RETEN2B	Plots the information about the retention times as prepared by program RETEN1.

Table E-2f Description of different programs in group 6

No.	Program	Function
1	DRAIN1	Computes preliminary information about drainage times. The program CORE3 must be executed before running this program.
2	DRAIN2	Computes more detailed information about drainage times. The program DRAIN1 must be executed before running this program.
3	DRAIN3A	Plots any of the following (using the data prepared by the program DRAIN2) (These plots are similar to Figs. 6.17-6.28 in chapter 6): • 50% drainage time against outflow amount. • 100% drainage time against outflow amount. • 50% drainage time against outflow rate at beginning. • 100% drainage time against outflow rate at beginning. • Outflow amount against outflow rate at beginning.
5	DRAIN3B	Computes and plots any of the following (using the data prepared by the program DRAIN2): • Statistics of Time for n % Drainage and Related Quantities. • Distribution of Time for n % Drainage.

```
You are going to edit dataset PREPDATA. Modify the name and
     dataset location corresponding to the SAS input file and
     output files for this program.

Also specify the unit of measurements for output quantities.

Note 1:
The SAS input file for this program is the SAS output of
the program PREPNAME.

Note 2:
The First  Output contains information about raw TSO data
files.
The Second Output contains information about monthly
activities.

Note 3:
The APPEND option = 1 will cause the current output to be added
at the end of the old contents of the output file whose
name is supplied at this stage.

Note 4:
Available options for unit of measurements:
1 : FPS (US customary units)
2 : Metric  system of units
```

Fig. E-1 Instructions provided by the data analysis program FILENFO1

```
.FSEDIT B.PREPDATA.................................................Obs 1..
. File Edit Search View Locals Globals Help

  Input SAS Dataset Name =========  Urad013.SAS.Sample

  Input SAS Member  Name =========  PrepName

  SAS Dataset Name (Output #1) ===  Urad013.SAS.Sample

  SAS Member  Name (Output #1) ===  FileNfo1

  SAS Dataset Name (Output #2) ===  Urad013.SAS.Sample

  SAS Member  Name (Output #2) ===  FileMon2

  Append? 1=Yes; 0=No (Output #1)=             0

  Append? 1=Yes; 0=No (Output #2)=             0

  Unit of measurements in output =             1

   # Option for unit is 1 for :     FPS (US customary units)

   # Option for unit is 2 for :     Metric  system of units
```

Fig. E-2 View of the SAS dataset PREPDATA (version for program FILENFO1) while edited with SAS editor - PROC FSEDIT

```
.. ...              ...              ....
3 Nowata urad348.DrainNw.data Nw9510
4 Pittsburg urad348.DrainPt.data Pt9510
.. ...              ...              ....
```

Fig. E-3 Part of a TSO input file for the program PREPNAME

Rainfall data for first couple of hours of an event

Site=Pittsburg * Year=1993 * Event No.=1 * on (yr-dy-tm)=1993-19.1740

Time	Time2	Rain (mm)	Flow (l)	Flow (l/hr)	Cum. Rn. (mm)	Int. Rn. (mm/hr)	Cum. Fl. (l)
1740	0.167	0.51	.	.	0.51	3.05382	0.000
1750	0.333	0.76	.	.	1.27	3.80371	0.000
1800	0.500	1.27	3.8	0.19	2.54	5.07987	3.785
1810	0.667	0.76	9.5	56.78	3.29	4.93741	13.248
1820	0.833	1.52	15.1	90.84	4.81	5.77817	28.388
1830	1.000	1.27	18.9	113.55	6.10	6.09585	47.313
1840	1.167	1.78	24.6	147.62	7.88	6.75464	71.915
1850	1.333	0.76	30.3	181.68	8.61	6.46146	102.195
1900	1.500	0.25	36.0	215.75	8.75	5.83319	138.153
1910	1.667	0.51	41.6	249.81	9.43	5.65973	179.788
1920	1.833	0.51	39.7	238.46	9.94	5.42540	219.530
1930	2.000	0.25	41.6	249.81	10.00	4.99988	261.165

Fig. E-4 Rainfall and outflow data as printed by program RETEN1

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20. Personal Telefax Communications with Larry Riley of Campbell Scientific, Inc., 815 W. 1800 North., Logan, UT 84321-1784, Phone: (801) 753-2342, Fax: (801) 750-9540 on September 15, 1995 (09:57). Fax message contains 5 pages (including cover).

21. Personal Telefax Communications with Craig Knox of Campbell Scientific, Inc., 815 W. 1800 North, Logan, UT 84321-1784, Phone: (801) 753-2342, Fax: (801) 750-9540 on September 15, 1995 (12:02). Fax message contains 3 pages (including cover).

22. Personal Telefax Communications with Rachel Burton of Campbell Scientific, Inc., 815 W. 1800 North, Logan, UT 84321-1784, Phone: (801) 753-2342, Fax: (801) 750-9540 on September 15, 1995 (14:38). Fax message contains 16 pages (including cover).