SUBSURFACE STORMFLOW CHEMISTRY FROM

A FORESTED HILLSLOPE IN THE

OUACHITA MOUNTAINS

By

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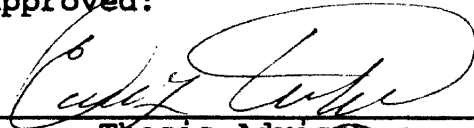
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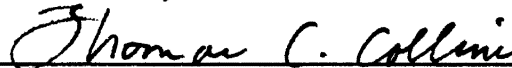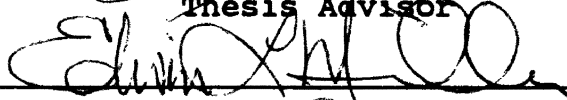
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CHAPTER I

INTRODUCTION

Forest watersheds are complex systems which provide important resources for our use. Forests provide jobs, water, recreation, raw materials, wildlife habitat, aesthetic beauty and a number of non-tangible benefits. Commercial activities within the forest such as timber harvest and replanting, require special considerations with respect to a watershed or small hillslope. Unique methods of operation are implemented to maximize the financial assets while minimizing the negative effects imposed on the soil structure, nutrient cycle balance, and hydrology of the site. In order to protect this complex system, it is important to understand the processes that determine the nutrient balance within a forested watershed.

Many factors influence the seasonal fluctuations of nutrient transport and subsurface flow. These factors include; rainfall intensity and frequency, percentage of throughfall, stemflow, infiltration rates, macropore abundance and proximity to stream channels, climate, and season. Although recent research by Miller (1984), Rochelle and Wigington (1986), and Turton (1989), has addressed bulk water chemistry and streamflow generation, little is known

about the chemical changes that occur during a storm event and the factors which control these fluctuations.

Because of acid precipitation and the application of chemicals throughout the forest, the need to improve our overall understanding of watershed water chemistry has become pertinent. Nutrient import and export balance fluctuations must be researched, understood, and maintained to provide for successful management practices in the commercial forest industry.

Objectives

This study concentrates on the subsurface flow chemistry of a forested hillslope in the Ouachita Mountains of central Arkansas. The research effort represents a first attempt at measuring the chemical changes of litter layer, A, B, and C horizon subsurface flow during rainfall events.

The following is a list of the objectives of this study:

1) To measure the changes in concentrations of mobile cations and anions in the subsurface flow of upper hillslopes from the litter layer, A, B, and C soil horizons during storms.

2) To determine the timing of subsurface flow chemistry changes during three individual storm events that occurred over three consecutive days.

CHAPTER II

LITERATURE REVIEW

Subsurface Flow on Forested Hillslopes

Subsurface flow, also called throughflow or interflow, is defined as infiltrated precipitation that travels through the soil to the stream without entering the regional groundwater table (Whipkey, 1965 and Dunne and Black, 1970a). Subsurface flow occurs within hillslopes composed of highly permeable soils underlain by less permeable layers such as fragipans, claypans or partially weathered shallow bedrock (Dunne 1978).

The subsequent discussion will describe the process of subsurface flow in forested hillslopes and the ancillary effects on subsurface flow water chemistry.

Subsurface stormflow on forested hillslopes has been the topic of detailed study by several researchers. Hursh (1944) suggested that biological channels may function as hydraulic pathways and increase lateral transmission rates. Furthermore, he concluded that the establishment and height of ephemeral water tables would be limited by these tremendous lateral transmission rates. Whipkey's (1965 and 1966) research indicated that subsurface stormflow may move

laterally without entering the groundwater. Weyman's (1970 and 1973), studies of throughflow on hillslopes, showed rapid subsurface flow in the B soil horizon, followed by a more gradual response in the B/C horizon. He concluded that throughflow is the dominant process of water transmission contributing to streamflow. A similar study of lateral flow was conducted on forested watersheds in the coastal plains of northern Mississippi by Beasley (1976). Subsurface flow from the A and A/B soil horizons were measured. His studies found that subsurface flow over an impermeable clay layer could account for as much as 90% of rainfall, during a calendar quarter. Subsurface flow from the B and C horizon accounted for half of the annual precipitation (Beasley, 1983). Beasley (1983) also showed, lateral flow above the B horizon to be negligible. Turton (1989) studied subsurface flow on a small forested watershed in the Ouachita Mountains of southeastern Oklahoma. He concluded that shallow subsurface flow contributed as much as 48% of the total streamflow and it began within 15 minutes of the onset of precipitation. He attributed the rapid streamflow response to macropore flow.

The chemical changes that occur in the water as it passes through the soil matrix, are a function of the infiltration pathway, the rate at which water passes through each soil horizon, and the chemical properties of each horizon.

Subsurface flow follows channels or pathways of least resistance known as preferential flow paths. Subsurface pathways include micropores, mesopores, and macropores. Examples of preferential flow paths or continuous macropores include: rodent holes, earthworm holes, decayed root channels, crotovinias, cracks between soil pedons, and cracks in underlying rocks (Horton, 1933; Hursh, 1944; Gaiser 1952; Aubertin, 1971; Bevin and Germann, 1982).

Macropores.

Macroporosity was defined by Mosley (1979) as the percentage of soil pores drained at a tension of 50 cm of water for 24 hours and by Luxmoore (1990) as the hydrologically active pores larger than 1 mm in diameter. Continuous macropores have small surface areas and behave much like physical conduits which can transport significant quantities of water while having little effect on water quality (Pilgram and Huff, 1978; Mosley, 1982; Bevin and Germann, 1982; Wilson and Luxmoore, 1988; Jardine et. al., 1989).

Subsurface flow velocities in macropores may be up to 300 times greater than velocities in the soil matrix (Mosley, 1979). Rapid buildup of water tables above impermeable layers have been attributed to the flow contribution of continuous cracks and macopores (McDonnel 1990). In order for subsurface flow to occur in macropores, they must be open to the atmosphere and have a positive head

of water at the openings such as stem flow accumulation at the bases of trees (Beasley 1976).

Mesopores.

The intermediate pore class termed mesopores, (Luxmoore, 1981) has also been shown to be capable of rapid hydraulic conductance. Mesopores have been functionally defined as drainable pores <0.1 mm diameter that are generally drain at field capacity (Luxmoore, 1990). Mesopore water is thought to mix rapidly with old water in the soil matrix pores, providing greater opportunities for chemical interaction between water and the soil along flowpaths. Mesopores are believed to be the key pore size class influencing solute transport and soil weathering process because they are hydrologically active for a large portion of the storm hydrograph (Wilson, 1990).

Soil Moisture and Subsurface Flow.

When soil water contents are intermediate, (between wilting point and field capacity) infiltration into small pores of the soil matrix result in subsurface storage (Wilson, 1990). Subsurface flow rates are not determined by gross rainfall or rainfall intensity under dry conditions (Wilson, 1990). The litter layer, organic coatings or linings on soil pedons, and clays create a resistance to wetting or "hydrophobicity". The hydrophobicity prevents infiltration into the soil matrix and encourages macropore

flow. Furthermore, macropores having organic linings retard cation movement to a greater extent than macropores with mineral coatings (Turner and Steel, 1988). Hydrophobicity is diminished as following storm events moisten the soil surface and the preferential flowpath surfaces. Preferential flow through macropores and mesopores are not only prevalent under dry conditions, but also during extreme wet conditions that occur throughout the winter (Wilson, 1990).

Canopy Effects on Water Chemistry

Transport of chemical constituents on the watershed begins via water movement of rainfall through the tree canopy. Rainfall duration and intensity determine the volume of throughfall, and stemflow infiltrating into the litter layer and the A, B, and C, soil horizons. Further chemical changes occur as water flows through soil horizons that posses variable chemical characteristics.

The chemistry of precipitation, whether basic or acidic plays a major role in the chemical interaction or changes that occur within the various soil horizons. Rainfall chemistry can be altered as precipitation comes in contact with leaf surfaces. This precipitation is known as throughfall. Actually, throughfall and stemflow chemistry regulate forest soil chemical equilibrium, more than that of rainfall measured in the open (NCASI 1983a). Throughfall and stemflow percentages of gross precipitation measured on the

Alum Creek Cooperative Watershed Number 11 in the Ouachita
Mountains, (Beasley et.al., 1988) were 87.3% and 1.78%
respectively.

Measurements of precipitation chemistry (Beasley et.
al., 1988) revealed a reduction in nitrates and ammonium
concentrations after passing through the canopy. The
reduction is contributed to direct uptake by the foliage.
Organic phosphates showed no appreciable modification, and
chlorides increased 2.8 times on pine-hardwood watersheds.

Ahmad Shah (1989) studied the influence of tree
canopies on throughfall water chemistry in the midlands of
England. Concentrations of sodium, potassium, calcium,
magnesium, ammonium, sulfate and chlorides increase as water
passed through tree canopies. The largest inputs occurred
during the winter months when rainfall was maximum.

Parker's (1983) studies of throughfall and stemflow
effects on forest nutrient cycles concluded that the
potassium content of rainfall was almost entirely due to
leaching from foliage. Therefore, temporal potassium
variations beneath pine trees are less than those variations
below deciduous tree species because the evergreen foliage
remains on the tree yearound. Calcium, magnesium,
potassium, and sulfate input and output balances have been
found to be dependent upon forest type (Johnson and Todd,
1990). Recent research on Ouachita Mountain watersheds (Nix
and Thornton, 1986) indicate a near equal balance of sulfate
input-output. These watersheds are especially susceptible

to cation leaching should sulfate inputs increase. Sulfate flux is reduced with depth because of adsorption by the crystalline Fe oxides within the soils (Johnson and Todd, 1983).

Undisturbed soils retain fewer chemicals or solutes than soils that have been disturbed (Jardine et. al., 1988). Much of the Ouachita Mountain forest sites, are rated as sensitive to acidic deposition because of the inherently low alkalinity of soils and streams (Omernik and Powers 1982).

Subsurface Flow and Water Chemistry

New and Old Water.

New water is added to the watershed during a rainfall event. Old water is water stored in the watershed prior to a rainfall event. Under some conditions, new water can displace old water from the subsurface matrix into convergence flow with continuous macropores (Cheng, 1988). Barnes (1992) conducted research on new and old water release on the same watershed as used in this study. He found new water to be dominant for all rainfall intensities, with the maximum new water concentrations coinciding with the peak flow rates of each event. Old water-release percentages were greatest during early stages of flow. Furthermore, he found old water release to be variable and independent of rainfall volume.

Translatory Flow.

The process of new water pushing "pre-event" water downward in a piston-like manner is referred to as translatory flow (Hewlet and Hibbert, 1967). As old water increases in depth and lateral flow, less solute attenuation occurs. Solute export from upper hillslopes is highly dependent upon subsurface flow rates and mineralogical homogeneities of the subcatchment.

Rodimine WT dye tracer experiments conducted (Hammermiester, 1982; Pearce et. al., 1986; Sklash et. al., 1986; Shanley and Peters, 1988) to stain soil peds and macropore openings indicate that streamflow is composed of "old" and new" water. Cheng (1988) found that a flushing effect occurs after a long duration of stormflow, and new water will eventually dominate streamflow.

CHAPTER III

MATERIALS AND METHODS

Study Area

Location

The study area was located on the Alum Creek
Experimental Forest in the central Arkansas (Saline County).
More specifically, the study was conducted on Alum Creek on
Cooperative Watershed 11 (Figure 1).

Streamflow and precipation has been continuously
monitored on Watershed 11 since 1978. Additional monitoring
of streamflow, peak flow and erosion have been conducted on
the study site (Miller et al., 1988).

Cooperative Watershed 11 occupies a north facing area
of 4.93 hectares. The legal description of the site is T2N,
R19W, NW1/4 sec. according to the United States Geological
Survey (USGS) Paron Southwest Quadrangle map.

Climate

The climate of Saline County Arkansas is characterized
as temperate-humid. Temperatures average 6.1 C in winter,
and 26.1 C in summer. During the period of 1951 to 1973, a
maximum temperature of 42.8 C and a minimum temperature of

ALUM CREEK WATERSHEDS
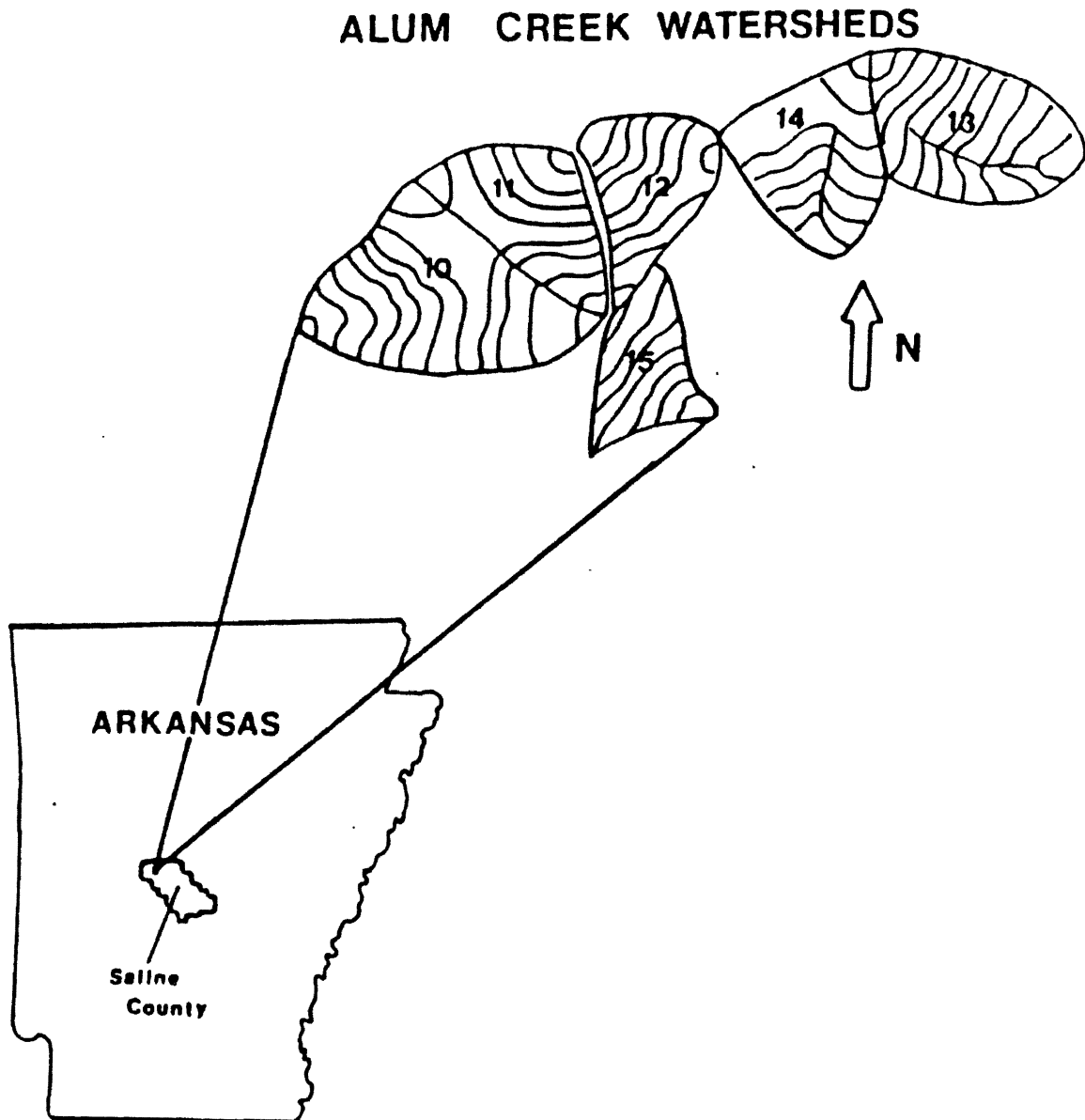
Figure 1. Location map of the Alum Creek Cooperative Watersheds (Modified from Miller et. al., 1988).

-21.7 C was recorded at the Alum Fork Station (Haley, 1979). The average annual temperature is 17 C (N.O.A.A., 1987). Average relative humidity ranges from approximately 55% during the afternoon to 85% at night.

Average annual precipitation for the study area is approximately 132 centimeters (cm). On the average, 69 cm falls between April and September (N.O.A.A., 1987). Although the majority of the annual precipitation falls as rainfall, 1 to 2 percent may fall as snow (Lawson, 1975).

Topography

Watershed 11 elevations range from (366 m) above sea level (MSL) at the top of the watershed and less than (335 m) at the outlet. Hillslopes on the upper 2/3 of the watershed are relatively smooth, with a constant gradient approximately 20-25% (Williams, 1989). The subsurface flow analyzed in this study was collected from the upper portion of watershed number 11. Average slopes of about 20 percent with steeper breaks up to 30 percent around stream channels were common on the watershed.

Geology

The Ouachita Mountains of today, are comprised of rounded ridge tops, smooth slopes, and broad basins. Sedimentary rocks provide the basal parent material for the watershed.

Pennsylvanian Jackfork sandstone and Mississippian Stanley Shale are the most representative sedimentary rocks present at the study site. Stone (1988) described the Jackfork sandstone as a thin to massive, light-brown, fine-grained, quartzitic sandstone. He described the Stanley shale as a black to brown, thin to massive, fine grained, feldspathic shale. The Stanley shale, in the study area, is often more of a weakly metamorphosed slate (Stone, 1989) (Figure 2).

The Alum Creek basin provides surface water for surrounding area lakes, such as Lake Winona. Local municipalities rely heavily on water from these lakes. The ground water of the region may be found in fractures of the sedimentary parent material. However, matrix porosity is low and most wells yield less than 38 liters per minute. The two regional aquifers lie over 600 meters below the surface and are not of economic use (Bryant et al., 1985).

Soils

The soils on the Alum Creek study site are classified by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) as Carnasaw-Townley-Pirum Association. These soils are specifically classified as Carnasaw stony silt loams (Haley, 1979). Carnasaw and Townley soils lie on hilltops, side slopes, and in low
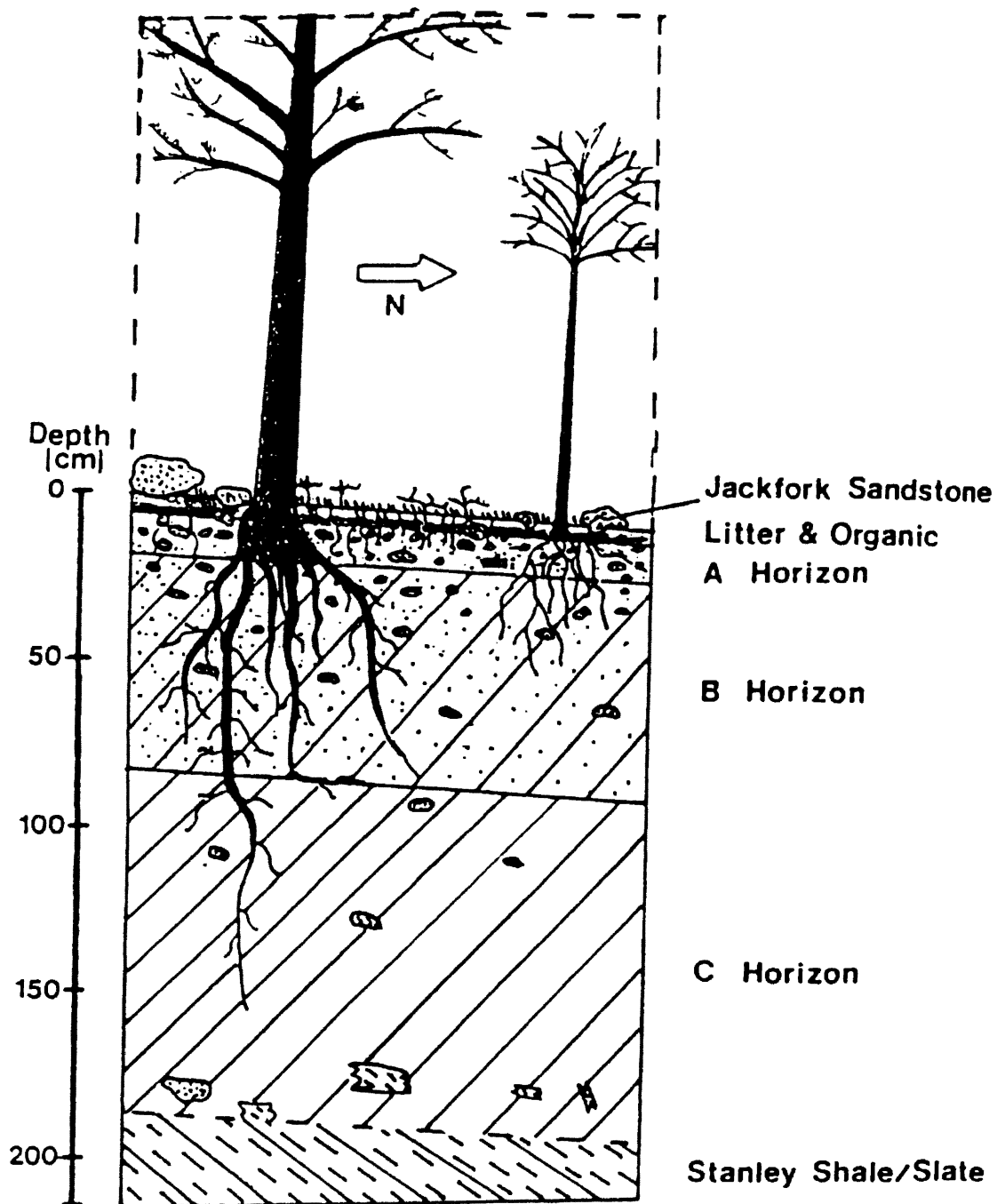
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Figure 2. Generalized soil and geology profile, based upon well construction data. (from Williams 1990)

valleys. The surface layer is dominantly gravelly silt loam which overlies a clayey subsoil, derived from weathered shale. The soils are fine-textured, well-drained, undulating and moderately deep (Haley, 1979).

Beasley et al. (1988) conducted experiments on a forested hillslope approximately 15 meters from the hillslope on which this study location. He described the soil profile as very strongly acid with a pH range of 3.56-3.77. The loamy A horizon, lies beneath a sandstone rock pavement approximately 15 cm thick. A strong developed clayey B horizon, extends to shale bedrock at approximately 100 cm.

The total depth of the C horizon is uncertain because there is not a clear boundary change. However, measurements on the site indicated an average depth of 186 cm (Figure 3). It should be noted that soil depth changes with topography. Near stream channels the soil horizons are thin and the B and C horizons are often indistinguishable. On flat upland regions the soil horizons are somewhat deeper.

According to Haley (1979), the saturated permeabilities of the soils under study range from 4.2×10^{-4} to 1.4×10^{-3} cm/sec in the upper horizon (0-20 cm), to 4.2×10^{-5} to 1.4×10^{-4} cm/sec in the lower horizon (20-100 cm). The available water capacity varies from .08 to 2.0 cm/cm.

Vegetation

The Alum Creek Watersheds are vegetated with both hardwoods and pines. On recently undisturbed sites, such as Watershed Number 11, short leaf pine (<u>Pinus eucinata</u>) dominates. Where forest harvest and pine regeneration practices have taken place, as in adjacent watersheds, loblolly pine (<u>Pinus taeda</u>) or short leaf pine may be found.

Hardwood species include: white oak (<u>Quercus alba</u>) red oak (<u>Quercus rubra</u>), Dogwood (<u>Cornus florida</u>), red maple (<u>Acer rubrum</u>), hickory (<u>Carya, sp.</u>) and black gum (<u>Nyssa silvatica</u>). The understory consists of various herbaceous species, such as green briar, poison ivy and various shrubs (Lawson 1985).

Field Methodology

To measure subsurface flow rates and chemistry, the following instrumentation was used. A continuously monitoring rain gage, and a subsurface flow collection system. Water samples for chemical analysis were collected with ISCO automatic pumping samplers. Water samples for chemical analysis were sent to the Oklahoma State University Forest Hydrology Laboratory.

Rain Gage

The United States Forest Service has been monitoring precipitation from the experimental forest since 1978. A

rain gage was located immediately adjacent to the study site. This gage was used to monitor precipitation inputs and timing. The gage is a standard continuously recording, weighing-bucket gage, which was placed in an area free from throughfall losses.

Water Sample Collection

Discrete samples of subsurface flow from the litter layer, A, B and C horizons were collected with ISCO automatic pumping samplers. Sampling intervals varied form 10 to 60 minutes depending on horizon and how rapidly subsurface flow changed during storms. Samples were immediately frozen following collection until laboratory analysis could be performed.

Subsurface Flow Collection System

Two subsurface flow collection systems were strategically placed in the watershed (Figure 3). These collection systems were used to monitor saturated interflow in the litter layer, A (includes A1 & E), B (includes Bt21, Bt22, & Bt23), and C horizons. The collection systems are based upon the design used by Whipkey (1965) and have been used by various researchers. Turton et al. (1988) modified the system to be continuously monitoring. Furthermore, care was taken in following the design criteria of Atkinson (1978), for the construction and placement of the throughflow troughs.
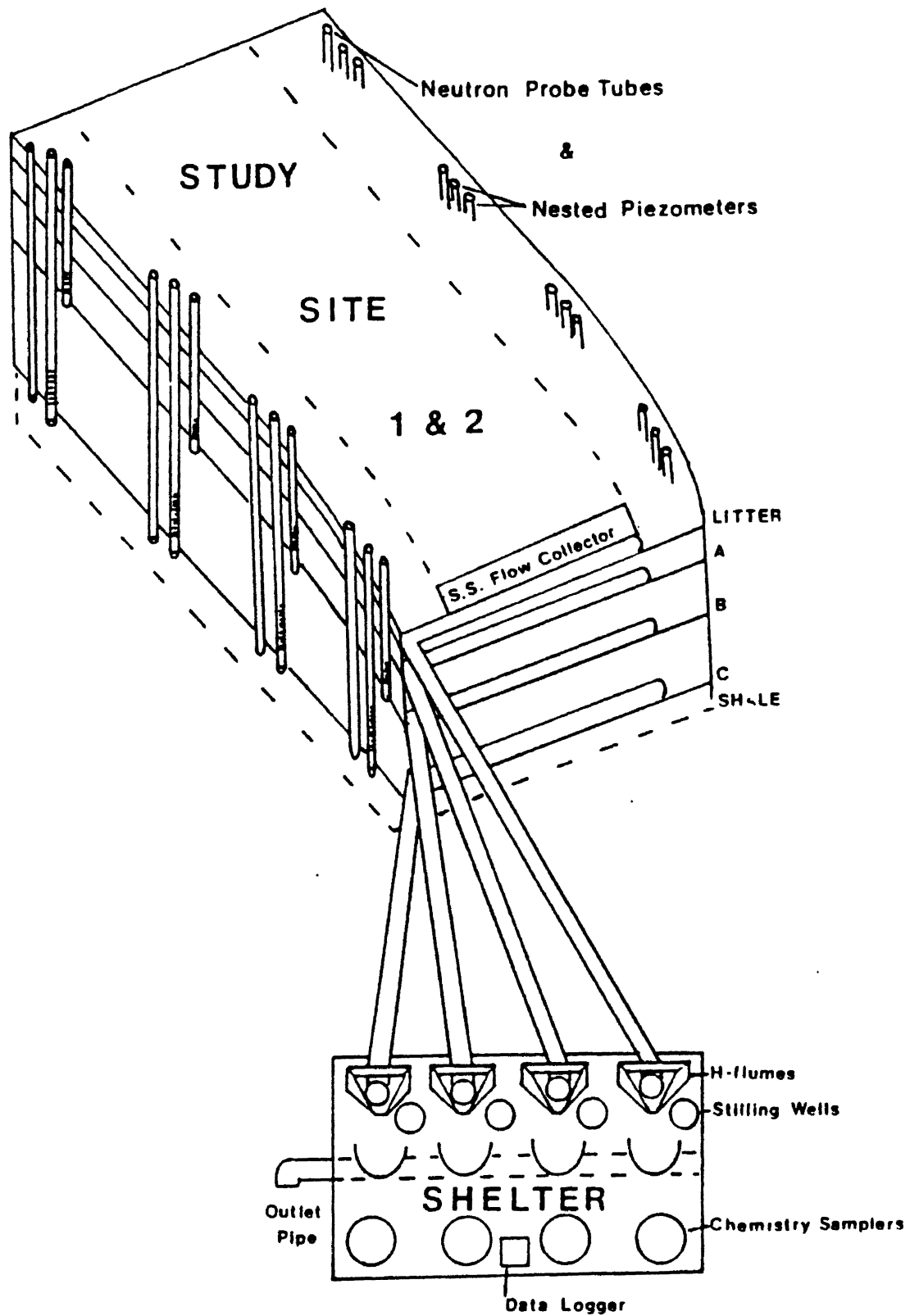
Figure 3. Subsurface flow collection system (based upon the design by Turton et. al., 1988).

The subsurface flow system consists of a 6.7 m long trench, excavated to bedrock (approximately 2 m). Four collection troughs were placed at the interface between the different soil horizons. The troughs direct the water toward a shelter, where 15.24 cm (6 inch) H-flumes and a data logging system was used to measure the timing, flow rate and the volume of subsurface flow. FW-1 water level recorders were used as a back up to the system. For a detailed description, see Turton et al. (1988).

Chemical Analysis

The chemical constituents investigated in this study, included cations, anions, pH, conductivity, and dissolved organic carbons. The subsurface water samples were analyzed for the following cations, Calcium (Ca^{++}), Magnesium (Mg^{++}), Potassium (K^+), and Sodium (Na^+). Anions analyzed consisted of Chloride (Cl^-), and Sulfate (SO_4^{-2}).

Cations.

The cation concentrations in the subsurface water samples were determined by testing samples on an Atomic Absorption (AA) spectrophotometer. The calcium (Ca^{++}) and Magnesium (Mg^{++}) were analyzed by lamp emission spectrophotometry. Potassium (K^+) and Sodium (Na^+) concentrations were determined by flame emission spectrophotometry. All cations were determined by comparing sample emmission levels to those developed to a standard

curve utilizing concentrations of 0.20, 0.50, 1.00, and 2.00 (mg/L) for each cation.

Anions.

Concentrations of anions in the subsurface water samples were determined by Ion Chromatograph (IC). Each anion was measured in comparison to standard IC solutions for each anion.

pH and Conductivity.

Both the pH and the conductivity of the subsurface water samples were determined by the use of respective meters. The pH meter was calibrated at two known points using a 7.00 pH solution and a 4.00 pH solution. The conductivity meter is calibrated by using a conductivity check solution.

Dissolved Organic Carbon Index.

A dissolved organic carbon index was determined by the use of a spectrophotometer. Tannic acid was used as the standard solution in the analysis. Standard solutions of 5, 10, 50, 100, 200, and 500 mg/L were prepared to compare to readings of the subsurface water samples.

Quality Assurance and Quality Control

Quality assurance and quality control was accomplished by analyzing duplicate samples every ten samples, and spike duplicate samples every twenty samples. The Oklahoma State University Forest Hydrology Laboratory operates in accordance with an Environmental Protection Agency Quality Control Program. A sample provided by the EPA was analyzed every twenty samples. The results were considered acceptable if within one standard deviation of the EPA mean sample concentration. In the event the results were not within standard deviation, a new laboratory standard curve was created.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

Data from three consecutive storms were chosen for analysis. Water chemistry data was obtained from analyzing water samples gathered from the subsurface flow collectors on the study site. Graphs were created using the selected data to illustrate rainfall depth, subsurface flow rate from the litter layer, A, B, and C soil horizons over time, and changes in chemical concentrations in the litter layer, A, B, and C horizons over time. The graphs are organized in chronological order of the storm events, 4/26/91, 4/27/91, and 4/28/91. They are also organized by chemical constituent.

Cations
Calcium   (Ca^{++})   Figures 4, 5, 6
Magnesium (Mg^{+})   Figures 7, 8, 9
Potassium (K^{+})   Figures 10,11,12
Sodium   (Na^{+})   Figures 13, 14, 15
Hydrogen   (H^{+})   Figures 16, 17, 18

Anions
Chloride (Cl^{-})   Figures 19, 20, 21
Sulfate (SO_4^{-2}) Figures 22, 23, 24

Other
Conductivity   Figures 25, 26, 27
DOC Index   Figures 28, 29, 30

TABLE I

RANGE OF WATER CHEMISTRY CONCENTRATIONS FOR 3 STORMS

APR. 26, 1991									
H ueq/l	COND uMHOS	Ca Ueq/l	Mg ueq/l	K ueq/l	Na ueq/l	CL ueq/l	NO3 ueq/l	SO4 ueq/l	DOC INDEX mg/l
LITTER 7.1	16.2	44.4	31.3	11.3	14.8	6.6	0	26.2	116
19.3	23.2	78.3	52.6	21	28.3	98.7	48.6	51.6	220
A Horiz. 8.7	17	39.4	31.3	12	16.1	10.9	0	26.5	123
19	26.1	64.4	60.2	16.6	30.4	80.4	17	53.2	238
B Horiz. 6.4	17.2	38.4	39.5	12.5	20	9.8	0	29.9	108
17.1	23.4	72.4	57.6	17.1	38.7	34.6	15.9	60.8	203
C Horiz. 0.1	20.2	12	107	1.5	58.3	46.2	0.1	24.1	0
0.2	21.6	14	116.9	4.1	68.7	63.3	0.2	26.8	0
RANGE 0.1	16.2	12	31.3	1.5	14.8	6.6	0	24.1	0
Apr. 26 19.3	26.1	78.3	116.9	21	68.7	98.7	48.6	60.8	238

APR. 27, 1991									
LITTER 15.6	17.1	40.9	31.3	11.5	16.5	9.2	0	35.9	175
17.3	20.7	53.9	41.4	13.3	20.4	31.3	0	40.6	192
A Horiz. 15.6	17.2	39.9	34.6	12.3	17.8	9.8	0	28.8	147
18	21	48.4	41.1	13.8	24.8	20.9	23.06	55	195
B Horiz. 11.9	17	26.9	38.7	10.2	14.4	8.4	0	34.6	73
16	23.4	51.9	51.8	13.6	33.1	37.6	11.14	56.9	185
C Horiz. 0.1	16.5	12.5	54.3	2	37.4	21.7	0	20.8	0
10.5	24.4	38.9	117.7	15.9	75.3	120.9	0	32.2	177
RANGE 0.1	16.5	12.5	31.3	2	14.4	8.4	0	20.8	0
Apr. 27 18	24.4	53.9	117.7	15.9	75.3	120.9	23.06	56.9	195

APR. 28, 1991									
LITTER 7.8	7.6	5.5	3.3	2	5.2	1.8	0	0	41
21.2	20.6	61.4	48.5	11	26.5	21.9	0	42.1	258
A Horiz. 18.4	17.6	40.4	33.7	8.4	12.6	7	0	27	165.8
21.4	20	55.4	42	12.5	23.5	21.8	20.6	45.4	244.9
B Horiz. 7.3	14.8	7.5	46.1	7.7	11.7	10.9	0	29.3	35.8
22.8	18.9	53.4	54.3	12.5	39.1	59.4	10.3	60	245.4
C Horiz. 3.8	14.2	14.5	48.5	4.6	19.6	1.6	0	29.8	33
15.5	19.4	41.4	60.9	12	31.3	44.4	0	54.5	236.2
RANGE 3.8	7.6	5.5	3.3	2	5.2	1.6	0	0	33
Apr. 28 22.8	20.6	61.4	60.9	12.5	39.1	44.4	20.6	54.5	236.2

Values listed are lowest and highest for each constituent

TABLE II

AVERAGE SOIL CHEMISTRY PROPERTIES
FOR WATERSHED 11
(Beasley et al. 1988)

Soil Property	A Horizon			B Horizon		
	A1	E		Bt21	Bt22	Bt23
pH	3.56	3.77		3.72	3.65	3.66
Total Exch. Acidity (meq/100g)	31.81	10.17		10.23	12.47	12.61
Exch. Al (meq/100g)	2.92	2.58		3.43	7.07	8.13
Exch. H (meq/100g)	1.95	0.92		1.83	1.34	1.36
Exch. Ca (meq/100g)	7.71	0.77		0.59	0.51	0.52
Exch. Mg (meq/100g)	1.17	0.33		0.40	0.56	0.63
Exch. Na (meq/100g)	0.97	0.85		0.88	0.86	0.95
Exch. K (meq/100g)	0.72	0.20		0.21	0.22	0.23
Soluble SO4 (meq/100g)	0.117	0.044		0.068	0.105	0.062
TKN (%)	0.379	0.078		0.062	0.054	0.069

TABLE III

BULK PRECIPITATION (BP) & BULK THROUGHFALL CHEMISTRY (TF)

	COND	Ca^{++}	Mg++	K^+	Na^+	CL^-	SO_4^{--}	H^+
	μmhos	μeq/L	μeq/L	μeq/L	μeq/L	μeq/L	μeq/L	μeq/L
BP	6.59	1.5	2.5	4.9	13.0	15.8	16.4	9.4
TF	7.95	4.5	7.4	17.6	16.5	9.1	22.1	5.7

Samples collected on 4/29/91

Changes in subsurface flow chemical concentrations were observed during each of the three storms. If subsurface flow concentration changes did not fall outside the 95% confidence limits, then the change is not significant. These concentration values were established by using twenty pairs of laboratory duplicate sample analyses for each constituent, to determine standard deviation, and 95% confidence limits. The confidence limit concentrations for each constituent are listed below (Table 4).

TABLE IV

95% CONFIDENCE LIMITS FOR EACH CONSTITUENT
BASED ON LAB DUPLICATE SAMPLE ANALYSIS

DOC INDEX mg/l	COND μmhos	Ca^{++} μeq/L	Mg^{++} μeq/L	K^+ μeq/L	Na^+ μeq/L	Cl^- μeq/L	SO_4^{--} μeq/L	H^+ μeq/L
± 3.5	± .42	± 5.2	± 3.3	± 1.2	± 7.1	± 6.6	± 3.0	± 2.8

Chemical Constituents

Calcium.

The litter layer, A, and B horizon subsurface flow calcium concentrations resembled one another during the storms of 4/26 and 4/27 (Figure 4 & 5). The calcium concentrations of storm 4/28 varied from 5.5 - 61.4 μeq/l (Table 1) following the fluctuations of the subsurface flow rate. The C horizon values for 4/26 & 4/27 storms ranged from 12 - 19 ueq/l (Table 1). C horizon concentrations increased to 38..9 μeq/l at near conclusion of the storm of 4/27 (Figure 5). Concentrations in the C horizon continued to increase during the storm of 4/28 to 41.4 μeq/l (Table 1). As C horizon concentrations of storm 4/28, increased, they became similar to the litter layer, A, and B horizon concentrations. The C horizon concentration changes of the storm of 4/28 closely resembled the subsurface flow rate

fluctuations, especially during the recession limb (Figure 6).

Sources of calcium in forest soil water include mineral weathering, biological processes and organic material decomposition (Hem 1982, Likens et al., 1977). Soils on the study site are low in available calcium (Table 2). Concentrations of calcium in incoming, or new water, are also low. The mean calcium concentrations in bulk precipitation and throughfall for the three storms were 1.5 μeq/l and 4.5 μeq/l respectively (Table 3). Calcium concentrations in subsurface flow from the litter layer, A, and B horizons were higher than C horizon concentrations, ranging between 30 and 60 μeq/l. Calcium sources included biological processes and decomposition. Pollen and dust on the forest floor also contributed small quantities of calcium. Low calcium concentrations in the C horizon reflect the low availability of calcium in the parent material. Biological processes in the C horizon contribute little calcium.

Figure 4. Rainfall, subsurface flow, and calcium concentrations for the storm 4/26/91

Figure 5. Rainfall, subsurface flow, and calcium concentrations for the storm 4/27/91

Figure 6. Rainfall, subsurface flow, and calcium
concentrations for the storm 4/28/91

Magnesium.

Magnesium concentrations in subsurface flow from the litter layer, A, and B horizons for the storm of 4/26 ranged between 31.3 - 60.2 μeq/l(Figure 7). The C horizon subsurface flow concentrations of storm 4/26 ranged from 107 - 116 μeq/l (Table 1). These concentrations were higher than the litter layer, A, and B horizon concentrations, but declined from 117 μeq/l to 54.3 μeq/l at near completion of the storm of 4/27. Magnesium concentrations within the litter layer, A, and B horizons varied between 31.3 - 51.8 μeq/l, during the storm of 4/27 (Figure 8). By the storm of 4/28, the C horizon concentrations decreased to a range of 48.5 - 60.9 μeq/l (Figure 9) which is only slightly higher than the B horizon value range of 46.1 - 54.3 μeq/l and the A horizon value range of 33.7 - 42 μeq/l.

Major sources of magnesium in forest soil water include mineral weathering of parent material and biological processes (Likens et al., 1977). Bulk precipitation concentrations of 2.5 μeq/l were increased to 7.4 μeq/l in the throughfall (Table 3). The exchangeable magnesium concentration in the upper portion of the A soil horizon was 1.17 meq/100g but dropped below .65 meq/100g in the lower horizons (Table 2). Concentrations of magnesium in the C horizon were considerably higher. Hem (1985) found magnesium concentrations to increase along the flow path of

groundwater due to magnesium being precipitated out of solution.

The C horizon magnesium concentrations of storms 4/26 and 4/27, indicated that during antecedent soil water conditions, the C horizon retained a greater concentration of magnesium than contained in precipitation and throughfall. This is due to weathering of parent material and cation exchange.

Figure 7. Rainfall, subsurface flow, and magnesium
concentrations for storm 4/26/91

Figure 8. Rainfall, subsurface flow, and magnesium concentrations for storm 4/27/91

Figure 9. Rainfall, subsurface flow, and magnesium
concentrations for storm 4/28/91

<u>Potassium</u>.

Potassium concentrations in subsurface flow from the litter layer, A, and B, soil horizons displayed some fluctuation during all three storms, ranging from 2 - 21 µeq/l (Table 1). The C horizon concentrations were lower than the other horizons with concentrations below 5 µeq/l for the storm of 4/26 (Figure 10), and below 8 µeq/l for the storm of 4/27 (Figure 11) until an increase to 15.9 µeq/l during the recession limb. This increase was followed on 4/28 (Figure 12) by a concentration range of 5 - 12.5 µeq/l (Table 1).

Sources of potassium in the forest soil water include mineral weathering releases, and small contributions from precipitation input (Likens et al. 1977). Potassium is extremely mobile in plant tissues, and is brought into solution as rainfall passes across leaf surfaces (Whitcomb 1987). Potassium concentrations increased from 4.9 µeq/l in bulk precipitation to 17.6 µeq/l in bulk throughfall (Table 3). Potassium was also released from decomposing organic material as throughfall flowed through the litter layer.

The upper portion of the A soil horizon had an exchangeable potassium concentration of .72 meq/100g which dropped to approximately .2 meq/100g in lower soil horizons (Table 2). Chemical analysis of the litter layer was not conducted, but other horizon concentrations suggest the

litter layer had the highest level of exchangeable potassium.

The range of potassium concentrations in the litter layer, A, and B soil horizons affirm that during the downward movement of throughfall, potassium ions become chemically "tied-up" or exchanged in the A and B horizons, until a significant amount of leaching occurs, such as three consecutive days of rainfall.

Antecedent soil water in the C horizon initially contained low potassium concentrations due to the of absence organic matter in the C horizon parent material. The C horizon concentrations did not increase until near end of the 4/27 storm because the A and B soil horizons supplied ample sites for potassium to chemically re-attach to soil pedons and root surfaces. When these sites became unavailable (occupied), the potassium ions were leached into the C horizon making the soil water similar to the other horizons.

Figure 10. Rainfall, subsurface flow, and potassium
concentrations for storm 4/26/91

Figure 11. Rainfall, subsurface flow, and potassium
concentrations for storm 4/27/91

Figure 12. Rainfall, subsurface flow, and potassium
concentrations for storm 4/28/91

Sodium.

Sodium concentrations in subsurface flow from the
litter layer, A, and B horizons varied from 14.8 - 38.7
μeq/l during the storm of 4/26 (Figure 13). The C horizon
concentrations were higher than other horizon values, and
ranged between 58.3 - 68.7 μeq/l during the storm of 4/26
(Table 1). Subsurface flow concentrations in all horizons
for the storm of 4/27 (Figure 14), resembled those of the
storm of 4/26. At the end of the 4/27 storm, C horizon
values decreased from a range of 75.3 - 57 μeq/l, to 37
μeq/l. By the storm of 4/28 (Figure 15), C horizon
concentrations decreased further to a range of 19.6 - 31.3
μeq/l. At this time, all horizon subsurface flow
concentrations became similar. Sodium concentrations in
subsurface flow are expected to be higher in the C horizon
during antecedent moisture conditions. The clay content in
each soil horizon increases along with soil depth,
permitting cation exchange to replace sodium with calcium or
other ions, and release sodium into solution.

Sources of sodium in forest soil water are
predominantly from mineral weathering releases and to a
lesser amount precipitation inputs (Likens et al., 1977).
A precipitation concentration of 13.0 μeq/l increased only
slightly to 16.5 μeq/l in throughfall (Table 3). This
concentration increase from bulk precipitation to bulk
throughfall, is small compared to the approximate threefold

increase of calcium, magnesium, and potassium. Since interactions of sodium with other ions is generally weak, once sodium is brought into solution, it tends to remain in solution (Hem 1985).
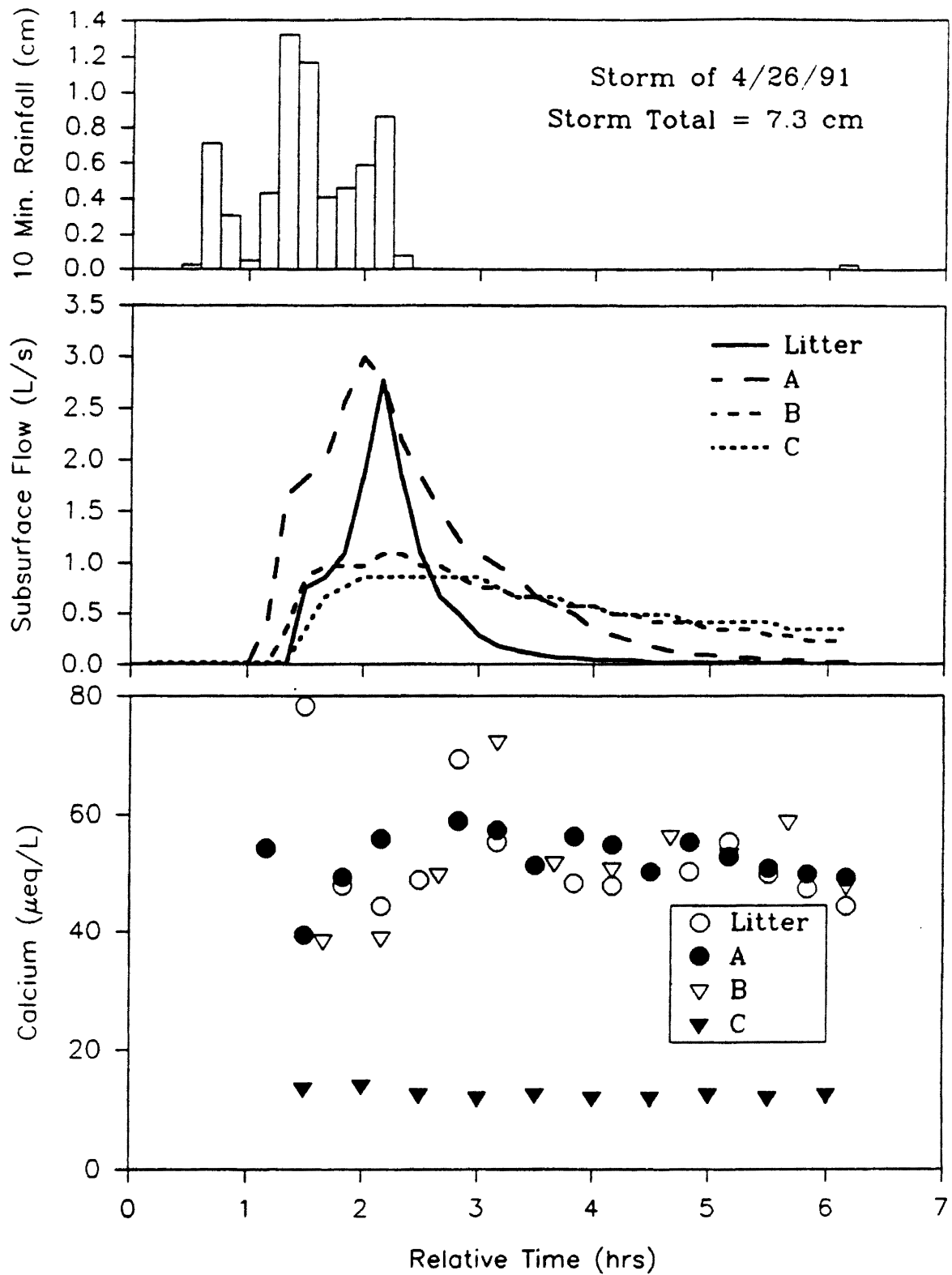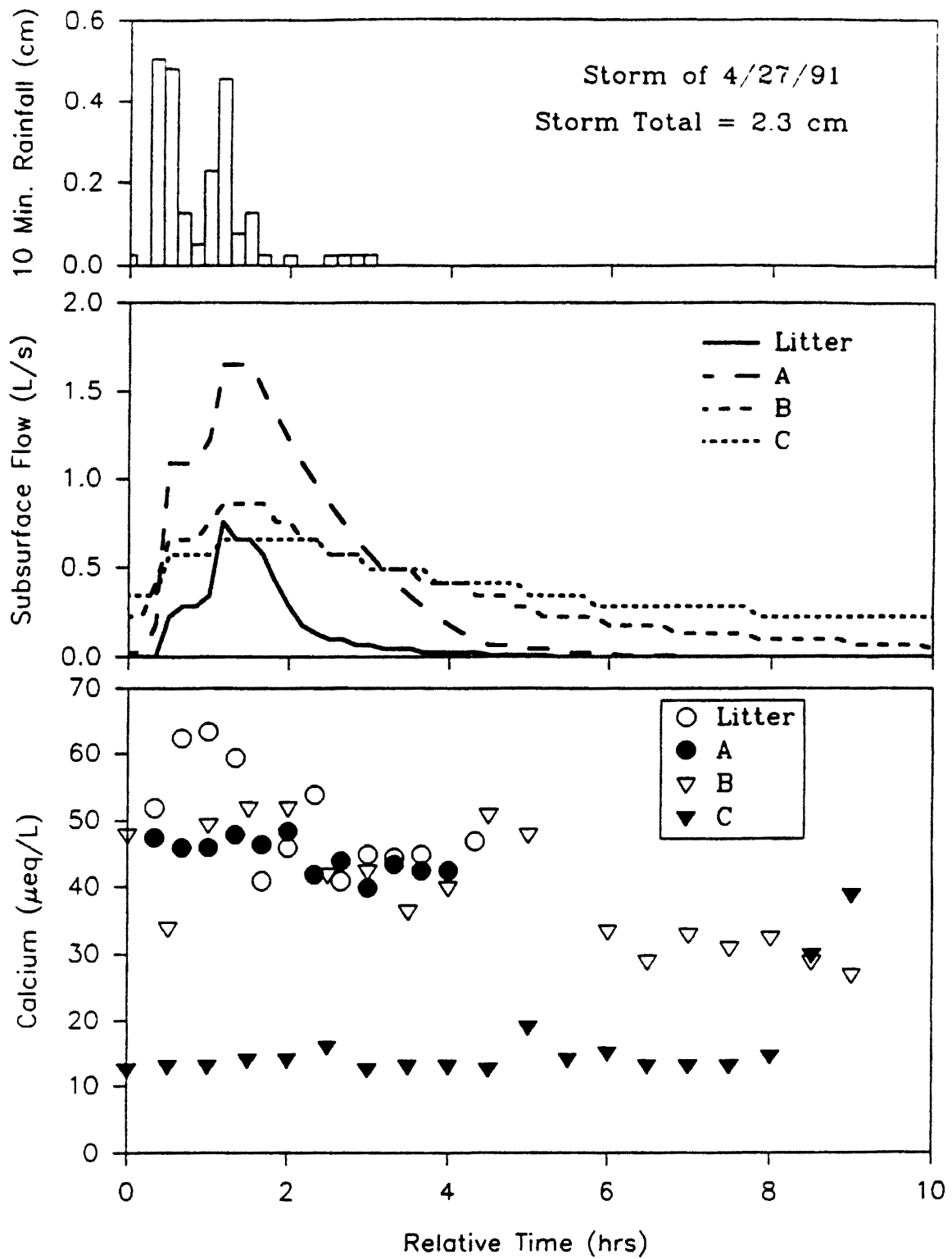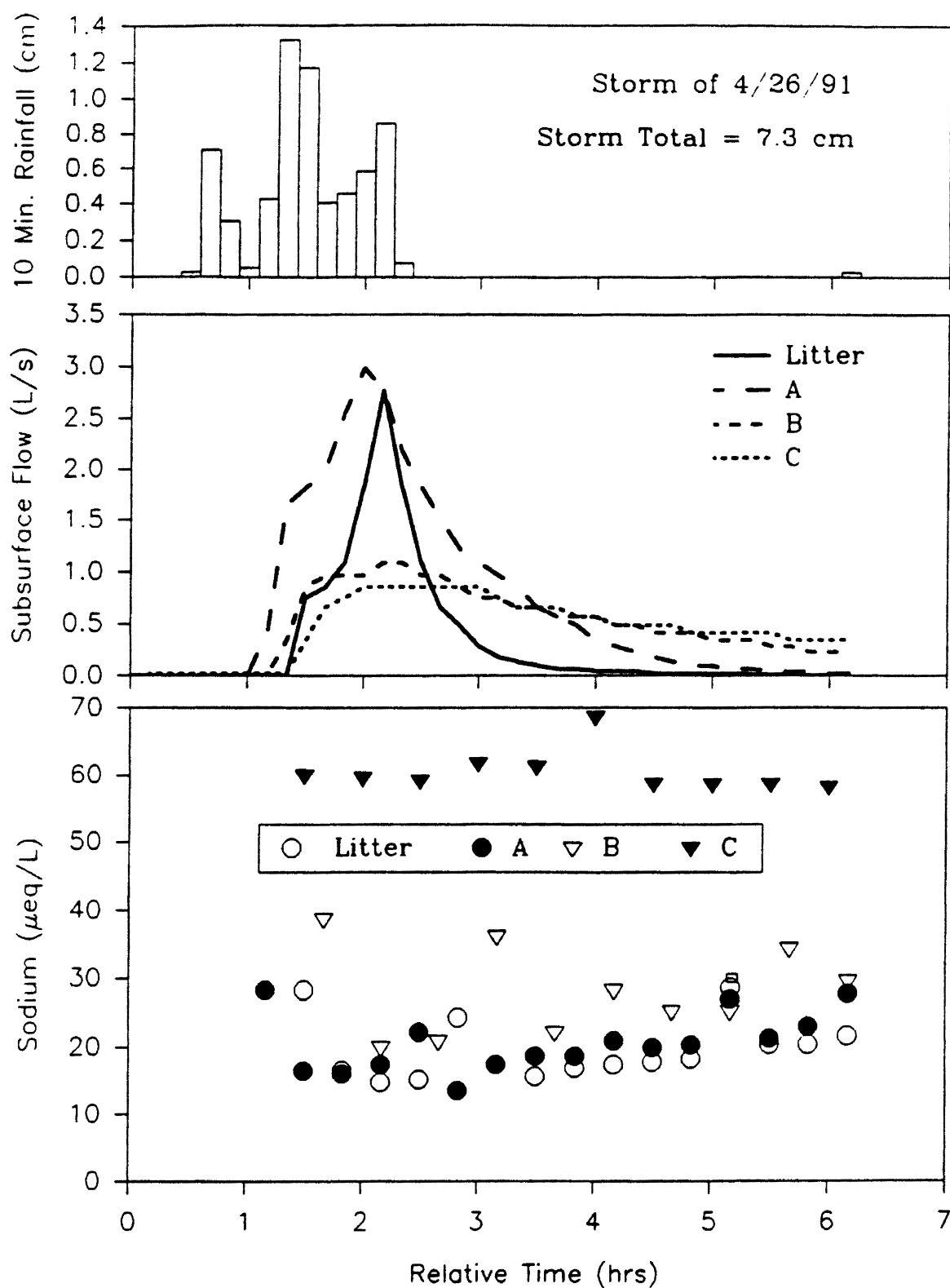
Figure 13. Rainfall, subsurface flow, and sodium
concentrations for storm 4/26/91
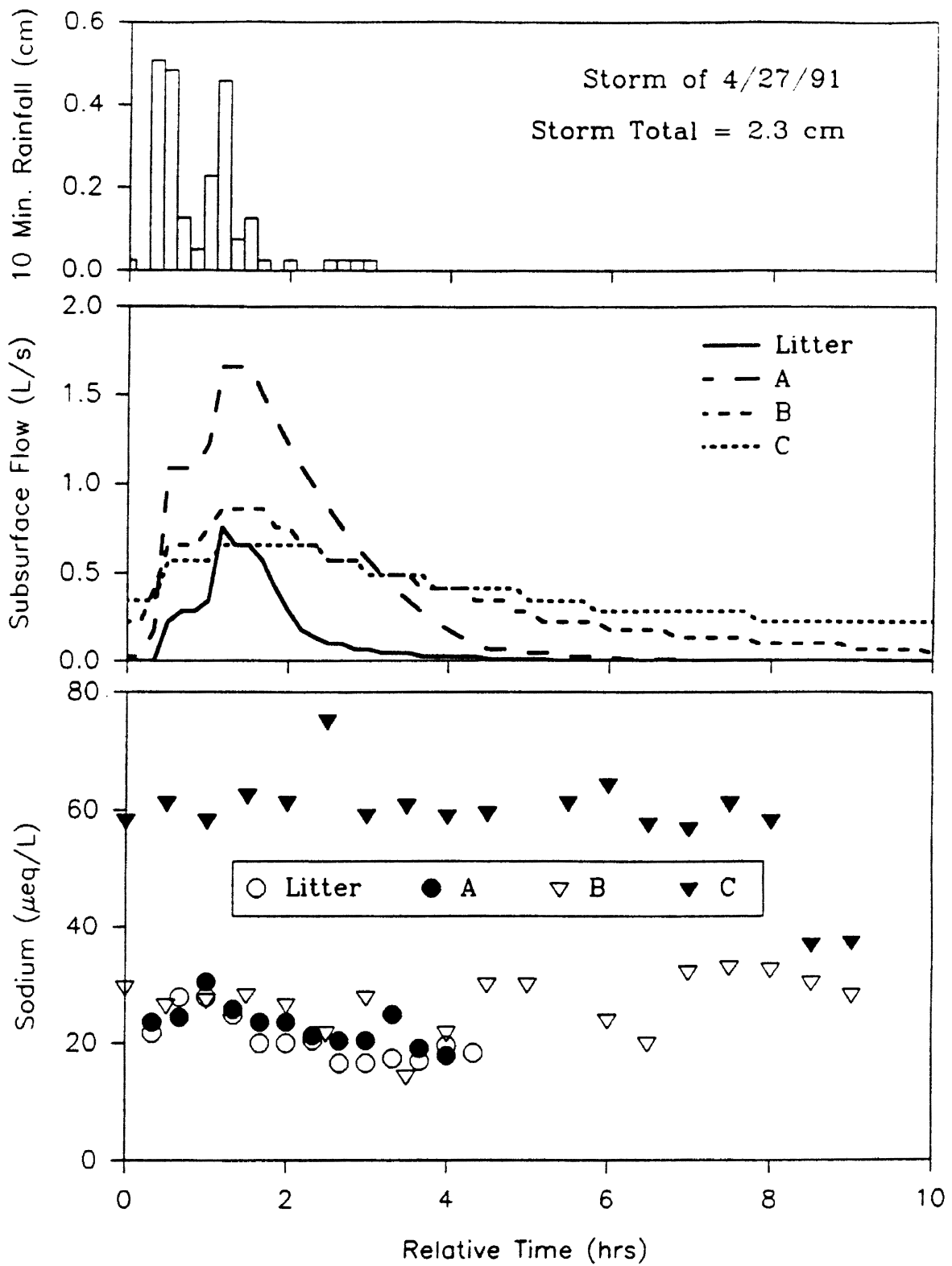
Figure 14. Rainfall, subsurface flow, and sodium
concentrations for storm 4/27/91
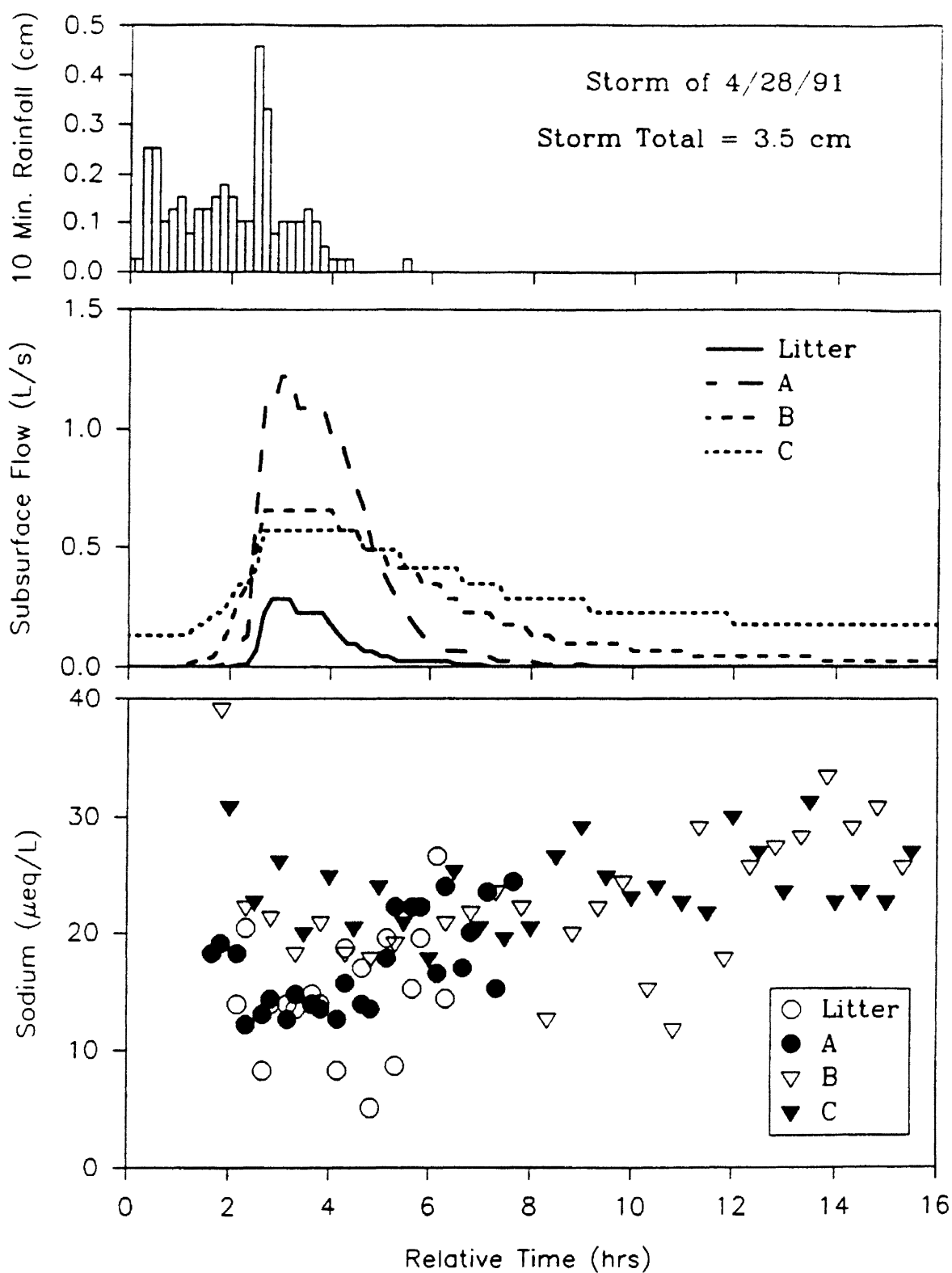
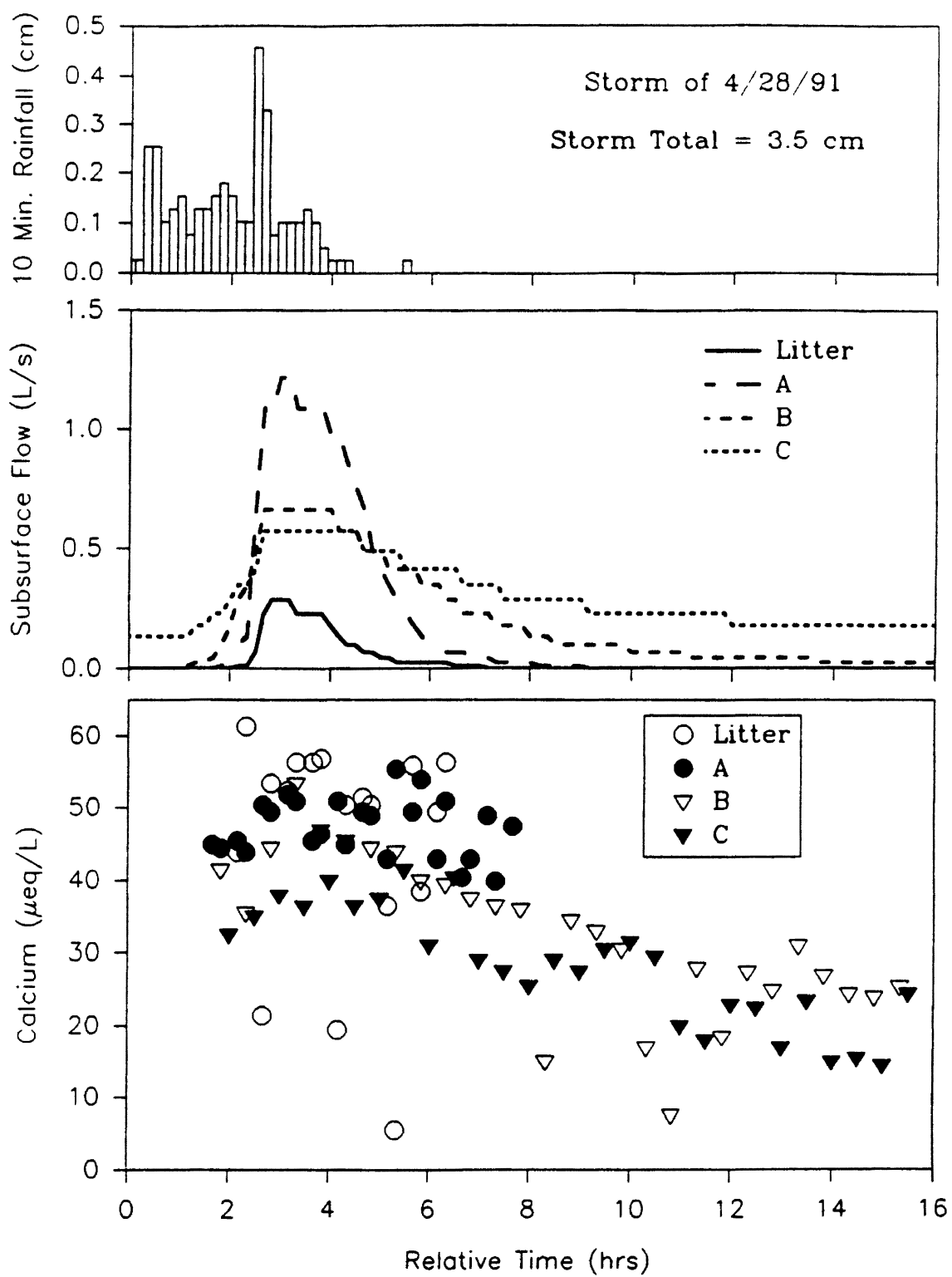Figure 15. Rainfall, subsurface flow, sodium
concentrations for storm 4/28/91

Hydrogen.

Hydrogen ion concentrations in subsurface flow from the litter layer, A, and B soil horizons increased from below 6.4 μeq/l to 19.3 μeq/l during the 4/26 & 4/27 storm events (Table 1). The C horizon concentrations, were much lower, remaining at 0.1 μeq/l during the 4/26 storm (Figure 16) and the majority of 4/27 storm (Figure 17). An increase in hydrogen ions occurred at near end of the 4/27 storm. The 4/28 storm, concentration changes reflected the fluctuations of the subsurface flow rates with a slight increase in hydrogen ion concentrations (Figure 18). Hydrogen ion concentrations increased in all horizons with each of the three consecutive storms. The C horizon concentrations of storm 4/28 increased to 15.5 μeq/l during peak flow of the storm and later decreased to 3.8 μeq/l. This displayed a tendency to return to pre-storm values when retention time was of sufficient length to allow water to interact with the C horizon's parent material.

Sources of hydrogen ions include throughfall, decomposing organic matter, and exchangeable hydrogen found in the soil profile. Throughfall was much more acidic than the antecedent soil water, and decomposing organic matter, released both organic acids and H_2SO_4. A value of 1.95 meq/100g exchangeable hydrogen was found in the upper portion of the A horizon (Table 2). As hydrogen ion

concentrations increase, pH decreases which affects the mobility of other constituents.
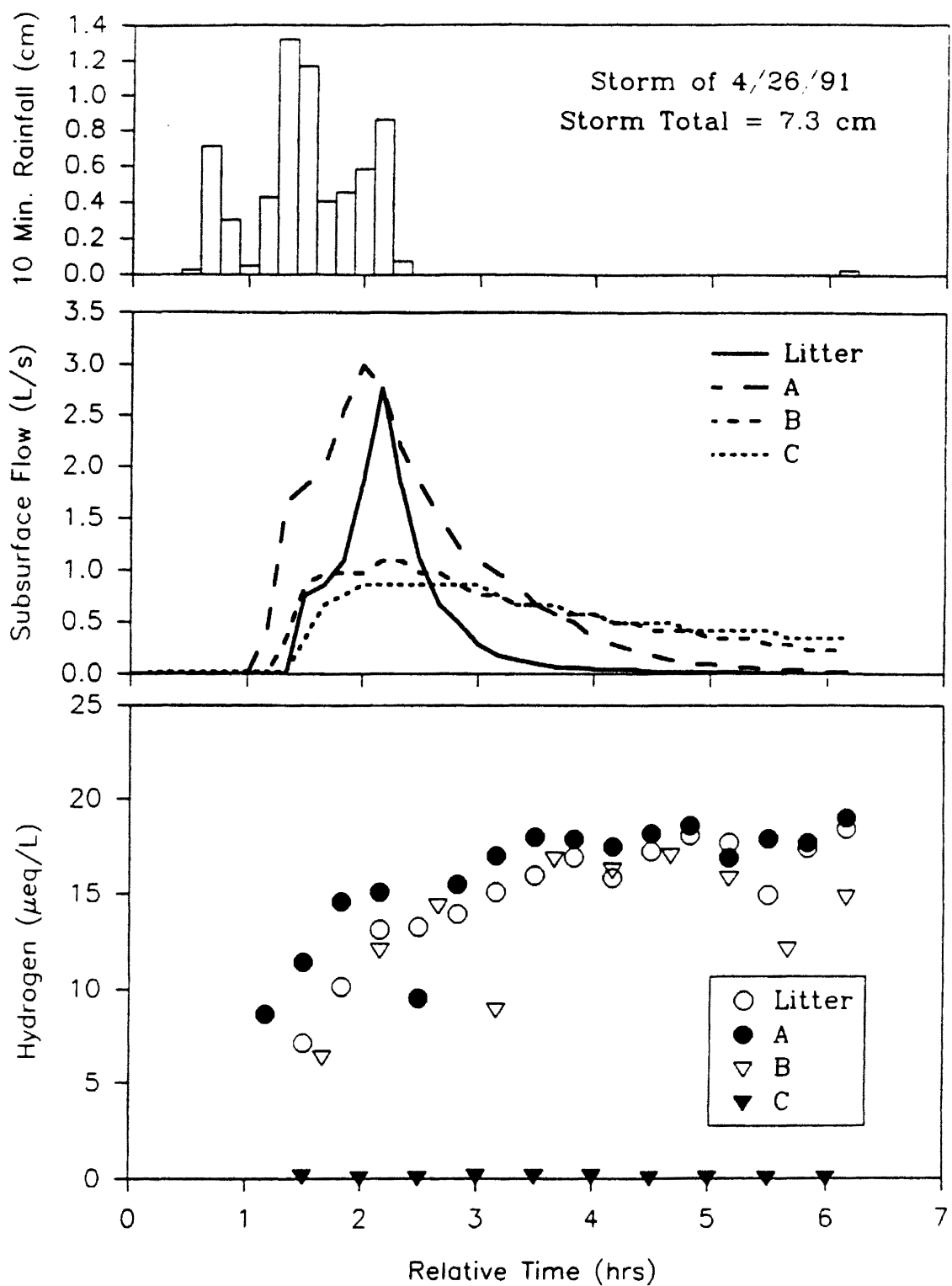
Figure 16. Rainfall, subsurface flow, and hydrogen
concentrations for storm 4/26/91
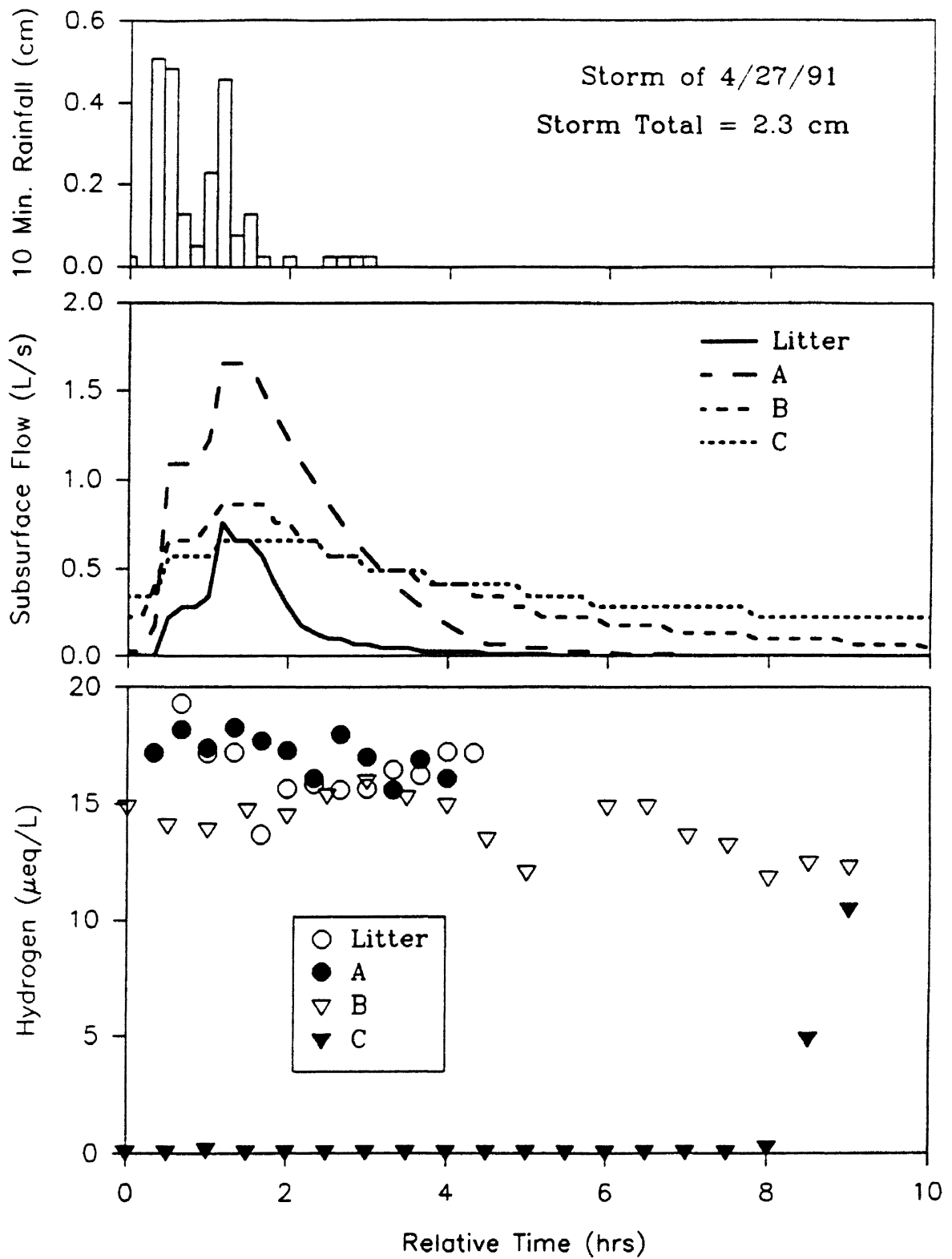
Figure 17. Rainfall, subsurface flow, and hydrogen
concentration for storm 4/27/91
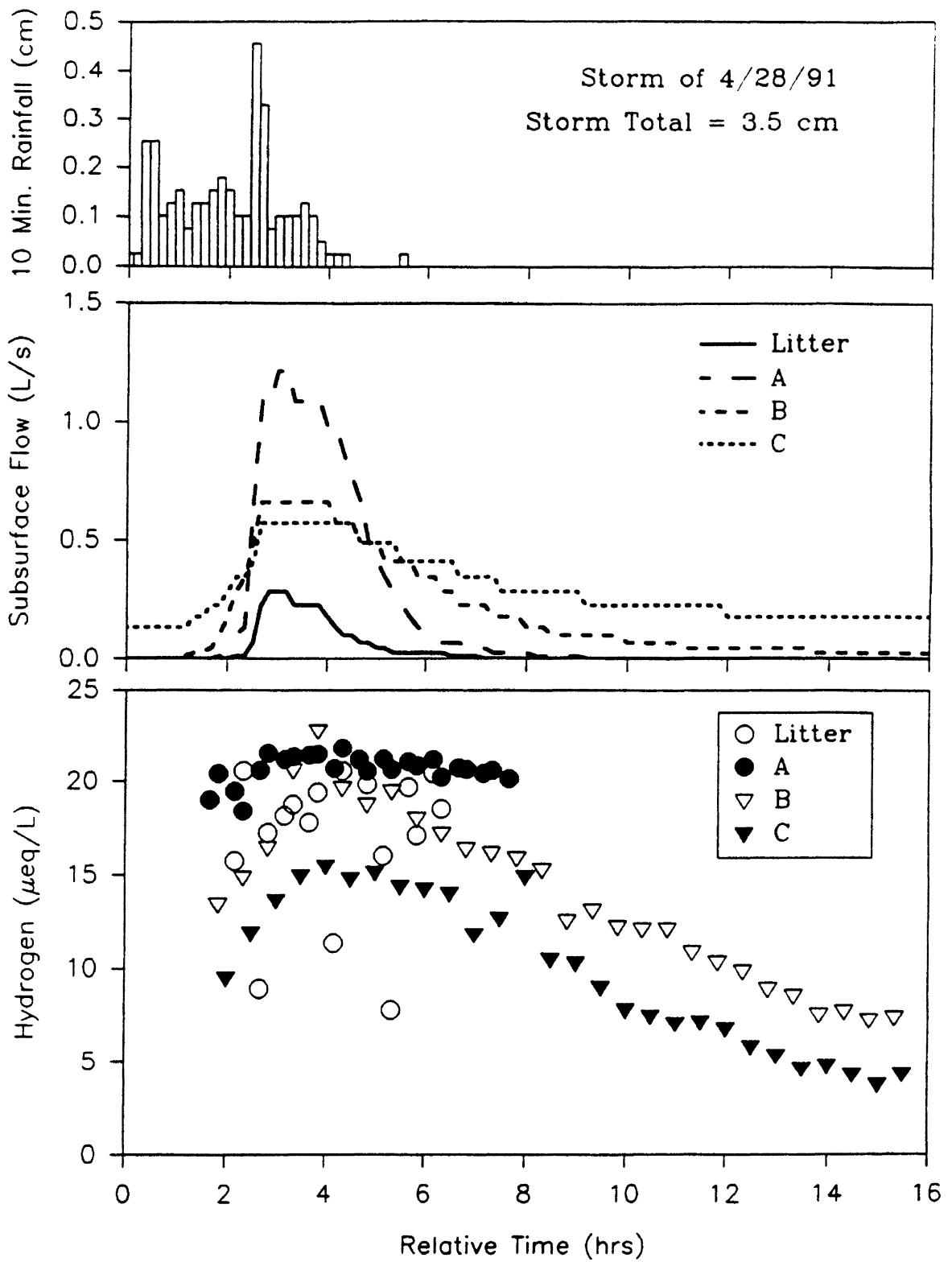
Figure 18. Rainfall, subsurface flow, and hydrogen
concentration for storm 4/28/91

Chloride.

Chloride concentrations in subsurface flow from the litter layer, A, and B, horizons ranged between 0 and 59.4 μeq/l (Table 1) during the three consecutive storms, while the C horizon subsurface flow concentrations remained higher than the other horizon concentrations. During the storms of 4/26 & 4/27 (Figure 19 & 20), the C horizon values ranged between 46.2 - 120.9 μeq/l, decreasing to 21.7 ueq/l at the end of the 4/27 storm. The C horizon concentrations for the storm of 4/28 (Figure 21), decreased to a range of 1.6 to 44.4 μeq/l. At this time, the C horizon closely resembled the other horizons. The primary source of chloride was provided by precipitation (Likens et al. 1977). The bulk precipitation concentration decreased from 15.8 μeq/l to 9.1 μeq/l in bulk throughfall (Table 3). Chloride in the precipitation became chemically "tied-up" to the forest canopy vegetation and decomposing organic material on the forest floor. Chloride concentrations in the C horizon are higher than other horizon values due to concentration from evaporation and transpiration. Another source of chloride in the C horizon subsurface flow was the sediment that comprises the parent material. Chloride is a conservative anion and is an excellent tracer for following subsurface flow through the soil profile.
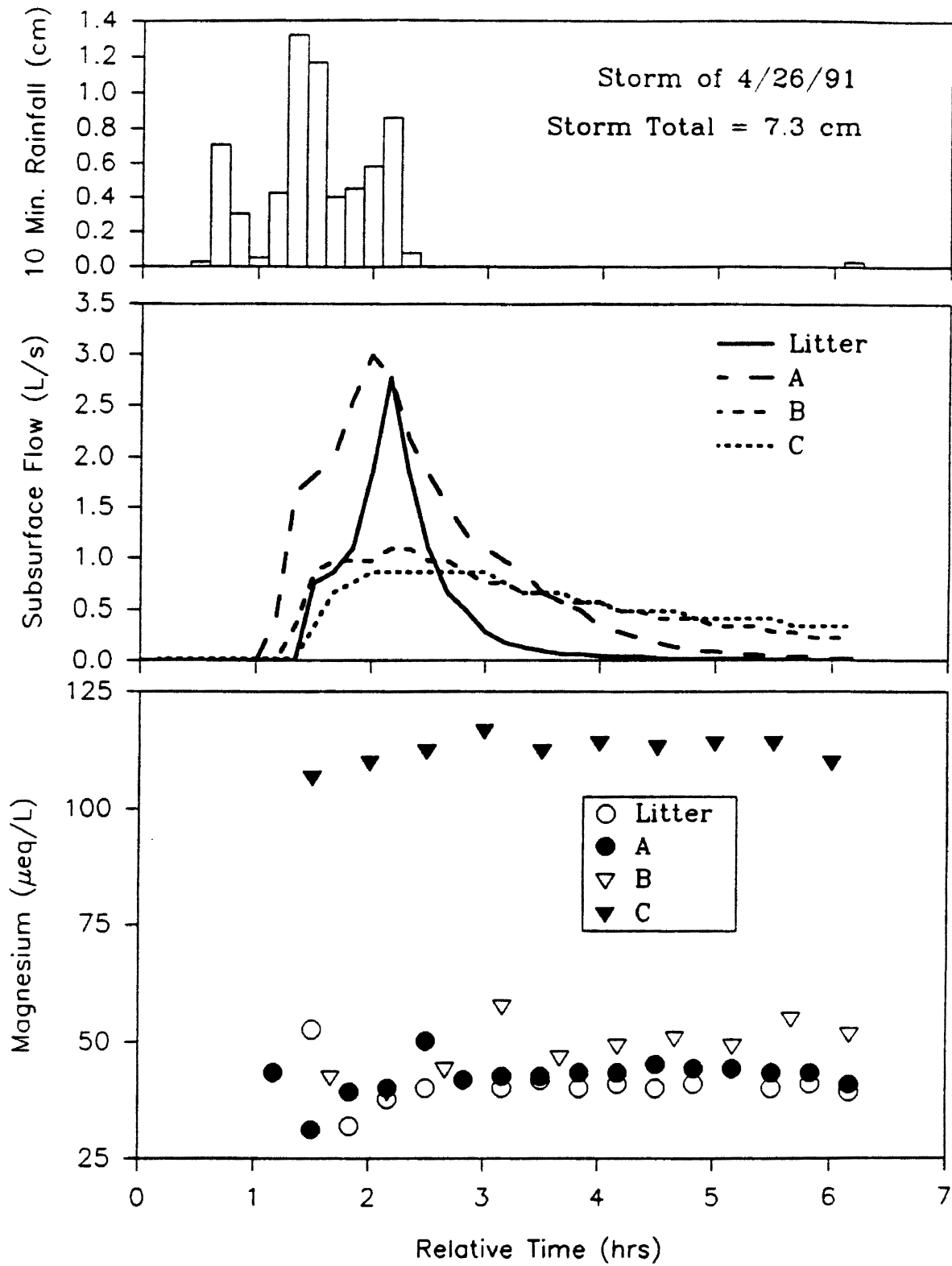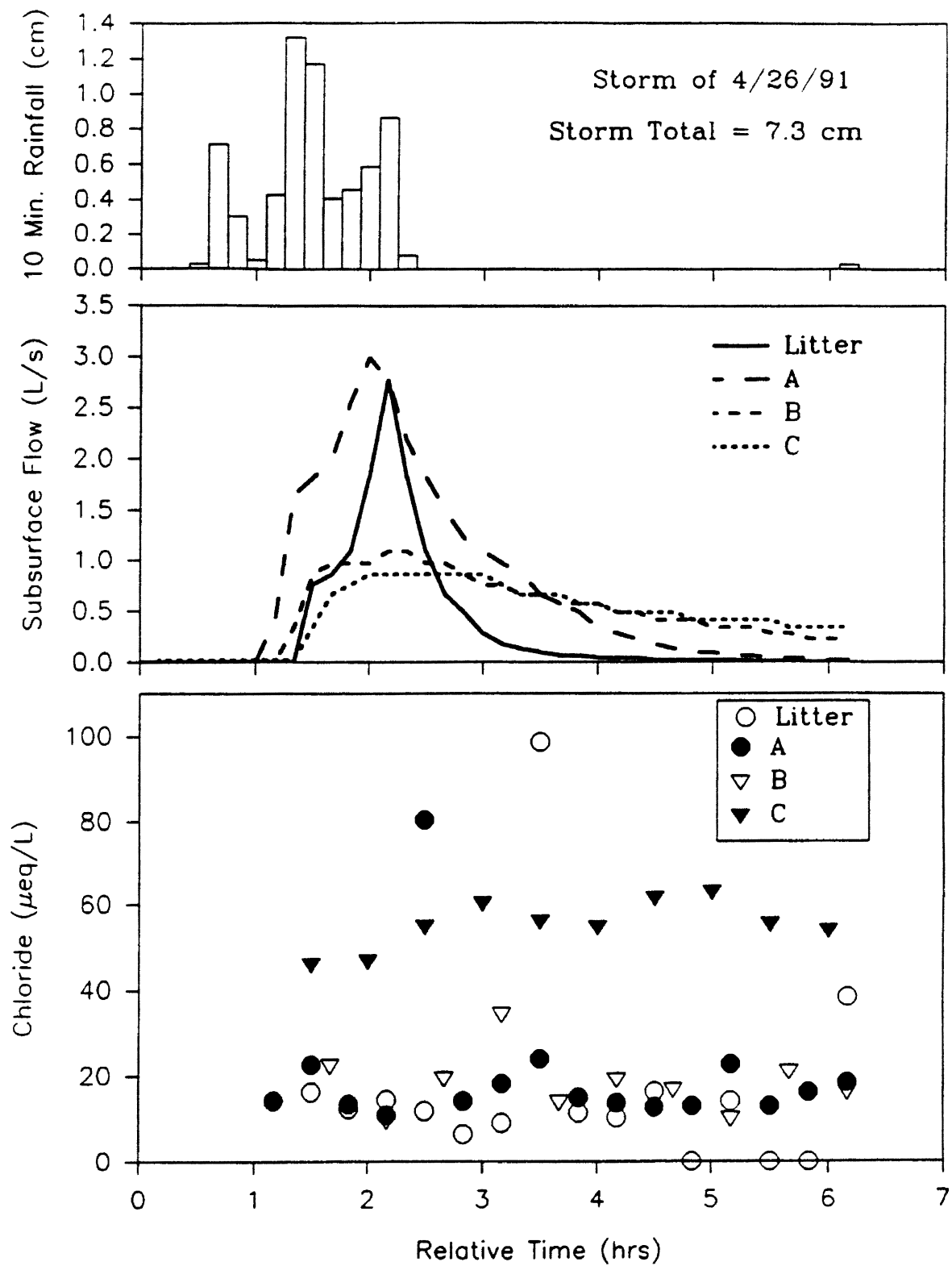
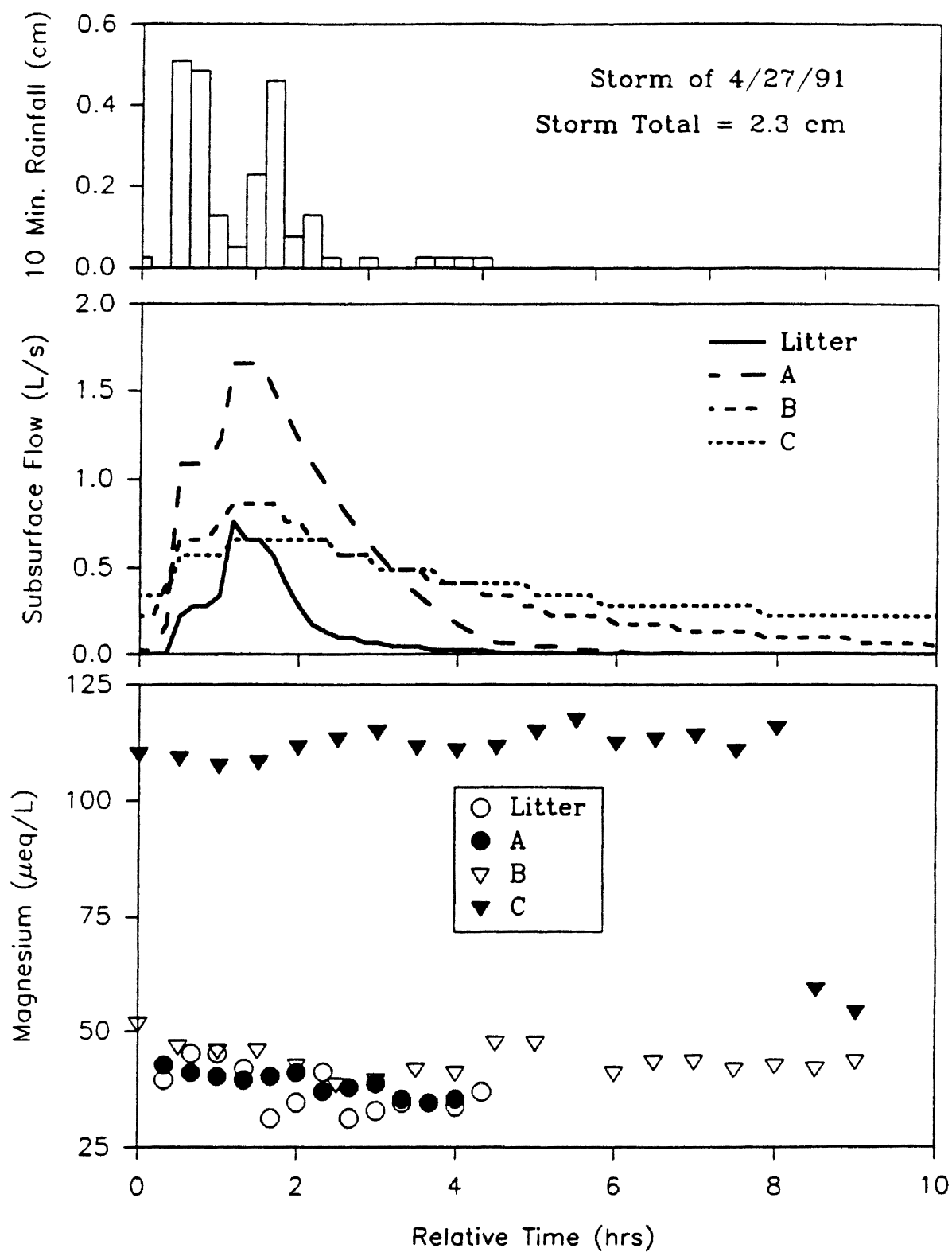Figure 19. Rainfall, subsurface flow, and chloride
concentration for storm 4/26/91
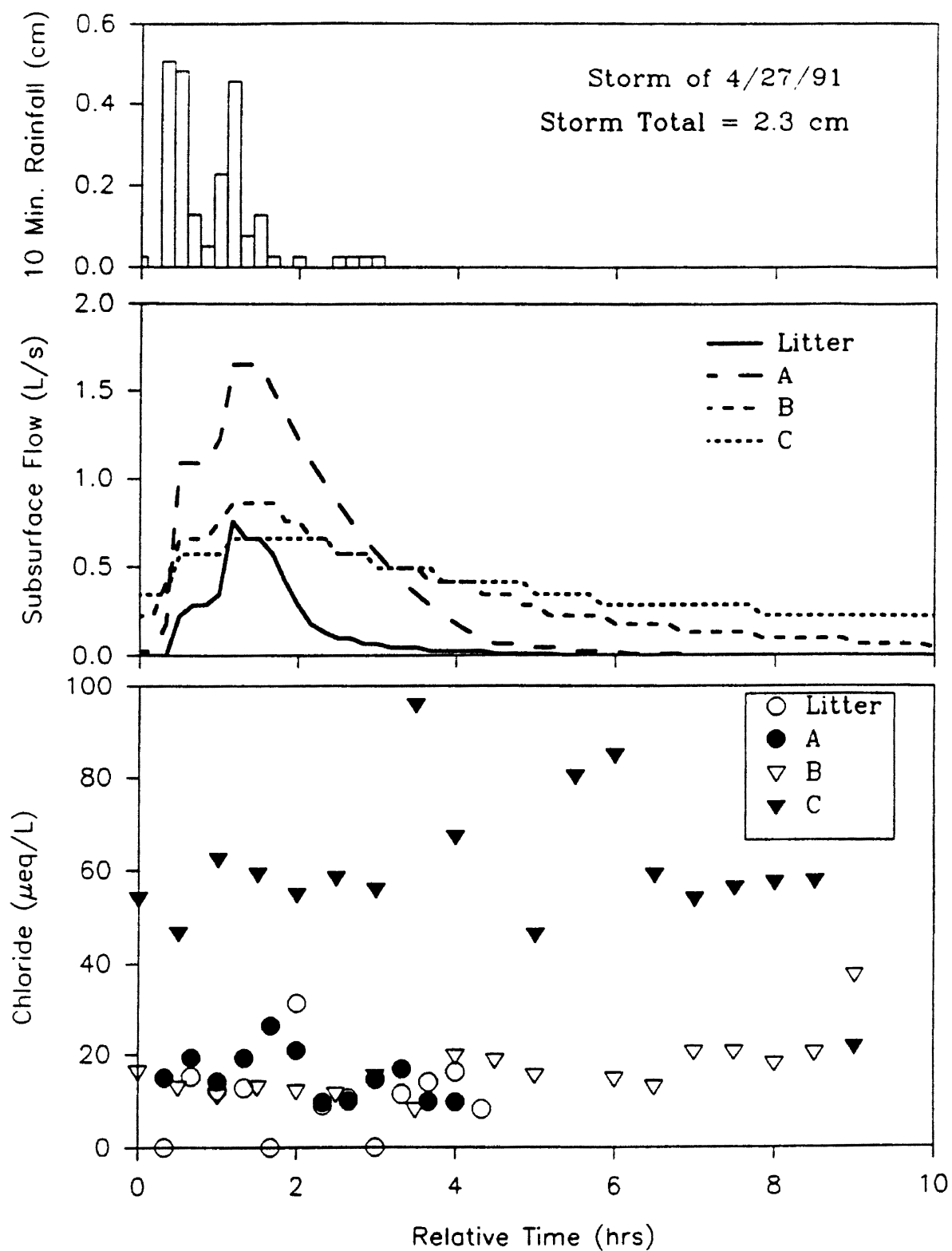
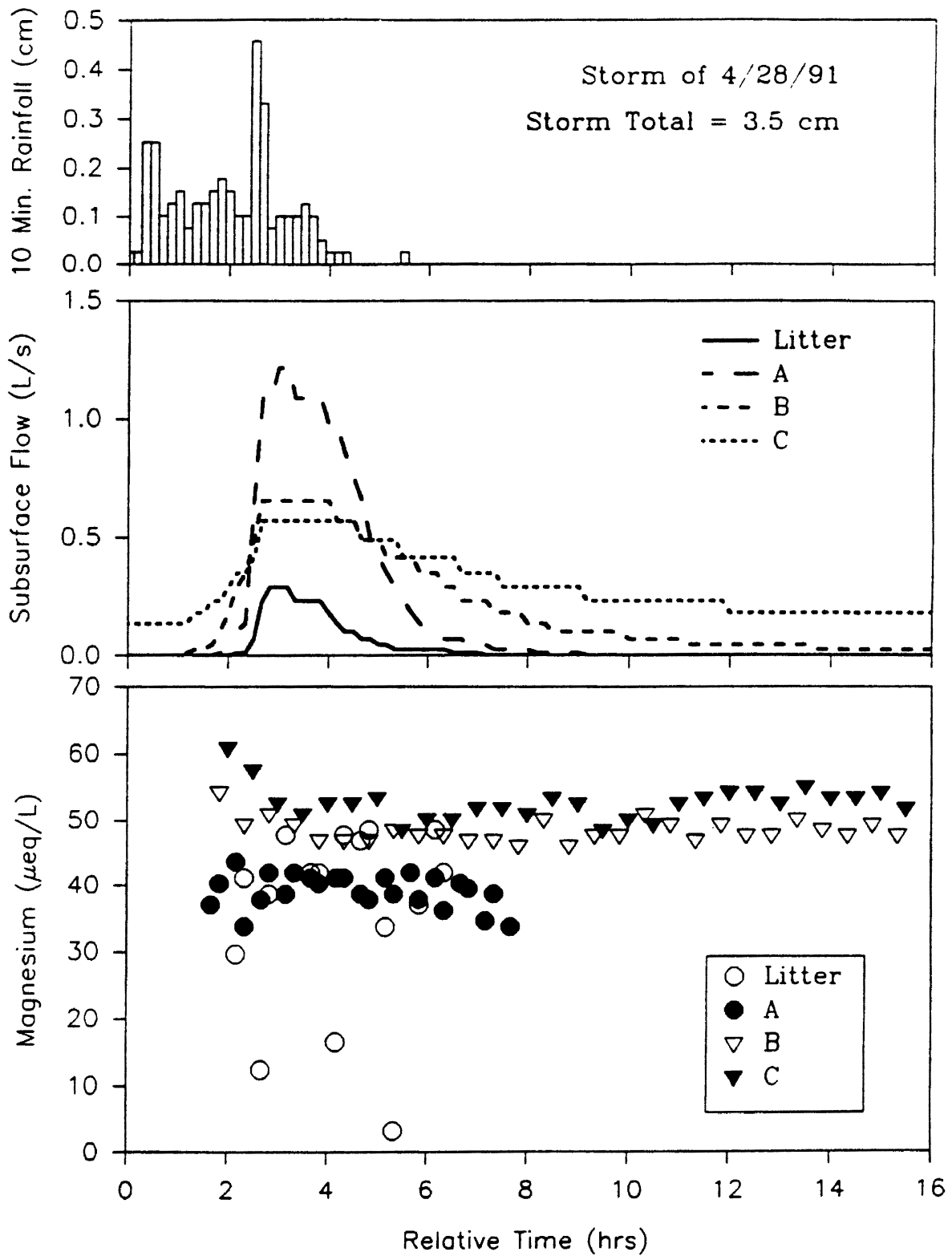Figure 20. Rainfall, subsurface flow, and chloride
concentration for storm 4/27/91
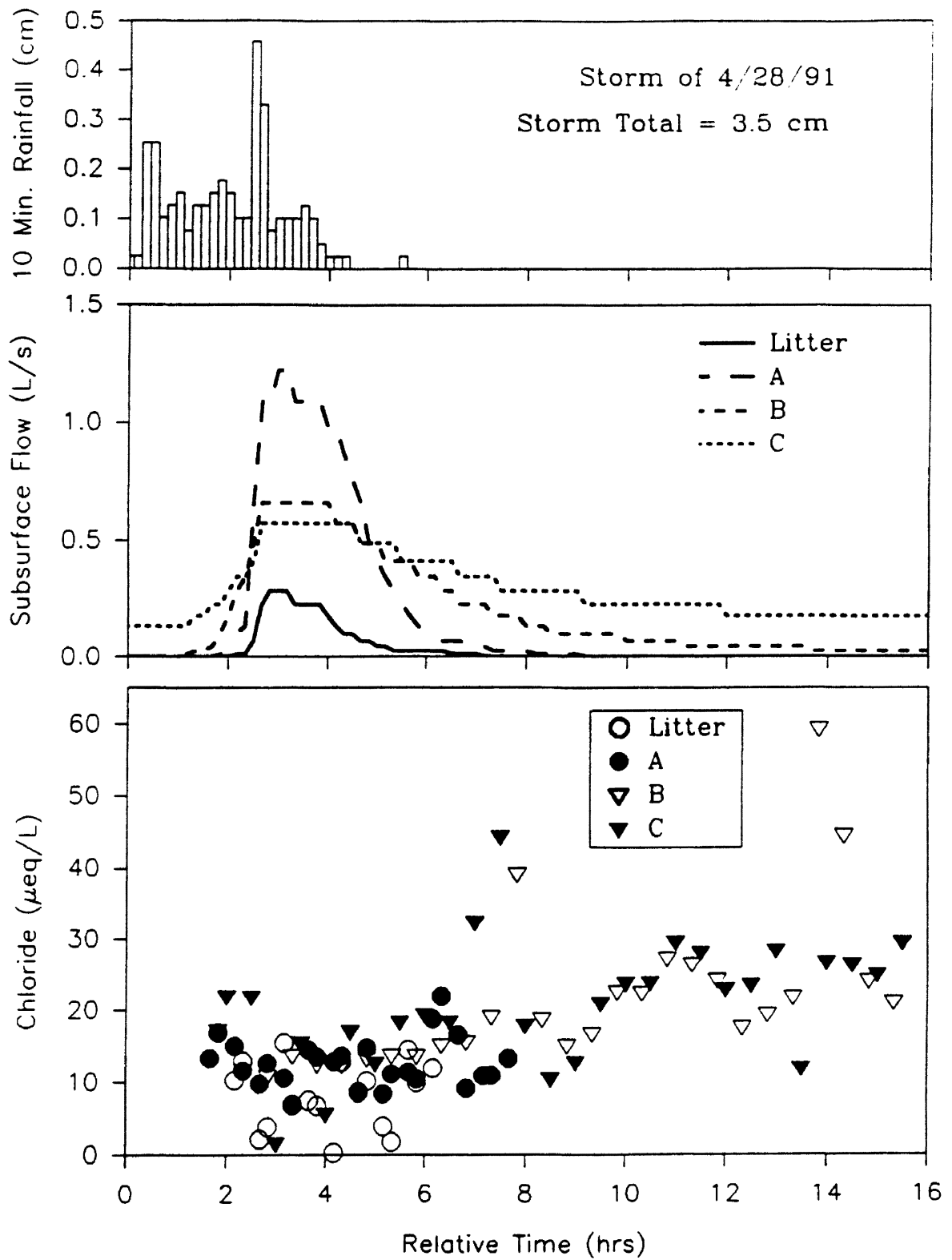
Figure 21. Rainfall, subsurface flow, and chloride
concentrations for storm 4/28/91

<u>Sulfate</u>.

Sulfate concentrations of subsurface flow from the 4/26 storm (Figure 22) in the litter layer, A, and B horizons varied within a range of 24.1 - 60.8 µeq/l (Table 1). Although the range is considerable, the litter layer, A, and B horizon values were similar to each other throughout the coarse of the variation. When graphed, the data formed a check mark shape which is a direct inverse of the subsurface flow rates graph. The same three horizons remained generally close with respect to each other on the 4/27 storm (Figure 23), forming the same check mark arrangement with slightly more attenuation. The 4/26 & 4/27 storms displayed small changes in the C horizon values between 24.1-32.2 µeq/l. C horizon concentrations for the storm of 4/28 (Figure 24), ranged between 29.8-54.5 µeq/l. The check mark shape is clearly articulated on this day with the least amount of deviation of the three storms. The check mark shape inversely corresponds to several other constituents within this study. A bulk precipitation concentration of 16.4 µeq/l increased to 22.1 µeq/l in the bulk throughfall (Table 3). Although sulfate concentrations increased while passing through the tree canopies, concentrations decreased in all horizons at peak subsurface flow periods and increased again as subsurface flow declined. Decreased sulfate concentrations were attributed to dilution from macropore flow of new water.
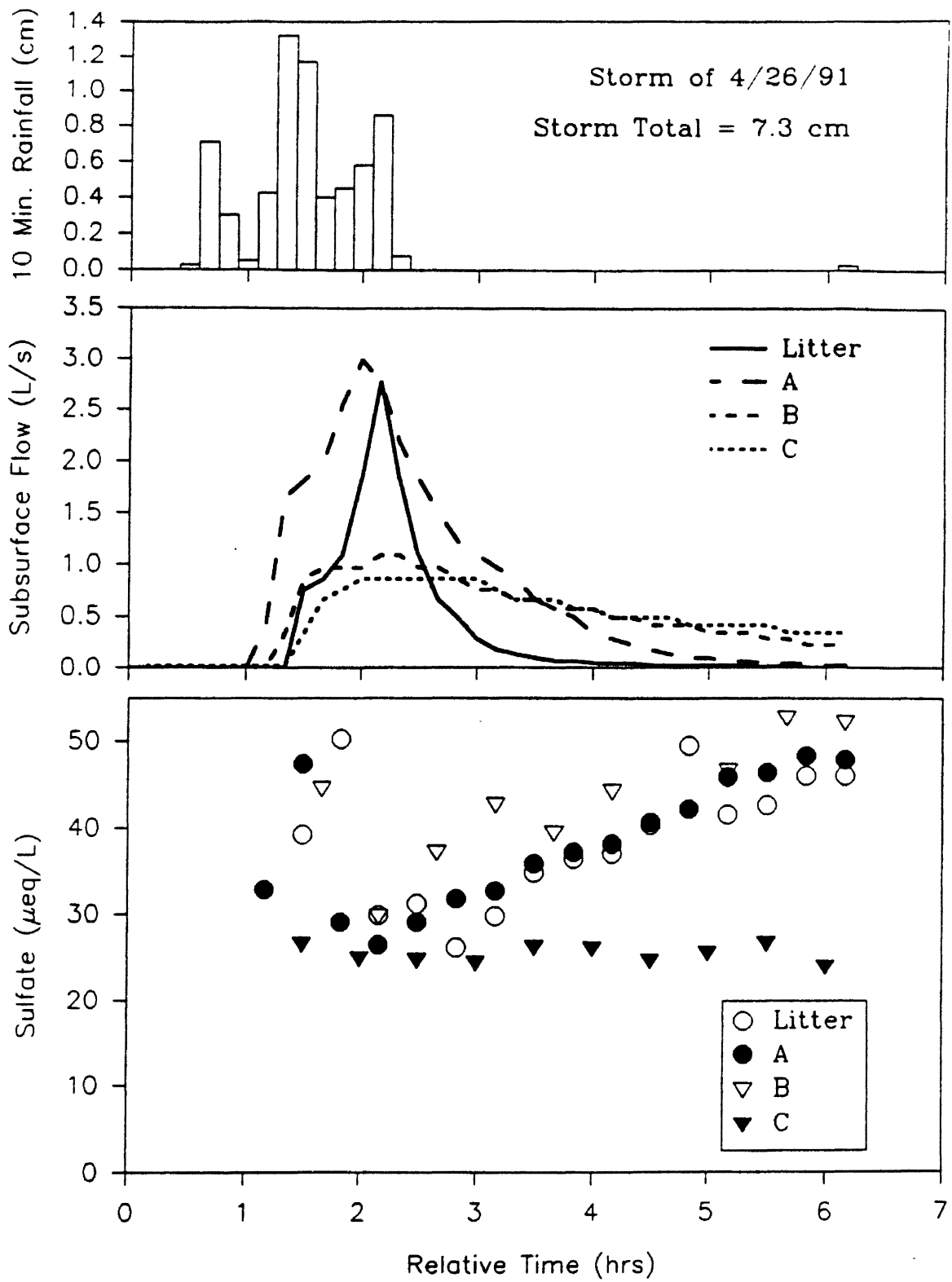
Figure 22. Rainfall, subsurface flow, and sulfate
concentrations for storm 4/26/91
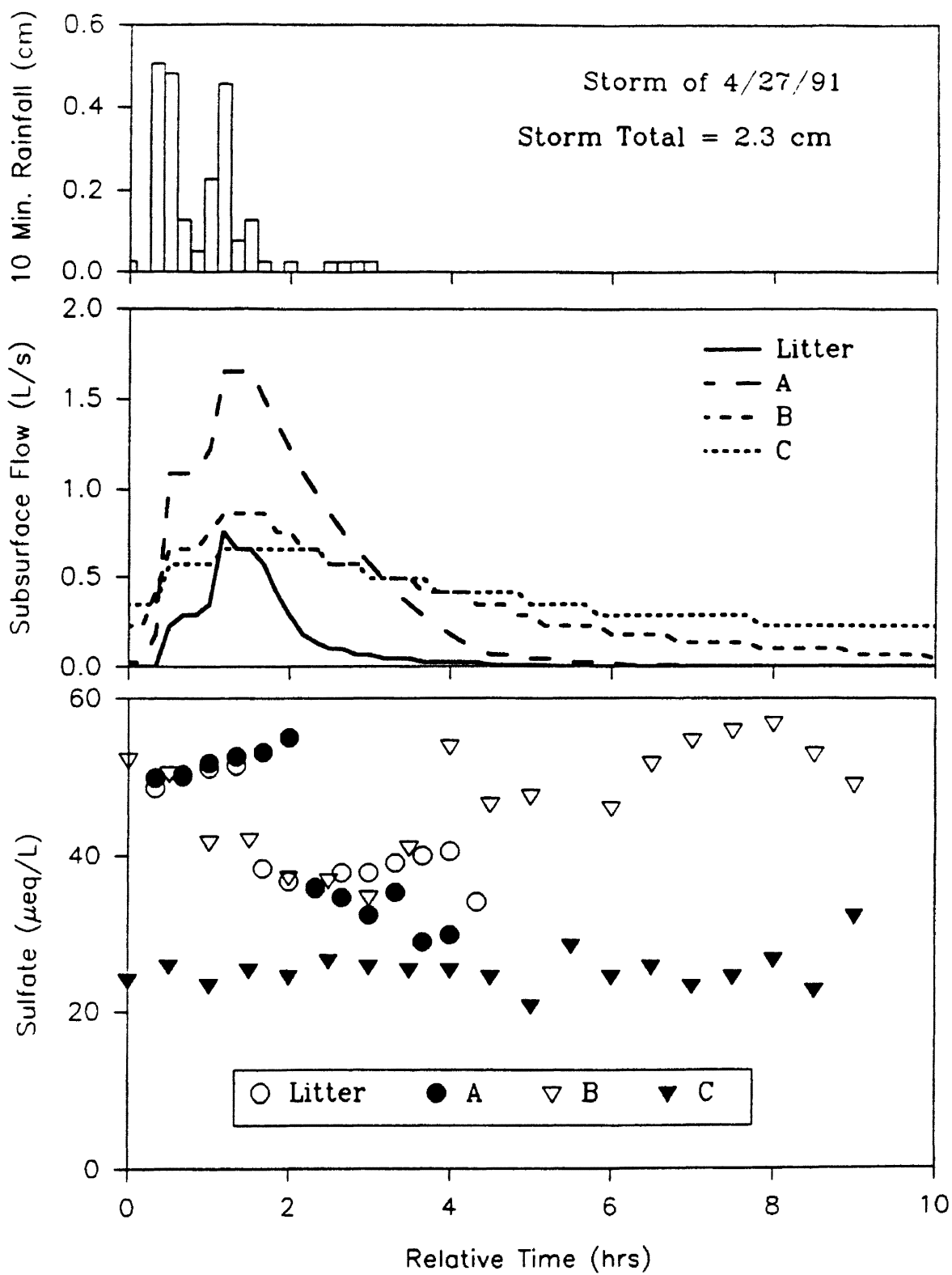
Figure 23. Rainfall, subsurface flow, and sulfate concentrations for storm 4/27/91
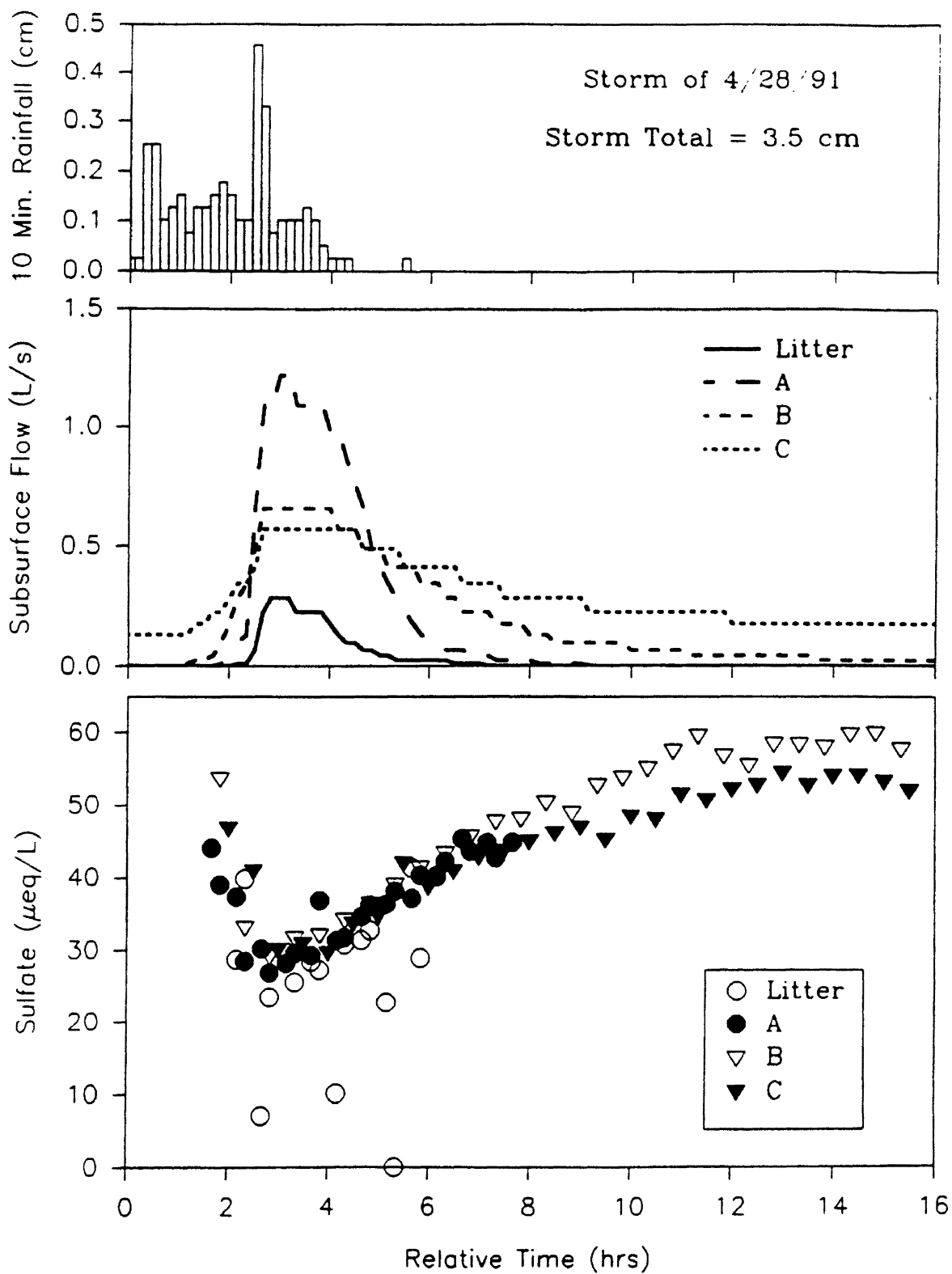
Figure 24. Rainfall, subsurface flow, and sulfate concentrations for storm 4/28/91

<u>Conductivity</u>.

Conductivity values in all soil horizons ranged between 16.2 - 26.1 µmhos (Table 1) during the 4/26 storm (Figure 25), 16.5 - 24.4 µmhos during the 4/27 storm (Figure 26), and 7.6 - 20.6 µmhos during the 4/28 storm (Figure 27). Conductivity attenuation is modest throughout the three day period. Conductivity increased from 6.59 µmhos in bulk precipitation to 7.95 µmhos (Table 3) in bulk throughfall. Increases in conductivity were attributed to the airborne dust and pollen picked up in precipitation, and decomposing organic matter in the litter layer. Although additions were made to the precipitation, the majority of the dust and pollen particles were washed away by the third consecutive day of storms causing the conductivity of storm 4/28 to be slightly lower than the previous two storms. The relationship between ion concentration and specific conductance is simple and direct (Hem 1985). Low conductivity implies a low ion concentration. Conductivity measurements have been used in other studies as a tracer to monitor ion dilution or concentration in subsurface flow. In this study conductivity concentrations indicate only a slight dilution occurring during the recession limb of storm 4/28.
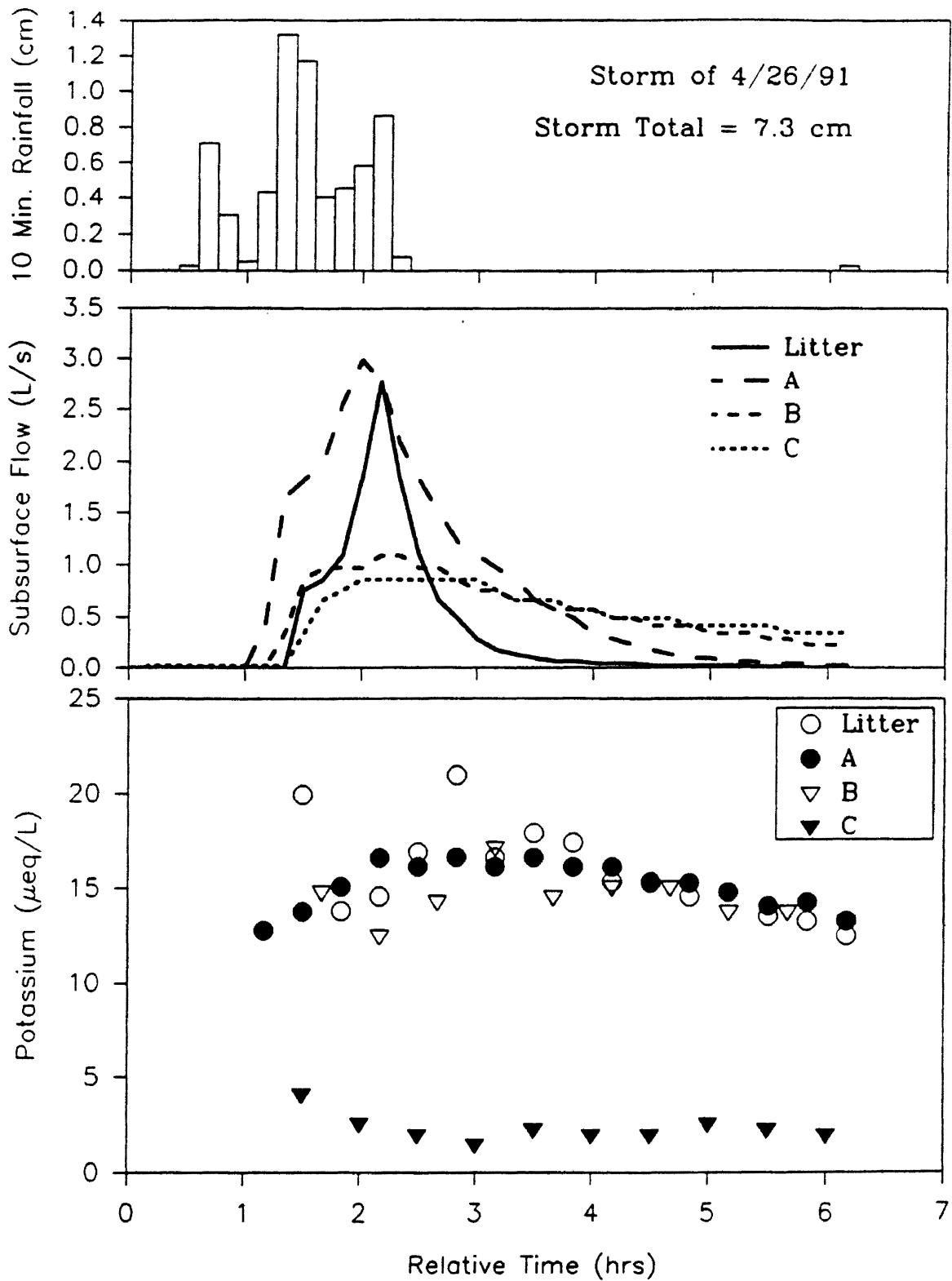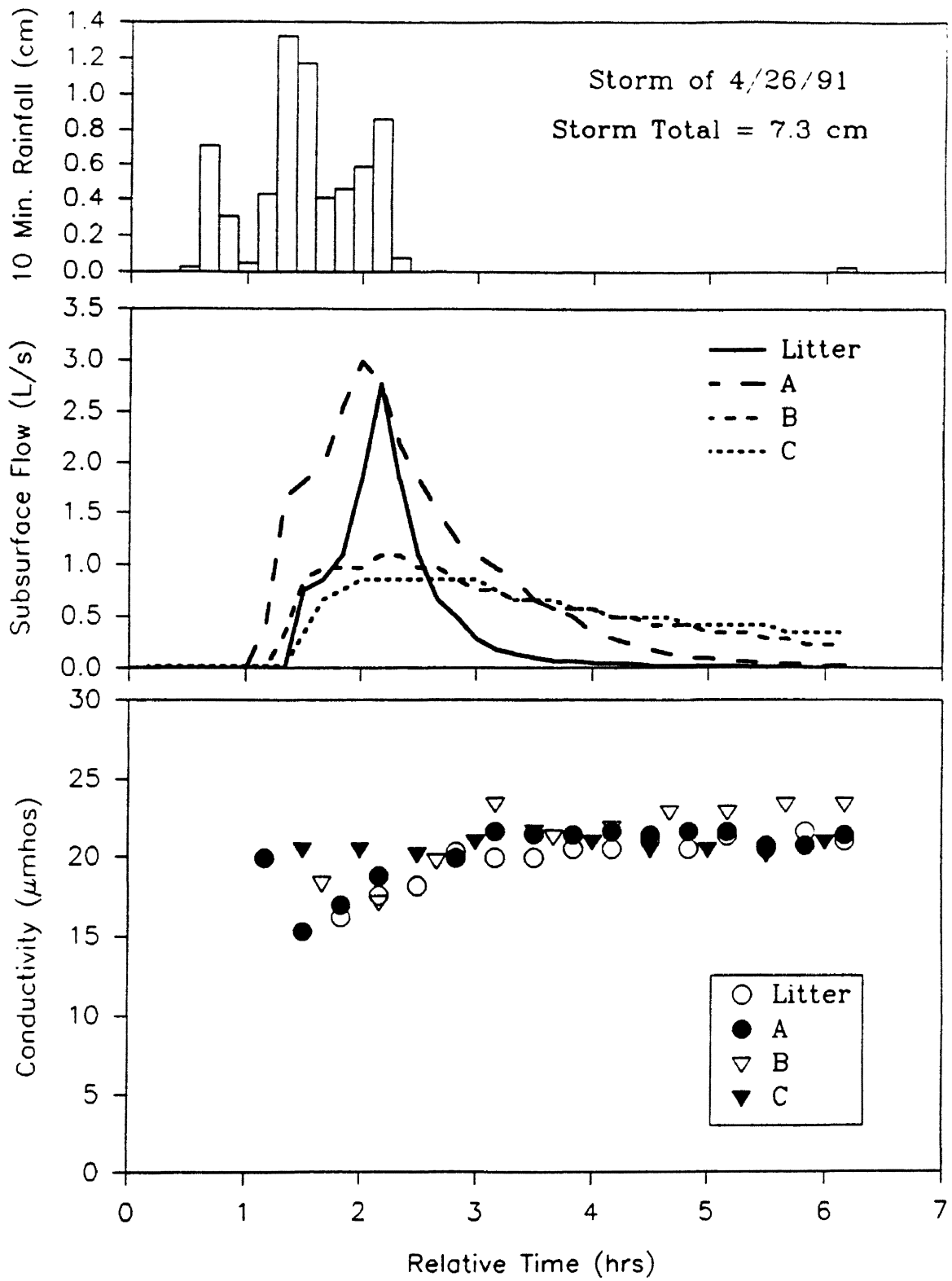
Figure 25. Rainfall, subsurface flow, and conductivity
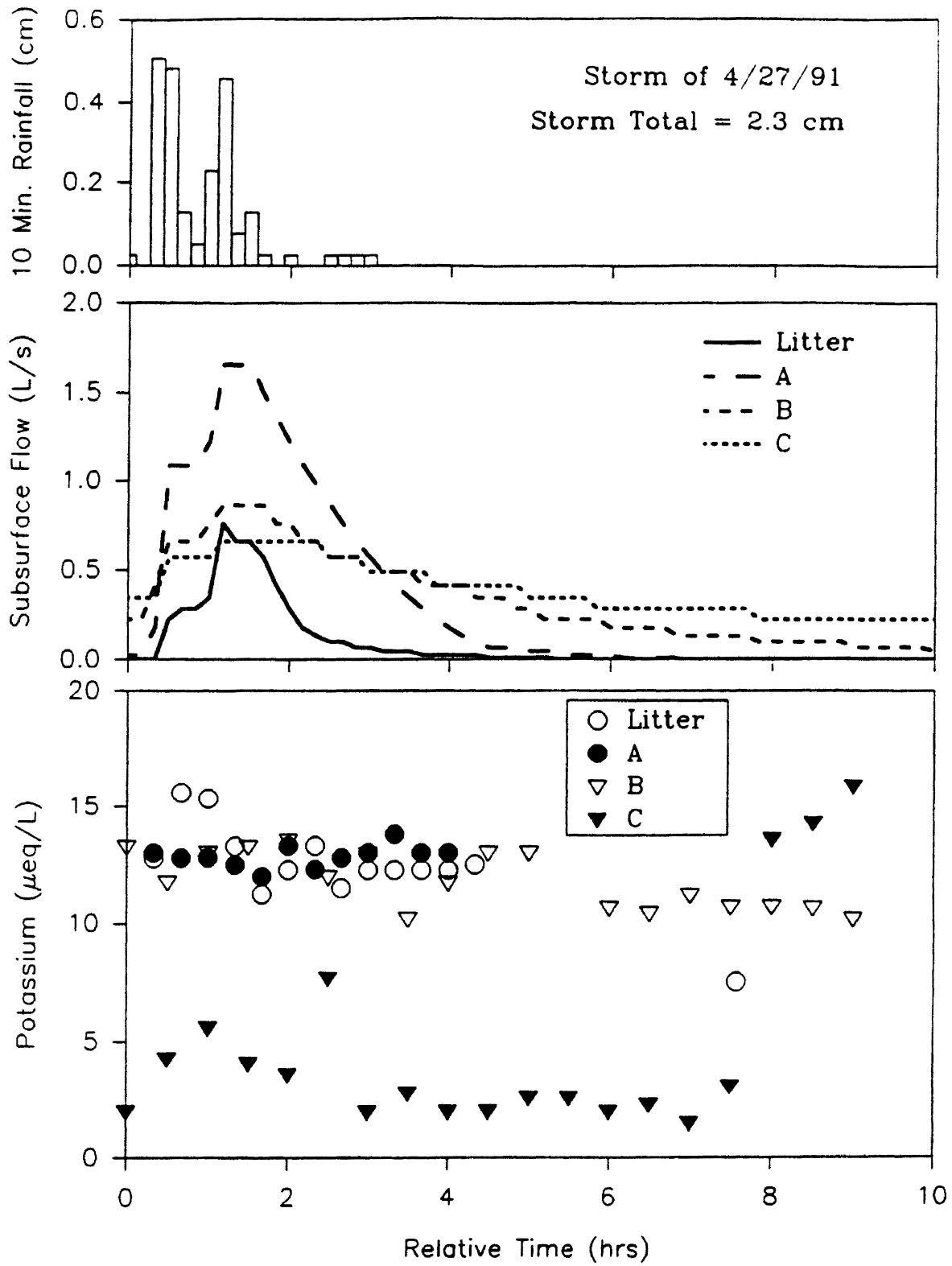concentrations for storm 4/26/91
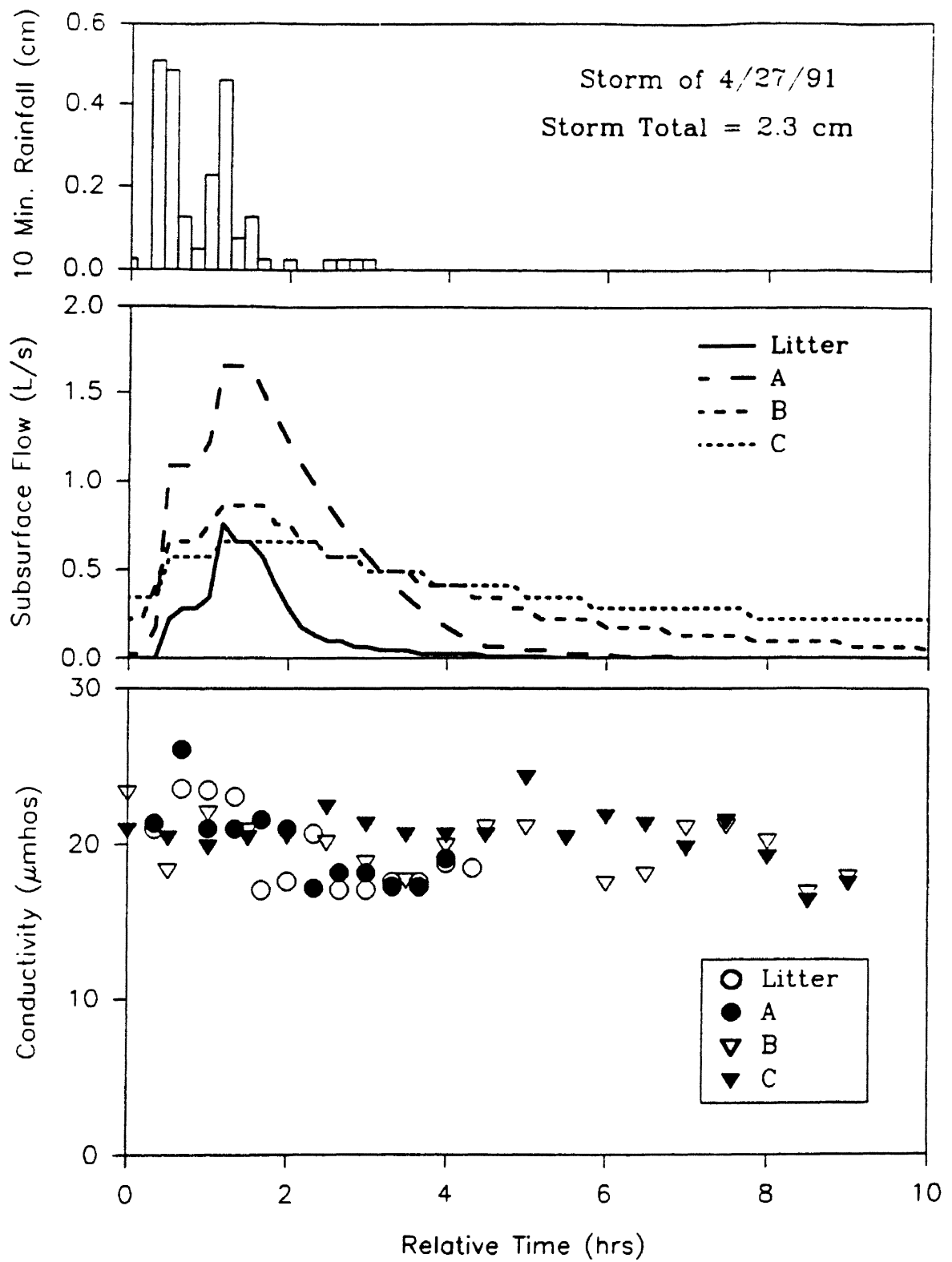
Figure 26. Rainfall, subsurface flow, and conductivity
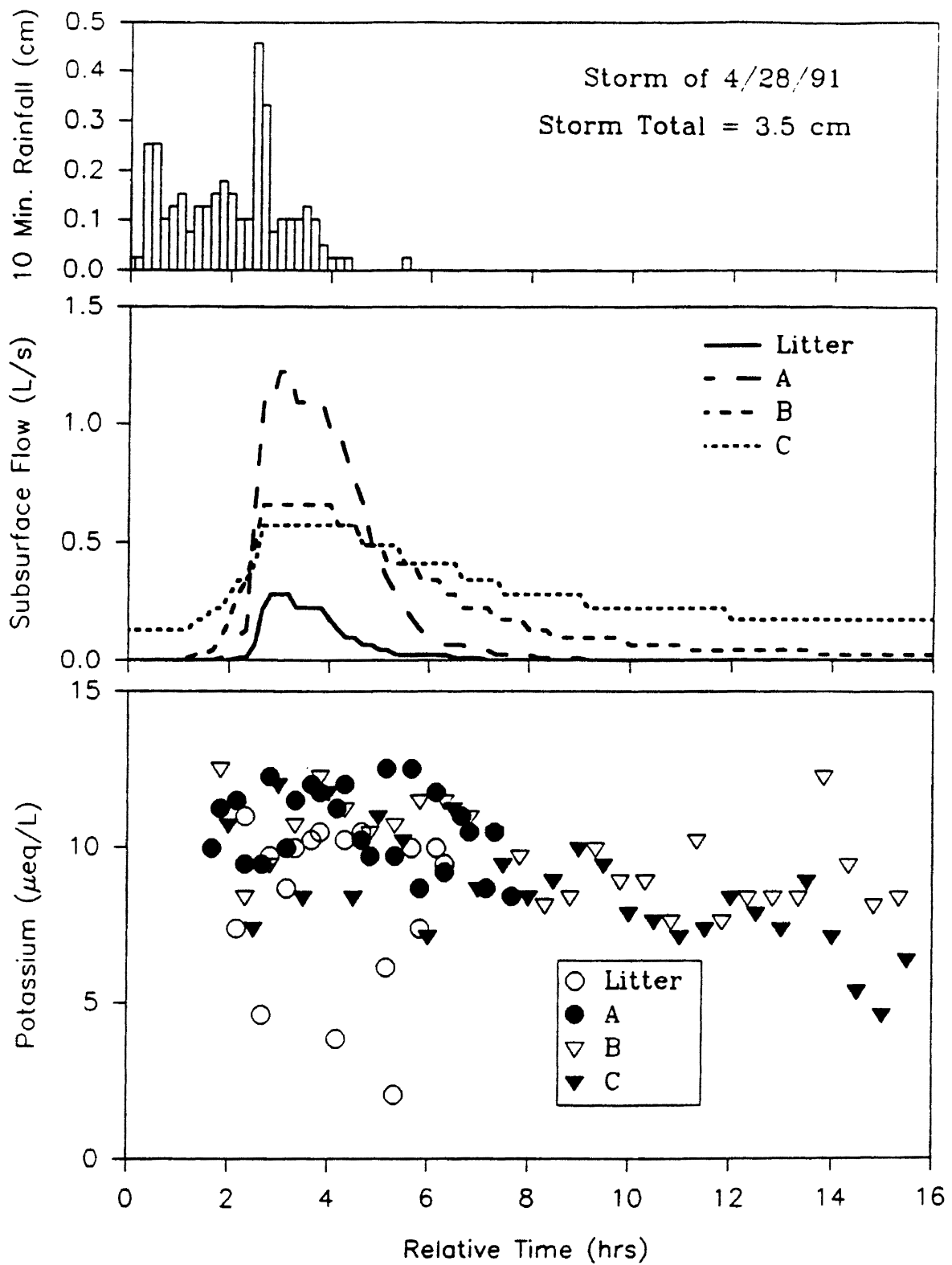concentrations for storm 4/27/91
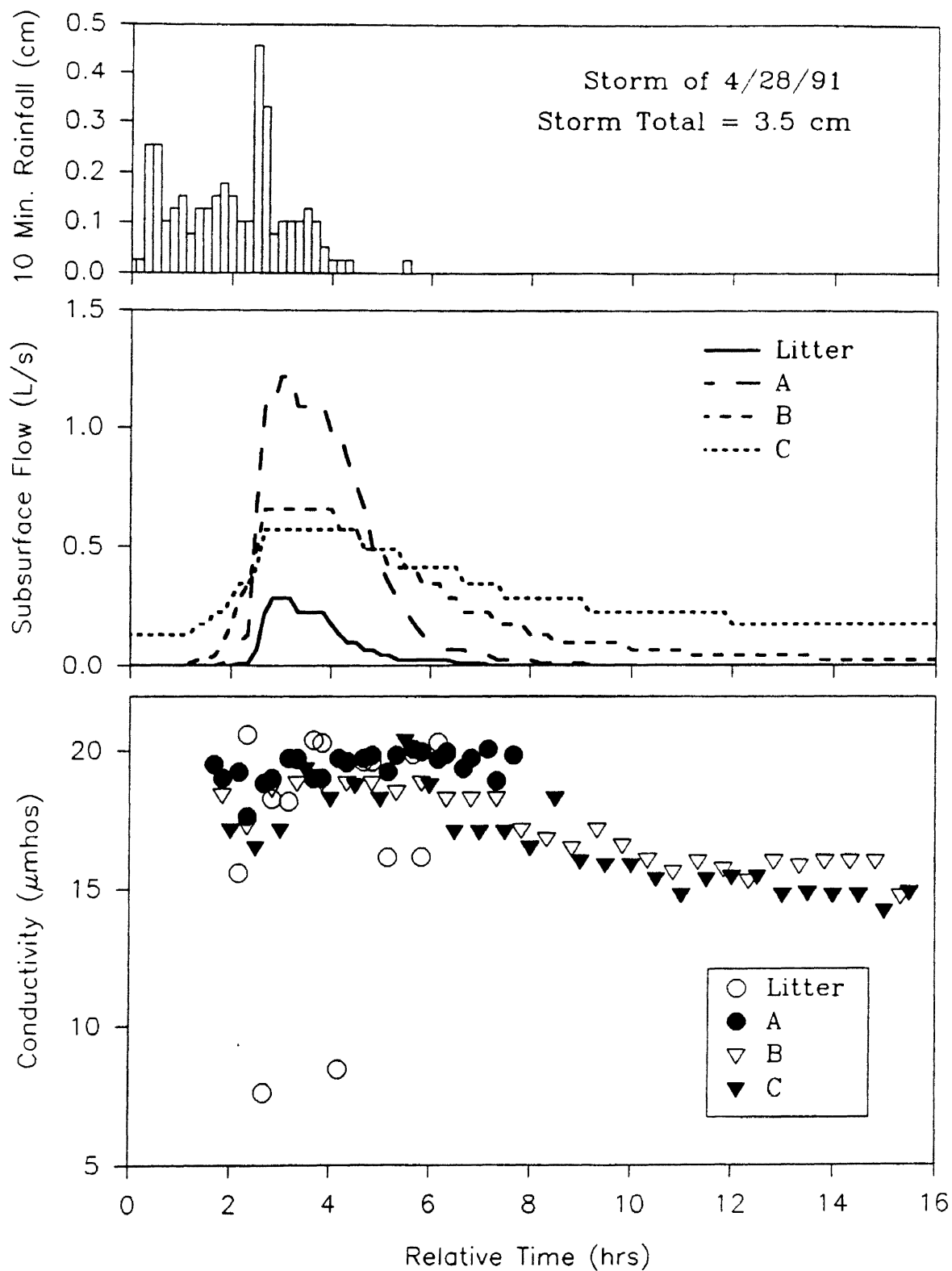
Figure 27. Rainfall, subsurface flow, and conductivity
concentrations for storm 4/28/91

Dissolved Organic Carbon Index (DOC).

DOC concentrations in subsurface flow from the litter layer, A, and B soil horizons varied between 108 - 238 mg/L and generally followed the changes in subsurface flow rates during the storm of 4/26 (Figure 28). DOC concentrations in the C horizon remained constant at 0 mg/l (Table 1) during the storm of 4/26. During the 4/27 storm (Figure 29), concentrations of the litter layer and A horizon decreased at peak subsurface flow and increased as subsurface flow declined. The B horizon concentrations changes resembled the fluctuations of the subsurface flow rates, especially during the recession limb of storm 4/27. The C horizon concentrations remained at 0 mg/l until near completion of the storm of 4/27, then increased to 177 mg/l. The C horizon concentrations of the 4/28 storm (Figure 30), closely resemble the other horizon concentrations by rising to 236.2 mg/l at peak flow, and decreasing during the recession limb to 33 mg/l. Fluctuations in the C horizon concentrations also followed the changes of the subsurface flow rates. Decomposing organic material within the litter layer contributed to the increase in dissolved organic carbons recorded during peak flow periods of the three storm dates. Information for bulk precipitation and bulk throughfall concentrations were not available, but were suspected to be low.
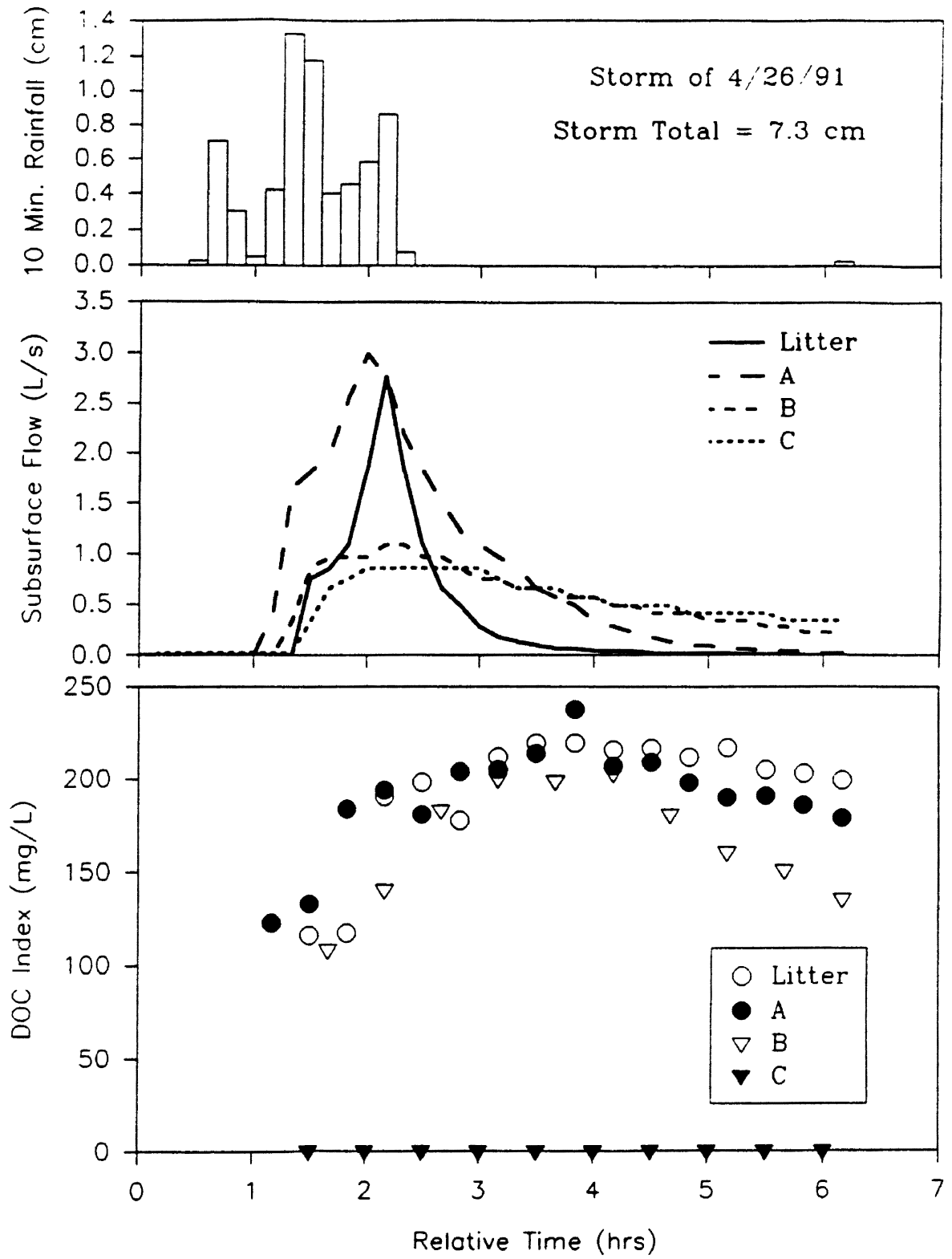
Figure 28. Rainfall, subsurface flow, and DOC Index
for storm 4/26/91
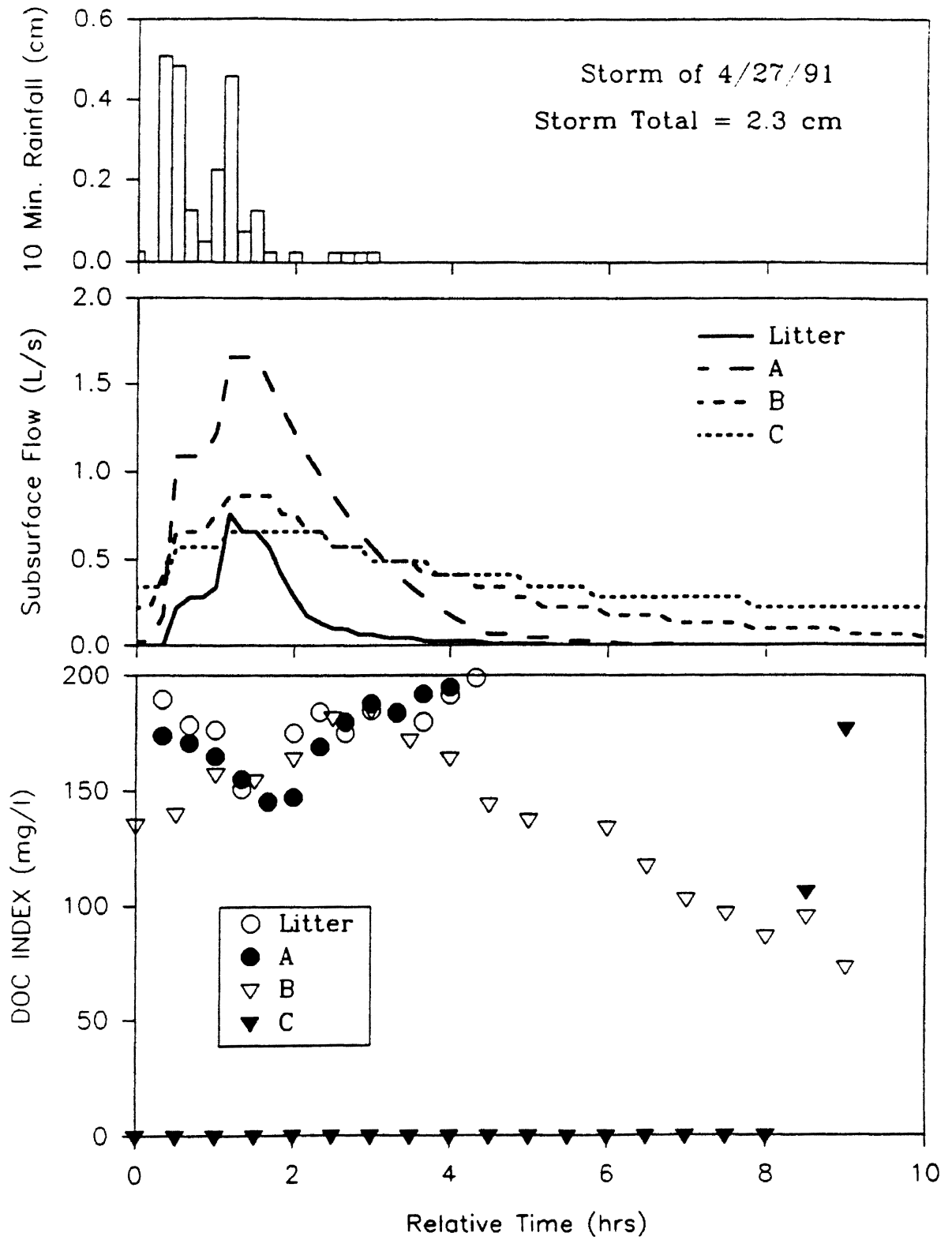
Figure 29. Rainfall, subsurface flow, and DOC Index
for storm 4/27/91
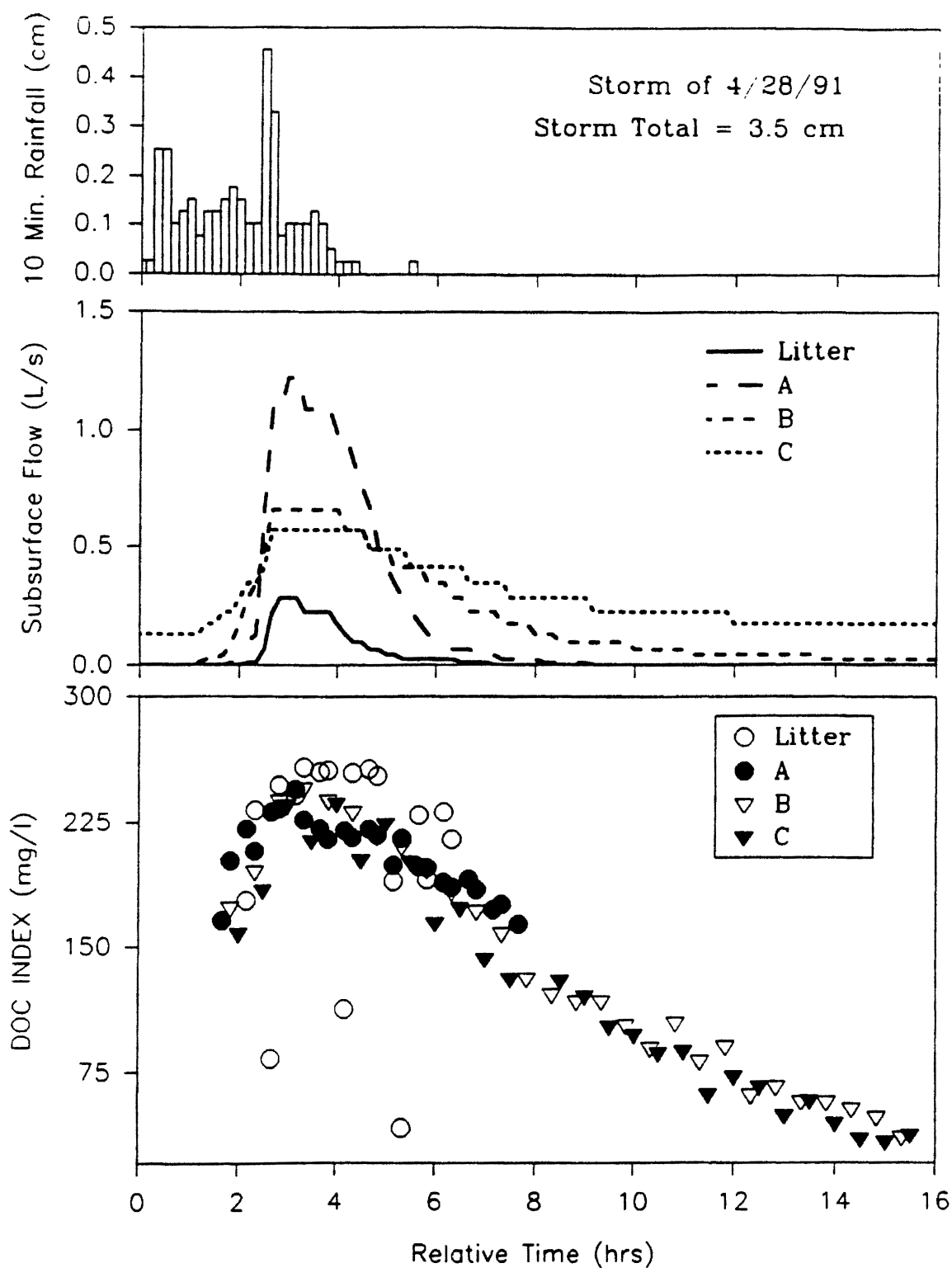
Figure 30. Rainfall, subsurface flow, and DOC Index
for storm 4/28/91

Common Trends

Some generalizations can be made about certain groups of constituents. All chemical constituents in this study except for conductivity, displayed a common trend throughout the three consecutive storm dates. This trend began on storm 4/26, when the chemical concentrations of each constituent in the litter layer, A, and B horizon closely resembled each other throughout the event. The C horizon concentrations remained unaffected by the other horizons changes. The litter layer, A, and B horizon concentrations for storm 4/27, again displayed the same tendency as in storm 4/26. The C horizon, remained unaffected by the other horizons until the last two hours of storm 4/27. At this time the C horizon concentrations increased or decreased rapidly, depending on the constituent, to merge with the concentrations of the litter layer, A, and B horizons. By the storm of 4/28, the C horizon concentrations had changed enough to closely resemble the litter layer, A and B horizon concentrations.

Another trend displayed among several constituents, was the correlation between the concentration fluctuations and the changes in subsurface flow rates of storm 4/28. Calcium, potassium, hydrogen, and dissolved organic carbon concentrations increased as subsurface flow rates increased in the A horizon and litter layer. The magnesium, sodium, and chloride concentrations in the C horizon directly

decreased in response to the increases in subsurface flow rates at near end of storm 4/27 and all of storm 4/28. The concentration fluctuations usually displayed a slight time delay behind subsurface flow rate changes. In sulfate concentrations, the relationship was evident, but in an inverse relationship. The check mark shape found in several of the constituents, is a mirror image of the subsurface flow rate of the A horizon and litter layer. This check mark shape illustrates dilution of the constituent occurring at peak rainfall and peak flow periods of a storm. The tail of the check mark shape is the return to the original concentration (pre-dilution) in the absence of new water. Constituents displaying the check mark, possessed a higher concentration in the antecedent soil water solution than did the new water (throughfall).

The individuality of each constituent's response in the C horizon can be attributed to a several factors. Incoming rainfall can release (lose) or dissolve (gain) ions during throughfall. Throughfall can leach constituents such as potassium or dissolved organic carbons into the soil profile, or allow cation exchange within the soil substituting calcium for sodium in solution. Depending on the rainfall intensity, the subsurface flow can follow various pathways. During peak rainfall intensities, macropore flow conducts new water rapidly through the soil profile allowing limited interaction between subsurface flow and individual constituents in the soil profile (Barnes

1992). The addition of new water can cause either dilution or concentration of an individual constituent in the soil. During low rainfall intensities, matrix flow allows more time for chemical interaction between constituents of new and old water. A combination of macropore flow, matrix flow, and displacement can occur during intermediate rainfall intensities, making it difficult to distinguish which process is responsible for a constituent concentration change.

Matrix flow is responsible for the rapid change in the C horizon at the end of storm 4/27. Saturation of the litter layer, A, and B horizons, caused matrix flow into the C horizon. This flow carried with it the chemical signature of the above horizons, and either mixed with or displaced old water causing concentrations in the C horizon to become chemically similar .

Macropore flow during peak rainfall intensities and subsurface flow periods is evident in the C horizon for the 4/28 storm. Calcium, potassium, hydrogen, sulfate, and dissolved organic carbon are concentrated with higher ionic strength new water, while magnesium, sodium, and chloride concentrations are diluted with new water possessing lower ionic strength of these constituents.

The concentration changes that occur during the recession limb of storm 4/28 are due to a combination of effects that occur as rainfall intensities and subsurface flow decline. Immediately following peak subsurface flow,

concentration changes may be attributed to both macropore flow and saturated matrix flow. As the subsurface flow further declines, macropore flow becomes less important with respect to concentration changes, giving way to predominantly matrix flow which allows constituents to attach to soil particles or substitute through cation exchange. During the recession of the 4/28 storm, calcium, potassium, hydrogen, and dissolved organic carbon decrease in concentration directly with the decline of subsurface flow rates. These constituents are attempting to return to the original concentration values present during antecedent moisture conditions.

CHAPTER IV

SUMMARY

This study has shown the complexity of chemical constituent response to consecutive rainfall. From the analysis of the precipitation and subsurface flow chemistry data, the following points were established.

1) Concentrations of constituents with biological sources such as calcium, potassium, hydrogen, and dissolved organic carbons were lower in the C horizon than litter layer, A, and B horizon during the storm of 4/26/91, and for the majority of the storm of 4/27/91.

2) Concentrations of constituents resulting from weathering and cation exchange such as magnesium, sodium, and chloride, were higher in the C horizon than all other horizons during the storm of 4/26, and the majority of storm of 4/27. At near completion of storm 4/27/91, C horizon concentrations changed rapidly to merge with litter layer, A and B horizon concentrations. C horizon concentrations resembled those of the litter layer, A and B horizons throughout the storm of 4/28/91.

3) During peak rainfall and subsurface flow for the storm of 4/28/91, C horizon concentrations of magnesium, sodium, chloride, and sulfate decreased while calcium, potassium, hydrogen, and dissolved organic carbon concentrations increased in response to new water additions from macropore flow.

4) During the recession of the storm of 4/28/91, B & C horizon concentrations of hydrogen, and dissolved organic carbon decreased while sulfate concentrations increased. This concentration change is attributed to matrix flow which allowed mixing and cation exchange to occur. These

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constituents displayed a tendency to return to pre-storm concentrations.

Throughout the storm of 4/26 and most of 4/27, the concentrations fluctuated very little within the litter layer, A and B horizons, but during the storm of 4/28, constituent concentrations fluctuated more in all horizons than any other storm date. The highest intensity rainfall occurred on 4/26 and the lightest intensity on 4/27. It is possible that the soil profile and old water within the soil profile possess a resistance to concentration change that is analogous to a titration effect where no significant change occurs until a certain level of water content is made available.

Because of the limited number of bottles in ISCO's automated pumping samplers, subsurface flow and chemical concentration data for extended periods after the storm of 4/28/91 were not available. In the future, C horizon soil chemistry data, and subsurface flow chemistry data from an entire storm cycle would prove useful to enable researchers to understand the complex chemistry cycle that occurs in conjunction with a storm.

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APPENDIX

SUBSURFACE FLOW CHEMISTRY

AND PRECIPITATION DATA

SSF UPP   APR26,91

DATE	TIME	REL TIME	L l/s	LAB no.	COND	ORGANIC ACID	Cl eq	NO3 eq	SO4 eq	H eq	NH4 eq	Alk eq	Ca eq	Mg eq	K eq	Na eq	PRECIP in	PRECIP cm
04/26/91	16:00	0	0														0.01	0.0254
04/26/91	16:10	0.166667	0														0.03	0.0762
04/26/91	16:20	0.333334	0														0.08	0.2032
04/26/91	16:30	0.5	0														0.03	0.0762
04/26/91	16:40	0.666667	0														0	0
04/26/91	16:50	0.833334	0														0.03	0.0762
04/26/91	17:00	1	0														0.04	0.1016
04/26/91	17:10	1.166667	0														0	0
04/26/91	17:20	1.333334	0														0	0
04/26/91	17:30	1.5	0														0	0
04/26/91	17:40	1.666667	0														0	0
04/26/91	17:50	1.833334	0														0	0
04/26/91	18:00	2	0														0	0
04/26/91	18:10	2.166667	0														0	0
04/26/91	18:20	2.333334	0														0	0
04/26/91	18:30	2.5	0														0.01	0.0254
04/26/91	18:40	2.666667	0														0	0
04/26/91	18:50	2.833334	0														0	0
04/26/91	19:00	3	0														0	0
04/26/91	19:10	3.166667	0														0	0
04/26/91	19:20	3.333334	0														0	0
04/26/91	19:30	3.5	0														0	0
04/26/91	19:40	3.666667	0														0	0
04/26/91	19:50	3.833334	0														0	0
04/26/91	20:00	4	0														0	0
04/26/91	20:10	4.166667	0														0	0
04/26/91	20:20	4.333334	0														0	0
04/26/91	20:30	4.5	0														0	0
04/26/91	20:40	4.666667	0														0	0
04/26/91	20:50	4.833334	0														0	0
04/26/91	21:00	5	0														0	0
04/26/91	21:10	5.166667	0														0	0
04/26/91	21:20	5.333334	0														0	0

Date	Time																	
04/26/91	21:30	5.5	0														0.12	0.3046
04/26/91	21:40	5.666667	0														0.01	0.0254
04/26/91	21:50	5.833334	0														0	0
04/26/91	22:00	6	0														0	0
04/26/91	22:10	6.166667	0														0	0
04/26/91	22:20	6.333334	0														0	0
04/26/91	22:30	6.5	0														0.01	0.0254
04/26/91	22:40	6.666667	0														0.28	0.7112
04/26/91	22:50	6.833334	0														0.12	0.3046
04/26/91	23:00	7	0														0.02	0.0508
04/26/91	23:10	7.166667	0														0.17	0.4318
04/26/91	23:20	7.333334	0														0.52	1.3206
04/26/91	23:30	7.5	0.75561	3840		116	16.3	0.00	39.3	7.1	2.89	2.00	78.3	52.6	19.9	26.3	0.46	1.1884
04/26/91	23:40	7.666667	0.86032														0.16	0.4064
04/26/91	23:50	7.833334	1.06955	3641	16.2	117	12.5	48.62	50.2	10.1	6.95	0.00	47.9	32.1	13.6	16.5	0.18	0.4572
04/27/91	00:00	8	1.81969														0.23	0.5842
04/27/91	00:10	8.166667	2.77057	3642	17.6	191	14.5	0.00	29.9	13.1	6.00	0.00	44.4	37.6	14.6	14.6	0.34	0.8636
04/27/91	00:20	8.333334	1.81969														0.03	0.0762
04/27/91	00:30	8.5	1.06955	3643	18.2	196	12.0	0.00	31.2	13.2	5.52	0.00	46.9	40.3	16.9	15.2	0	0
04/27/91	00:40	8.666667	0.65039														0	0
04/27/91	00:50	8.833334	0.48959	3644	20.3	176	6.6	12.99	26.2	13.9	3.81	0.00	69.4	42.0	21.0	24.4	0	0
04/27/91	01:00	9.000001	0.28563														0	0
04/27/91	01:10	9.166667	0.17629	3645	19.9	212	9.2	0.00	29.8	15.1	NS	0.00	55.4	40.3	16.6	17.4	0	0
04/27/91	01:20	9.333334	0.13301														0	0
04/27/91	01:30	9.500001	0.09905	3646	19.9	220	96.7	0.00	34.8	16.0	5.92	0.00	51.4	42.0	17.9	15.7	0	0
04/27/91	01:40	9.666667	0.06792														0	0
04/27/91	01:50	9.833334	0.06792	3647	20.5	220	11.5	0.00	36.5	16.9	6.73	0.00	46.4	40.3	17.4	17.0	0	0
04/27/91	02:00	10	0.04528														0	0
04/27/91	02:10	10.16667	0.04528	3648	20.5	216	10.4	0.00	37.1	15.8	6.85	0.00	47.9	41.1	15.3	17.4	0	0
04/27/91	02:20	10.33333	0.04528														0	0
04/27/91	02:30	10.5	0.02547	3649	21	217	16.4	0.00	40.4	17.3	7.25	0.00	50.4	40.3	15.3	17.6	0	0
04/27/91	02:40	10.66667	0.02547														0	0
04/27/91	02:50	10.83333	0.02547	3650	20.5	212	0.0	0.00	49.5	18.1	6.79	0.00	50.4	41.1	14.6	18.3	0	0
04/27/91	03:00	11	0.02547														0	0
04/27/91	03:10	11.16667	0.02547	3651	21.3	217	14.2	0.00	41.6	17.7	NS	0.00	55.4	44.4	14.6	26.7	0	0
04/27/91	03:20	11.33333	0.01132														0	0
04/27/91	03:30	11.5	0.01132	3652	20.5	205	0.0	0.00	42.7	15.0	8.53	0.00	49.9	40.3	13.6	20.4	0	0
04/27/91	03:40	11.66667	0.01132														0	0
04/27/91	03:50	11.83333	0	3653	21.6	203	0.0	0.00	46.0	17.4	8.51	0.00	47.4	41.1	13.3	20.4	0	0
04/27/91	04:00	12	0														0	0
04/27/91	04:10	12.16667	0	3654	21	199	36.5	0.00	46.0	18.5	6.02	0.00	44.4	39.5	12.5	21.7	0.01	0.0254
04/27/91	04:20	12.33333	0														0	0

SSF UPPER DATE	TIME	REL TIME	A l/s	LAB no.	COND	ORGANIC ACID	Cl eq	NO3 eq	SO4 eq	H eq	NH4 eq	Alk eq	Ca eq	Mg eq	K eq	Na eq	PRECIP	PRECIP cm
			0															
04/26/91	16:00	0	0														0.01	0.0254
04/26/91	16:10	0.166667	0														0.03	0.0762
04/26/91	16:20	0.3333337	0														0.08	0.2032
04/26/91	16:30	0.5000003	0														0.03	0.0762
04/26/91	16:40	0.666667	0														0	0
04/26/91	16:50	0.8333337	0														0.03	0.0762
04/26/91	17:00	1.0000004	0														0.04	0.1016
04/26/91	17:10	1.166667	0														0	0
04/26/91	17:20	1.3333337	0														0	0
04/26/91	17:30	1.5000004	0														0	0
04/26/91	17:40	1.666667	0														0	0
04/26/91	17:50	1.8333337	0														0	0
04/26/91	18:00	2.0000004	0														0	0
04/26/91	18:10	2.166667	0														0	0
04/26/91	18:20	2.3333337	0														0.01	0.0254
04/26/91	18:30	2.5000004	0														0	0
04/26/91	18:40	2.6666671	0														0	0
04/26/91	18:50	2.8333337	0														0	0
04/26/91	19:00	3.0000004	0														0	0
04/26/91	19:10	3.1666671	0														0	0
04/26/91	19:20	3.3333337	0														0	0
04/26/91	19:30	3.5000004	0														0	0
04/26/91	19:40	3.6666671	0														0	0
04/26/91	19:50	3.8333337	0														0	0
04/26/91	20:00	4.0000004	0														0	0
04/26/91	20:10	4.1666671	0														0	0
04/26/91	20:20	4.3333338	0														0	0
04/26/91	20:30	4.5000004	0														0	0
04/26/91	20:40	4.6666671	0														0	0
04/26/91	20:50	4.8333338	0														0	0
04/26/91	21:00	5.0000004	0														0	0
04/26/91	21:10	5.1666671	0														0	0
04/26/91	21:20	5.3333338	0														0.12	0.3048
04/26/91	21:30	5.5000004	0														0.01	0.0254
04/26/91	21:40	5.6666671	0														0	0
04/26/91	21:50	5.8333338	0														0	0
04/26/91	22:00	6.0000004	0														0	0

04/26/91	22:10	6.166667	0														0	0
04/26/91	22:20	6.333334	0														0.01	0.0254
04/26/91	22:30	6.5	0														0.26	0.7112
04/26/91	22:40	6.666667	0														0.12	0.3048
04/26/91	22:50	6.833334	0														0.02	0.0508
04/26/91	23:00	7	0														0.17	0.4318
04/26/91	23:10	7.166667	0.41316	3812	19.9	123	14.3	17.06	32.9	8.7	NS	0.00	54.4	43.6	12.8	26.3	0.52	1.3208
04/26/91	23:20	7.333334	1.65555														0.46	1.1684
04/26/91	23:30	7.5	1.81969	3813	15.3	133	22.7	8.92	47.4	11.4	NS	0.00	39.4	31.3	13.8	18.5	0.16	0.4064
04/26/91	23:40	7.666667	1.99232														0.18	0.4572
04/26/91	23:50	7.833334	2.56115	3814	17	184	13.4	0.00	29.1	14.6	NS	0.00	49.4	39.5	15.1	16.1	0.23	0.5842
04/27/91	00:00	8	2.99131														0.34	0.8636
04/27/91	00:10	8.166667	2.77057	3815	18.8	194	10.9	0.00	26.5	15.1	NS	0.00	55.9	40.3	16.6	17.4	0.03	0.0762
04/27/91	00:20	8.333334	2.17061														0	0
04/27/91	00:30	8.5	1.81969	3816		181	80.4	0.00	29.1	9.5	NS	10.00		50.2	16.1	22.2	0	0
04/27/91	00:40	8.666667	1.4999														0	0
04/27/91	00:50	8.833334	1.21973	3817	19.9	204	14.2	0.00	31.8	15.5	NS	0.00	58.9	42.0	16.6	13.5	0	0
04/27/91	01:00	9.000001	1.08955														0	0
04/27/91	01:10	9.166667	0.97069	3818	21.6	205	16.2	0.00	32.7	17.0	NS	0.00	57.4	42.8	16.1	17.4	0	0
04/27/91	01:20	9.333334	0.86032														0	0
04/27/91	01:30	9.500001	0.65939	3819	21.4	214	24.0	0.00	35.9	18.0	NS	0.00	51.4	42.8	16.6	18.7	0	0
04/27/91	01:40	9.666667	0.57166														0	0
04/27/91	01:50	9.833334	0 48959	3820	21.4	238	15.0	0.00	37.2	17.9	NS	0.00	56.4	43.6	16.1	18.7	0	0
04/27/91	02:00	10	0.34526														0	0
04/27/91	02:10	10.16667	0.28583	3821	21.6	207	13.8	0.00	38.2	17.5	NS	0.00	54.9	43.6	16 1	20.9	0	0
04/27/91	02:20	10.33333	0.2264														0	0
04/27/91	02:30	10.5	0.17829	3822	21.4	209	12.8	0.00	40.7	18.2	NS	0.00	50.4	45.3	15.3	20.0	0	0
04/27/91	02:40	10.66667	0.13301														0	0
04/27/91	02:50	10.83333	0.09905	3823	21.6	198	13.1	0.00	42.2	18.6	NS	0.00	55.4	44.4	15.3	20 4	0	0
04/27/91	03:00	11	0.09905														0	0
04/27/91	03:10	11.16667	0.06792	3824	21.6	190	22.8	0.00	45.9	16 9	NS	0.00	52.9	44.4	14.8	27.0	0	0
04/27/91	03:20	11.33333	0.06792														0	0
04/27/91	03:30	11.5	0.04528	3825	20.7	191	13 1	0.00	46.4	17.9	NS	0.00	50.9	43.6	14.1	21.3	0	0
04/27/91	03:40	11.66667	0.04528														0	0
04/27/91	03:50	11.83333	0.04528	3826	20.7	186	16.3	0.00	48.3	17.7	NS	0.00	49.9	43.6	14.3	23.1	0	0
04/27/91	04:00	12	0.02547														0.01	0.0254
04/27/91	04:10	12.16667	0.02547	3827	21.4	179	18.6	0.00	47.9	19.0	NS	0.00	49.4	41.1	13.3	27.8	0	0
04/27/91	04:20	12.33333																

SSF UPPER DATE	TIME	REL TIME	B l/s	LAB no.	COND	ORGANIC ACID	Cl eq	NO3 eq	SO4 eq	H eq	NH4 eq	Alk eq	Ca eq	Mg eq	K eq	Na eq	PRECIP	PRECIP cm
			0															
04/26/91	16:00	0	0														0.01	0.0254
04/26/91	16:10	0.166667	0														0.03	0.0762
04/26/91	16:20	0.3333337	0														0.08	0.2032
04/26/91	16:30	0.5000003	0														0.03	0.0762
04/26/91	16:40	0.666667	0														0	0
04/26/91	16:50	0.8333337	0														0.03	0.0762
04/26/91	17:00	1.0000004	0														0.04	0.1016
04/26/91	17:10	1.166667	0														0	0
04/26/91	17:20	1.3333337	0														0	0
04/26/91	17:30	1.5000004	0														0	0
04/26/91	17:40	1.666667	0														0	0
04/26/91	17:50	1.8333337	0														0	0
04/26/91	18:00	2.0000004	0														0	0
04/26/91	18:10	2.166667	0														0	0
04/26/91	18:20	2.3333337	0														0.01	0.0254
04/26/91	18:30	2.5000004	0														0	0
04/26/91	18:40	2.6666671	0														0	0
04/26/91	18:50	2.8333337	0														0	0
04/26/91	19:00	3.0000004	0														0	0
04/26/91	19:10	3.1666671	0														0	0
04/26/91	19:20	3.3333337	0														0	0
04/26/91	19:30	3.5000004	0														0	0
04/26/91	19:40	3.6666671	0														0	0
04/26/91	19:50	3.8333337	0														0	0
04/26/91	20:00	4.0000004	0														0	0
04/26/91	20:10	4.1666671	0														0	0
04/26/91	20:20	4.3333336	0														0	0
04/26/91	20:30	4.5000004	0														0	0
04/26/91	20:40	4.6666671	0														0	0
04/26/91	20:50	4.8333336	0														0	0
04/26/91	21:00	5.0000004	0														0	0
04/26/91	21:10	5.1666671	0														0	0
04/26/91	21:20	5.3333336	0														0.12	0.3048
04/26/91	21:30	5.5000004	0														0.01	0.0254
04/26/91	21:40	5.6666671	0														0	0
04/26/91	21:50	5.8333336	0														0	0
04/26/91	22:00	6.0000004	0														0	0

Date	Time																	
04/26/91	22:10	6.166667	0														0	0
04/26/91	22:20	6.333334	0														0.01	0.0254
04/26/91	22:30	6.5	0														0.28	0.7112
04/26/91	22:40	6.666667	0														0.12	0.3048
04/26/91	22:50	6.833334	0														0.02	0.0508
04/26/91	23:00	7	0														0.17	0.4318
04/26/91	23:10	7.166667	0.34526														0.52	1.3208
04/26/91	23:20	7.333334	0.86032														0.46	1.1684
04/26/91	23:30	7.5	0.97069	3868	18.4	106	22.6	15.92	44.6	6.4	0.00	5.99	38.4	42.8	14.8	38.7	0.16	0.4064
04/26/91	23:40	7.666667	0.97069														0.18	0.4572
04/26/91	23:50	7.833334	0.97069														0.23	0.5842
04/27/91	00:00		1.06955	3869	17.2	140	9.8	14.06	29.9	12.1	4.29	0.00	38.9	39.5	12.5	20.0	0.34	0.8636
04/27/91	00:10	8.166667	1.06955														0.03	0.0762
04/27/91	00:20	8.333334	0.97069														0	0
04/27/91	00:30	8.5	0.97069	3870	19.8	183	19.6	12.57	37.3	14.4	4.13	0.00	49.9	44.4	14.3	20.9	0	0
04/27/91	00:40	8.666667	0.86032														0	0
04/27/91	00:50	8.833334	0.75561														0	0
04/27/91	01:00	9.000001	0.75561	3871	23.4	200	34.6	6.93	42.8	9.0	7.39	0.00	72.4	57.6	17.1	36.1	0	0
04/27/91	01:10	9.166667	0.65939														0	0
04/27/91	01:20	9.333334	0.65939														0	0
04/27/91	01:30	9.500001	0.57166	3872	21.3	199	14.1	0.00	39.5	16.9	5.40	0.00	51.9	46.9	14.6	22.2	0	0
04/27/91	01:40	9.666667	0.57166														0	0
04/27/91	01:50	9.833334	0.57166														0	0
04/27/91	02:00	10	0.48959	3873	21.9	203	19.4	0.00	44.4	16.3	5.16	0.00	50.9	49.4	15.1	26.3	0	0
04/27/91	02:10	10.16667	0.48959														0	0
04/27/91	02:20	10.33333	0.41318														0	0
04/27/91	02:30	10.5	0.41318	3874	22.9	181	16.9	0.00	60.8	17.1	6.06	0.00	56.4	51.0	15.1	25.2	0	0
04/27/91	02:40	10.66667	0.41318														0	0
04/27/91	02:50	10.83333	0.34526														0	0
04/27/91	03:00	11	0.34526	3875	22.9	160	10.3	0.00	46.7	15.9	4.27	0.00	53.4	49.4	13.8	25.2	0	0
04/27/91	03:10	11.16667	0.34526														0	0
04/27/91	03:20	11.33333	0.28583														0	0
04/27/91	03:30	11.5	0.28583	3876	23.4	151	21.3	0.00	52.9	12.1	4.05	0.00	58.9	55.1	13.8	34.4	0	0
04/27/91	03:40	11.66667	0.2264														0	0
04/27/91	03:50	11.83333	0.2264														0	0
04/27/91	04:00	12	0.2264	3877	23.4	135	16.4	0.00	52.3	14.9	3.89	0.00	47.9	51.8	13.3	29.6	0.01	0.0254
04/27/91	04:10	12.16667	0.2264														0	0

SSF UPPER DATE	TIME	REL TIME	C l/s	LAB no.	COND	ORGANIC ACID	Cl eq	NO3 eq	SO4 eq	H eq	NH4 eq	Alk eq	Ca eq	Mg eq	K eq	Na eq	PRECIP in	PRECIP cm
04/28/91	16:00	0	0.02547														0.01	0.0254
04/28/91	16:10	0.166667	0.02547														0.03	0.0762
04/28/91	16:20	0.3333337	0.02547														0.08	0.2032
04/28/91	16:30	0.5000003	0.02547														0.03	0.0762
04/28/91	16:40	0.666667	0.02547														0	0
04/28/91	16:50	0.8333337	0.02547														0.03	0.0762
04/28/91	17:00	1.0000004	0.02547														0.04	0.1016
04/28/91	17:10	1.166667	0.02547														0	0
04/28/91	17:20	1.3333337	0.02547														0	0
04/28/91	17:30	1.5000004	0.02547														0	0
04/28/91	17:40	1.666667	0.02547														0	0
04/28/91	17:50	1.8333337	0.02547														0	0
04/28/91	18:00	2.0000004	0.02547														0	0
04/28/91	18:10	2.166667	0.02547														0	0
04/28/91	18:20	2.3333337	0.02547														0.01	0.0254
04/28/91	18:30	2.5000004	0.02547														0	0
04/28/91	18:40	2.6666671	0.02547														0	0
04/28/91	18:50	2.8333337	0.02547														0	0
04/28/91	19:00	3.0000004	0.02547														0	0
04/28/91	19:10	3.1666671	0.02547														0	0
04/28/91	19:20	3.3333337	0.02547														0	0
04/28/91	19:30	3.5000004	0.02547														0	0
04/28/91	19:40	3.6666671	0.02547														0	0
04/28/91	19:50	3.8333337	0.02547														0	0
04/28/91	20:00	4.0000004	0.02547														0	0
04/28/91	20:10	4.1666671	0.02547														0	0
04/28/91	20:20	4.3333336	0.02547														0	0
04/28/91	20:30	4.5000004	0.02547														0	0
04/28/91	20:40	4.6666671	0.02547														0	0
04/28/91	20:50	4.8333336	0.02547														0	0
04/28/91	21:00	5.0000004	0.02547														0	0
04/28/91	21:10	5.1666671	0.02547														0	0
04/28/91	21:20	5.3333336	0.02547														0.12	0.3048
04/28/91	21:30	5.5000004	0.02547														0.01	0.0254
04/28/91	21:40	5.6666671	0.02547														0	0
04/28/91	21:50	5.8333336	0.02547														0	0
04/28/91	22:00	6.0000004	0.02547														0	0

Date	Time																	
04/26/91	22:10	6.166667	0.02547														0	0
04/26/91	22:20	6.333334	0.02547														0.01	0.0254
04/26/91	22:30	6.5	0.02547														0.28	0.7112
04/26/91	22:40	6.666667	0.02547														0 12	0 3048
04/26/91	22:50	6.833334	0.02547														0.02	0.0508
04/26/91	23:00	7	0.02547														0.17	0.4318
04/26/91	23:10	7.166667	0.02547														0.52	1.3208
04/26/91	23:20	7.333334	0.34526	3784	20.5	0	46.2	0.00	26.7	0.2	NS	145.32	13.5	107.0	4.1	60.0	0.46	1.1684
04/26/91	23:30	7.5	0.65939														0.16	0.4064
04/26/91	23:40	7.666667	0.75561														0.18	0.4572
04/26/91	23:50	7.833334	0.86032	3785	20.5	0	46.9	0.00	25.0	0.1	NS	148.65	14.0	110.3	2.6	59.6	0.23	0.5842
04/27/91	00:00	8	0.86032														0.34	0.8636
04/27/91	00:10	8.166667	0.86032														0.03	0.0762
04/27/91	00:20	8.333334	0.86032	3786	20.2	0	55.0	0.00	24.9	0.1	NS	155.32	12.5	112.7	2.0	59.2	0	0
04/27/91	00:30	8.5	0.86032														0	0
04/27/91	00:40	8.666667	0.86032														0	0
04/27/91	00:50	8.833334	0.86032	3787	21	0	60.5	0.00	24.5	0.2	NS	158.65	12.0	116.9	1.5	61.6	0	0
04/27/91	01:00	9.000001	0.75561														0	0
04/27/91	01:10	9.166667	0.65939														0	0
04/27/91	01:20	9.333334	0.65939	3788	21.6	0	56.3	0.00	26.3	0.2	NS	153.32	12.5	112.7	2.3	61.3	0	0
04/27/91	01:30	9.500001	0.65939														0	0
04/27/91	01:40	9.666667	0.57166														0	0
04/27/91	01:50	9.833334	0.57166	3789	21	0	55.0	12.26	26.2	0.2	NS	153.32	12.0	114.4	2.0	66.7	0	0
04/27/91	02:00	10	0.48959														0	0
04/27/91	02:10	10.16667	0.48959														0	0
04/27/91	02:20	10.33333	0.48959	3790	20.5	0	61.9	0.00	24.6	0.1	NS	158.65	12.0	113.6	2.0	58.7	0	0
04/27/91	02:30	10.5	0.48959														0	0
04/27/91	02:40	10.66667	0.41318														0	0
04/27/91	02:50	10.83333	0.41318	3791	20.5	0	63 3	0.00	25.7	0.1	NS	153.32	12.5	114.4	2.6	58.7	0	0
04/27/91	03:00	11	0.41318														0	0
04/27/91	03:10	11.16667	0.41318														0	0
04/27/91	03:20	11.33333	0.41318	3792	20.2	0	55.8	0.00	26.8	0.1	NS	141.32	12.0	114.4	2.3	58.7	0	0
04/27/91	03:30	11.5	0.34526														0	0
04/27/91	03:40	11.66667	0.34526														0	0
04/27/91	03:50	11.83333	0.34526	3793	21	0	54.2	0.00	24.1	0.1	NS	126.65	12.5	110.3	2.0	58.3	0	0
04/27/91	04:00	12	0.34526														0.01	0.0254
04/27/91	04:10	12.16667	0.34526														0	0

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DATE	TIME	REL TIME	L l/s	LAB no.	COND	ORGANIC ACID	Cl equ	NO3 equ	SO4 equ	H equ	NH4 equ	Alk equ	Ca equ	Mg equ	K equ	Na equ	PRECIP in	PRECIP cm
04/27/91	04:10	0	0														0.01	0.0254
	04:20	0.166667	0														0	0
04/27/91	04:30	0.333334	0	3855	21	190	0.0	0.00	48.7	17.2	7.72	0.00	51.9	39.5	12.8	21.7	0.2	0.508
04/27/91	04:40	0.5	0.2264														0.19	0.4826
04/27/91	04:50	0.666667	0.26583	3856	23.6	179	15.3	0.00	50.4	19.3	3.89	0.00	62.4	45.2	15.6	27.8	0.05	0.127
04/27/91	05:00	0.833334	0.26583														0.02	0.0508
04/27/91	05:10	1	0.34526	3857	23.5	177	12.4	6.64	51.2	17.2	8.87	0.00	63.4	45.2	15.3	27.8	0.18	0.2286
04/27/91	05:20	1.166667	0.75561														0.18	0.4572
04/27/91	05:30	1.333334	0.65939	3858	23.1	151	12.9	6.21	51.6	17.2	8.92	0.00	59.4	42.0	13.3	24.8	0.03	0.0762
04/27/91	05:40	1.5	0.65939														0.05	0.127
04/27/91	05:50	1.666667	0.57166	3859	17.1	145	0.0	0.00	38.3	13.7	5.83	0.00	40.9	31.3	11.3	20.0	0.01	0.0254
04/27/91	06:00	1.833334	0.41316														0	0
04/27/91	06:10	2	0.26583	3860	17.62	175	31.3	0.00	36.6	15.6	8.86	0.00	45.9	34.6	12.3	20.0	0.01	0.0254
04/27/91	06:20	2.166667	0.17829														0	0
04/27/91	06:30	2.333334	0.13301	3861	20.7	184	9.2	0.00	35.9	15.8	3.51	0.00	53.9	41.1	13.3	20.4	0	0
04/27/91	06:40	2.5	0.09905														0.01	0.0254
04/27/91	06:50	2.666667	0.09905	3862	17.1	175	10.6	0.00	37.8	15.6	3.44	0.00	40.9	31.3	11.5	16.5	0.01	0.0254
04/27/91	07:00	2.833334	0.06792														0.01	0.0254
04/27/91	07:10	3	0.06792	3863	17.1	185	0.0	0.00	37.8	15.6	5.40	0.00	44.9	32.9	12.3	16.5	0.01	0.0254
04/27/91	07:20	3.166667	0.04526														0	0
04/27/91	07:30	3.333334	0.04526	3864	17.6	184	11.5	0 00	39.1	16.4	4.30	0.00	44.4	34.6	12.3	17.4	0	0
04/27/91	07:40	3.5	0.04526														0	0
04/27/91	07:50	3.666667	0.02547	3865	17.8	180	14.0	0.00	40.0	16.2	4.65	0.00	44.9	34.6	12.3	17.0	0	0
04/27/91	08:00	3.833334	0.02547														0	0
04/27/91	08:10	4	0.02547	3866	16.8	192	16.1	0.00	40.6	17.3	0.00	0.00	42.4	33.7	12.3	18.6	0	0
04/27/91	08:20	4.166667	0.02547														0	0
04/27/91	08:30	4.333334	0.02547	3867	18.5	199	8.3	0.00	34.0	17.2	NS	0.00	46.9	37.0	12.5	18.3	0	0
04/27/91	08:40	4.5	0.01132														0	0
04/27/91	08:50	4.666667	0.01132														0	0
04/27/91	09:00	4.833334	0.01132														0	0
04/27/91	09:10	5	0.01132														0	0
04/27/91	09:20	5.166667	0.01132														0	0
04/27/91	09:30	5.333334	0														0	0
04/27/91	09:40	5.5	0														0	0
04/27/91	09:50	5.666667	0														0	0
04/27/91	10:00	5.833334	0														0	0
04/27/91	10:10	6	0														0	0
04/27/91	10:20	6.166667	0														0	0
04/27/91	10:30	6.333334	0														0	0
04/27/91	10:40	6.5	0														0	0
04/27/91	10:50	6.666667	0														0	0

SSF UPPER

DATE	TIME	REL TIME	A l/s	LAB no.	COND	ORGANIC ACID	Cl equ	NO3 equ	SO4 equ	H equ	NH4 equ	Alk equ	Ca equ	Mg equ	K equ	Na equ	PRECIP in	PRECIP cm
04/27/91	04:10	0	0.02547														0.01	0.0254
04/27/91	04:20	0.166667	0.02547														0	0
04/27/91	04:30	0.333334	0.17829	3828	21.4	174	15	0	50	17.2	NS	0	47.4	42.8	13	23.5	0.2	0.508
04/27/91	04:40	0.5	1.08955														0.19	0.4826
04/27/91	04:50	0.666667	1.08955	3829	20.1	171	19.3	0	50.2	18.2	NS	0	45.9	41.1	12.8	24.4	15.3	20.4
04/27/91	05:00	0.833334	1.08955														14.8	27.0
04/27/91	05:10	1	1.21973	3830	21	165	14.2	0	51.8	17.4	NS	0	45.9	40.3	12.8	30.4	0.09	0.2286
04/27/91	05:20	1.166667	1.65555														0.18	0.4572
04/27/91	05:30	1.333334	1.65555	3831	21	155	19.2	0	52.6	18.3	NS	0	47.9	39.5	12.5	25.7	0.03	0.0762
04/27/91	05:40	1.5	1.65555														0.05	0.127
04/27/91	05:50	1.666667	1.4999	3832	21.6	145	26.4	0	53.2	17.7	NS	0	46.4	40.3	12	23.5	0.01	0.0254
04/27/91	06:00	1.833334	1.35557														0	0
04/27/91	06:10	2	1.21973	3833	21	147	20.9	0.00	55.0	17.3	NS	0.00	46.4	41.1	13.3	23.5	0.01	0.0254
04/27/91	06:20	2.166667	1.08955														0	0
04/27/91	06:30	2.333334	0.97069	3834	17.2	169	9.8	0	35.7	16.10	NS	0.0	41.9	37.00	12.3	21.3	0	0
04/27/91	06:40	2.5	0.86032														0.01	0.0254
04/27/91	06:50	2.666667	0.75561	3835	18.2	180	10.0	0.00	34.6	18.0	NS	0.00	43.9	37.9	12.8	20.4	0.01	0.0254
04/27/91	07:00	2.833334	0.65039														0.01	0.0254
04/27/91	07:10	3	0.57166	3836	18.2	188	14.6	23.06	32.3	17.0	NS	0.00	39.9	36.7	13.0	20.4	0.01	0.0254
04/27/91	07:20	3.166667	0.48959														0	0
04/27/91	07:30	3.333334	0.41316	3837	17.3	184	16.8	0.00	35.2	15.6	NS	0.00	43.4	35.4	13.8	24.8	0	0
04/27/91	07:40	3.5	0.34526														0	0
04/27/91	07:50	3.666667	0.28583	3838	17.3	192	9.9	0.00	28.8	18.9	NS	0.00	42.4	34.6	13.0	19.1	0	0
04/27/91	08:00	3.833334	0.2284														0	0
04/27/91	08:10	4	0.17829	3839	19.1	195	9.8	0.00	29.7	18.1	NS	0.00	42.4	35.4	13.0	17.8	0	0
04/27/91	08:20	4.166667	0.13301														0	0
04/27/91	08:30	4.333334	0.09905														0	0
04/27/91	08:40	4.5	0.06792														0	0
04/27/91	08:50	4.666667	0.06792														0	0
04/27/91	09:00	4.833334	0.06792														0	0
04/27/91	09:10	5	0.04526														0	0
04/27/91	09:20	5.166667	0.04526														0	0
04/27/91	09:30	5.333334	0.04526														0	0
04/27/91	09:40	5.5	0.02547														0	0
04/27/91	09:50	5.666667	0.02547														0	0
04/27/91	10:00	5.833334	0.02547														0	0
04/27/91	10:10	6	0.02547														0	0
04/27/91	10:20	6.166667	0.01132														0	0
04/27/91	10:30	6.333334	0.01132														0	0
04/27/91	10:40	6.5	0.01132														0	0
04/27/91	10:50	6.666667	0.01132														0	0
04/27/91	11:00	6.833334	0.01132														0	0

Date	Time	Value				
04/27/91	11:10	7	0			
04/27/91	11:20	7.166667	0		0	0
04/27/91	11:30	7.333334	0		0	0
04/27/91	11:40	7.5	0		0	0
04/27/91	11:50	7.666667	0		0	0
04/27/91	12:00	7.833334	0		0	0
04/27/91	12:10	8	0		0	0
04/27/91	12:20	8.166667	0		0	0
04/27/91	12:30	8.333334	0		0	0
04/27/91	12:40	8.5	0		0	0
04/27/91	12:50	8.666667	0		0	0
04/27/91	13:00	8.833334	0		0	0
04/27/91	13:10	9.000001	0		0	0
04/27/91	13:20	9.166667	0		0	0
04/27/91	13:30	9.333334	0		0	0
04/27/91	13:40	9.500001	0		0	0
04/27/91	13:50	9.666667	0		0	0
04/27/91	14:00	9.833334	0		0	0
04/27/91	14:10	10	0		0	0
04/27/91	14:20	10.16667	0		0	0
04/27/91	14:30	10.33333	0		0	0
04/27/91	14:40	10.5	0		0	0
04/27/91	14:50	10.66667	0		0	0
04/27/91	15:00	10.83333	0		0	0
04/27/91	15:10	11	0		0	0
04/27/91	15:20	11.16667	0		0	0
04/27/91	15:30	11.33333	0		0	0
04/27/91	15:40	11.5	0		0	0
04/27/91	15:50	11.66667	0		0	0
04/27/91	16:00	11.83333	0		0	0
04/27/91	16:10	12	0		0	0
04/27/91	16:20	12.16667	0		0	0
04/27/91	16:30	12.33333	0		0	0
04/27/91	16:40	12.5	0		0	0
04/27/91	16:50	12.66667	0		0	0
04/27/91	17:00	12.83333	0		0	0
04/27/91	17:10	13	0		0	0
04/27/91	17:20	13.16667	0		0	0
04/27/91	17:30	13.33333	0		0	0
04/27/91	17:40	13.5	0		0	0
04/27/91	17:50	13.66667	0		0	0
04/27/91	18:00	13.83333	0		0	0
04/27/91	18:10	14	0		0	0
04/27/91	18:20	14.16667	0		0	0
04/27/91	18:30	14.33333	0		0.01	0.0254
04/27/91	18:40	14.5	0		0	0

SSF UPPER

DATE	TIME	REL TIME	B l/s	LAB no.	COND	ORGANIC ACID	Cl equ	NO3 equ	SO4 equ	H equ	NH4 equ	Alk equ	Ca equ	Mg equ	K equ	Na equ	PRECIP in	PRECIP cm
04/27/91	04:10	0	0.2264	3677	23.4	135	16.4	0.00	52.3	14.9	3.89	0.00	47.9	51.8	13.3	29.6	0.01	0.0254
04/27/91	04:20	0.166667	0.2264														0	0
04/27/91	04:30	0.333334	0.41318														0.2	0.508
04/27/91	04:40	0.5	0.65939	3678	18.4	140	13.1	0.00	50.6	14.1	NS	0.00	33.9	46.9	11.8	29.5	0.19	0.4829
04/27/91	04:50	0.666667	0.65939														0.05	0.127
04/27/91	05:00	0.833334	0.65939														0.02	0.0508
04/27/91	05:10	1	0.75561	3679	22.1	157	11.4	0.00	41.8	13.9	3.94	0.00	49.4	46.1	13.0	27.4	0.09	0.2286
04/27/91	05:20	1.166667	0.86032														0.18	0.4572
04/27/91	05:30	1.333334	0.86032														0.03	0.0762
04/27/91	05:40	1.5	0.86032	3680	21	155	13.2	0.00	42.2	14.8	3.76	0.00	51.9	46.1	13.3	29.3	0.05	0.127
04/27/91	05:50	1.666667	0.86032														0.01	0.0254
04/27/91	06:00	1.833334	0.75561														0	0
04/27/91	06:10	2	0.75561	3681	20.6	164	12.3	0.00	37.2	14.5	3.76	0.00	51.9	42.6	13.6	29.5	0.01	0.0254
04/27/91	06:20	2.166667	0.65939														0	0
04/27/91	06:30	2.333334	0.65939														0	0
04/27/91	06:40	2.5	0.57166	3682	20.2	182	11.7	0.00	36.9	15.4	3.46	0.00	41.9	36.7	12.0	21.7	0.01	0.0254
04/27/91	06:50	2.666667	0.57166														0.01	0.0254
04/27/91	07:00	2.833334	0.57166														0.01	0.0254
04/27/91	07:10	3	0.57166	3683	18.9	185	15.4	11.14	34.6	16.0	NS	0.00	42.4	39.5	13.0	27.8	0.01	0.0254
04/27/91	07:20	3.166667	0.48959														0	0
04/27/91	07:30	3.333334	0.48959														0	0
04/27/91	07:40	3.5	0.48959	3684	17.8	172	8.4	0.00	41.2	15.3	7.50	0.00	36.4	42.0	10.2	14.4	0	0
04/27/91	07:50	3.666667	0.41318														0	0
04/27/91	08:00	3.833334	0.41318														0	0
04/27/91	08:10	4	0.41318	3685	20	164	19.8	0.00	53.9	15.0	3.07	0.00	39.9	41.1	11.8	21.7	0	0
04/27/91	08:20	4.166667	0.41318														0	0
04/27/91	08:30	4.333334	0.34528														0	0
04/27/91	08:40	4.5	0.34528	3686	21 2	144	18.9	0.00	46.7	13.5	3.28	0.00	50.9	47.7	13.0	30.0	0	0
04/27/91	08:50	4.666667	0.34528														0	0
04/27/91	09:00	4.833334	0.28583														0	0
04/27/91	09:10	5	0.28583	3687	21.2	137	15.6	0.00	47.7	12.1	4.16	6.67	47.9	47.7	13.0	30.0	0	0
04/27/91	09:20	5.166667	0.2264														0	0
04/27/91	09:30	5.333334	0.2264														0	0
04/27/91	09:40	5.5	0.2264	3688		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0	0
04/27/91	09:50	5.666667	0.2264														0	0
04/27/91	10:00	5.833334	0.2264														0	0
04/27/91	10:10	6	0.17829	3689	17.6	134	14.9	0.00	46.3	14.9	NS	0.00	33.4	41.1	10.7	23.9	0	0
04/27/91	10:20	6.166667	0.17829														0	0
04/27/91	10:30	6.333334	0.17829														0	0
04/27/91	10:40	6.5	0.17829	3690	18.2	118	13.2	0.00	51.9	14.9	4.19	0.00	26.9	43.6	10.5	20.0	0	0
04/27/91	10:50	6.666667	0.17829														0	0
04/27/91	11:00	6.833334	0.13301														0	0

04/27/91	11:10	7	0.13301	3891	21.2	103	20.6	0.00	54.7	13.7	0.00	0.00	32.9	43.6	11.3	32.2	0	0
04/27/91	11:20	7.166667	0.13301														0	0
04/27/91	11:30	7.333334	0.13301														0	0
04/27/91	11:40	7.5	0.13301	3892	21.3	97	20.6	0.00	56.0	13.3	0.00	0.00	30.9	42.0	10.7	33.1	0	0
04/27/91	11:50	7.666667	0.13301														0	0
04/27/91	12:00	7.833334	0.09905														0	0
04/27/91	12:10	8	0.09905	3893	20.3	86	18.1	0.00	56.9	11.9	0.00	0.00	32.4	42.8	10.7	32.6	0	0
04/27/91	12:20	8.166667	0.09905														0	0
04/27/91	12:30	8.333334	0.09905														0	0
04/27/91	12:40	8.5	0.09905	3894	17	95	20.3	0.00	53.0	12.5	NS	0.00	28.9	42.0	10.7	30.4	0	0
04/27/91	12:50	8.666667	0.09905														0	0
04/27/91	13:00	8.833334	0.09905														0	0
04/27/91	13:10	9.000001	0.06792	3895	18	73	37.6	10.92	49.2	12.3	0.00	0.00	28.9	43.6	10.2	28.3	0	0
04/27/91	13:20	9.166667	0.06792														0	0
04/27/91	13:30	9.333334	0.06792														0	0
04/27/91	13:40	9.500001	0.06792														0	0
04/27/91	13:50	9.666667	0.06792														0	0
04/27/91	14:00	9.833334	0.06792														0	0
04/27/91	14:10	10	0.04528														0	0
04/27/91	14:20	10.16667	0.04528														0	0
04/27/91	14:30	10.33333	0.04528														0	0
04/27/91	14:40	10.5	0.04528														0	0
04/27/91	14:50	10.66667	0.04528														0	0
04/27/91	15:00	10.83333	0.04528														0	0
04/27/91	15:10	11	0.04528														0	0
04/27/91	15:20	11.16667	0.04528														0	0
04/27/91	15:30	11.33333	0.04528														0	0
04/27/91	15:40	11.5	0.02547														0	0
04/27/91	15:50	11.66667	0.02547														0	0
04/27/91	16:00	11.83333	0.02547														0	0
04/27/91	16:10	12	0.02547														0	0
04/27/91	16:20	12.16667	0.02547														0	0
04/27/91	16:30	12.33333	0.02547														0	0
04/27/91	16:40	12.5	0.02547														0	0
04/27/91	16:50	12.66667	0.02547														0	0
04/27/91	17:00	12.83333	0.02547														0	0
04/27/91	17:10	13	0.02547														0	0
04/27/91	17:20	13.16667	0.02547														0	0
04/27/91	17:30	13.33333	0.02547														0	0
04/27/91	17:40	13.5	0.02547														0	0
04/27/91	17:50	13.66667	0.01132														0	0
04/27/91	18:00	13.83333	0.01132														0	0
04/27/91	18:10	14	0.01132														0	0
04/27/91	18:20	14.16667	0.01132														0	0
04/27/91	18:30	14.33333	0.01132														0.01	0.0254
04/27/91	18:40	14.5	0.01132														0	0

VITA

Mark D. Mc Burnett

Canidate for the Degree of

Master of Science

Thesis: SUBSURFACE STORMFLOW CHEMISTRY FROM A FORESTED
HILLSLOPE IN THE OUACHITA MOUNTAINS

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