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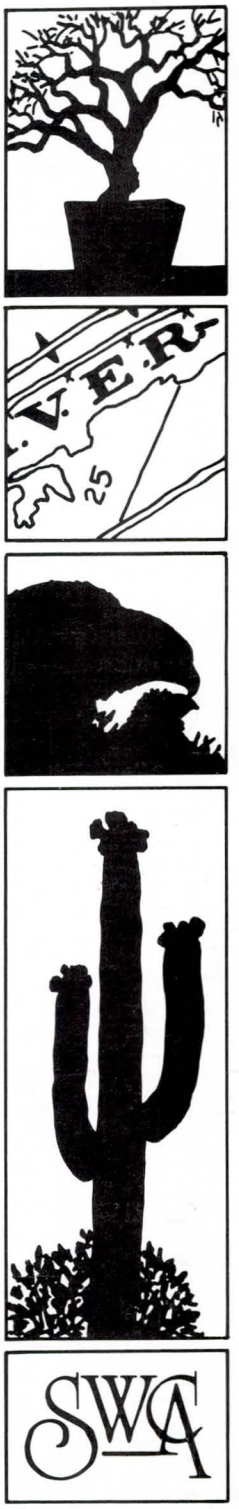
A STUDY OF URBAN STORMWATER RUNOFF FROM TWO SMALL WATERSHEDS, PHOENIX ARIZONA

SUMMER 1986



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A STUDY OF

URBAN STORMWATER RUNOFF

FROM TWO SMALL WATERSHEDS,

PHOENIX ARIZONA

SUMMER 1986

Prepared For

Environmental Services Department
Salt River Project
P.O. Box 52025
Phoenix, Arizona 85072-2025

Prepared By

SWCA, Inc.
3014 N. Hayden, Suite 108
Scottsdale, Arizona 85251

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EXECUTIVE SUMMARY

Greater Phoenix is one of the fastest growing metropolitan areas in the United States. A number of factors, including climate, life style and a favorable business environment, have contributed to this phenomenal growth. Rapid urbanization of agricultural lands has occurred as a result.

Salt River Project is the primary provider of municipal, agricultural and industrial water in greater Phoenix. Surface water and pumped groundwater are distributed throughout the metropolitan area by a series of open canals. Project canals are also an integral component of the area's stormwater runoff disposal system. Two of these, the Arizona and Grand Canals, are the focus of this study. Presently, 190 known drains and watercourses discharge directly into the 61 km (kilometer; 38 miles) Arizona Canal. The Grand Canal has at least 155 drains and watercourses along its 42 km (26 mile) course. Urbanization of watersheds adjacent to SRP canals may affect the quantity and quality of stormwater which is discharged into canal waters.

This study characterizes two small urban watersheds within the City of Phoenix with respect to size, percent impervious area, land use and other physical parameters. It describes the intensity, duration, frequency and other characteristics of five storm events during the summer monsoon of 1986. Concentration and event mean concentration of selected water quality parameters

in urban stormwater runoff are presented.

Stormwater studies are exceptionally site-specific. It is difficult to extrapolate the results from one watershed to another. Sources of variation include soils, local geology and land use characteristics, among others. Also, the summer monsoon in central Arizona is extremely variable with respect to space and time. Rainfall may occur on one side of a street and not on the other. This characteristic makes it highly desirable to have one or several real-time recording rain gauges within the watershed of interest. This study, however, relies on real-time gauges maintained by the City of Phoenix near the watersheds studied.

Stormwater runoff from the study watersheds at Metrocenter on the Arizona Canal and 43rd Avenue on the Grand Canal is relatively clean for most parameters evaluated when compared to metropolitan areas sampled during EPA's Nationwide Urban Runoff Program. However, high concentrations of fecal coliform exist in one of the storm drains sampled. These concentrations may indicate cross-contamination by sanitary sewers. Dissolved organic carbon observed in collected samples and originating from various sources may pose problems for municipal water treatment plants concerned with trihalomethane formation during the treatment process. Limited sampling indicates that stormwater

runoff elevates biochemical oxygen demand, fecal coliform numbers and concentrations of total suspended solids in canals. Volatile organic compounds and pesticides were not sampled during the study because interpretation of data would be very difficult and beyond the scope of this study. Sample size for most parameters analyzed during the study is 21. For example, there are a total of 21 measurements of dissolved lead concentration from water samples collected on two watersheds during five different storm events.

CHAPTER I

INTRODUCTION

Salt River Project (SRP) is the primary provider of municipal, agricultural and industrial water to metropolitan Phoenix. The Arizona Canal provides raw water to the Cities of Glendale and Phoenix to meet municipal demands. The remainder of the water is used for agricultural and landscape irrigation. The Grand Canal provides water for irrigation and livestock. Although delivery contracts do not contain water quality clauses, SRP strives to deliver the highest quality water to water users. This goal is potentially affected by the effects of stormwater runoff.

Salt River Project canals are an integral component of the Phoenix metropolitan stormwater runoff disposal system. Presently, an estimated 190 drains and watercourses empty into the 61 km (38 mile) Arizona Canal (Salt River Water Users' Association 1986). Of these, 97 are classified as drains and 93 are natural watercourses which enter the canal over the bank with concrete or earthen spillways. The Grand Canal has 155 drains and watercourses along its 42 km (26 mile) course (Salt River Water Users' Association 1986). These include 129 drains and 26 watercourses. Only 14 of 199 drains on both canals are greater than 76 cm (centimeters; 30 inches) in diameter. Many drain pipes and ditches have been in place due to agricultural production and have been incorporated into the urban storm drain

system during rapid urbanization (pers. comm. Hank Clow, SRP). Actual numbers of drains, retention basins and open laterals discharging into SRP canals may be greater. A 1984 inventory, not reflected in the most recent maps of the water distribution system (Salt River Valley Water Users' Association 1986), indicates that 1411 drains and retention basins occur along the Arizona and Grand Canals (Appendix C).

The Nationwide Urban Runoff Program (NURP), Sponsored by the United States Environmental Protection Agency (EPA), demonstrates the potential impacts of stormwater runoff on quality of receiving waters (Athayde et al. 1983). However, a high degree of site specificity, with respect to these impacts, exists. Geology, soils, land uses and myriad of other local conditions exert considerable influence on the quality of urban stormwater runoff and its impact on receiving waters. Seventy-seven of the designated priority pollutants have been reported in stormwater runoff by NURP investigators. Heavy metals, particularly copper, zinc and lead, are the most commomly occurring priority pollutants. Coliform bacteria and oxygen demanding substances are also prevalent in urban stormwater runoff.

The overall objectives of this study are to assess the concentration and distribution of selected pollutants in stormwater runoff from small urban watersheds during the summer monsoon. The watersheds studied are at Metrocenter on the Arizona Canal and near 43rd Avenue on the Grand Canal. Runoff

from the Metrocenter watershed is discharged into a retention basin which, periodically, may be pumped into the Arizona Canal. At 43rd Avenue, stormwater runoff is discharged directly into the Grand Canal. Stormwater discharge into the canal system may affect water quality. However, the site-specific nature of stormwater runoff (Athayde et al. 1983) prohibits results of this study from being extrapolated to other small urban watersheds in metropolitan Phoenix. Rather, the efforts of this study are directed toward characterization of individual watersheds and storm events.

In central Arizona the summer monsoon usually begins in early July, although the monsoon's onset varies from year to year (Turnage and Mallory 1941, Bryson 1957, Green 1960, Sellers and Hill 1974). Nearly half of the annual precipitation falls between July and October. Storm events are generally high intensity, convective and occur in widely scattered areas during the late afternoon and evening. Recognizing the constraints imposed by temporal and spatial variation in summer storm events and the sampling logistics of capturing the 'first-flush' of stormwater runoff, this study:

- characterizes two watersheds, potentially discharging into SRP canals, with respect to size, percent impervious area and land use,
- describes the intensity, duration and frequency of runoff producing storms over the watersheds during the summer monsoon of 1986 and
- quantifies the quality of stormwater runoff from each watershed.

CHAPTER II

METHODS AND MATERIALS

Description of Study Areas

Five criteria were established to select study watersheds. First, two watersheds with contrasting land uses which ultimately discharged stormwater into the Arizona or Grand Canals were desired. Sampling sites required suitable channelization of runoff to permit determination of discharge based on stage and channel dimensions. Proximity of real time rain gauges was the third criterion. Access to each site was also required to accommodate a water level recorder, stilling well, automatic water sampler and instrument shelter. Finally, hydrologically simple watersheds were sought.

The selected watersheds were delineated on aerial photography (1:1200 scale) with the aid of site visits, storm drain maps provided by SRP and the City of Phoenix and drainage reports (Williams and Ellis Consulting Engineers 1967 and Arthur Beard Engineers, Inc. 1967). Watershed area and percent impervious area were estimated by planimetery from aerial photography. Roof areas were not included in the impervious area estimates except in unusual cases (e.g., Metrocenter) where a large percentage of an area was commercially zoned and runoff from roofs was delivered directly to impervious surfaces (Williams and Ellis Consulting Engineers, 1967).

Metrocenter - Arizona Canal

The watershed is immediately north of the Arizona Canal, west of Black Canyon Freeway and includes the area west of 29th Avenue (extended), east of 35th Avenue and south of Cochise Drive. It is dominated by Metrocenter, a shopping mall, and associated parking facilities (Figure 1). A multi-family housing development and a vacant lot cleared for development are within, or contribute to, the watershed. Physical features include apartments offices, retail space and paved public streets with gutters. Pertinent characteristics of the watershed are:

- 41.3 ha (hectares; 102 acres) in area
- commercial and multi-family residential land use
- 64.4% impervious area
- 0.4% slope northeast to southwest
- 379.5 - 374.9 m (meters; 1245-1230 feet) above sea level
- 0.4% slope of pipe sampled.

Stormwater runoff is carried by storm sewer to a retention basin immediately north of the Arizona Canal. The basin is equipped with a pump which discharges water into the Arizona Canal. The retention basin and pump are operated by the City of Phoenix. Usually, the basin is pumped once or twice per summer (pers. comm. Alex Chavez, City of Phoenix). During the period of study, 1 July - 15 September 1986, the pump was not started.

Initially, a storm sewer lateral near the intersection of 31st Avenue and Mission Lane was selected as the sample site.

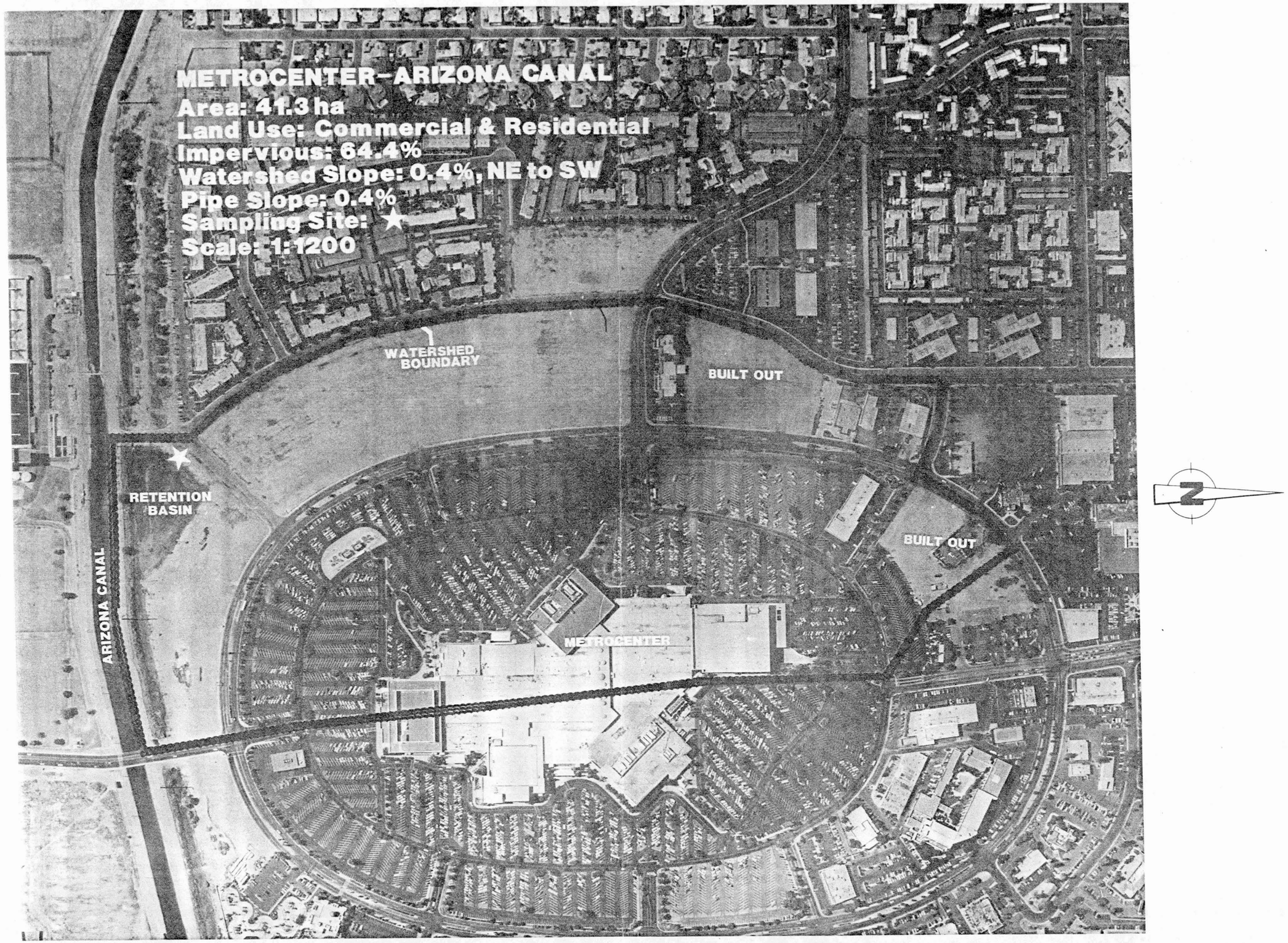

FIGURE 1. THE METROCENTER WATERSHED ADJACENT TO THE ARIZONA CANAL.

This site, approximately 300 m (985 feet) southwest of Metrocenter, was abandoned as a sample site in mid-August because volume of water collected in the lateral during each of three storm events in July and early August was insufficient to activate the water level recorder and automatic water sampler. The equipment was moved to a manhole located approximately 15 m (50 feet) southwest of the initial location, in a cul-de-sac at the intersection of 31st Avenue and Mission Lane. The manhole provided access to a vault within the 122 cm (centimeter; .48 inch) storm sewer main which drains into the retention basin. A stilling basin and water level recorder were mounted in the vault approximately 10 m (33 feet) upstream of the automatic sampler intake. It was deployed at the mouth of the 122 cm (48 inch) storm drain, approximately 0.5 m (1.6 feet) upstream of the opening.

43rd Avenue - Grand Canal

The watershed lies directly north of the Grand Canal and immediately east of 43rd Avenue. It includes the area west of 39th Avenue, east of 43rd Avenue and south of Clarendon Avenue. The watershed is dominated by light industries including metal fabricating, plating, concrete block production and automobile repair facilities (Figure 2). Structures include buildings, paved and unpaved parking, storage and manufacturing areas and public streets. Most streets are paved although some are not

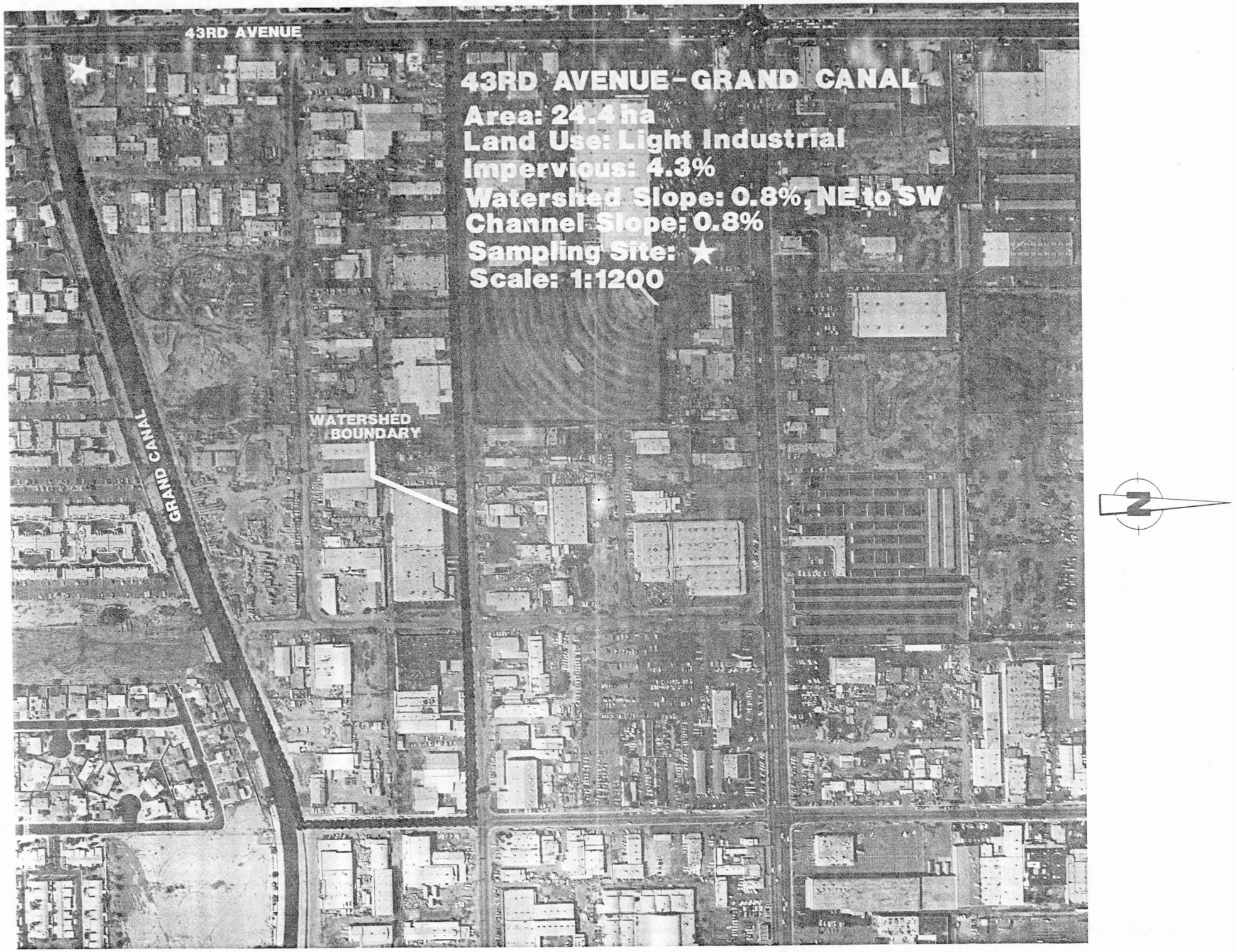

FIGURE 2. THE 43RD AVENUE WATERSHED ADJACENT TO THE GRAND CANAL.

guttered. Characteristics of the watershed include:

- 24.4 ha (60 acres) in area
- light industrial land use
- 4.3% impervious area
- 0.8% slope northeast to southwest
- 338.3 - 335.9 m (1110-1102 feet) above sea level
- 0.8% slope of channel sampled

Runoff is carried along an unlined, irrigation return ditch which terminates at the northeast corner of 43rd Avenue and the Grand Canal. The ditch parallels the Grand Canal for approximately 850 m (2790 feet) between 39th and 43rd Avenues at a distance of 5 m (16 feet) from the northern canal bank. The ditch is 1.2 m (4 feet) wide and 0.6 m (2 feet) deep. At 43rd Avenue, the ditch meets a concrete control structure housing a 61 cm (24 inch) pipe, which discharges into the Grand Canal beneath the 43rd Avenue bridge. A water level recorder, stilling basin and automatic water sampler were located overhead on the control structure.

Climatological Data

A storm event was defined as beginning at the start of precipitation and ending when the last rainfall was followed by six consecutive hours without rain. Climatological data for storm events on the watersheds sampled, antecedent dry days, amount and duration of rainfall were obtained from real-time rain gauges maintained by the City of Phoenix at Fire Stations 25 (FS

25) and 30 (FS 30). Fire Station 25 is located approximately 3 km (1.9 miles) west of the 43rd Avenue site at 59th Avenue and Indian School Road (Figure 3). It is outside the 43rd Avenue watershed. Fire Station 30 is located 2 km (1.2 miles) southeast of the Metrocenter site at 27th Avenue and Northern Avenue (Figure 3). It is also outside of the Metrocenter watershed.

Rainfall intensity (mm/hour) and volume (m^3) were calculated from these data. Return period, the probability of reoccurrence of a storm of a given intensity and duration, was determined from Figure 4.14 in the Northwest Storm Drainage Study - Volume II (Arthur Beard Engineers, Inc. 1977). Storms less than one hour long were considered instantaneous on the 168 hour charts utilized on fire station rain gauges.

The City of Phoenix maintains real-time electronic rain gauges at six fire stations, Deer Valley Airport and the Municipal Building. They are frequently incapacitated by intense lightning storms characteristic of the summer monsoon. Generally, precipitation records for the Metrocenter watershed were obtained from FS 30 and records for the 43rd Avenue watershed were obtained from FS 25. Occasionally, though, one or the other gauge malfunctioned and data for both watersheds were from the lone, operating gauge.

Discharge Measurements

During three storm events (4 July, 20/21 July and 7 August at Metrocenter) current velocity was estimated with a float at

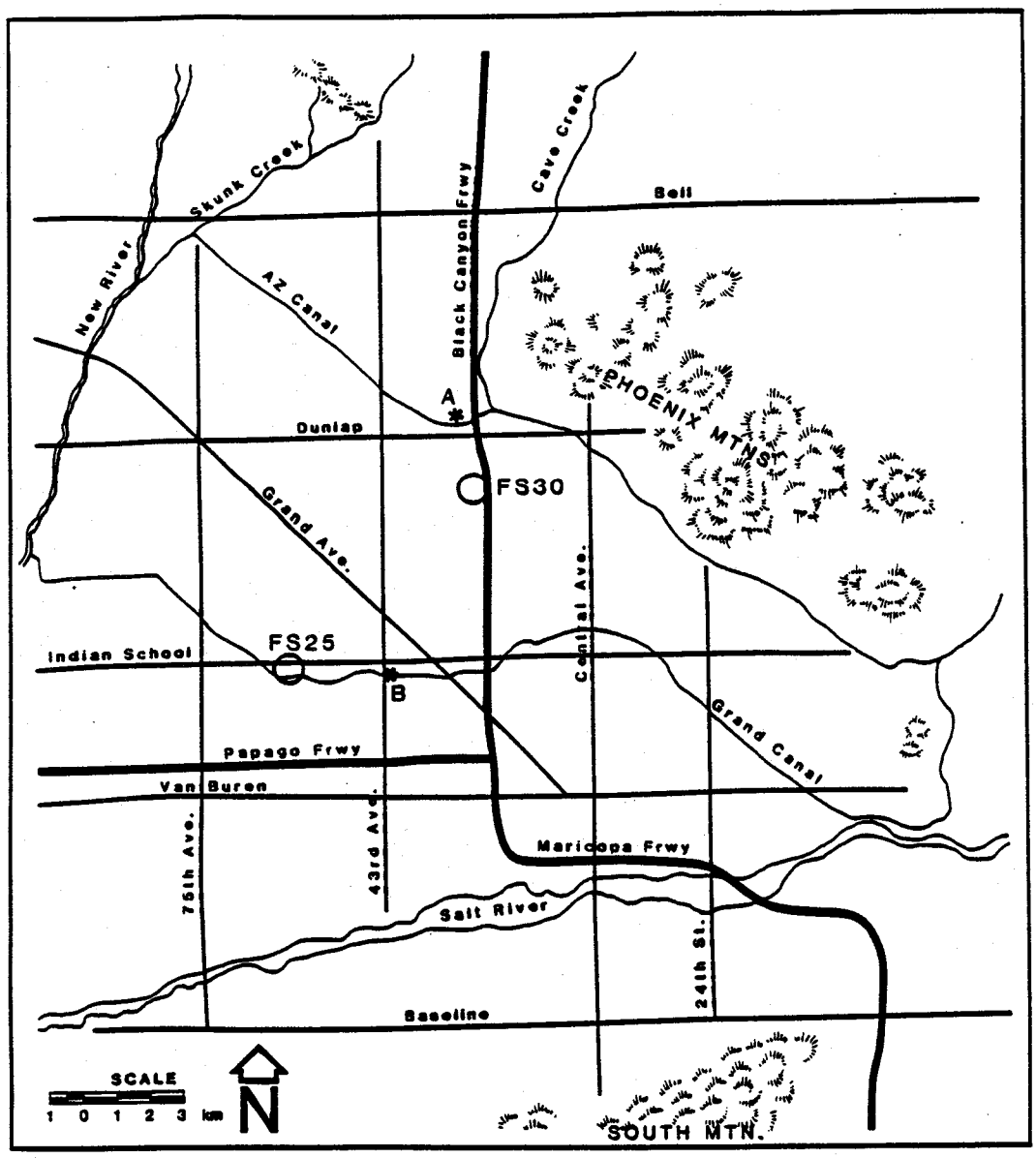

FIGURE 3. LOCATION OF THE METROCENTER (A) AND 43RD AVENUE (B) WATERSHEDS AND THEIR PROXIMITY TO REAL-TIME RAIN GAUGES AT FIRE STATIONS (FS) 25 AND 30 IN PHOENIX, ARIZONA.

the mouth of a 122 cm (48 inch) storm drain. Discharge was calculated from pipe cross-sectional area, stage and velocity (Robins and Crawford 1954).

During the 23 August storm at Metrocenter and the 28 August storm at 43rd Avenue, stage measurements, taken just upstream of the concrete pipe, were automatically logged throughout the period of runoff on a water level recorder (Belfort Instrument Company Catalog No. 5-FW-1). The recorder contained a 3 volt battery-operated chart drive running at 96 hours per revolution and the pen traced a stage ratio of 1:12. A 12 unit rise in water level results in a one unit rise on the chart. A 10 cm (4 inch) counter-weighted float was placed inside of a 13 cm (5 inch) stilling basin. Stilling basins were fabricated and mounted at each sampling point within the study watersheds to facilitate accurate stage measurements. Stage discharge relationships were developed using the runoff analysis and tabulation technique presented in Plates 9 and 10 of the report titled Preliminary Storm Drainage Report 43rd Avenue Storm Drain (Williams and Ellis Consulting Engineers 1967). Hydrographs, stormwater discharge in cubic meters per minute as a function of time since the beginning of runoff, were developed for storms occurring at Metrocenter on 4 July, 20 July, 7 August and 23 August and at 43rd Avenue on 28 August.

Water Samples

Grab samples of stormwater runoff were collected on 4 July,

20 July and 7 August in conjunction with each manual discharge measurement at Metrocenter. These events were sampled at the mouth of a 122 cm (48 inch) storm sewer which discharges directly into a retention basin. Grabs were taken by filling bottles just below the water surface.

Automatic samplers collected water 23 August at Metrocenter and 28 August at 43rd Avenue. The ISCO (Instrumental Specialties Co. Model 1680) sampler, powered by a 12 volt DC automotive battery, drew water at 15 minute intervals throughout the runoff period. At Metrocenter and 43rd Avenue, the open intake was anchored approximately 2 cm (1 inch) above the pipe invert and channel bottom, respectively. Intakes were positioned to avoid suction of bottom sediments into the sampler while allowing sample collection from the first flush of stormwater. First flush was defined as the condition in which a disproportionately high constituent concentrations are carried in the ascending leg of the hydrograph. A water level sample actuator (ISCO Model 1640) was set in the toggle mode and positioned 2 cm (1 inch) above the intake. Following cessation of runoff, water samples were transferred to the laboratory for analysis. When volume of sample required for analysis exceeded the volume collected in a given interval, flow-weighted composite samples were analyzed. All water samples (manual grab and automatic) were collected from the same location. The 28 August event, with a 25 year return period, destroyed the stilling well deactivating the automatic

water sampler.

Conductivity was measured in the field with a YSI Model S-C-T meter (Yellow Springs Instrument Co., Inc.) after standardization with a 0.005 M KCl solution. Specific conductance values were corrected to 25 ^{o}C (Wetzel and Likens 1979). Water temperature was measured manually with a mercury thermometer.

Container type, preservatives and holding times for parameters of interest followed specific requirements (Table 1). Ten water quality parameters were measured during the study. Dissolved and total cadmium and oil and grease were only analyzed during the first storm event, 4 July. Container types, preservatives and holding times for cadmium and oil and grease were the same as those utilized for lead and total recoverable petroleum hydrocarbon, respectively. Electrical conductivity (EC, uS/cm), total suspended solids (TSS, mg/L), total dissolved solids (TDS, mg/L), total lead (tPb, mg/L), dissolved lead (dPb, mg/L), total recoverable petroleum hydrocarbons (PHC, mg/L), five day biochemical oxygen demand (BOD, mg/L) and fecal coliform (FC, MPN/100 mL) were routinely monitored in runoff samples. Whatman GF/C filters (1.2 um pore size) were used for TDS and TSS determinations. Samples analyzed for total lead were prepared for analysis by digestion with a concentrated nitric acid digestion and hydrogen peroxide (EPA 1982). Prior to analysis for dissolved metals, samples were filtered through Millipore type HA membrane filters (0.45 um pore size). Field and

TABLE 1. CONTAINER TYPE, PRESERVATION REQUIREMENTS AND HOLDING TIME FOR SIX WATER QUALITY PARAMETERS ANALYZED.

Parameter	Container Type	Preservative	Holding Time
TSS	1000 ml plastic with plastic cap	cool to 4 °C	7 days
TDS	1000 ml plastic with plastic cap	cool to 4 °C	7 days
Pb	500 ml acid washed with plastic cap	HNO_3 to pH 2	6 months
PHC	500 ml plastic with plastic cap	H_2SO_4 to pH 2 cool to 4 °C	28 days
BOD	500 ml plastic with plastic cap	cool to 4 °C	48 hours
FC	125 ml sterile plastic with plastic cap and sterile	$Na_2S_2O_3$ cool to 4 °C	6 hours

laboratory methods employed during the study followed those suggested by the EPA or American Public Health Association (Table 2).

Water quality conditions in the Arizona and Grand Canals were assessed periodically during the study. Samples were collected during periods when canals were not receiving stormwater runoff. Incidental samples during or shortly after storms were collected from the Arizona Canal on two occasions. A Van Dorn collecting bottle was used to collect mid-channel canal samples from a depth of one meter. Parameters analyzed were those previously discussed.

Pollutographs and Event Mean Concentration

Pollutographs (i.e., discharge-independent plots of instantaneous concentration of a constituent parameter versus time from the onset of stormwater discharge) were prepared for each storm monitored. If the concentration of a pollutant was reported as less than the detection limit, a value of one-half of the detection limit was used.

Event mean concentration (EMC) (i.e., the total constituent mass contained in runoff from a storm event divided by the total runoff volume produced during that event) facilitated comparisons between this study and others (Athayde et al. 1983). If, for a given storm event, a flow-weighted composite sample was collected, the constituent concentration measured in that sample would be an approximation of the true EMC. The true EMC would

TABLE 2. SUMMARY OF FIELD AND LABORATORY METHODS.

Parameter	Method	Method No.	Detection Limit
FIELD			
Discharge	a. cross-sectional area and float	---	---
	b. stage-discharge relationship	---	---
Temperature	mercury therometer	---	---
Conductivity	electrometric	SM 205[A]	---
LABORATORY			
TSS (mg/L)	gravimetric	EPA 160.2[B]	---
TDS (mg/L)	gravimetric	SM 208C	---
t and d Pb (mg/L)	AA, direct aspiration	EPA 239.1	0.02
PHC (mg/L)	IR spectroscopy	EPA 418.1	0.2
BOD (mg/L)	5 day, 20 ^{o}C	EPA 405.1	1.0
FC (MPN/100ml)	multiple tube fermentation	SM 908C	2.2

A) American Public Health Association. 1985. Standard Methods for the Examination of Water and Wastewater, 16th Edition. Washington, D.C.

B) Environmental Protection Agency. 1983. Methods for Chemical Analysis of Water and Wastes. EPA 600/4-70. EPA Environmental Monitoring and Support Laboratory, Cincinnati, OH.

only be approached as the number of stormwater aliquots comprising the sample approached infinity. Because discrete samples were collected, constituent EMCs were determined by mathematical integration. Event mean concentrations were equal to the area under the loadograph (instantaneous pollutant loading rate in units of mass per time versus time since the beginning of a storm) divided by the area under the hydrograph. The equation used was:

$$EMC = \frac{\int C(t)q(t)dt}{\int q(t)dt.}$$

where, $C(t)$ = constituent concentration at time, t
$q(t)$ = discharge at time, t

Using the trapezoid rule as an approximation of integration, this equation was rewritten as:

$$EMC = \frac{\sum (t_{n+1} - t_n)\ (1/2)\ (C_n q_n + C_{n+1} q_{n+1})}{\sum (t_{n+1} - t_n\ (1/2)\ (q_n + q_{n+1}).}$$

Event mean concentrations could only be calculated for those storms during which samples were taken over the entire hydrograph. These occurred 7 and 23 August at Metrocenter and 28 August at 43rd Avenue.

Runoff coefficients were calculated as the total volume of runoff generated by a storm event divided by the total volume of precipitation falling on the watershed. A totally impervious

watershed would have a runoff coefficient approaching 1.0 and a totally pervious watershed would have a runoff coefficient of zero.

CHAPTER III

RESULTS

Precipitation Events and Runoff

Precipitation, coincident with measured runoff, was recorded on four occasions at Metrocenter, 4 July, 20 July, 7 August and 23 August (Table 3). A storm event on 28 August also produced runoff, however, no discharge was measured at Metrocenter because the stilling basin was damaged by high flows. The FS 30 rain gauge, near Metrocenter, functioned during early July. It missed five subsequent precipitation events (17, 19, 20, 21 and 22 July). Data presented in Table 3 for the Metrocenter watershed on 20 July were collected from FS 25. In August, the FS 30 gauge functioned all month, sampling five precipitation events (7, 9, 23, 28 and 29 August).

At 43rd Avenue there was only one storm event, 28 August, which produced measurable runoff. The FS 25 rain gauge, nearest the study watershed, recorded seven storm events during July (1, 2, 3, 4, 20, 21 and 22) even though no measurable runoff was produced at the sampling site. It was not functioning during three August events (9, 28 and 29). Data for the storm event on 28 August were from FS 30.

A long dry period preceded the study. Only 0.50 mm (millimeters) of precipitation was recorded at Phoenix Sky Harbor Airport from April to June. This included rain on 1 April and 17 June (0.25 mm during each event). The storm of 17 June was

TABLE 3. SUMMARY OF STORMS PRODUCING RUNOFF ON THE METROCENTER AND 43RD AVENUE WATERSHEDS.

WATERSHED	DATE OF STORM EVENT	ANTECEDENT DRY DAYS	DURATION OF RAINFALL (HOURS)	AMOUNT OF RAINFALL (mm)	RAINFALL INTENSITY (mm/HOUR)	RETURN PERIOD[A] (YEARS)	RAINFALL VOLUME (m^3)	RUNOFF VOLUME (m^3)	RUNOFF COEFFECIENT
Metrocenter (Arizona Canal)	4 July	≥16[B]	4.25	7.87	1.85	<1	-	-	-
	20 July[C]	16.6	3.50	10.92	3.12	<1	-	-	-
	7 August	16.8	<1.00	0.76	-	<1	313.7	125.3	0.40
	23 August	13.8	<1.00	0.76	-	<1	313.7	188.6	0.60
43rd Avenue (Grand Canal)	28 August[D]	>51.0[E]	2.75	58.17	21.15	25	14,218.5	146.5	0.01

A) From Northwest Storm Drainage Study, Volume II, City of Phoenix Project No. ST-74206.00. Arthur Beard Engineers, Inc., 1977.
B) Precipitation was noted at the Fire Station (FS) 30 rain gauge on July 1 - 3, however, it is just outside of the watershed. No event occurred within the watershed until 4 July.
C) Data for this event were collected at FS 25 rather than by the FS 30 rain gauge. FS 30 is the gauge closest to the Metrocenter watershed.
D) Data for this event were collected at FS 30 rather than by FS 25 rain gauge. FS 25 is closest to the 43rd Avenue watershed.
E) This period is measured from the date equipment was deployed, 8 July 1986, until the first precipitation event to produce runoff on the watershed.
F) Multiply mm by 0.0394 to convert to inches.

assumed to have fallen on the Metrocenter watershed, leading to an estimated antecedent dry period of 16 days by 4 July. Prior to the first runoff at Metrocenter, rainfall was recorded at FS 30 and FS 25 on 1 July (3.05 and 0.25 mm), 2 July (0.76 and 0.25 mm), and 3 July (0.51 and 1.52 mm), respectively.

The runoff producing event of 4 July started at 0315 hours and continued until 0720 hours. Rainfall intensity during the 4.35 hour storm was light. The event had a return period of less than one year. Sampling was conducted on the hydrograph's receding limb. At FS 25, 6.60 mm of rain was reported from 0245 to 0715 hours on 4 July. Intensity was light and no flow was produced in the 43rd Avenue channel.

The FS 30 gauge failed to record the 20 July rainfall event. At FS 25, 10.92 mm of rain fell intermittently between 2100 and 0300 hours (3.5 hours duration) after 16.6 antecedent dry days. The storm was a low intensity event and had a return period of less than one year. Sampling at Metrocenter began on a falling hydrograph of stormwater runoff at 2325 hours. Although there was precipitation near the 43rd Avenue watershed on 20 July, no runoff occurred.

On 7 August, FS 30 recorded 0.76 mm of rain at 2015 hours (instantaneous). The event had a return period of less than one year. At Metrocenter, rainfall occurred from 2030 to 2040 hours. Discharge from the storm drain began at 2040 hours and continued for 40 minutes. Samples were taken during the entire

hydrograph of stormwater runoff. No precipitation or runoff was noted at the 43rd Avenue watershed.

FS 30 recorded 0.76 mm of rain at 1900 hours (instantaneous) on 23 August. Return period was less than one year. The ISCO sampler collected samples from the start of stormwater discharge at 1940 hours to 2110 hours when discharge ceased. Precipitation and runoff were not recorded at the 43rd Avenue watershed.

FS 30 recorded 57.15 mm of rain from 2130 to 2400 hours on 28 August. It was a very intense storm with a return period of 25 years. An additional 1.02 mm was recorded from 0100 to 0115 hours on 29 August. The stilling basin for the liquid level recorder was damaged by high discharge. No estimate of discharge was made and no samples were collected. The ISCO sampler at 43rd Avenue began collecting samples at 2330 hours and continued until 0245 hours on 29 August, during the entire period of recorded discharge.

Pollutographs and Event Mean Concentrations

Four storm events were monitored at Metrocenter (4 July, 20 July, 7 August and 23 August) and one event was monitored at 43rd Avenue (28 August). Discharge measurements and discrete runoff samples were collected during each of these rainfall events. Table 4 presents a summary of stormwater discharge and water quality data. These data were used to develop hydrographs and pollutographs and to calculate EMCs. Pollutographs for the five storms were presented with the associated hydrograph to aid in

TABLE 4. FIELD AND LABORATORY RESULTS FROM STORMWATER RUNOFF SAMPLES COLLECTED FROM THE METROCENTER AND 43RD AVENUE WATERSHEDS.

Site (1986)	Time (hrs)	Dura. (hrs)	Total (m^3)	Discharge (m^3/min)	EC (uS/cm)	TSS (mg/L)	TDS (mg/L)	tPb[A] (mg/L)	dPb[A] (mg/L)	tCd (mg/L)	dCd (mg/L)	O&G (mg/L)	PHC[A] (mg/L)	BOD (mg/L)	FC (MPN/100ml)
Metrocenter	0720	1.00		6.81		45	85	<0.02	<0.02	<0.005	<0.005	<0.02	<0.20		
4 July	0800	1.67		4.96		18	94	<0.02	<0.02	<0.005	<0.005	<0.36	<0.20		
	0820	2.00		3.19											
	0840	2.34		1.70		14	98	<0.02	<0.02	<0.005	<0.005	<0.02	<0.20		
	0925	3.09	413.9	0.44											
Metrocenter	2325	0.50		7.05											
20 July	2345	0.83		7.13	106	55	123	0.03	<0.02				0.98	29	>2400
	0015	0.35		9.55	80	34	95	<0.02	<0.02				0.54	24	>2400
	0045	1.83		4.49	84	30	98	<0.02	<0.02				0.38		
	0115	2.33		1.68	128	21	121	<0.02	<0.02				<0.20		
	0145	2.58	725.4	0.34	155	15	135	<0.02	<0.02				<0.20		
Metrocenter	2030	0.00		0.00											
7 Aug.	2040	0.17		2.25	676	206	488	0.11	<0.02				1.74		
	2050	0.33		3.03	352	229	495	0.25	0.04				1.17	150	5.4×10^5
	2100	0.50		2.68	451	175	490	0.16	<0.02				0.60		
	2120	0.83		1.22	412	161	605	0.13	<0.02				<0.20		
	2140	1.17	125.3	0.79											
Metrocenter	1925	0.00		0.00											
23 Aug.	1940	0.25		0.89	646	570	482	0.13	<0.02				<0.20		
	1955	0.50		2.44											
	2010	0.75		2.77	816	11	546	<0.02	<0.02				<0.20		
	2025	1.00		2.26											
	2040	1.25		1.86	765	11	572	<0.02	<0.02				<0.20	310	$>2.4 \times 10^7$
	2055	1.50		1.31											
	2110	1.75		0.77	670	205	880	0.07	0.02				0.92		
	2125	2.00	188.5	0.55											
43rd Ave.	2330	0.00		0.00											
28 Aug.	2345	0.25		1.02		313	226	0.11	<0.02				0.37	25	2.4×10^6
	2400	0.50		1.55	214										
	2415	0.75		1.38											
	2430	1.00		1.22	198	250	198	0.07	<0.02				0.20	16	2.4×10^6
	2445	1.25		1.02											
	0100	1.50		0.91	196										
	0115	1.75		0.77		157	180	0.03	0.02				<0.20		
	0130	2.00		0.63	194										
	0145	2.25		0.51											
	0200	2.50		0.36	196	132	182	0.05	<0.02				<0.20		
	0215	2.75		0.25											
	0230	3.00		0.12	196										
	0245	3.25	146.4	0.05		161	186	0.09	<0.02				<0.20	79	2.2×10^6

A) Values below the detection limit are divided by 2 when loads are calculated.

identification and interpretation of the first flush.

Metrocenter

Runoff and water quality parameters on 4 July and 20 July (Figures 4 and 5) reflect conditions on the receding limb of the hydrograph. Following the first sample, constituent concentrations declined as discharge decreased. Event mean concentrations were not calculated because the first flush was not sampled.

Pollutographs for the 7 August storm (Figure 6) exhibited a first flush response for all constituents except TDS. Constituent concentrations were highest in the ascending leg of the hydrograph. In contrast, TDS concentration increased towards the end of the runoff event rather than decreasing. This tendency was noted in each of the other storm events sampled at Metrocenter.

Concentrations of TSS and tPb exhibited a double peak during the 23 August storm (Figure 7). Typically, a double peak on the pollutograph would be accompanied by a double peaked hydrograph, however a single peak of stormwater runoff was recorded. Total dissolved solids, PHC and dPb increased toward the end of the stormwater discharge.

With the exception of TDS, event mean concentrations for sampled constituents were lower during the 23 August storm than the 7 August storm (Table 5). These storms differed only in antecedent dry days, runoff volume and runoff coefficient (Table 3).

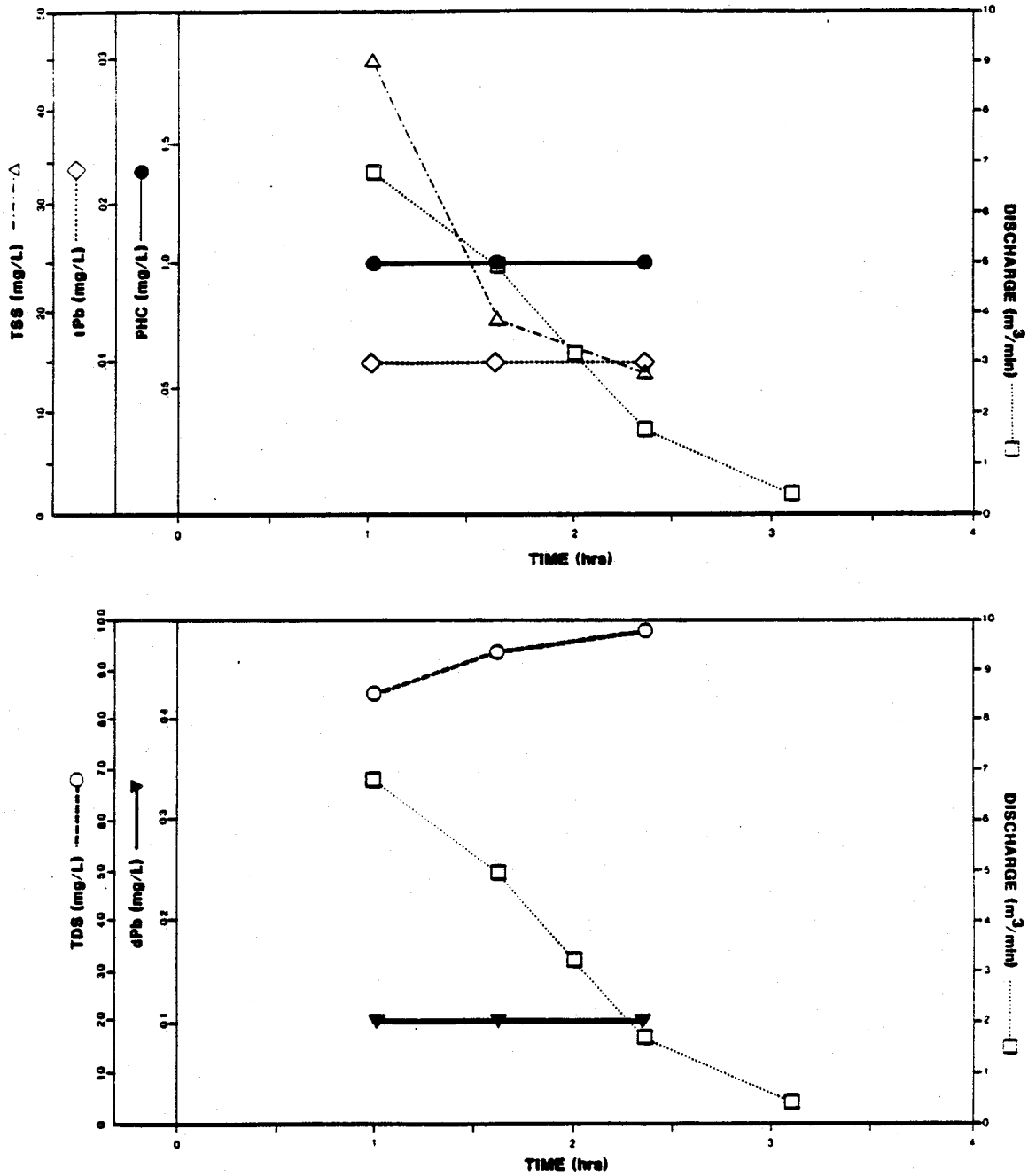

FIGURE 4. POLLUTOGRAPHS OF TSS, tPb, PHC (UPPER), TDS AND dPb (LOWER) WITH THE HYDROGRAPH OF STORMWATER RUNOFF ON 4 JULY AT METROCENTER.

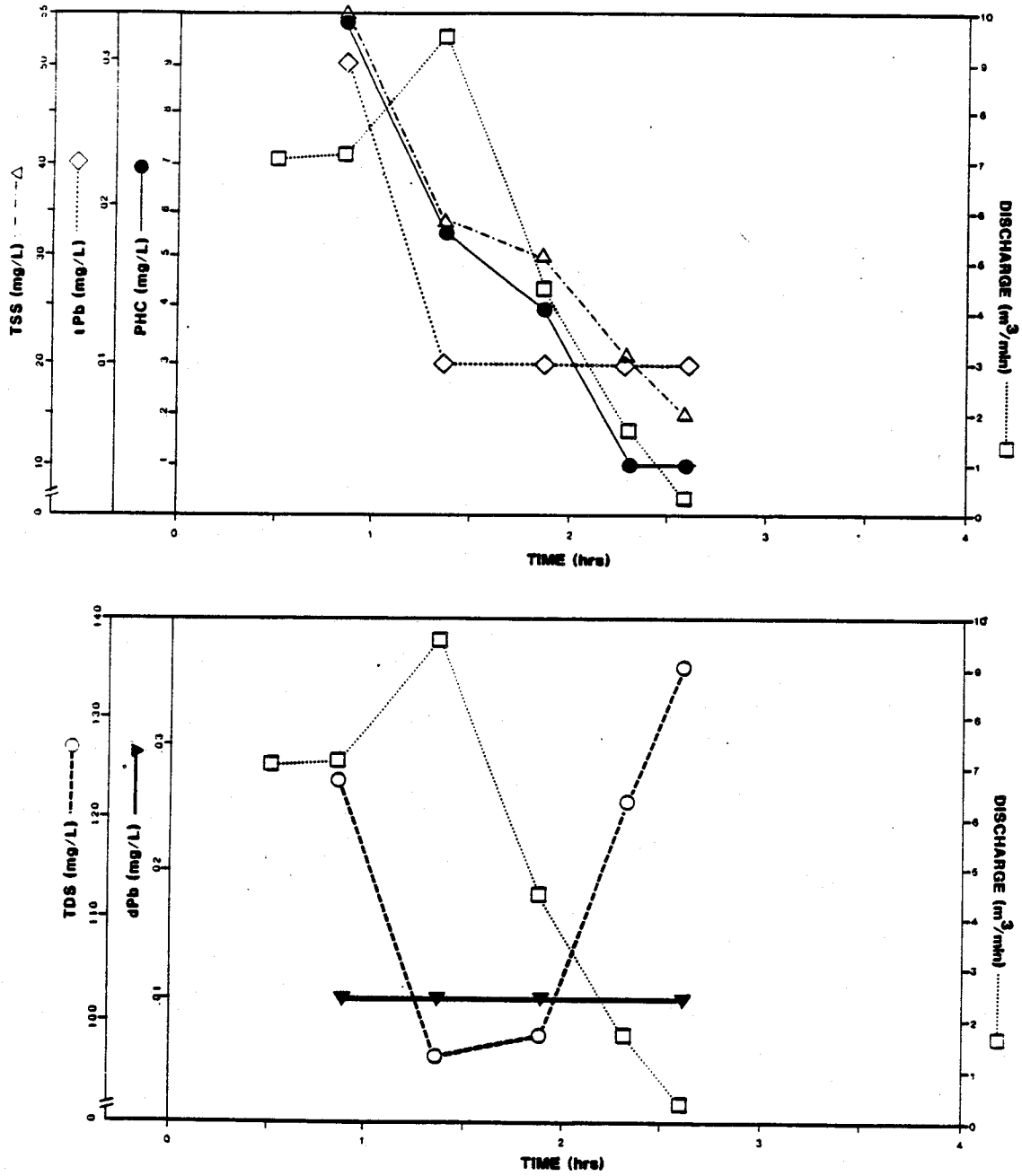

FIGURE 5. POLLUTOGRAPHS OF TSS, tPb, PHC (UPPER), TDS AND dPb (LOWER) WITH THE HYDROGRAPH OF STORMWATER RUNOFF ON 20 JULY AT METROCENTER.

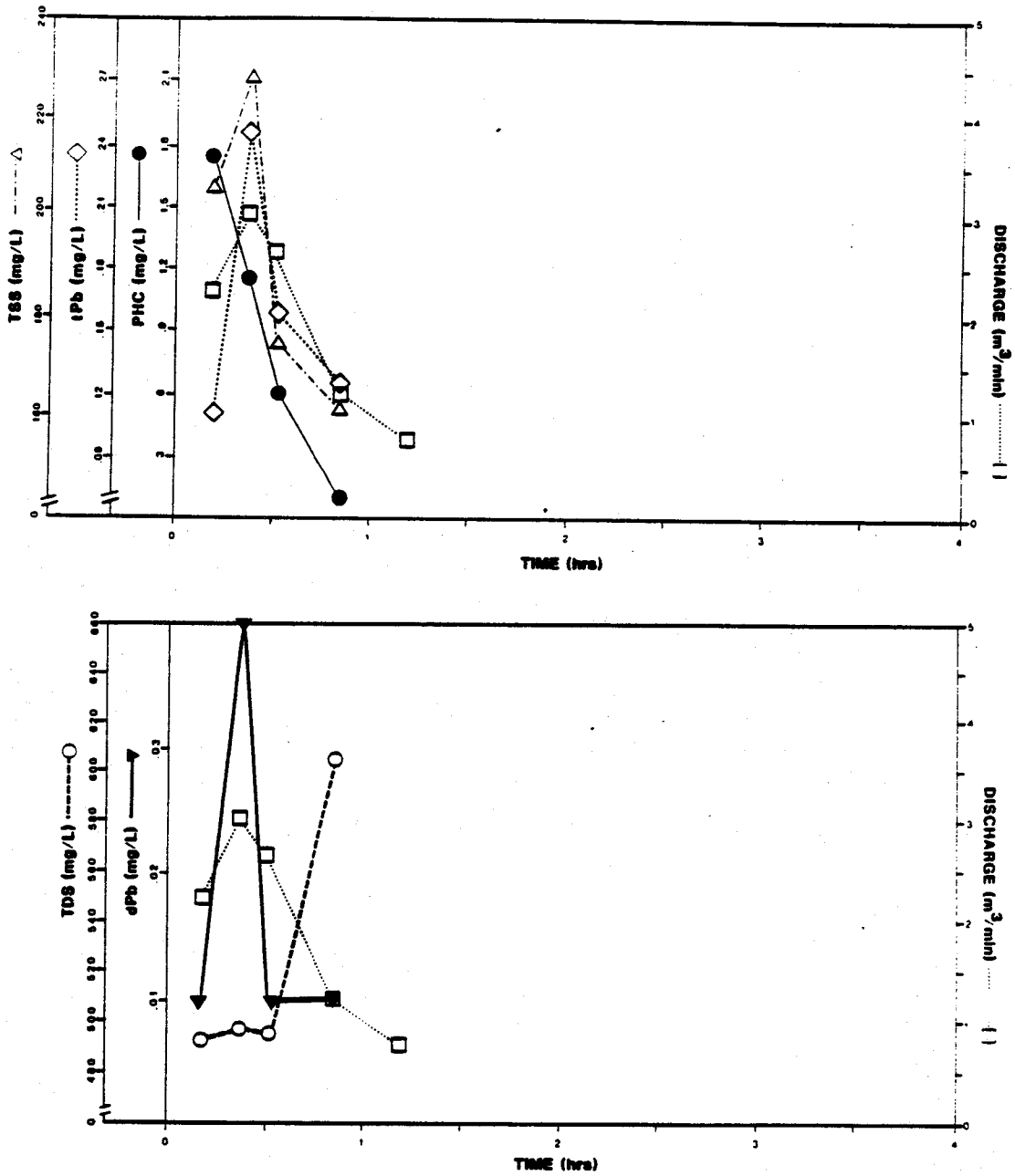

FIGURE 6. POLLUTOGRAPHS OF TSS, tPb, PHC (UPPER), TDS AND dPb (LOWER) WITH THE HYDROGRAPH OF STORMWATER RUNOFF ON 7 AUGUST AT METROCENTER.

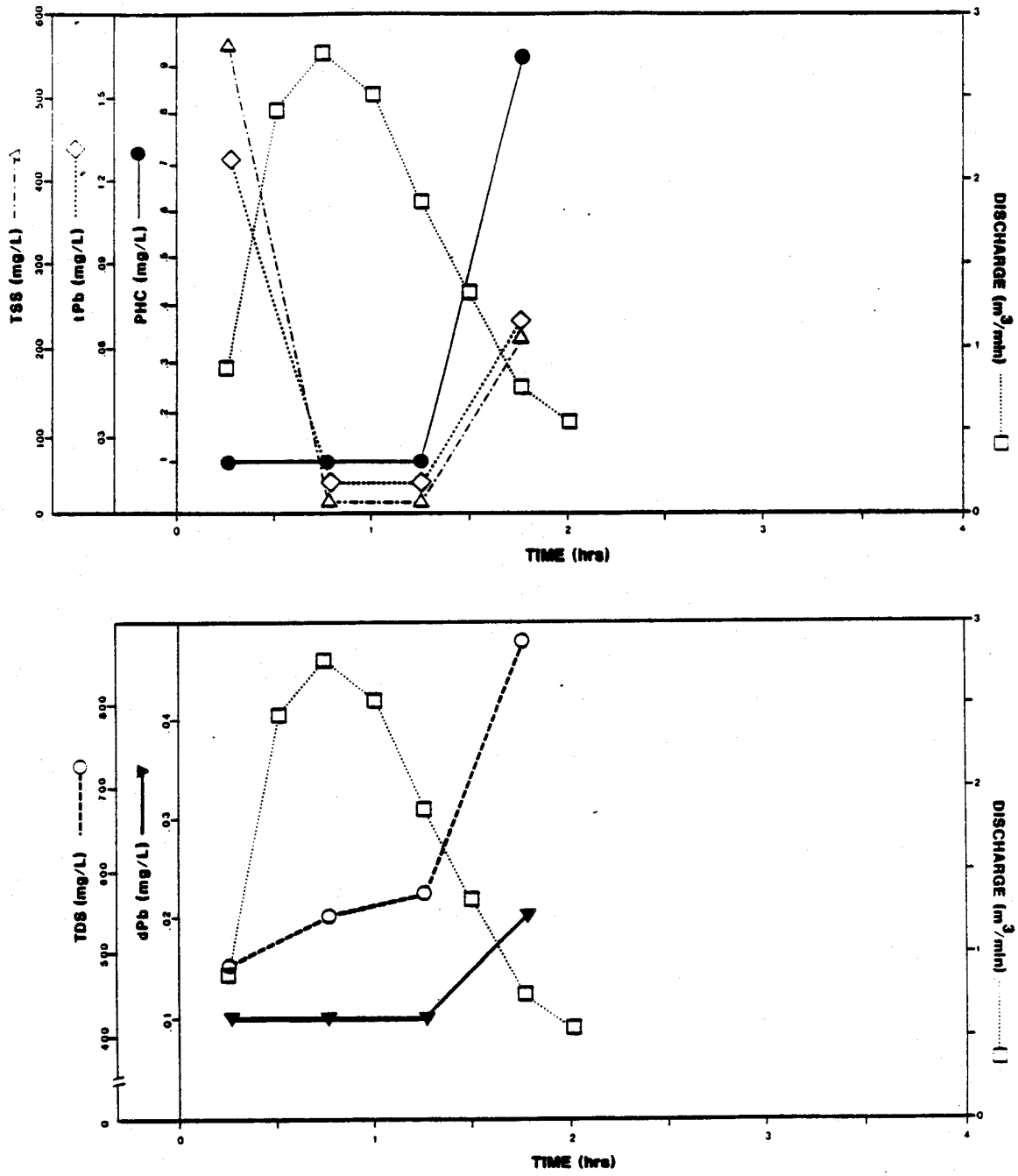

FIGURE 7. POLLUTOGRAPHS OF TSS, tPb, PHC (UPPER), TDS AND dPb (LOWER) WITH THE HYDROGRAPH OF STORMWATER RUNOFF ON 23 AUGUST AT METROCENTER.

TABLE 5. POLLUTANT EVENT MEAN CONCENTRATIONS FOR THE METROCENTER AND 43RD AVENUE WATERSHEDS.

Date	Parameter	Event Mean Concentration (mg/L)
Metrocenter		
7 August 1986	TSS	195.60
	TDS	504.50
	tPb	0.17
	dPb	0.02
	PHC	0.86
23 August 1986	TSS	97.10
	TDS	589.50
	tPb	0.03
	dPb	0.01
	PHC	0.13
43rd Avenue		
28 August 1986	TSS	225.90
	TDS	197.70
	tPb	0.06
	dPb	0.01
	PHC	0.20

43rd Avenue

The hydrograph from the 28 August storm indicated a moderate peak discharge and a long period of receding flow (Figure 8). Given the low proportion of impervious area within the watershed and the low runoff coefficient for the event (Table 3), the majority of precipitation probably percolated into the soil rather than running off. Total suspended solids, TDS, tPb and PHC exhibited a first flush response in the 28 August runoff. However, tPb concentration showed a slight increase at the tail of the hydrograph. Dissolved lead peaked on the descending limb of the hydrograph.

For the single storm event sampled at 43rd Avenue, event mean concentrations were lower than those reported at Metrocenter for all constituents except TSS (Table 5). Event mean concentrations for TDS were consistently high during both August events at Metrocenter while the single event mean concentration for TDS at 43rd Avenue was relatively low.

Baseline Conditions - Arizona and Grand Canals

Four water samples were collected from the Arizona Canal adjacent to the Metrocenter site (Table 6). Samples from 4 July and 29 August were taken following a storm event and provided information on canal water quality following stormwater inflow. Those from 11 July and 10 August were collected during periods of no precipitation. Notably, TSS, BOD and FC were elevated following stormwater discharge into the canal.

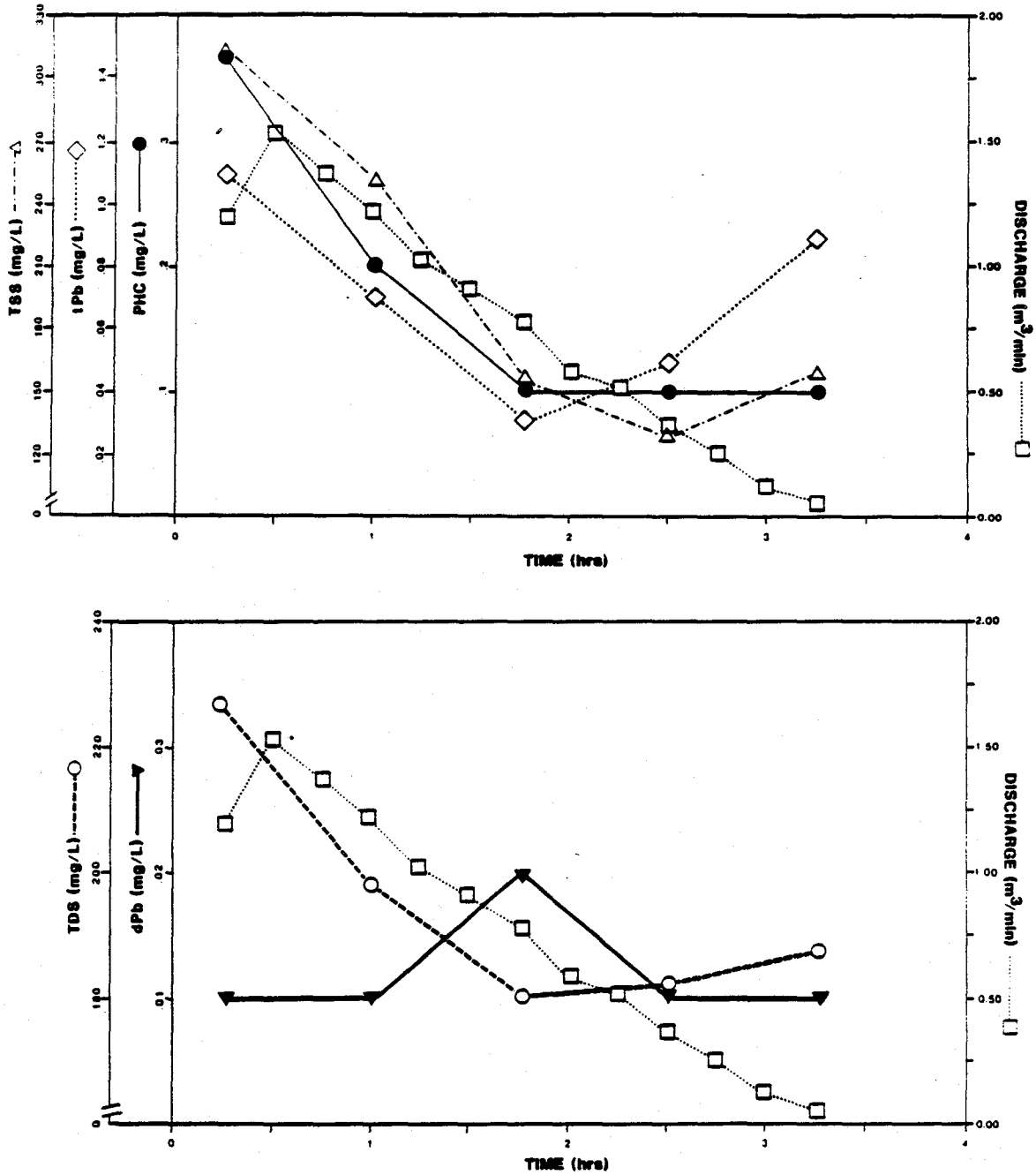

FIGURE 8. POLLUTOGRAPHS OF TSS, tPb, PHC (UPPER), TDS AND dPb (LOWER) WITH THE HYDROGRAPH OF STORMWATER RUNOFF ON 28 AUGUST AT 43RD AVENUE.

TABLE 6. FIELD AND LABORATORY RESULTS OF WATER SAMPLES COLLECTED FROM THE ARIZONA CANAL AT METROCENTER AND THE GRAND CANAL AT 43RD AVENUE COMPARED TO STATE OF ARIZONA SURFACE WATER STANDARDS FOR dPb, tCD, AND FC.

CANAL	DATE	EC (uS/cm)	TSS (mg/L)	TDS (mg/L)	tPb (mg/L)	dPb (mg/L)	tCd (mg/L)	dCd (mg/L)	PHC (mg/L)	BOD (mg/L)	FC (MPN/100ml)
ARIZONA	4 JULY[A]	—	38	408	<0.02	<0.02	0.010	<0.005	0.36	—	—
	11 JULY	—	21	454	0.02	<0.02	0.013	<0.005	<0.20	1.4	130
	10 AUG.	736	12	457	0.02	<0.02	—	—	<0.20	<1.0	>2400
	29 AUG.[A]	—	273	138	<0.02	<0.02	—	—	<0.20	6.0	130,000
GRAND	11 JULY	—	15	436	<0.02	<0.02	0.006	<0.005	<0.20	<1.0	79
	10 AUG.	690	17	462	0.04	<0.02	—	—	<0.20	<1.0	920
SURFACE WATER STANDARDS											
Drinking Water		—	—	—	—	—	0.01	—	—	—	4000
Agriculture I[B]		—	—	—	—	10.0	0.05	—	—	—	4000
Agriculture L[C]		—	—	—	—	0.10	0.05	—	—	—	4000

A) Collected at conclusion of precipitation event.
B) Agricultural Irrigation; "Water Quality Standards for Surface Waters", R9-21-208 Appendix 2, State of Arizona
C) Agricultural Livestock Watering; "Water Quality Standards for Surface Waters", R9-21-208 Appendix 2, State of Arizona

Samples from the Grand Canal were collected on 11 July and 10 August. They provided information on canal water quality during periods of no precipitation (Table 6). Limited sampling suggested that FC concentrations in the Grand Canal were lower than in the Arizona Canal.

CHAPTER IV

DISCUSSION

This study characterizes two small watersheds within metropolitan Phoenix with respect to size, percent impervious area, land use and other physical parameters. It describes the storm events during the summer monsoon of 1986 including intensity, duration, and return period. Instantaneous concentration and event mean concentration of selected pollutants in urban stormwater runoff from the watersheds are presented. These represent 21 data points for each water quality parameter, except BOD and FC, from five storms on two urban watersheds. Baseline canal conditions are also characterized.

Precipitation

Summer precipitation events in central Arizona, the monsoon, are typically of high intensity, short duration and cover a limited geographic area. Storm cells are highly mobile and typically move across the Phoenix metropolitan area from the south and east to the north and west (Turnage and Mallory 1941, Sellers and Hill 1974). The July storms sampled are typical of summer monsoon events. The August 7 and 23 events at Metrocenter were low intensity events and produced limited precipitation. All of these storm had a return period of less than one year. The 28 August event was of high intensity, producing substantial rainfall and occurring over a broad geographic area. It had a 25 year return period.

Conductivity

Conductivity is an indirect measurement of TDS and the two parameters are correlated ($r = 0.80$, $p < 0.001$, $n=19$). A stronger correlation would be expected if water were free of weakly dissociated organics. Field personnel noted highly colored samples on 7 and 23 August. Coloration may have been the result of high concentrations of dissolved and colloidal organic materials (e.g., tannins, fulvic and humic acids, humates and other lignin derivatives) in the runoff. These organics are common secondary products in vascular plants (Swain 1979). Storm events on these dates were low intensity events producing little rainfall and runoff.

Increasing concentrations of dissolved organic carbon may enhance trihalomethane formation potential. The use and maintenance of free chlorine residuals for oxidation/disinfection of raw water containing dissolved organic carbon may facilitate trihalomethane production. Trihalomethanes in drinking water are a health risk (Ohler 1986). The Arizona Canal currently provides raw water to drinking water plants in Glendale and Phoenix.

Suspended and Dissolved Solids

Urban stormwater runoff is a common source of solids. Concentrations of TSS in stormwater from the Metrocenter and 43rd Avenue watersheds are greater than TSS concentrations in the Arizona and Grand Canals during non-storm periods (Table 7).

TABLE 7. COMPARISON OF STORMWATER RUNOFF QUALITY WITH BASELINE CANAL CONDITIONS.

Constituent	Concentrations Measured in Stormwater Runoff[A]	---Ambient Canal Conditions[B]--- Arizona	Grand
TSS (mg/L)	11-570	12-21	15-17
TDS (mg/L)	85-880	454-457	436-462
tPb (mg/L)	<0.02-0.25	0.02	<0.02-0.04
dPb (mg/L)	<0.02-0.04	<0.02	<0.02
PHC (mg/L)	<0.20-1.74	<0.20	<0.20
BOD (mg/L)	16-310	<1.0-1.4	<1.0
FC (MPN/100ml)	>2400->24×10^6	130->2400	79-920

A) Minimum and maximum measured concentrations in the discrete samples collected during all storm events at both sampling sites.

B) Minimum and maximum concentrations measured during this study.

Water quality criteria for TSS do not exist, however, other contaminants may sorb onto sediments in urban stormwater runoff (Athayde et al. 1983).

Arizona Canal samples collected at the conclusion of precipitation events also have higher TSS concentrations than samples collected during dry weather periods (Table 6) indicating the potential for elevating TSS concentrations as a result of stormwater runoff into canals. Field observations during the study indicate that canal water quality (e.g., TSS) may also be affected to a similar degree by management activities which disturb bottom sediments.

Event mean concentrations for TDS in stormwater runoff from the Metrocenter watershed do not differ greatly from baseline Arizona Canal conditions. At 43rd Avenue, however, TDS event mean concentration on 28 August was approximately half of baseline TDS concentrations in the Grand Canal (Table 7). A comparison of TDS concentrations immediately after a storm with those measured under baseline conditions in the Arizona Canal (Table 6) also suggests that stormwater runoff reduces TDS concentration. This trend may vary between storm events and seasonally.

The percent of total TSS and TDS load as a function of the percent of runoff volume is plotted for the three August storm events (Figure 9). Percent TSS over the duration of runoff varied from storm to storm. At Metrocenter, 60% of the TSS load

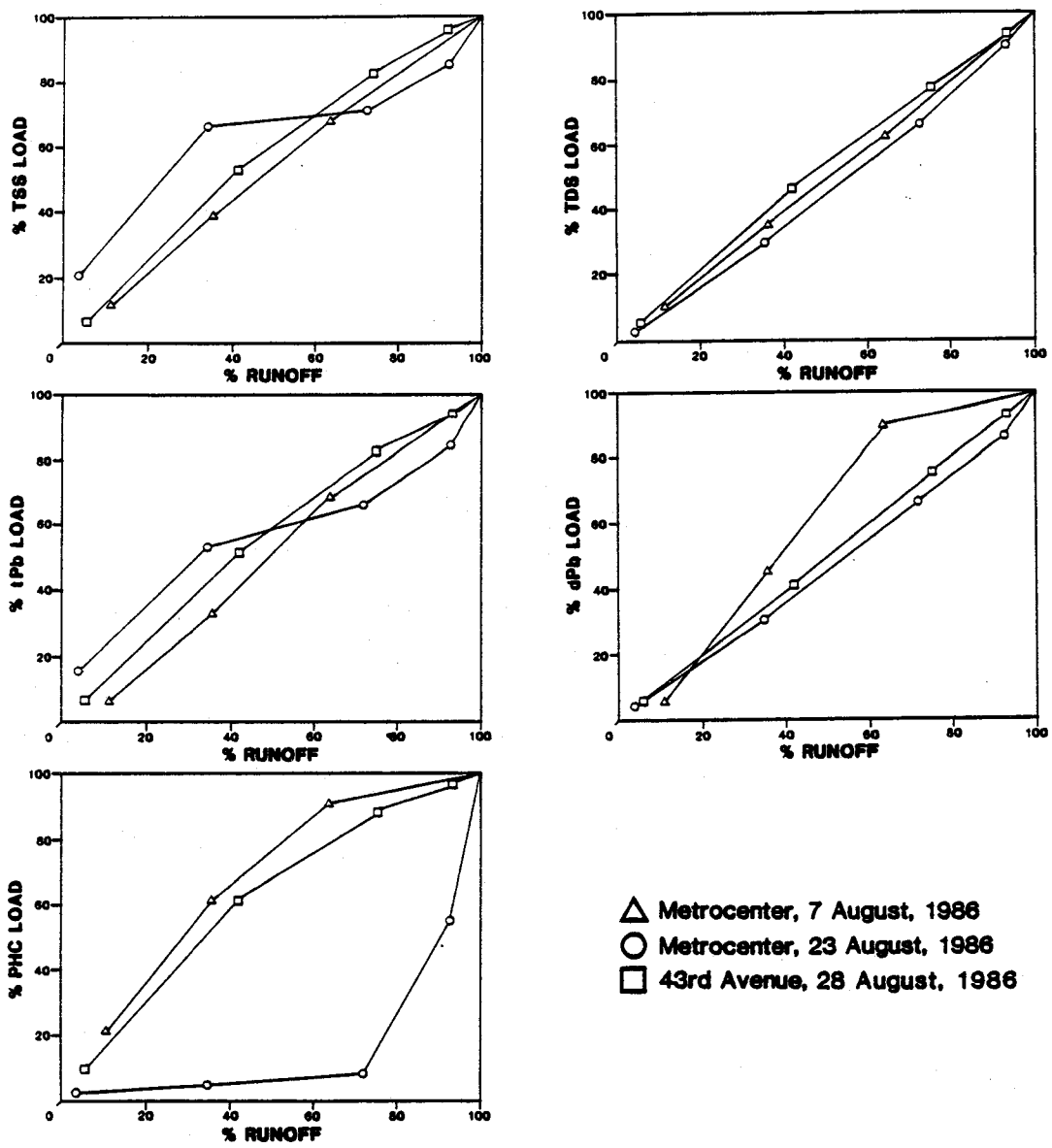

FIGURE 9. PERCENT OF TOTAL TSS, TDS, tPb, dPb, AND PHC AS A FUNCTION OF THE PERCENT OF RUNOFF VOLUME DURING STORMS ON 7 AND 23 AUGUST ON THE METROCENTER WATERSHED AND 28 AUGUST ON THE 43RD AVENUE WATERSHED.

was flushed from the watershed by 55% of the total runoff volume on 7 August. In contrast, the data from 23 August indicate that 60% of the TSS load was carried by the first 29% of the total volume of runoff. Total dissolved solids during each storm are evenly distributed over the period of measured runoff.

Heavy Metals

Heavy metals, including lead and cadmium, are naturally occurring elements, generally with low ambient concentrations. Both are priority pollutants and commonly found in urban runoff. Lead and cadmium have been detected in 94% and 48%, respectively, of the samples analyzed during the NURP (Athayde et al. 1983). High concentrations of metals, particularly in urbanized areas, are commonly associated with automobiles (Galvin and Moore 1982). The transition from leaded to unleaded gasoline has reduced the amount of lead applied to the environment. Other sources of anthropogenic lead include tires, lead-based solder and paints (Galvin and Moore, 1982). Cadmium is used in electroplating, pigments, plastics, printing ink, paint, fluorescent tubes, television tubes, some batteries, insecticides and helminthicides (Faust and Aly 1981).

Only a small fraction of the total lead concentration in stormwater runoff from Metrocenter and 43rd Avenue is in the dissolved form. Most lead from the study watersheds is in the particulate form (Tables 4 and 5). Pollutographs for total lead (Figures 4 - 8) generally follow TSS pollutographs. Finally, the

percent of total lead as a function of the percent of runoff volume is similar to the relationship between percent TSS and percent runoff (Figure 9). These results suggest that a large fraction of tPb is associated with particulate material. Toxicants are readily sorbed onto particulate matter and then transported to receiving waters with suspended solids in stormwater runoff. Thus, suspended solids play a major role as transporters of toxic organic and inorganic pollutants to receiving waters (Hoffman et al. 1982, Athayde et al. 1983).

Lead concentration in stormwater runoff at Metrocenter and 43rd Avenue fall within the minimum and maximum values reported by the NURP study (Athayde et al. 1983). Measured cadmium levels from Metrocenter are less than the detection limit of 0.005 mg/L, however, only three runoff samples were analyzed for this constituent. Cadmium was eliminated from subsequent analyses of runoff because of budget limitations.

Lead concentrations in the Arizona and Grand Canals are generally lower than State surface water standards. However, total cadmium concentrations in the Arizona Canal on 4 and 11 July equal or exceed State surface water standards for a domestic water source (State of Arizona 1980). In light of these preliminary findings, subsequent studies may wish to focus on cadmium. It was eliminated from subsequent analyses of canal waters because of budget constraints.

Properly designed retention basins are effective in reducing TSS load entering receiving waters from stormwater runoff (Athayde et al. 1983). Reducing TSS load also implies a reduction in tPb and other heavy metals sorbed onto particulate matter entering receiving waters.

Petroleum Hydrocarbons

In general, relatively low PHC concentrations are present in the samples from Metrocenter and 43rd Avenue. Thirteen of the 21 samples analyzed have concentrations less than the analytical detection limit of 0.20 mg/L. Pollutographs of PHC follow those of TSS, suggesting an association with particulate matter. Petroleum hydrocarbons also exhibit a first flush effect.

Potential sources of bias were introduced into samples collected for PHC analyses. Samples were collected and transported to the laboratory in plastic bottles because amber glass bottles, generally recommended for this purpose, were not available. Also, automatic water samplers were equipped with tygon tubing, as opposed to teflon tubing which was not available. A fraction of the PHCs in these samples may have sorbed onto the walls of the plastic bottles or tygon tubing and were not measured during the analysis. Finally, the solvent trichlorotrifluoroethane, used to rinse sample bottles, may have extracted a PHC fraction from the plastic sample bottles. Blank and spiked samples, run as analytical quality controls, indicate a potential five percent negative bias in samples collected and

analyzed in this manner. Results reported herein are, however, comparable to PHC concentrations reported in the literature (Hoffman et al. 1982, Gavin and Moore 1982).

There are no EPA water quality criteria specifically addressing allowable concentrations of PHCs in a domestic water supply. Arizona and EPA criteria state that domestic water supplies should be virtually free from oil and grease, particularly from the tastes and odors that emanate from petroleum products (State of Arizona 1980, EPA 1986). Forty-four percent (7 of 16) of the stormwater runoff samples from Metrocenter have PHC concentrations greater than the detection limit and, thus, may exceed the oil and grease criterion. Concentrations in stormwater runoff, however, are probably greatly diluted if, and when, they enter the Arizona Canal.

Biochemical Oxygen Demand

The concentration of oxygen-demanding constituents in stormwater runoff from Metrocenter and 43rd Avenue is greater than concentrations present during non-storm periods in the Arizona and Grand Canals (Table 7). This study, however, does not definitively address the impact of stormwater BOD on dissolved oxygen levels in canals. Although oxygen-demanding materials may reduce dissolved oxygen concentration of canal waters, it is doubtful the demand is sufficient to deplete available dissolved oxygen in canals. Waters of both canals pass through drop structures and ample opportunities for re-aeration

via turbulent mixing with air appear to exist.

Fecal Coliform

Bacterial concentrations in urban stormwater runoff are commonly high. Fecal coliform counts are typically in the tens to hundreds of thousand per 100 mL during warm weather (Athayde et al. 1983). However, exceptionally high concentrations of fecal coliform exist in some samples collected during the study. Four of the seven stormwater samples from study watersheds supported millions of organisms per 100 mL of water.

A nearly continuous base flow occurs in the Metrocenter storm drain. Extensive repairs of the storm drain were necessary following the construction of Metrocenter (pers. comm. Robert Ellis, Ellis - Murphy Engineers, Inc.). These circumstances, coupled with high fecal coliform concentrations, suggest that the storm drain may be cross-contaminated by leakage from sanitary sewers. Alternatively, coliform bacteria may be able to survive and reproduce in storm sewers with a base flow which are dark and warm. A similar explanation has been suggested to explain high fecal coliform populations in warm, moist sands in the apparent absence of a known source of contamination (pers. comm. S. Brickler, University of Arizona).

Extremely high fecal coliform concentrations also characterize the 43rd Avenue site, however, sample sizes are very small. Only three samples from a single storm event have been analyzed. We have no reason to believe that cross connections

with sanitary sewerage exists at this site.

Land Use

Due to the small number of stormwater samples collected from the study watersheds and the limited number of storms sampled, it is difficult to discuss the effect of land use. No differences between the study watersheds at Metrocenter and 43rd Avenue, directly attributable to land use, are apparent although land use may effect quality of urban stormwater runoff (Athayde et al. 1983).

Comparative Studies

The TSS and tPb concentrations measured during this study are within minimum and maximum values reported for other Phoenix and Tucson watersheds (Table 8). However, dPb appears substantially lower while TDS and FC are higher than concentrations measured on other urban watersheds in Arizona. Variation in sampling and analytical techniques in each of the studies may account for some differences. Watershed and storm event characteristics must be considered as well. A comparison with studies nationwide indicates that BOD and FC levels at Metrocenter and 43rd Avenue are greater than those measured during other urban stormwater runoff studies (Table 9). All other constituents are in concentrations comparable to one or more of the nationwide studies.

TABLE 8. COMPARISON OF POLLUTANT CONCENTRATIONS MEASURED AS PART OF THIS STUDY WITH CONCENTRATIONS MEASURED DURING OTHER ARIZONA URBAN RUNOFF STUDIES.

Constituent	Measured Concentrations as Part of This Study		Measured Concentrations Reported by Schmidt(1981)[A]	Measured Concentrations Reported by Resnick et al., (1983)[B]
	Discrete Samples	EMCs		
TSS (mg/L)	11-570	97.1-225.9	117-2350	70-6324
TDS (mg/L)	85-880	197.7-589.5	---	139-873
tPb (mg/L)	<0.02-0.25	0.03-0.17	0.01-0.24	---
dPb (mg/L)	<0.02-0.04	0.01-0.02	<0.01-0.29	---
PHC (mg/L)	<0.20-1.74	0.13-0.86	---	---
BOD (mg/L)	16-310	---	---	---
FC (MPN/100ml)	$>2400->24 \times 10^{6}$	---	---	$0-1.4 \times 10^{8}$

A) These numbers represent concentrations measured in stormwater grab samples collected from two storm drains (15th Avenue and 43rd Avenue) in Phoenix, AZ.

B) These data represent minimum and maximum concentrations in composite samples from the Railroad Watershed, an industrial area in Tucson, Arizona, summer 1970-1975.

TABLE 9. COMPARISON OF POLLUTANT EVENT MEAN CONCENTRATIONS MEASURED AS PART OF THIS STUDY WITH CONCENTRATIONS MEASURED DURING OTHER NATIONWIDE URBAN RUNOFF STUDIES.

Constituent	This Study	Knoxville, TN NURP Study[A]	Bellevue, WA NURP Study[B]	Commercial Area Warwick, RI[C]	EPA NURP[D] Residencial	EPA NURP[D] Commercial
TSS (mg/L)	97.1-225.9	3.8-32,914	1-2740	1.6-252.0	101	69
TDS (mg/L)	197.7-589.45	13.4-180.0	8-788	---	---	---
tPb (mg/L)	0.03-0.17	0.47-2.13	0.004-1.8	---	0.144	0.104
dPb (mg/L)	0.01-0.02	0.001-0.02	---	---	---	---
PHC (mg/L)	0.13-0.86	---	<1-10 (oil/grease)	0.98-2.15	---	---
BOD (mg/L)	16-310[E]	3.3-32.9	<0.1-40	---	10	9.3
FC (MPN/100ml)	$>2400->24 \times 10^{6}$[E]	$100-8.6 \times 10^{5}$	$1-6.6 \times 10^{4}$	---	---	---

A) Mulligan et al., (1984)
B) Pitt et al., (1984)
C) Hoffman et al., (1982)
D) Athayde et al., (1983)
E) These data represent concentration ranges measured in discrete samples. Because of insufficient data points, EMCs could not be calculated for these parameters.

Retention Basin

One aspect of this study was to have been an evaluation of the retention basin's performance at Metrocenter. The basin's operational criteria are flexible. Accumulated stormwater is pumped into the Arizona Canal when half-full or more and additional runoff is probable (pers. comm. A. Chavez, City of Phoenix). The basin was not pumped during the sampling period. Observations during field sampling indicate that the position of pump intake relative to the storm drain discharge point increases the probability that the basin will not operate at maximum efficiency in settling solids if discharge into the basin is occurring coincident with waters being pumped into the canal. The basin is effectively 'short-circuited' by the closeness of the pump to the storm drain discharge point. Additionally, a sanitary sewer crosses the retention basin. Potentially, stormwater runoff could enter this sewer and discharge into the receiving sewage treatment plant. However, more significant impacts may occur if leaks allow raw sewage to enter the basin and its contents are pumped directly into the Arizona Canal. Special precautions should be taken to minimize the potential for leaks of this type.

Water Quality Standards and Criteria

A myriad of standards and criteria regulate water quality on the State and Federal level. The State of Arizona has Surface Water Quality Standards, Primary and Secondary Drinking Water

Standards and Action Levels. Of the numerous Federal regulations and guidelines, amendments to the Safe Drinking Water Act are particularly relevant (Thompson 1986).

The State's Surface Water Quality Standards (State of Arizona 1980) regulate the Arizona and Grand Canals and define protected uses including domestic water supplies (Arizona Canal only), agricultural irrigation and agricultural livestock watering. The standards are not enforceable during periods of high runoff and probably not directly applicable to stormwater runoff from urban watersheds. While Federal guidelines may be applicable to stormwater runoff, they are unenforceable.

Arizona's Primary and Secondary Drinking Water Standards (State of Arizona 1984) are applicable to treated waters from a domestic water source. They are enforced by the Arizona Department of Health Services. Waters leaving a treatment plant must meet primary standards for inorganic and organic contaminants. While inorganics are usually removed during treatment, organics may not be affected by treatment. The presence of organics for which standards are set, notably Endrin, Lindane, Toxaphene, Methoxychlor, 2-4-D and 2-4,5-T, in stormwater runoff and the canals is unknown.

The State of Arizona has also established a set of Action Levels for a number of volatile organic compounds and pesticides, many of which are carcinogenic (State of Arizona 1985). Strictly speaking, Action Levels are non-enforceable and serve as

guidelines for maintenance of high quality drinking water. The State may request remedies, such as mixing, when Action Levels are exceeded. Also, it is probable that most of the compounds listed will, in the future, be regulated by the EPA.

Trihalomethanes and the potential for their formation are of considerable concern to SRP and local municipalities as THMs in finished water are higher than median values nationwide (Ohler and Caldwell 1985, Ohler 1986). State and Federal agencies have established a maximum contaminant level of 0.10 mg/L for total trihalomethanes (Federal Register, 29 November 1979, State of Arizona 1984). By 1987, EPA anticipates proposing revised regulations for disinfection by-products, including total trihalomethanes.

CHAPTER V

RECOMMENDATIONS

The study team has drafted four recommendations for consideration by SRP and other interested parties. It is felt they will contribute to the continued delivery of high quality water to municipal and agricultural water users.

- Install a more extensive system of real time rain gauges throughout metropolitan Phoenix. This instrumentation will be invaluable to designers of future storm drains, planners and other concerned parties.

- Monitor trihalomethane formation potential in the Arizona Canal at water treatment plant intakes before, during and after winter and summer storm events. The effect of dissolved organic matter carried in runoff and discharged into the canal can thus be assessed.

- Collect water from all storm drains with a continuous base flow and analyze samples for fecal coliforms. If substantially large numbers are measured (>1,000,000 MPN/100mL), check suspect drain(s) for cross-connections with sanitary sewerage.

- Collect sediments from the bottoms of the Arizona and Grand Canals and analyze samples for heavy metals and acid and base extractable priority pollutants. Seasonal and temporal changes in physiochemical processes in canals may release these compounds into the water column at various times of the year.

CHAPTER VI

REPORT PREPARATION PERSONNEL

PROJECT MANAGEMENT	George A. Ruffner, Ph.D. SWCA, Inc.
	E. Marco Aieta, Ph.D. James M. Montgomery, Inc.
WATER QUALITY SPECIALISTS	Frederick A. Amalfi SWCA, Inc.
	Stephen B. Ellingson SWCA, Inc.
	I. Elaine Wallace James M. Montgomery, Inc.
INSTRUMENTATION	John S. Lang James M. Montgomery, Inc.
PROJECT TECHNICIAN	Stephanie Statler SWCA, Inc.

APPENDIX A

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APPENDIX B

DEFINITION OF TERMS

Event Mean Concentration -

The total constituent mass contained in the runoff from a storm event, divided by the total volume of runoff produced during that event.

First Flush -

The condition in which disproportionately high constituent concentrations are carried in the ascending leg of the hydrograph.

Hydrograph -

Stormwater discharge in cubic meters per minute as a function of time since the beginning of runoff.

Pollutograph -

A plot of instantaneous pollutant concentration in mg/L versus time since the beginning of the storm.

Return Period -

The probability of occurrence of a storm of a given intensity and duration.

Runoff Coefficient -

The total volume of runoff generated by a storm event divided by the total volume of precipitation falling on the watershed.

Storm Event -

The elapsed time from the beginning of precipitation and ending with the last rainfall and including six subsequent hours without rain.

Summer Monsoon -

Period of time when the daily average dew point is equal to or greater than 55 degrees Fahrenheit.

APPENDIX C

SALT RIVER PROJECT
STORM DRAINAGE POLICY

The Problem . . . For SRP

	Street Drains	Canal Drains	Detention Basins
Northside	1249 (est)	150 (est)	12
Southside	344 (est)	104 (est)	62
Total	1593	254	74

Plus - Overland Flows into Open Laterals and Canals

The Policy . . .

The purpose of the policy is to encourage long range storm drain planning based on an integrated system that optimizes use of SRP's system while minimizing storm drainage impacts to the SRP system.

Established in February 1985 with concurrence of all local municipalities and agencies.

Policy on Storm Drainage into SRP Facilities

1. All new storm drain connections will require an outlet of equal flow rate to a governmental storm drain, river bed or other facility that can adequately dispose of storm runoff.

2. Existing drains that are moved, modified or adjusted due to street widening, intersection improvements, etc., will require an outlet of equal flow rate to a governmental storm drain, river bed, or other discharge facility.

3. New, or replacement of existing drain connections will not exceed 12 inches in diameter at any site or discharge at a combined flow rate greater than the outlet unless otherwise justified.

4. Distance for inlet to outlet will be a function of the available capacity for the transportation of storm flow

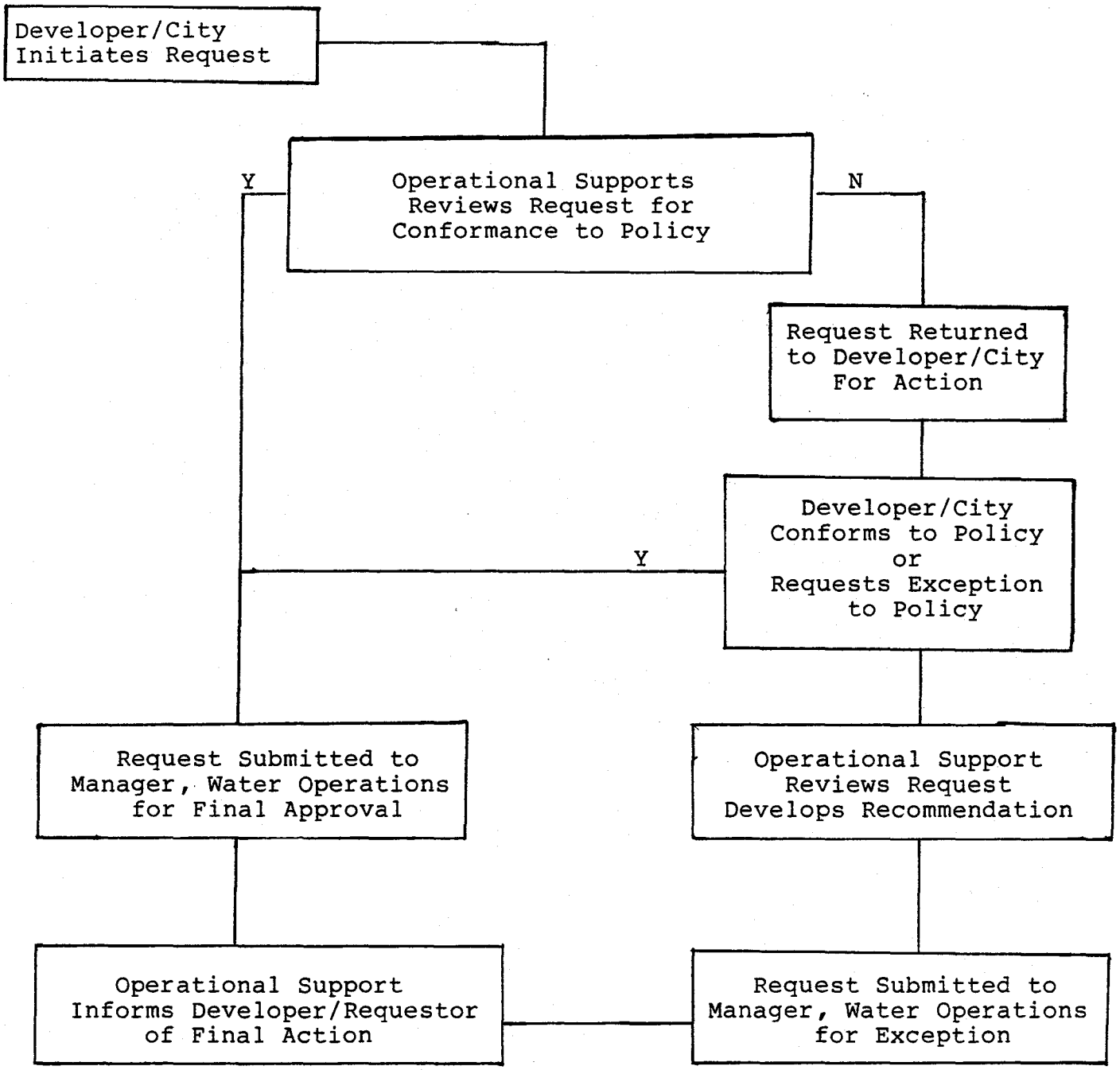
between the inlet and outlet.

5. Detention basin discharge pumping will require an outlet of equal flow rate to the maximum pumping capacity and SRP's ability to transport the storm water.

6. Water quality impacts on shareholders are to be considered.

7. All drains should have an outlet of equal flow rate to a governmental storm drain or to a river bed by January 1, 1995, or be scheduled for removal from the SRP system.

The Procedure . . .



1. All requests for new or modified storm drain connections are submitted to the manager, operational support, for processing.

2. Requests are reviewed for conformance to policy. If request is in conformance it is submitted to the manager, water operations, for final approval. If the request does not conform the request is denied and returned to the requestor review the city storm drain system, both existing and proposed, consider on-site retention, or consider dry wells.

3. All drain connections, discharge rates and/or exceptions to policy for storm water into SRP facilities must be approved by the manager of water operations.

The Problem . . . For The Cities

Increased urbanization of agricultural lands creating increased volumes and faster storm runoff

Increasing obligation to dispose of storm water specifically localized problems which require immediate solutions

Increasing costs of construction of storm drain systems

Insufficient money

City Storm Drain Status

	Master Plan	Implementation	Construction
Phoenix	XX	XX	XX
Tempe	XX	XX	XX
Mesa	XX	XX	XX
Glendale	XX		
Peoria	In Process		
Scottsdale	XX		
Chandler	In Process		
Gilbert	In Process		

Cooperative Storm Drain Facilities

Existing

1. SRP Lateral/City Storm Drain Connections (SRP, COP)

Northside	65
Southside	41

2. Grand Canal Outlets (SRP, COP)
   32nd St, 24th St, 16th St, 7th St, 7th Ave, 15th Ave, 19th Ave, 27th Ave, 35th Ave, 43rd Ave, 59th Ave

   Total 11

3. Papago Freeway Drainage Channel Connections (SRP, MCHD)
   99th Ave, 107th Ave

   Total 2

Proposed

1. Gila Drain Joint Use Pipeline (SRP, Tempe)

2. 48th Street Storm Drain -Western Canal Outfall
   (SRP, Tempe, Phoenix, Gilbert)

3. Price Road Joint Storm Drain
   (SRP, FCD, Mesa, Chandler, Gilbert, ADOT)

4. 80 Acre & Downtown Detention Basins
   (SRP, Gilbert)

5. Papago Freeway Channel/Phoenix Storm Drain Connections
   67th Ave, 75th Ave, 83rd Ave, 91st Ave
   (SRP, Phoenix, MCHD, ADOT)

6. ACDC

Summary

Purpose

Review SRP's current problems, policies and procedures regarding acceptance and disposal of stormwater.

Discussion

Problems
Policy
Procedures
City Storm Drain Construction Status
SRP/City Cooperative Efforts

Questions

APPENDIX D

METRIC-ENGLISH CONVERSIONS

Multiply	By	To Obtain
Kilometers (km)	0.6214	Miles
Meters (m)	3.2808	Feet
Centimeters (cm)	0.3937	Inches
Millimeters (mm)	0.0394	Inches
Hectares (ha)	2.4710	Acres