Characterization of Roadway Runoff Prior to Treatment

Research Report SPR-223-2223

Prepared for
The Rhode Island Department of Transportation

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16. Abstract

Proper design of roadway runoff treatment systems requires the knowledge of the pollutants present, peak concentrations, volumetric mass loading and seasonal variations. Three sampling locations in the State of Rhode Island having different Average Daily Traffic (ADT) values, drainage areas and land uses were selected to characterize roadway runoff. A total of six rain storms, including two winter and four non-winter storms were sampled. The collected water samples were analyzed for suspended solids, metals, nutrients, organic and inorganic chemicals. Both natural (leaf fall) and Anthropogenic (application of deicing agents) seasonal characteristics were found to be factors affecting the concentration and loads of Calcium, Chloride, Nitrate, Sodium and TOC. A first flush period during which the contaminants and mass loadings are present in high concentrations was observed at all of the sites for most of the contaminants. The range of ADT values selected for this study did not affect the magnitude of the pollutant concentrations and loads. Land use and seasonal characteristics appeared to have the most impact on the magnitude of mass loadings from roadway runoff.

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Preface

This research project was conducted by the Civil & Environmental Engineering Department at the University of Rhode Island under contract to the Rhode Island Department of Transportation. Funds were provided through the Federal Highway Administration and the RIDOT.

The investigation was carried out by Dr. Leon T. Thiem, Associate Professor of Civil & Environmental Engineering, Dr. Eid A. Alkhatib, Assistant Research Professor at the University of Rhode Island, Mr. Arvind Panganamamula, Graduate Research Assistant in the Civil & Environmental Engineering Department at the University of Rhode Island and Mr. Sampath Bade, Graduate Research Assistant in the Civil & Environmental Engineering Department at the University of Rhode Island.

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List of Abbreviations

ADP	Antecedent Dry Period
ADT	Average Daily Traffic
ASCE	American Society of Civil Engineers
BMPs	Best Management Practices
CVE	Civil & Environmental Engineering Department
EMC	Event Mean Concentration
FF	First Flush
FHWA	Federal Highway Administration
GAC	Granular Activated Carbon
HDPE	High Density Polyethylene
MCL	Maximum Contaminant Levels
MEP	Maximum Extent Practicable
MS4	Municipal Separate Storm Sewer System
NA	Not Analyzed
nd	None Detected
NPDES	National Pollution Discharge Elimination System
NPS	Nonpoint Sources
O&G	Oil & grease
PFF	Post First Flush
RPU	Runoff Purification Unit
SR	State Route
TOC	Total Organic Carbon
TSS	Total Suspended Solids
URI	University of Rhode Island
USEPA	United States Environmental Protection Agency
VSS	Volatile Suspended Solids

1. Introduction

1.1 Rationale for Study

Roadway runoff can be a significant non-point source of ground and surface water pollution (Kobriger et al., 1984). The USEPA (Environmental Protection Agency) has established concentration standards for various pollutants that have been found to be present in roadway runoff to protect aquatic life and drinking water supplies. Past studies (Kobriger et al., 1984) have shown that peak concentrations of metals and other pollutants (chloride, nutrients, oil & grease and TSS) in roadway runoff in both winter and non-winter seasons can be higher than the EPA Aquatic Water Quality Criteria and/or Drinking Water Standards.

The type and concentrations of contaminants found in roadway runoff are affected by seasonal (winter and non-winter) changes. Even though there are four seasons, the most significant changes in the mix and concentration of pollutants occur between winter and non-winter conditions. The start of winter season can be defined as that time of the year when roads are first treated with deicing chemicals. Non-winter conditions occur when the application of deicing agents has ceased and all residuals have been flushed from the roads. During the winter season the median constituent concentrations in highway runoff were found by a researcher to be highest for all the constituents (Kobriger et al., 1984). Table 1.1 lists the literature values of road runoff contaminants from both winter and non-winter sampling periods compared to EPA standards and Rhode Island River Baseline Concentrations.

Table 1.1 A Comparison of Road Runoff Constituents from Winter and Non-Winter Sampling Periods With Reference to EPA Aquatic Water Quality Criterion, RI River Baseline Concentrations and EPA Drinking Water Standards (Kobriger 1984, Dupuis 1985)

Constituents (mg/L)	Non-Winter		Winter		EPA Aquatic Water Quality Criterion		RI Baseline River Study[*]	EPA Drinking Water Standards
	Range	Median	Range	Median	Acute	Chronic	Range	
Cadmium	<0.0001-0.004	<0.0001	<0.0001-0.006	0.002	0.002	0.002	0.00005-0.00029	0.01
Chloride	4-2,900	83	11-35,000	2,360	NONE	NONE	5.2-42.7	250[**]
Chromium	<0.0001-0.007	<0.0001	<0.0001-0.018	0.005	0.07	0.042	NA	0.05
Copper	0.007-0.037	0.014	0.005-0.059	0.022	0.0084	0.0058	0.009-0.012	1.0[**]
Iron	1.7-13.0	4.9	1.3-46.0	21.2	NONE	NONE	0.15-0.64	0.3[**]
Lead	0.1-2.2	0.6	0.1-6.3	2.5	0.025	0.001	0.0009-0.0150	0.05
Nickel	<0.0005-0.22	<0.0005	0.005-0.2	0.1	1.1	0.056	NA	0.1[***]
Nitrate	0.38-2.73	0.77	0.22-2.2	0.83	NONE	NONE	0.02-3.65	10.0
Oil & Grease	1.0-22.0	5.0	8.0-27.0	30	NONE	NONE	NA	NONE
Phosphate	0.1-0.73	0.33	0.11-1.21	0.54	NONE	NONE	0.01-0.03	NONE
Sodium	8.0-1,400	159.0	9.8-22,500	1,450	NONE	NONE	4.4-18.8	NONE
TSS	17-938	157	26-1,860	461	NONE	NONE	0.4-3.7	<1.0
Zinc	0.11-0.77	0.36	0.21-2.9	1.3	0.18	0.047	NA	5.0[**]

NA = Not Analyzed   [*] URI Civil Engineering Study, 1991   [**] Proposed MCL   [***] Secondary MCL

The National Pollutant Discharge Elimination System (NPDES) stormwater program requires that Municipal Separate Storm Sewer Systems (MS4) provide treatment of stormwater runoff to the "maximum extent practicable" (MEP). In particular, the Part 2 NPDES permit application requires that MS4s develop a stormwater management program that reduces the impact of non-point sources (NPS) on receiving water bodies. There are no current regulations governing the treatment of roadway runoff from roadways in the State of Rhode Island.

Constituent concentrations in roadway runoff are site specific (Dorman et al., 1987). Depending upon the type of land use adjacent to a road, that roadway can be classified as being urban, suburban or rural. Urban development which is adjacent to a roadway reduces the pervious area and increases the impervious area (such as roof tops, streets, parking lots, and sidewalks). A rural area is mostly undeveloped with more pervious area, and a suburban area is a moderately developed area. Roads passing through urbanized areas have contaminant concentrations much higher than those passing through rural areas. Trace metal concentrations in urban areas can be up to five times greater than those in the rural areas. Nutrients are usually two to three times greater and suspended particulate material can be more than three times higher in an urbanized area than in other areas. A comparison of roadway runoff (Driscoll et al., 1988) of selected contaminant concentrations from both urban and rural areas is presented in Table 1.2. Fifty percent of all the studied sites had a median concentration less than those values listed in the table.

Table 1.2 Comparison of Road Runoff Constituents from Urban and Rural Areas (FHWA/RD-88/006)

Constituents, (mg/L)	Urban	Rural
Copper	0.054	0.022
Lead	0.40	0.08
Nitrate	0.76	0.46
Phosphate	0.40	0.16
TSS	142	41
Zinc	0.33	0.08

In 1982 a study was conducted by Harned (Harned et al., 1982) on the effects of runoff from a 4.8 mile segment of interstate highway I-85 on streamflow and water quality in the Sevenmile Creek Basin, a rural area in the state of North Carolina. The Average Daily Traffic (ADT) of the segment was 25,000 vehicles per day. Metals concentrations in the soils and in the water infiltrating the soil zone near the highway were found to be as much as ten times greater than the background levels. The measured trace metal concentrations of cadmium, chromium, copper, lead, nickel, and zinc in the runoff discharged into streams in the basin exceeded the maximum recommended levels for the protection of aquatic life, and lead and cadmium concentrations measured in the runoff frequently exceeded the EPA drinking water standards.

In the State of Rhode Island, a study has been published on highway runoff. In 1984, Hoffman, et al., (Hoffman et al., 1985) studied the effects of runoff pollutants (cadmium, copper, iron, lead, manganese, PAH, TSS and zinc) from interstate highway I-95 and State Route 10. The study section had an ADT of 101,500 vehicles per day and a drainage area of 0.448 km^2. Pollutant discharge data were generated based on a 30 minute interval of sampling. Using their data, the researchers extrapolated that 50% of the total pollutant inputs of lead, PAH, TSS and zinc which were discharged into the Pawtuxet River came from this highway runoff.

To better estimate the pollutant discharge rate in stormwater runoff, they recommended a higher sampling frequency and coverage of the entire storm event. Their other recommendation was to conduct runoff studies from roads carrying lesser traffic to determine if they can have deleterious impacts on receiving waters.

Little knowledge exists about roadway runoff from roads with ADT values under 30,000 vehicles per day. Many sensitive areas such as groundwater recharge areas and surface waters are crossed by roadways with low ADT values. Therefore, the objectives of this study were:

1. To establish temporal variations for three winter and three non-winter storms.
2. To characterize the first flush for pollutants in the runoff from three different roadway sites having ADT values less than 30,000 vehicles per day.
3. To determine if a relationship exists between the constituent mass load in runoff and adjacent land use.

1.2 Selection of Sampling Sites

In order to select the sampling sites several criteria were utilized: 1) the ADT value of a road should be anywhere between 2,000 and 15,000 vehicles per day, 2) the land use around the road should vary from rural to urban, and 3) the drainage areas for the collected runoff should be no less than 9,000 m^2. In addition to these criteria, runoff from the adjacent land had to be minimal.

Once the required ADT range was decided on, the 1993 Rhode Island Traffic Flow Map was consulted to evaluate promising locations with the required daily traffic values. The type of adjacent land use was determined by a field inspection. Each location was then visited to insure compliance with field sampling criterion, such as access to a suitable sampling location. To verify the ADT values taken from the RI Traffic Flow Map traffic field counts were made between December 13-17, 1993.

The three locations that were selected for sampling were on Post Road, State Route 2 (SR 2), and State Route 165 (SR 165). Table 1.3 lists the selected sites and summarizes their characteristics.

Table 1.3 Site Characteristics

Site	Length (m)	Area (m^2)	Average Daily Traffic (ADT), Dec 13-17, 1993	Land Use Classification
Post Road	976	54,228	11,700	Urban
State Route 2	823	11,291	9,700	Suburban
State Route 165	777	9,470	2,100	Rural

Post Road - Kent County

The stretch of Post Road between Main Avenue and Veterans' Memorial Drive was selected for analysis. This section of Post Road has an ADT value of 11,700 vehicles per day with four travel lanes (each 3.0 m wide) and shoulders with curbs on both sides (1.8 m wide). Many side roads (11 local streets) are connected to this section of Post Road.

Unlike the other sites (SR 2 and SR 165) the roadway runoff from Post Road is influenced by the runoff from residential, business, and commercial establishments. The contribution to the total runoff from the paved roadway is 25%, from parking lots is 52%, from side roads is 14%, and from houses (mainly from roofs and lawns) is 9%. All drainage areas were calculated using as-built plans as well as several site investigations.

The runoff from this section of Post Road is collected through an underground storm drain system. Storm drains collect runoff from side roads and parking lots into pipes ranging in size from 0.30 m to 0.91 m (see Figure 1.1). The runoff that is collected discharges through a 0.91 m diameter pipe into an earthen channel which eventually leads into Gorton Pond. Samples were collected directly from the pipe just before the runoff is discharged into the earthen channel.

Figure 1.1 is a schematic of the studied segment of Post Road, showing the storm drain system. The areas (not to scale) of the parking lots and side roads contributing to the roadway runoff are also outlined. The earthen channel near Gorton Pond is also marked on this schematic.

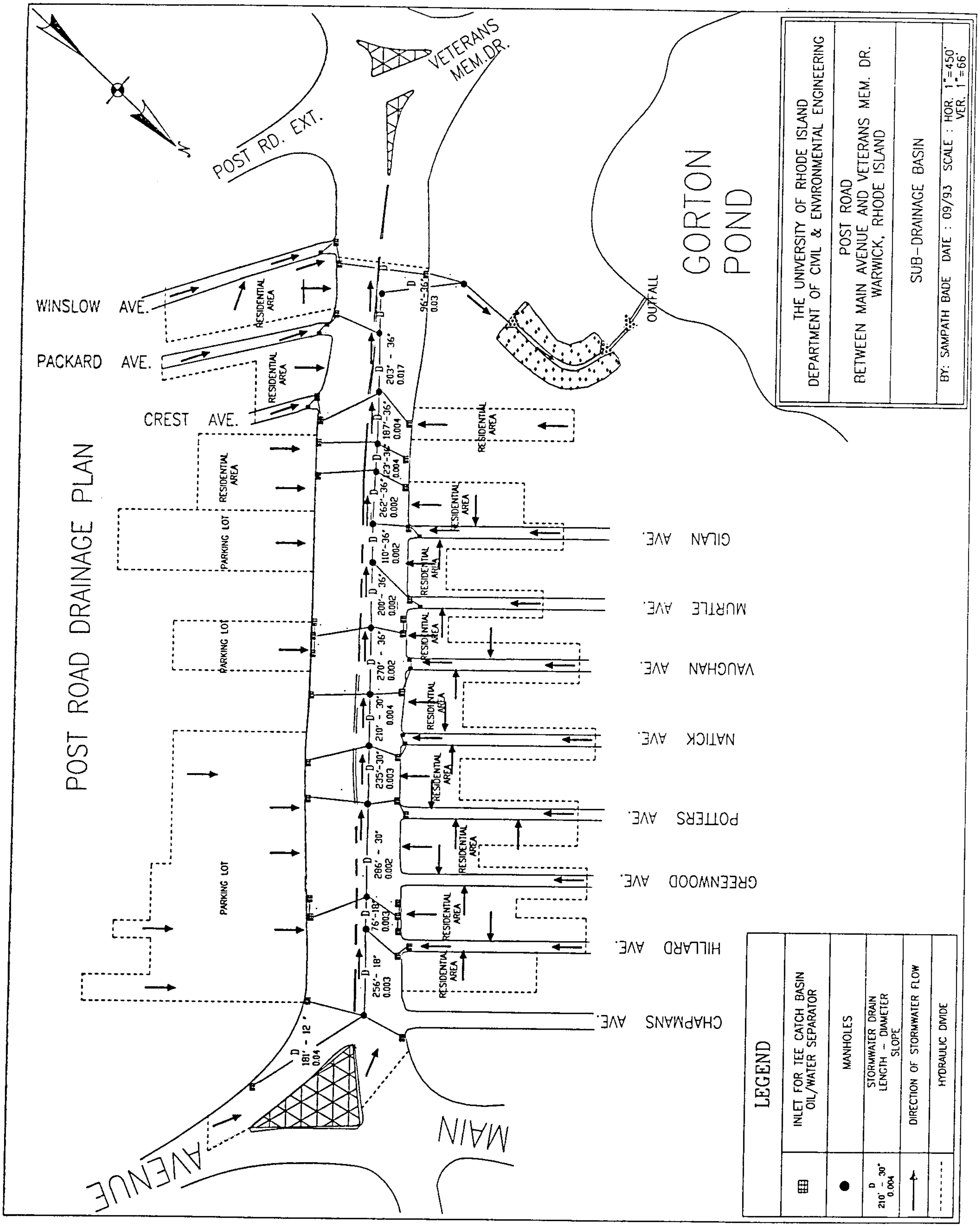

Figure 1.1 Drainage Plan - Post Road

State Route 2 - Washington County

The sampling location on SR 2 is located near the Rhode Island Veterans' Cemetery. This section of State Route 2 has a measured ADT of 9,700 vehicles per day which is in the middle range of the three sites. This site includes a few business establishments and a low density residential development. The roadway runoff discharged from this sampling segment of SR 2 is discharged into the woods by the side of the road through paved waterways. In order to collect all of the roadway runoff in this roadway segment, each of the three paved waterways in the segment was blocked with sandbags to divert roadway runoff to the sampling location.

Figure 1.2 illustrates the direction in which the runoff flows within the road and illustrates the drainage area in detail. SR 2 is a two lane (3.66 m each), two shoulder (3.05 m each), 45 MPH speed limit road. The road has a mountable curb in this section, which directs the roadway runoff into the paved waterways. There is no runoff contribution from the unpaved roads which intersect with SR 2.

State Route 165 - Washington County

This site is located near Arcadia State Park. It has a very low ADT value of 2,100 vehicles per day. This site is rural in nature and is basically undeveloped. The overall drainage system on SR 165 is the same as SR 2.

This section of SR 165 is a two-lane road (each 3.7 m wide) with a shoulder on either side (each 2.4 m wide). Runoff from both the travel lanes and shoulders is collected and discharged to the paved waterways. In order to divert all of the road runoff towards the

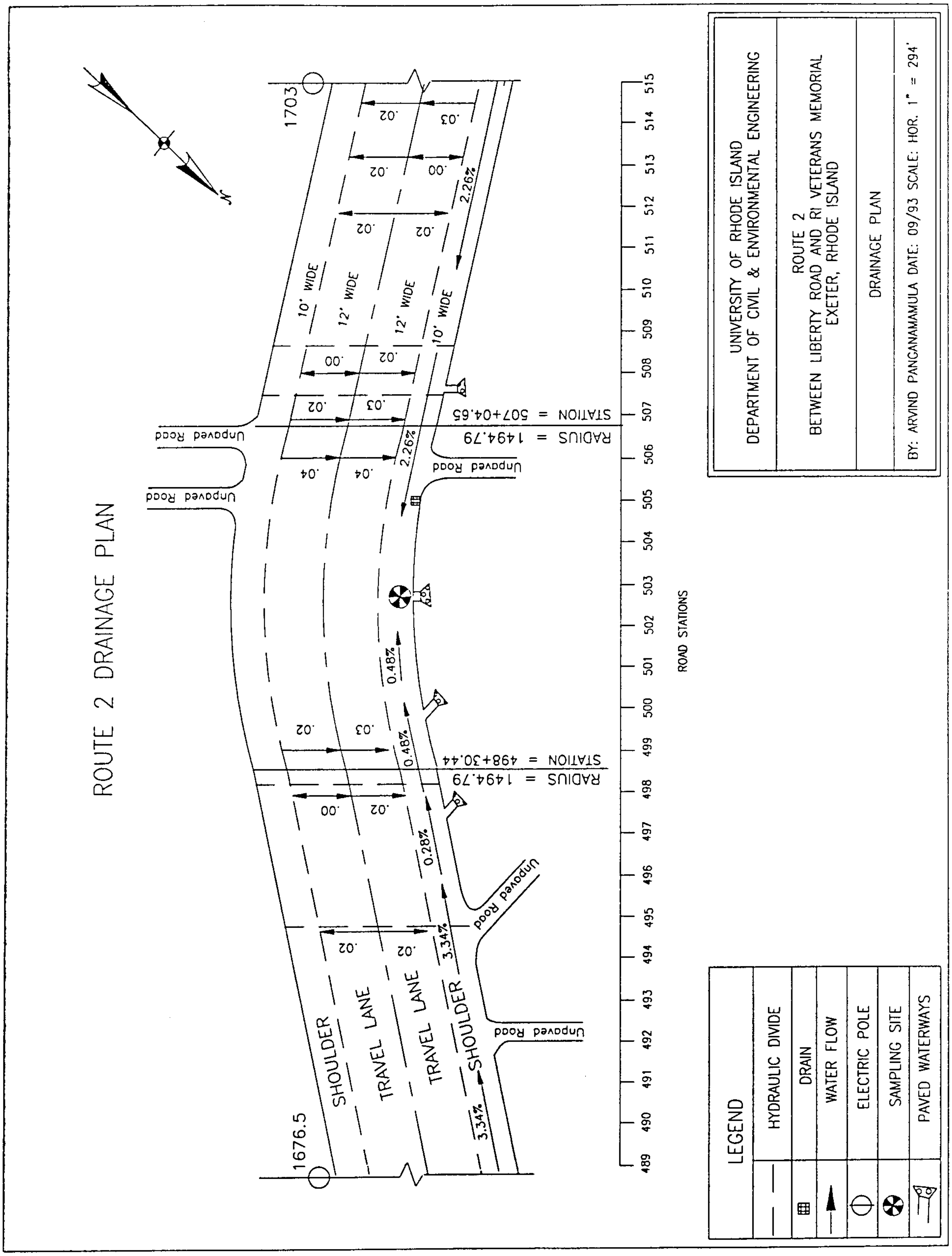

Figure 1.2 Drainage Plan - State Route 2

sampling location nine of the existing paved waterways were blocked with sandbags. As at SR 2, there is no runoff contribution from other sources. Figure 1.3 is a schematic of the drainage area showing the hydraulic divide and the flow direction of runoff. The sampling location is also marked (wheel sign).

1.3 Selection of Constituents

Sixteen constituents were analyzed for in each runoff sample that was collected. All of the sixteen constituents were shown to be found at elevated levels in highway runoff (Kobriger et al., 1984) and several of these constituents were also found to cause potential health and/or environmental hazards. Vehicle wear, highway maintenance, dustfall and deicing agents were found to be some of the prime sources of these constituents (Yu, 1993). Atmospheric sources were also found to contribute a significant amount of the pollutant load in highway runoff (Barrett et al. 1993). Other researchers (Harrison et al., 1985) found that rainfall can contribute up to 78% of some ionic constituents including calcium, chloride, magnesium, potassium and sulfate. Dustfall loading was also identified as a significant source of pollution in highway runoff (Gupta et al. 1981). They observed that highways near urban areas have higher levels of pollutant loadings from dustfall than those in rural areas.

Table 1.4 lists twelve of the sixteen constituents analyzed, their impacts on receiving waters and their source(s). High concentrations of trace metals can affect the quality of drinking water where groundwater is the main source of water supply. Many of these trace metals originate from vehicles. Nutrients affect both human health and aquatic life if

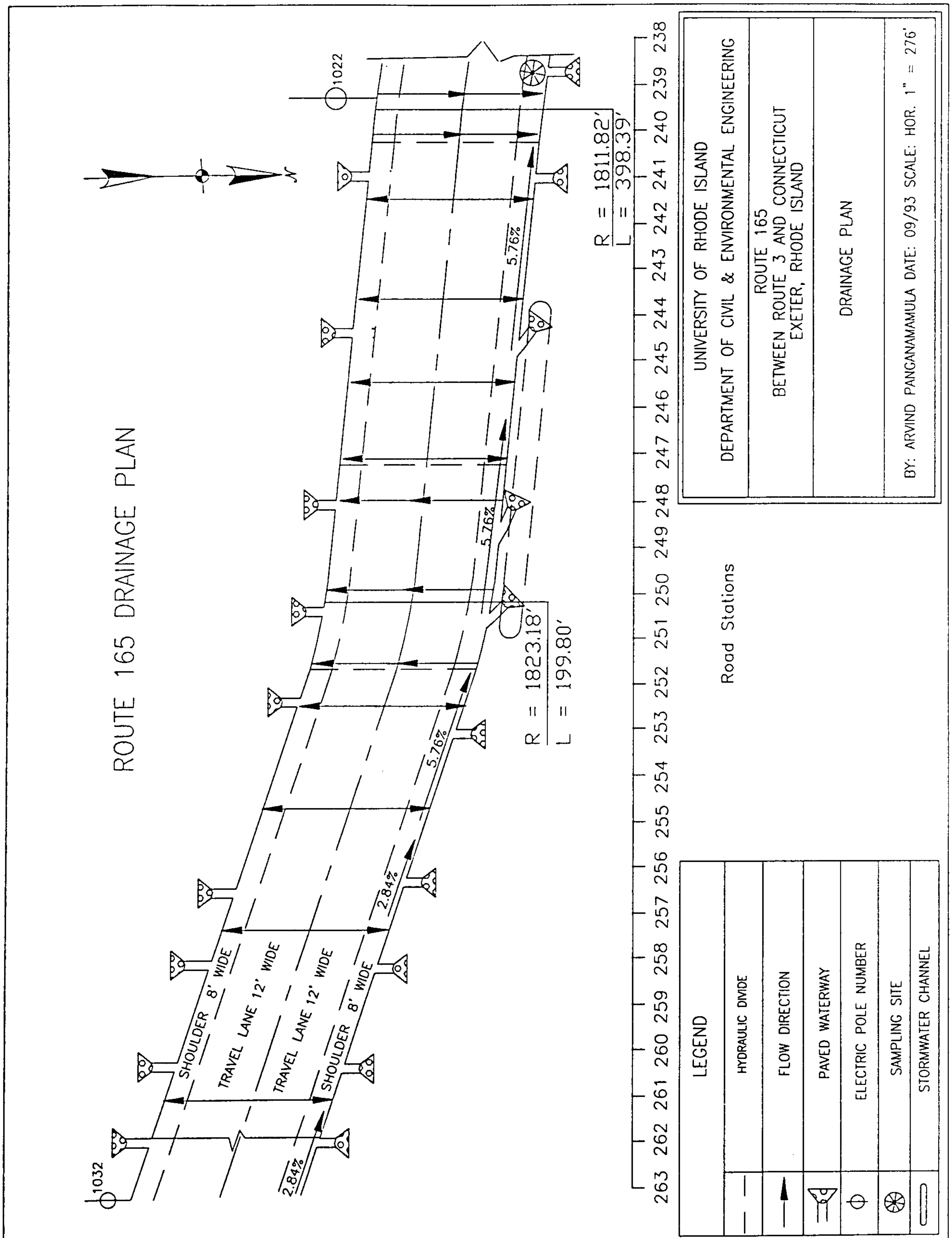

Figure 1.3 Drainage Plan - State Route 165

Table 1.4 Pollutant effects on receiving waters. Effects of Highway Runoff on Receiving Waters. Volume III, Resource Document for Environmental Assessments. FHWA/RD-84/064.

Constituent	EPA Guidance Critical Levels	Impact	Source(s)
Cadmium	59 μg/L	Saltwater aquatic life	Tire wear
Chloride	250 mg/L	Domestic water supply	Deicing
Chromium	50 μg/L	Human health	Brake
Copper	< 1 mg/L	Taste & odor	Engine
Iron	50 μg/L	Domestic water supply	Body rust
Lead	50 μg/L	Human health	Tire wear
Nickel	100 μg/L	Human health	Diesel
Nitrate	10 mg/L	Domestic water supply	Fertilizers
Oil & Grease	Surface waters free from floating oils	Freshwater aquatic life	Oils & greases
Phosphate	0.10 μg/L	Marine/estuarine waters	Fertilizers
TSS	Should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life	Freshwater fish and other aquatic life	Pavement wear, sanding
Zinc	5 mg/L	Taste & odor	Oil, grease

present in excess. Fertilizers and decomposition of leaves during the Fall season are the main sources for nutrients in the environment.

1.4 Sampling

A major goal of the sampling strategy was to capture the period immediately after the beginning of the rainfall when the concentrations of roadway runoff are changing rapidly. The sampling during this initial rainfall period (approximately 30 minutes in duration) was at a higher frequency so as to capture the rapid initial changes in the roadway runoff composition. In general, samples were collected at least every five minutes during this period.

After the initial high constituent concentration change period most of the constituent concentrations drop down to a base level. The principal reason for sampling during this period is to determine the total load of the constutuents discharged for the entire storm event, which is a useful parameter in the design of treatment units. Since during the base level period changes in constituent concentrations were minimal, the sampling interval time was gradually increased to one sample every 30 minutes.

A variety of bottles were used to collect runoff samples. All the bottles were prepared prior to sampling. Both glass and plastic (HDPE - High Density Polyethylene) bottles of different sizes were used depending upon the type of constituent to be analyzed. Table 1.5 lists the bottles used, their size and the type of preparation.

Table 1.5. List of Type/Size of Bottles Used for Sampling

Constituent(s)	Material	Size	Preparation
Metals	Plastic (HDPE)	60 mL	Acid rinsed (HNO_3)
Nutrients	Plastic (HDPE)	60 mL	Acid rinsed (H_2SO_4)
Oil & Grease	Glass	1000 mL	Deionized water rinsed
TOC	Glass	120 mL	Deionized water rinsed
TSS/VSS, Chloride	Plastic (HDPE)	1000 mL	Deionized water rinsed

1.5 Flow Measurements

Roadway runoff flow could be measured continuously during a storm to determine the pollutant loads coming off of the drainage area. The flow rate and total roadway runoff volume will determine the size of the treatment unit. In this study, runoff flow was measured using a V-notch weir that was installed at sites SR 2 and SR 165, and by the depth of the flow at the discharge of a pipe at the Post Road site.

A V-notch weir is a sharp edged 'V' shaped plate over which the collected roadway runoff water flows. The depth to the crest of the plate is measured and is used in the V-notch equation to determine the flow at that instant. Two V-notch weirs with channel boxes were constructed with plywood and plastic in the Civil Engineering department and were used at sites SR 2 and SR 165 to measure the runoff flow. The dimensions of the weir box were 0.91 m long, 0.45 m wide, and 0.30 m deep. The two V-notches were calibrated at URI with known flows to determine coefficient of discharge prior to field installation.

The V-notch assembly was placed horizontally on the paved waterway where the samples were collected. Whenever a sample was collected, the depth over the crest was measured by using a ruler. The depth reading was then substituted in the V-notch equation to calculate the flow. The V-notch equation is given by:

$$Q = 1.65H^{2.5} \tag{1}$$

where Q = flow in m^3/s H = head over the crest in meters

Manning's equation was used to determine the flow through the partly full pipes at the Post Road site. A 0.91 m pipe discharged the runoff from this site into the earthen channel where the samples were collected. The slope of the pipe at this section was 0.04 m/m. A Manning's roughness coefficient of 0.013 was used for this pipe. The only parameter that was measured in the field was the depth of water in the pipe. Manning's equation is as follows:

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{2}$$

$$Q = V * A \tag{3}$$

where Q = flow, m^3/s

V = velocity of water in the pipe, m/s

A = cross-sectional area of the flow section of the channel, m^2

n = Manning's roughness coefficient (concrete pipe)

R = hydraulic radius which is area/wetted perimeter, m

S = channel bottom slope, m/m

2. Results and Analysis

During the period from December, 1993 to November, 1994 a total of six storms were sampled. Of the six storms sampled, two were collected during winter conditions and four were collected during non-winter conditions. One non-winter storm was sampled in December (10-11, 1993) and the rest were sampled between the months of July and November (July 27-28, August 18 and November 1, 1994). The total rainfall received at each site, the date when the storm was sampled and the air temperature are listed in Table 2.1. For each of the storms, field installed rain gauge readings were recorded to determine the total rain received at the site. The rain gauge readings were also utilized in measuring the intensity of the rainfall. The level of rain in the rain gauge was recorded when either a sample was collected or after every 15 minutes. The antecedent dry periods for each of the measured storms was at least three days.

Mr. Steve Cascione of Ocean State Weather was sub-contracted to assist in weather prediction. The role of the meteorologist was to predict the timing (start to finish) and the quantity of rainfall. Successful predictions would minimize mobilization costs resulting from unsuitable storms (<0.5 cm). Prediction of the winter storms was good with only one unsuccessful deployment. The prediction of summer storms was difficult due to their quick development. During the summer months there were six unsuccessful mobilizations. In spite of the unsuccessful mobilizations the use of a weather forecaster was cost effective.

The total rainfall at all the sites during nonwinter period ranged between 0.5-4.1 cm and 2.8-5.1 cm during the winter. A review of all of the levels of contaminants collected

Table 2.1 Storm Characteristics

Storm	Date	Site	Total Rainfall (cm)	Temperature (°C)	Season	Antecedent Dry Period (Days)
		Post Rd	1.7			
Storm I	December 10-11, 1993	SR 2	1.8	11	Non-Winter	4
		SR 165	2.1			
		Post Rd	4.9			
Storm II	March 9-10, 1994	SR 2	4.3	0	Winter	4
		SR 165	5.1			
		Post Rd	3.0			
Storm III	March 21-22, 1994	SR 2	3.5	5	Winter	3
		SR 165	2.8			
		Post Rd	0.60			
Storm IV	July 27-28, 1994	SR 2	1.4	22	Non-Winter	4
		SR 165	0.50			
		Post Rd	2.8			
Storm V	August 18, 1994	SR 2	2.3	13	Non-Winter	4
		SR 165	4.1			
		Post Rd	0.53			
Storm VI	November 1, 1994	SR 2	0.66	10	Non-winter	4
		SR 165	0.66			

from each of the six storms indicated that the only major differences in both contaminant concentrations and presence were between the winter and non-winter storms and the adjacent land use. As a result, the data from the six storms was grouped and analyzed as winter and non-winter.

2.1 Concentration vs Time

The concentration of a constituent (Y-axis) when plotted against time (X-axis) will determine the trend of concentration changes as the storm progresses . Figures A1-A18 in appendix A are the concentration vs time graphs for all the storms.

The concentrations of roadway runoff contaminants will vary with time during a given storm event. This variation can be due to changes in rainfall intensity throughout the storm, as well as an initial quick washing of the contaminants deposited during the antecedent dry period. The highest contaminant concentrations generally occur during the beginning period of a storm. If high contaminant concentrations can damage a sensitive area then a knowledge of the time and the duration of the high concentration period is important.

2.2 Statistical Analysis

A statistical analysis was done on all the data collected to identify relationships between various constituents of roadway runoff. The computer software program SigmaStat was used for the above analysis. Correlation coefficients were determined for all the sites for each of the storms. In general correlation coefficients greater than 0.6 indicate a strong relationship between the constituents. A negative correlation coefficient means that one of the variables increases while the other decreases. A detailed study of the correlation coefficients established that the constituent concentration was dependent on the conductivity, flow, TSS and VSS. The conductivity was a surrogate for dissolved contaminants and the TSS and VSS could represent the solid fraction. Tables 2.2-2.7 summarizes the degree of correlation of all the contaminants in relation to conductivity, flow, TSS and VSS for all the sites for the winter and nonwinter seasons. In order to illustrate the association of the constituents with the indicative parameters qualitative terms such as High and Good have been reported. The numerical values of the correlation coefficients are presented in Tables A1-A6 of Appendix A.

A high degree of correlation with TSS indicates that the constituent is present in the particulate form. The constituent with a high degree of correlation with conductivity is present in the dissolved form in the runoff. Based on this analysis all of the constituents were grouped into three types listed in Table 2.8. Type I constituents are present in the particulate, and Type II in the dissolved form. Type III constituents are present in an intermediate stage (fraction present in particulate and rest in dissolved form).

Table 2.8 List of constituents belonging to Type I, II, or III

Constituents	Type
Cadmium, Iron, Lead, TSS/VSS	I
Calcium, Chloride, Magnesium, Nickel, Nitrate, Sodium	II
Chromium, Copper, Oil & Grease, Phosphate, TOC, Zinc	III

Degree of Correlation Between Parameters - Average of Two Winter Storms

Table 2.2 Degree of Correlation Between Parameters for Post Road

	Cadmium	Calcium	Chloride	Chromium	Conductivity	Copper	Iron	Lead	Nickel	Nitrate	Oil & Grease	Phosphorus	Sodium	TOC	TSS	VSS	Zinc
Flow		<u>Good</u>															
TSS				Good											NA	High	
VSS				Good											High	NA	
Conductivity	Good	Good	High		NA				Good				High				

Table 2.3 Degree of Correlation Between Parameters for State Route 165

	Cadmium	Calcium	Chloride	Chromium	Conductivity	Copper	Iron	Lead	Nickel	Nitrate	Oil & Grease	Phosphorus	Sodium	TOC	TSS	VSS	Zinc
Flow		<u>Good</u>	<u>Good</u>							<u>Good</u>			<u>Good</u>				
TSS	Good			Good		High	Good	Good							NA	High	
VSS	Good			Good		High	Good	Good							High	NA	
Conductivity		High	High		NA								High				

Table 2.4 Degree of Correlation Between Parameters for State Route 2

	Cadmium	Calcium	Chloride	Chromium	Conductivity	Copper	Iron	Lead	Nickel	Nitrate	Oil & Grease	Phosphorus	Sodium	TOC	TSS	VSS	Zinc
Flow																	
TSS	Good	Good	Good		Good	Good	Good		Good	Good	Good		Good	Good	NA	Good	Good
VSS							Good								Good	NA	
Conductivity	Good	High	Good	Good	NA	High	Good		High	High			High	High	Good		High

High DC ≥ 0.8 — Good 0.60 ≤ DC < 0.80 — NA Not Applicable

<u>High</u> DC ≤ -0.8 — <u>Good</u> -0.60 ≥ DC > -0.80

Degree of Correlation(DC) Between Parameters - Average of Four Non-Winter Storms

Table 2.5 Degree of Correlation Between Parameters for Post Road

	Cadmium	Calcium	Chloride	Chromium	Conductivity	Copper	Iron	Lead	Magnesium	Nickel	Nitrate	Oil & Grease	Sodium	TOC	TSS	VSS	Zinc
Flow		Good															
TSS				High	Good	High	High	Good	Good	Good		Good		Good	NA		
VSS	Good			High	Good	High	High	High	Good	Good		High			High	NA	High
Conductivity	Good	Good	High		NA	Good			Good	Good		Good	Good	High	Good	Good	Good

Table 2.6 Degree of Correlation Between Parameters for State Route 165

	Cadmium	Calcium	Chloride	Chromium	Conductivity	Copper	Iron	Lead	Magnesium	Nickel	Nitrate	Oil & Grease	Sodium	TOC	TSS	VSS	Zinc
Flow																	
TSS	High	Good	Good		Good		Good	High		Good	Good	High	Good	High	NA	High	High
VSS	Good	Good	Good		Good		High	High	Good		Good	High	Good	High	High	NA	Good
Conductivity	High	High	High		NA		High	Good	High	Good	High	High	High		Good	Good	High

Table 2.7 Degree of Correlation Between Parameters for State Route 2

	Cadmium	Calcium	Chloride	Chromium	Conductivity	Copper	Iron	Lead	Magnesium	Nickel	Nitrate	Oil & Grease	Sodium	TOC	TSS	VSS	Zinc
Flow																	
TSS				Good				Good		Good		Good			NA	High	Good
VSS				Good			Good	Good				High			High	NA	Good
Conductivity		High	High		NA				Good	Good	High	High	High	High			High

High $DC \geq 0.8$ Good $0.60 \leq DC < 0.80$ NA Not Applicable

High $DC \leq -0.8$ Good $-0.60 \geq DC > -0.80$

2.3 Characterization of First Flush

During the initial period of a rainfall event the mass loading (product of concentration and flowrate) is high for a finite rainfall volume and then decreases quickly. This is due to the rapid removal of the high amounts of the previously deposited materials. This initial period containing the high mass loading can be defined as the first flush period.

First flush is an important parameter in the design of roadway runoff treatment units. Roadway runoff can be difficult to treat since the high flow rates are variable and can include several peaks. If the first flush volume of water can be identified and isolated, it is possible that only this volume will require treatment. As a result, the roadway runoff treatment units may be downsized.

Graphs plotted between percent cumulative mass loads and rainfall for all three sites and six storms were used to visually determine the first flush periods. In general all the graphs show a sharp rise in the initial stages of the rainfall and then flatten out. The highest point of the steepest slope of the curve in the initial stages of the rainfall was marked off as to the amount of the first flush rainfall and the percentage total mass removed. Figure 2.1 illustrates the first flush separation for Storm I at the Post Road site.

Type II (present in dissolved form) constituents showed a distinct first flush with a single change in the slope of the graph. Type I (particulate form) and Type III (intermediate form) constituents exhibited more than one change in slope of the graphs. For this case the top of the steepest slope was marked as the end of the first flush point.

Type I and Type III constituents exhibited first flush characteristics similar to that of

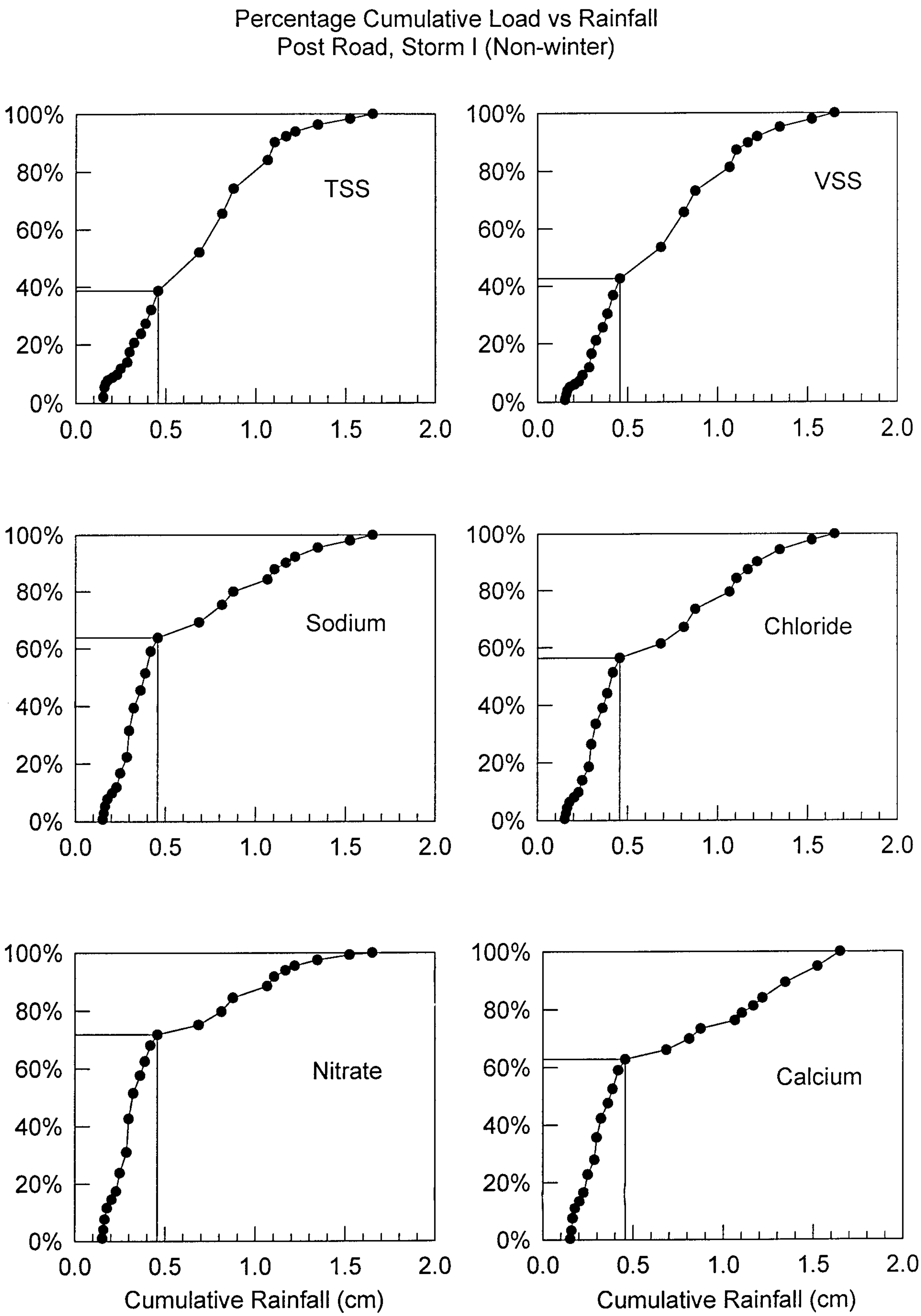

Figure 2.1 Identification of First Flush for Post Road Sampling Site, Storm I

TSS and Type II constituents exhibited first flush characteristics similar to that of chlorides. Table 2.9 summarizes the average of the first flush characteristics previously identified as particulate and dissolved.

The amount of rainfall required to produce a first flush ranged between 0.2 and 1.4 cms. The percentage of total mass removed during this period was between 9 and 90. With the exceptions of Post Road for storms III and V, SR 2 for storm IV and SR 165 for storms I and IV a higher percentage of the total mass of the constituents present in dissolved form were removed than in the particulate form. This appeared to be much true for the winter than for the non-winter storms. The amount of rainfall required for 80 percent of the total mass of the constituent to be removed was between 0.20 and 4.0 cms.

The percentage of mass removed and the amount of rainfall required to produce first flush during the winter and nonwinter seasons at each of the sites were determined and are listed in Table 2.10. With the exception of magnesium, which was not analyzed for all storms, the storms during the winter season required a greater amount of rainfall to complete the first flush than the nonwinter season. The snow on the ground before the rainfall event acts as a trap for the constituents. These are released when a sufficient amount of rainfall has occurred to melt the snow. The low ambient temperatures during the winter season increases the viscosity of the runoff water thus decreasing the mobilization of the constituents.

The mass loads in the first flush and total mass were calculated for all the storms for the three sites. Table 2.11 lists the seasonal average loads present in the first flush and the seasonal average total mass loads for each of the sites. Greater differences in seasonal mass loads excepting the deicing agents (calcium and chloride and sodium) were observed at SR

Table 2.9 First Flush Characteristics

Storm	Site	Total Rainfall (cm)	Total Duration (min)	Rain to produce First Flush (cm)		Percent Total Mass Removed in First Flush		Rain for 80% Total Mass Removed	
				Particulate/ Intermediate	Dissolved	Particulate/ Intermediate	Dissolved	Particulate/ Intermediate	Dissolved
Storm I	SR 2	1.8	295	0.80	0.80	62	80	1.13	0.80
	SR 165	2.1	345	1.00	1.00	85	70	0.90	1.30
	Post Rd	1.7	310	0.46	0.48	39	60	0.95	1.10
Storm II	SR 2	4.3	810	1.00	1.00	25	80	3.60	1.00
	SR 165	5.1	642	1.20	1.00	28	78	3.20	1.60
	Post Rd	4.9	945	1.40	1.30	32	89	3.40	1.20
Storm III	SR 2	3.5	560	0.50	0.30	25	90	2.10	0.10
	SR 165	2.8	565	0.33	0.30	25	88	2.10	0.20
	Post Rd	3.0	585	0.60	0.45	79	50	2.20	0.50
Storm IV	SR 2	1.4	142	0.50	0.50	22	12	1.60	1.40
	SR 165	0.5	22	0.38	0.38	50	50	0.44	0.44
	Post Rd	0.6	155	NFF	NFF	NFF	NFF	0.58	0.58
Storm V	SR 2	2.3	193	0.50	0.40	9	30	1.60	2.00
	SR 165	4.1	170	0.80	0.40	38	42	3.60	4.00
	Post Rd	2.8	165	0.40	0.20	39	30	1.60	1.60
Storm VI	SR 2	0.66	147	0.26	0.26	10	22	0.64	0.63
	SR 165	0.66	190	0.20	0.20	18	52	3.20	3.00
	Post Rd	0.53	230	0.20	0.20	48	65	0.50	0.50

NFF No First Flush

Table 2.10 Summary of Average Seasonal First Flush Characteristics for all of the Sites and Constituents

Constituent	Post Road				State Route 2				State Route 165			
	Winter		Non-Winter		Winter		Non-Winter		Winter		Non-Winter	
	Percent Mass in First Flush	Rainfall for First Flush cm	Percent Mass in First Flush	Rainfall for First Flush cm	Percent Mass in First Flush	Rainfall for First Flush cm	Percent Mass in First Flush	Rainfall for First Flush cm	Percent Mass in First Flush	Rainfall for First Flush cm	Percent Mass in First Flush	Rainfall for First Flush cm
Cadmium	59	0.89	42	0.36	68	0.65	37	0.45	52	0.70	47	0.58
Calcium	77	0.78	55	0.36	65	0.65	31	0.47	83	0.65	44	0.47
Chloride	82	1.01	37	0.29	84	0.65	36	0.49	81	0.65	56	0.49
Chromium	29	0.94	33	0.36	34	0.80	25	0.45	30	0.71	36	0.57
Copper	43	0.93	41	0.36	36	0.80	19	0.38	28	0.66	43	0.59
Iron	34	1.00	45	0.36	29	0.75	25	0.37	23	0.70	56	0.54
Lead	33	1.00	28	0.36	30	0.75	35	0.57	31	0.76	47	0.56
Nickel	50	0.94	34	0.36	33	0.80	35	0.42	47	0.65	58	0.54
Nitrate	44	0.84	60	0.36	29	0.75	33	0.49	20	0.65	38	0.51
Oil & Grease	53	0.83	60	0.33	60	0.75	42	0.43	60	0.65	64	0.63
Sodium	84	0.89	50	0.36	89	0.65	43	0.49	85	0.66	64	0.49
TOC	65	1.00	44	0.36	33	0.80	28	0.44	32	0.65	38	0.54
TSS	23	0.89	39	0.36	25	0.75	26	0.52	31	0.77	53	0.61
VSS	31	0.89	43	0.36	27	0.75	25	0.49	35	0.75	50	0.54
Zinc	51	0.93	41	0.36	37	0.80	26	0.37	22	0.70	44	0.49

Table 2.11 Seasonal Average Mass Loads of Constituents in First Flush and Total mass for the Three Sampling Stations

Constituent	Post Road				State Route 2				State Route 165			
	Winter		Non-Winter		Winter		Non-Winter		Winter		Non-Winter	
	Mass in FF g	Total Mass g	Mass in FF g	Total Mass g	Mass in FF g	Total Mass g	Mass in FF g	Total Mass g	Mass in FF g	Total Mass g	Mass in FF g	Total Mass g
Cadmium	2.38e-01	4.03e-01	1.42e-01	3.47e-01	4.85e-02	6.66e-02	8.59e-03	2.27e-02	6.76e-03	1.42e-02	5.21e-03	1.30e-02
Calcium	3.41e+03	4.11e+03	2.22e+03	3.16e+03	1.59e+02	2.15e+02	4.24e+01	1.89e+02	1.31e+03	1.63e+03	3.14e+01	7.56e+01
Chloride	2.17e+05	2.59e+05	6.36e+03	1.20e+04	9.29e+04	1.06e+05	2.26e+02	7.57e+02	4.23e+04	5.09e+04	4.28e+02	8.69e+02
Chromium	1.01e+01	3.11e+01	2.05e+00	5.84e+00	2.00e+00	5.27e+00	1.10e-01	4.88e-01	3.37e+00	9.25e+00	1.32e-01	4.87e-01
Copper	2.19e+01	5.04e+01	2.19e+01	6.24e+01	2.46e+00	6.54e+00	1.01e+00	6.19e+00	1.44e+00	4.57e+00	2.18e+00	7.33e+00
Iron	3.69e+03	9.90e+03	3.29e+02	9.96e+02	4.42e+02	1.43e+03	2.84e+01	1.84e+02	6.03e+02	2.52e+03	1.56e+01	4.36e+01
Lead	3.00e+01	8.17e+01	8.06e+00	2.81e+01	4.94e+00	1.47e+01	7.39e-01	2.36e+00	7.38e+00	1.98e+01	4.93e-01	1.24e+00
Nickel	2.35e+03	4.49e+03	4.43e+02	8.32e+02	1.20e+02	3.75e+02	1.71e+01	3.95e+01	1.72e+01	3.55e+01	1.75e+01	2.19e+01
Nitrate	9.93e+00	2.30e+01	1.70e+00	3.34e+00	6.48e-01	2.28e+00	1.26e-01	4.38e-01	5.64e-01	3.14e+00	6.09e-02	1.29e-01
Oil & Grease	3.70e+02	6.79e+02	4.38e+02	6.20e+02	3.59e+01	6.36e+01	1.67e+01	4.76e+01	2.51e+01	4.18e+01	1.35e+01	2.18e+01
Sodium	1.88e+05	2.23e+05	1.79e+03	3.10e+03	8.78e+04	9.42e+04	6.92e+01	1.85e+02	3.44e+04	3.86e+04	1.66e+02	2.73e+02
TOC	1.06e+04	1.59e+04	4.11e+03	8.01e+03	4.78e+02	1.45e+03	1.71e+02	7.02e+02	1.84e+02	5.87e+02	1.40e+02	4.07e+02
TSS	1.12e+05	4.42e+05	1.57e+04	7.05e+04	1.09e+04	4.78e+04	1.75e+03	7.78e+03	2.75e+04	8.14e+04	1.36e+03	2.77e+03
VSS	2.71e+04	8.38e+04	7.09e+03	2.67e+04	2.30e+03	8.66e+03	4.46e+02	2.18e+03	3.32e+03	8.40e+03	3.88e+02	8.89e+02
Zinc	2.05e+02	4.01e+02	6.63e+01	1.46e+02	1.51e+01	4.16e+01	2.40e+00	1.05e+01	6.88e+00	3.29e+01	1.18e+00	3.76e+00

165 and SR 2. The seasonal influence on the mass loads was minimal at the Post Road site. The adjacent land use at the Post Road site (urbanized) was the controlling factor for the constituent loadings.

2.4 Event Mean Concentration

Runoff pollutant concentrations and loadings will not only vary from location to location based on adjacent land use but will also vary from season to season. For the purpose of runoff studies, seasons can be broadly classified into winter and non-winter. Conditions that differ between a winter and a non-winter storm are natural (leaf fall) and anthropogenic (use of deicing chemicals and sand during winter conditions).

To compare two different locations or storm events, a common base or a primary measure is necessary, and Event Mean Concentration (EMC) was used in this work. The EMC of a pollutant is the total mass of contaminants released from a storm divided by the total runoff volume during the storm event. If discrete samples are taken over the period of the runoff event, an acceptable approximation of the EMC can be computed from the individual concentrations and the corresponding flow values (Shelley et al., 1987). The EMC values of the measured parameters for all storms and sites are presented in Figure 2.2.

Percentage cumulative mass vs rainfall graphs were used to visually mark the first flush point as explained in section 2.3. The quantity of runoff, and the mass in the first flush and post first flush were determined. The ratio of the mass of constituent and the volume of runoff in the first flush resulted in a first flush mean concentration. The post first flush mean concentration was similarly calculated. Tables 2.12-2.14 summarize the seasonal first flush,

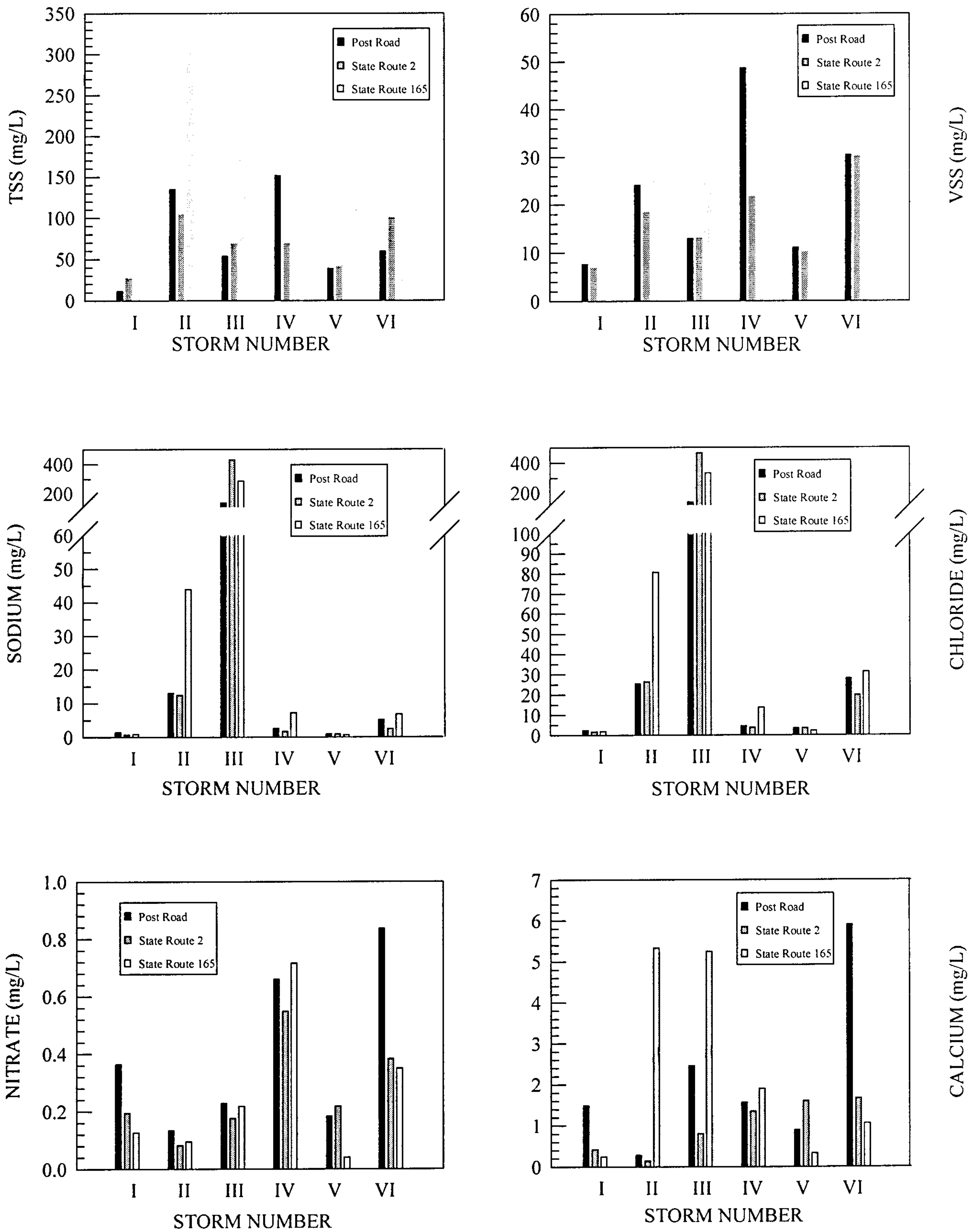

Figure 2.2 Event Mean Concentrations at all Three Sites for all Six Storms

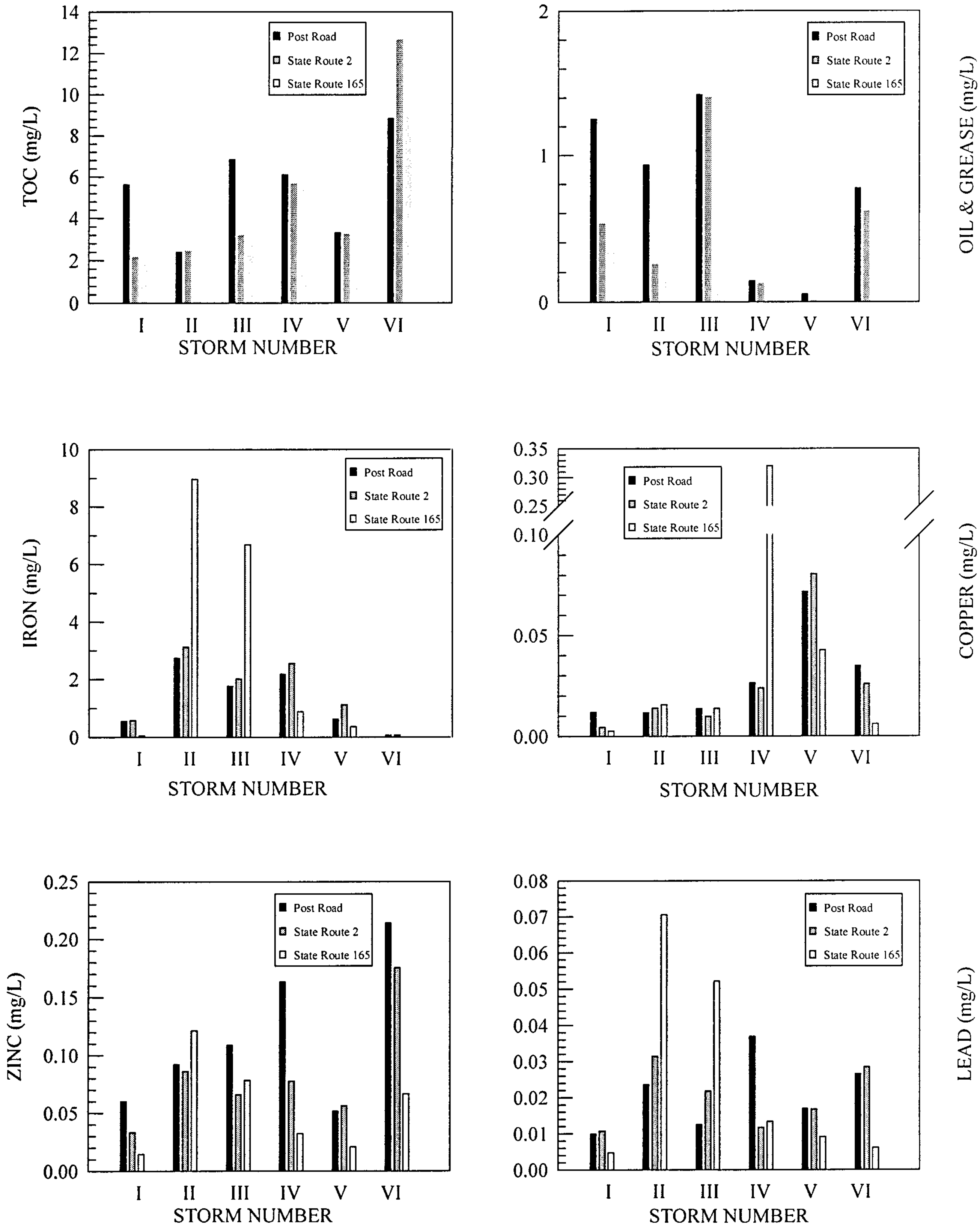

Figure 2.2 Event Mean Concentrations at all Three Sites and for all Six Storms (contd.)

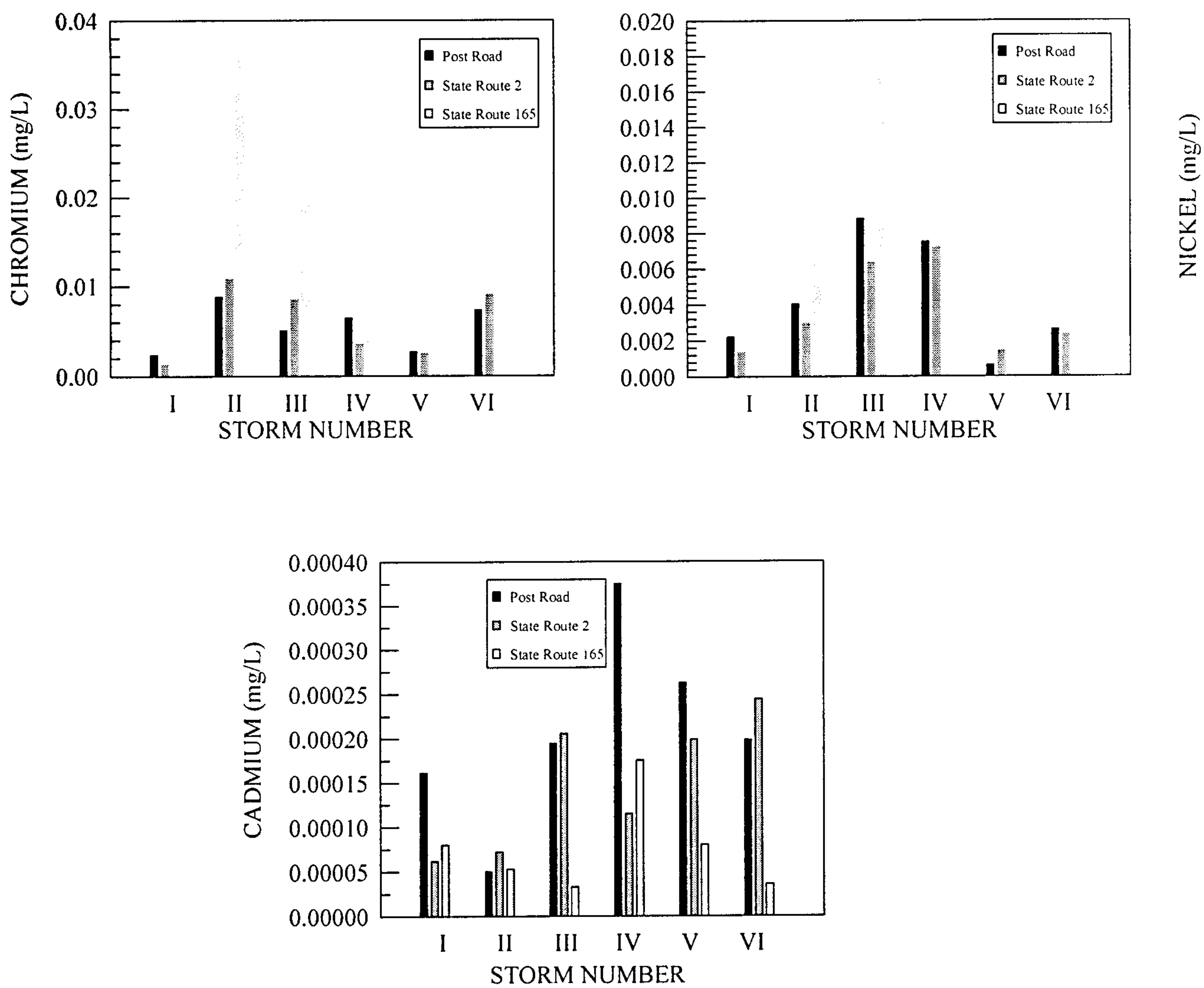

Figure 2.2 Event Mean Concentrations at all Three Sites for all Six Storms (contd.)

Table 2.12 Event Mean Concentrations for Winter and Nonwinter Storms for Post Road Sampling Site

Constituent	Post Road					
	Winter			Non-winter		
	First Flush Average mg/L	Post First Flush Average mg/L	Average EMC mg/L	First Flush Average mg/L	Post Flush Average mg/L	Average EMC mg/L
Cadmium	3.80e-04	6.90e-05	1.20e-04	3.80e-04	1.60e-04	2.10e-04
Calcium	6.70e+00	2.71e-01	1.37e+00	5.69e+00	1.63e+00	2.76e+00
Chloride	2.13e+02	1.93e+01	8.26e+01	2.08e+01	8.65e+00	1.14e+01
Chromium	5.67e-03	8.49e-03	6.96e-03	5.21e-03	4.05e-03	4.14e-03
Copper	1.84e-02	1.18e-02	1.27e-02	6.14e-02	3.30e-02	3.95e-02
Iron	1.97e+00	2.57e+00	2.25e+00	9.09e-01	3.19e-01	4.18e-01
Lead	1.52e-02	2.12e-02	1.81e-02	2.19e-02	1.84e-02	1.78e-02
Nickel	1.97e+00	8.53e-01	1.18e+00	1.01e+00	5.69e-01	6.94e-01
Nitrate	7.47e-03	5.77e-03	6.42e-03	4.03e-03	1.00e-03	1.82e-03
Oil & Grease	3.87e-01	1.21e-01	1.82e-01	1.03e+00	2.15e-01	4.61e-01
Sodium	3.64e+02	1.50e+01	7.56e+01	4.55e+00	1.77e+00	2.51e+00
TOC	1.11e+01	2.31e+00	4.63e+00	1.03e+01	4.81e+00	5.93e+00
TSS	5.99e+01	1.31e+02	9.41e+01	4.74e+01	3.69e+01	3.69e+01
VSS	1.95e+01	1.70e+01	1.86e+01	1.94e+01	1.60e+01	1.64e+01
Zinc	1.74e-01	8.08e-02	1.01e-01	1.71e-01	8.65e-02	1.09e-01

Table 2.13 Event Mean Concentrations for Winter and Nonwinter Storms for State Route 2 Sampling Site

Constituent	State Route 2					
	Winter			Nonwinter		
	First Flush Average EMC mg/L	Post Flush Average EMC mg/L	Average EMC mg/L	First Flush Average EMC mg/L	Post Flush Average EMC mg/L	Average EMC mg/L
Cadmium	1.61e-03	4.40e-05	1.40e-04	2.60e-04	1.40e-04	1.60e-04
Calcium	3.96e+00	1.37e-01	4.74e-01	1.88e+00	1.12e+00	1.26e+00
Chloride	2.45e+03	3.41e+01	2.46e+02	1.20e+01	6.22e+00	7.24e+00
Chromium	1.34e-02	8.32e-03	9.66e-03	5.09e-03	4.01e-03	4.12e-03
Copper	1.87e-02	1.02e-02	1.19e-02	4.14e-02	3.26e-02	3.37e-02
Iron	3.33e+00	2.39e+00	2.57e+00	1.73e+00	1.01e+00	1.08e+00
Lead	3.60e-02	2.39e-02	2.66e-02	2.12e-02	1.49e-02	1.69e-02
Nickel	1.63e+00	6.84e-01	8.27e-01	4.92e-01	2.65e-01	3.18e-01
Nitrate	6.78e-03	4.29e-03	4.65e-03	5.90e-03	2.58e-03	3.06e-03
Oil & Grease	3.49e-01	7.42e-02	1.30e-01	6.14e-01	2.62e-01	3.36e-01
Sodium	2.39e+03	1.65e+01	2.21e+02	2.92e+00	1.12e+00	1.44e+00
TOC	4.35e+00	2.51e+00	2.81e+00	8.31e+00	5.44e+00	5.93e+00
TSS	9.27e+01	8.87e+01	8.61e+01	7.47e+01	5.71e+01	5.93e+01
VSS	1.97e+01	1.54e+01	1.57e+01	1.90e+01	1.67e+01	1.72e+01
Zinc	1.39e-01	6.40e-02	7.62e-02	1.29e-01	7.98e-02	8.55e-02

Table 2.14 Event Mean Concentrations for Winter and Nonwinter Storms for State Route 165 Sampling Site

Constituent	State Route 165					
	Winter			Nonwinter		
	First Flush Average mg/L	Post Flush Average mg/L	Average EMC mg/L	First Flush Average mg/L	Post Flush Average mg/L	Average EMC mg/L
Cadmium	1.10e-04	2.90e-05	4.30e-05	1.40e-04	7.00e-05	9.30e-05
Calcium	2.38e+01	1.22e+00	5.29e+00	1.74e+00	6.42e-01	8.87e-01
Chloride	1.13e+03	3.91e+01	2.07e+02	3.25e+01	7.64e+00	1.23e+01
Chromium	3.53e-02	2.45e-02	2.74e-02	4.32e-03	2.93e-03	3.32e-03
Copper	1.84e-02	1.35e-02	1.46e-02	1.03e-01	9.08e-02	9.28e-02
Iron	8.41e+00	8.00e+00	7.83e+00	6.59e-01	2.15e-01	3.26e-01
Lead	7.57e-02	5.49e-02	6.13e-02	1.48e-02	5.71e-03	8.29e-03
Nickel	2.36e-01	7.22e-02	1.06e-01	3.15e-01	9.18e-02	1.81e-01
Nitrate	8.29e-03	1.28e-02	1.21e-02	2.86e-03	1.85e-03	2.18e-03
Oil & Grease	5.31e-01	7.99e-02	1.56e-01	6.22e-01	2.19e-01	3.08e-01
Sodium	9.93e+02	1.94e+01	1.66e+02	8.86e+00	2.32e+00	3.89e+00
TOC	4.25e+00	1.76e+00	2.10e+00	6.88e+00	3.83e+00	4.48e+00
TSS	3.03e+02	2.27e+02	2.46e+02	3.78e+01	1.85e+01	2.47e+01
VSS	4.14e+01	2.24e+01	2.68e+01	1.22e+01	7.12e+00	8.39e+00
Zinc	1.09e-01	1.02e-01	9.99e-02	6.45e-02	2.49e-02	3.35e-02

post first flush and the event mean concentration for all the sites.

Although peak concentrations for some roadway runoff pollutants were higher during the non-winter storm, pollutant loadings are higher during the winter storms. The effect of the addition of deicing chemicals is clearly seen by the increases in concentration of contaminants such as chloride, sodium, and TSS.

2.5 Normalized Load vs ADT

The normalized load is the total mass of a pollutant divided by the total rainfall during the storm event and the total drainage area contributing to the sampling location. The roadway runoff loads were normalized and plotted against ADT values to determine what relationships existed between different sites and storms and these results are presented in Figure 2.3. Other studies have shown that metals such as, chromium, copper, nickel and zinc, can increase up to 10 fold with an increase in mean traffic density (Ward, 1990). The major differences are seasonal variations and adjacent land use. Post Road has the highest ADT, but the difference between SR 2 and Post Road ADT values appear to be not as significant as the difference in land use. This seems to indicate that urbanization contributes towards greater pollution. As expected for SR 2 and SR 165 chloride, chromium, iron, nickel, sodium and TSS show a sharp increase in their loadings (Figure 2.3) during the winter season, because of the use of deicing chemicals. The sand used on the pavements is most likely the source of the higher loadings of suspended solids and the other contaminants associated with them. Cadmium and zinc are only slightly affected by the change in seasonal conditions. Copper, lead, oil & grease loading rates appear not to be affected by

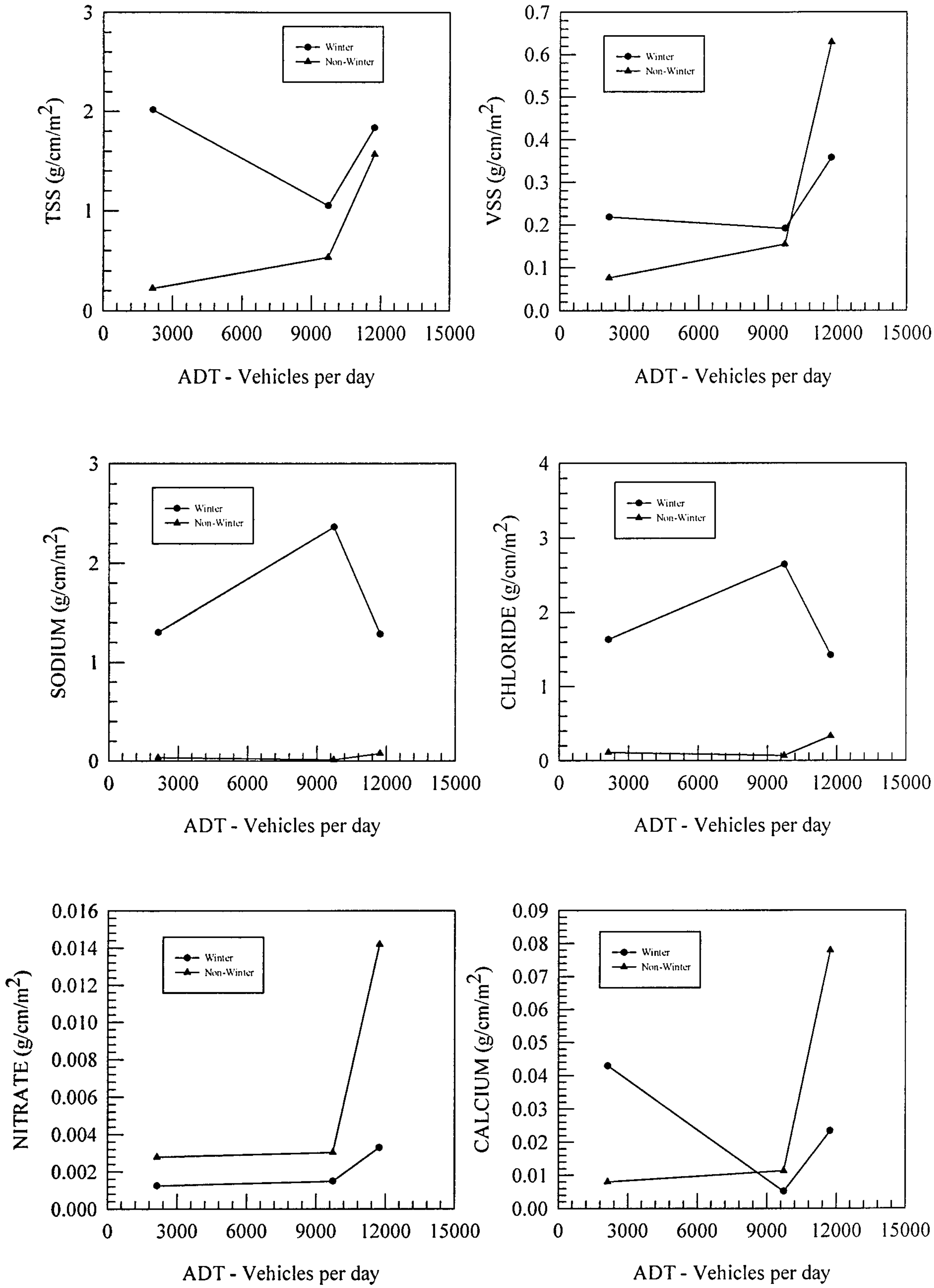

Figure 2.3 Normalized Seasonal Mass Load vs ADT at the Three Sampling Sites

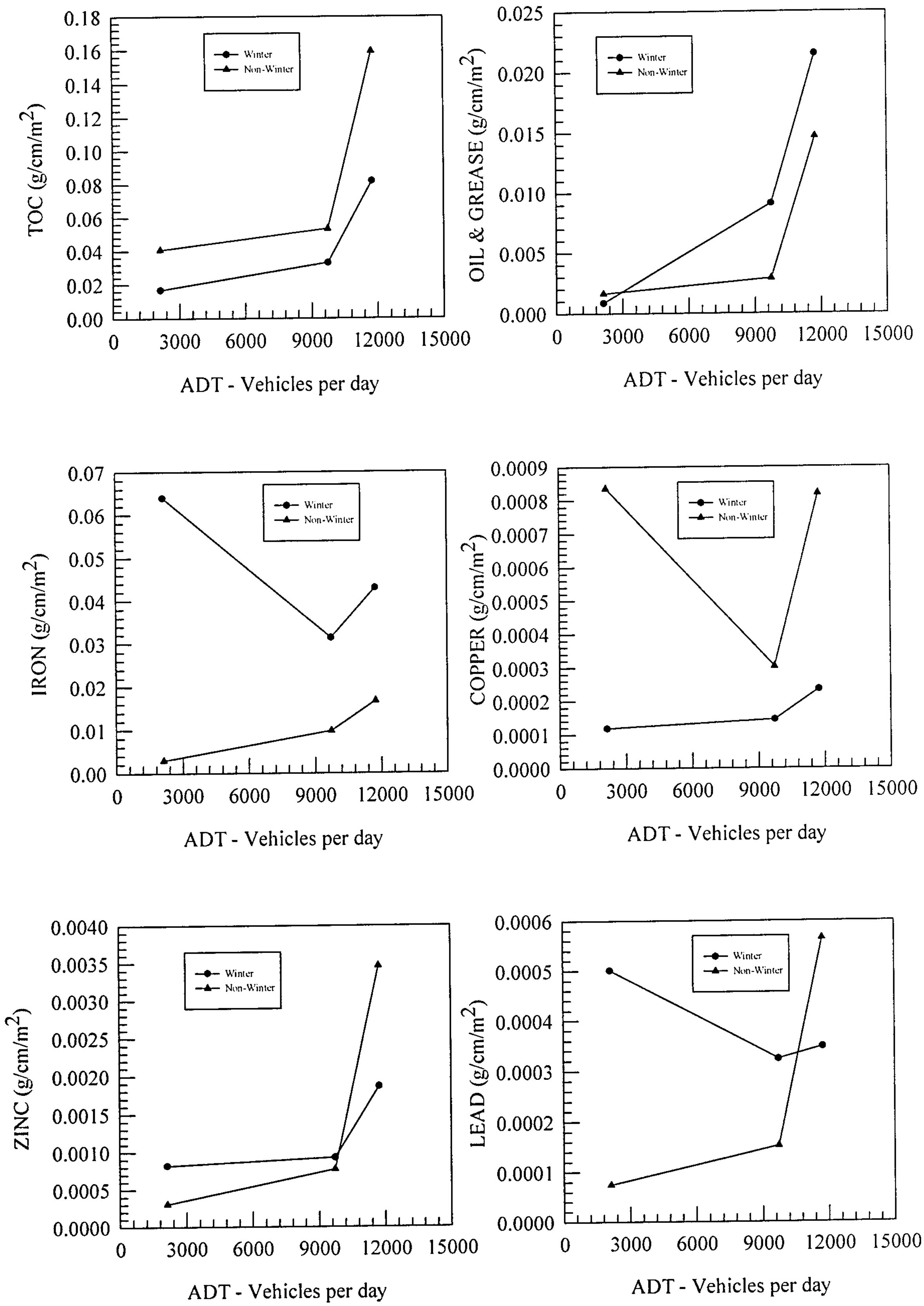

Figure 2.3 Normalized Seasonal Mass Loads vs ADT at the Three Sampling Sites (contd.)

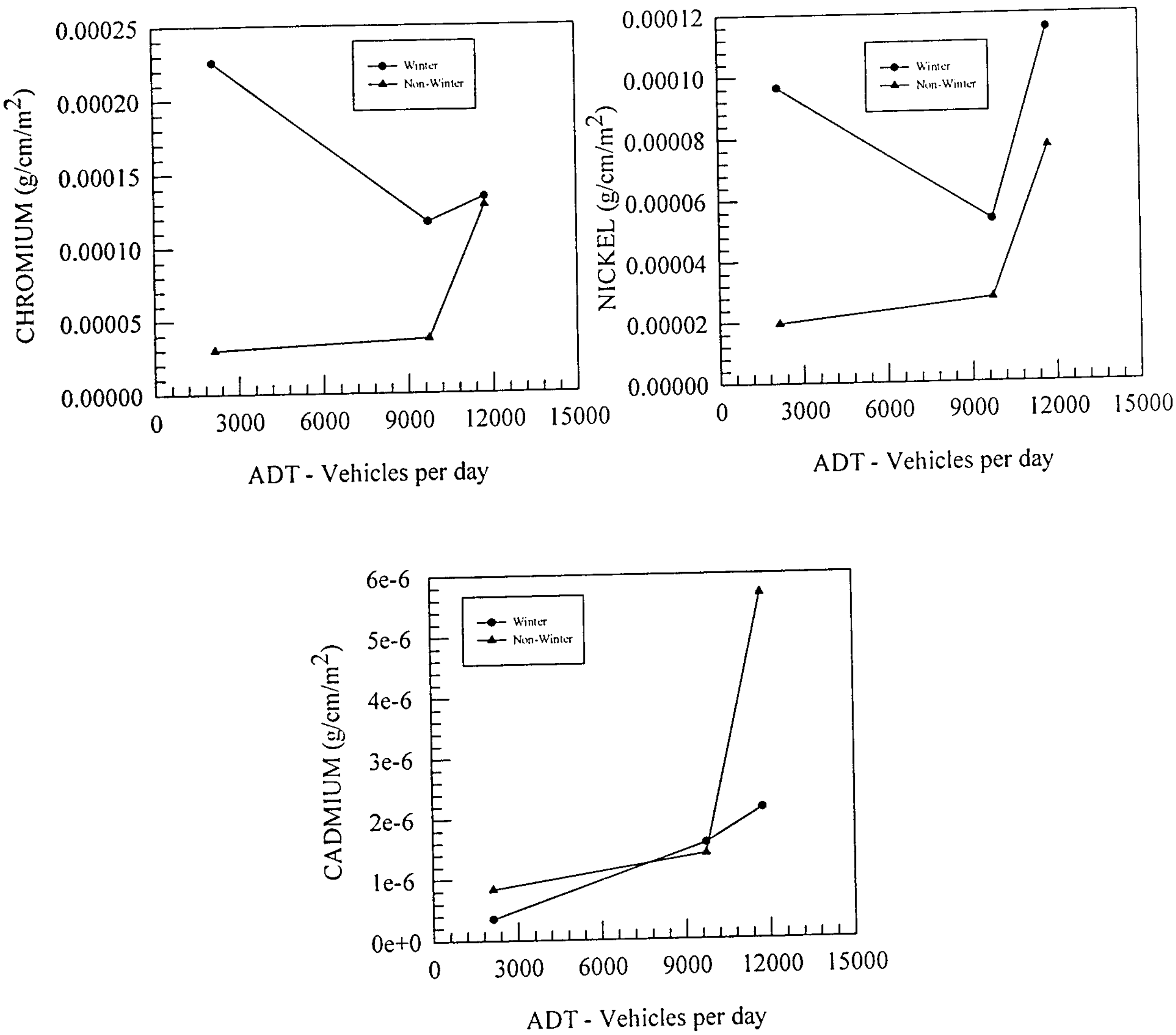

Figure 2.3 Normalized Seasonal Mass Loads vs ADT at the Three Sampling Sites (contd.)

the use of deicing chemicals or sand during the winter season. As expected, due to non-usage of fertilizers and low plant activity, nitrate values are lower for the winter condition. As ADT values did not appear to be a major factor affecting the pollutant loadings, a different analytical approach was taken.

2.6 Normalized Load vs Area

A factor that at first appears to affect the pollutant loads is the Antecedent Dry Period (ADP). ADP is defined as the number of dry days prior to the sampling day. A dry day is defined as one where the total rainfall received is less than 0.025 cm. Though the accumulation of pollutants increases with the increase of the number of dry days or ADP, past studies (Stotz, 1987) have determined that the wind movement associated with moving vehicles is responsible for blowing away the accumulated pollutants to the sides of the roadways. Studies (Ellis et al., 1984) conducted on ADP and pollutant loads have concluded that pollutant loads do not proportionally increase with the ADP. Since both ADP and ADT were found as not being significant factors contributing towards pollutant loads, normalized loads were plotted against the drainage area of each location (Figure 2.4) to discover the effect of the drainage area. The new normalized loads were redefined as the total mass of the pollutant divided by the total quantity of rainfall during a storm event. All the constituents except for chloride and sodium show a similar pattern of increase with an increase in the drainage area. Chloride and sodium do not follow this trend for the non-winter season, indicating that the size of the drainage area has little effect on the total load for these constituents. The differences in normalized loads versus drainage areas for this study can

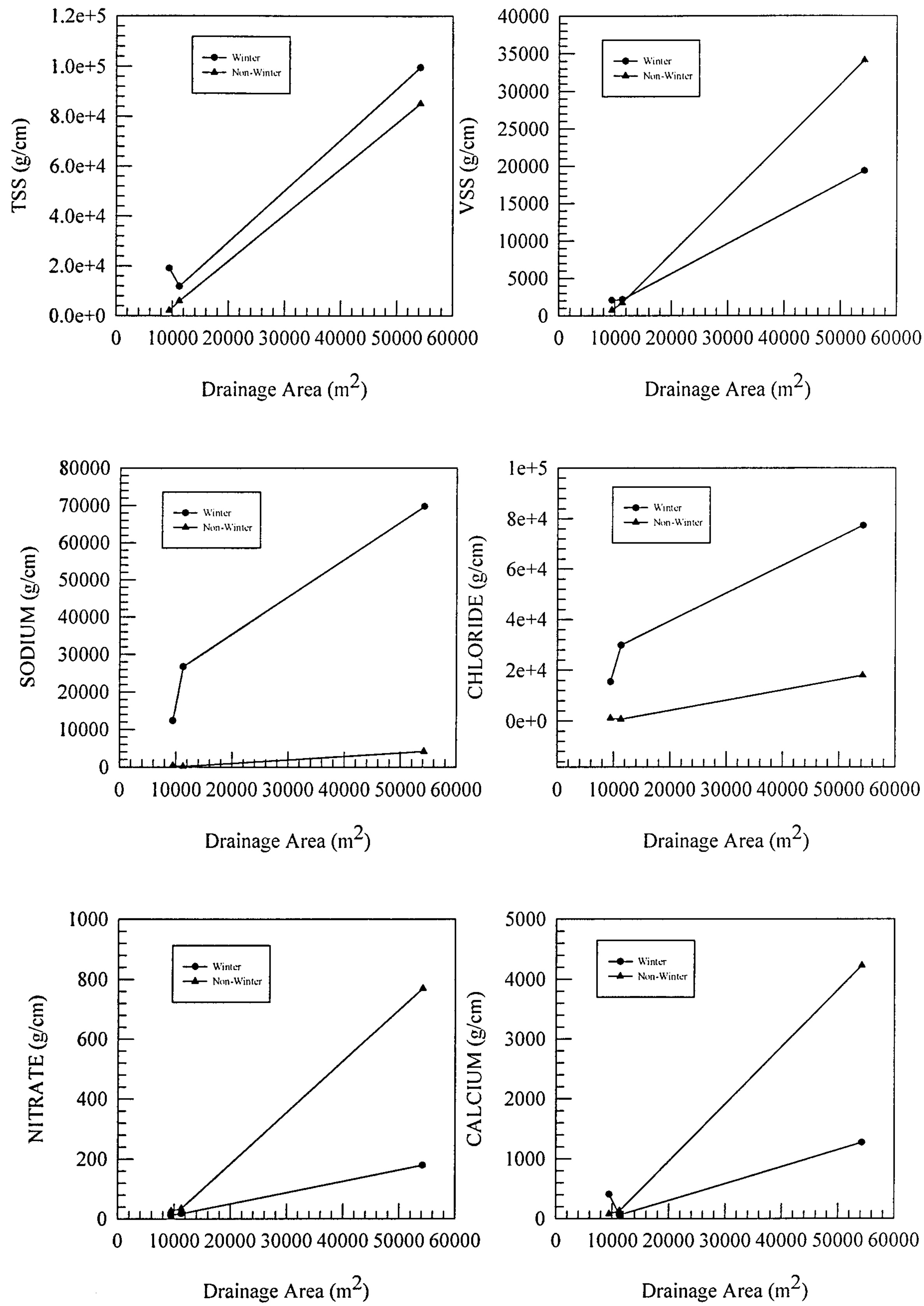

Figure 2.4 Normalized Seasonal Mass Loads vs Drainage Area at the Three Sites

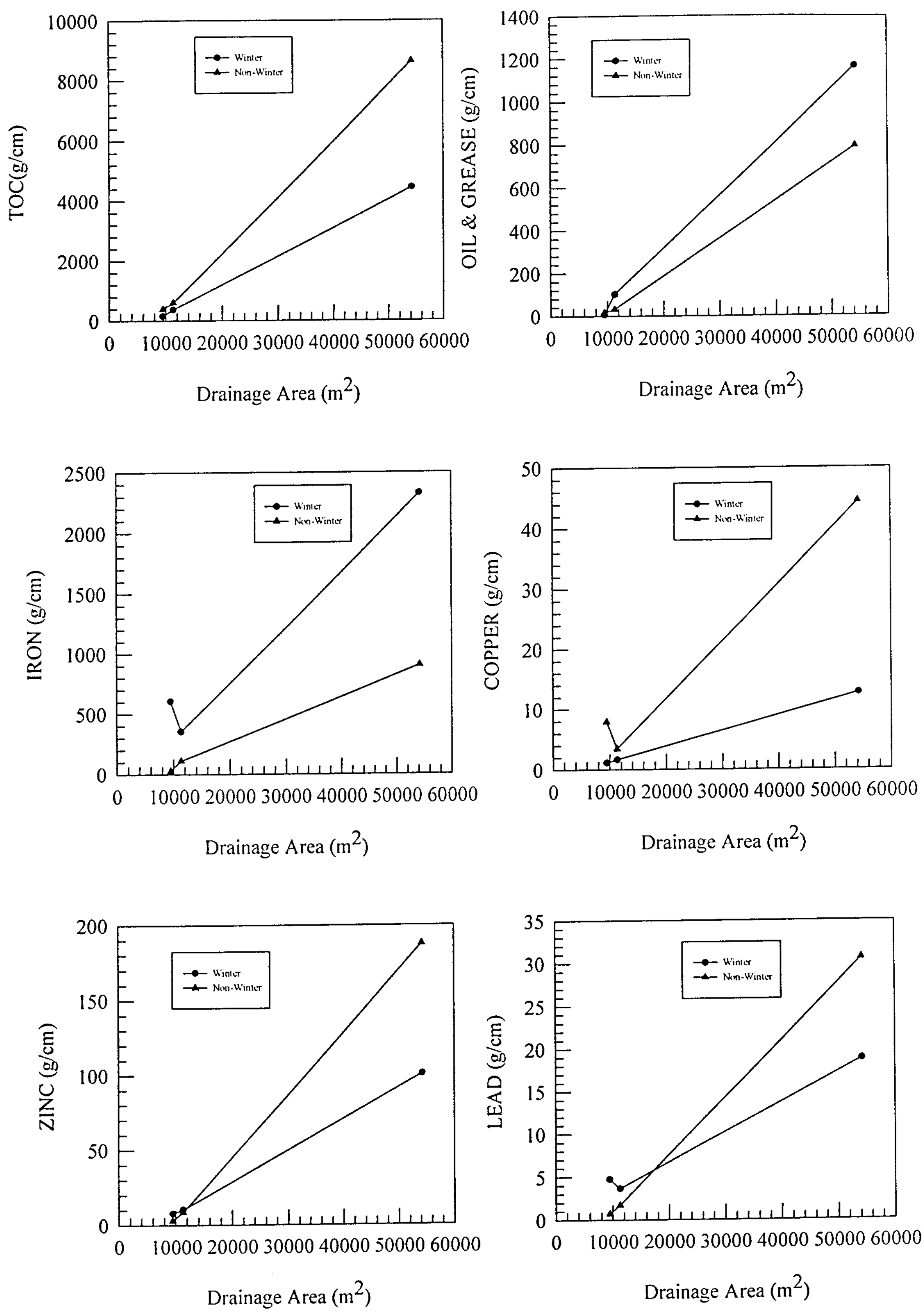

Figure 2.4 Normalized Seasonal Mass Loads vs Drainage Area at the Three Sites (contd.)

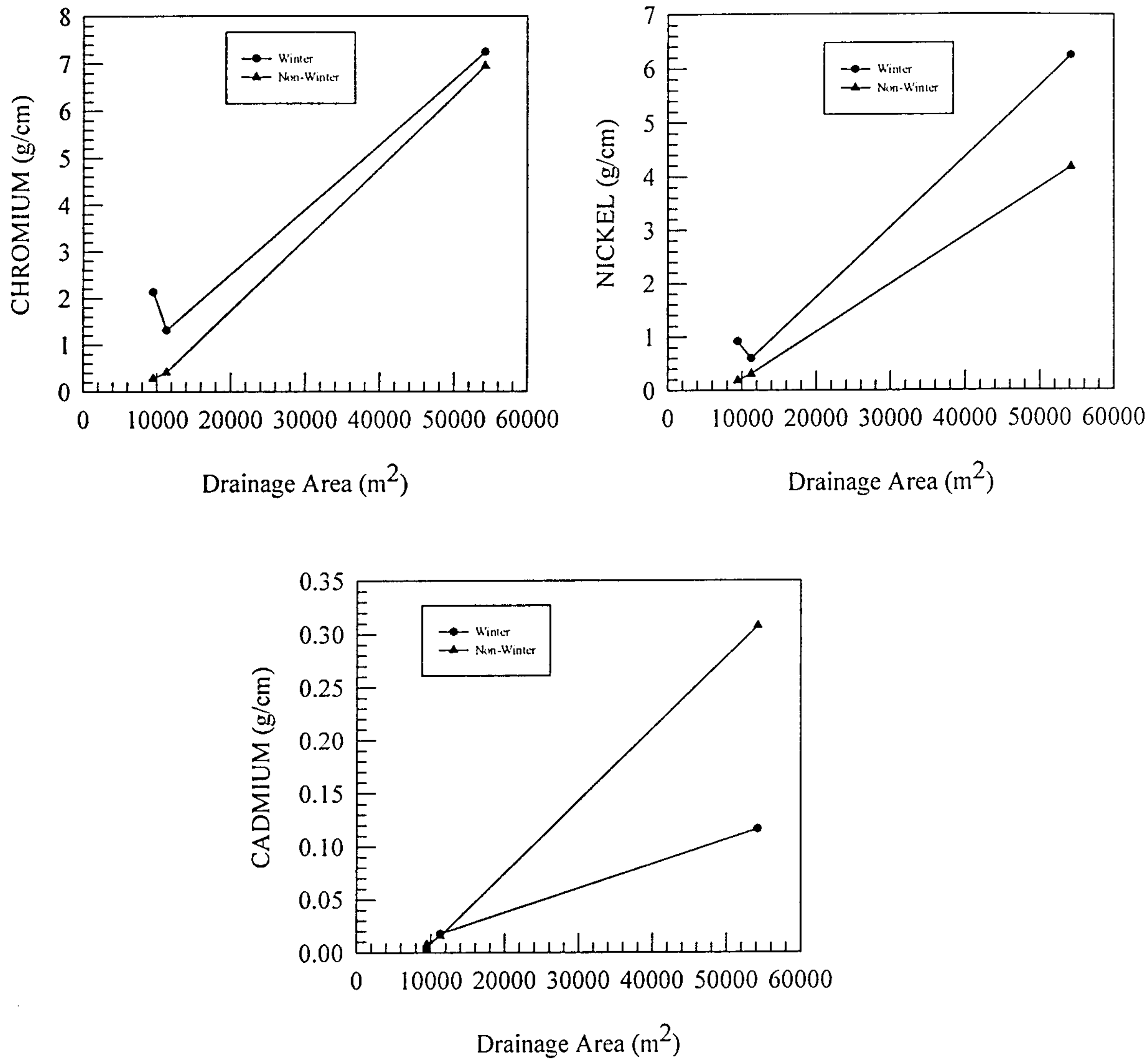

Figure 2.4 Normalized Seasonal Mass Loads vs Drainage Area at the Three Sites (contd.)

be attributed more to adjacent land use that the size of the drainage area since the largest drainage area (Post Road) is classified as urban.

2.7 Summary of Seasonal and Land Use Variations of Normalized Mass Loadings

The magnitude of seasonal effects on the mass loadings at a particular site can be quantified by calculating the ratios of the winter and nonwinter normalized mass loadings ($g/cm/m^2$). Table 2.15 summarizes the ratios of seasonal normalized mass loads for all the constituents for each of the three sites. All numbers greater than 1 indicate higher mass loadings for winter storms. All of the three sites exhibited seasonal variations for some constituents. For all sites chloride, chromium, iron, nickel, sodium, and TSS were higher during the winter storms and copper, nitrate and TOC were lower.

Table 2.16 was created to allow a comparison between sites in both winter and non-winter conditions so that land use effects could be better documented. The sites can be defined by land use into the categories ranging from urban (Post Road), suburban (SR 2) and rural (SR 165). If the ratios of Post Road to SR 165 and Post Road to SR 2 are greater than 2, then land use is a dominant factor. Another way of exploring land use is to observe the ratios of SR 2 and SR 165. If this ratio falls between 0.5 and 2.0 then land use is dominant.

Table 2.17 summarizes the constituents which have the greatest increase from nonwinter to winter. This table was created by selecting the highest normalized mass load ratios from table 2.15 within a constituent column and assigning that constituent to the appropriate site. The land use patterns at the Post Road site dampened the seasonal variations.

Table 2.15 Seasonal Variation at the Three Land Use Sites - Ratio of Normalized Mass Loads (Winter/Nonwinter)

	Cadmium	Calcium	Chloride	Chromium	Copper	Iron	Lead	Oil & Grease	Nickel	Nitrate	Sodium	TOC	TSS	VSS	Zinc
Post Road	0.38	0.30	4.31	1.04	0.29	2.58	0.62	1.46	1.50	0.23	17.06	0.51	1.17	0.57	0.54
SR 2	1.13	0.46	40.61	3.15	0.48	3.22	2.13	3.17	1.93	0.49	182.53	0.62	1.97	1.24	1.20
SR 165	0.42	5.35	14.62	7.50	0.14	21.76	6.69	0.53	4.90	0.45	36.89	0.41	9.01	2.86	2.69

Table 2.16 Land Use Variations at the sites - Ratio of Normalized Mass Loads

		Cadmium	Calcium	Chloride	Chromium	Copper	Iron	Lead	Oil & Grease	Nickel	Nitrate	Sodium	TOC	TSS	VSS	Zinc
Winter	PR/SR 165	6.10	0.54	0.87	0.59	1.98	0.67	0.69	24.80	1.19	2.64	0.99	4.86	0.91	1.64	2.27
	SR2/SR 165	4.47	0.12	1.62	0.52	1.22	0.49	0.65	10.50	0.55	1.19	1.82	1.96	0.52	0.88	1.13
	PR/SR 2	1.36	4.49	0.54	1.14	1.62	1.37	1.07	2.36	2.16	2.22	0.54	2.48	1.75	1.87	2.02
Non Winter	PR/SR 165	6.78	9.70	2.96	4.27	0.98	5.67	7.54	8.94	3.91	5.09	2.14	3.91	7.01	8.25	11.36
	SR2/SR 165	1.67	1.41	0.58	1.23	0.36	3.32	2.03	1.75	1.40	1.09	0.37	1.31	2.39	2.03	2.53
	PR/SR 2	4.07	6.86	5.08	3.46	2.71	1.71	3.72	5.12	2.79	4.69	5.82	2.99	2.94	4.07	4.50

PR Post Road

Table 2.18 was derived from the data in table 2.16. The ratios of normalized mass loads of Post Road to SR 165 and SR 2 to SR 165 were compared and the highest value for each constituent was assigned to the appropriate site. The Post Road site showed the highest normalized loads for most of the constituents.

Table 2.17 Constituents with the Highest Maximum Increase from Nonwinter to Winter for all Sites

Site	Constituents
Post Road	None
SR 2	Cadmium, Chloride, Oil & Grease, Sodium
SR 165	Calcium, Chromium, Iron, Lead, Nickel, TSS, VSS, Zinc

Table 2.18 Constituents with the Highest Normalized Loads

		Constituents
Winter	Post Road	Cadmium, Copper, Nickel, Nitrate, Oil & Grease, TOC, VSS, Zinc
	SR 2	Chloride, Sodium
	SR 165	Calcium, Chromium, Iron, Lead, TSS
Non Winter	Post Road	All (except Copper)
	SR 2	None
	SR 165	Copper

3. Conclusions

A statistical correlation was developed using the independent variables TSS and conductivity as representative of the suspended and dissolved fractions. As a result of this analyses the constituents were divided as follows:

Type I	Cadmium, Iron, Lead, TSS and VSS
Type II	Calcium, Chloride, Magnesium, Nickel, Nitrate, Sodium
Type III	Chromium, Copper, Oil & Grease, Phosphate, TOC, Zinc

Seasonal activities such as the use of deicing agents, or the falling of the leaves impacted the total mass and concentration of many constituents. Deicing agents used during the winter season contributed to the measurement of high concentrations of calcium, chloride, and sodium. The greatly increased winter normalized mass loads ($g/cm \cdot m^2$) of chromium, iron, lead, nickel and zinc at rural (SR 165) and chromium, iron, lead and nickel at suburban (SR 2) and iron at urban (Post Road) was attributed to an increased chemical and physical corrosion during the winter season. The decomposition of fall leaves during Storm VI (fall season) contributed to an increase in the measured EMCs of nutrients and TOC by a factor of at least three as compared to the EMC values for winter storms.

First flush characteristics were shown to exist for all measured contaminants but not during all of the storms. The percentage of the total mass of the particulate fraction that was collected during the first flush for winter and nonwinter conditions was 27% and 36%. The percentage of the total mass of dissolved fraction collected during the winter and nonwinter conditions was 83% and 43% respectively. The rainfall required to collect the first flush was less than 1.4 cm for all conditions and constituents.

The urban site (Post Road) showed the highest normalized loads for most of the constituents and demonstrated the impact of land use on the contaminant generation. The magnitude of the land use effects at the Post Road site overshadowed the seasonal impacts. The ADT was found not to be a factor affecting the pollutant loads in roadway runoff within the range of ADT values that were studied.

4. Recommendations

To determine the extent and importance of highway runoff effect and whether it should be treated or not, we need to evaluate its effect on receiving waters. The use of the receiving water body, size, potential for dispersion, and biological factors are just some of the factors which must be evaluated. Stream and lake sediments have been found to be a reservoir for heavy metals and a source of bioconcentration of metals. Metal concentrations in groundwater have been detected at elevated levels in the vicinity of the highways (Harned, 1983).

A comparison between the range of roadway runoff contaminant concentrations measured in this study with a previous study that measured baseline conditions in RI rivers showed that roadway runoff concentrations exceeded all measured parameters. This strongly suggests that direct discharge of roadway runoff into rivers could act to degrade their existing water quality.

Based on the results obtained from this study, it was evident that the maximum concentrations of copper, lead and zinc present in roadway runoff exceeded the USEPA aquatic water quality criteria (total of six criteria). Table 4.1 compares the pollutant concentration ranges and medians during the first flush from the three sites and all six storms with USEPA's Aquatic Water Quality Criterion.

Table 4.1. A Comparison of Road Runoff Contaminants from Winter and Non-Winter Sampling Periods for the Three Sampling Sites With Reference to EPA Aquatic Water Quality Criterion, RI River Baseline Concentrations and EPA Drinking Water Standards

Contaminants (mg/L)	Non-Winter First Flush		Winter First Flush		EPA Aquatic Water Quality Criterion		RI Baseline River Study*	EPA Drinking Water Standards
	Range	Median	Range	Median	Acute	Chronic		
Cadmium	0.0001-0.001	0.0003	0.0001-0.013	0.0007	0.002	0.002	0.00005-0.00029	0.01
Chromium	0.0007-0.36	0.0043	0.0039-0.028	0.0111	0.07	0.042	NONE	0.05
Copper	0.0047-0.38	0.0215	0.013-0.055	0.0292	0.0084	0.0058	0.009-0.012	1.0**
Iron	0.6-49.3	1.0	1.4-12.0	4.4	NONE	NONE	0.15-0.64	0.3**
Lead	0.0075-1.22	0.0111	0.0078-0.077	0.0268	0.025	0.001	0.0009-0.0150	0.05
Nickel	0.0001-0.047	0.0041	0.0072-0.02	0.0138	1.1	0.056	NONE	0.1***
Sodium	1.2-20.0	4.5	158.0-17400.0	1740	NONE	NONE	4.4-18.8	NONE
Zinc	0.03-1.6	0.13	0.1-0.9	0.26	0.18	0.047	NONE	5.0**
Chloride	2.5-38.2	6.95	286.0-24625.0	1740	NONE	NONE	5.2-42.7	250**
Nitrate	0.4-3.2	1.34	0.3-2.1	1.15	NONE	NONE	0.02-3.65	10.0
Phosphate	< 0.01	< 0.01	< 0.01	< 0.01	NONE	NONE	0.01-0.03	NONE
Oil and Grease	0.7-4.8	1.7	1.4-6.0	4.6	NONE	NONE	NONE	None Permitted
Total Suspended Solids	10.0-230.0	33.25	16.0-508.0	186	NONE	NONE	0.4-3.7	<1.0

* URI Civil Engineering Study, 1991 ** Proposal MCL *** Secondary MCL

Concentrations of cadmium, chromium, iron, lead, chloride, oil and grease, and TSS as expressed as turbidity that were measured in the roadway runoff exceeded the recommended levels.

The concentration of contaminants measured in roadway runoff exceeded baseline levels in RI rivers as well as several water quality standards. Depending upon regulations, all roadway runoff will require some degree of treatment in order to prevent an increase in the level of constituents present in the receiving waters.

The Best Management Practices (BMPs) for treatment/control of highway runoff recommended by the FHWA include construction of wetland, detention ponds and vegetative infiltration systems. Current BMPs require the construction of an extensive drainage system to convey the runoff to a particular site (centralization) and once transported to the central sites large areas (10-15 acres) are needed for construction of artificial wetlands and/or detention basins. BMPs require high construction and maintenance costs for detention basins and also are less effective in removing the pollutants during winter conditions.

Treatment methods need to be developed which can meet the following criteria:

1. Effective removal of pollutants
2. Low initial cost with minimal maintenance required
3. Hydraulic capability to treat the runoff from at least the first flush period

The following treatment processes can remove the contaminants which were measured in this study and have the potential for causing environmental harm. The processes have been applied and have been proven successful for other waste streams and have the potential for meeting the treatment criteria stated above.

Trace metals (iron, lead, copper, zinc, chromium, nickel, cadmium)
Particulate fraction removed by Coarse Filtration
Dissolved fraction removed by Chemical Precipitation utilizing calcium carbonate

TOC (polyaromatic hydrocarbons, total petroleum hydrocarbons, oil and grease)
Particulate fraction removed by Coarse Filtration
Dissolved fraction removed by granular activated carbon adsorption

TSS (organic and inorganic suspended solids)
Coarse filtration

Nutrients (nitrate and phosphate)
Biological action within a coarse filter

Our recommendation is to construct a pilot plant which incorporates the above treatment processes such that a field design can be easily developed. A laboratory filtration simulation system (Runoff Purification Units, RPU) could be developed at the CVE laboratories to study various combinations of low-cost filter materials and their removal efficiencies for the various categories of pollutants present in roadway runoff. The RPU should consist of four six inch diameter columns (Figure 4.1) which incorporate the following combination of treatment processes:

Column 1	1 m of native soil
Column 2	0.5 m of coarse filter material with a 0.5 m bed of granular activated carbon (GAC)
Column 3	0.5 m of coarse filter material with a 0.5 m bed of calcium carbonate
Column 4	0.5 m of coarse filter material with 0.25 m bed of calcium carbonate and 0.25 m bed of GAC

A full scale design to treat the runoff from Gordon Pond, which is the discharge

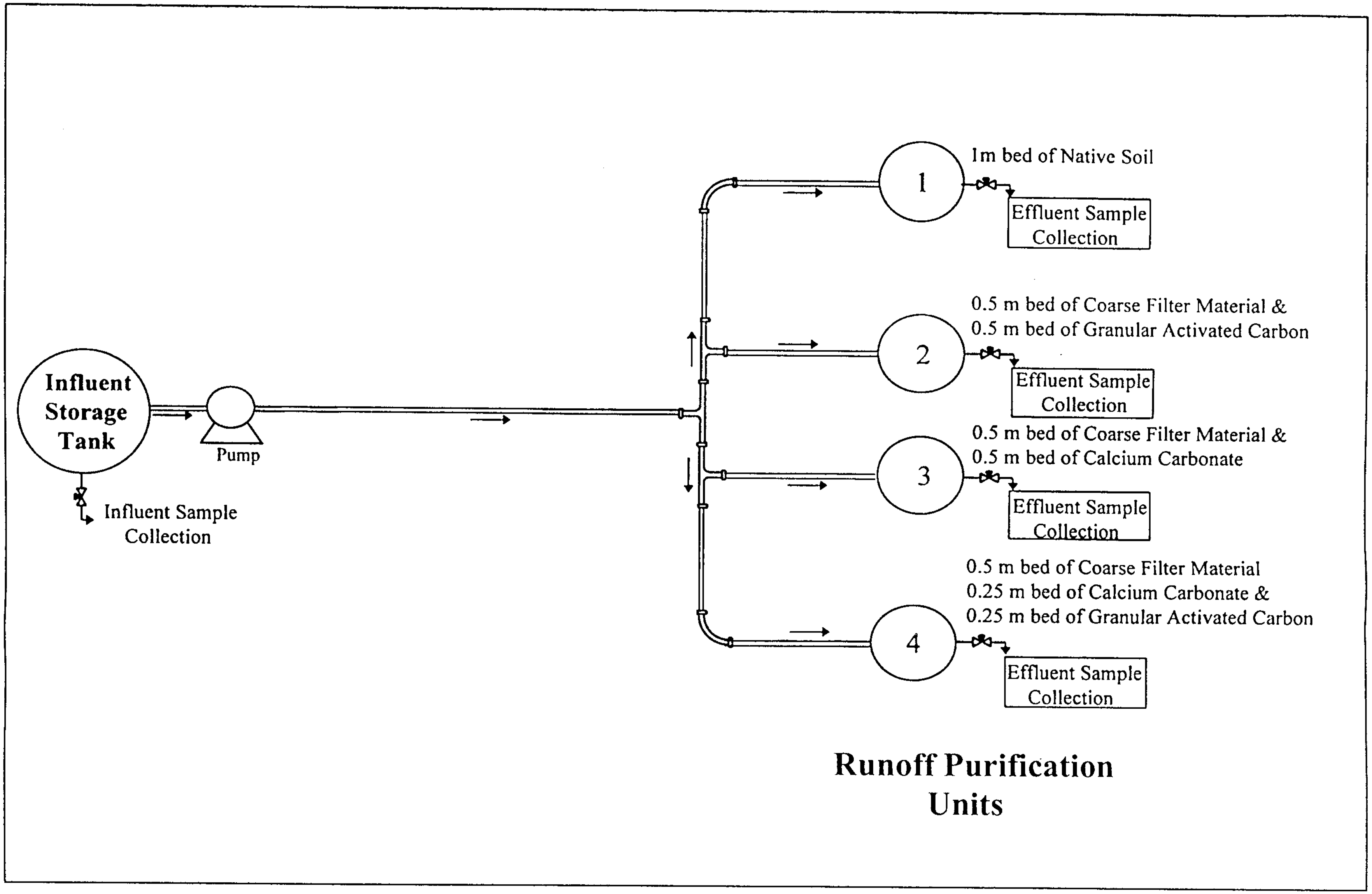

Figure 4.1 Laboratory Simulation of Runoff Purification Units

point for runoff from the Post Road site, is proposed.

A ten year design storm was considered to calculate the filtration surface area requirement. A rainfall intensity of 8.2 cm/hr (3.25 in/hr) and a duration of 20 minutes (corresponding to the typical first flush period) would require a surface filter area of 17 m^2 (184 ft^2) with 4 m long sides. A total depth of 1 m is proposed. Figure 4.2 shows the cross-section of the proposed Runoff Purification Unit (RPU). The top layer consists of a 0.3 m bed of coarse filtering material which serves to reduce the scour due the potential high roadway runoff approach velocity and also removes suspended materials. A 0.2 m bed of GAC beneath this first layer would adsorb any dissolved organic contaminants. A final layer of 0.2 m of calcium carbonate would precipitate any dissolved trace metals. Finally, a 0.3 m gravel bed at the bottom of the filter assembly would support the layers above it.

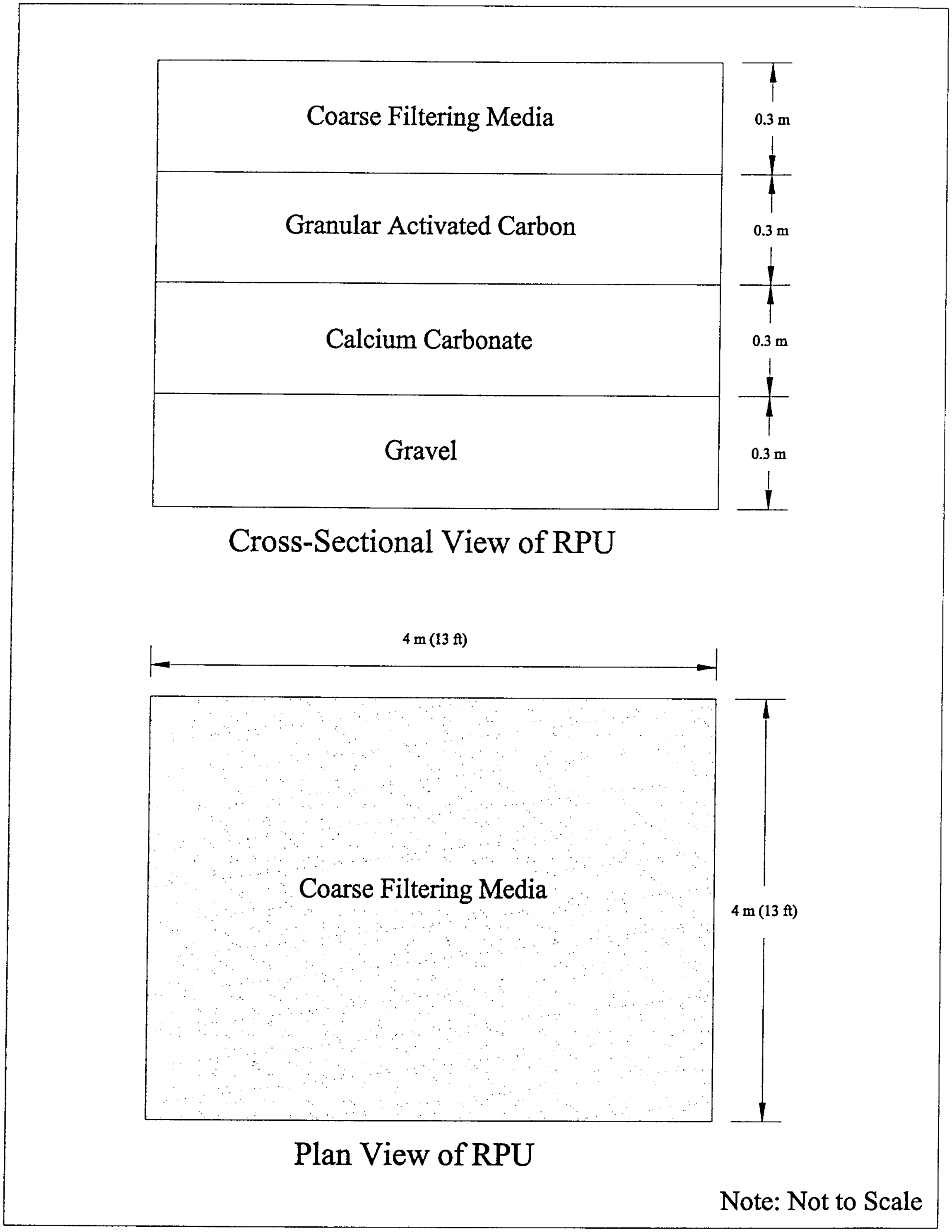

Figure 4.2 Cross-Section of Runoff Purification Unit

Appendix A

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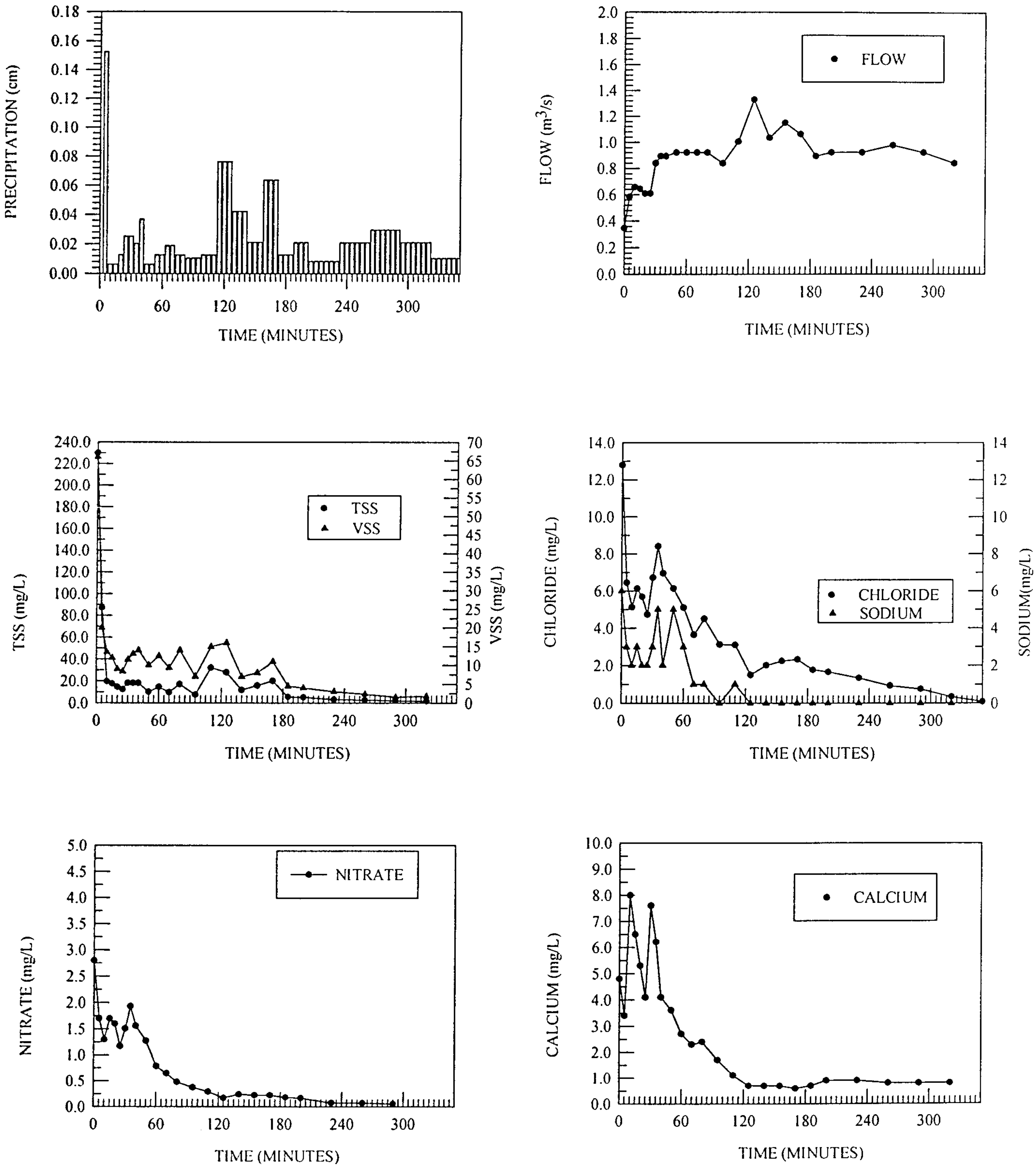
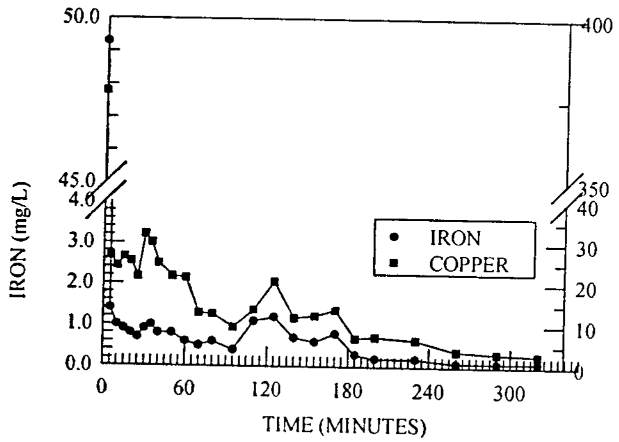
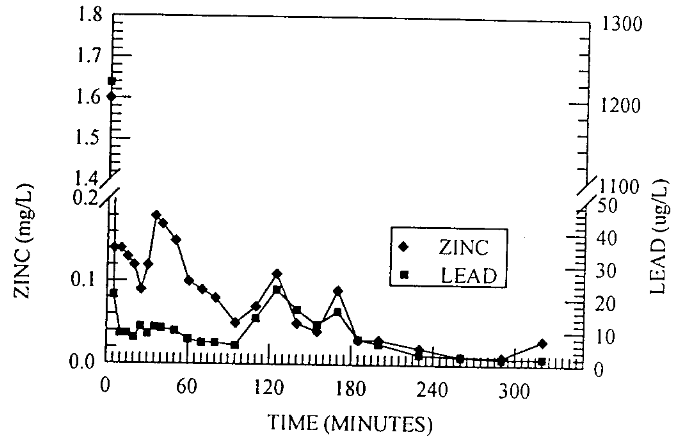
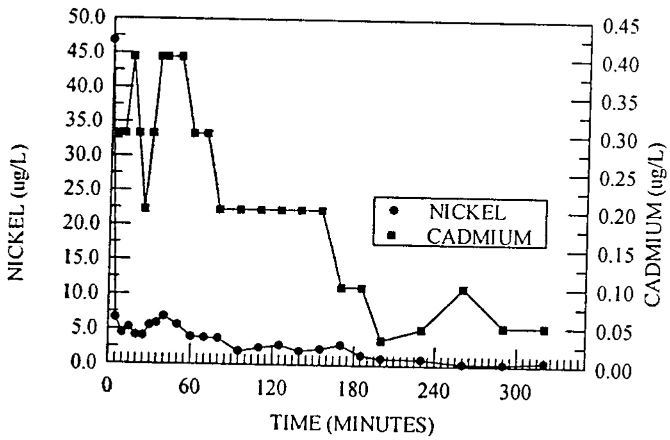
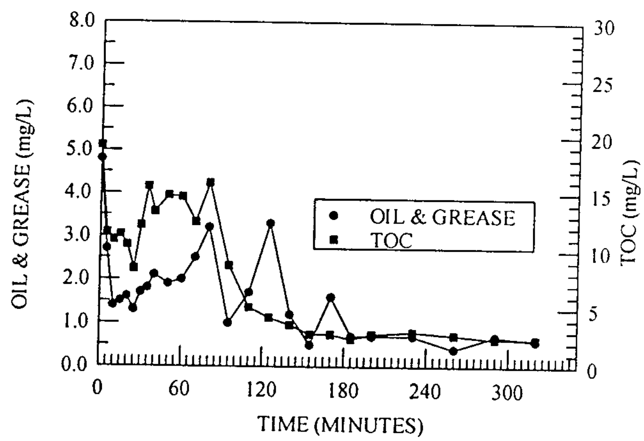


Figure A1. Storm I Collected Data - Post Road Sampling Site









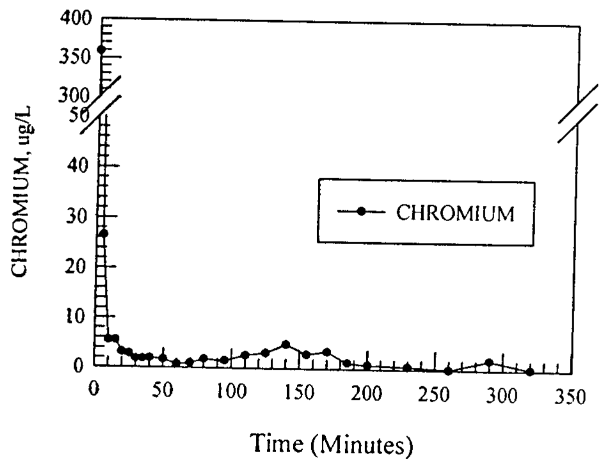


Figure A1. Storm I Collected Data - Post Road Sampling Site (contd.)

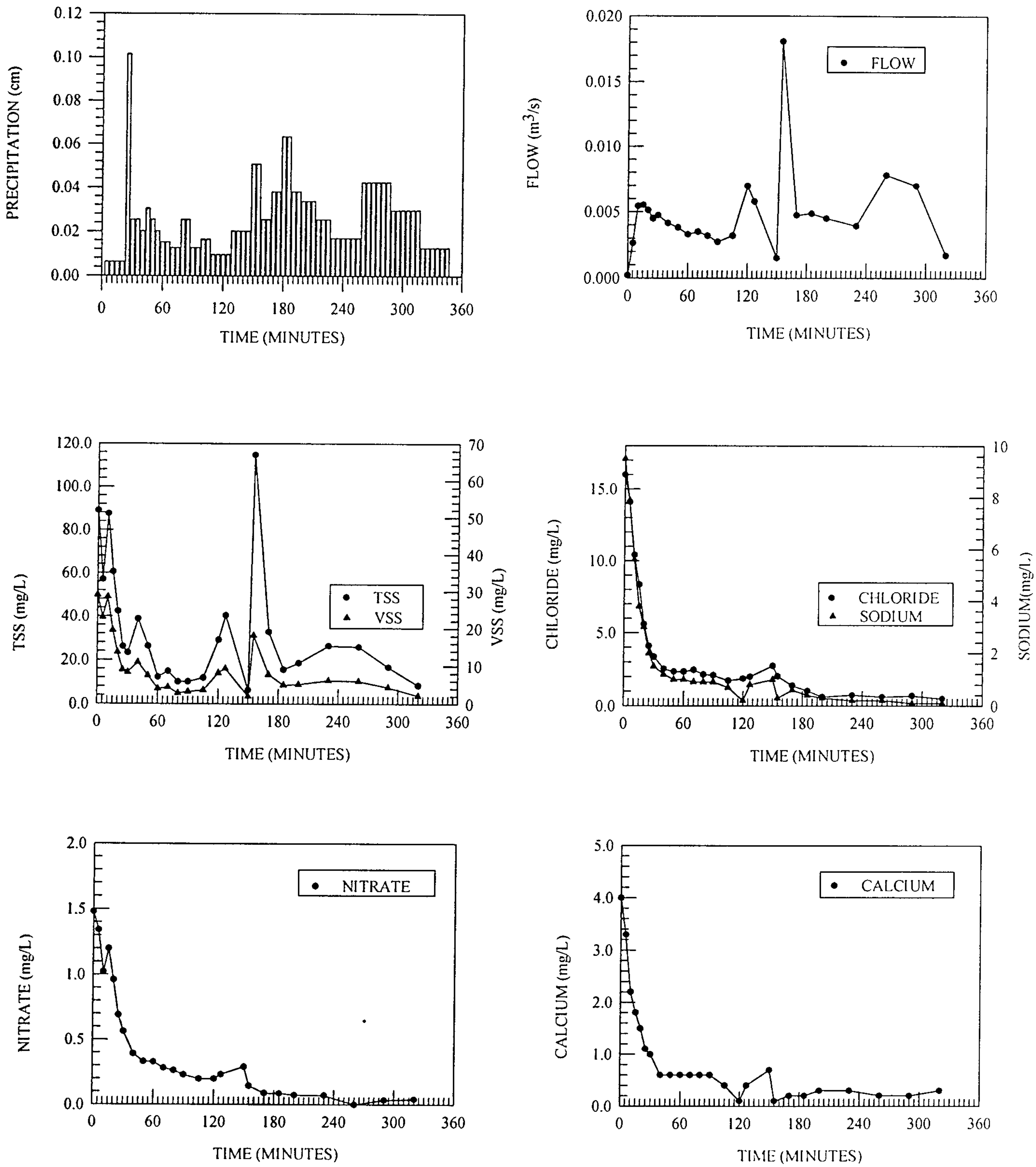
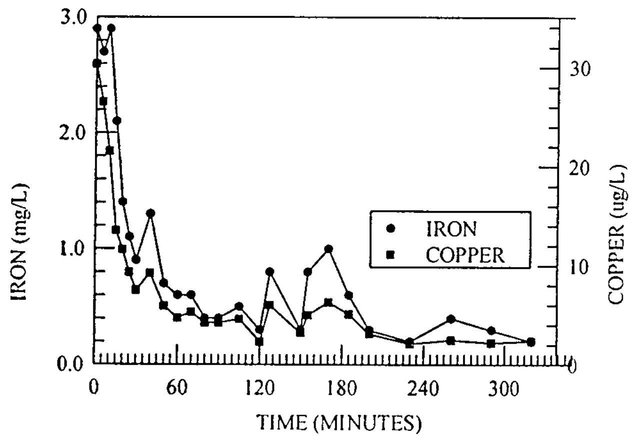
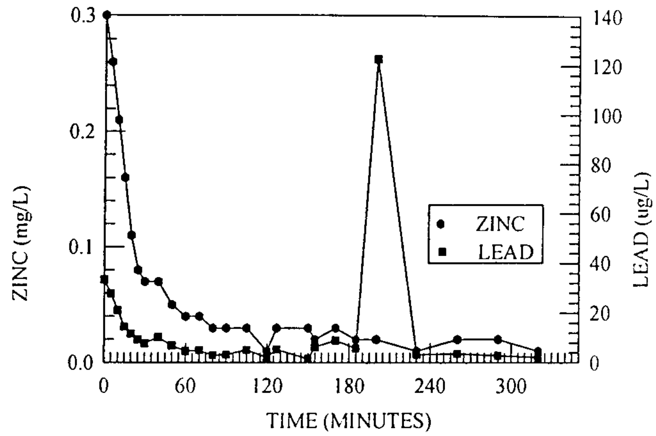
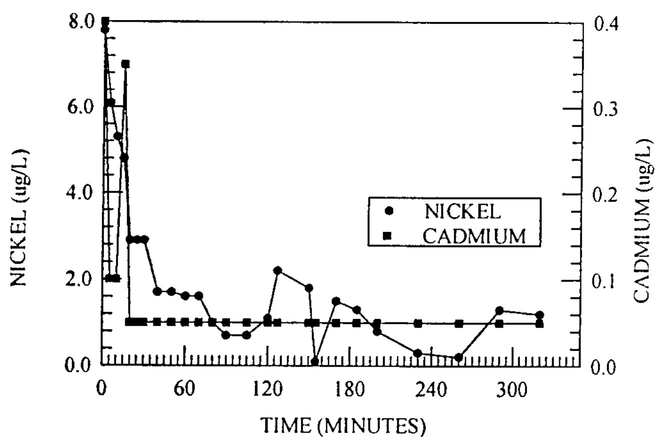
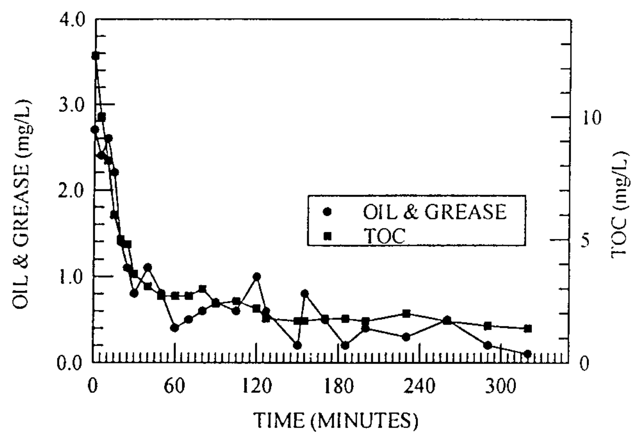


Figure A2. Storm I Collected Data - State Route 2 Sampling Site









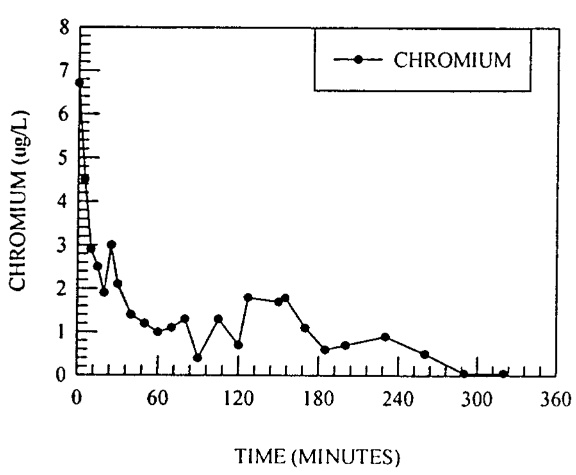


Figure A2. Storm I Collected Data - State Route 2 Sampling Site (contd.)

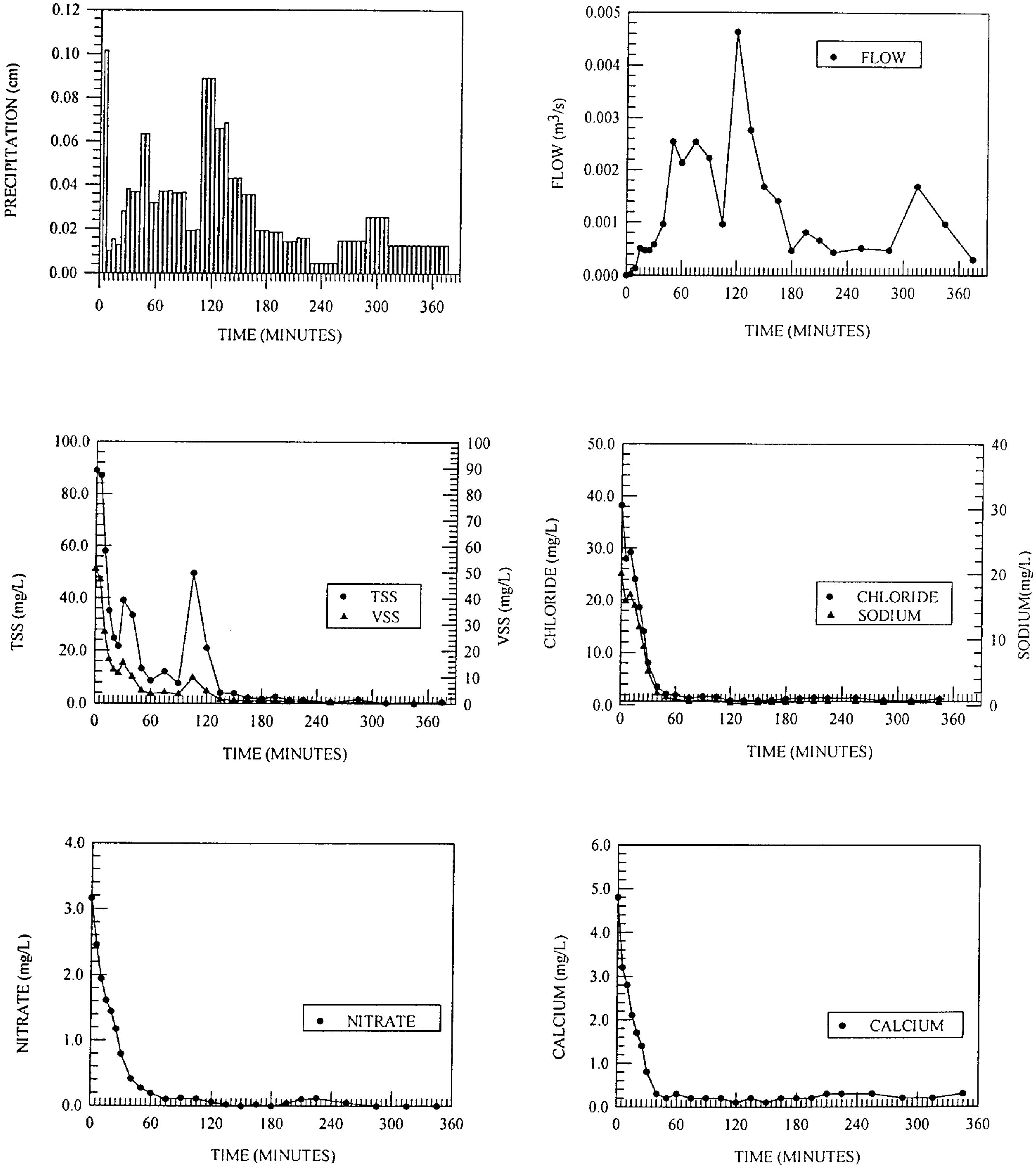
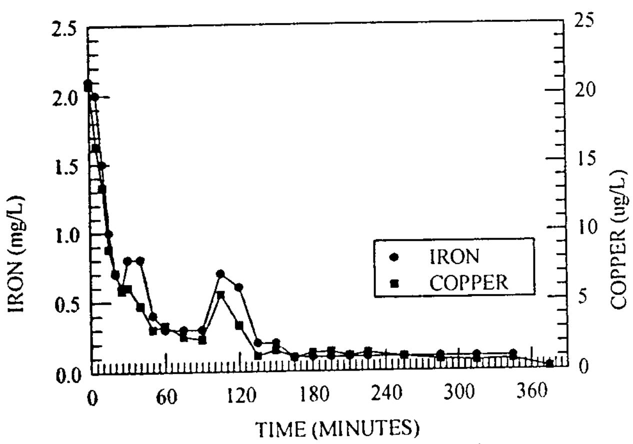
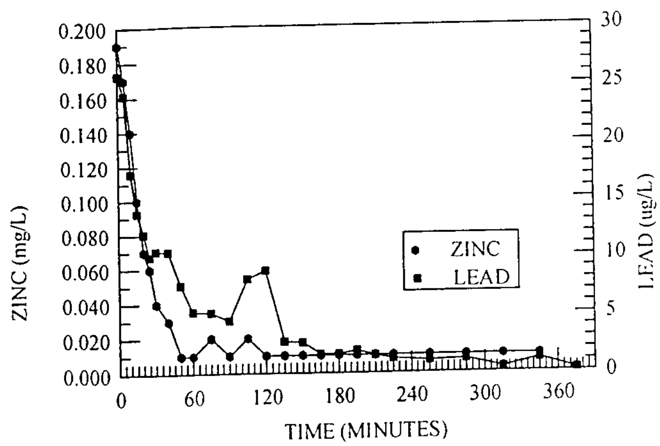
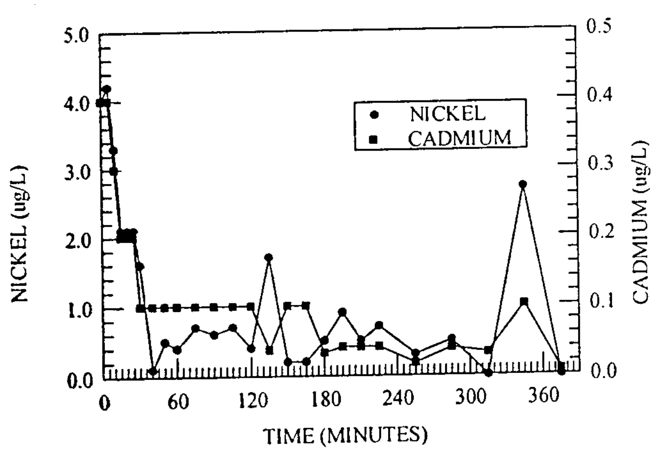
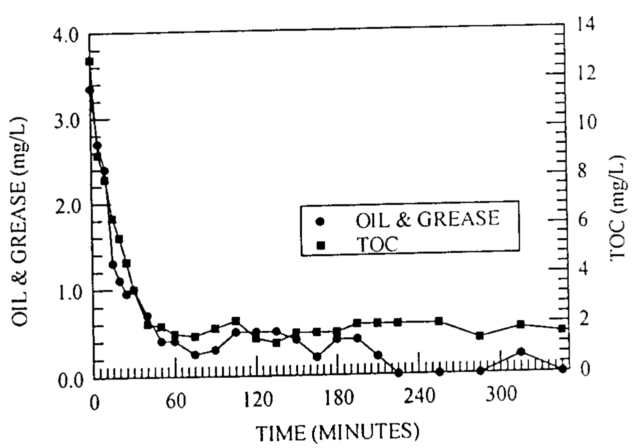


Figure A3. Storm I Collected Data - State Route 165 Sampling Site









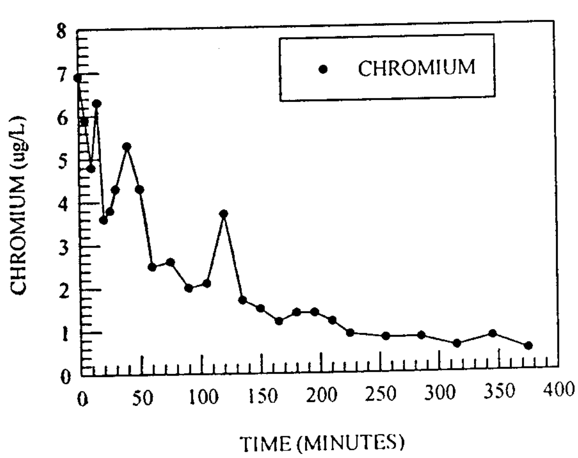


Figure A3. Storm I Collected Data - State Route 165 Sampling Site (contd.)

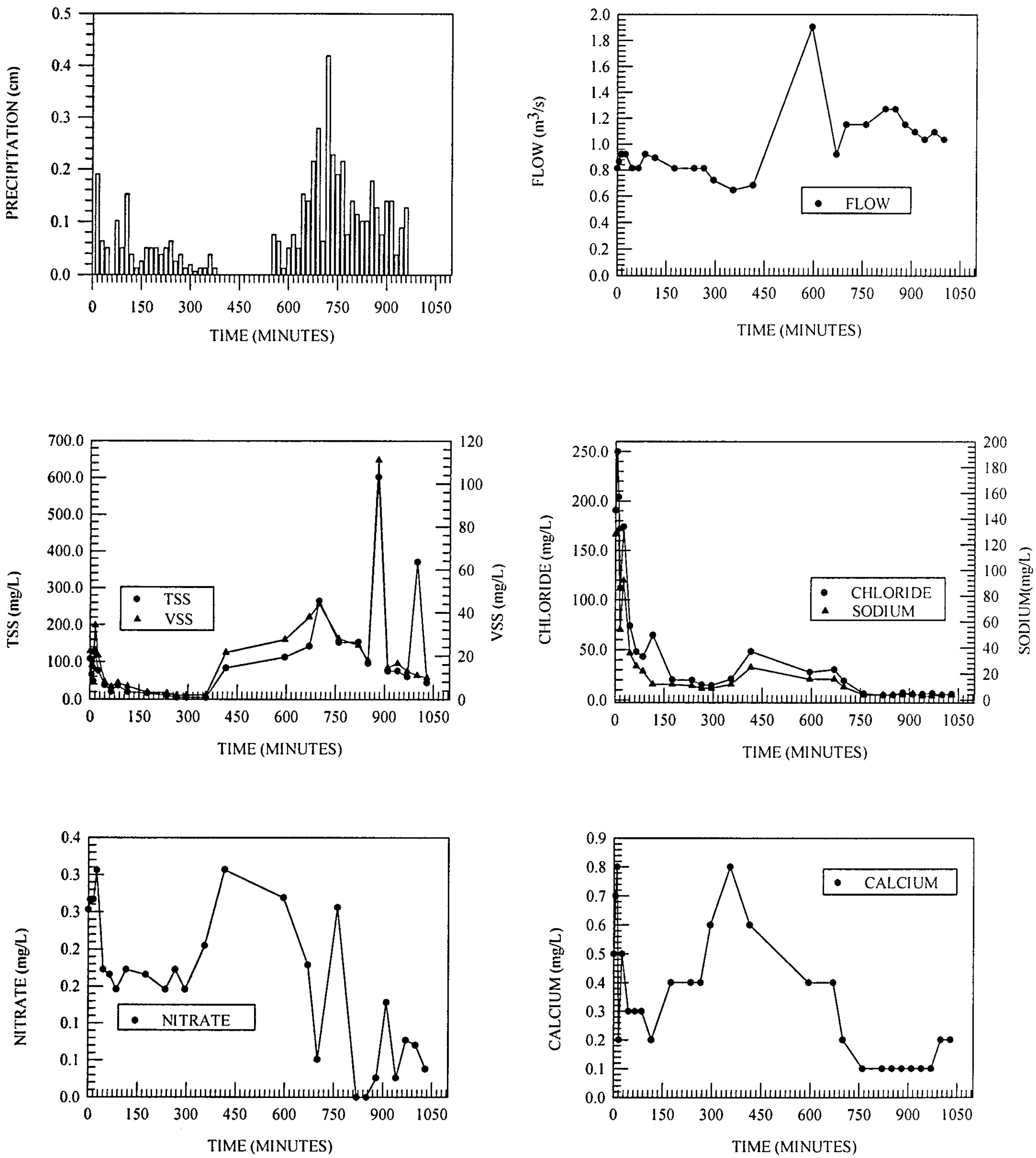
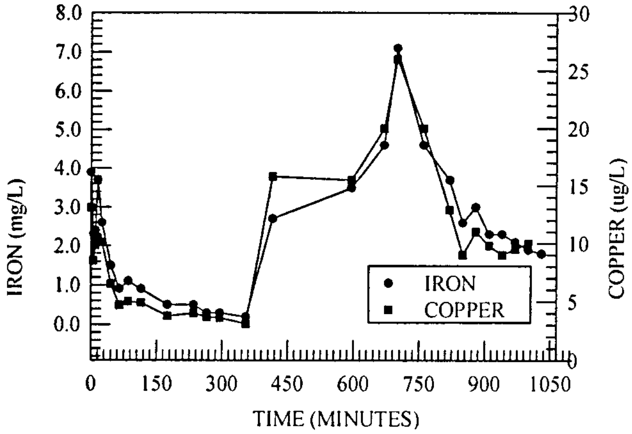
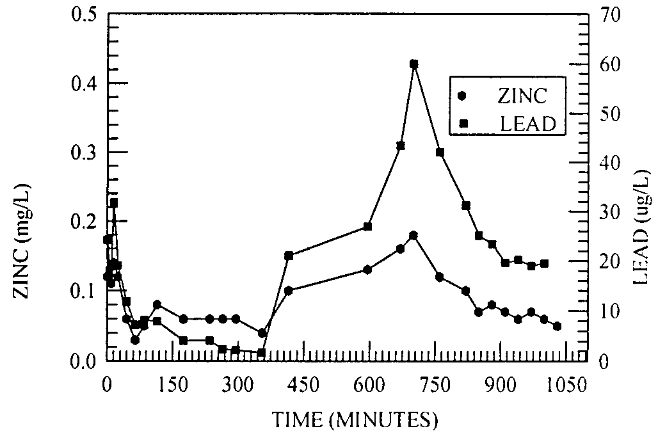
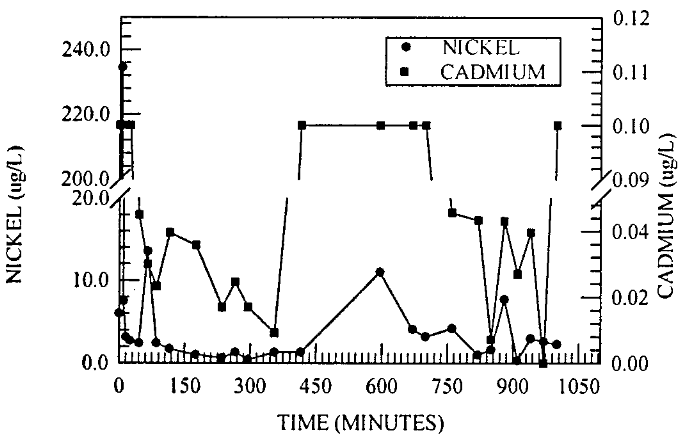
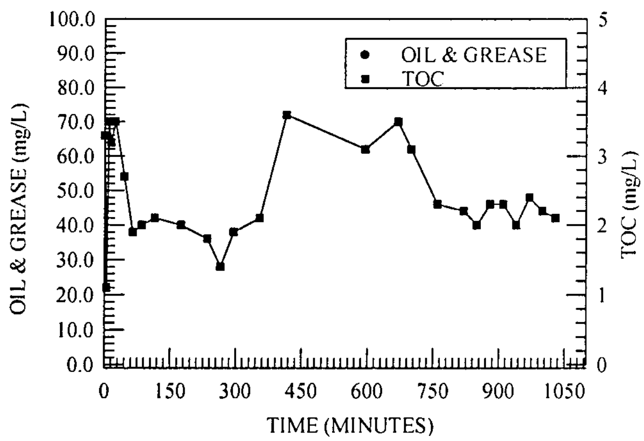


Figure A4. Storm II Collected Data - Post Road Sampling Site









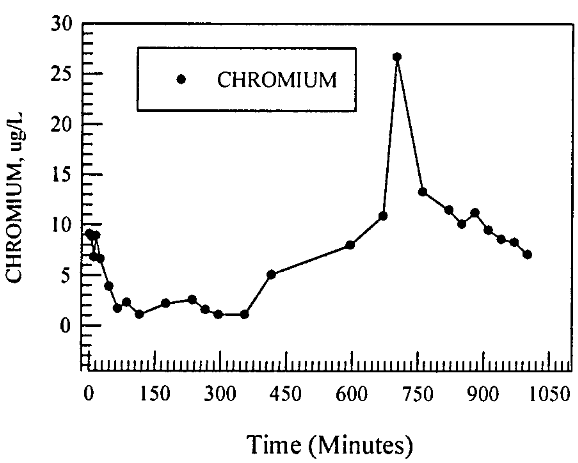


Figure A4. Storm II Collected Data - Post Road Sampling Site (contd.)

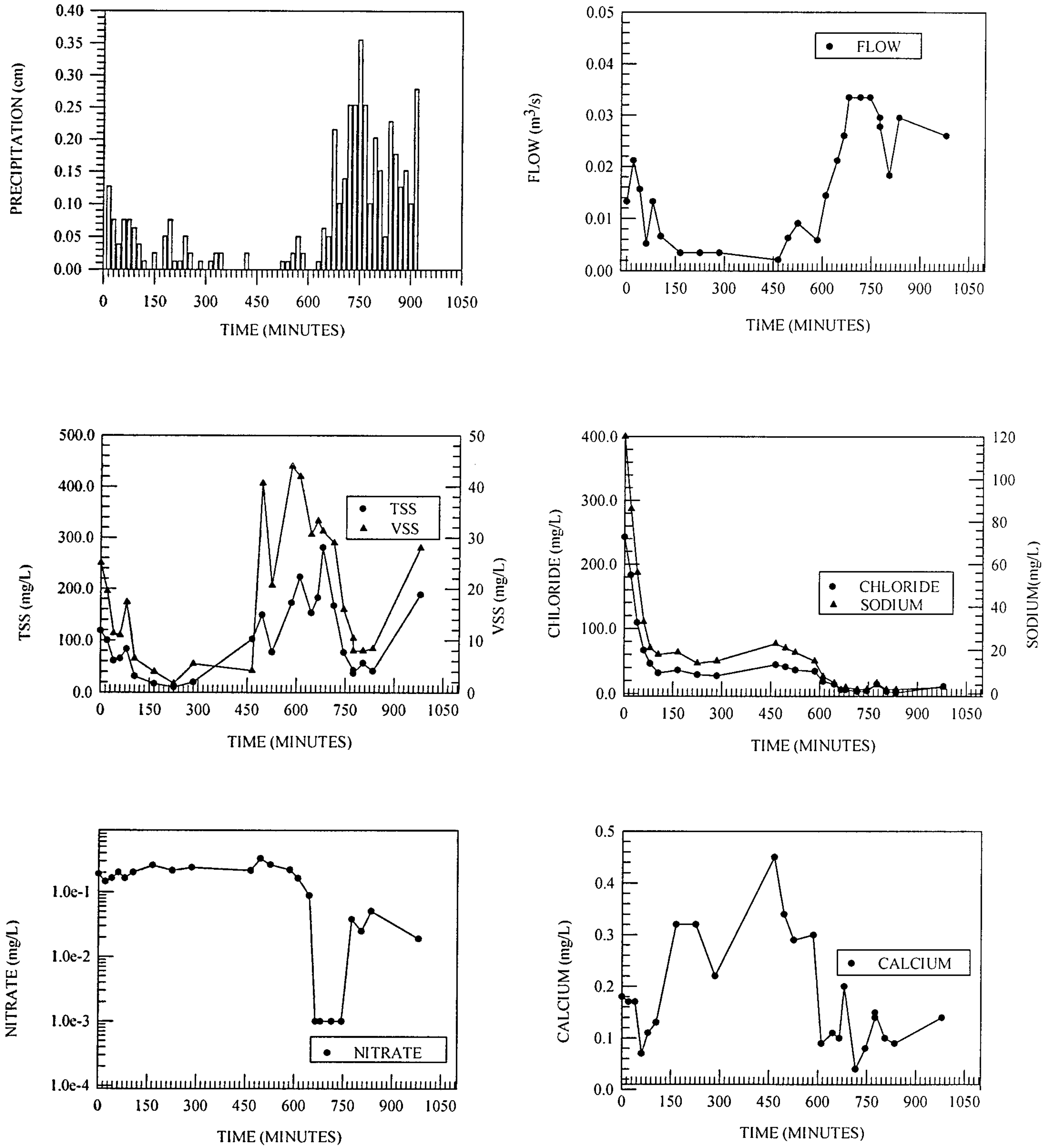


Figure A5. Storm II Collected Data - State Route 2 Sampling Site

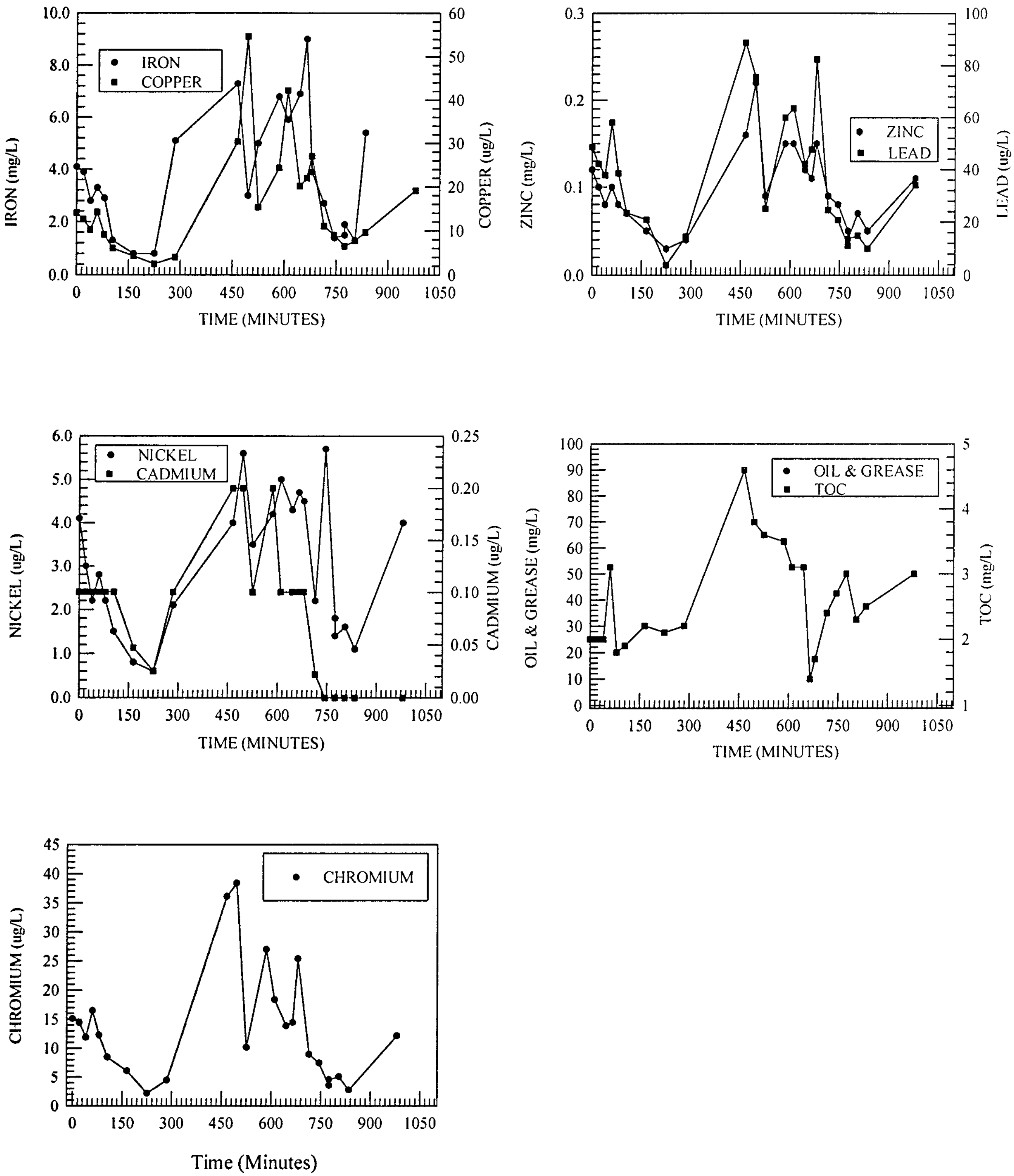


Figure A5. Storm II Collected Data - State Route 2 Sampling Site (contd.)

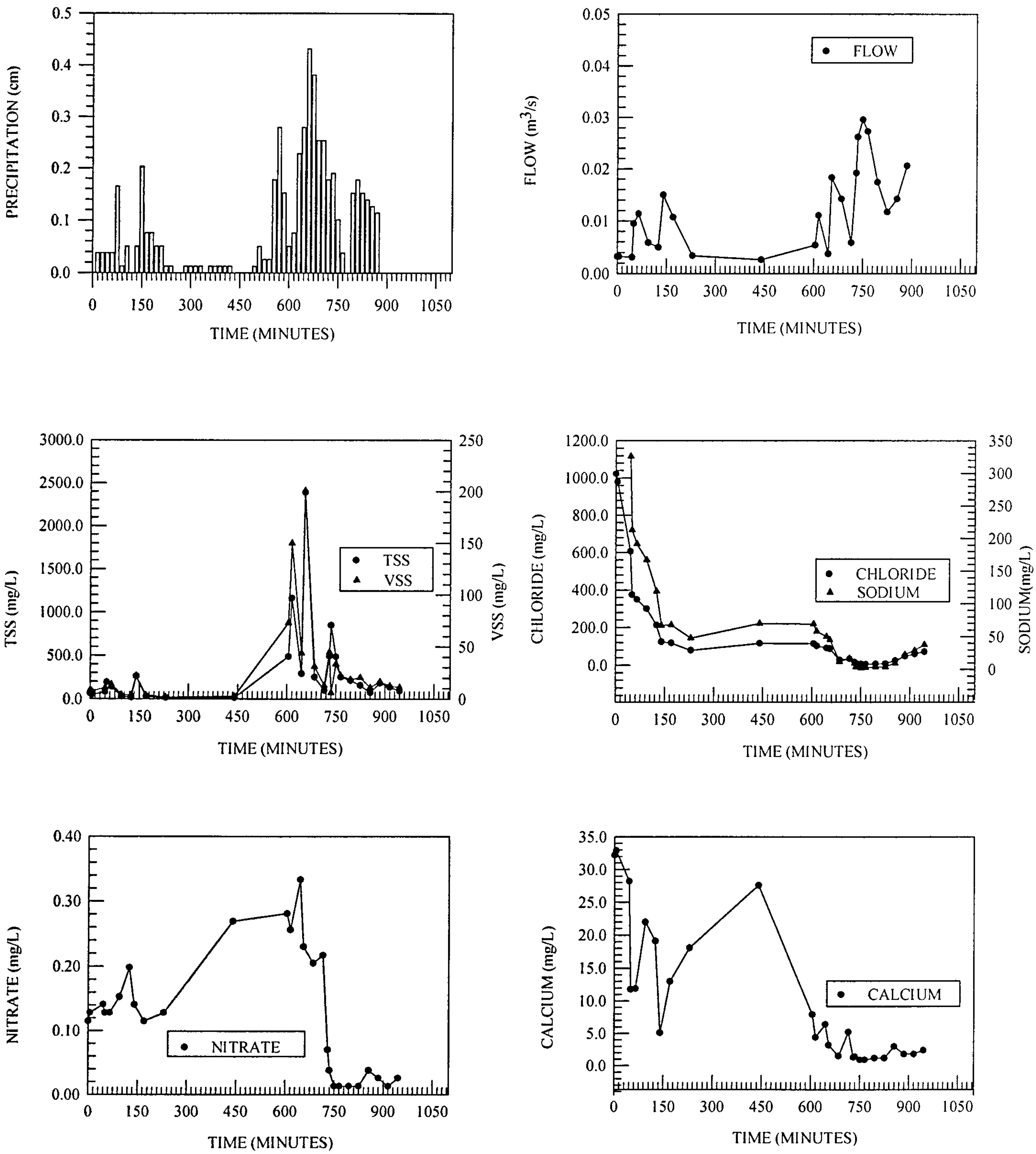
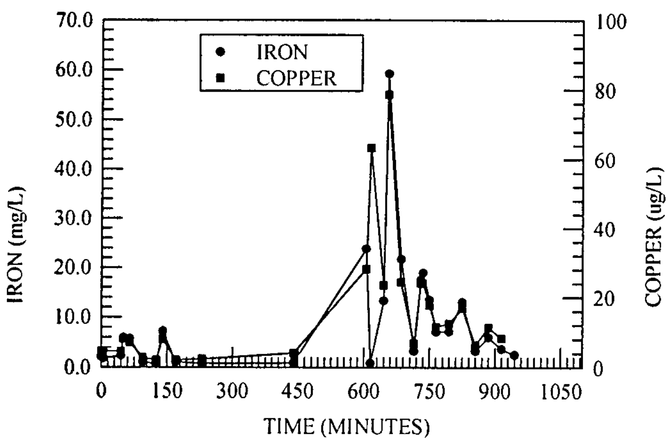
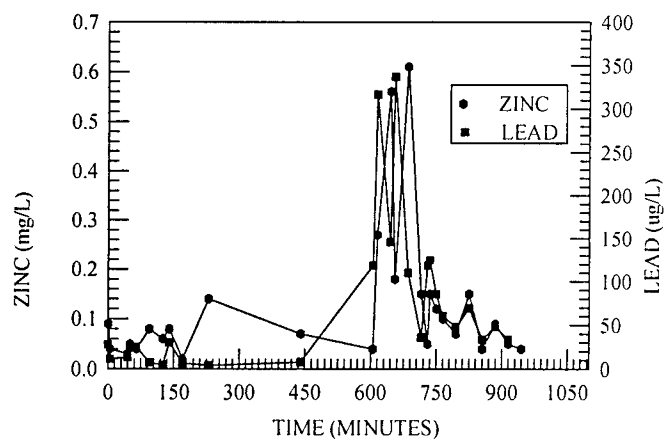
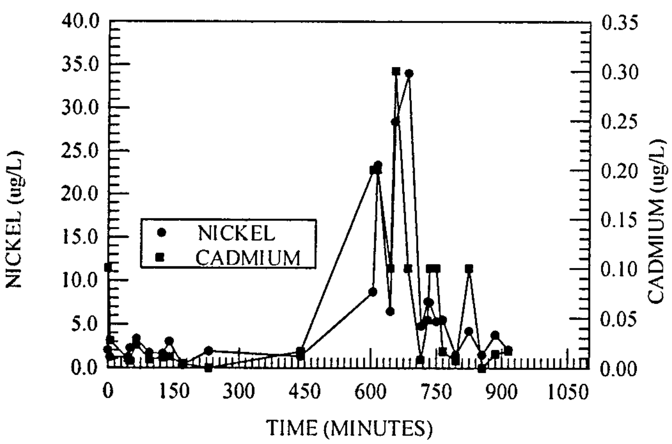
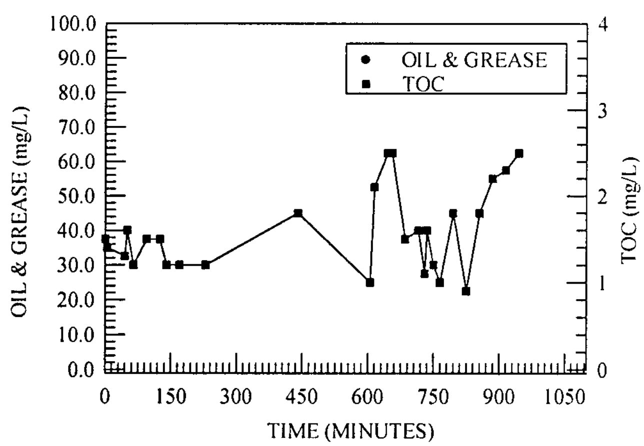


Figure A6. Storm II Collected Data - State Route 165 Sampling Site









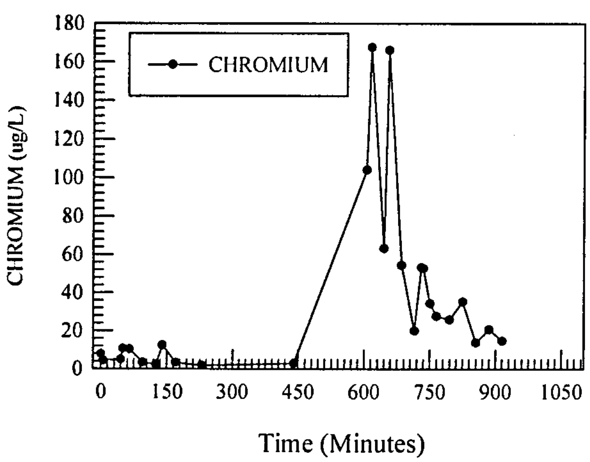


Figure A6. Storm II Collected Data - State Route 165 Sampling Site (contd.)

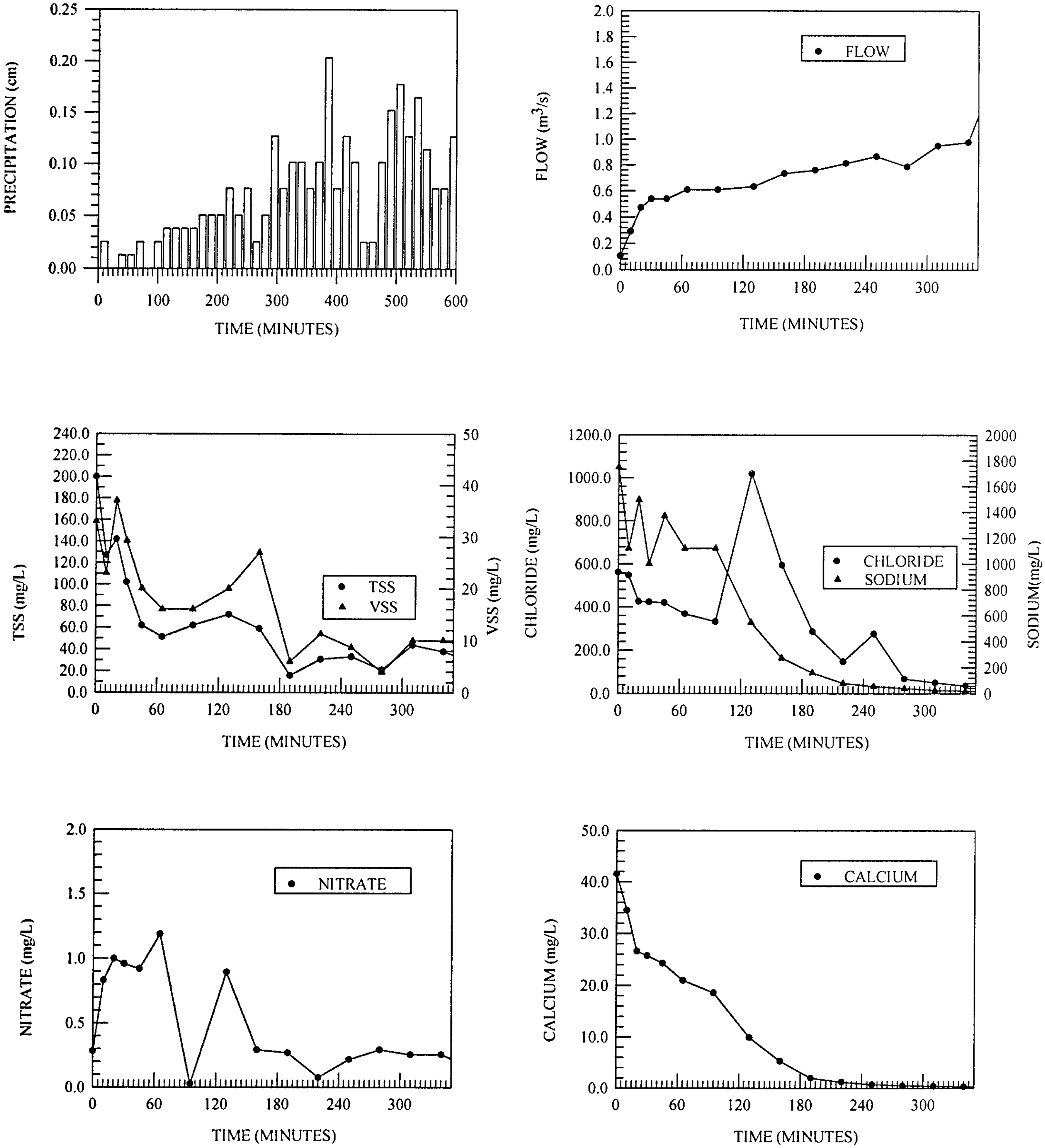
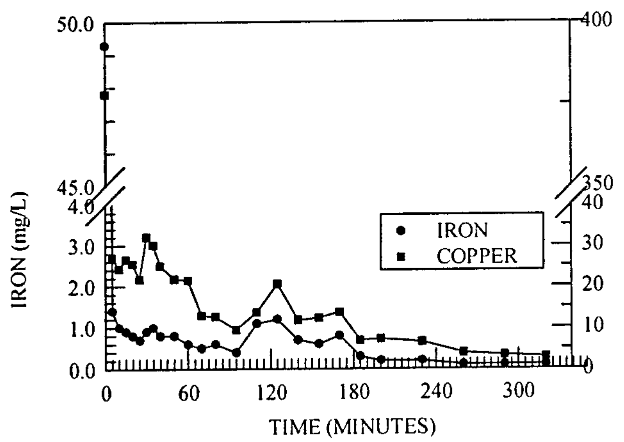
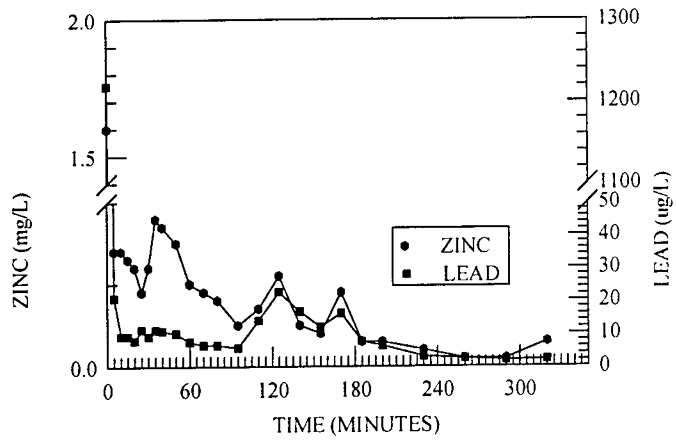
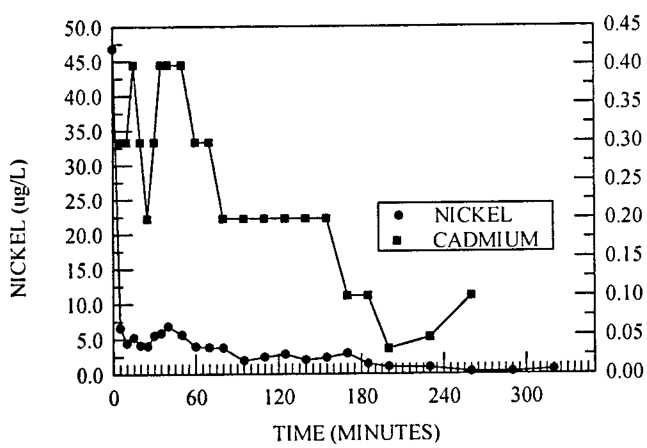
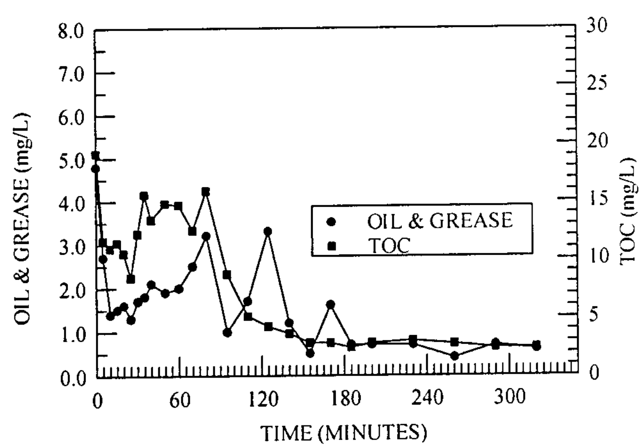


Figure A7. Storm III Collected Data - Post Road Sampling Site









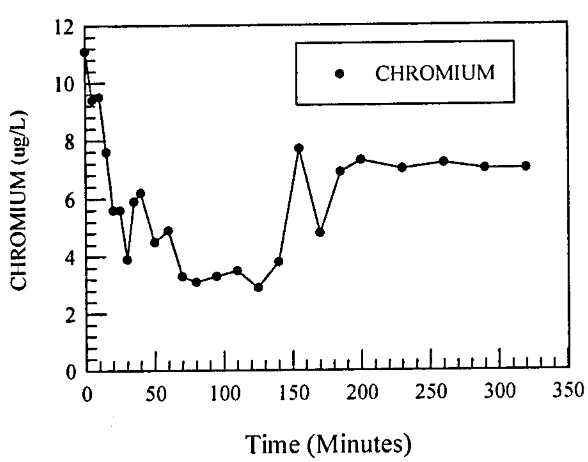


Figure A7. Storm III Collected Data - Post Road Sampling Site (contd.)

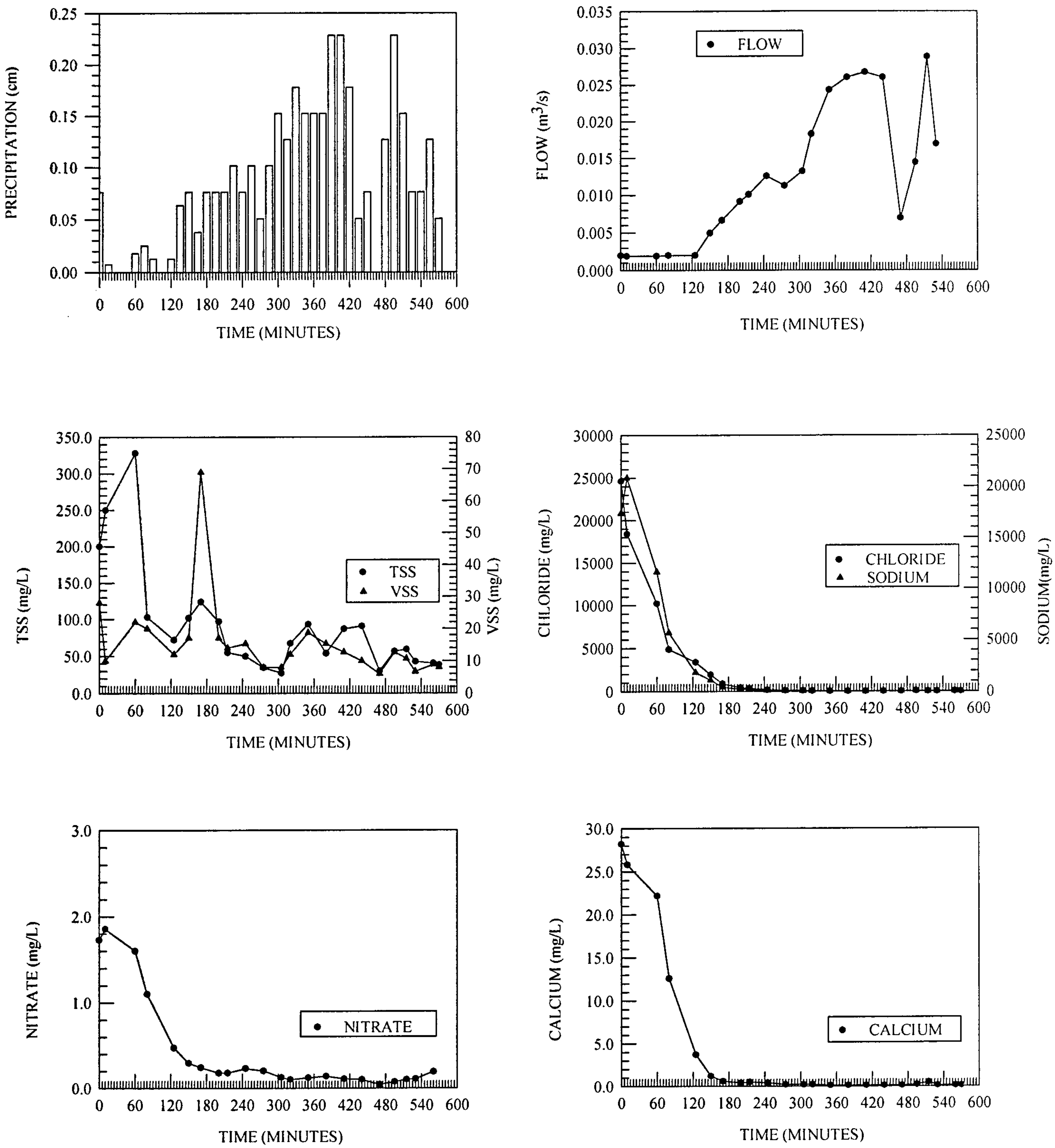


Figure A8. Storm III Collected Data - State Route 2 Sampling Site

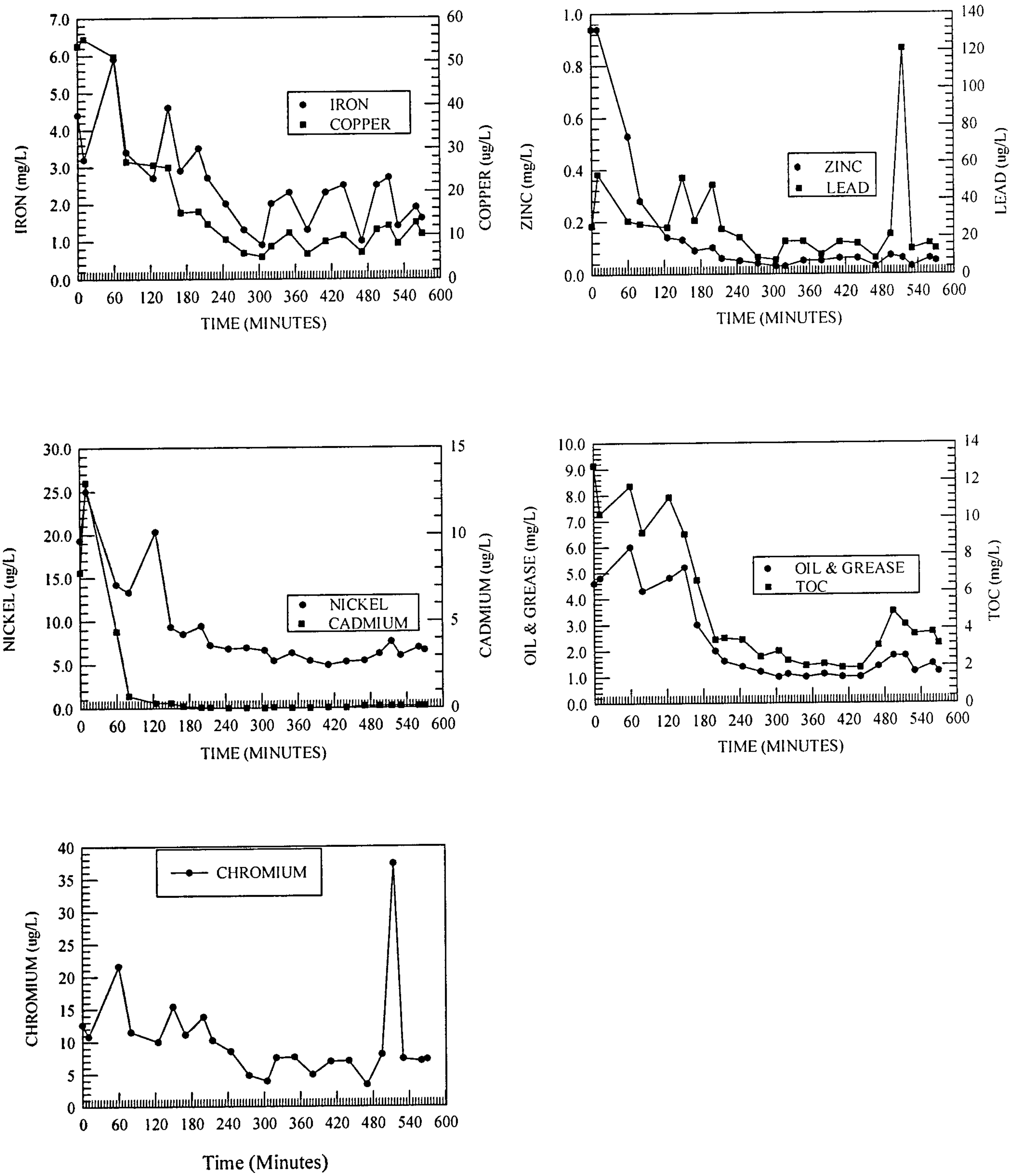


Figure A8. Storm III Collected Data - State Route 2 Sampling Site (contd.)

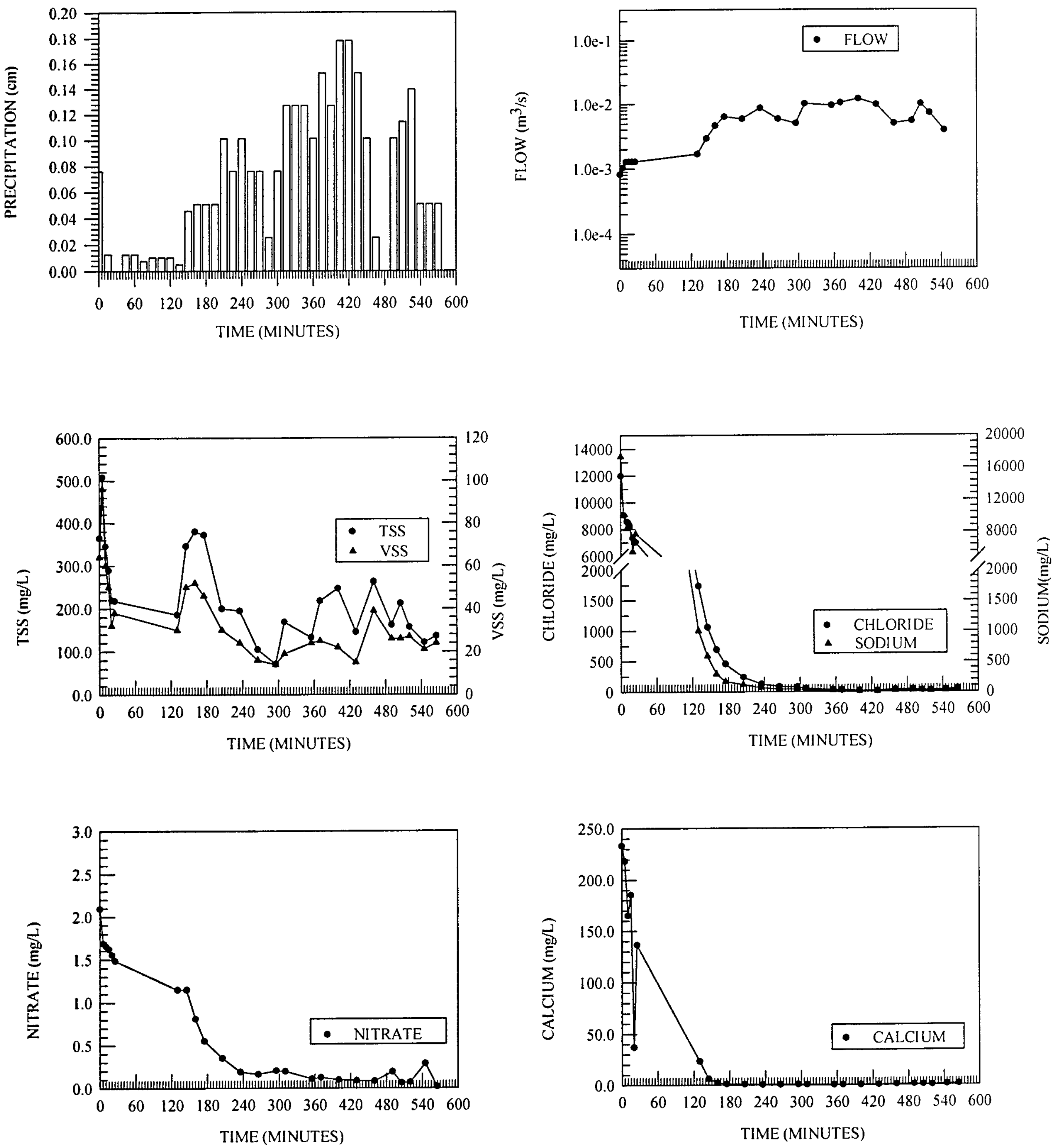
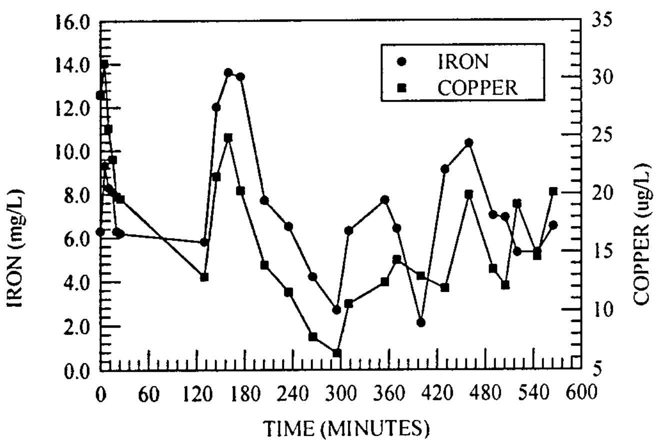
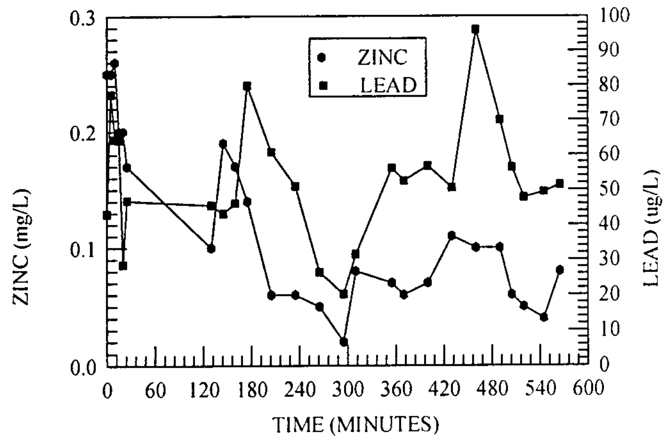
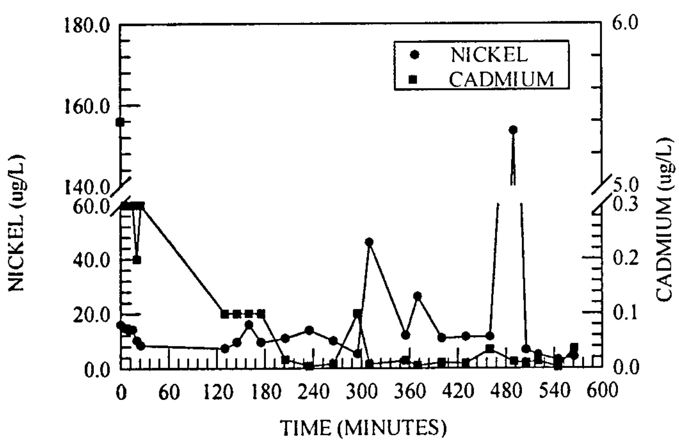
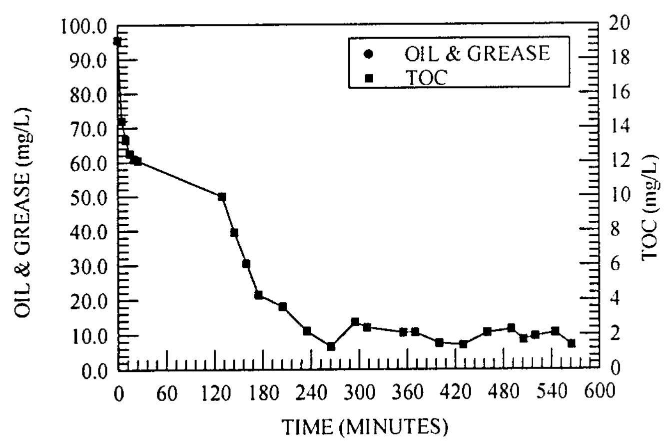


Figure A9. Storm III Collected Data - State Route 165 Sampling Site









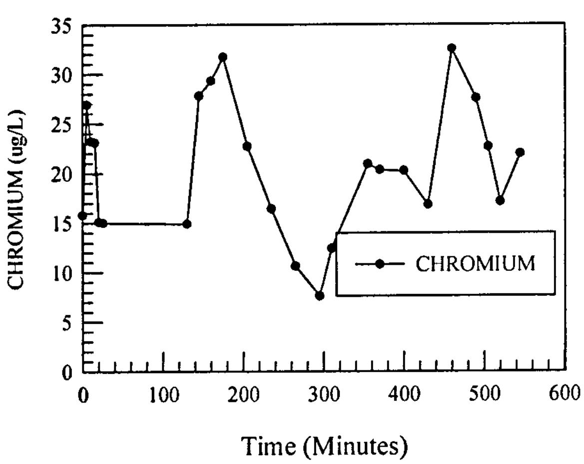


Figure A9. Storm III Collected Data - State Route 165 Sampling Site (contd.)

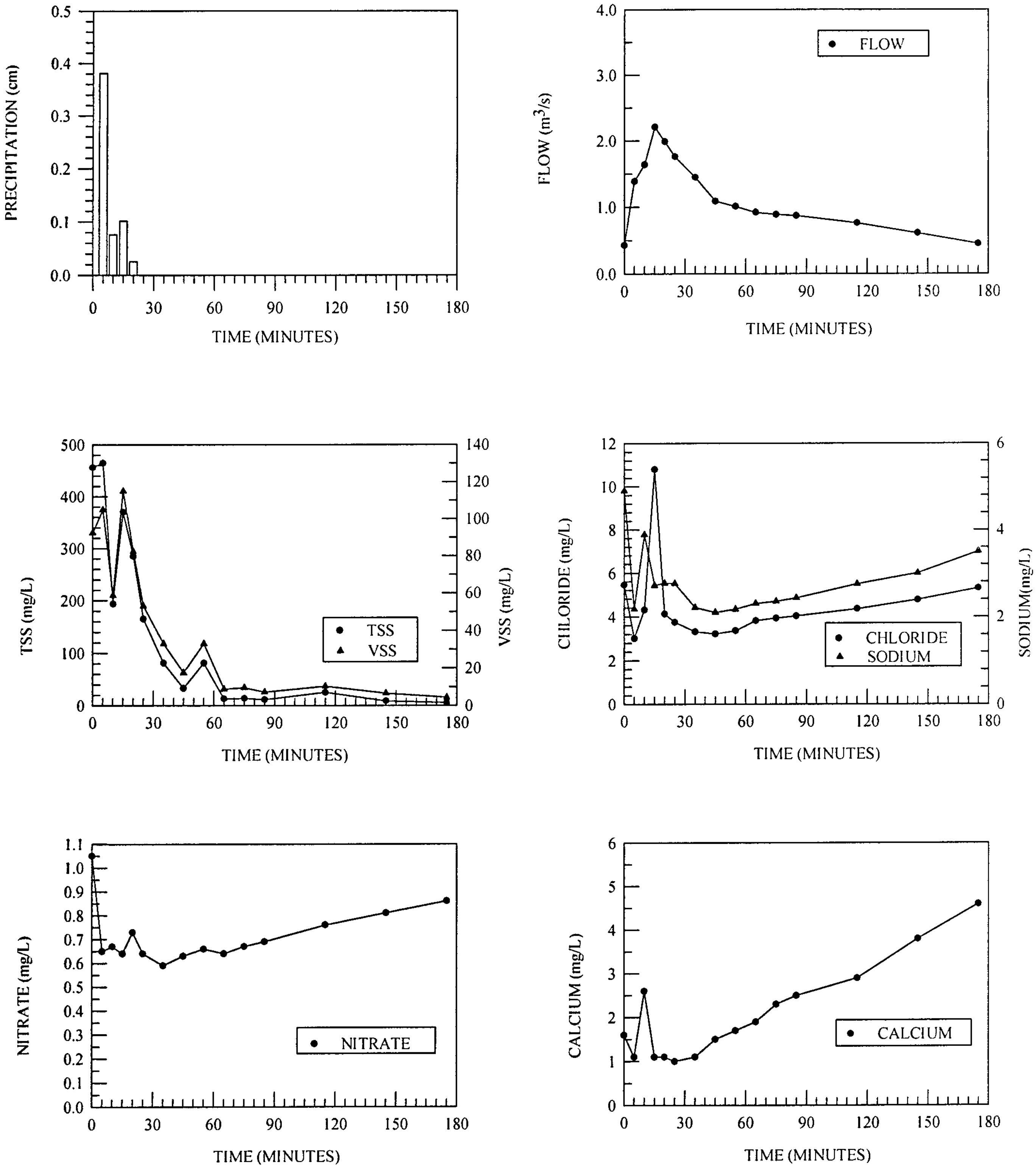
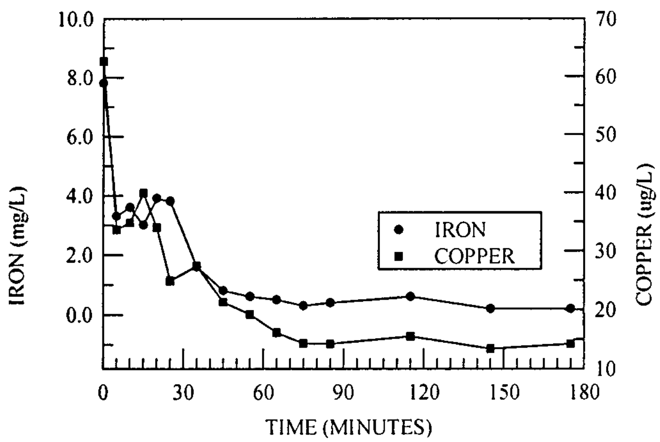
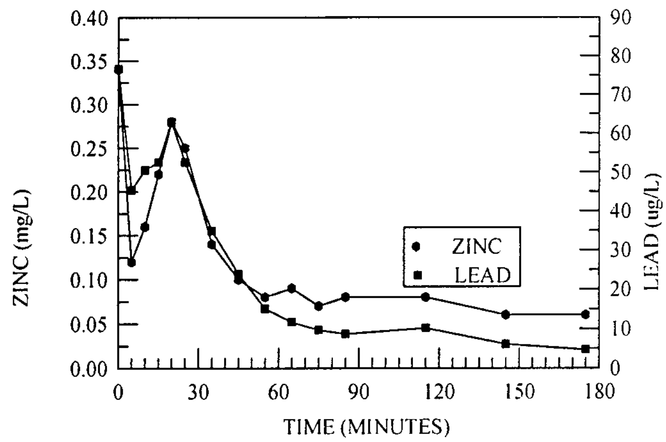
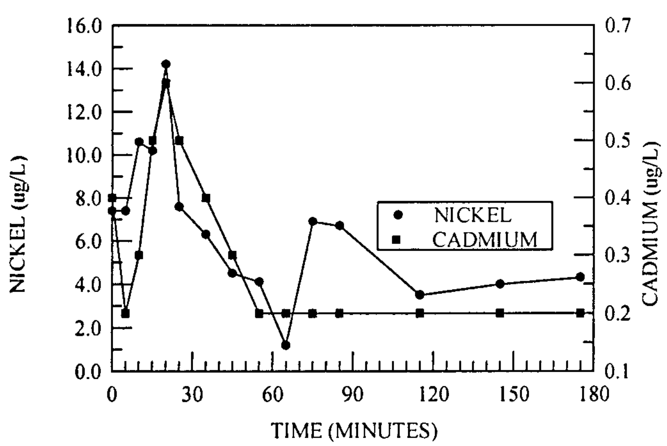
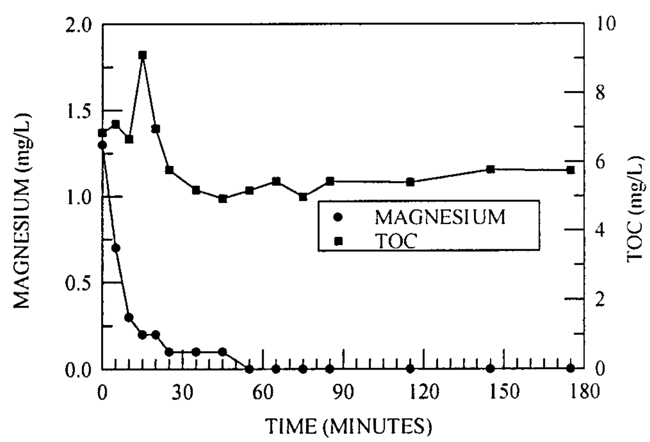


Figure A10. Storm IV Collected Data - Post Road Sampling Site









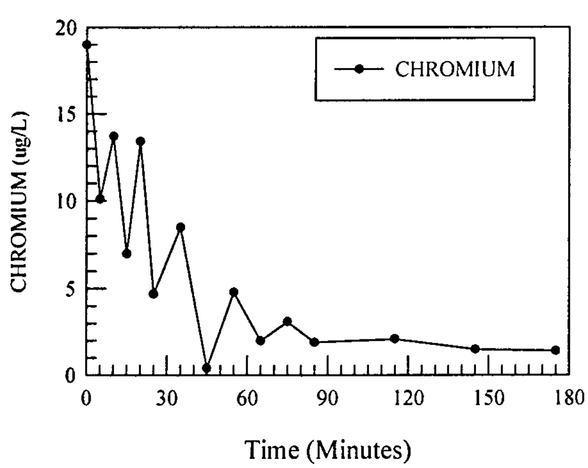


Figure A10. Storm IV Collected Data - Post Road Sampling Site (contd.)

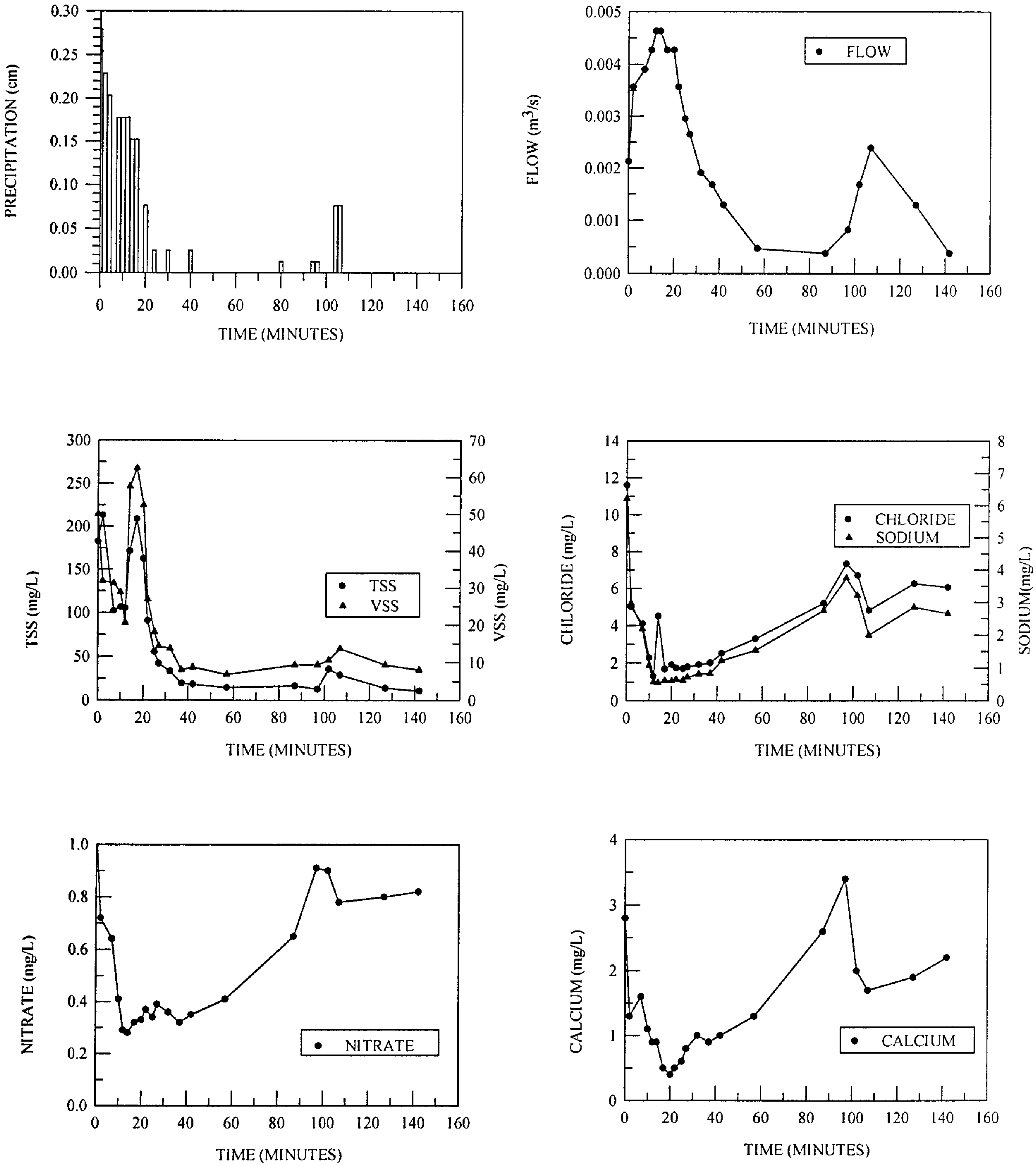


Figure A11. Storm IV Collected Data - State Route 2 Sampling Site

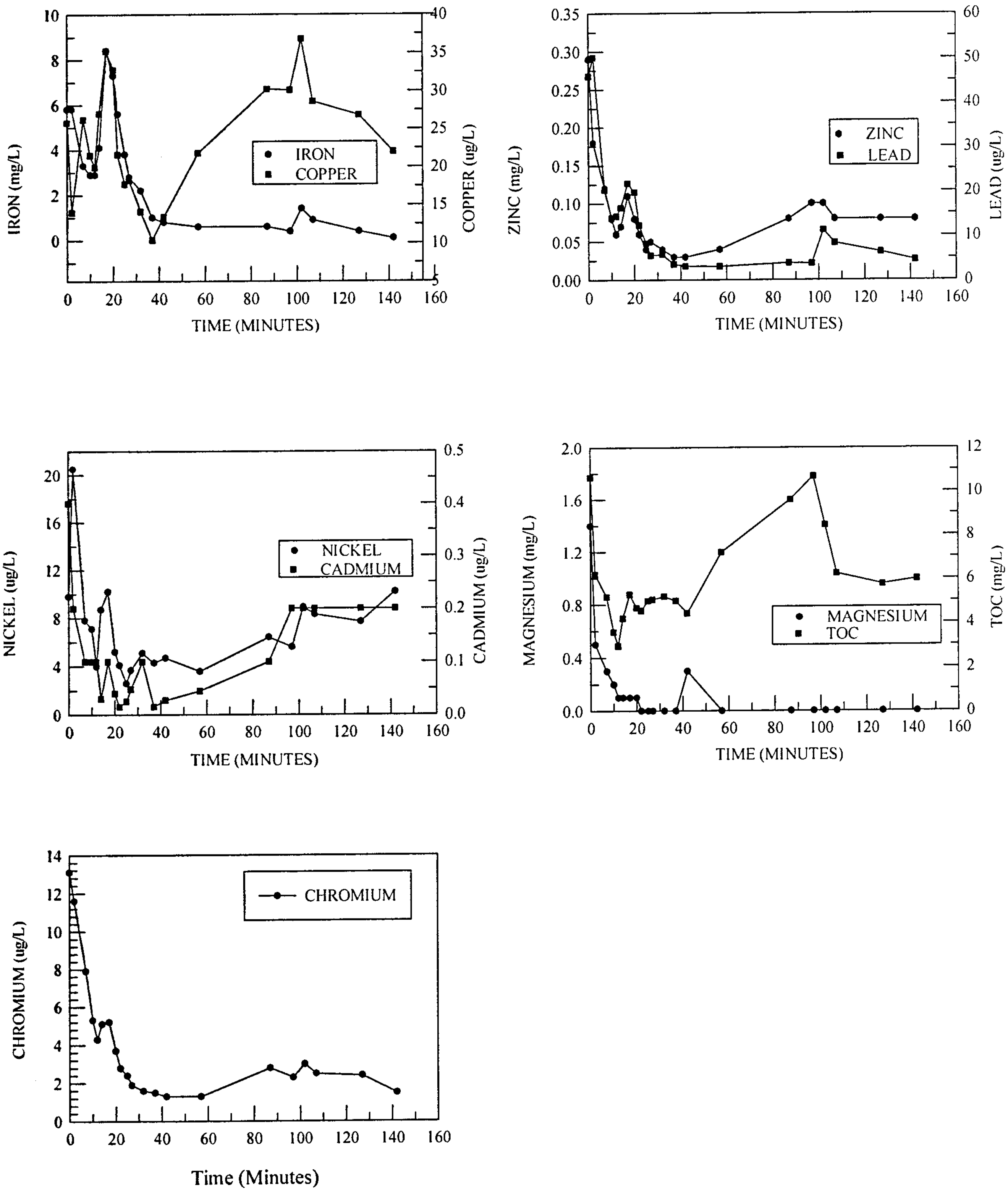


Figure A11. Storm IV Collected Data - State Route 2 Sampling Site (contd.)

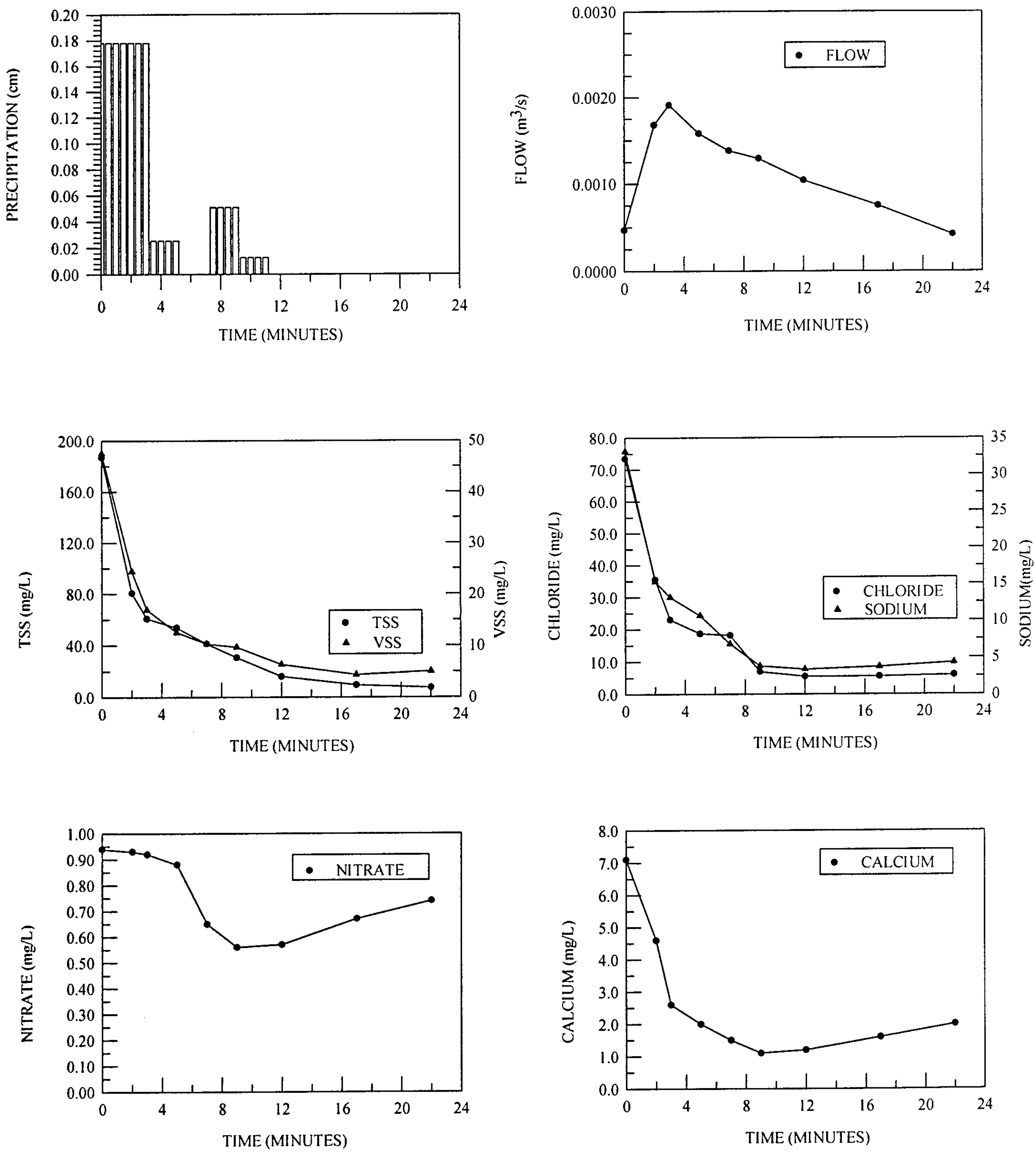


Figure A12. Storm IV Collected Data - State Route 165 Sampling Site

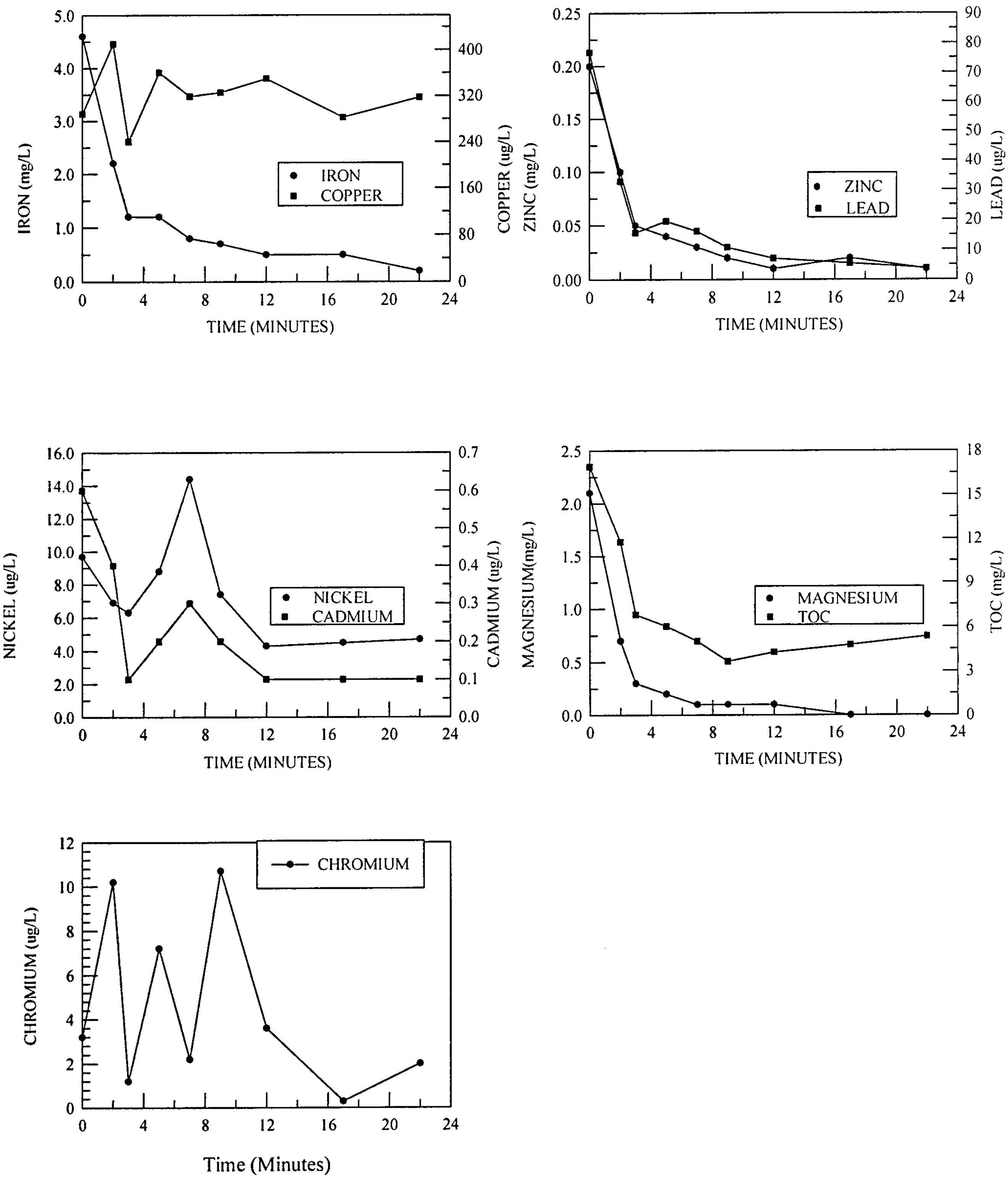


Figure A12. Storm IV Collected Data - State Route 165 Sampling Site (contd.)

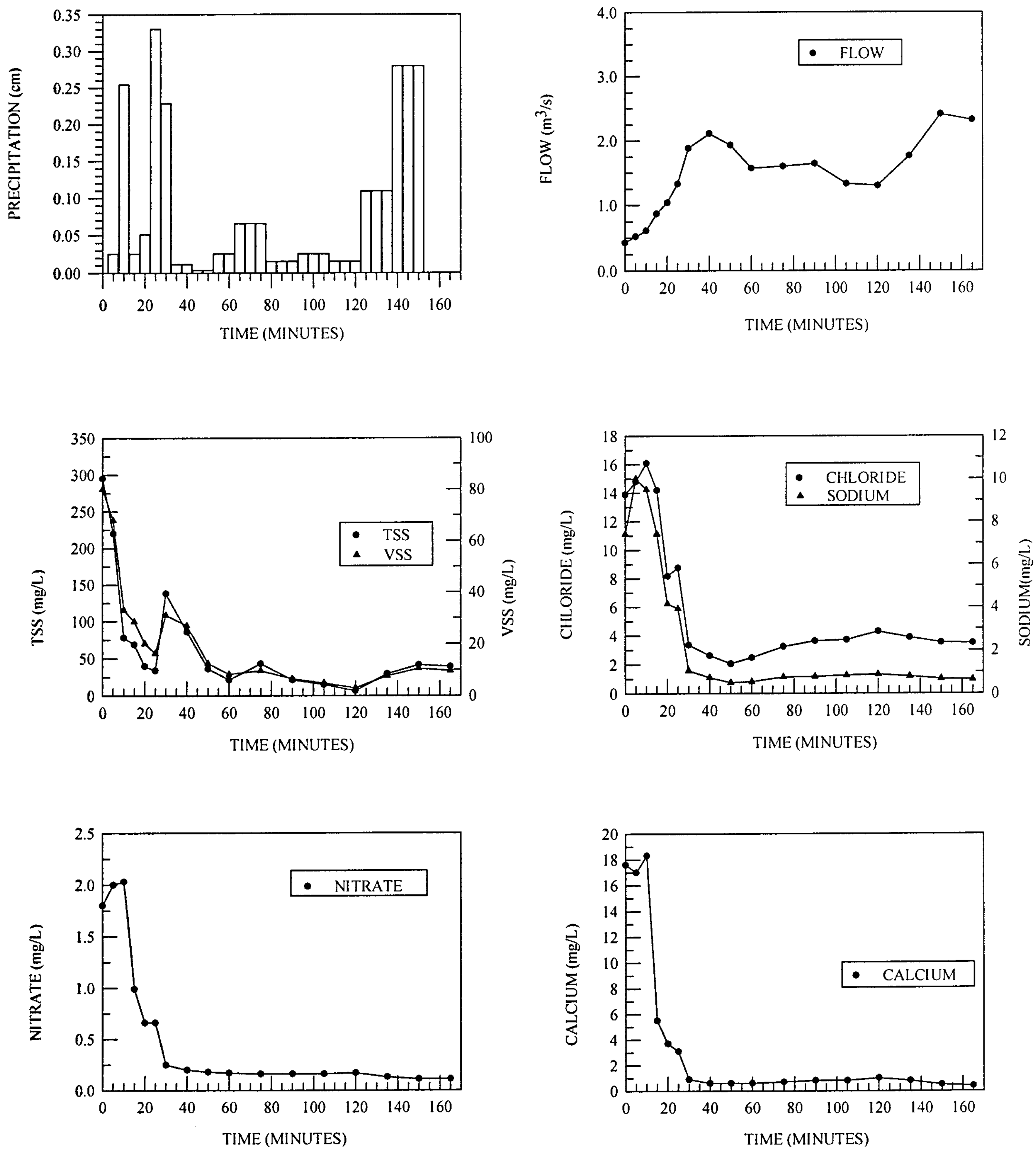


Figure A13. Storm V Collected Data - Post Road Sampling Site

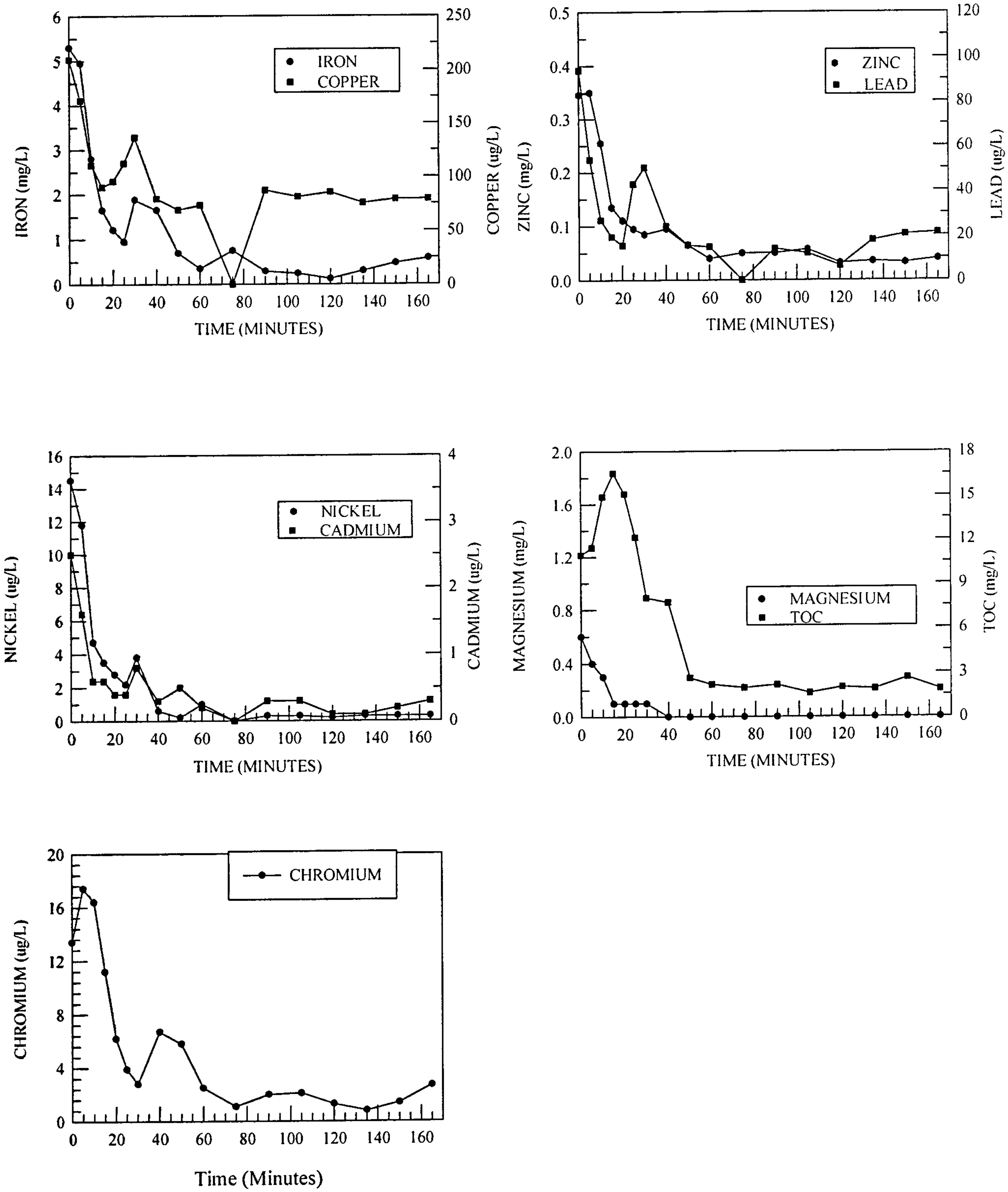


Figure A13. Storm V Collected Data - Post Road Sampling Site (contd.)

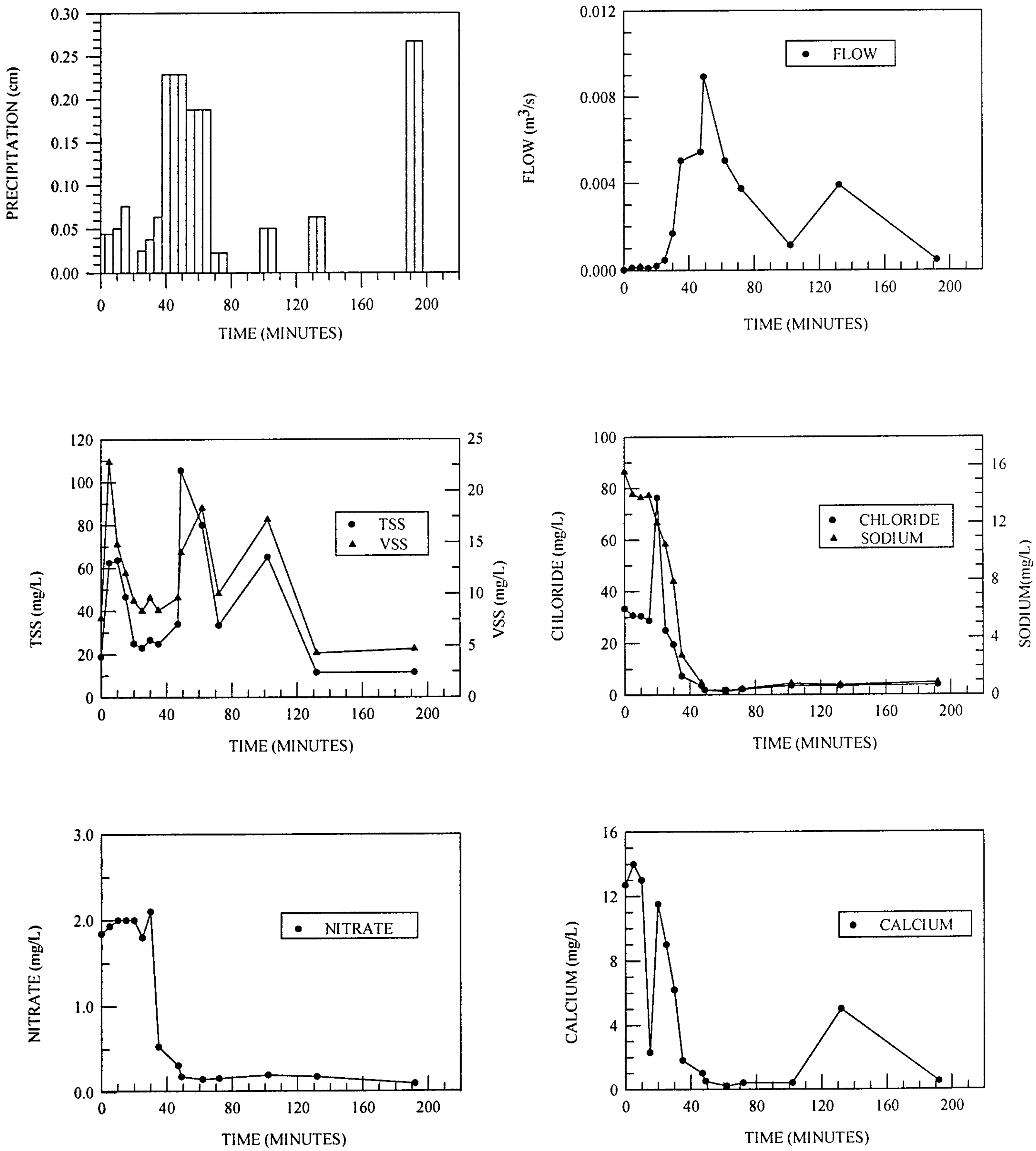


Figure A14. Storm V Collected Data - State Route 2 Sampling Site

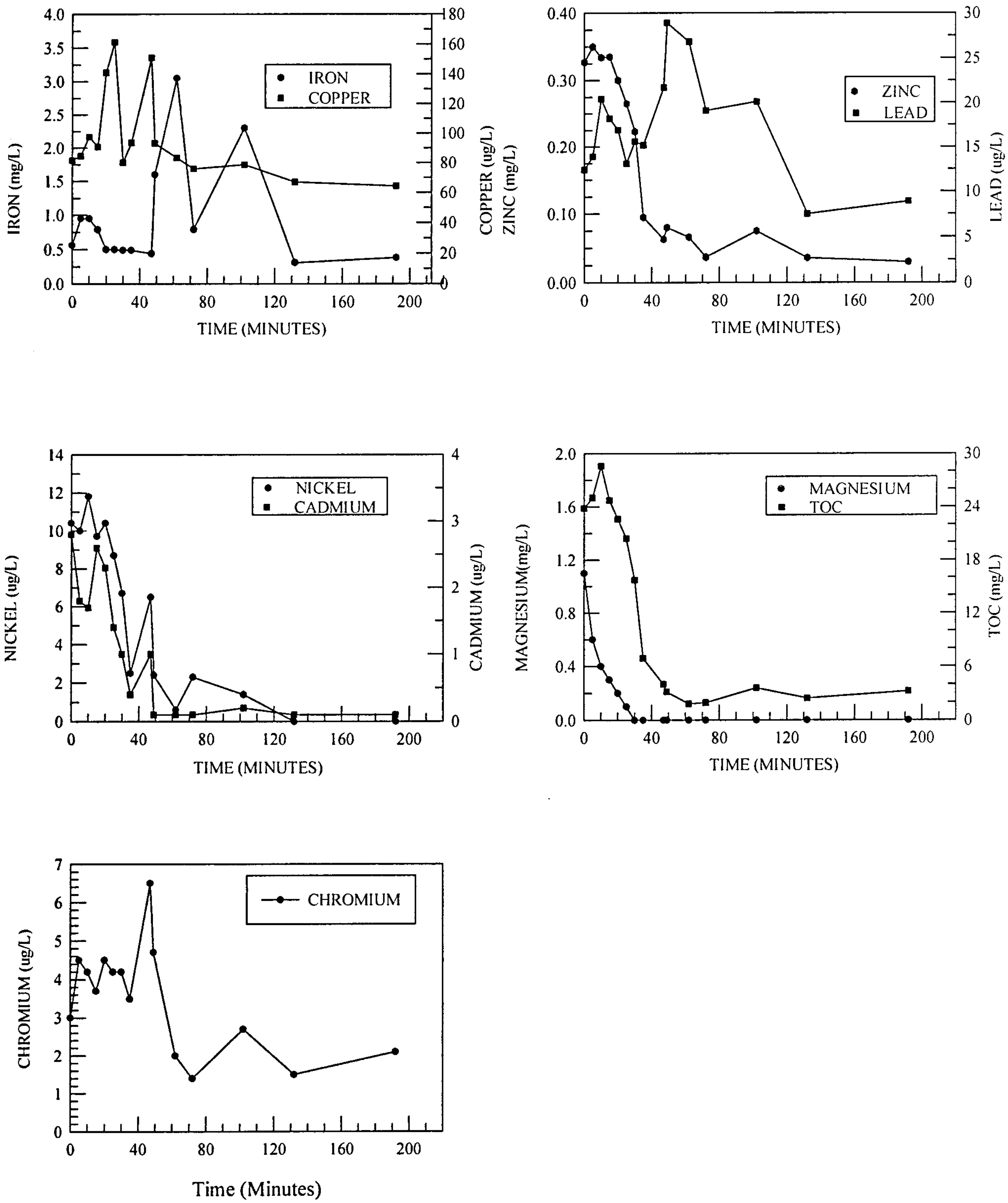


Figure A14. Storm V Collected Data - State Route 2 Sampling Site (contd.)

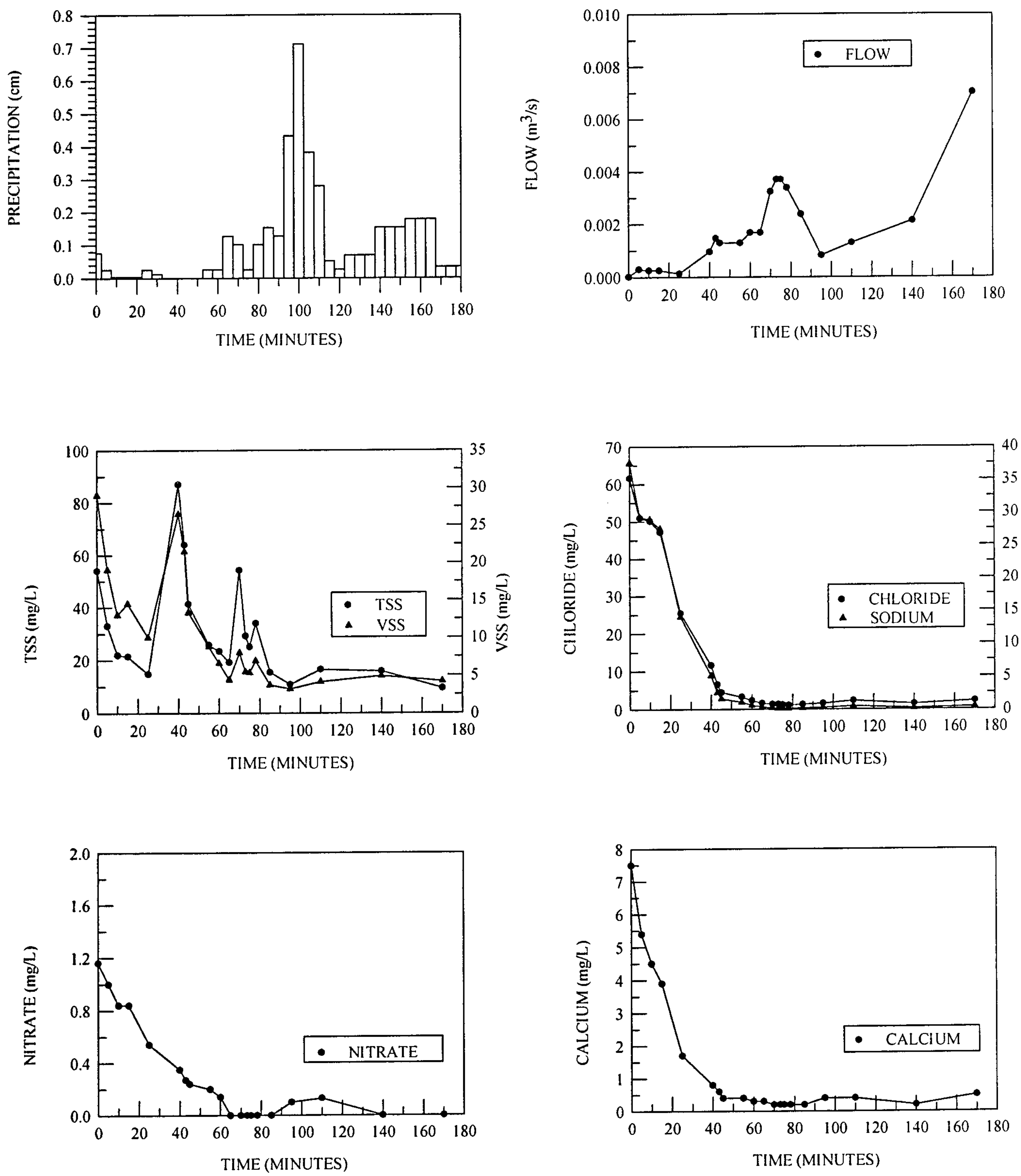
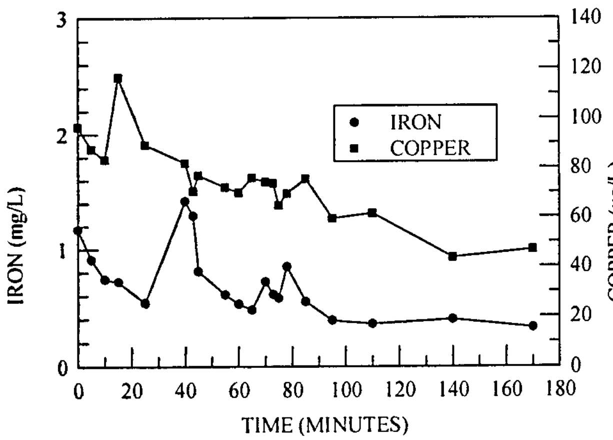
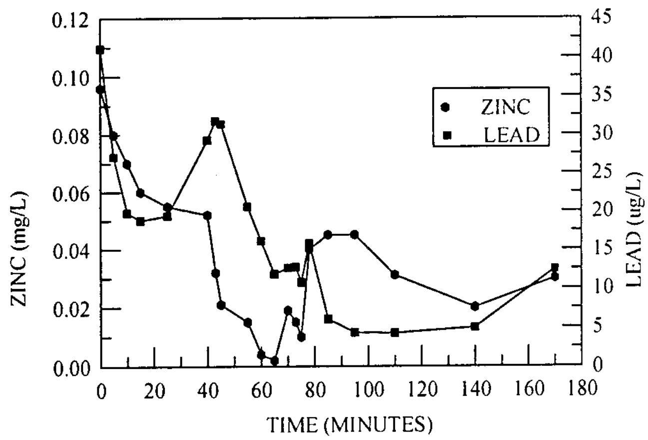
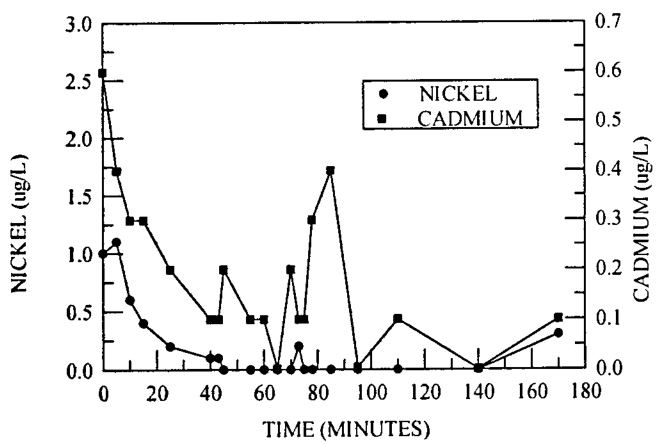
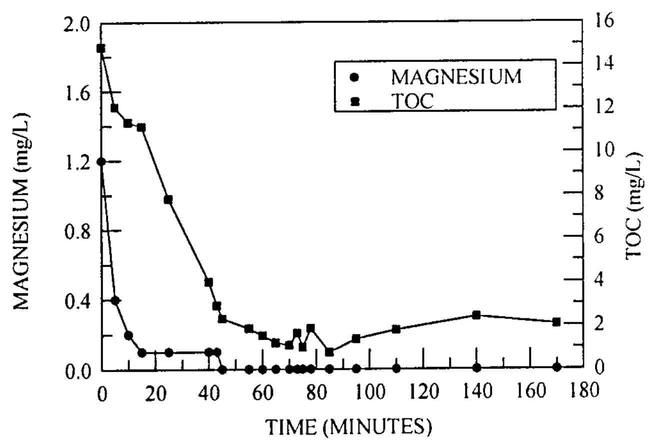


Figure A15. Storm V Collected Data - State Route 165 Sampling Site









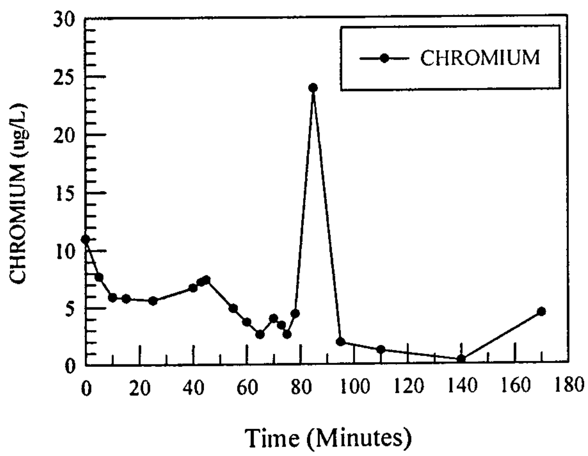


Figure A15. Storm V Collected Data - State Route 165 Sampling Site (contd.)

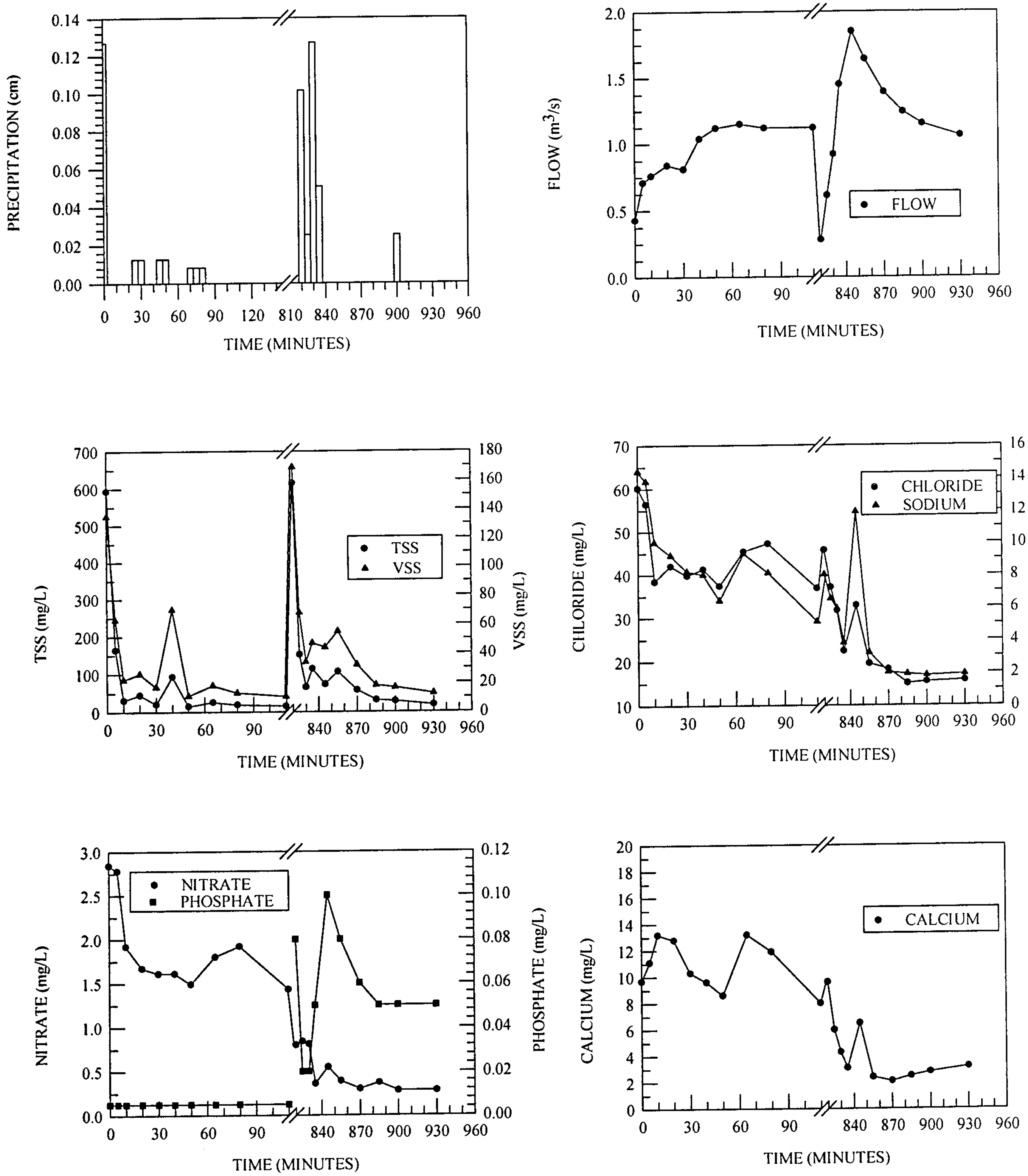


Figure A16. Storm VI Collected Data - Post Road Sampling Site

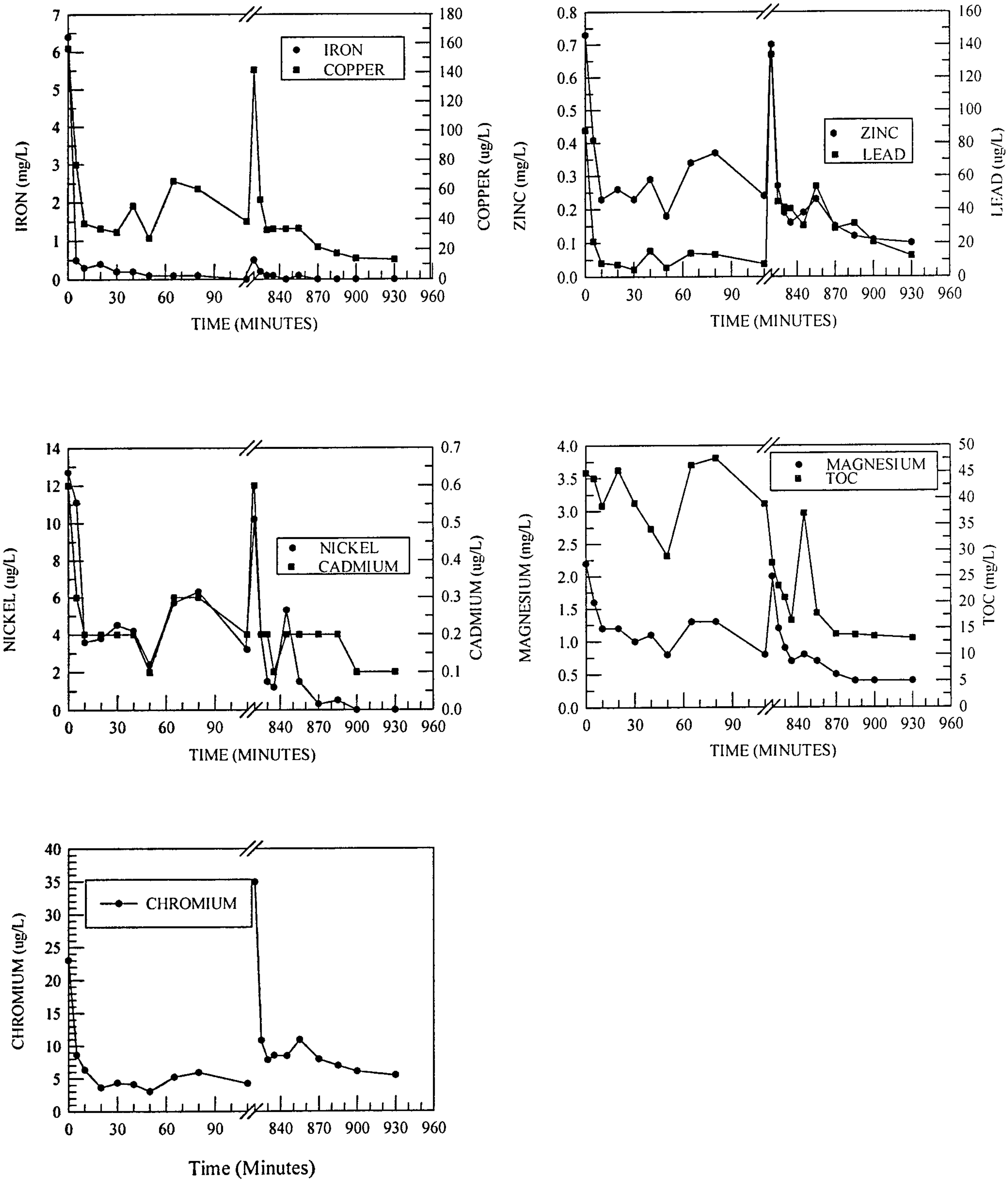


Figure A16. Storm VI Collected Data - Post Road Sampling Site (contd.)

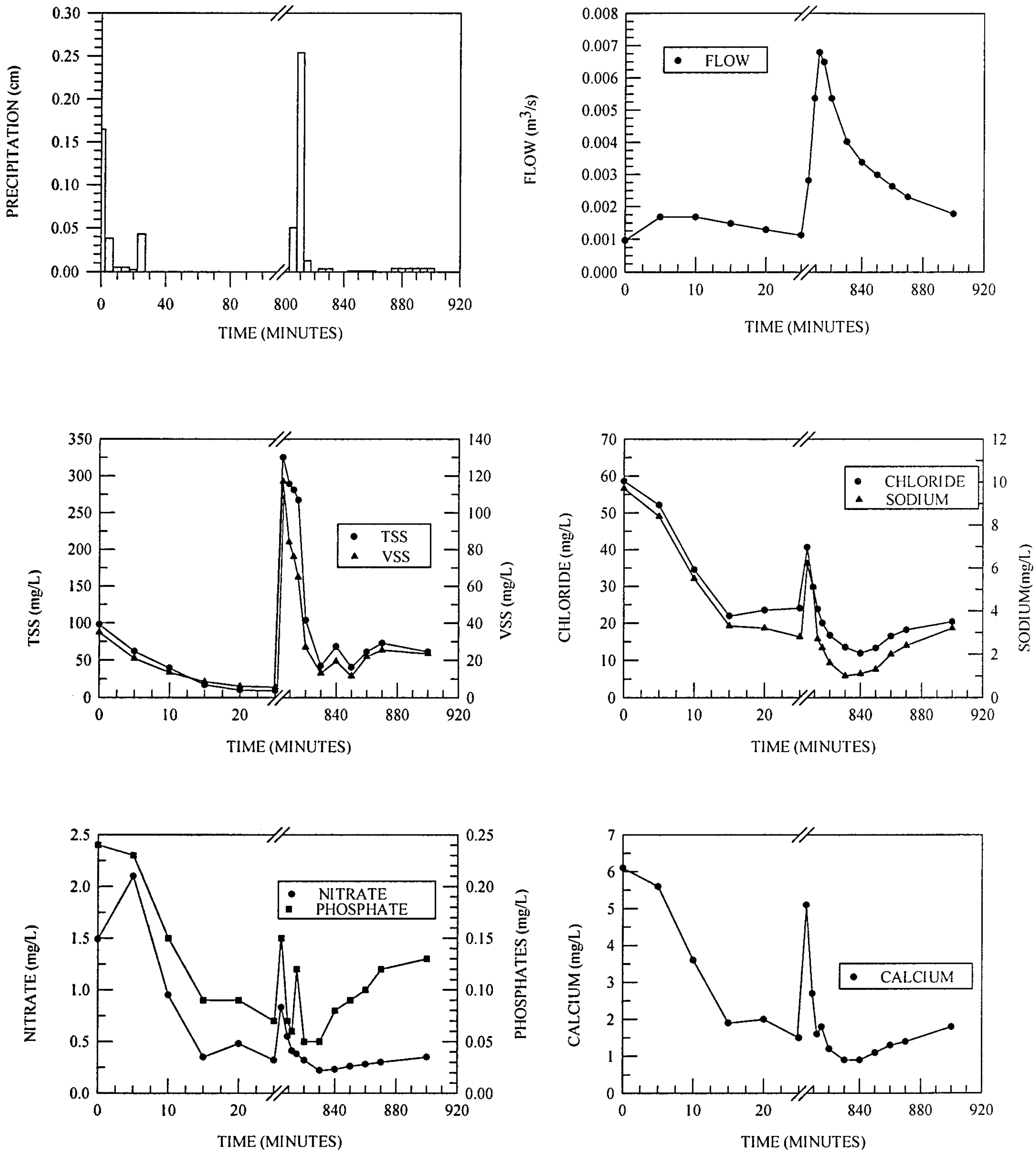


Figure A17. Storm VI Collected Data - State Route 2 Sampling Site

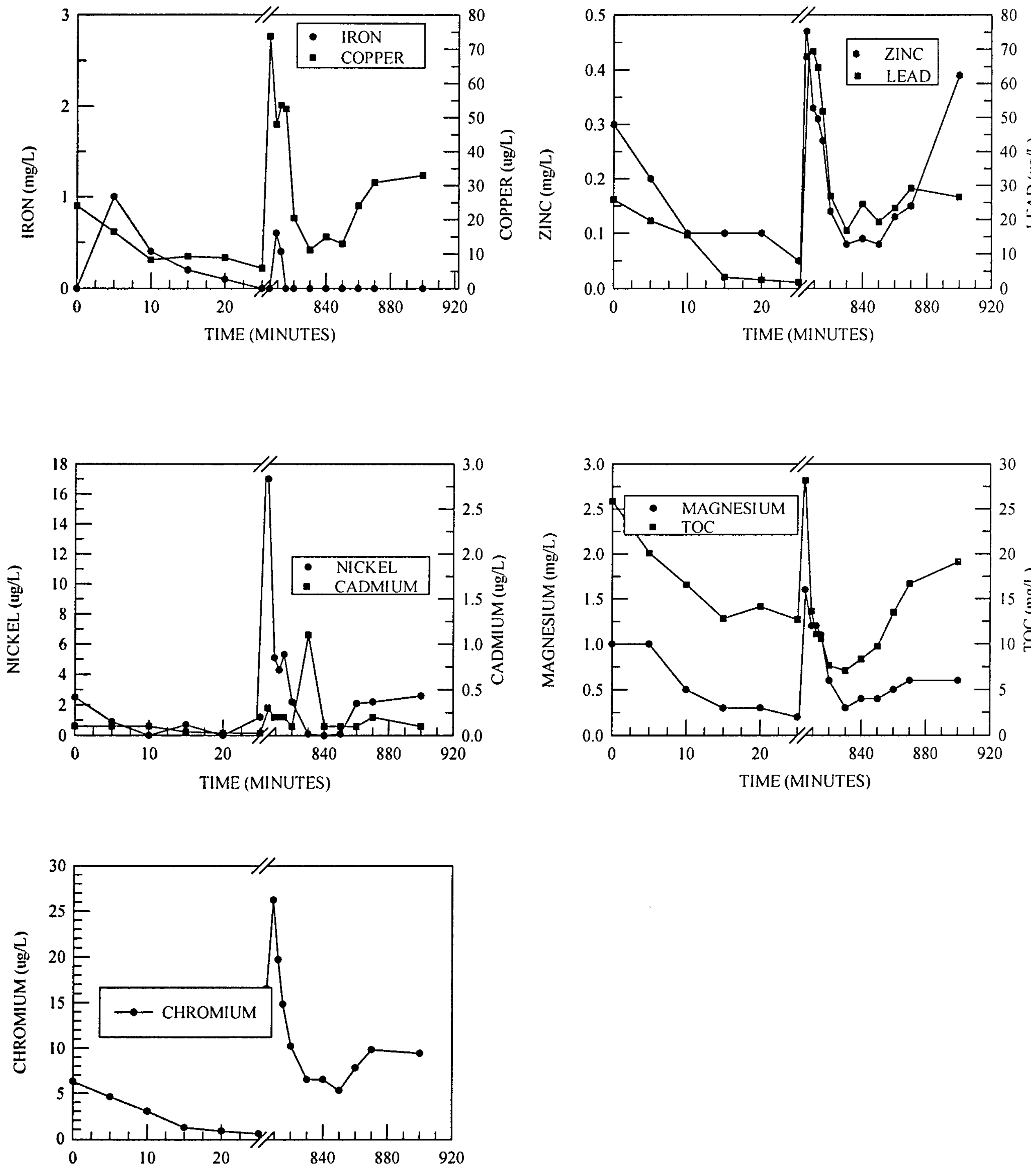


Figure A17. Storm VI Collected Data - State Route 2 Sampling Site (contd.)

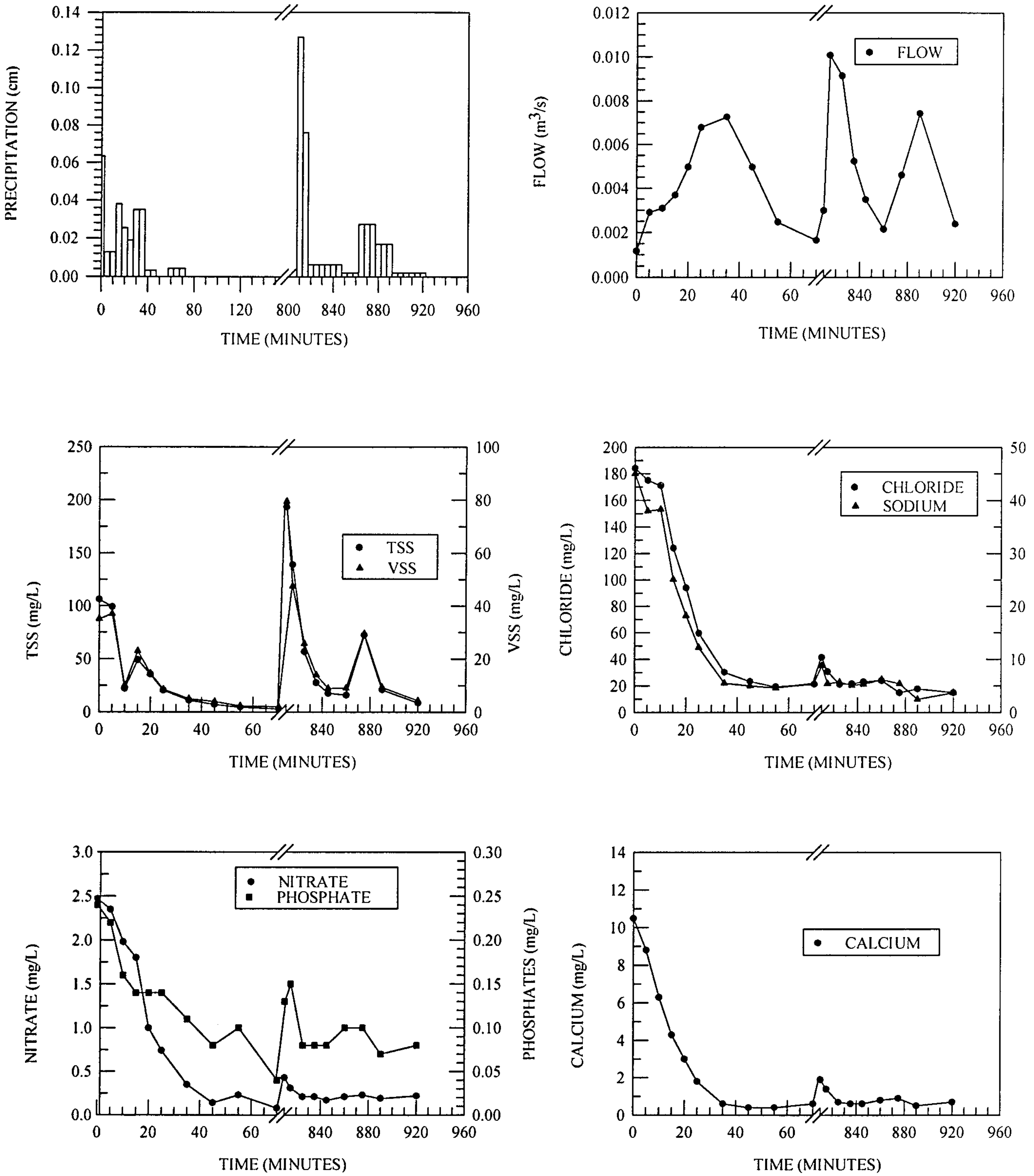


Figure A18. Storm VI Collected Data - State Route 165 Sampling Site

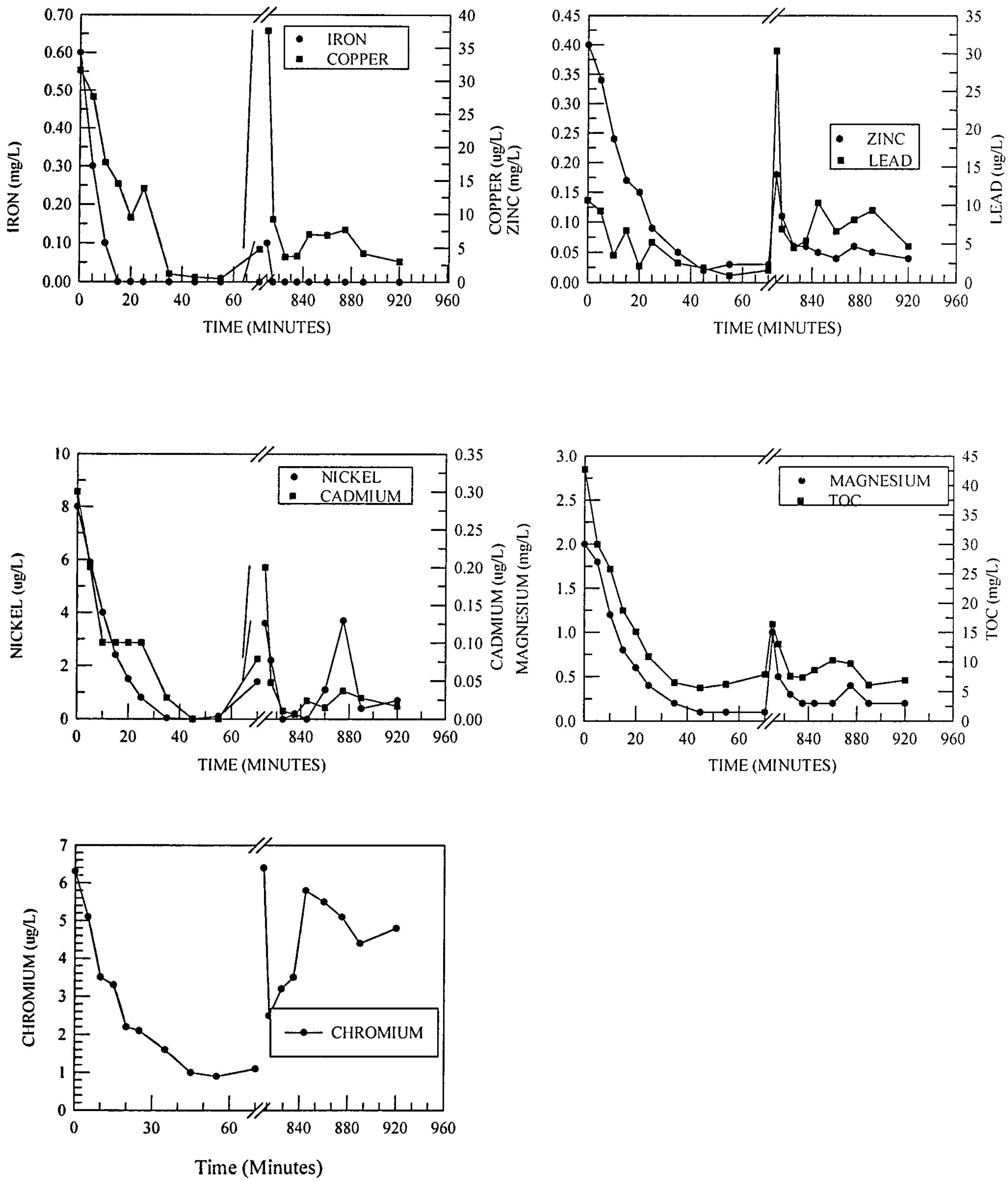


Figure A18. Storm VI Collected Data - State Route 165 Sampling Site (contd.)

Degree of Correlation Between Parameters - Average of Two Winter Storms

Table A1 Degree of Correlation between the parameters for winter season, Post Road

	TSS	VSS	Cond	Na	Cl	NO_3	PO_4	Ca	Fe	Cu	Zn	Pb	Ni	Cr	Cd	TOC	O&G
Flow	-0.11	-0.13	-0.55	-0.53	-0.48	-0.41	-0.08	-0.66	-0.01	-0.05	-0.11	0.18	-0.33	-0.04	-0.21	-0.28	-0.01
TSS	1.00	0.85	0.19	0.25	0.10	-0.03	0.35	0.17	0.57	0.56	0.46	0.35	0.30	0.72	0.22	0.16	-0.15
VSS		1.00	0.31	0.35	0.27	0.17	0.17	0.23	0.51	0.49	0.46	0.39	0.24	0.66	0.37	0.29	-0.09
Cond			1.00	0.93	0.91	0.59	-0.10	0.73	0.37	0.35	0.56	0.19	0.62	0.17	0.67	0.47	0.22

Table A2 Degree of Correlation between the parameters for winter season, State Route 165

	TSS	VSS	Cond	Na	Cl	NO_3	PO_4	Ca	Fe	Cu	Zn	Pb	Ni	Cr	Cd	TOC	O&G
Flow	-0.03	-0.23	-0.56	-0.60	-0.63	-0.74	0.32	-0.73	-0.09	-0.18	-0.35	0.15	-0.04	0.07	-0.32	-0.43	-0.23
TSS	1.00	0.93	-0.22	0.20	0.18	0.44	-0.15	0.12	0.73	0.90	0.51	0.69	0.52	0.74	0.70	0.50	0.20
VSS		1.00	-0.17	-0.13	0.28	0.58	-0.16	0.23	0.62	0.94	0.28	0.69	0.56	0.72	0.78	0.56	0.33
Cond			1.00	0.99	0.99	0.16	-0.33	0.85	-0.26	-0.27	-0.22	-0.28	-0.26	-0.27	-0.08	-0.14	-0.25

Table A3 Degree of Correlation between the parameters for winter season, State Route 2

	TSS	VSS	Cond	Na	Cl	NO_3	PO_4	Ca	Fe	Cu	Zn	Pb	Ni	Cr	Cd	TOC	O&G
Flow	0.02	-0.06	-0.39	-0.38	-0.40	-0.44	0.16	-0.47	-0.31	-0.45	-0.41	-0.08	-0.52	-0.09	-0.34	-0.56	-0.42
TSS	1.00	0.62	0.69	0.75	0.70	0.72	-0.16	0.70	0.77	0.78	0.72	0.45	0.61	0.53	0.66	0.66	0.66
VSS		1.00	0.47	0.50	0.53	0.50	-0.13	0.49	0.66	0.56	0.52	0.48	0.48	0.54	0.39	0.59	0.51
Cond			1.00	0.84	0.78	0.89	-0.08	0.87	0.75	0.86	0.82	0.56	0.80	0.61	0.70	0.99	0.22

Degree of Correlation Between Parameters - Average of Four Non-Winter Storms

Table A4 Degree of Correlation for Non-Winter Seasonal Storms, Post Road

	TSS	VSS	Cond	Na	Cl	NO_3	Ca	Mg	Fe	Cu	Zn	Pb	Ni	Cr	Cd	TOC	O&G
Flow	-0.39	-0.31	-0.45	-0.50	-0.38	-0.47	-0.64	-0.52	-0.38	-0.39	-0.41	-0.15	-0.30	-0.38	-0.27	-0.23	-0.28
TSS	1.00	0.10	0.63	0.58	0.58	0.23	0.20	0.79	0.83	0.93	0.50	0.78	0.67	0.90	0.56	0.77	0.74
VSS		1.00	0.64	0.53	0.58	0.21	0.17	0.76	0.82	0.88	0.88	0.83	0.74	0.89	0.71	0.59	0.83
Cond			1.00	0.79	0.96	0.51	0.68	0.60	0.59	0.66	0.69	0.42	0.76	0.49	0.66	0.89	0.65

Table A5 Degree of Correlation for Non-Winter Seasonal Storms, State Route 165

	TSS	VSS	Cond	Na	Cl	NO_3	Ca	Mg	Fe	Cu	Zn	Pb	Ni	Cr	Cd	TOC	O&G
Flow	-0.22	-0.24	-0.40	-0.40	-0.40	-0.32	-0.41	-0.34	-0.30	-0.24	-0.52	-0.30	-0.23	-0.06	-0.25	-0.42	-0.40
TSS	1.00	0.95	0.77	0.74	0.75	0.69	0.79	0.46	0.79	0.58	0.83	0.81	0.72	0.43	0.83	0.90	0.93
VSS		1.00	0.72	0.69	0.70	0.66	0.74	0.74	0.85	0.59	0.79	0.84	0.59	0.41	0.79	0.86	0.97
Cond			1.00	0.99	0.99	0.93	0.95	0.89	0.82	0.44	0.92	0.70	0.72	0.51	0.85	0.10	0.96

Table A6 Degree of Correlation for Non-Winter Seasonal Storms, State Route 2

	TSS	VSS	Cond	Na	Cl	NO_3	Ca	Mg	Fe	Cu	Zn	Pb	Ni	Cr	Cd	TOC	O&G
Flow	0.39	0.36	-0.43	-0.44	-0.52	-0.44	-0.49	0.01	0.24	0.09	-0.15	0.38	-0.13	0.26	0.10	0.54	-0.10
TSS	1.00	0.86	0.42	0.38	0.35	0.28	0.24	0.59	0.50	0.53	0.68	0.69	0.64	0.68	0.35	-0.54	0.72
VSS		1.00	0.36	0.31	0.30	0.21	0.25	0.50	0.66	0.53	0.61	0.77	0.56	0.65	0.24	0.32	0.93
Cond			1.00	0.98	0.94	0.94	0.92	0.67	0.26	0.46	0.83	0.35	0.68	0.49	0.38	0.91	0.94

Table A7 Mass of Constituents in First Flush and Total Mass for all of the Storms, Post Road Sampling Site

Constituent	Post Road											
	Mass In First Flush (gm)						Total Mass (gm)					
	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5	Storm 6	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5	Storm 6
Cadmium	1.44e-01	1.65e-01	3.12e-01	NFF	1.74e-01	1.08e-01	2.85e-01	2.77e-01	5.29e-01	2.44e-01	6.28e-01	2.30e-01
Calcium	1.65e+03	1.03e+03	5.79e+03	NFF	8.87e+02	4.11e+03	2.63e+03	1.54e+03	6.67e+03	1.02e+03	2.14e+03	6.83e+03
Chloride	2.48e+03	1.09e+05	3.26e+05	NFF	4.48e+02	1.62e+04	4.40e+03	1.40e+05	3.79e+05	2.95e+03	8.27e+03	3.25e+04
Chromium	1.65e+00	1.71e+01	3.06e+00	NFF	1.76e+00	2.73e+00	4.21e+00	4.85e+01	1.38e+01	4.21e+00	6.47e+00	8.48e+00
Copper	9.73e+00	2.86e+01	1.52e+01	NFF	3.30e+01	2.28e+01	2.10e+01	6.37e+01	3.72e+01	1.71e+01	1.72e+02	4.02e+01
Iron	4.22e+02	6.10e+03	1.28e+03	NFF	5.22e+02	4.35e+01	9.88e+02	1.50e+04	4.79e+03	1.41e+03	1.51e+03	7.49e+01
Lead	6.07e+00	5.11e+01	8.84e+00	NFF	1.07e+01	7.37e+00	1.75e+01	1.29e+02	3.40e+01	2.40e+01	4.04e+01	3.07e+01
Nickel	8.88e+02	3.30e+03	1.41e+03	NFF	1.99e+01	4.20e+02	2.22e+03	5.13e+03	3.86e+03	9.18e+01	1.29e+02	8.93e+02
Nitrate	2.12e+00	1.42e+01	5.69e+00	NFF	8.76e-01	2.09e+00	3.92e+00	2.21e+01	2.39e+01	4.89e+00	1.52e+00	3.02e+00
Oil & Grease	4.61e+02	4.85e+02	2.56e+02	NFF	1.53e+02	7.01e+02	6.42e+02	7.37e+02	6.21e+02	4.29e+02	4.38e+02	9.68e+02
Sodium	1.64e+03	6.00e+04	3.16e+05	NFF	8.07e+02	2.92e+03	2.57e+03	7.18e+04	3.74e+05	1.68e+03	2.17e+03	5.97e+03
TOC	6.14e+03	7.28e+03	1.38e+04	NFF	3.01e+03	3.19e+03	9.94e+03	1.32e+04	1.86e+04	3.97e+03	7.92e+03	1.02e+04
TSS	8.24e+03	1.94e+05	2.98e+04	NFF	2.87e+04	1.03e+04	2.13e+04	7.39e+05	1.45e+05	9.86e+04	9.31e+04	6.90e+04
VSS	5.78e+03	4.44e+04	9.79e+03	NFF	8.36e+03	7.14e+03	1.35e+04	1.32e+05	3.52e+04	3.16e+04	2.65e+04	3.52e+04
Zinc	5.45e+01	2.65e+02	1.46e+02	NFF	3.30e+01	1.11e+02	1.06e+02	5.06e+02	2.96e+02	1.06e+02	1.23e+02	2.48e+02

NFF No First Flush

Table A8 Mass of Constituents in First Flush and Total Mass for all of the Storms, State Route 2 Sampling Site

Constituent	State Route 2											
	Mass In First Flush (gm)						Total Mass (gm)					
	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5	Storm 6	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5	Storm 6
Cadmium	8.68e-03	2.38e-02	7.32e-02	3.38e-03	2.14e-02	9.02e-04	1.15e-02	4.66e-02	8.65e-02	1.64e-02	4.65e-02	1.64e-02
Calcium	5.44e+01	4.44e+01	2.73e+02	1.96e+01	6.32e+01	3.26e+01	7.89e+01	9.03e+01	3.39e+02	1.92e+02	3.75e+02	1.12e+02
Chloride	2.61e+02	1.37e+04	1.72e+05	6.58e+01	2.32e+02	3.43e+02	3.30e+02	1.70e+04	1.95e+05	5.48e+02	8.23e+02	1.33e+03
Chromium	9.38e-02	3.26e+00	7.37e-01	1.72e-01	1.34e-01	4.02e-02	2.45e-01	6.97e+00	3.56e+00	5.02e-01	5.98e-01	6.07e-01
Copper	3.36e-01	3.62e+00	1.30e+00	2.51e-01	3.28e+00	1.94e-01	8.44e-01	8.96e+00	4.12e+00	3.39e+00	1.88e+01	1.72e+00
Iron	3.81e+01	6.87e+02	1.98e+02	5.99e+01	1.34e+01	2.17e+00	1.08e+02	2.01e+03	8.44e+02	3.62e+02	2.63e+02	5.00e+00
Lead	1.82e+00	7.89e+00	1.99e+00	4.70e-01	4.99e-01	1.66e-01	1.99e+00	2.02e+01	9.14e+00	1.66e+00	3.91e+00	1.90e+00
Nickel	5.54e+01	5.49e+01	1.84e+02	6.32e+00	5.10e-01	6.17e+00	9.75e+01	1.62e+02	5.88e+02	1.77e+01	1.54e+00	4.10e+01
Nitrate	8.89e-02	6.34e-01	6.61e-01	2.29e-01	1.35e-01	5.15e-02	2.47e-01	1.90e+00	2.66e+00	1.02e+00	3.29e-01	1.55e-01
Oil & Grease	3.19e+01	4.16e+01	3.02e+01	8.99e+00	1.80e+01	7.97e+00	3.61e+01	5.31e+01	7.41e+01	7.80e+01	5.09e+01	2.56e+01
Sodium	1.08e+02	6.79e+03	1.69e+05	3.71e+01	8.17e+01	4.99e+01	1.28e+02	8.03e+03	1.80e+05	2.43e+02	2.03e+02	1.67e+02
TOC	2.19e+02	5.80e+02	3.75e+02	7.75e+01	2.05e+02	1.84e+02	4.02e+02	1.57e+03	1.34e+03	8.04e+02	7.57e+02	8.47e+02
TSS	3.13e+03	1.52e+04	6.73e+03	2.07e+03	1.10e+03	6.97e+02	5.04e+03	6.70e+04	2.86e+04	9.79e+03	9.62e+03	6.69e+03
VSS	7.99e+02	3.15e+03	1.46e+03	4.17e+02	3.03e+02	2.64e+02	1.28e+03	1.19e+04	5.45e+03	3.07e+03	2.34e+03	2.02e+03
Zinc	2.95e+00	1.90e+01	1.13e+01	2.08e+00	2.90e+00	1.66e+00	6.13e+00	5.55e+01	2.77e+01	1.10e+01	1.31e+01	1.17e+01

Table A9 Mass of Constituents in First Flush and Total Mass for all of the Storms, State Route 165 Sampling Site

Constituent	State Route 165											
	Mass In First Flush (gm)						Total Mass (gm)					
	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5	Storm 6	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5	Storm 6
Cadmium	1.19e-02	9.34e-03	4.18e-03	3.81e-03	4.33e-03	8.31e-04	1.43e-02	2.17e-02	6.77e-03	7.48e-03	2.80e-02	2.08e-03
Calcium	2.20e+01	1.63e+03	9.81e+02	4.38e+01	3.22e+01	2.74e+01	4.46e+01	2.18e+03	1.08e+03	8.11e+01	1.16e+02	6.11e+01
Chloride	2.37e+02	2.48e+04	5.98e+04	4.03e+02	3.02e+02	7.68e+02	3.31e+02	3.30e+04	6.87e+04	5.87e+02	7.59e+02	1.80e+03
Chromium	3.18e-01	6.05e+00	6.98e-01	7.92e-02	1.09e-01	2.27e-02	3.95e-01	1.45e+01	4.00e+00	1.81e-01	1.17e+00	2.00e-01
Copper	3.75e-01	2.34e+00	5.46e-01	5.24e+00	3.00e+00	1.06e-01	4.51e-01	6.34e+00	2.80e+00	1.36e+01	1.49e+01	3.45e-01
Iron	7.86e+00	9.22e+02	2.84e+02	2.33e+01	3.10e+01	3.81e-01	9.21e+00	3.67e+03	1.38e+03	3.74e+01	1.27e+02	7.47e-01
Lead	7.44e-01	1.31e+01	1.71e+00	3.64e-01	8.25e-01	3.97e-02	8.47e-01	2.88e+01	1.07e+01	5.68e-01	3.18e+00	3.45e-01
Nickel	6.14e+01	2.74e+01	6.95e+00	8.12e-01	2.20e+00	5.64e+00	6.48e+01	5.52e+01	1.57e+01	1.97e+00	3.41e+00	1.76e+01
Nitrate	8.20e-02	8.31e-01	2.98e-01	1.43e-01	3.35e-03	1.53e-02	1.18e-01	2.56e+00	3.71e+00	3.00e-01	4.60e-02	5.24e-02
Oil & Grease	2.04e+01	2.46e+01	2.55e+01	1.40e+01	1.02e+01	9.55e+00	2.26e+01	3.86e+01	4.49e+01	3.05e+01	1.42e+01	2.00e+01
Sodium	1.26e+02	1.40e+04	5.47e+04	2.02e+02	1.52e+02	1.83e+02	1.63e+02	1.80e+04	5.92e+04	3.07e+02	2.34e+02	3.88e+02
TOC	1.81e+02	1.60e+02	2.09e+02	1.20e+02	1.26e+02	1.31e+02	3.32e+02	6.20e+02	5.53e+02	2.39e+02	5.43e+02	5.12e+02
TSS	2.03e+03	4.47e+04	1.04e+04	1.04e+03	1.95e+03	4.36e+02	2.35e+03	1.24e+05	3.90e+04	1.52e+03	5.19e+03	2.01e+03
VSS	5.74e+02	5.43e+03	1.20e+03	2.72e+02	5.20e+02	1.88e+02	6.78e+02	1.16e+04	5.20e+03	4.47e+02	1.58e+03	8.48e+02
Zinc	1.70e+00	9.83e+00	3.93e+00	9.30e-01	8.69e-01	1.21e+00	2.61e+00	4.96e+01	1.62e+01	1.37e+00	7.22e+00	3.82e+00