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I am submitting herewith a thesis written by William H. Johnson entitled "An Urban Stormwater Quality Model Developed for Third and Fourth Creeks, Knoxville, Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Engineering, with a major in Environmental Engineering.

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AN URBAN STORMWATER QUALITY MODEL DEVELOPED FOR THIRD AND FOURTH CREEKS, KNOXVILLE, TENNESSEE

A Thesis

Presented for the

Master of Engineering

Degree

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DEDICATION

The author wishes to dedicate his thesis to Ms. Rebecca Ann Johnson whose encouragement was appreciated.

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ABSTRACT

A linear model was used to compare the pollutant loads from two Knoxville watersheds resulting from two separate and isolated storm events on each basin with data taken from another urban watershed and several stripmined watersheds. The linear model was developed from work done at The University of Tennessee, Knoxville. The pollutants studied were Fe, Mn, Pb, Zn, Mg, Cd, COD, TOC, and SS. It was found that the age and development of a watershed affects the pollutant load on a watershed. It was also found that changes in the sources of pollutants can be related to changes in pollutant loads on a watershed.

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CHAPTER I

INTRODUCTION

Urban Water Quality

At this time, less than 5 percent of land area in the United States is metropolitan, but it includes 65 percent of the population [2]. Urban areas have a significant environmental impact. Ninety-four to 95 percent of the BOD load for streams is directly attributed to urban runoff during storms [19]. Toxic pollutants in urban runoff have high concentrations with a moderate-size city discharging between 100,000 and 250,000 pounds of lead each year through storm runoff [19]. Pollutants in urban runoff can be attributed to the land surface, catch basins, and combined system sewers.

Urban nonpoint source pollutant modeling is relatively new. Most models deal with stormwater quantity and not quality. Stormwater quality modeling is now evolving rapidly with emphasis being placed on nonpoint sources.

Federal Requirements

The Federal Water Pollution Control Act of 1972 [25] has had an impact upon the way people use the nation's water resources. The authors of this bill realized that a comprehensive and integrated planning approach would be required to deal with water quality problems. Pisano [19] states:

> Section 208 plans are intended to address actual problems. With the limited time and resource available, it is important that each agency focus on elements it can realistically implement--solutions that will greatly improve water quality.

Some of the planning elements of Section 208 as listed by Pisano [19] are:

1. Description of planning area.
2. Assessment of existing and potential water quality problems.
3. Assessment of water quality problems caused by non-point sources' pollutants.
4. Needs for urban and industrial stormwater systems.
5. Target abatement schedules for pollutant sources.
6. Assessment of environmental, social, and economic impact of carrying out the plan.

Pisano [19] states that the most important results of the 208 program are identification of existing and potential problems, identification of causes of these problems and establishment of strategies to be implemented to eliminate these causes of water quality problems.

The 208 study must evaluate the pollution potential of both point and nonpoint sources. The nonpoint pollutional sources are the most difficult for the researcher to model. Nonpoint pollutional sources can be defined as sources which are not concentrated at distinct points, are diffuse and cannot be monitored at a point of origin.

Project Objectives

This investigation was implemented as part of an ongoing study at The University of Tennessee, Knoxville to regionalize a mathematical model of stormwater runoff which can be used for predicting changes in streamflow quantity and quality as a function of land use and rainfall characteristics. The project attempts to develop a model which is a function of land use and hydrologic response characteristics.

Study Objectives

This study had three objectives:

1. To characterize the effect of urbanization on water quality by analyzing stormwater quality from work done by Barkdoll [2] and Brown [6].

2. To determine the source for certain water quality constituents; Iron (Fe), Manganese (Mn), Lead (Pb), Zinc (Zn), Magnesium (Ms) and Cadmium (Cd).

3. To compare the water quality constituents; Total Organic Carbon (TOC), Carbonaceous Oxygen Demand (COD), Suspended Solids (SS), Total Solids (TS), Zn, Pb, Mn, Fe and Cd for two Knoxville urban basins with water quality constituents of an urban basin of a different region and of several nonurban strip-mined basins.

CHAPTER II

LITERATURE REVIEW

One of the first studies examining the impact of urban storm-water as a pollutant was done by Sartor et al. [21]. The objectives of their study were:

1. Determine the amounts and types of material that commonly collect on street surfaces.

2. Determine the effectiveness of conventional public works practices in preventing these materials from polluting receiving waters.

3. Evaluate the significance of this source of water pollution.

Their study stated that street-surface contaminants were defined as being those materials which are found on street surfaces and which are capable of being washed off during average rain storms. This definition eliminates sidewalks, yards, driveways, parking lots and building roofs. Therefore, the quality of water entering the storm sewer was only partly a function of street contaminants.

One of the conclusions they reached was that a great portion of the overall pollution potential is associated with the fine solids fraction of the street surface contaminants. It was also indicated that significant amounts of heavy metals (primarily Zn and Pb) were detected in the contaminated materials collected from the street faces.

Sartor et al. [21] concluded that the very fine silt-like material accounted for only 5.9 percent of the total solids, but this

fine material accounted for over half of the heavy metals. Work done by Perhac [18] shows that metals are carried with particulates. Wilber and Hunter [28] have also monitored heavy metals from two heavily urbanized watersheds at Lodi, New Jersey. The heavy metals found in quantity were lead, zinc and copper. Wilber and Hunter [29] showed most of the lead and zinc at Lodi were associated with particulates. Betson and McMaster [5] developed a first generation nonpoint source mineral water model. To them geology and climate were considered the two needed independent variables which should be considered in developing a nonpoint source water quality model. Other variables influencing water quality such as soils, vegetation and, to some degree, human activities were considered the result of the interaction of geology and climate.

Betson's model was developed from rating curves developed by Walling [26] which have the form:

$$\text{Load} = a^1 Q^{b+1}$$

where Q = stream flow, cubic feet/second (Cfs) or cubic meters/minute (m^3/min)

Load = constituent transport lb/day or kilograms/day (kg/day)

a^1 and b = coefficients

Campbell and Caddie [7] divided discharge by drainage area to get a steady state rating curve as follows:

$$\text{CONC} = a \frac{Qb}{DA}$$

DA = drainage area

CONC = Concentration

Betson and McMaster [5] state that the two coefficients a and b can be determined at any location where any concurrent constituent concentration and streamflow discharge data are available. The coefficients can be determined by log transforming the equation and using linear regression. The two other equations used in the regression analysis were:

$$a = N_1F + N_2C + N_3S + N_4I + N_5U$$

$$b = N_1F + N_2C + N_3S + N_4I + N_5U$$

where

a,b = coefficients in the equation

$N_1 - N_5$ = regression coefficients

F = fraction of the watershed that is forested

C = drainage area fraction over carbonate rock

S = drainage area fraction over igneous rock

U = drainage area fraction over unconsolidated rock

Two of the requirements of this model were that no known significant point pollution sources are allowed within the watershed and that a minimum of 10 samples with concurrent flow values are required.

The model developed could use any flow rate depending on the data collected. The average prediction error for the model stayed within $\pm$30 percent for most of the constituents and was only above 60 percent for two mineral constituents which would indicate a usable model. Sartor et al. [21] also developed the following model for water quality

$$Nc = No\ (1 - e^{-krt})$$

where

No = initial weight of material of a given particle size, grams (gr)

t = time of rainfall, minutes (min)

r = rainfall intensity, inches per hour (in/hr)

Nc = weight of material of a given particle size removed after time = t (min)

k = coefficient depending on street surface characteristics

This model was used to simulate the amount of pollutants removed from street surfaces during a rainfall event. Sartor et al. [21] indicated that the type of street surface determined the amount of pollutants accumulated.

Sartor et al. [21] also used the following mathematical relationship to determine the effectiveness of the removal of dust and dirt fractions by street sweepers:

$$M = M^* + (Mo - M^*)e^{-kE}$$

M = the amount of street surface contaminants remaining after sweeping (lb)

Mo = the initial amount of contaminants (lb)

E = the amount of sweeping effort involved in equipment, min/1,000 sq ft

M* and k = dimensionless empirical constants dependent on sweeper characteristics, particle size of contaminants and street surface

Their study showed that many pollutants were contained on roads and that most methods of removal were not completely effective. The fact that they did not measure the amount of pollutants on the road at any time prevented them from being able to determine the fraction of removal for any storm event.

Colston [8] did a study on Third Fork Creek, an urban watershed in Durham, North Carolina. The pollutants he examined were the following: COD, TOC, Biological Oxygen Demand (BOD), Total Kieldahl Nitrogen, NH_4N, NO_2-NO_3 , Total Phosphorous, TS, Volatile Solids (VS), (SS), Volatile Suspended Solids (VSS), Cobalt (CO), Chromium (CR), Copper (Cu), Fe, Mn, Nickel (Ni), Pb, Zn, Calcium (Ca), Mg, Aluminum (Al), Alkalinity and Fecal coliforms

Colston [8] developed regression equations which originally included four variables: rate of runoff, elapsed time from start of storm, elapsed time from last storm and elapsed time from last peak. Colston [8] determined that the rate of discharge and the time from storm start were the most significant variables. With the equation changed to reflect this fact, he was able to fit the data to the model with a correlation coefficient R^2 having a range of 0.72 to 0.94. With the resulting equations, Colston predicted the annual pollutant yields for 1972 on the basin.

Barkdoll et al. [3] did a study of the effect of dustfall on the Third Creek watershed in Knoxville, Tennessee. His first model was a deterministic model or system stimulation in the form:

$$C = \frac{DN}{Vol} \tag{1}$$

where

C = average concentration of constituents within a storm hydrograph

D = dustfall rate (weight/unit time)

N = time since last storm; that is antecedent dry period

Vol = runoff volume

The assumptions used were:

1. Removal of contaminants by runoff is 100 percent efficient.

2. No carry-over of effect from storm to storm; that is, each storm is an isolated event.

3. All dustfall becomes a water contaminant.

4. Dustfall is the only source of water quality impairment.

5. Dustfall jars are a true measure of dustfall.

This model presented some interesting results, in the comparison of the ratio of predicted concentrations to concentrations of observed values. The ratio, k, was assumed to be predicted with a confidence of ±0.2. If the ratio is less than 0.8 as is the case for Fe, Mg and Mn, it may be assumed that there are more sources for these materials than just dustfall. If the ratio is 1.0±0.2, then it may be assumed that dustfall is the major source of this contaminant. If the ratio is >1.2 as is the case for total dissolved solids (TDS) then it is assumed that there are sinks (removal points) for this type of pollutant.

The second type of model that was used by Barkdoll et al. [3] was a variation of the model developed by Sartor et al. [21] and is presented as follows:

$$C = \frac{Mt}{RO}\left(1 - e^{-RO/RO_c}\right) \qquad (2)$$

where

C = average concentration of pollutant during stormwater runoff

Mt = the total mass of contaminant material within a watershed that could be removed by runoff

RO = volume of runnoff

RO_c = that amount of runoff which produced 63.2 percent removal of accumulated contaminants

e = 2.718 base of natural logarithms

The model was then multiplied by RO to obtain the form

$$C \cdot RO = Mt\ (1 - e^{-RO/RO_c}) \qquad (3)$$

where

C · RO mass loadings for a given storm

Next a nonlinear least squares program was used to optimize Mt and RO_c with respect to stream flow and water quality data. The assumptions of this model are:

1. Removal follows at an exponential rate.
2. Concentration of a constituent is caused entirely by runoff.
3. Accumulation of a constituent is a constant.
4. Each storm is an isolated event with respect to all other storms.

The correlation coefficients for this parametric model range from 0.67 to 0.91 indicating that for most contaminants the model fits the data well.

Barkdoll et al. [3] also show a comparison of his parametric model with that of a street surface model. From Table 1 it can be seen that the street surface model gives most values which are less

than Barkdoll's model. The street surface models tend to be more conservative and indicate that street surface loads only produce about 45 percent of the total pollutant loads for urban stormwater runoff.

Table 1. Mass of Pollutant Available for Removal by Runoff for Street Surface Model and for Parametric Model [3].

Pollutant	Parametric Model (kg)	Street Surface Model (kg)
SS	520,000	19,611
COD	11,677	1,354
PO_4	27.5	9.4
Pb	43.2	13.6
Hg	0.05	1.6

Brown [6] worked on two models developed by Barkdoll [2]. He investigated both the deterministic and parametric models previously shown. From Brown's [6] work, the coefficients of determination developed for the deterministic model were low. This would indicate that this model did not adequately fit the data, and was therefore a poor model. The coefficients of determination for the parametric model were high. High coefficients indicate that the model fits the data relatively well and could be used to get reliable results from which predictions for watersheds could be made.

Use of Nonpoint Source Water Quality Models

According to Frankell [11], the intent of Section 208 of the Water Pollution Control Act Amendments, 1972, is to define areas of substantial water quality problems due to urban-industrial concentrations for local planning and management.

Some of the specific criteria for area and agency designation include:

1. Preference for areas with urban-industrial concentrations.
2. Areas with substantial water quality problems.

Land use and nonpoint source pollutants come under a comprehensive program for management of water qualities. In order to fulfill the intent of Section 208, models which determine the effects of nonpoint sources must be made.

CHAPTER III

METHOD AND PROCEDURE

Study Area Description

Two watersheds in Knoxville, Tennessee were examined in this study--Third and Fourth Creeks. Both watersheds are well urbanized, but have different land use characteristics. The land use patterns were stable during this study (Table 2).

Table 2. Study Area Description

Watershed	Drainage Area Km^2	mil^2	Impervious %	Primary Land Use
Fourth Creek	2.12	.82	45	Commercial
Third Creek	4.14	1.6	28	Industrial-Residential

Third Creek

The Third Creek watershed which is shown in Figure 1 is an older urban area. Approximately 14 percent of this watershed's land area is developed for industrial activities. Of prime importance in the area are trucking depots, a plastic molding plant, a veneer mill, a marble mill, an iron foundry and a linen service. The industries are located adjacent to the main storm channels or adjacent to one of the minor channels. The residential section accounts for nearly 71 percent of the study land area, with most of the older houses in this area using coal for heating. The houses in the area are



Figure 1. Map of Third Creek Watershed.

connected to sanitary sewers. The length of the main channel is 8,800 feet with 6,400 feet of contributing channels. The slope of the main channel is approximately 2.3 percent and the maximum elevation drop is 300 feet. There are over 22 miles of road in the study area. There are no major highways through the study area, although it is at the junction of two major interstate highways and there is one secondary highway through the study area 7,000 feet long.

The geology of the watershed has been well documented by the Tennessee Division of Geology [12]. The Knox Group which consists of dolomite, magnesium limestone and limestone crosses the watershed. The underlying strata is Maynardville limestone which contains limestone, magnesium limestone and dolomite; Maryville limestone which contains limestone and magnesium limestone; and Rogersville shale which contains argillaceous and calcareous shale. The Tennessee Division of Geology [12] has tested Knox dolomite. The analysis is:

$MgCO_3$ to range from 5.7 - 33.6 percent

Silica to range from 3.0 - 13.4 percent

The Maynardville limestone is a magnesium limestone with an analysis by the Tennessee Division of Geology of:

$MgCO_3$ of about 10 percent

Silica content of less than 4 percent

This limestone is less siliceous than that of the Knox group. From the Tennessee Division of Geology [12] an analysis of the limestone in the area yields the following:

$CaCO_3$ 97.76 percent

$MgCO_3$ 1.20 percent

Iron and alumina .44 percent

Phosphorus .034 percent

By analyzing the area minerals, a better understanding of the pollutant sources can be obtained. The Copper Ridge dolomite formation, which is the youngest Cambrian formation in eastern Tennessee, runs along the southern boundary of the watershed. At this formation's outcrops, it contains residual clay, sandstone and chert, stained yellow-red and black by iron and manganese oxides. There is also considerable marble found in the area with the following analysis performed on the marbe cut at mills in Knox County:

Calcium Carbonate 95 percent

Silica 1 percent

Iron oxide .2 to .5 percent

The Knox Group also contains the Mascot formation which contains most of the zinc deposits. Zinc has been found in this formation as far west as Love's Creek. Because the Knox Group is in the basin, zinc may be a natural basin element.

The study area is in a karst region which by definition means the terrain has drainage and relief characteristics associated with relatively high rock solubilities. This would indicate that the area has ground cavities which would allow water losses in places other than the main test stream. The flow is not lost to ground caverns. The basin is underlain with shale which the underground water flows along until it gets to the end of the basin and surfaces again.

On the watershed, the upper reaches consist of shopping center sewers and storm sewers. These flow into open channel drainage

with a drop in elevation of 160 feet in the study area from the outer area of the watershed to where the samples were taken.

Fourth Creek

Fourth Creek basin, shown in Figure 2, is quite different from Third Creek. Fourth Creek exhibits the usual traits of a karst watershed. In a study by Betson [4], the average water runoff losses for Fourth Creek were about 50 percent. This 50 percent loss is due to ground loss to underground caverns such as found in karst regions.

Fourth Creek basin overlays the Holston, Lenoir, Mascot and Copper Ridge geologic formations. According to the Tennessee Division of Geology [12], the Holston formation consists of dense, coarsely crystalline limestone also called Tennessee marble which ranges from pink to grayish-red and reddish-brown. The beds are abundantly fossiliferous in a calcarenite matrix. The Lenoir formation is a medium-gray fossiliferous limestone. There are a few beds of yellowish-gray or mottled-gray dolomite in the formation, and clay and silt are concentrated along the irregular bedding planes. The Mascot formation contains very finely crystalline gray dolomite. Twenty-five percent of the formation consists of gray and grayish-red stromatolites, with light-colored cherts. This formation contains rich zinc ores. The Copper Ridge formation also on Fourth Creek has been described for Third Creek. It also contains zinc. Because both formations contain zinc and are on the Fourth Creek basin, it can be assumed that they are sources of zinc on the basin.

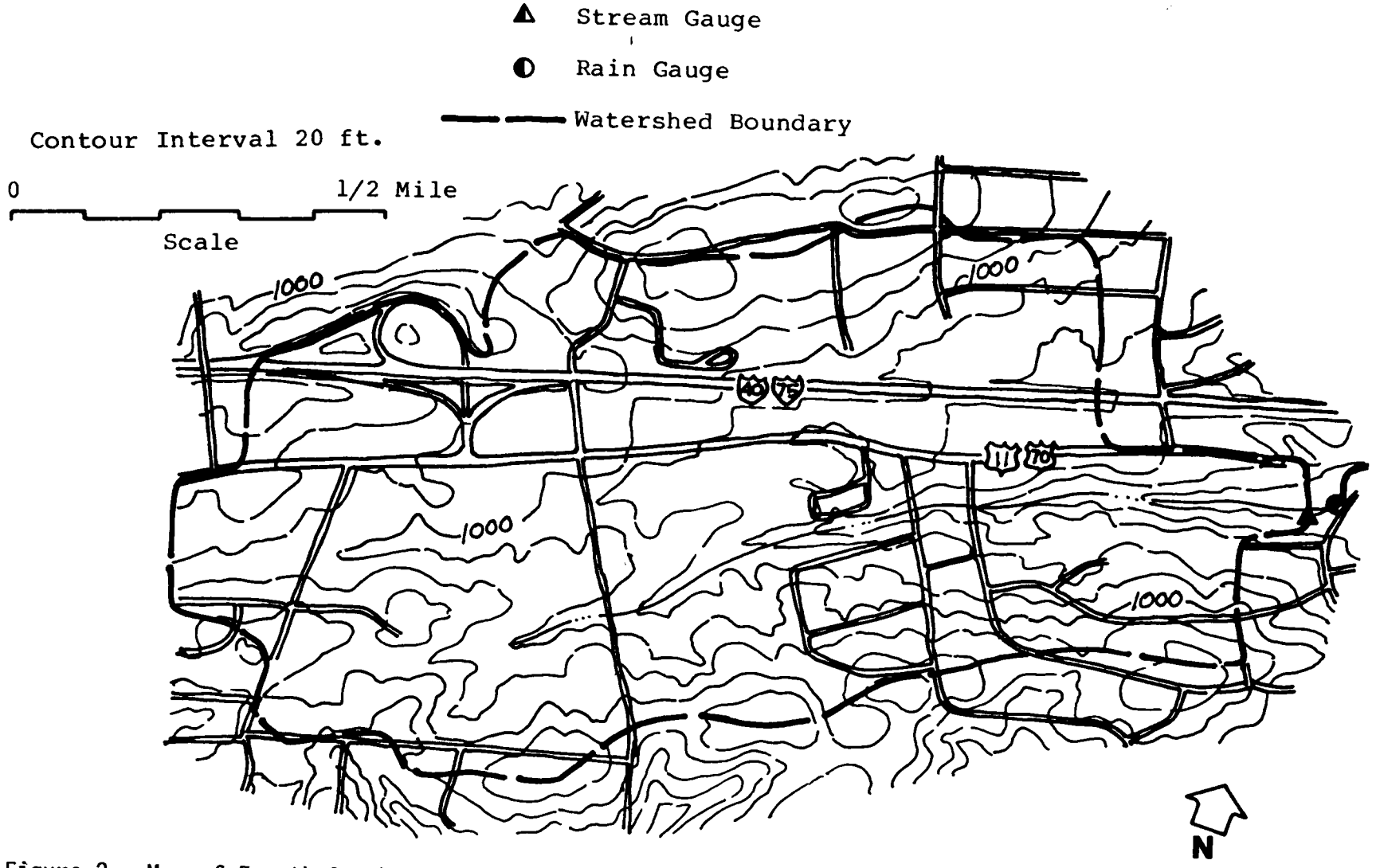


Figure 2. Map of Fourth Creek Watershed.

Data Acquisition

The data were collected during two storms which occurred in November and December 1977.

Sampling procedure, equipment and supplies. The sampling equipment and supplies consisted of the following:

1. 4 oz. polyethylene bottles
2. 800 ml. polyethylene bottles
3. Concentrated sulfuric acid
4. Concentrated nitric acid
5. Concentrated hydrochloric acid
6. Flashlight
7. Watch
8. Recording streamflow gauges placed on Third and Fourth Creeks in 1971 by TVA
9. Ruler

Four samples were taken on each watershed at 15- or 30-minute intervals. Three of the four samples were immediately acidified with their respective acids, which were hydrochloric, sulfuric and nitric acides. One sample was not acidified. Instantaneous depth of flow was taken from TVA streamflow charts and obtained manually by use of a ruler to check the calibration of the TVA charts.

Methods for Sample Analysis

1. The instantaneous depth values were converted to instantaneous streamflow by the use of rating curves developed for Third and Fourth Creeks by TVA.

2. The samples which were acidified by hydrochloric acid were analyzed for TOC on a Beckman Model 915 Total Organic Analyzer.

3. The samples acidified with sulfuric acid were analyzed for COD according to Standard Methods.

4. The nonacidified samples were used to determine TS and SS.

5. The samples which were acidified by nitric acid were analyzed for metals on a Perkin Elmer Model 403 Atomic Absorption Spectrophotometer with either graphite furnace or flame methods depending on the metal concentrations of the samples.

Data Analysis

In order to determine and compare maximum pollutant loads from a watershed, an equating system was developed with guidance from Dr. Don Overton. The load modulus, representing the ratio of pollutant to amount of runoff, was derived for this purpose. The load modulus was derived from the parametric model developed for Fourth Creek by Barkdoll [3]. Barkdoll's model is in the form

$$C = \frac{Mt}{RO} \left(1 - e^{-RO/RO_c}\right) \tag{4}$$

where

Mt = the total mass of contaminant material within a watershed that could be removed by runoff units (mass) (lbs)

C = average concentration of pollutant during stormwater runoff units (lbs/acre)

RO = volume of runoff units (vol) (acre-in)

RO_c = that amount of runoff which produced 63.2 percent removal of (acre-in) accumulated contaminants units (vol)

e = 2.718

With RO having the units (acre-in) of runoff and C having the units (lb/acre-in) then (RO) · (C) will have the units (lbs). This number would represent the total mass of the pollutant removed for any storm with runoff volume of RO.

Multiplying both sides of Barkdoll's equation by RO

$$(C)\ (RO) = Mt\ (1 - e^{-RO/RO_c}) \tag{5}$$

Let L = total load

$$\therefore L = (C)\ (RO) \tag{6}$$

$$\therefore L = M_c\ (1 - 2^{-RO/RO_c}) \tag{7}$$

Assume that for any watershed the total mass of a contaminant, which can be removed by runoff, is a constant. This assumption agrees with Barkdoll's work. Then assume that RO_c for any watershed is a constant, which also agrees with Barkdoll's work. From these assumptions and the previous equation, it can be assumed that L (total pollutant load) is a function of (RO) runoff.

From Thomas [24] the first and second terms for the general Taylor series expansion for any function are:

$$f(a) = mt\ (1 - e^{-RO/RO_c}) \quad \text{where } RO = o \tag{8}$$

$$. = Mt\ (1 - e^{o}) \tag{9}$$

$$= 0$$

the second term becomes

$$f^{1}(a) \cdot (x - a) = \frac{Mt}{RO_c}\ (e^{-RO/RO_c})\ (RO - a) \tag{10}$$

$$= \frac{Mt}{RO_c}\ (e^{-RO/RO_c})\ (RO - 0) \tag{11}$$

$$= \frac{MT}{RO_c}\ (RO) \tag{12}$$

$\therefore$

the equation for total load becomes

$$L = \frac{Mt}{RO_c} \cdot RO \tag{13}$$

As shown by Barkdoll and previously assumed, Mt and RO_c for any watershed and constituent are constant. Now it can be assumed that the ratio of Mt to RO_c is a constant.

That constant is defined as the load modulus for a watershed. It is a function of slope, soil type, pollutant source, percent forest, percent imperviousness and urbanization of a watershed.

As developed and for comparison in this study, total pollutant load (L) is a linear function of storm runoff. The validity of this statement is shown in Figures 3 through 7 reproduced from Barkdoll [3], which depict his data with a linear model superimposed. By looking at the figures, one can see a close fit. It should be noted that the runoff from the new storms have .01 inches of runoff for both of

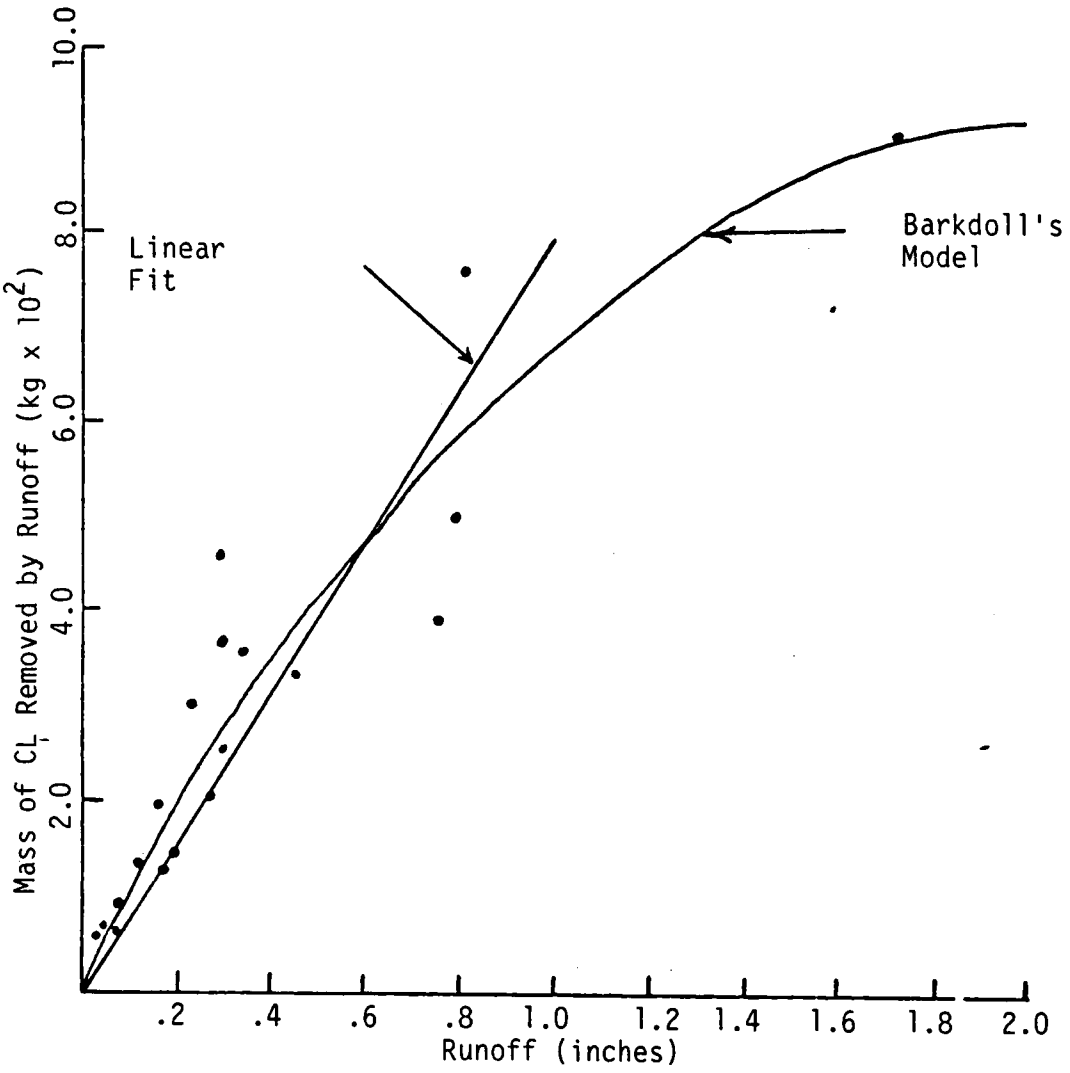


Figure 3. Removal of Cl by Runoff [3].

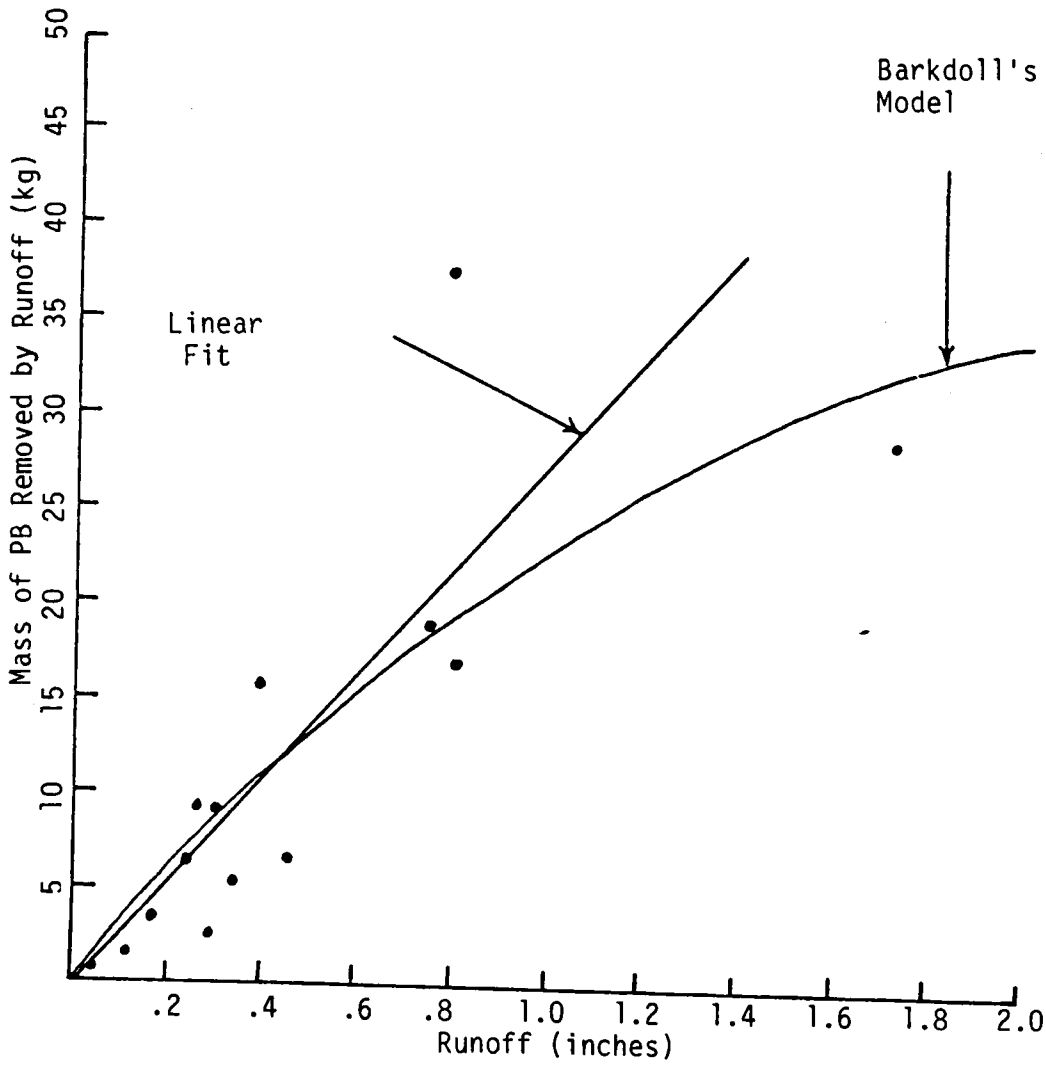


Figure 4. Removal of Pb by Runoff [3].

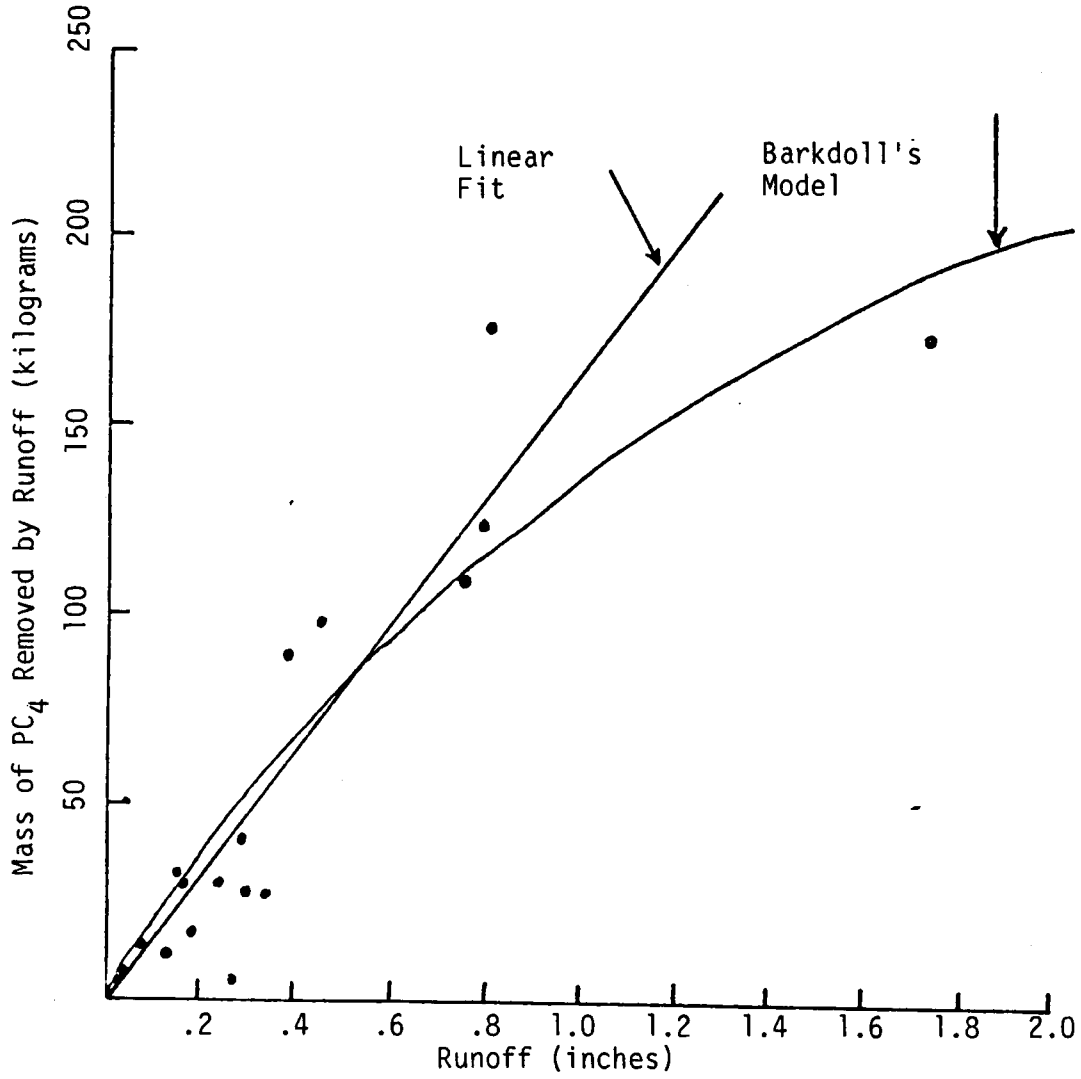


Figure 5. Removal of PO_4 by Runoff [3].

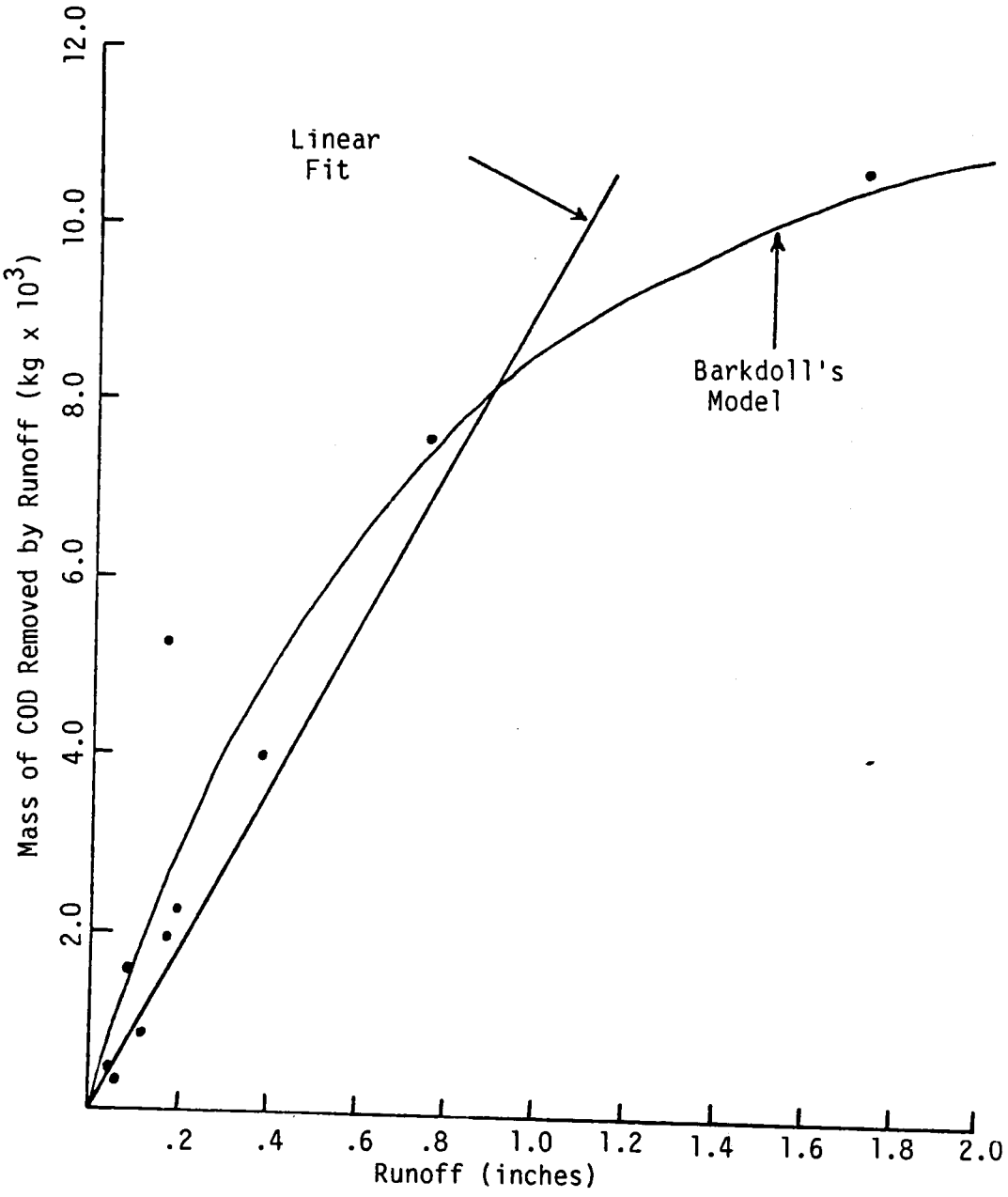


Figure 6. Removal of COD by Runoff [3].

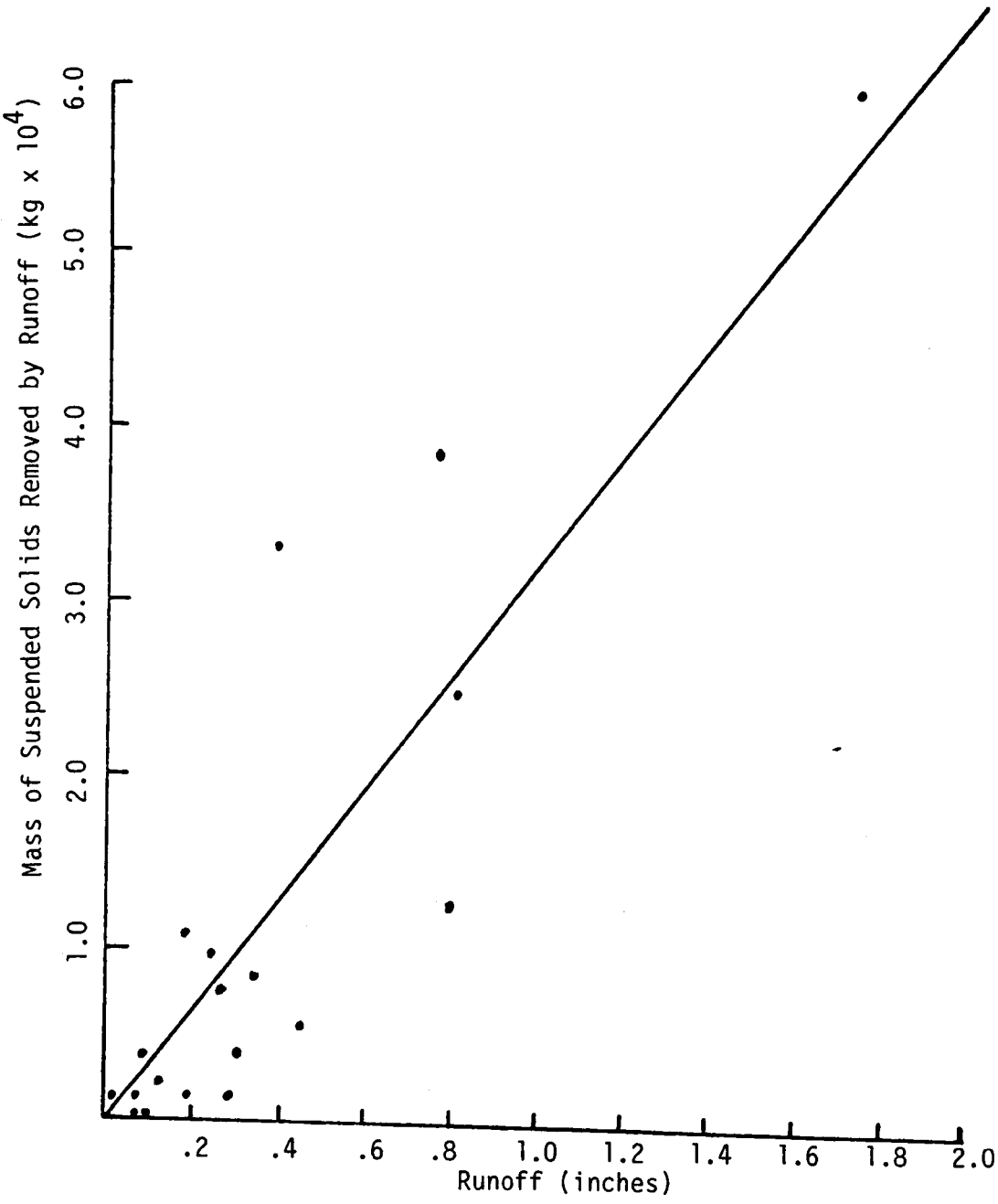


Figure 7. Removal of SS by Runoff [3].

Fourth Creek's storms and .1 and .4 inches for the storms on Third Creek, all of which are within the range of Barkdoll's data.

A program was used to determine the load modulus for the data gathered and for TVA data previously gathered. Mass flow, which is defined as (C) and has the units (lb/sec), was derived first by multiplying instantaneous concentration by instantaneous flow and by a conversion constant. Transport density was then found by the following:

$$\delta = \frac{\Sigma CQ}{\Sigma Q^2}$$

δ = transport density (lb/ft^3)

C = mass flow (lb/sec)

Q = instantaneous runoff (ft^3/sec)

By multiplying the transport density by a conversion constant (36.30), the load modulus was obtained in (lb/acre-in).

CHAPTER IV

RESULTS AND DISCUSSION

Storm Data

There were two storms examined in this study. The results from the samples are presented in Tables 17 through 20 in the Appendix. It should be noted that the samples were taken according to the rules stated in Chapter III.

The load moduli developed from these data are presented in Table 21 in the Appendix and the pollutographs, i.e., graphs of concentration versus time, are presented as Figures 9 through 46 in the Appendix.

Pollutant Load Change on a Dynamic Watershed

There is a considerable decrease in the load moduli of metals developed for the new Fourth Creek data versus that developed for the TVA data obtained from 1972 to 1973 as is shown in Table 3. This difference can be justified by a change in pollutant source characteristics from the time of the first set of data to the time of the new data which is explained as follows. The geology of the basin indicates that the soil is a major source of the three metals, Fe, Mn, and Mg. According to the Tennessee Division of Geology [12], the soils of the Fullerton-Bolton-Clarksville Soil Association have developed over dolomite which is the predominant species in the area. The Fullerton soils have brown cherty silt loam in the A horizons and cherty yellowish-red and red firm clay in the B horizons. The Bolton

Table 3. Optimized Load Moduli--Fourth Creek

Constituent	T.V.A. Data	lb/ac-- in New Data	Percent Difference
Fe	22.2	1.56	93
Mn	.5	.104	79
Mg	2.24	.581	74
Pb	.11	.0579	47

soils have dark brown loam A horizons and dark reddish-brown or dark red friable silty clay B horizons. The Clarksville soils contain more than 35 percent chert. Clarksville A horizons are pale brown cherty silt loam, and Clarksville B horizons are yellowish-brown and strong brown cherty silt loam and silty clay loam. Fullerton, Bolton and Clarksville soils are very strongly acid. The high rainfall, about 47 inches a year, results in a large amount of water carrying soluble and suspended mineral materials downward in the soil. This action gives the surface soil layers a pale-colored leached look. This also gives the B horizon the maximum accumulation of minerals. As can be seen from Tables 4 and 5, Tennessee Division of Geology [12], the A horizons have a depth of from 0 to 9 inches, and the B horizons have a depth of from 9 to 70 inches for both Clarksville and Fullerton soils.

As has been stated in the study area description, Mn, Mg and Fe are present naturally on the watershed. The highest concentrations of these metals in the soil, as explained above, occur in the B

Table 4. Clarksville Soil

Horizon and Depth	Characteristics
A1 0-1 in	Dark-grayish-brown cherty silt loam
A2 1-8 ins	Pale-brown cherty silt loam
B1 8-12 lins	Light-yellowish-brown cherty silt loam
B2 12-70 ins	Yellowish-brown and strong-brown cherty silt loam and cherty silty clay loam Chert content, 35 percent
B3	Chert bed interstices filled with yellowish soil

Table 5. Fullerton Soil

Horizon and Depth	Characteristics
A1 0-6 ins	Brown silt loam
A2 6-9 ins	Pale-brown cherty silt loam
B1 9-13 ins	Strong-brown silty clay loam
13-17 ins	Yellowish-red clay loam
B2 13-70 ins	Red clay
17-70 ins	Red clay

horizon. These concentrations occur because of the cleansing of the A horizon.

TVA obtained their samples from May 1972 to October 1973 from Fourth Creek. A major shopping center was being constructed during the early part of their study. During the construction of the parking lot, the top 8-12 inches of soil were cleared in order to remove roots and top soil. The B horizon with its high concentrations of metals became the top horizon. Without vegetation this layer became susceptible to scour and solution which makes the soil which contained Fe, Mn and Mg available as a source for these metals during the time their data was acquired.

The new load moduli for the metals Fe, Mg and Mg for Fourth Creek were collected during 1977. That part of the basin under construction during 1972 was covered with asphalt. The asphalt eliminated the shopping center area as a geological source of metals because there is no scour or solution of the soil or the B horizon. This change in source may account for the decrease in the metal pollutants.

The metal Pb also had a change in source characteristics as indicated by the load moduli for Pb having a 47 percent reduction. From Lexen and Harrison [13] it was established that leaded petrol was the major source of lead along highways. Also, from work done by Ewing [10], Pb is present along routes traveled by automobiles.

As shown in the study area description, there are two highways through the Fourth Creek basin. Also, there are parking lots for all of the strip commercial establishments. All of these parking lots and highways are collectors of Pb from gasoline. It was also stated by the Tennessee Division of Geology [12] that there are no

known traces of natural Pb in the study area. There are also no known point sources of Pb in the study area, all of which establishes that gasoline is the major source of Pb on the watershed.

Anderson [1] produced a graph, partially reproduced as Figure 8, which shows total gas pool Pb content versus time. This graph indicates the gas pool Pb content for 1973 was 2.2 grams/gal and for the end of 1977 was 1.1 grams/gal. This indicates that there should be a 50 percent drop in the amount of Pb available to the watershed if all other factors remain constant. The load modulus developed for Pb on this watershed shows a 47 percent reduction which would indicate that this occurred to some extent.

Load Moduli on Third Creek

The metals Fe and Mg, as shown in Table 6, have essentially the same load moduli for the older TVA data and for the new data on Third Creek. Third Creek is a static watershed with regard to these metals. The soil and the iron foundry are the predominant sources of iron on the watershed. The soil at Third Creek has considerable clay. It was shown in the study area description that the clay in this area contains high iron concentrations. Table 7 presents some average emmissions from foundries. The particulates from a foundry contain high Fe concentrations, thereby creating a point source of Fe for the watershed. Major sources of Mg on the watershed are the soil and the marble plant. The study area description indicates dolomite which contains high amounts of Mg to be prevalent in the study area. The marble cut at the marble plant contains Mg. The dust from this cutting process settles at the plant site and is

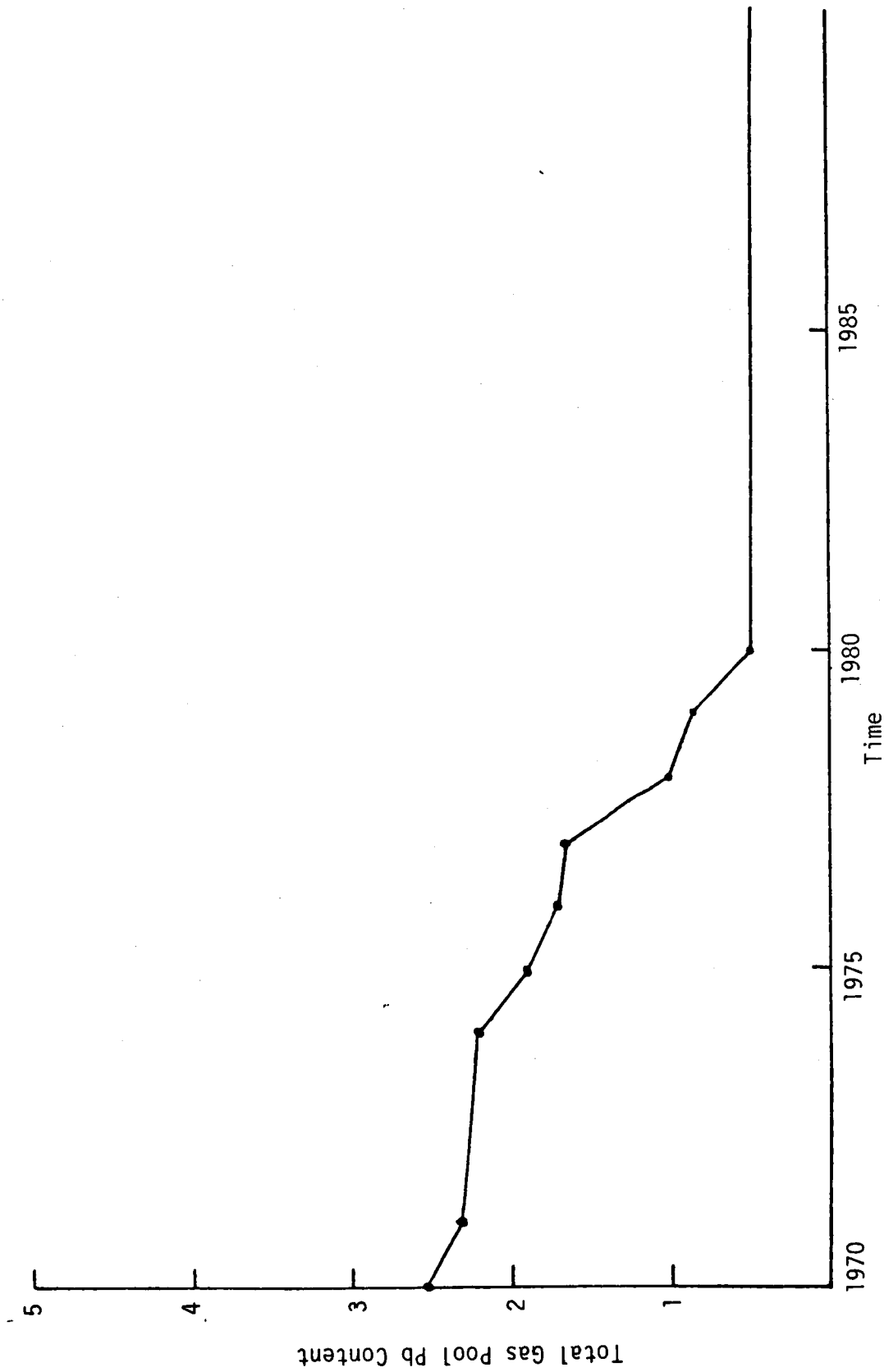


Figure 8. Lead Content of Gasoline Total Gas Pool [1].

Table 6. Optimized Load Moduli--Third Creek (lb/ac-in)

Constituent	T.V.A. Data	New Data
Fe	3.84	3.77
Mn	.27	.647
Mg	1.38	1.96
Pb	.204	.0814

Table 7. Emission for Iron Foundries

Type of Furnace	Particulates (lb/ton)
Cupola	
Uncontrolled	17
Wet Cap	8.0
Impingement Scrubber	5.0
High-energy Scrubber	.8
Electrostatic Precipitator	.6
Bag House	.2
Reverberatory	2.0
Electric Industion	1.5

available as a pollutant in runoff. Therefore the marble plant site acts as a source of Mg.

From the data in Table 6, it is evident that the new load modulus developed for Mn is 3 times the one developed for the TVA data. This indicates that there was a source change during the two storms. This element is found in the soil along the ridge as stated in the study area description. There was some sidewalk construction work along the ridge which may account for this increase during one or both storms.

Pb was the only metal to have a decreased load modulus for the Third Creek watershed as shown in Figure 8. The only known sources for Pb on this watershed are Pb in gaoline and Pb in paint on some of the older houses. Most of the 60 percent reduction of Pb can be attributed to the lowered amount of Pb in gasoline since 1974 when the TVA data were obtained. Some of the lower Pb in the runoff may be due to less lead in outdoor paint in the last few years.

Fourth Creek Watershed and Third Creek Watershed

Table 8 shows that all of the load moduli for metals on Fourth Creek are less than the load moduli for metals from Colston's [8] data but it can also be seen that the load moduli are of the same relative magnitude. The difference in land use characteristics on Colston's watershed and those on Fourth Creek would cause different load moduli. The fact that the load moduli are of the same order of magnitude indicates that the load moduli model would work with drainage basins of different areas.

Table 8. Optimized Load Moduli for Fourth Creek and Colston's Data (lb/ac-in)

Constituent	Fourth Creek	Colston
SS	69.72	457.
TS	144.15	438.
Zn	.0349	.13
Fe	1.56	5.11
Mn	.104	.34
Mg	.581	2.88
Pb	.0579	.1
COD	169.	39.6
TOC	26.6	10.8

The SS and TS load moduli are less than those developed from Colston's [8] data. It should be noted that the amount of solids load in runoff is related to the amount of flow and raw channel of the streambed. Fourth Creek has less erosion than does Colston's basin. This fact may be indicated by the difference in the two streambeds.

The COD and TOC load moduli indicate that Fourth Creek has a higher organic loading than Colston's basin as shown by the higher load moduli.

Third Creek Load Moduli Versus Colston's Data Load Moduli

The metals Fe, Mn, Mg, and Pb for Third Creek have approximately the same load moduli as those developed for Colston's data as shown in Table 9. Although the load moduli are the same, it does not mean that Colston's basin is the same as Third Creek, but that the total interaction between the sources of the pollutants and the removal process is the same.

It should be noted that the load modulus for Pb on Third Creek is less than for Colston's data by only 20 percent. This would indicate that the loadings for Pb on Colston's study watershed would be similar to that on the Third Creek watershed. The difference is due in part to the time frame difference in which the data were taken. As was shown earlier, the lead content of gasoline, which is a major source of Pb on an urban watershed, is less with time.

The Zn load modulus is 10 times that developed for Colston's data. The known sources of Zn on Third Creek are soil and tire wear. The fact that the soil on Third Creek has Zn was shown in the study area description. Automobile tires also contain Zn. It can be

Table 9. Optimized Load Moduli--Third Creek Versus Colston's Data (lb/ac-in)

Constituent	Third Creek	Colston's Data
SS	247.	457.
TS	287.	439.
Zn	1.21	.13
Fe	3.77	5.11
Mn	.647	.34
Mg	1.96	2.88
Pb	.0814	.1
COD	246.	39.6
TOC	51.2	10.8

speculated that the major difference is due to the fact that the Third Creek basin contains natural Zn.

The load moduli for SS and TS were less than those developed for Colston's [8] data. The reason for this is not known at this time.

The COD and TOC values for Third Creek were both higher than those developed for Colston's data. This indicates that the loadings for Third Creek are higher.

Fourth Creek Water Quality

The load moduli developed for the Fourth Creek metals Fe, Mn and Pb, shown in Table 10, are greater than the load moduli developed from the Knoxville drinking water data provided by Mike Tucker, a chemist with the Knoxville Utility Board. These three metals can be removed with water treatment and would add just a small fraction to the cost of clean water treatment.

Table 10 shows Mg is the only metal with a lower load modulus than that developed for Knoxville's drinking water. There are no definite criteria set for this element, and because of its miniscule quantity, there would be no economic cost associated with its removal for water consumption.

From Table 11 it is evident that the Fourth Creek load moduli for all metals, except Cd and Zn, are greater than those developed from criteria set by the Environmental Protection Agency (EPA). Of the metals examined and in amounts greater than the National Standards, only Pb is considered dangerous to health. If one looks at this water as a municipal raw water supply, staining of clothes and

Table 10. Load Moduli of Fourth Creek and Knoxville Drinking Water (lb/ac-in)

Constituent	Fourth Creek	Knoxville Water
Fe	1.56	6.8×10^{-3}
Mn	.104	eq. 0[a]
Pb	.0579	eq.0[a]
Mg	.514	1.34

[a]eq.0 means that by the KUB methods of analysis there was none present in appreciable quantities

Table 11. Load Moduli of Fourth Creek and National Drinking Water Standards (lb/ac-in)

Constituent	Fourth Creek	National Standards Drinking Water
Zn	.0349	1.13[a]
Fe	1.56	.0679
Mn	.1041	.0113
Mg	.381	None stated
Pb	.0379	.0113
Cd	.00018	.00226

[a]National standards converted from EPA standards

precipitation in pipes would be the main concern due to the fact that Fe, Mn and Mg are present.

Third Creek Water Quality

The load moduli developed for the Third Creek metals are all greater than the load moduli developed for Knoxville's water, as shown in Table 12. The metals Fe, Mn and Mg would be removed with normal water treatment. They are not of concern to health; therefore, the removal for aesthetic reasons would be the only concern in treating this water for drinking. Pb is the only metal which presents health problems and it can be removed by precipitation.

Table 13 shows all the metals examined to be greater than the National Standards. Zn, Fe, Mn and Mg would be removed from the water with normal practices and because their standards were set for public welfare and not health as shown in Water Quality Criteria 1972 [27], only the cost of removal would cause concern if the water was to be used for drinking. Pb and Cd are two metals for which the standards were set for health. In normal water treatment these two elements also would be removed and, if care is taken that there be no short circuiting in the treatment system, their removal should also cause little concern.

It should be noted that the organic loading is high. With proper treatment, organics can be removed.

Comparison of Urban Watersheds with Strip-Mined Watersheds

Table 14 shows the Third and Fourth Creek urban watersheds to have approximately the same range of concentrations of Fe, Mn and

Table 12. Load Moduli of Third Creek and Knoxville Drinking Water (lb/ac-in)

Constituent	Third Creek	Knoxville Water
Fe	3.77	6.8×10^{-3}
Mn	.06469	eq. 0[a]
Pb	.0814	eq. 0[a]
Mg	1.96	1.34

[a]National standards converted from EPA standards

Table 13. Load Moduli for Third Creek and National Drinking Water Standards (lb/ac-in)

Constituent	Third Creek	National Standards Drinking Water
Zn	1.21	1.13[a]
Fe	3.77	.0679
Mn	.6469	.0113
Mg	1.96	None stated
Pb	.0814	.0113
Cd	.0074	.00226

[a]National standards converted from EPA standards

Table 14. Concentration Ranges for Metals on Stripped and Urban Basins (mg/l)

Basin	Fe	Mn	Mg
Bills	0 - 50.8	.18 - 1.4	0 - 19
Bowling	4.0 - 26	.01 - .82	1.2 - 3.02
Green	2.01 - 56	.01 - 5.6	17.8 - 26.0
Indian	4 - 100	.06 - 3.7	22. - 49
Anderson	.2 - 1.65	.06 - 3.21	.49 - 17
Urban			
Fourth	.16 - 6.64	.089 - .547	1.38 - 14.8
Third	.3 - 25.5	.29 - 6.62	3.97 - 14.8

[a]Strip mined data taken from Minear et al. [15]

Mg in storm runoff as the strip mined watersheds; Bills, Bowling, Green, Indian and Anderson. The metals Fe, Mn and Mg on both Third Creek and Fourth Creek watersheds have soil as a source. The soil is the source of these metals on the strip-mined watersheds also. Because both strip mining and urbanization both make the soil a more available source for contaminants, one can conclude that urbanization acts similarly to strip mining of a watershed.

Table 15 shows the load moduli for both strip-mined and urban watersheds for the metals Fe, Mn and Mg to be nearly the same.

With the soil as a source for most of the elements studied, removal of vegetation causes an increase in the load moduli. Because both urbanization and strip mining remove vegetation from a watershed and increase the load modulus for any contaminant on a watershed, they have similar effects on a watershed.

Air Pollution and Urban Runoff

Table 16 shows the load moduli for dustfall in Knoxville and the load moduli of Third Creek and Fourth Creek for the metal Fe, Mn and Mg. Except for Mg. the load moduli for the fallout are smaller by at least a factor of 10. Mg if found in the soil over all of Knox County. The fallout would contain Mg from local sources and not just blown in from other areas. It can be concluded that there is only a small effect on runoff due to sources outside of the drainage basin for the elements studied. The major sources of the elements shown are those which are active in or on the watershed itself.

Table 15. Optimized Load Moduli of Metals During Stormflow (lb/ac-in)[a]

Basin	Fe	Mn	Mg
Mined			
Bills	3.73	.18	2.2
Anderson	22.2	.7	3.416
Indian Fork	9.22	.4	5.19
Green	9.7	.39	3.48
Blowing	2.3	.043	.52
Unmined			
Lowe	.12	.002	.4
Urban			
Colston's	5.15	.34	2.8
Fourth	1.56	.104	.581
Third	3.77	.647	1.96

[a]Strip mined data taken from Minear et al. [15]

Table 16. Load Moduli of Metals for Knoxville Fallout and Urban Runoff (lb/ac-in)

Basin	Fe	Mn	Mg
Fourth Creek	1.56	.104	.581
Third Creek	3.77	.647	1.96
Total Fallout	.04	.011	.17

Pollutographs

Pollutographs are graphs of concentration versus time. Figures 9 through 46 (Appendix) are pollutographs with graphs of flow versus time imposed on them for the data taken. It is evident that the occurrence of maximum concentrations corresponds to peak flow for most of the elements studied. Therefore, to determine the load modulus for a drainage basin, only one sample is required at the proximity of maximum flow. This also indicates that there would be two load moduli needed for each basin, one at low flow conditions and one at storm flow conditions. From these two load moduli the amount of mass for a contaminant which is removed from a watershed under each condition may be predicted.

CHAPTER V

CONCLUSIONS

The following conclusions are based on the results described in Chapter IV.

1. The two watersheds studied produced different amounts and types of pollutants as a result of different land uses.

2. The urban watersheds studied produced pollutant loads equivalent to those observed in strip mined watersheds in east Tennessee. These effects were associated with construction and development.

3. The study watersheds which were static in development over the study period approached a steady pollutant load.

4. During construction and development activity in the study watersheds, some of the metal pollutant levels observed appeared to be directly related to the watershed soil characteristics.

5. The lead content of urban runoff from the study watersheds appeared to decline in recent years and this parallels changes in the use of lead in the automobile industry, specifically as fuel additives.

CHAPTER VI

RECOMMENDATIONS

The following recommendations are made to improve the results of this study.

Data should be taken at high and low flows on Third Creek in order to determine the difference in the total load coming from the watershed under these circumstances. As can be seen from the pollutographs (Figures 9 through 46 in the Appendix), there is a difference in concentration for high and low flows.

Samples should be taken at the beginning as well as during the peak and receding portions of the runoff hydrograph. The data is needed to determine at what time most of the material on the watershed has been removed by runoff.

More storms need to be analyzed to determine load moduli in order to remove any bias in storm events. If more storms were examined the Fourth Creek data might be closer to the TVA data.

Other constituents such as pH, oil and alkalinity need to be studied in order to determine what might be sinks for some of the metals examined and sources for the organics found.

Dynamic watersheds such as Fourth Creek need to be studied in order to determine sources and sinks for pollutants during development as well as how more deterioration occurs with each segment of urbanization.

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APPENDIX

Table 17. Third Creek Raw Data November Storm

Time hr.	Flow cfs.	COD mg/l	P.S. mg/l	CD mg/l	Pb mg/l	Mn mg/l	SS mg/l	Fe mg/l	Ms mg/l	Zn mg/l	TOC mg/l
0	1.	592.	304.	.00021	.00355	.142	44.	.3	14.8	.049	161.
.5	1.6	181.	292.	.0001	.00933	.104	40.	.39	14.8	.058	57.
1.	2.3	509.	300.	.0012	.0717	.109	32.	.991	13.2	.098	151.
1.5	3.8	730.	308.	.00122	.086	.186	36.	2.69	9.93	.147	191.
2.	5.8	631.	296.	.00141	.108	.293	108.	2.69	9.66	.176	171
2.5	11.9	453.	420.	.00235	.129	.541	228.	4.12	8.22	.294	134
3.	9.1	592.	280.	.00167	.0746	.355	149.	3.28	6.07	.196	166
3.5	7.9	530.	288.	.00231	.0640	.349	102.	4.21	6.01	.284	175.
4.	10.3	631.	332.	.004	.106	.411	16.	4.2	5.43	.392	165.
4.5	10.2	670.	334.	.00335	.075	.32	92.	3.95	4.97	.333	192.
5.	11.9	671	220.	.00264	.119	.355	152.	4.3	4.99	.352	168.
5.5	12.9	592.	244.	.0039	.0988	.325	140.	3.83	4.63	.333	171.
6.	15.4	627.	240.	.00291	.106	.385	146.	4.31	4.83	.372	153.
6.5	14.4	431.	220.	.00431	.099	.379	100.	4.29	4.68	.392	115.
7.	10.3	823.	248.	.00691	.106	.429	149.	3.95	4.69	.529	194.
7.5	7.8	431.	224.	.00631	.0733	.311	120.	3.68	4.97	.549	121.
8.	6.0	352.	212.	.00641	.0801	.29	108.	3.19	3.97	.470	98.
8.5	4.9	131.	228.	.00545	.0644	.222	84.	2.66	3.79	.333	42.
9	3.8	313.	256.	.0037	.0512	.207	40.	2.26	6.06	.254	92.
9.5	3.7	431.	272.	.00385	.0391	.174	24.	2.1	6.45	.215	124.
10.	3.6	313.	164.	.00293	.0234	.133	68.	1.81	6.00	.176	96.
10.5	3.0	326.	156.	.00251	.0271	.118	52.	1.59	7.31	.156	98.
11.	2.4	339.	200.	.00193	.0238	.133	72.	1.49	7.86	.137	121.
11.5	2.4	401.	200.	.00176	.0183	.112	92.	2.35	8.14	.137	119.
12.	4.4	450.	336.	.00263	.152	.296	188.	4.15	8.	.216	.35.
12.5	106.	705.	934.	.00882	.207	1.21	800.	11.43	7.86	.686	168.
12.75	147.	1223.	1748.	.00784	.525	2.66	1476.	20.	10.21	5.39	240.
13.	170.	1636.	1784.	.00943	.206	6.62	1876.	25.5	14.07	12.38	290.
13.25	148.	1065.	1136	.0876	.299	1.95	844.	16.2	6.45	4.44	226.
13.5	108.	768.	724.	.0512	.945	1.05	520.	11.1	4.69	1.95	201.
13.75	88.	631.	508.	.01491	.181	.835	420.	8.9	4.28	.863	177
14.	76.	768.	404.	.01031	.153	.666	336.	7.56	4.08	.784	211.
14.5	51.	395.	308.	.00639	.860	.444	256.	5.63	3.97	.471	111.
15.	36.	505.	280.	.0045	.0571	.355	188.	4.54	4.14	.333	153.
15.5	27.	465.	268.	.00324	.048	.293	152.	3.27	4.41	.275	141.

Table 18. Third Creek Raw Data December Storm

Time	Flow cfs.	COD mg/l	Tg mg/l	CD mg/l	Pb gm/l	Mn mg/l	SS mg/l	Fe mg/l	Ms mg/l	Zn mg/l	TOC mg/l
0.	6.08	38	60	.5	.0494	.118	20	1.42	9.98	.0842	34.1
.5	9.6	46	336	.72	.0556	.237	20	2.02	11.2	.128	43.6
1.0	10.7	39	304	.711	.366	.207	12	1.84	8.88	.122	45.1
1.5	9.3	41	272	.72	.0357	.228	28	2.02	8.	.151	37.8
2.0	7.12	70	222	.74	.0329	.16	20	2.92	7.03	.128	31.9
2.5	8.97	50	228	.61	.0348	.145	12	1.94	7.17	.135	33.6
3.0	8.4	68	224	.541	.0278	.13	12	1.65	7.37	.12	36.8
3.5	7.92	41	216	.502	.0201	.112	4	1.47	7.59	.102	28.0
4.0	6.55	48	232	.312	.0165	.112	4	1.33	8.	.0941	33.8
4.5	6.0	41	228	.263	.0137	.104	4	1.21	8.41	.0922	30.3

Table 19. Fourth Creek Raw Data November Storm

Time hr	Flow cfs.	SS mg/l	Mn mg/l	Fe mg/l	Pb mg/l	Ts mg/l	Cd mg/l	Zn mg/l	Ms mg/l	TOC mg/l	COD mg/l
0	.1	24	.355	1.68	.0821	228	.00039	.0902	4.99	285	599
.25	.067	28	.325	1.26	.0893	164	.00031	.0804	4.64	234	599
.5	.13	24	.385	1.26	.077	176	.00035	.0764	4.83	142	613
.75	.5	72	.379	2.0	.0787	232	.0004	.0824	4.68	82	626
1.0	.36	40	.429	1.76	.113	236	.00035	.0882	4.69	114	222
1.25	.1	44	.311	1.43	.0992	192	.00035	.0765	4.97	243	185
1.5	.04	20	.29	1.17	.0765	172	.00112	.0745	3.97	38	424
1.75	.114	56	.222	1.51	.0818	216	.00032	.0862	3.79	29	586
2.0	1.39	76	.19	2.18	.106	328	.00054	.0843	1.71	32	485
2.25	1.5	28	.089	2.02	.106	128	.00049	.0323	1.6	108	480
2.5	.4	40	.089	1.5	.0818	172	.00035	.0725	1.38	141	586
2.75	.22	48	.083	1.34	.101	264	.00101	.0784	1.46	153	465
3.0	.08	28	.065	1.26	.0756	188	.00037	.0765	1.66	132	465
3.25	.06	28	.044	1.18	.0697	156	.00074	.0784	1.71	168	383
3.5	.02	24	.044	1.09	.0662	128	.00034	.0784	1.6	66	396
3.75	.02	24	.059	1.0	.0593	168	.00049	.0745	1.71	38	404
4.0	.02	192	.222	1.51	.0134	332	.00013	.0431	4.69	111	706
4.25	4.37	436	.547	6.64	.117	680	.00053	.1288	2.97	136	1020
4.5	.25	260	.314	4.97	.0955	480	.00054	.112	2.17	105	61
4.75	.067	76	.202	3.33	.073	212	.00043	.0882	1.71	124	268
5.0	.047	144	.0888	1.9	.0554	324	.00041	.0765	1.52	143	38
5.25	.047	156	.133	2.17	.0362	300	.00043	.0745	1.5	121	76
5.5	.718	132	.213	2.77	.0461	300	.00043	.0686	1.38	87	118
5.75	.28	104	.133	2.01	.0362	224	.00021	.0569	1.24	99	117
6.0	.076	641	.133	1.76	.0332	160	.00031	.0629	1.24	98	78
6.25	.04	52	.133	1.43	.0258	168	.00027	.0647	1.21	101	117

Table 20. Fourth Creek Raw Data December Storm

Time hr	Flow cfs.	SS mg/l	Mn mg/l	Fe mg/l	Pb mg/l	Ts mg/l	Cd mg/l	Zn mg/l	Mg mg/l	TOC mg/l	COD mg/l
0	.01	.52	.142	4.24	.143	436	.00101	.396	14.6	25.6	1280
.25	1.66	144.	.104	3.78	.145	376	.00091	.167	14.8	55.6	1040
.5	6.2	292.	.109	.79	.360	692	.00095	.177	13.24	38.1	639
.75	.835	204.	.186	5.11	.223	336	.00065	.139	9.93	25.2	300
1.0	.1	96.	.293	3.34	.142	120	.00056	.107	9.66	28.2	460
1.25	.067	52.	.541	2.35	.107	244	.00032	.098	8.22	23.1	838
1.5	.03	8.	.355	1.68	.089	216	.00043	.096	6.07	15.8	120
1.75	.028	48.	.349	.16	.0914	252	.00051	.0784	6.01	16.8	107
2.0	.027	16.	.411	1.54	.0849	332	.00051	.0941	5.43	11.4	115
2.25	.171	40.	.32	1.6	.0931	204	.00047	.0941	4.97	16.3	450

Table 21. Load Moduli for New Data

Constituent	Third Creek (lb/ac-in)	Fourth Creek (lb/ac-in)
TS	287.	144.15
SS	247.	69.22
COD	246.	169.
TOC	51.2	26.6
Zn	1.21	.0349
Fe	3.77	1.56
Mn	.6460	.1041
Mg	.96	.581
Cd	.0074	.00018
Pb	.0814	.0579

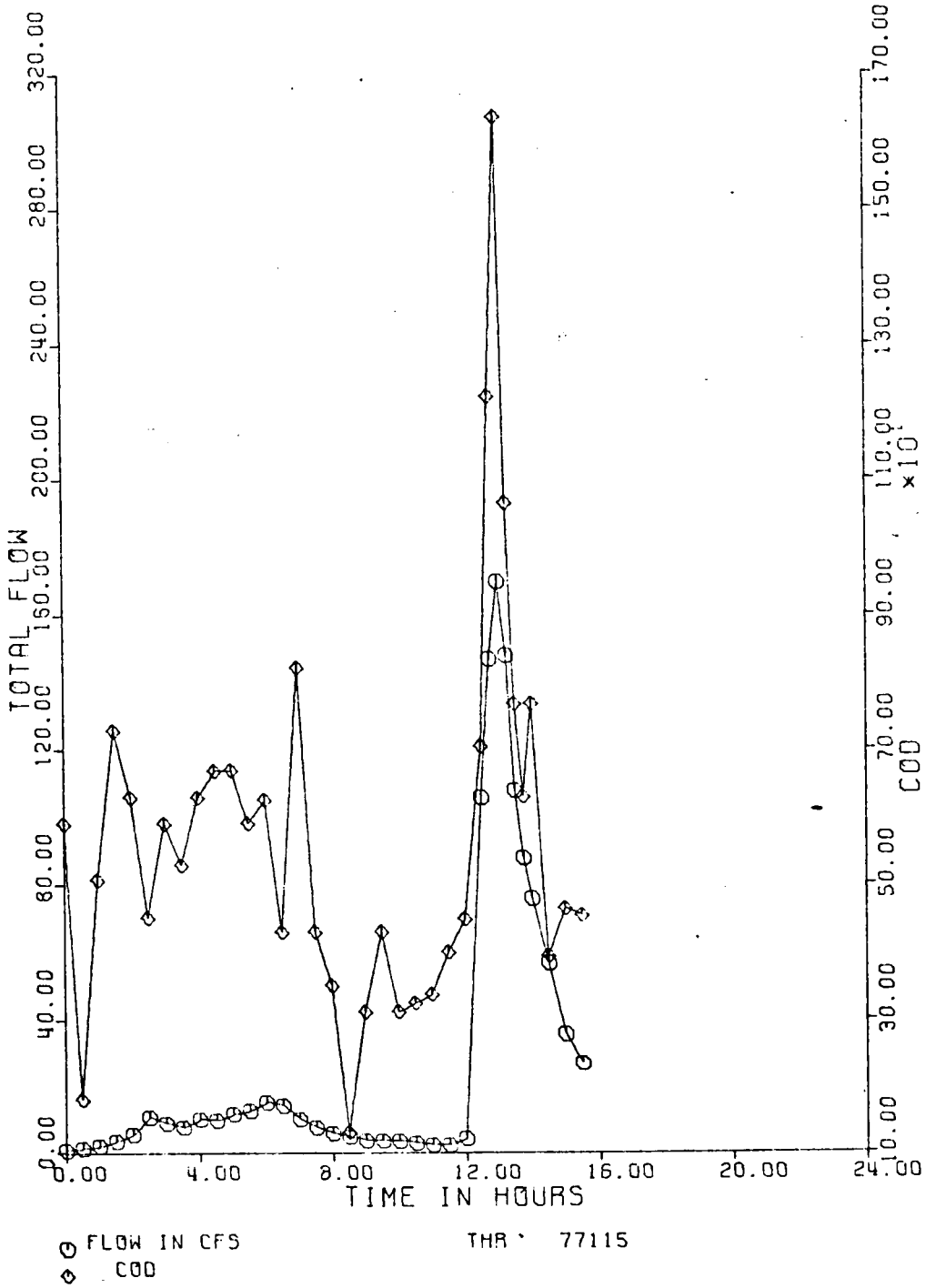


Figure 9. Third Creek Pollutograph for COD November Storm.

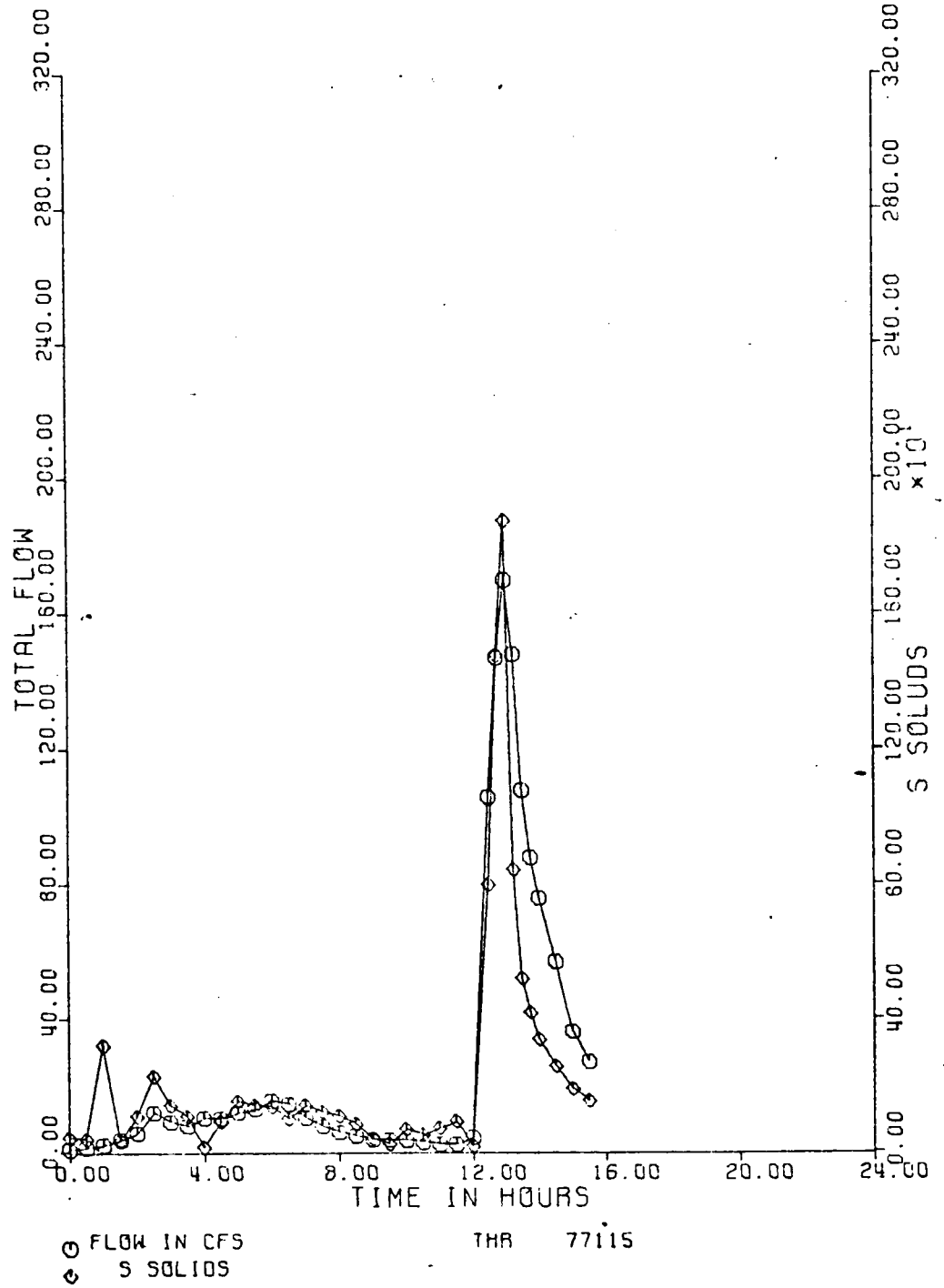


Figure 10. Third Creek Pollutograph for SS November Storm.

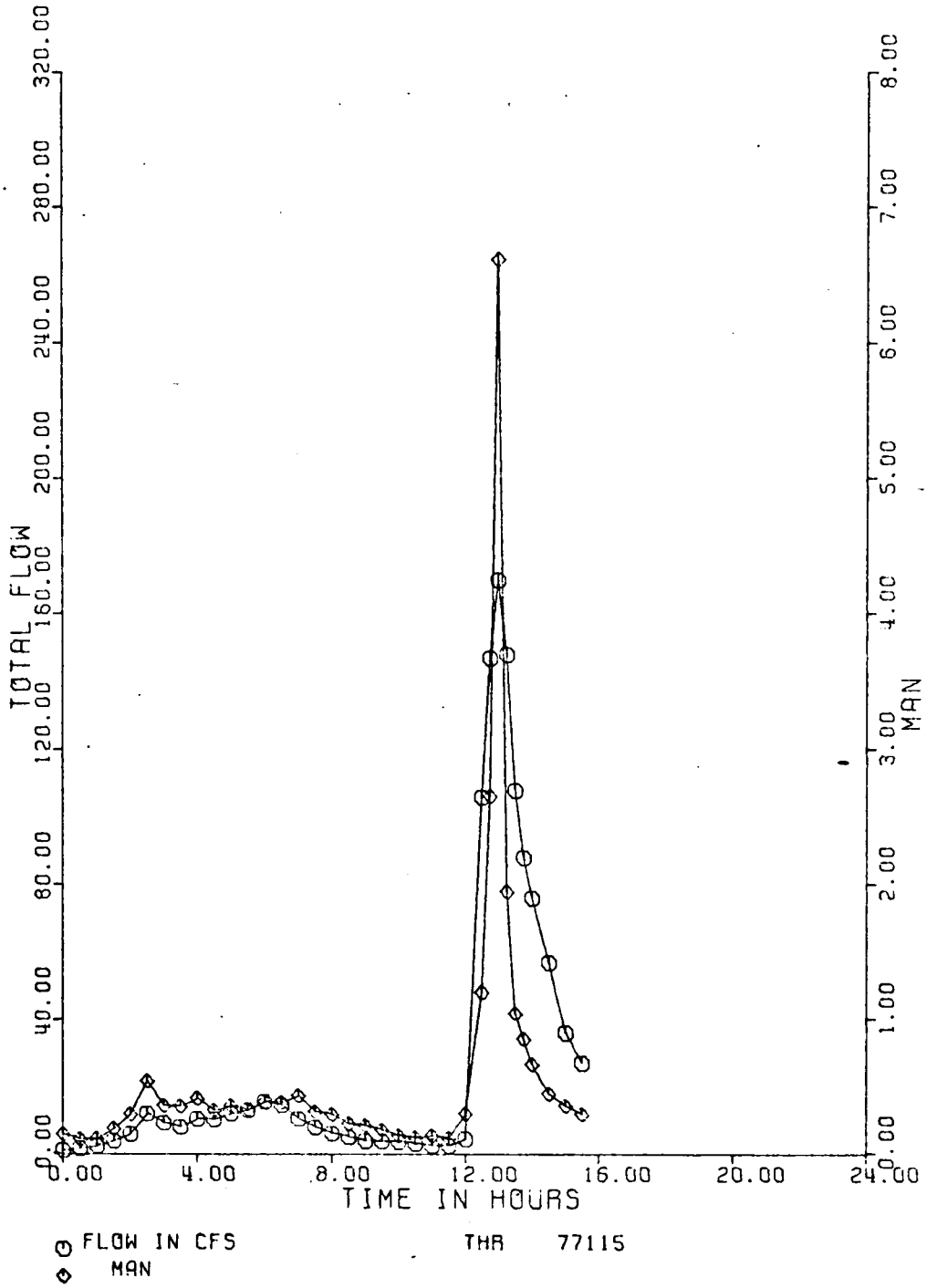


Figure 11. Third Creek Pollutograph for Mn November Storm.

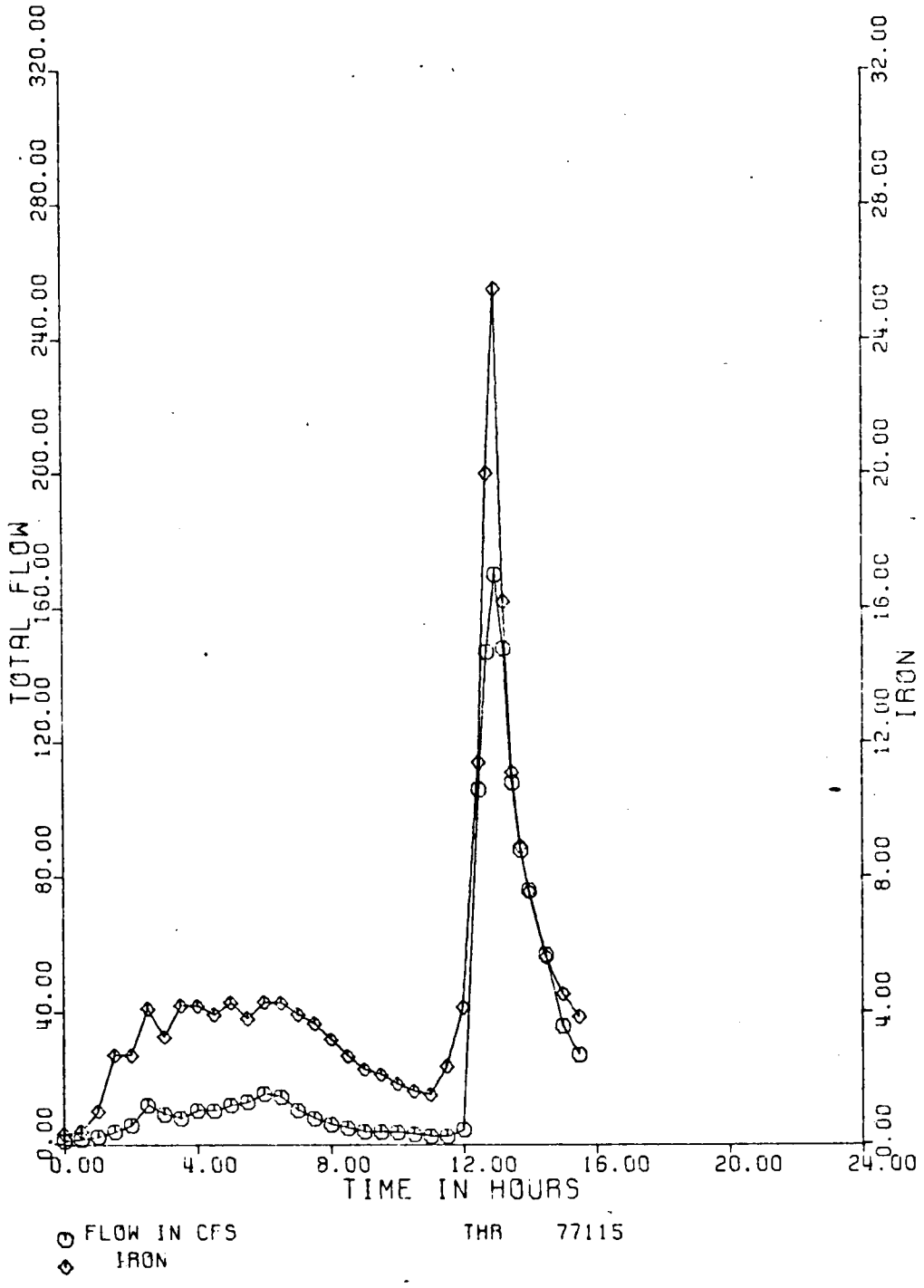


Figure 12. Third Creek Pollutograph for Fe November Storm.

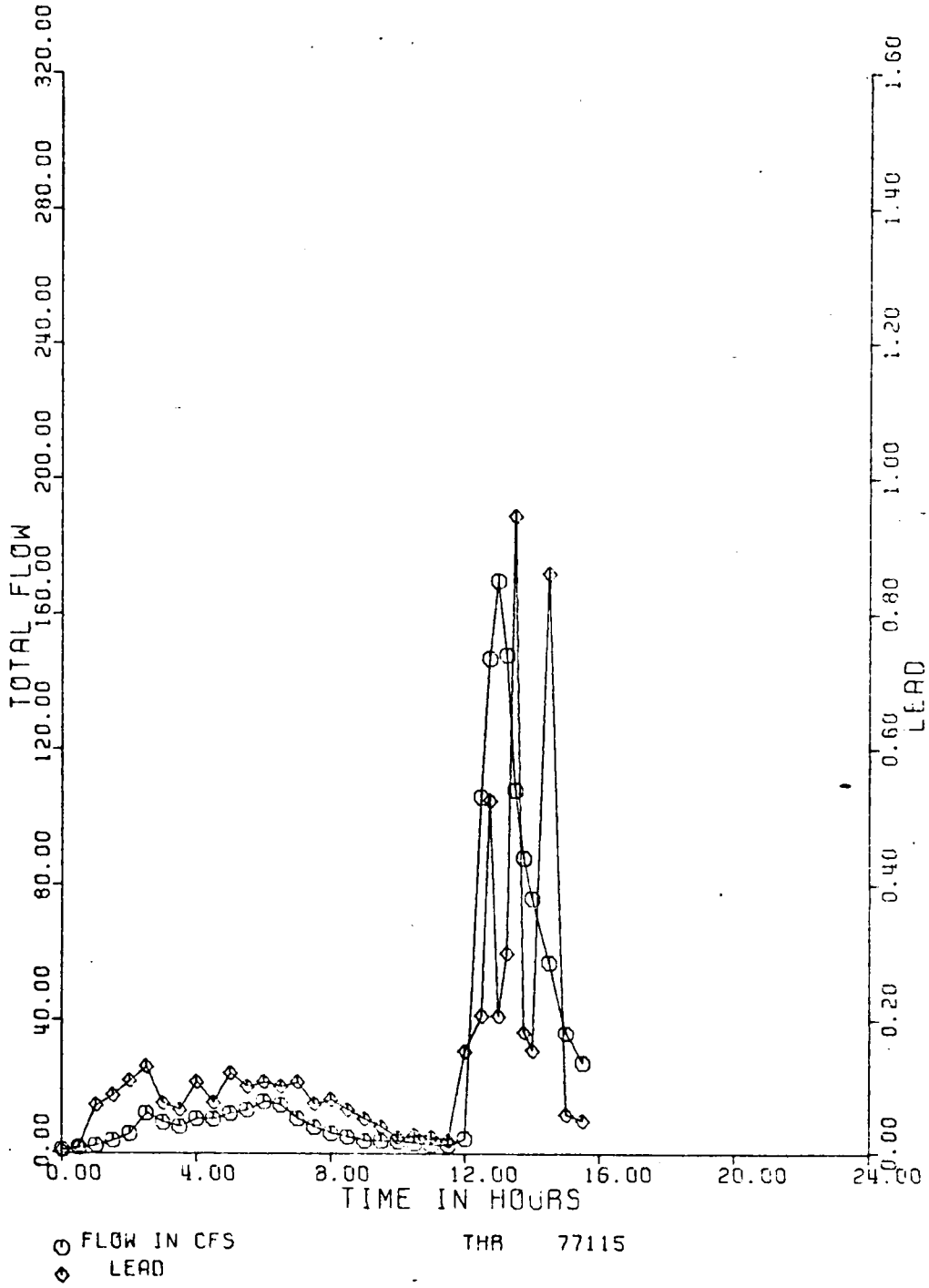


Figure 13. Third Creek Pollutograph for Pb November Storm.

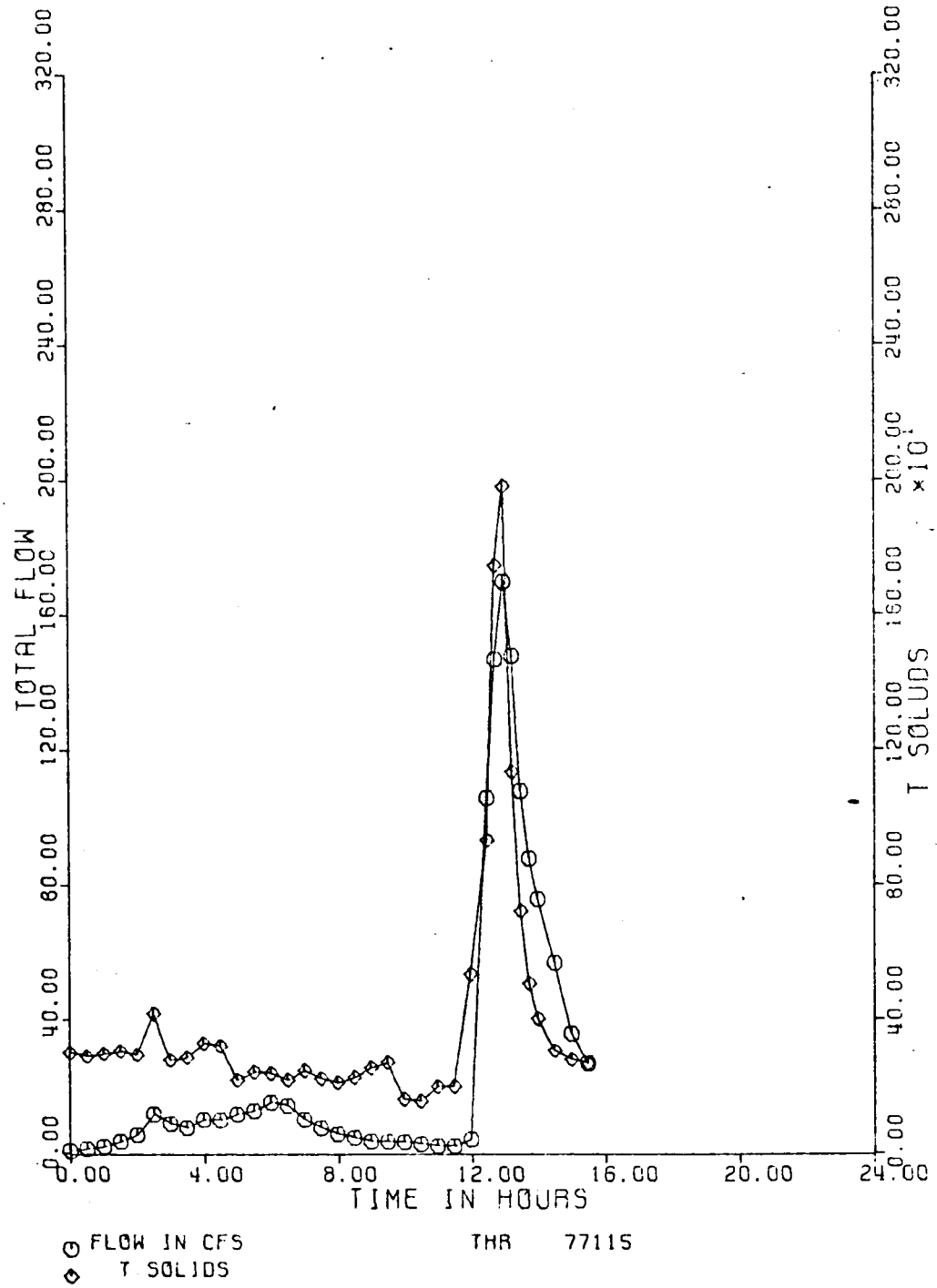


Figure 14. Third Creek Pollutograph for TS November Storm.

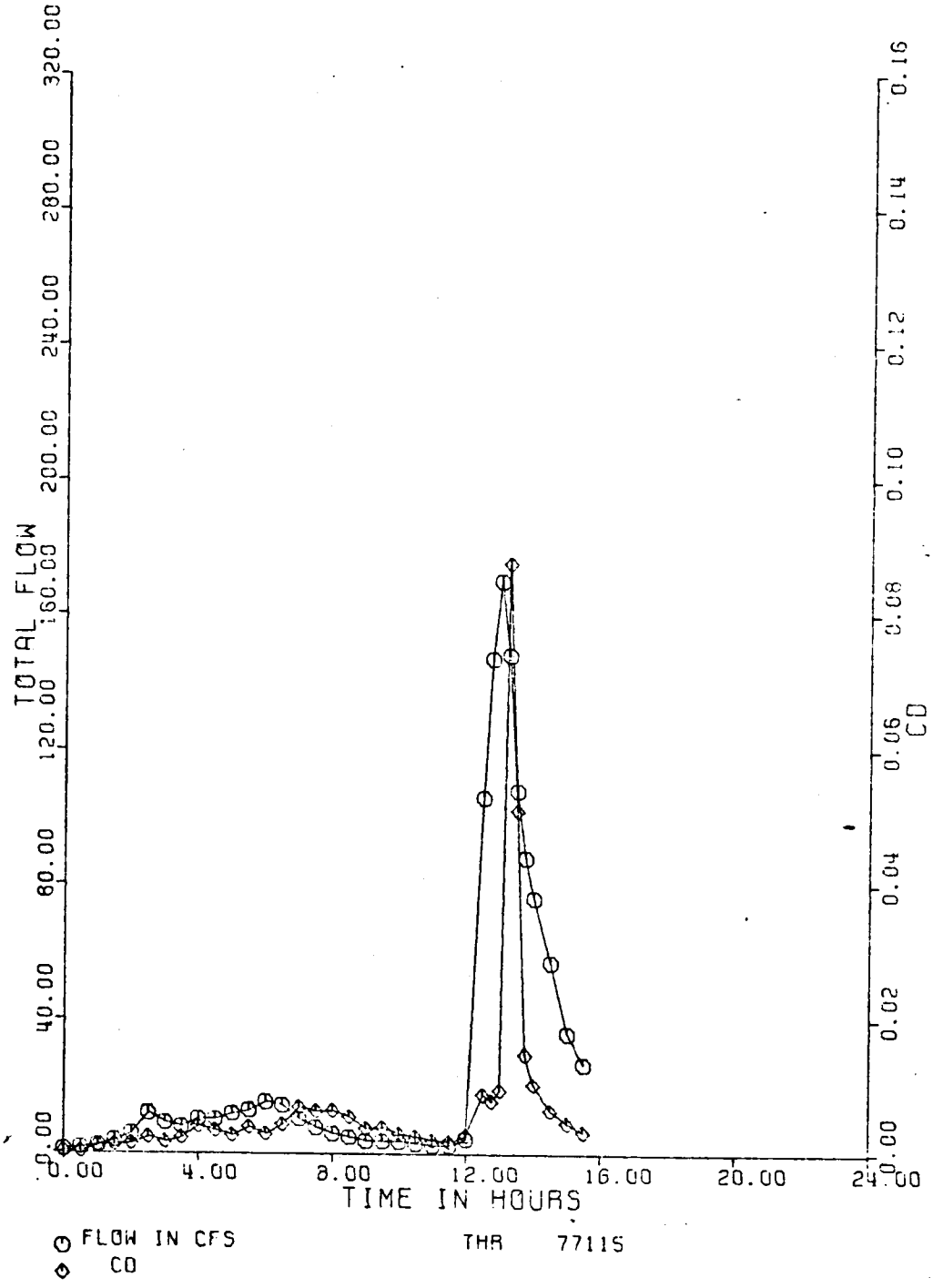


Figure 15. Third Creek Pollutograph for Cd November Storm.

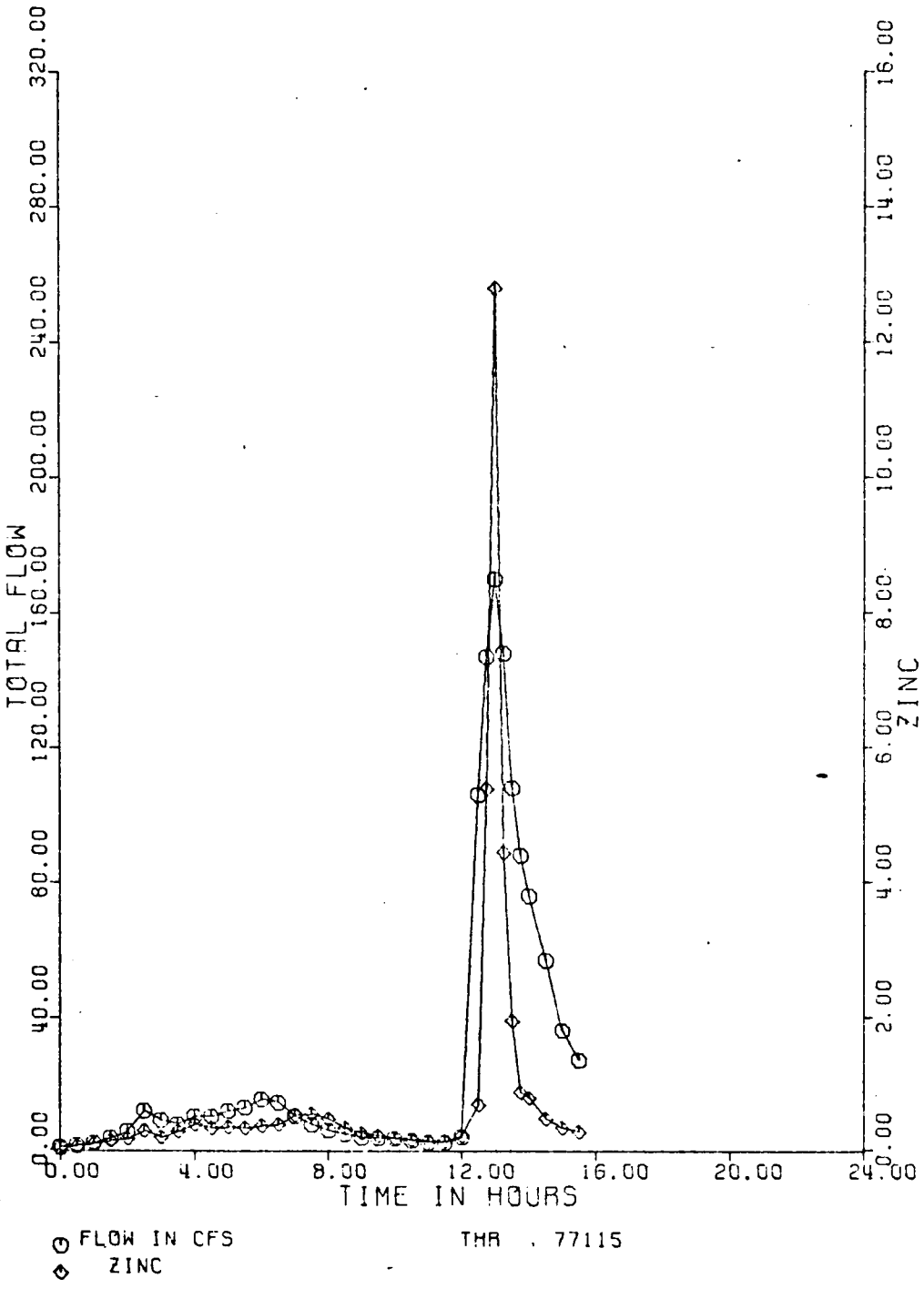


Figure 16. Third Creek Pollutograph for Zn November Storm.

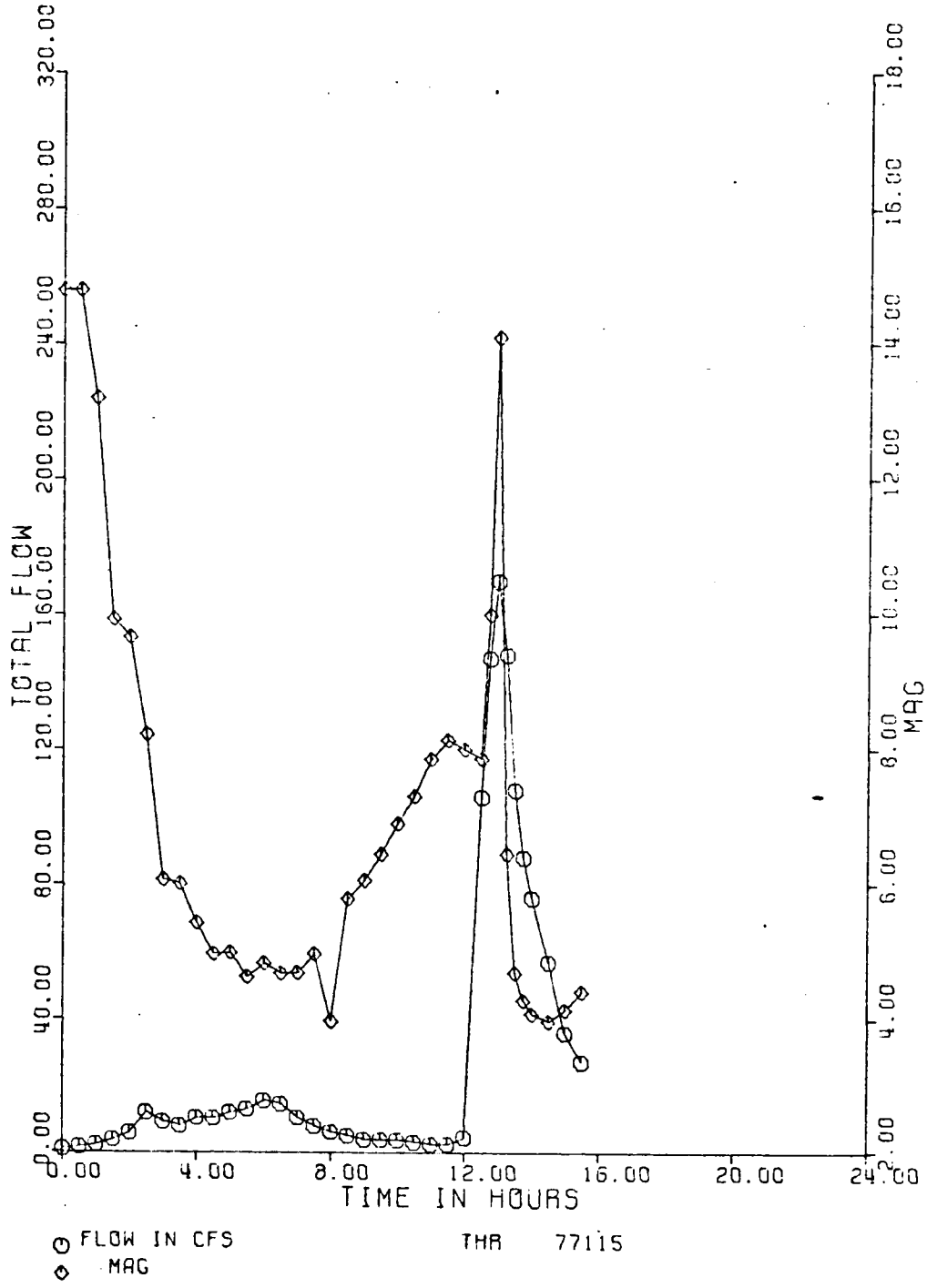


Figure 17. Third Creek Pollutograph for Mg November Storm.

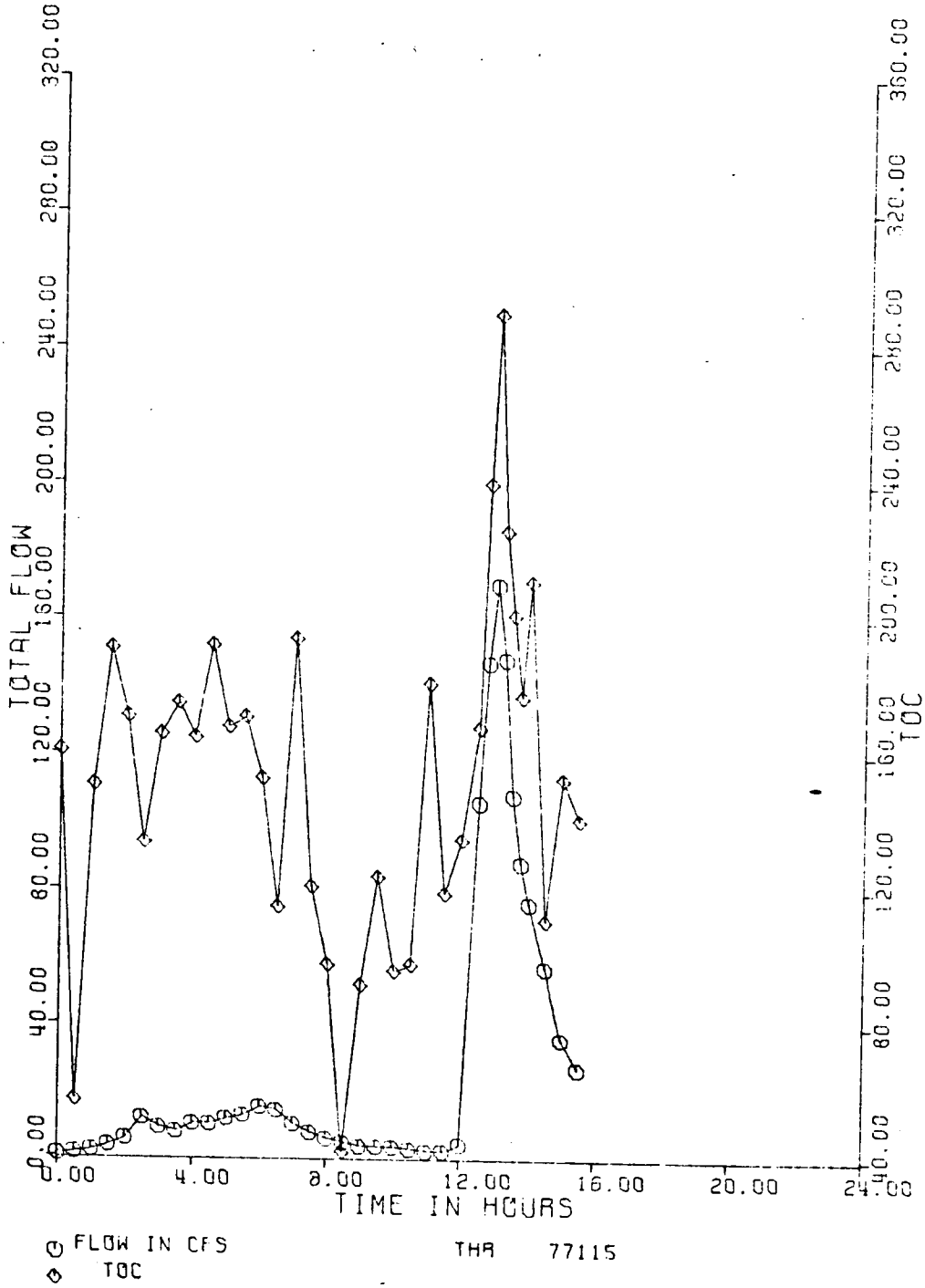


Figure 18. Third Creek Pollutograph for TOC November Storm.

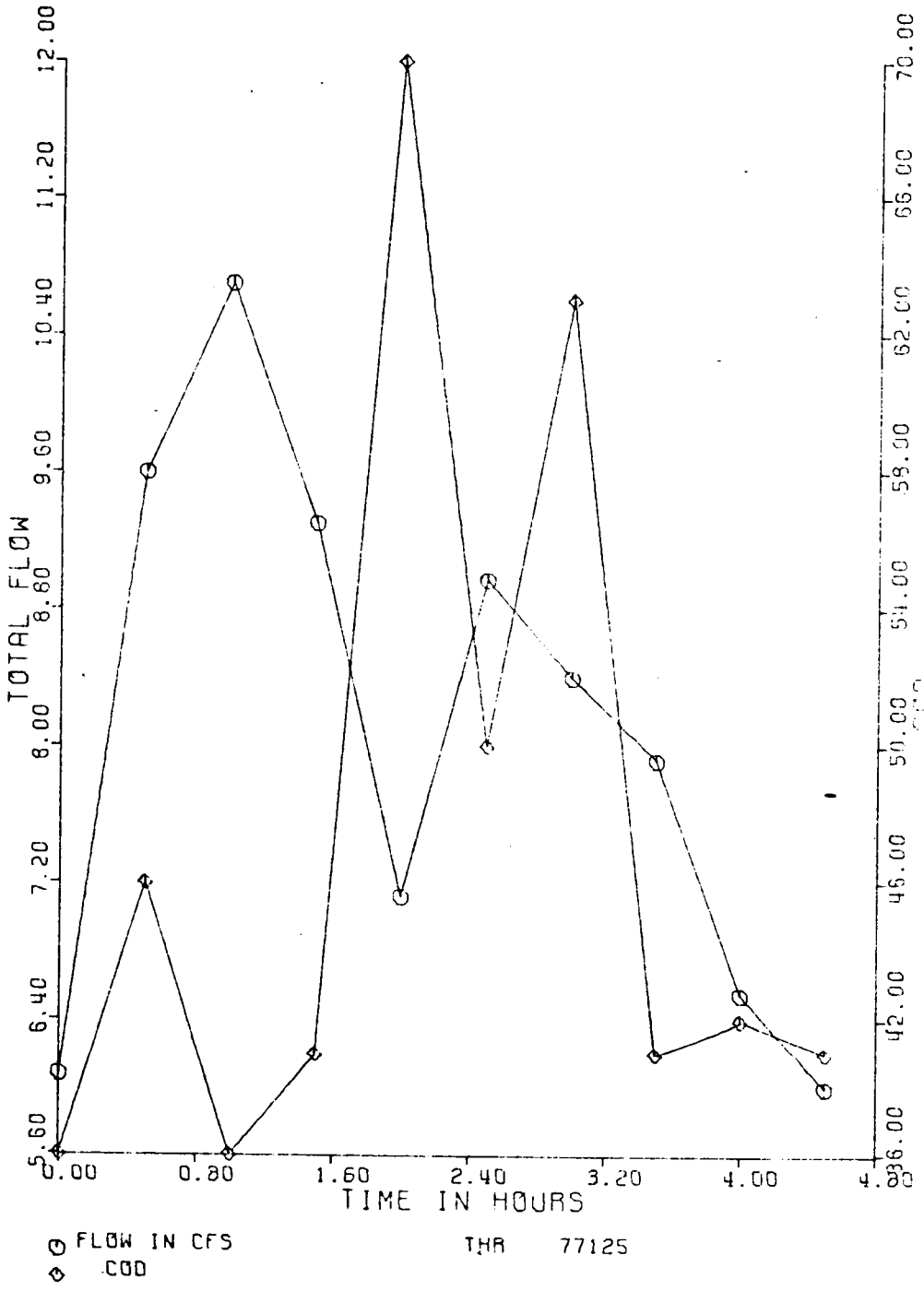


Figure 19. Third Creek Pollutograph for COD December Storm.

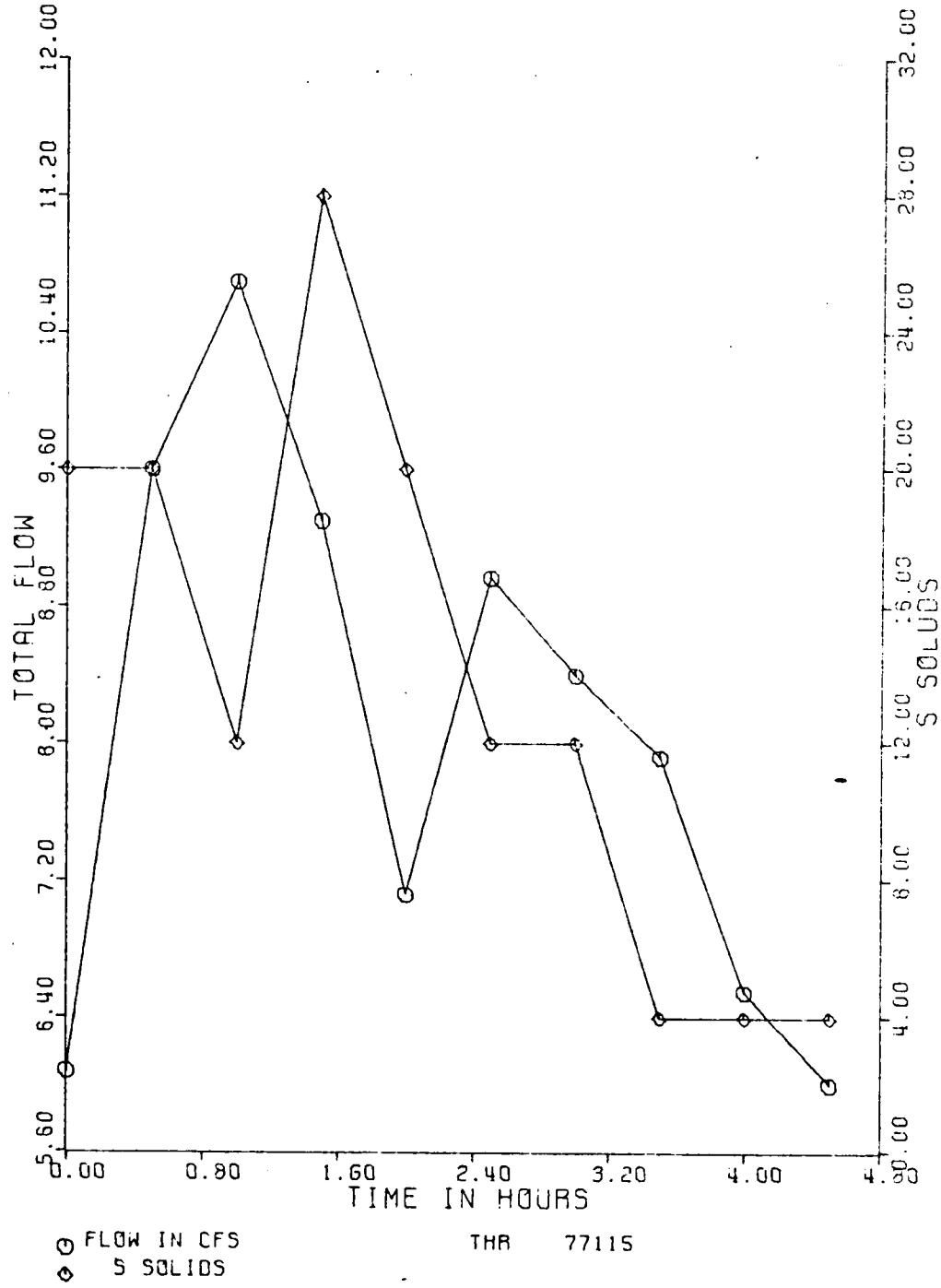


Figure 20. Third Creek Pollutograph for SS December Storm.

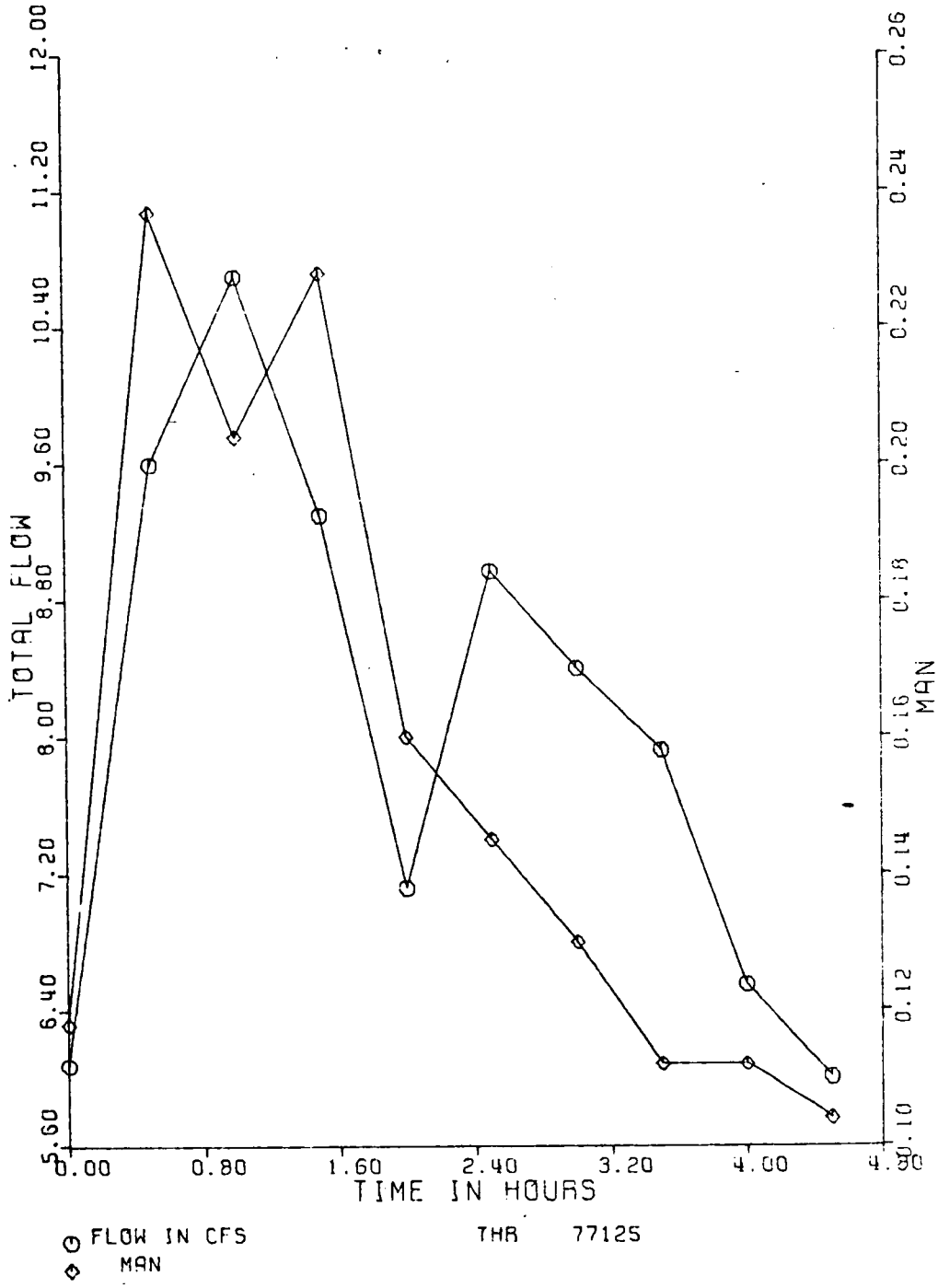


Figure 21. Third Creek Pollutograph for Mn December Storm.

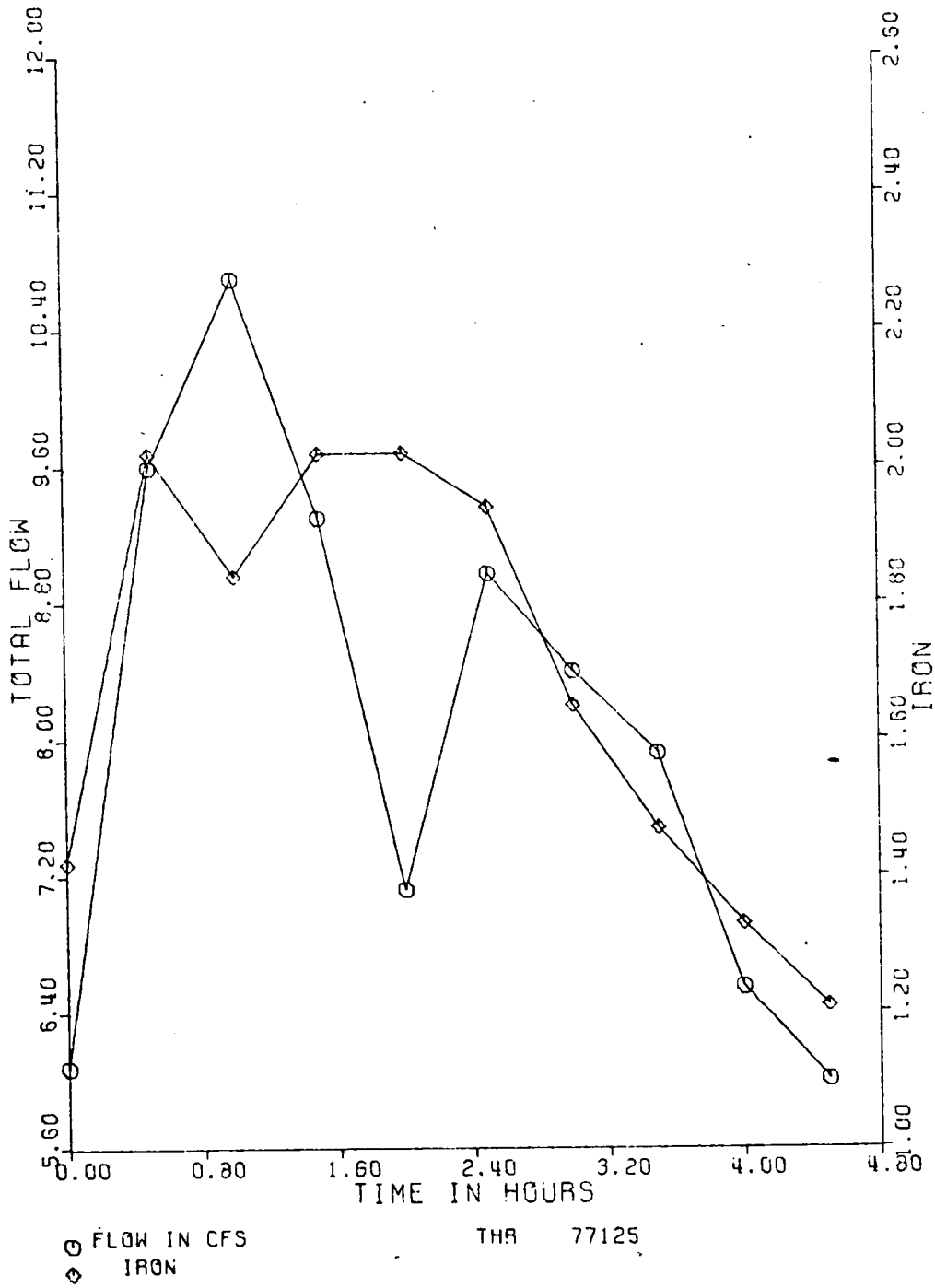


Figure 22. Third Creek Pollutograph for Fe December Storm.

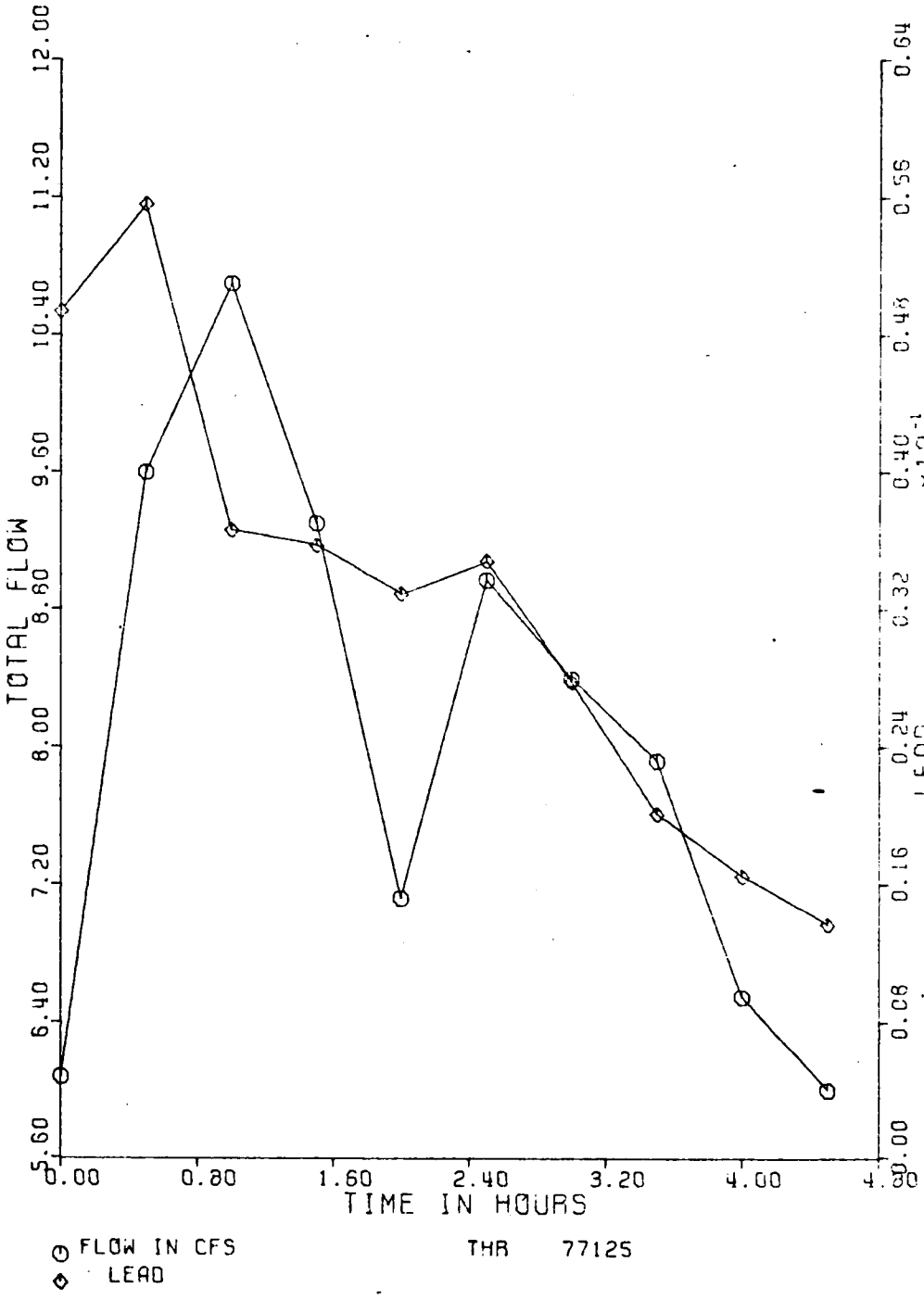


Figure 23. Third Creek Pollutograph for Pb December Storm.

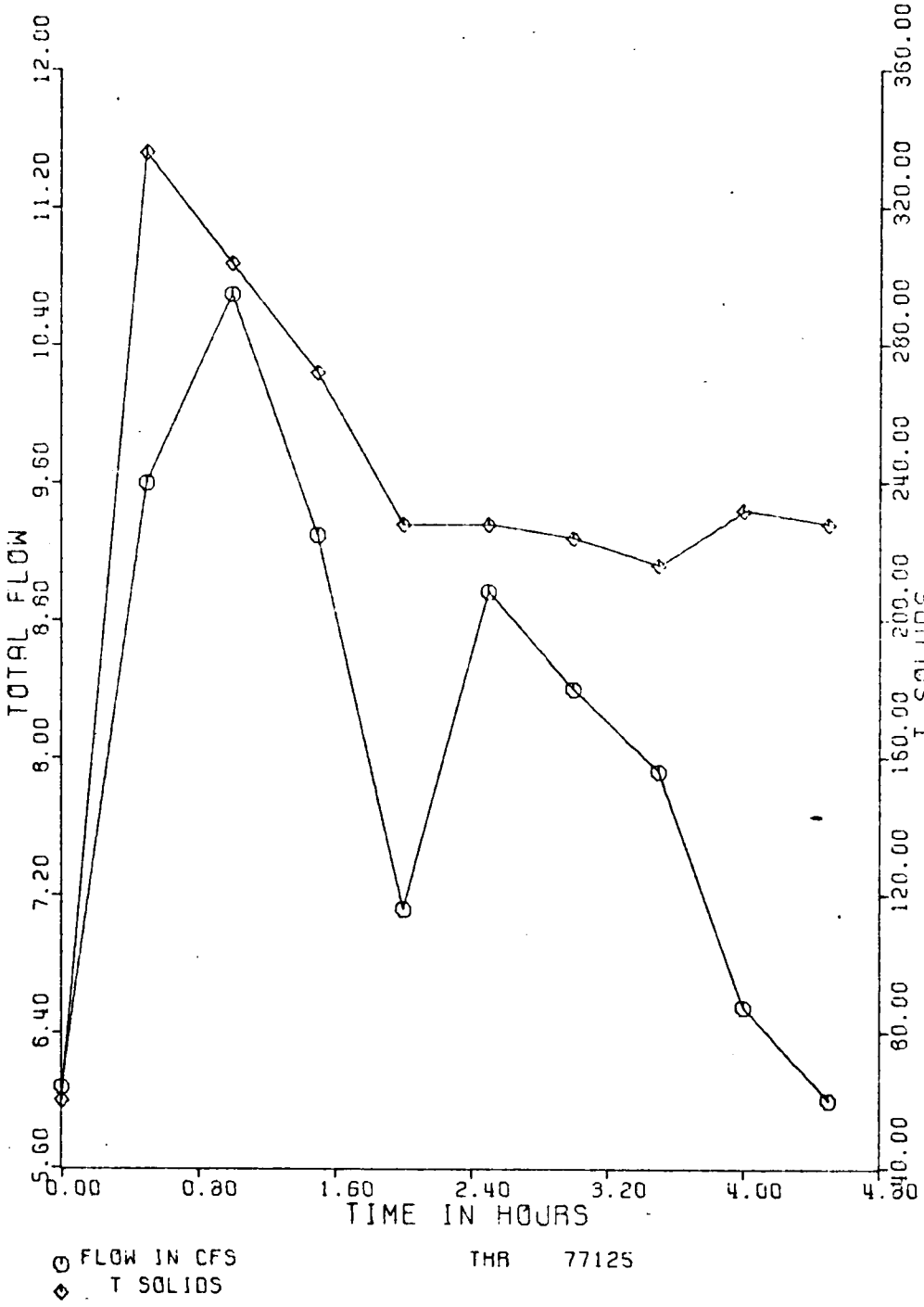


Figure 24. Third Creek Pollutograph for TS December Storm.

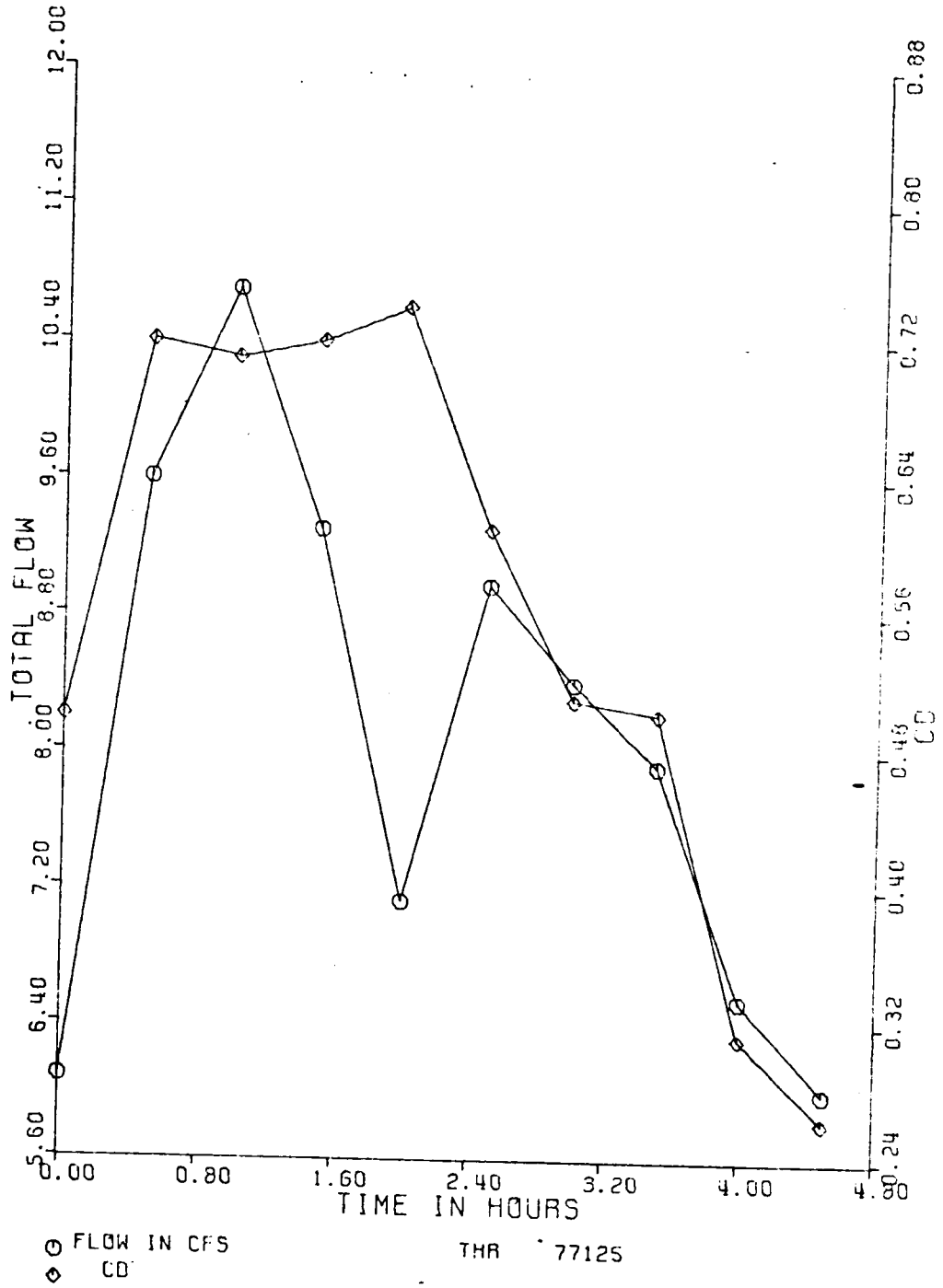


Figure 25. Third Creek Pollutograph for Cd December Storm.

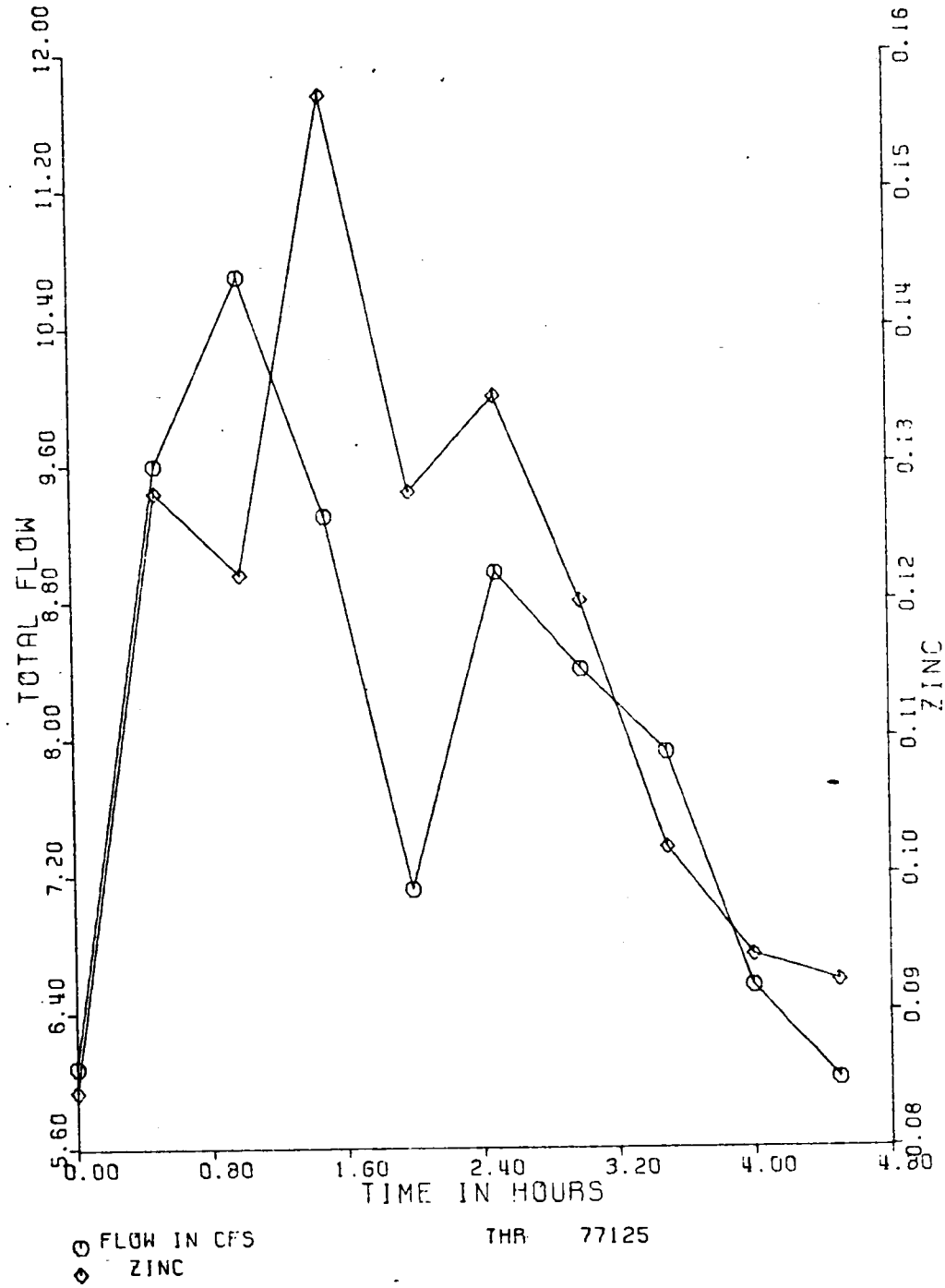


Figure 26. Third Creek Pollutograph for Zn December Storm.

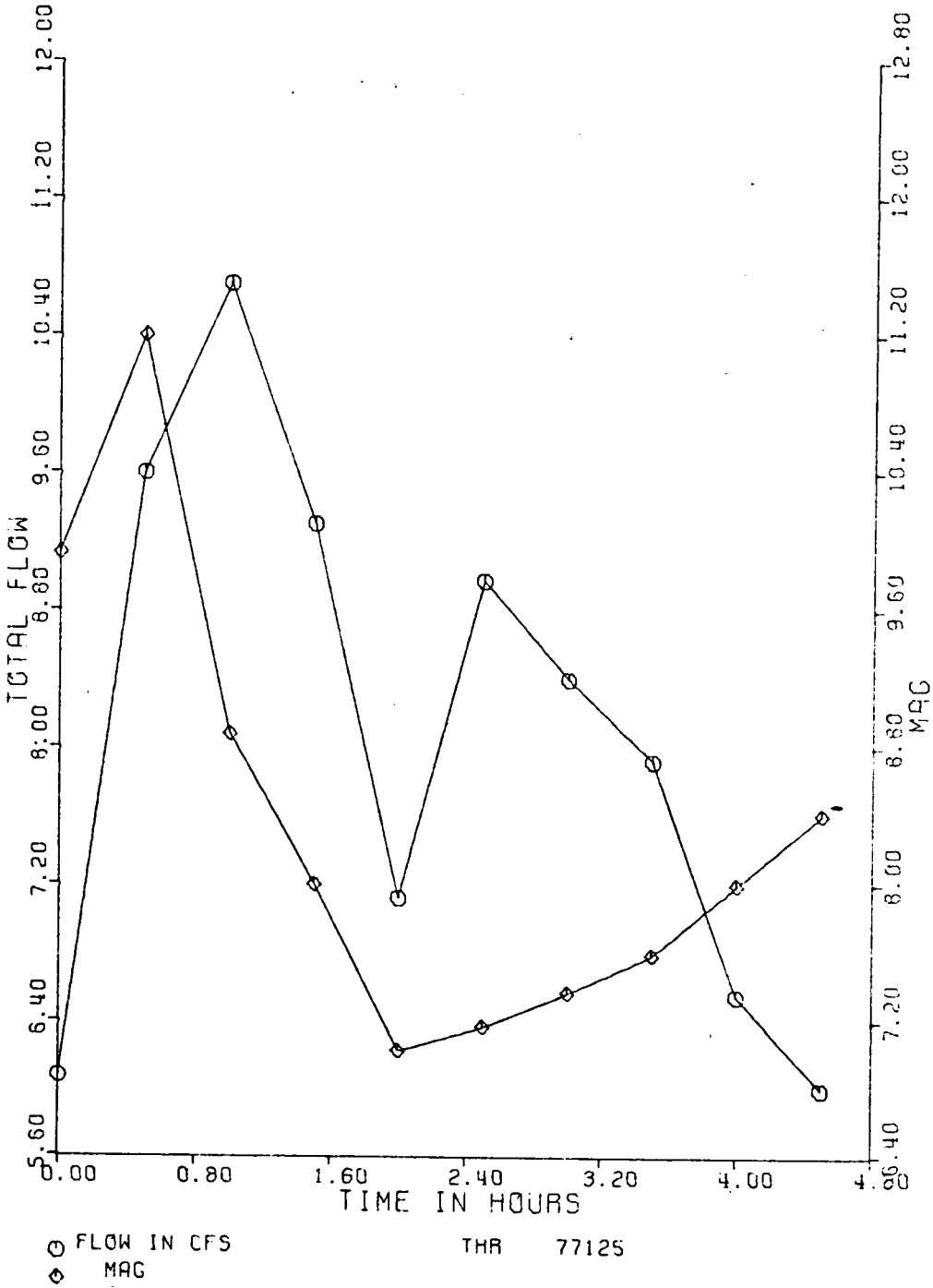


Figure 27. Third Creek Pollutograph for Mg December Storm.

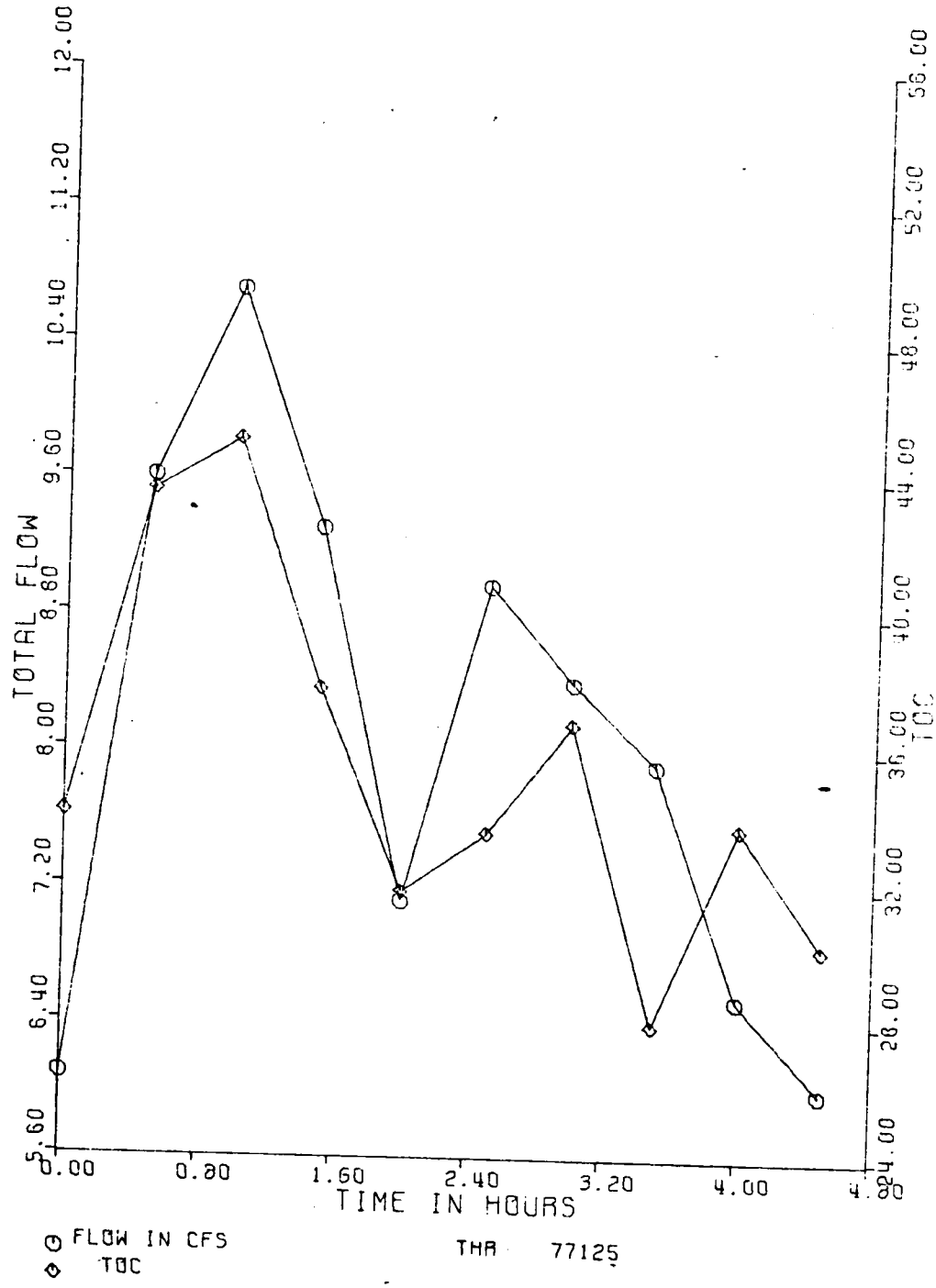


Figure 28. Third Creek Pollutograph for TOC December Storm.

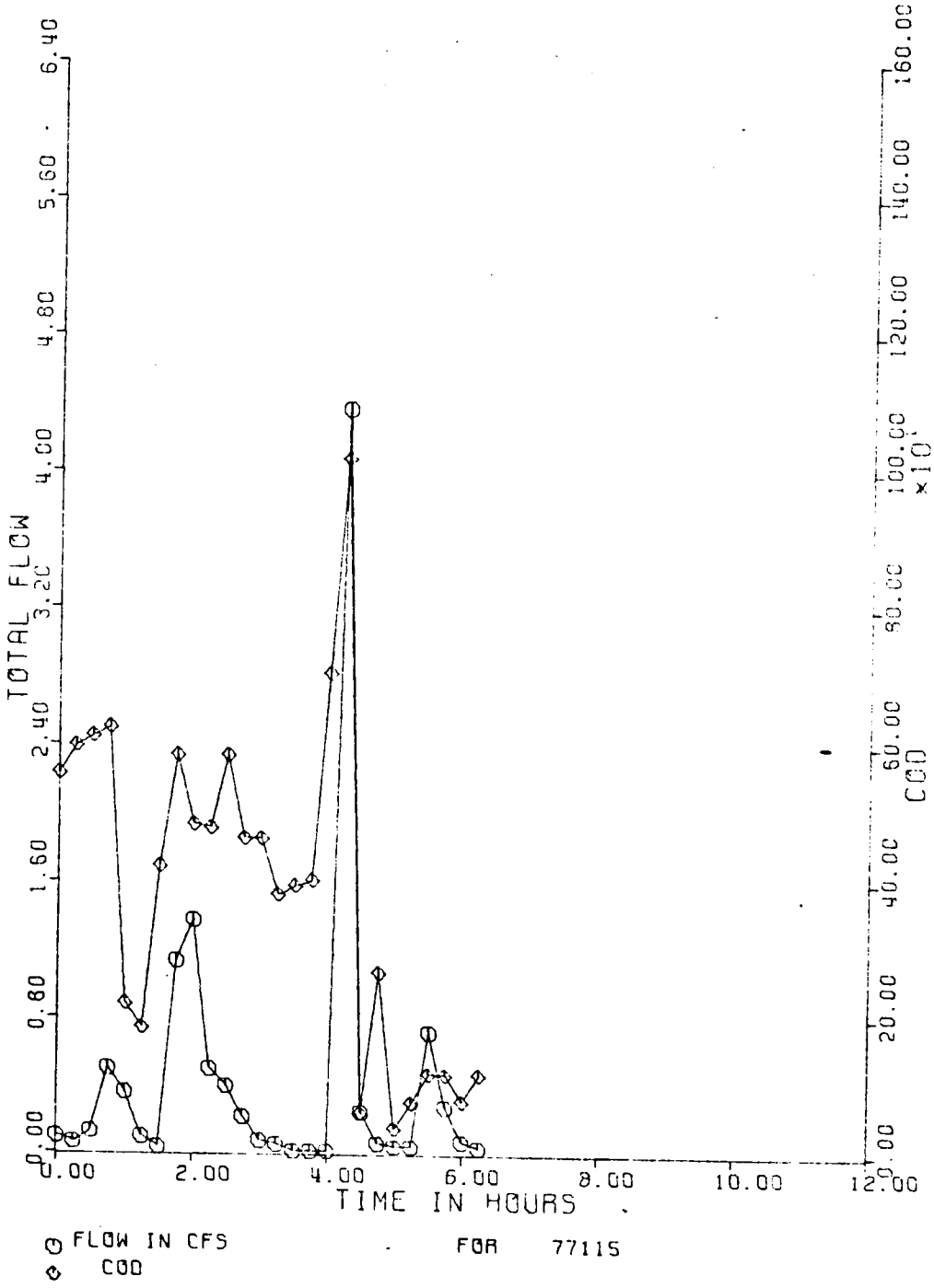


Figure 29. Fourth Creek Pollutograph for COD November Storm.

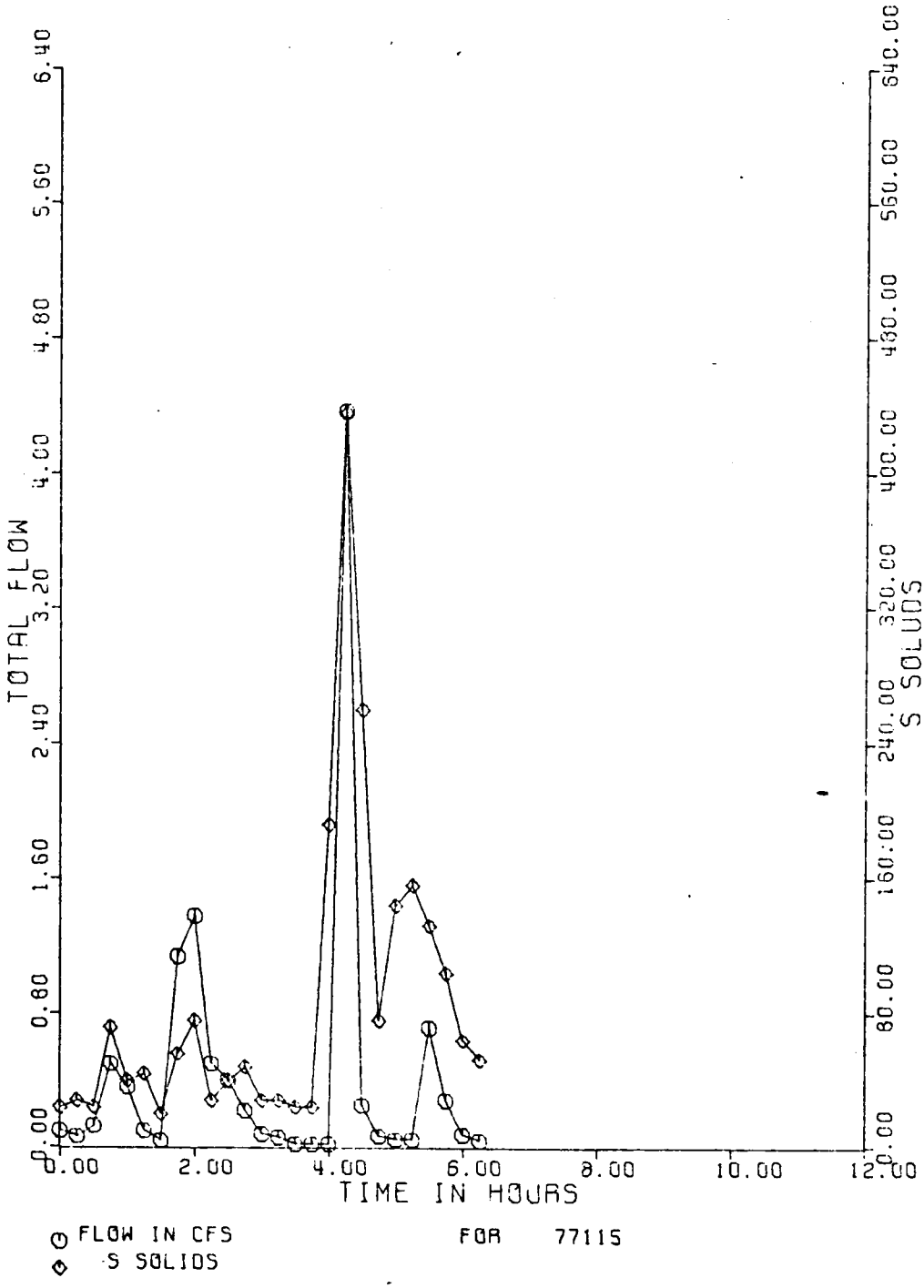


Figure 30. Fourth Creek Pollutograph for SS November Storm.

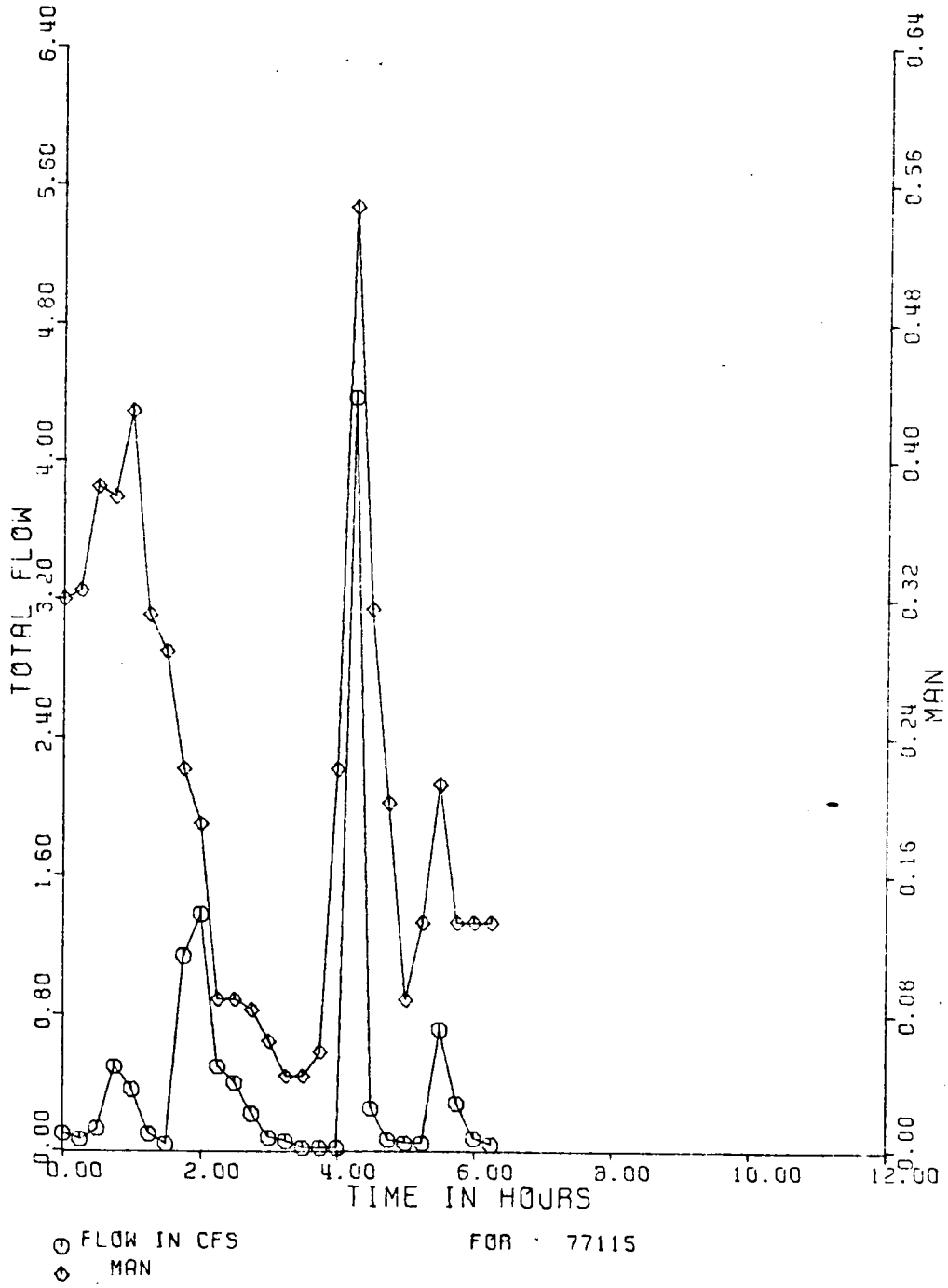


Figure 31. Fourth Creek Pollutograph for Mn November Storm.

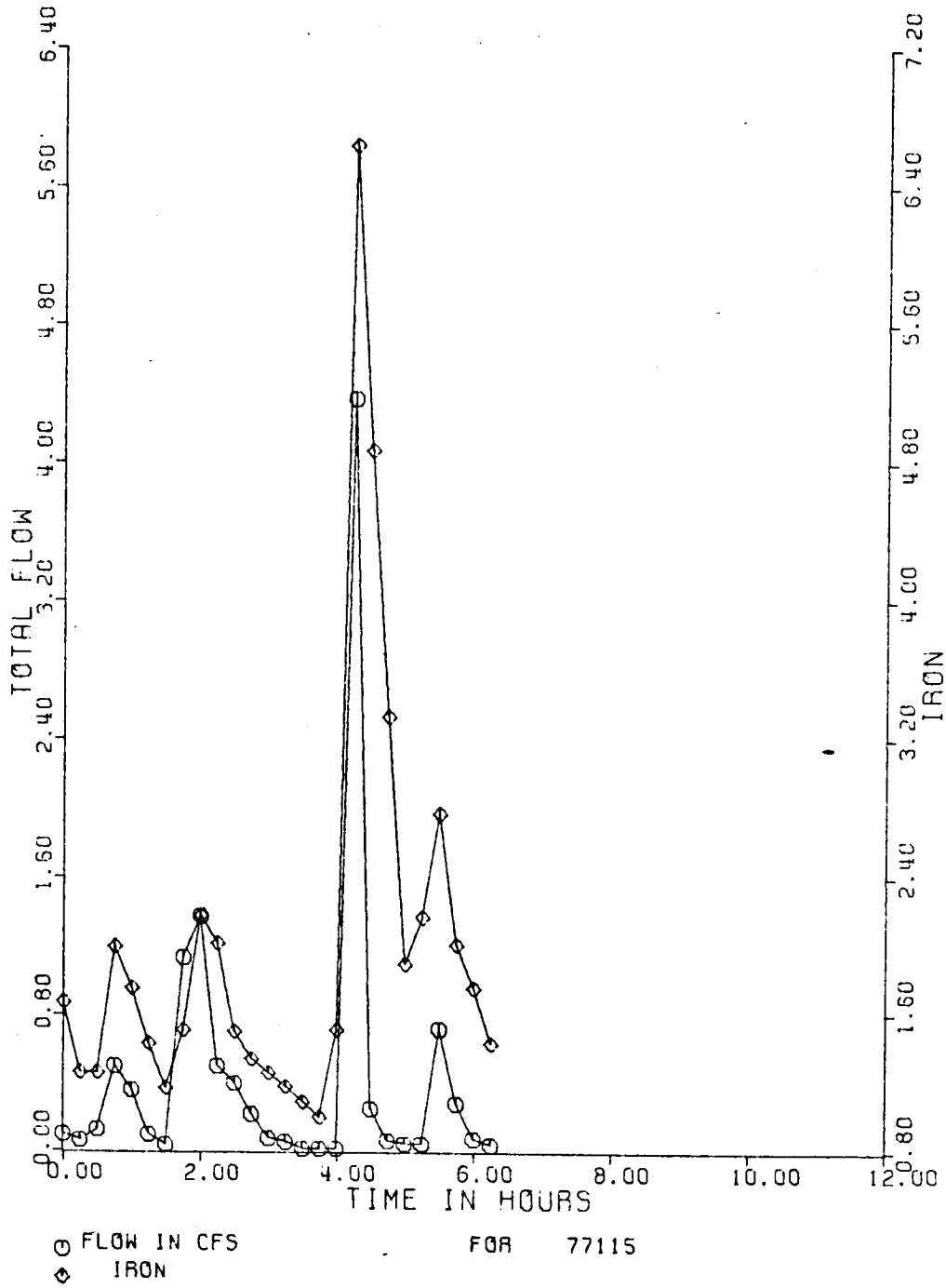


Figure 32. Fourth Creek Pollutograph for Fe November Storm.

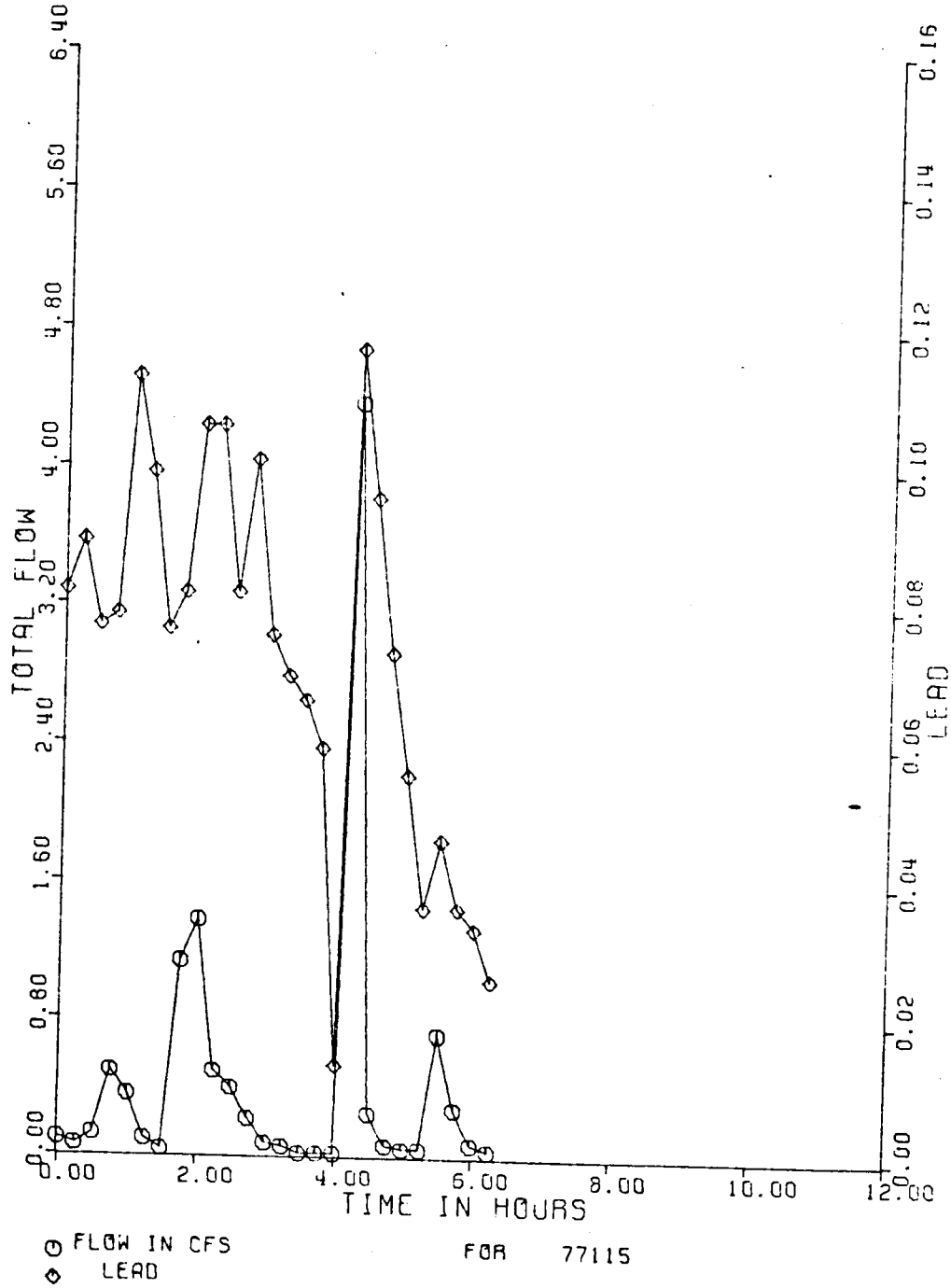


Figure 33. Fourth Creek Pollutograph for Pb November Storm.

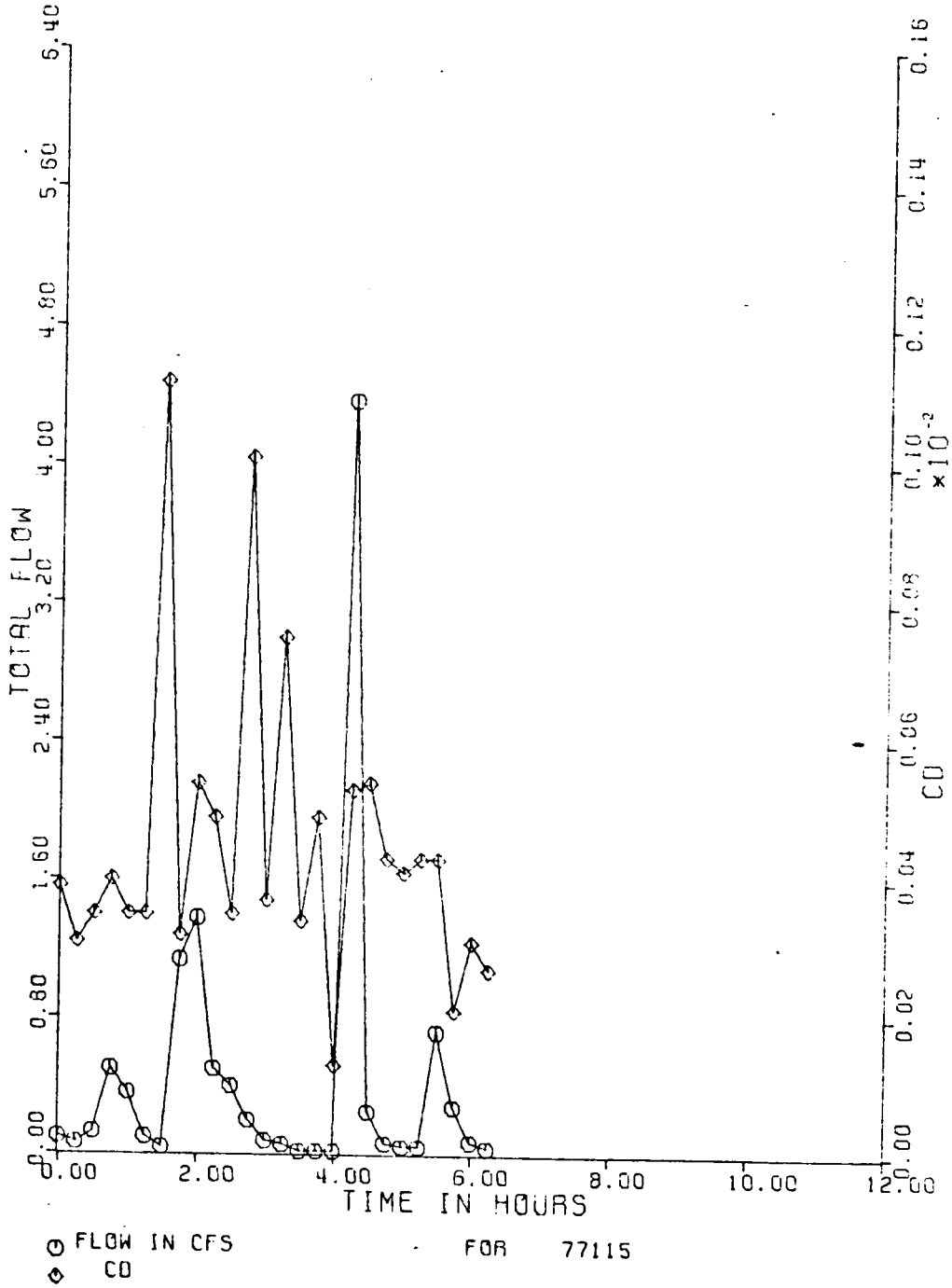


Figure 34. Fourth Creek Pollutograph for Cd November Storm.

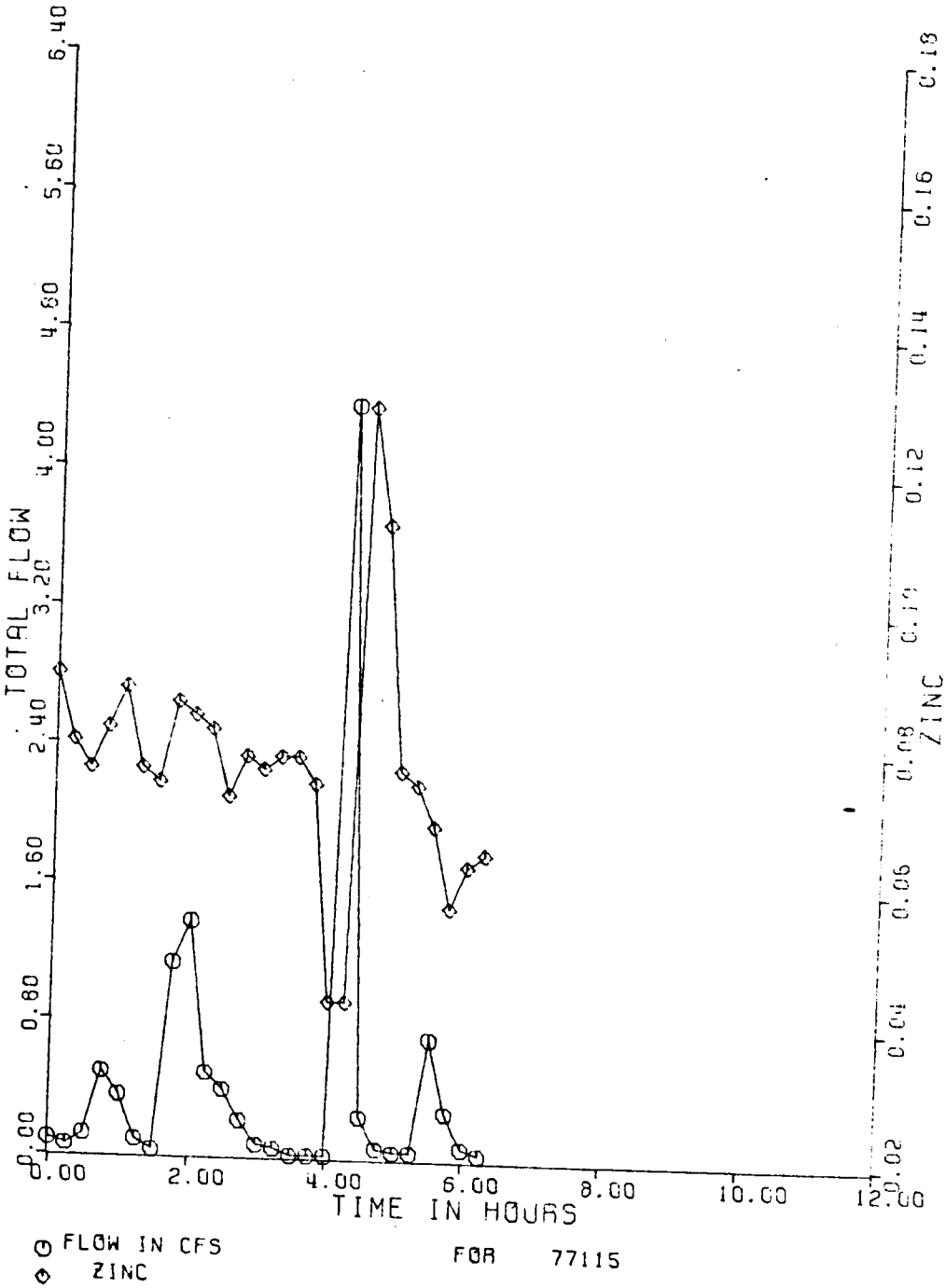


Figure 35. Fourth Creek Pollutograph for Zn November Storm.

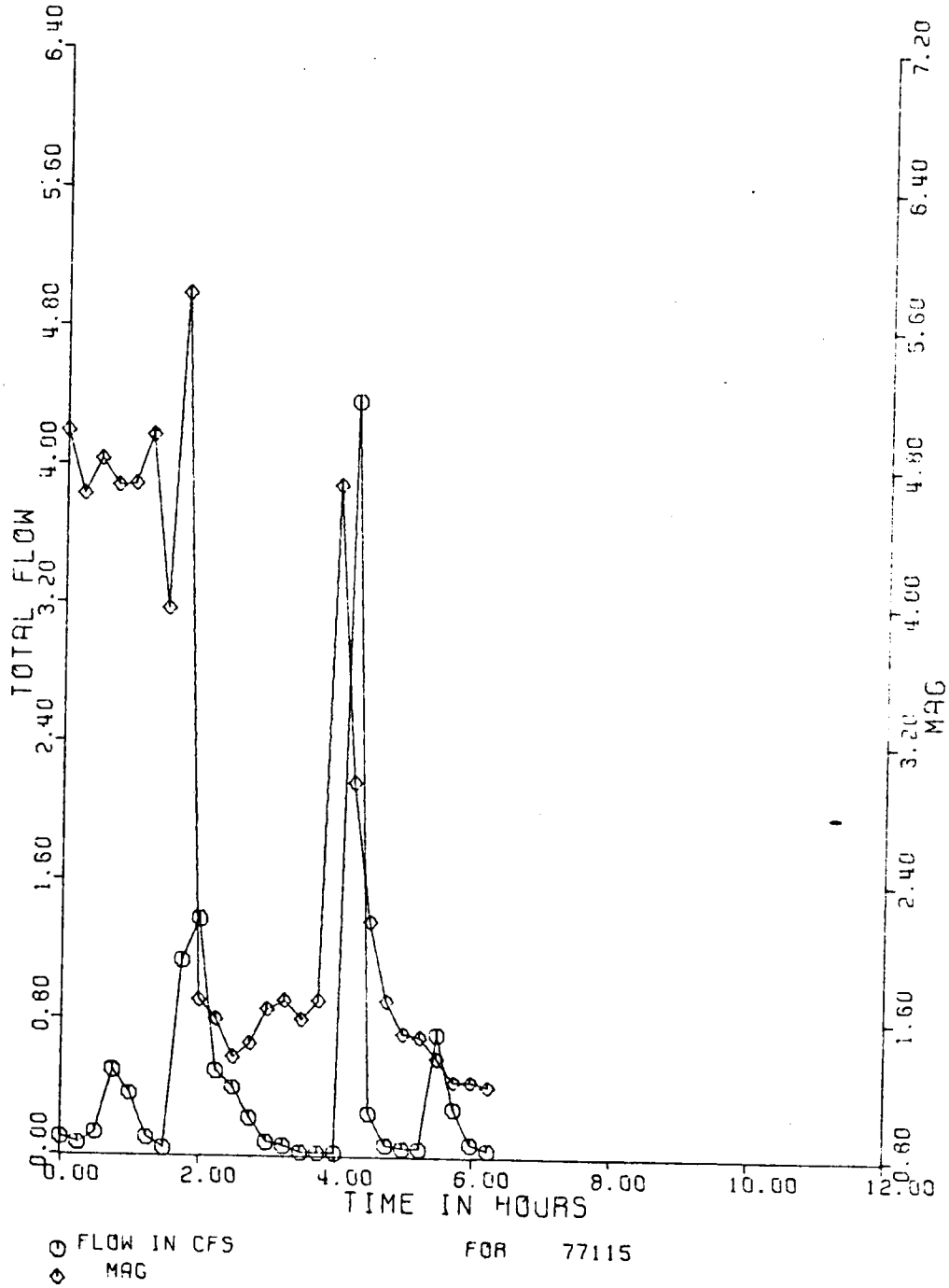


Figure 36. Fourth Creek Pollutograph for Mg November Storm.

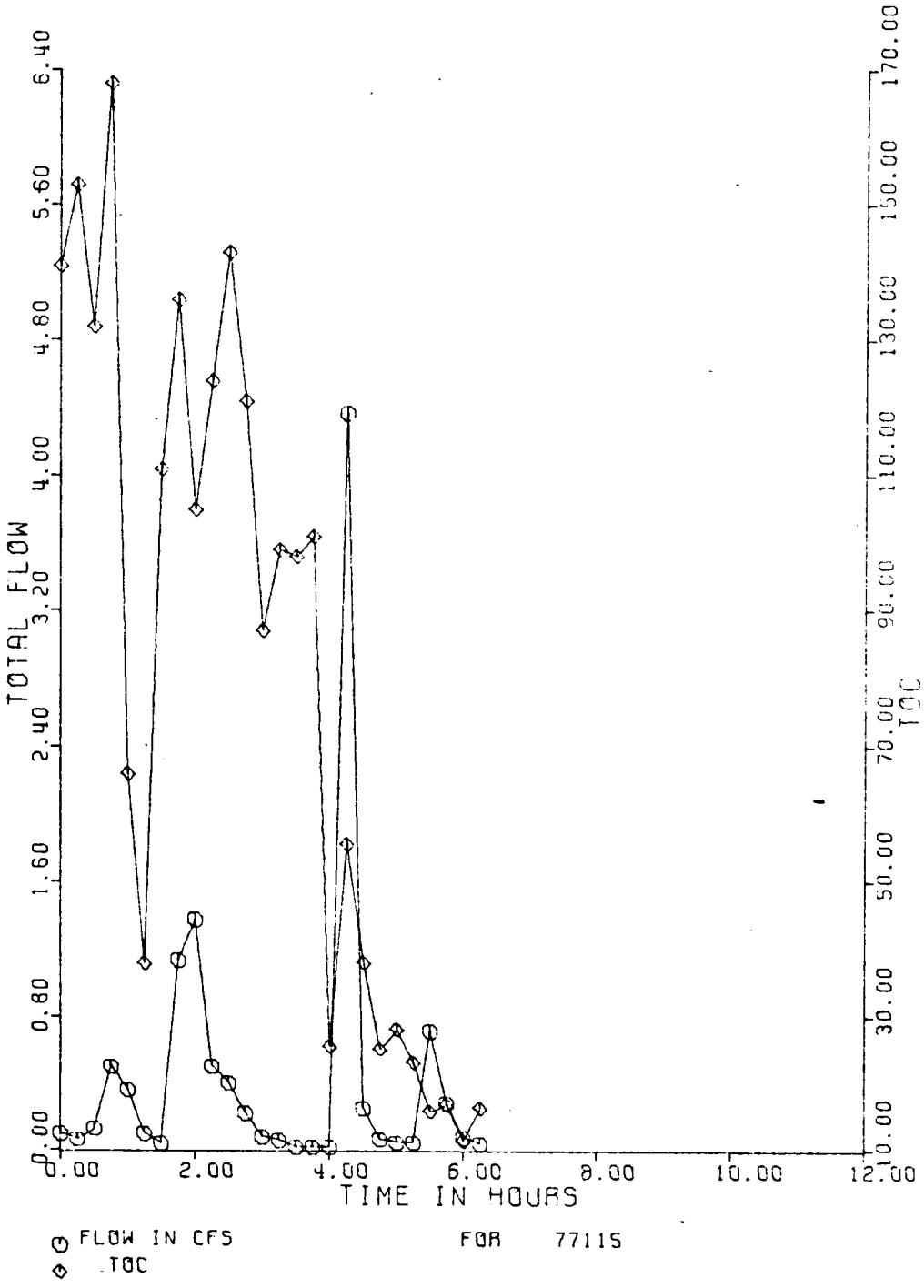


Figure 37. Fourth Creek Pollutograph for TOC November Storm.

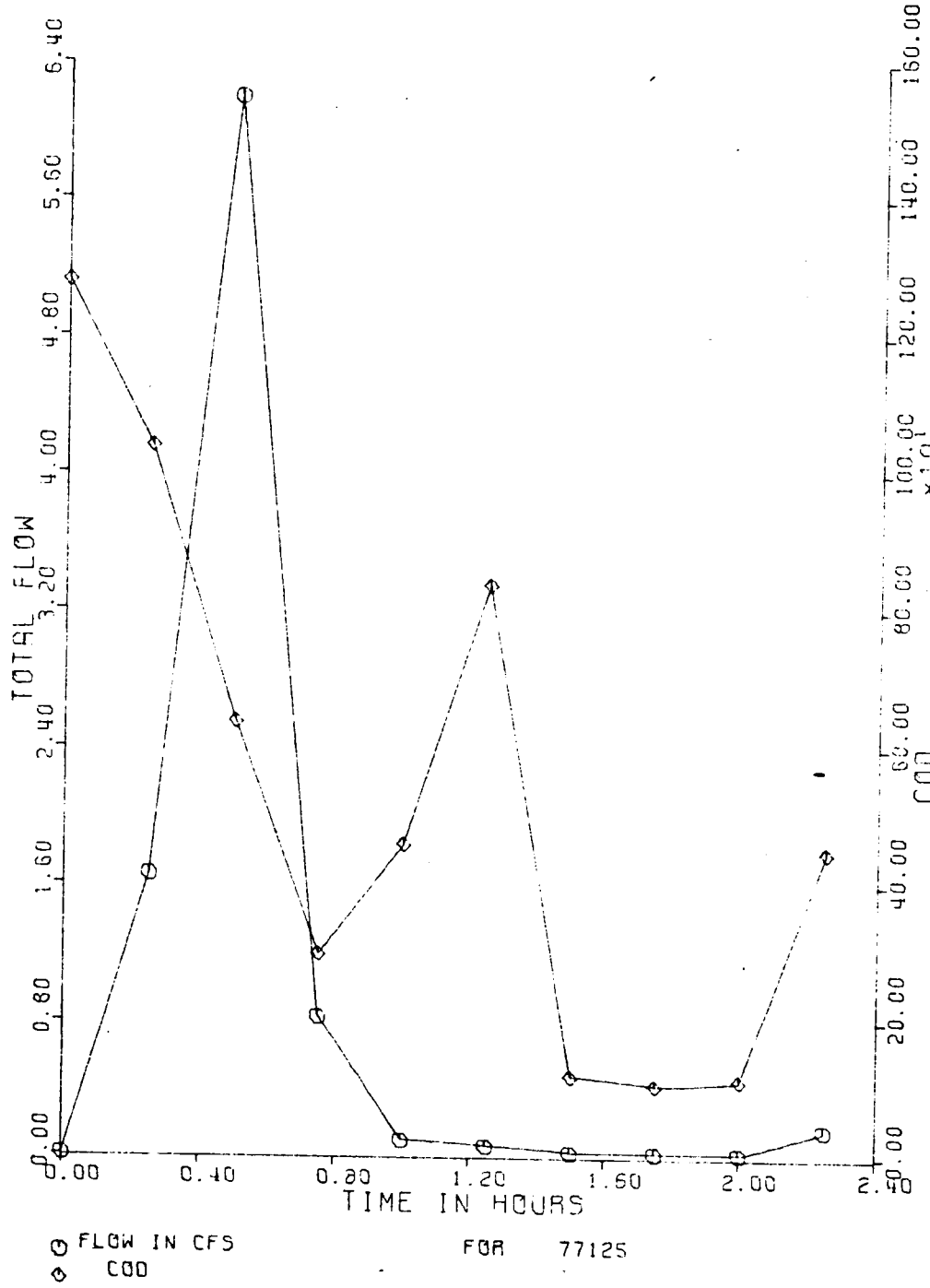


Figure 38. Fourth Creek Pollutograph for COD December Storm.

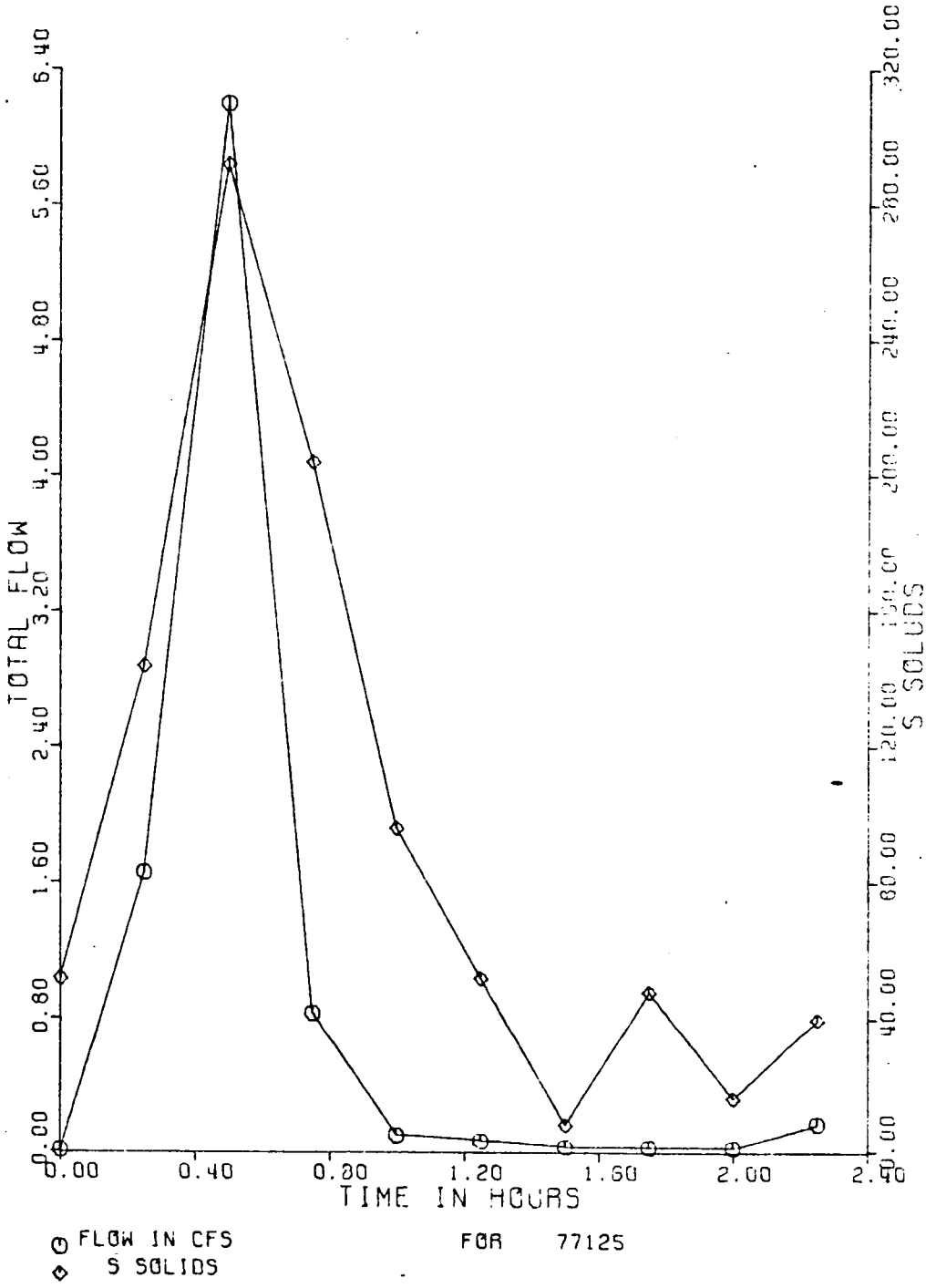


Figure 39. Fourth Creek Pollutograph for SS December Storm.

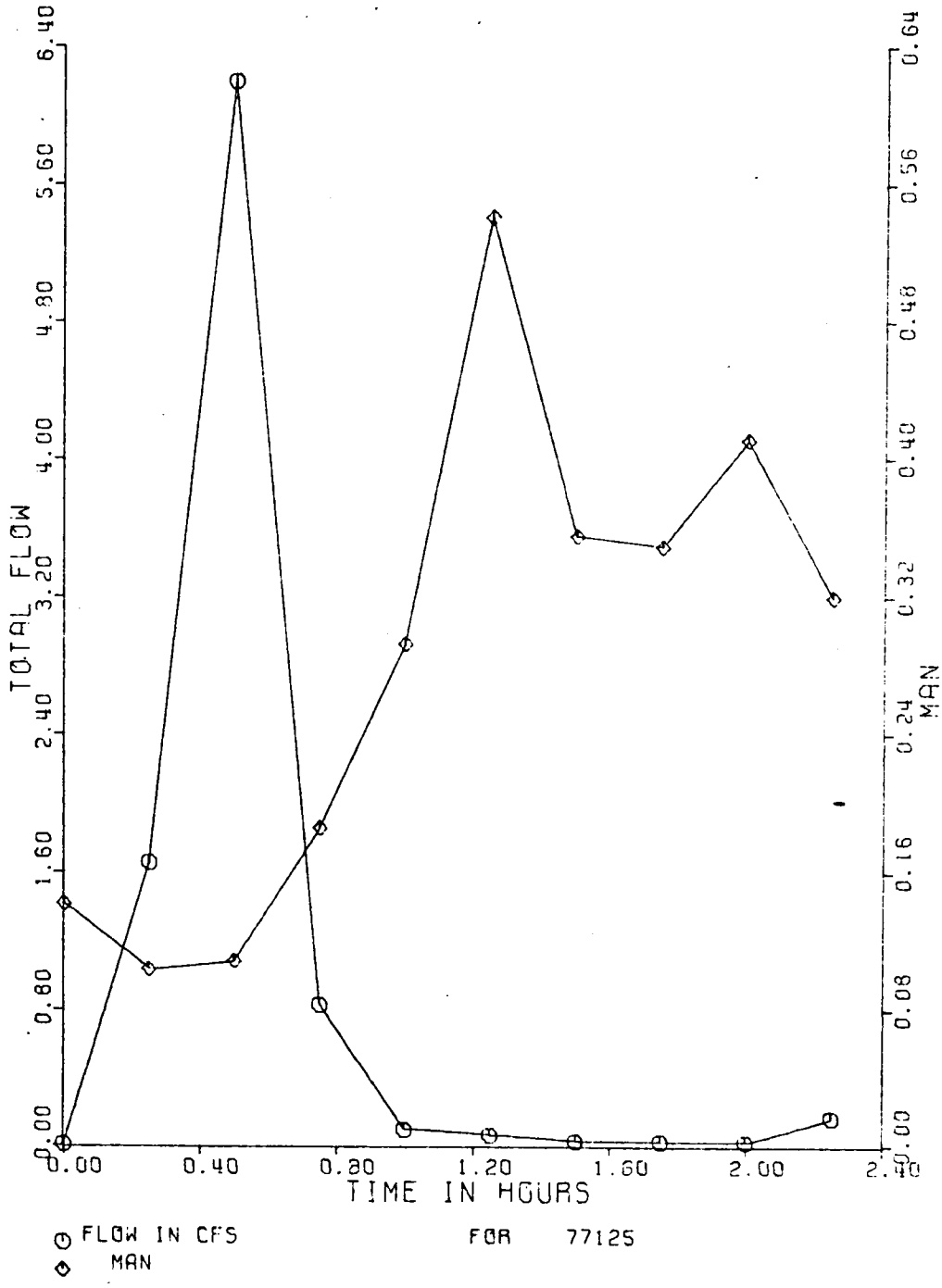


Figure 40. Fourth Creek Pollutograph for Mn December Storm.

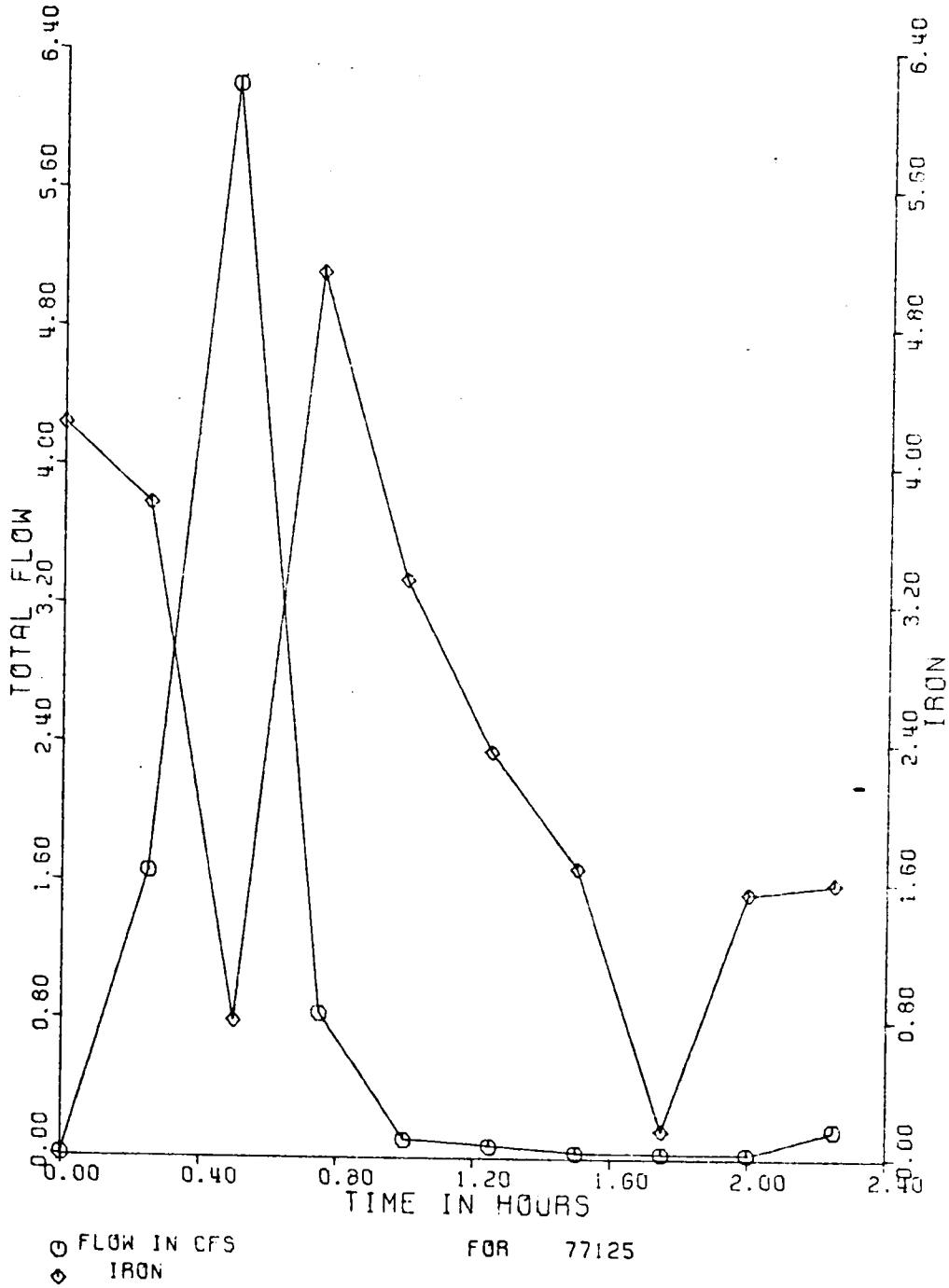


Figure 41. Fourth Creek Pollutograph for Fe December Storm.

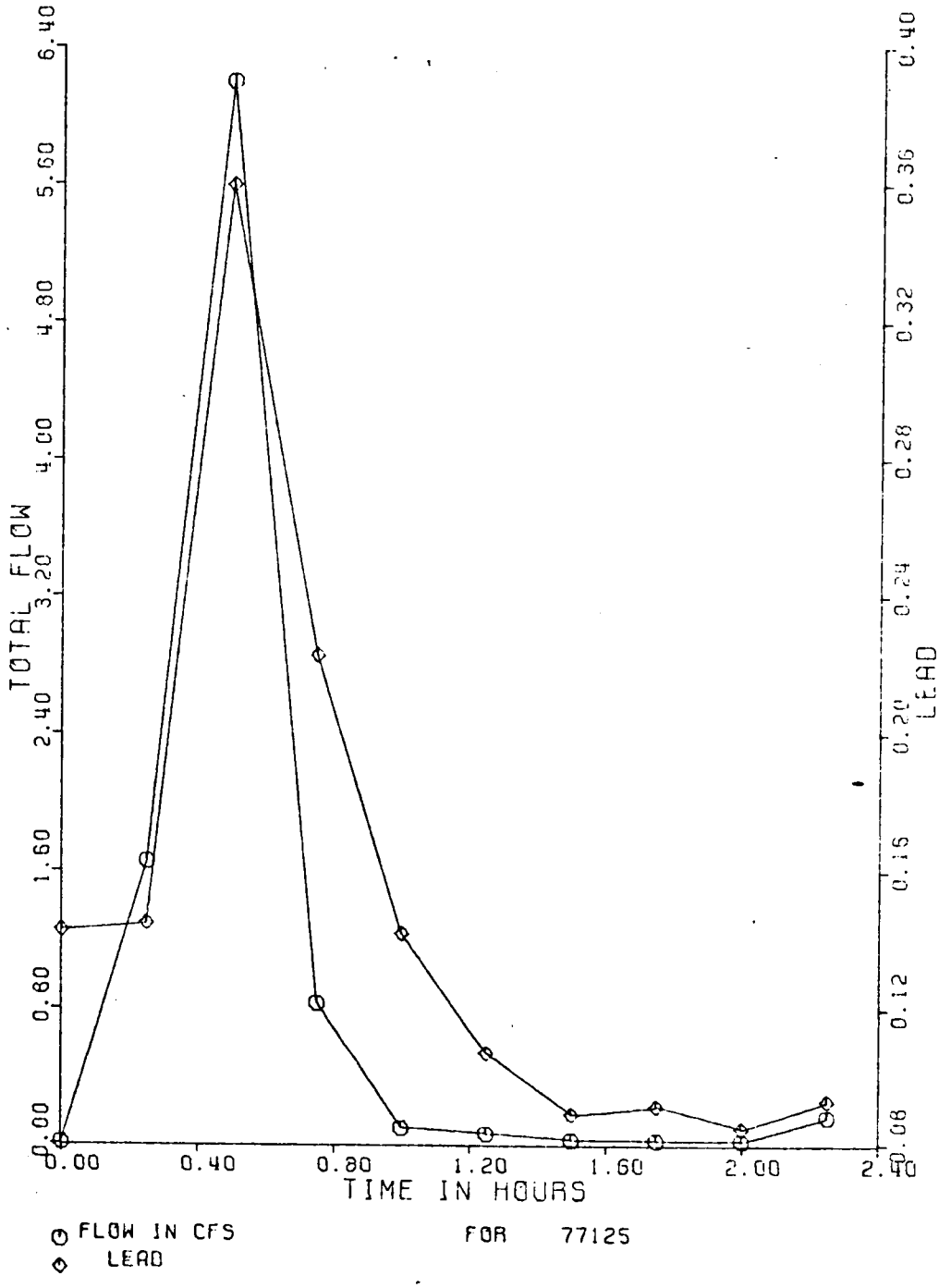


Figure 42. Fourth Creek Pollutograph for Pb December Storm.

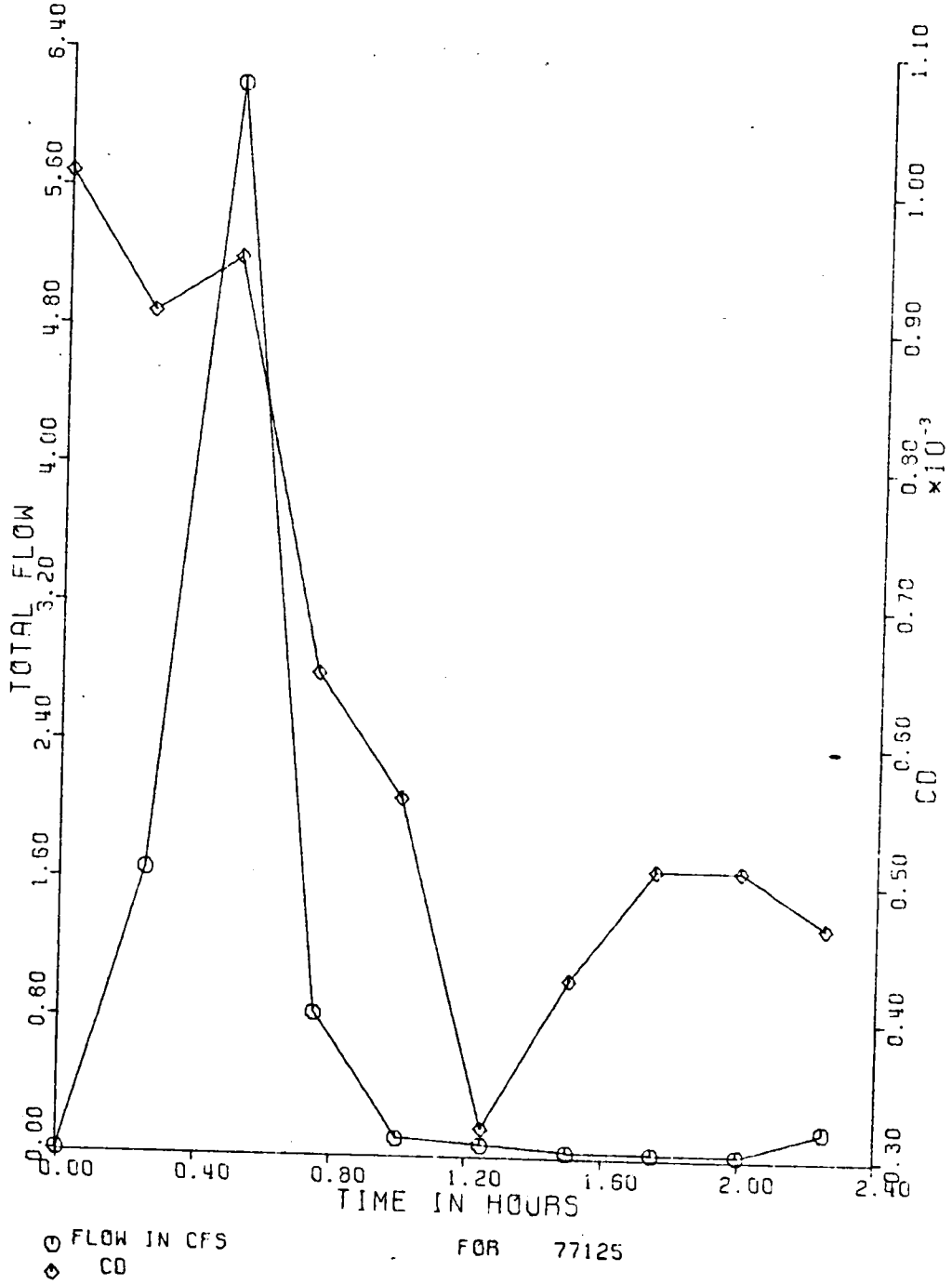


Figure 43. Fourth Creek Pollutograph for Cd December Storm.

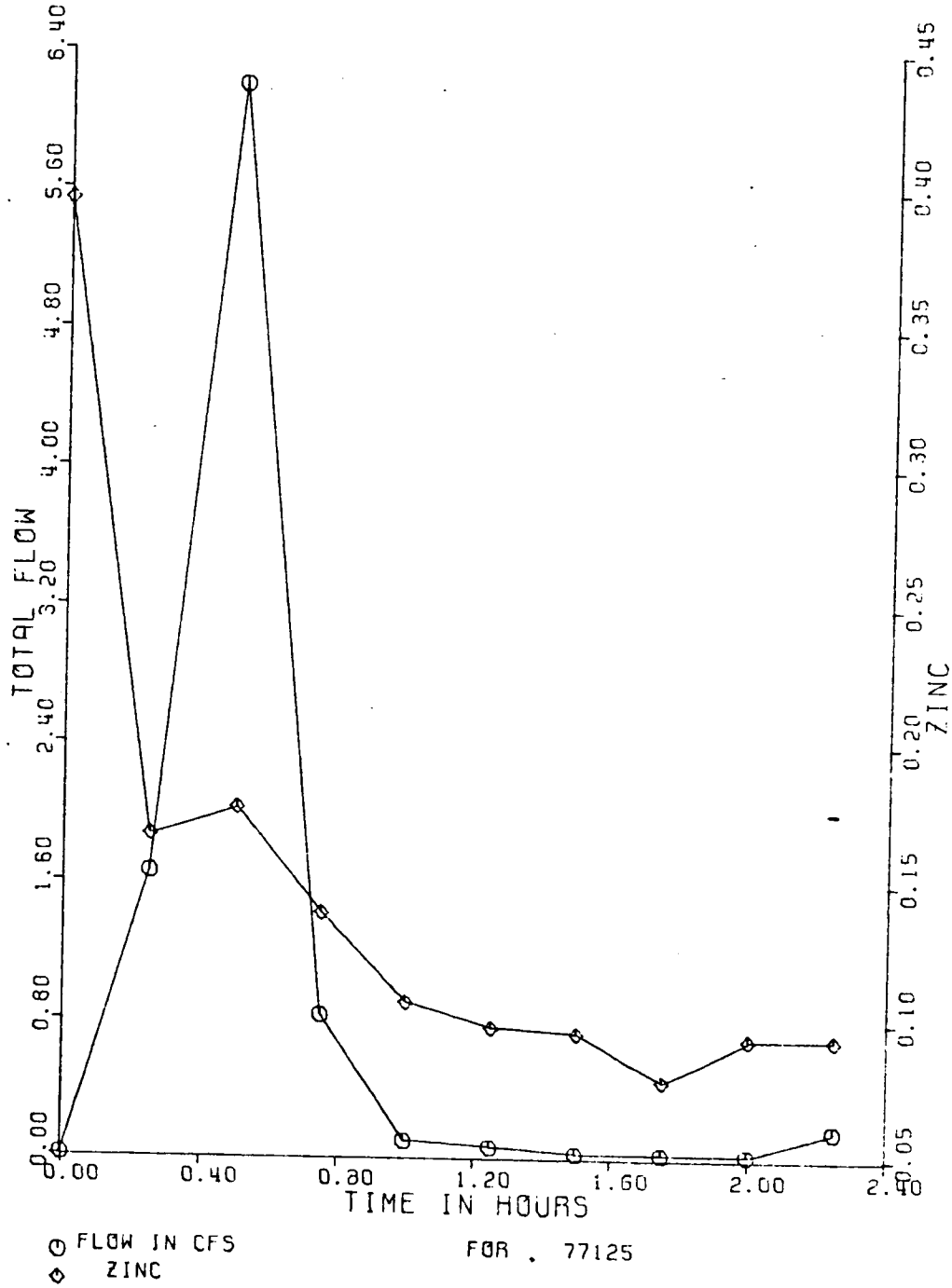


Figure 44. Fourth Creek Pollutograph for Zn December Storm.

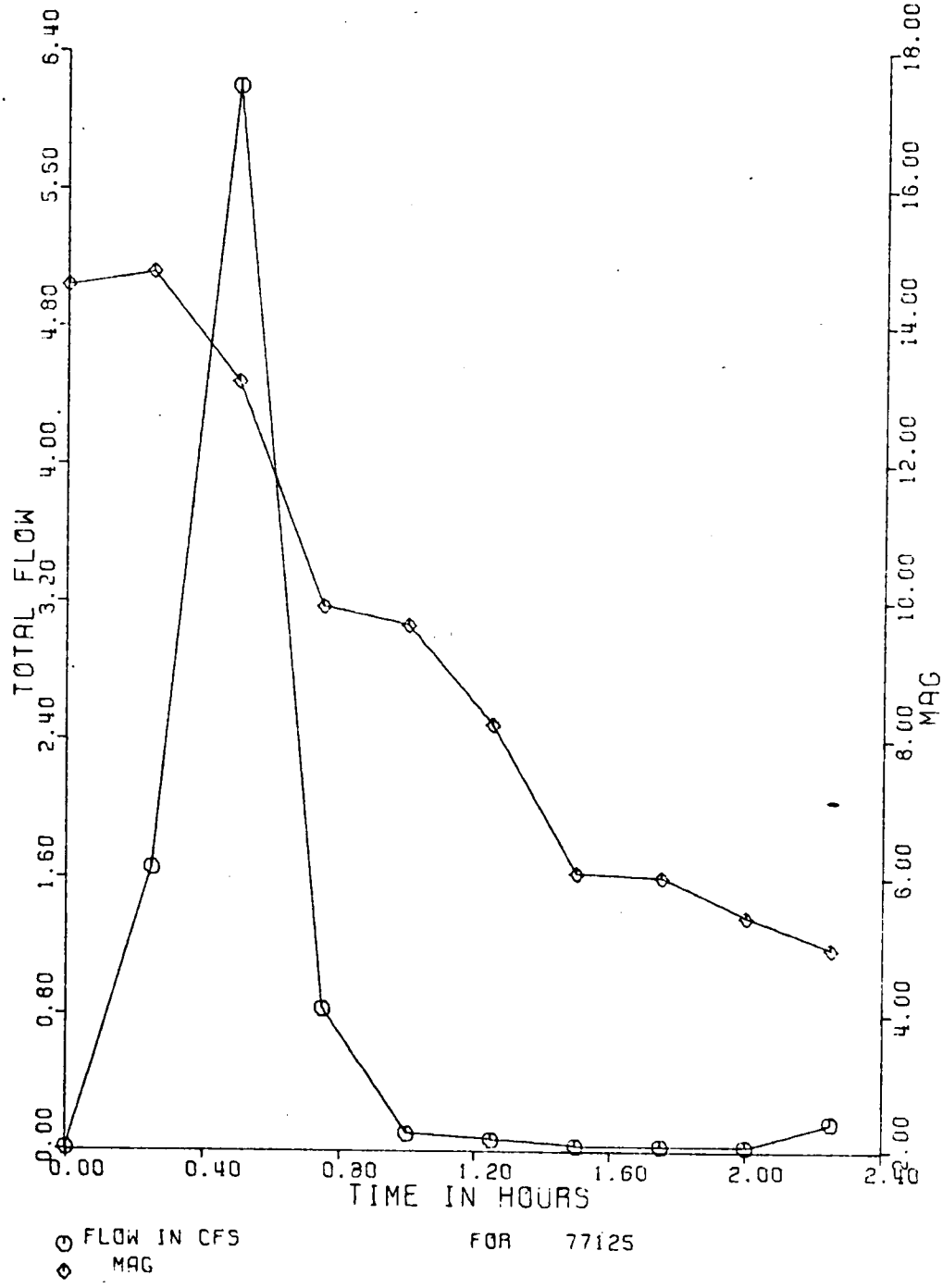


Figure 45. Fourth Creek Pollutograph for Mg December Storm.

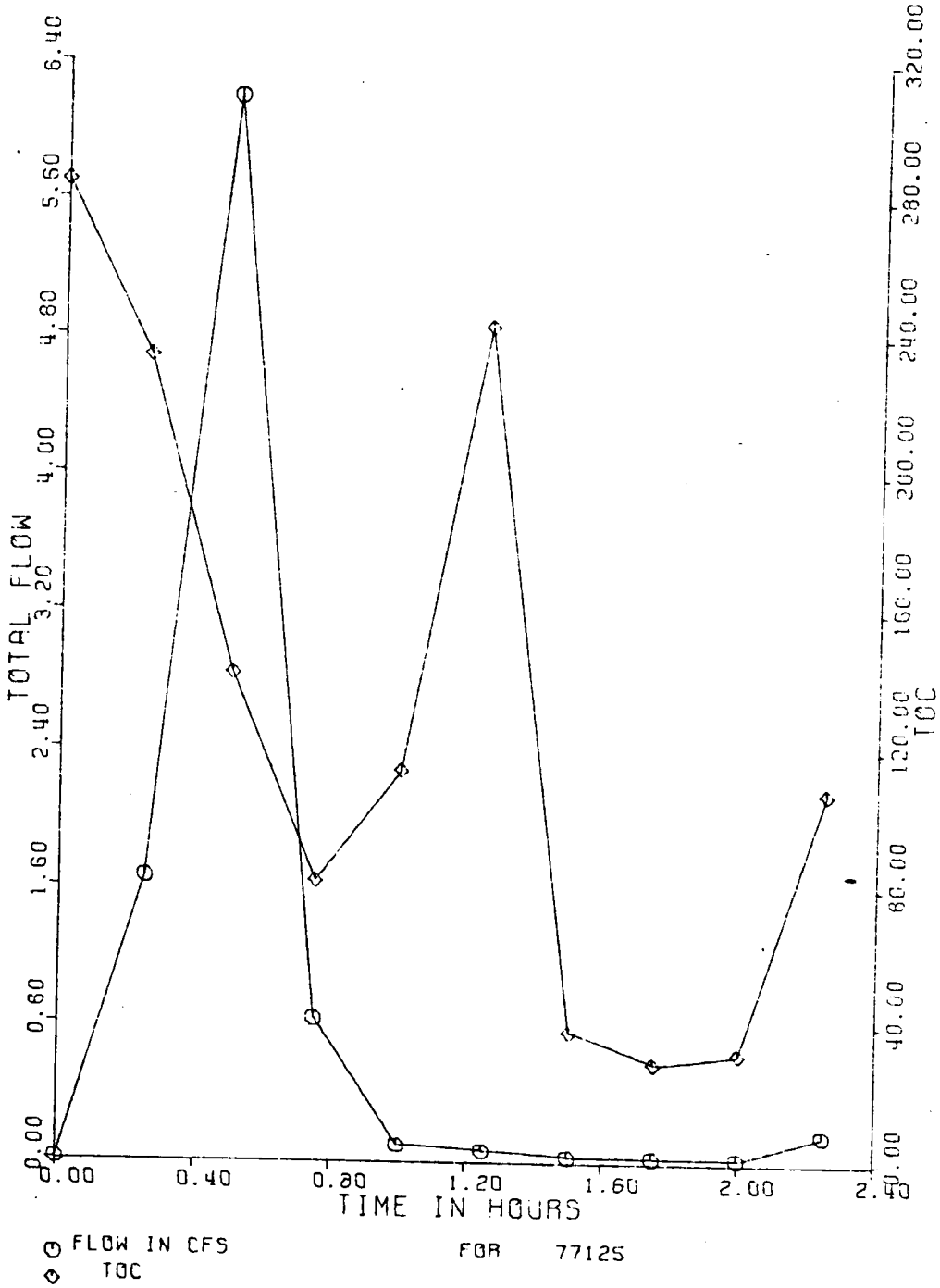


Figure 46. Fourth Creek Pollutograph for TOC December Storm.

VITA

William H. Johnson was born in Chattanooga, Tennessee on November 11, 1952. He graduated from McCallie High School in Chattanooga, Tennessee in 1970. He entered The University of Tennessee, Knoxville in the fall of 1970 and received a Bachelor of Science degree in Civil Engineering in August 1975. He entered the Graduate School at The University of Tennessee, Knoxville in September 1976 and received the Master of Engineering degree with a major in Environmental Engineering in December 1980.