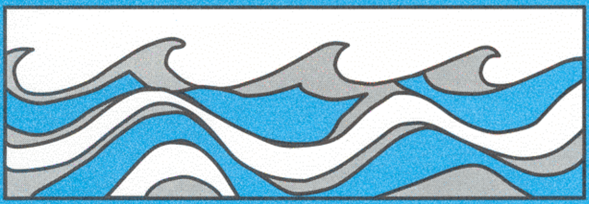
University of Washington
Department of Civil and Environmental Engineering

OPERATION OF DETENTION FACILITIES FOR URBAN STREAM QUALITY ENHANCEMENT

Lisa K. Dally
Dennis P. Lettenmaier
Stephen J. Burges
Mark M. Benjamin



Water Resources Series
Technical Report No. 79
July 1983

Seattle, Washington
98195

Department of Civil Engineering
University of Washington
Seattle, Washington 98195

OPERATION OF DETENTION FACILITIES FOR URBAN STREAM QUALITY ENHANCEMENT

Lisa K. Dally
Dennis P. Lettenmaier
Stephen J. Burges
Mark M. Benjamin

Water Resources Series
Technical Report No. 79

July 1983

Department of Civil Engineering
University of Washington
Seattle, Washington, 98195

OPERATION OF DETENTION FACILITIES
FOR URBAN STREAM QUALITY ENHANCEMENT

by

Lisa K. Dally, Dennis P. Lettenmaier, Stephen J. Burges
and Mark M. Benjamin

Water Resources Series
Technical Report No. 79

July 1983

Project Completion Report: "Operation of Detention Facilities for Urban Stream Quality Enhancement"

Project Period: October 1, 1980 - August 31, 1983

Principle Investigators: Dennis P. Lettenmaier, Research Associate Professor
Stephen J. Burges, Professor
Mark M. Benjamin, Associate Professor
Department of Civil Engineering
University of Washington

U.S. Bureau of Reclamation
Office of Water Research Grant No.: 14-34-0001-0504

Department of Civil Engineering
University of Washington
Seattle, Washington, 98195

OPERATION OF DETENTION FACILITIES FOR URBAN STREAM QUALITY ENHANCEMENT

by

Lisa K. Dally, Dennis P. Lettenmaier, Stephen J. Burges
and Mark M. Benjamin

Water Resources Series
Technical Report No. 79

July 1983

Project Completion Report: "Operation of Detention Facilities for Urban Stream Quality Enhancement"

Project Period: October 1, 1980 - August 31, 1983

Principle Investigators: Dennis P. Lettenmaier, Research Associate Professor
Stephen J. Burges, Professor
Mark M. Benjamin, Associate Professor
Department of Civil Engineering
University of Washington

U.S. Bureau of Reclamation
Office of Water Research Grant No.: 14-34-0001-0504

ABSTRACT

The efficiencies of two existing urban stormwater detention facilities in reducing pollutant loadings to receiving waters was investigated. The study utilized two field sites in King County, Washington: a 76 acre residential subdivision in the Vasa Creek/Lake Sammamish drainage basin, and the other a transit operating base in the Kelsey Creek/Lake Washington drainage basin.

Inflow and outflow hydrographs were estimated for a total of twelve storms, along with pollutant concentrations ranging from 3.75 minutes to 1 hour. The principal water quality concern at the residential site was solids transport. Resuspension of sediment in this dry pond was a major problem, and resulted in negative pollutant removal efficiencies for most storms. Multiple inflow concentration peaks during lengthy winter storms appeared to be related to sediment generation from residential construction activity.

The principal water quality concerns at the transit site, which largely consists of paved transit storage and maintenance areas, were oil and grease, cadmium, lead, zinc, phosphorus and solids. This facility, which is a wet pond, had a significant effect in transforming cadmium and lead from particulate to soluble phase. For this reason, the pollutant removal efficiencies for modest storms appeared to be negative, while for lesser storms, and for particulate pollutants, removal efficiencies were generally positive. Additional experiments utilizing 'synthetic' storms generated from fire hydrant releases, indicated that pipe flushing can be an important source of pollutants during intense storms.

The so-called first flush effect, the tendency of a disproportionately large fraction of the pollutant loading from a storm to occur in the early stages of the rising limb of the hydrograph, was apparent for grease and oil, particulate lead, particulate cadmium, and total suspended solids at the transit site. First flush was not generally exhibited at the residential site. The peak concentrations and loadings did not appear to be related to traffic volume or antecedent conditions. In addition, selected base flow sampling indicated that dry weather runoff, considered on an annual basis, may contribute a total pollutant loading similar to that resulting from stormwater runoff over a year.

ACKNOWLEDGEMENTS

The work reported herein constitutes the Master of Science in Engineering thesis of the first author, under the direction of Drs. Lettenmaier, Burges, and Benjamin. Financial support for the project was provided by the Office of Water Research and Technology of the U.S. Department of the Interior (now the Office of Water Research of the U.S. Bureau of Reclamation) under its focused research program. Matching support, in the form of a research contract for the portion of the project carried out at its Transit East Operating Base, was provided by the Transit Development Section of the Municipality of Seattle (METRO) with the assistance of METRO's Water Quality Division. Matching in kind was provided by the Department of Public Works of the City of Bellevue. We are particularly grateful to Mr. Robert Swartz and Ms. Joanne Davis at METRO, and Ms. Pam Bissonnette of the City of Bellevue, for their assistance in coordinating funding and project management with their respective agencies.

Technical assistance was provided by Msrs. Dan Sturgill, Gary Yoshida, and Rocky Wells of METRO's Water Quality Laboratory, who analyzed many of the samples, and Mr. David Renstrom of the City of Bellevue who assisted in equipment setup and verification of the sample design at both sites. Mr. David Galvin of METRO's Toxicants Program provided insights on the interpretation of East Base results, while Msrs. Ed Prych and James Ebbert of the U.S. Geological Survey assisted in loaning sampling equipment and providing data collected in a concurrent U.S. Geological Survey project in the same general area. Professor Brian Mar, of the University of Washington Department of Civil Engineering, made helpful suggestions in the experimental design and data interpretation aspects of the project, drawing on his experience with highway runoff quality monitoring.

Throughout the course of the project, student helpers performed many tasks. Particularly appreciated were the efforts of Mr. David Stensby, who constructed the sampling sheds at both sites, and installed much of the equipment. Msrs. David Sommers, Sinclair Wang, and Greg Laird, and Ms. Lilly Ng assisted in collection of data and laboratory analyses, as well as entering processed data into the computer. Finally, the assistance of Ms. Jane Lybecker in promptly and accurately typing this document is much appreciated.

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

LIST OF FIGURES

LIST OF FIGURES - Continued

LIST OF FIGURES - Continued

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

Urbanization causes a reduction in the natural hydrologic retention, or storage capacity of a catchment that otherwise takes the form of depression storage, permeable soil strata, and other means of water storage. Man-made detention facilities can be used to supplement losses in natural retention. Artificial detention storage can provide flow and/or flood control by retaining, buffering and attenuating flows.

Detention or retention basins can simultaneously be used to remove particulate pollutants from stormwater runoff. Recognition of urban runoff as a major source of non-point pollution has recently motivated the inclusion of water quality considerations in stormwater management. Modification of existing flow control detention basins for use as dual purpose basins wherein removal and storage of particulates and associated pollutants will also be accomplished provides a readily available, albeit partial solution to urban runoff pollution problems.

The purpose of this study is to assess pollutant removal efficiency of two existing detention ponds originally designed solely for flood control purposes. Tradeoffs between storage for runoff control and pollution control will be identified as well as design considerations.

The terms retention and detention are used interchangably by many authors. Technically, detention basins are small impoundments used to detain storm flows over short periods. Detention basins are characterized by <u>ungated</u> <u>outlets</u>. If release is controlled by outlet structures for purposes of lengthening retention times, the basin may be called a <u>retention</u> basin. However, this subtle distinction matters little from a practical standpoint and the terms retention and detention will be used interchangably throughout this report. Such basins can be classified further as dry basins or wet basins. Wet basins contain a permanent volume of water (dead pool) below elevations at which flood waters are stored.

Detention basins are designed to meet criteria specified for a given geographic area; either by ordinance or regulation. The design criteria are based on the premise that specified design storms occurring after development have no additional adverse impacts on the receiving water body and channel structure than similar storms occurring without development. The scope of the impacts addressed by recent legislation is being widened to include not only flood related effects, but also negative impacts on the quality and biota of receiving waters.

In this study, the efficiencies of two existing urban stormwater detention ponds in reducing pollutant loading to receiving waters was investigated. Inflow and outflow hydrographs, pollutant concentrations, and loadings were estimated for each site; one characterized by a single-family residential land use, and the other by a light industrial land use.

CHAPTER TWO

A REVIEW OF CURRENT LITERATURE

A. Related Policies

Many local governments throughout the U.S. have adopted detention ordinances to mitigate urban flooding problems. These ordinances typically require control of increased runoff from developing urban areas by use of retention structures which reduce peak flows entering receiving waters. The retention facilities evaluated in this study were built in accordance with City of Bellevue and King County drainage ordinances (Appendix A) requiring on-site detention of stormwater to reduce storm runoff peaks to levels compatible with the natural, pre-development channel systems.

Traditionally, flood control and channel protection were the sole objectives of most urban stormwater management programs. However, several studies have concluded that concentrations of specific pollutants in stormwater runoff are greater than concentrations from many point source discharges (Northern Virginia Planning Commission, 1978; Whipple et al., 1974; Randall, 1979; Helsel et al., 1979; Sartor et al., 1974). The pollutants of greatest concern include total suspended solids, zinc,lead, cadmium, chromium, copper and total phosphorus (Waneilista et al., 1977; Sartor et al., 1974; Whipple et al., 1978). More recently, petroleum hydrocarbons have been identified as major toxic components of urban runoff (Wilber and Hunter, 1975; Whipple et al., 1978; Wakeham, 1977). Whipple et al. (1978) and Whipple and Hunter (1979) report the most common generic toxic pollutant in urban runoff to be petroleum hydrocarbons, followed by lead, copper, cadmium, Polychlorinated Biphenyls (PCB's), and pesticides.

A dual purpose approach to stormwater management has been pioneered by the Delaware and Raritan Canal Commission via New Jersey state regulations and by the Northern Virginia Planning District Commission via Fairfax County regulations (Kropp, 1982). Basin-wide water quality monitoring of the Occoquan watershed of Northern Virginia indicated that runoff from urbanized areas had a greater impact on reservoir water quality than did the discharges from existing sewage treatment plants (Randall et al, 1982).

The Fairfax County ordinace requires the installation of porous and pervious pavements, swale drainage, elimination of curbs and gutters, narrowing of paved roads as well as use of both wet and dry dual purpose detention ponds. The county has a flood and erosion control requirement for two- and ten-year peak flow rates as well as a required 40 hour retention period for the "settleablility" design storm. The settleability design storm is defined as .86 inches of runoff for all impervious catchments and lesser amounts corresponding to the percentage of imperviousness. The exact basis for defining the size of the design storm is not apparent from the literature; however, small floods have been found to contain disproportionately high concentrations of pollutants in addition to being more numerous. Therefore, a smaller storm than that used for runoff control purposes would be a likely design storm for water quality control purposes (Kropp, 1982).

To achieve water quality control, the New Jersey ordinance requires 90 percent of the runoff produced from the settleability design storm (1.25 inches of rainfall in two hours) to be retained for 37 hours (Kropp, 1982). Required detention times are based on laboratory studies by Whipple (1981) and Whipple and Hunter (1981) which determined settleability requirements for urban runoff pollutants. Data indicated that retaining runoff over a 36 hour period (with a mean retention time of 18 hours) should be adequate to settle approximately 60 percent of TSS, lead and hydrocarbons, while approximately 45 percent of BOD, copper and phosphates would settle.

As a result of changing stormwater management philosophies, new design techniques are being developed to control first flush pollutant loading effects and flood hazards in many areas of the eastern U.S. These techniques include dual purpose retention basins, separate quality and quantity control basins, and non-structural water quality control measures. Dendrou et Delleur (1982) emphasize the need to consider detention facilities in conjunction with other elements of storm drainage systems on a regional basis.

Planners are becoming concerned with both cost and difficulty of insuring maintenance of many small detention basins . Master or regional detention basins serving larger areas jointly may be more economical than smaller ponds. Some localities have recognized that stormwater control must be planned on a catchment-wide basis as opposed to a sub-area, piecemeal approach for water quality as well as flood control purposes. Smiley and Haan (1976) have shown that under some circumstances, the installation of an unplanned series of detention basins may aggravate downstream flooding. This will be the case when runoff from a downstream sub-catchment is detained and the delayed hydrograph from the detention basin coincides with the arrival of flow from the upstream segment of a catchment.

The most recent development in the field is the use of regional retention basins involving sub-catchment network design. The City of Bellevue, Washington, for instance, is installing a series of flood control retention structures which were designed on a regional basis.

B. Dual Purpose Retention Basin Performance Studies

Detention storage as a stormwater management alternative for flood control and pollutant removal has been investigated by many researchers in the past five years. Detention pond pollutant removal efficiency has been investigated both in the field (Griffin et al., 1978; Bedient et al., 1980; Oliver and Grigoropoulos, 1981; McCuen, 1980; Davis et al., 1978; Ferrara and Hildick-Smith, 1982; Hey, 1982; Driscoll, 1982), and in laboratory settleability studies (Whipple and Hunter, 1981; Randall et al., 1982). In addition, several computer models have been developed to test efficiencies of different pond designs in varying hydrologic regimes. These models are discussed in greater detail in Section C.

1. Field Studies

Early studies focused on quantifying pollutant loadings from catchments to determine if dual purpose retention pond use was necessary. Griffin et al. (1978) identify land use characteristics which affect both the quality and quantity of runoff. A sequential discrete sampling method was used on 21 catchments in Northern Virginia to determine pollutant loadings, and to formulate predictive loading equations for each pollutant based on catchment characteristics, rainfall duration and intensity. Griffin also found that insoluble pollutant forms exhibit a different removal mechanism than soluble forms. A first flush characteristic removal was only exhibited by pollutants in an insoluble form.

The first flush phenomenon observed by Griffin et al. can be more clearly illustrated by the following series of figures taken from Whipple et al., 1983:

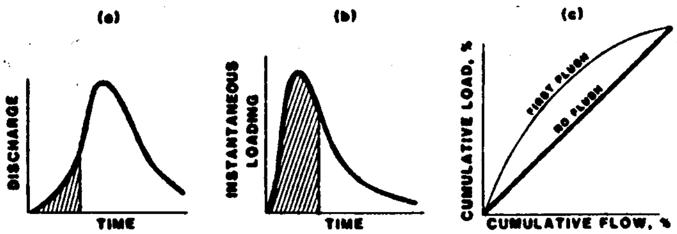


Figure 2.1. Essentials of the first flush phenomenon.

The first flush effect concentrates pollutant loads in the first portion of the runoff volume. For any given fraction of the total flow, a greater fraction of the total load has been generated during the storm. The first flush phenomenon was observed for a number of constituents during a runoff event occurring in a Northern Virginia townhouse development (Northern Virginia Planning Commission, 1978).

Extractable metals, total nitrogen and total phosphorus exhibited the greatest tendancy towards the first flush effect, while soluble forms exhibited the least tendency.

Farris et al. (1979) noticed that first flush mass emission patterns coincided closely with the shape of the runoff hydrograph. A storm causing a sudden initial peak flow followed by a gradual decline was most often associated with a first flush observation. The fact that pollutant mass emission rates remained proportional to the flow rate for storms of low intensity suggests that some minimum flow is required for complete flushing; and until the required intensity or volume is reached, removal will be proportional to flow, and the first flush phenomena will not occur. During small storms, the first flush effect may not occur. Therefore, first flush may not be a function of time within a storm event (attributable to the exponential washoff of available pollutants with time), as previously hypothesized, but more likely, a function of flow rate. If the majority of storms in a region are typified by a sudden initial flow and subsequent decline of flow, pollutant loading will appear to take on a first flush character, when in fact, what is observed is simply the flow governing delivery of pollutants.

If first flush does exist, antecedent conditions (dry period length, and factors indicating pollutant deposition rates) should be related to the magnitude and duration of the resulting pollutant loading. Farris et al. (1979) found no direct relationship between the average pollutant loading and the number of preceding dry days for several catchments in Seattle. Little (1982) also found that the variation of pollutant concentrations in highway runoff composite samples was not dependent on antecedent conditions. Little's study also correlated traffic volume at the time of the storm, precipitation duration and intensity with pollutant concentration in stormwater runoff. Bedient et al. (1980) have attempted to identify pollutant load-runoff relationships for several catchments in the Houston area. During this study, the effect of the antecedent dry period length was investigated and no significant correlation was found between number of dry days preceding a storm event and observed concentrations or loads. This finding is similar to that of Whipple and Hunter (1977) and Jewell et al (1980). The latter studies used data from residential sites in northern New Jersey. However, Medina (1981) found that inter-event (dry weather) conditions markedly influenced the quantity and quality of resultant runoff in a more urban land use setting in Des Moines, Iowa.

Bedient used discrete storm sampling to quantify total suspended solids (TSS), total phosphorus (TP), and total Kjeldahl nitrogen (TKN) concentrations and loadings. These data were used to develop a simple loading model to predict mass flows during individual storms and sequential storm series. The model assumes a first-order decay process for pollutant washoff to simulate decreasing availability of runoff pollutants and dilution effects. The defining equations are:

$$C(t + \Delta t) = C(t) \times e^{-(br(t)\Delta t)}$$

$$C(0) = C_0$$

where C_o = initial concentration

$r(t)$ = runoff rate from hydrograph

b = washoff decay rate

This model requires upper and lower concentration limits derived from actual storm data to derive the washoff decay rate. Therefore, stormwater monitoring is required to determine upper and lower bounds of concentration for individual watersheds before the loading model can be used for a specific catchment (Bedient et al., 1978; 1980).

The efficiency of detention processes for the control of runoff water quality has been investigated by Davis et al. (1978). A 45 acre catchment in Montgomery County, Maryland was used as a study site for the project. Regression analysis provided the following relationships:

1. Pollutant loads in inflow versus land use and rainfall characteristics which govern inflow.
2. Water quality parameters versus sediment load.
3. Trap efficiencies versus detention basin design.
4. Water quality parameters versus detention basin design.
5. Water quality parameters versus flow governing characteristics such as rainfall and land use.

Regression equations were not verified with additional field data; therefore, the preceding relationships cannot be considered significant. The relationship between inflow and outflow from a retention basin, and 17 water quality parameters was determined. In the prediction of inflow loadings, only flow rate was used as a predictor variable. One of two general equations was used to predict loading based on sample data:

$$P = a+bQ$$

or $$P = cQ^d$$

where

a,b,c,and d are regression coefficients

P = pollutant mass load

Q = inflow

The form of the equation used is dependent upon the pollutant of interest.

The effects of first flush are not described by these relationships because first flush is a function of time, as well as flow rate. Again, the inflow pollutant loadings predicted by this study are catchment-specific, therefore the predictor equations developed are not applicable to other sites.

In addition to developing inflow pollutant load predictor equations based on runoff flow rate into a detention pond, Davis also formulated equations to quantify the efficiency of the pond in terms of its ability to reduce peak flows and to limit the sediment in the outflow. Regression analysis provided equations for Peak Reduction Factor (PRF), a measure of peak flow reduction, and Trap Efficiency (TE), defined as sediment removal efficiency. Predictor variables in this regression included land use and precipitation characteristics. Medina (1981) emphasizes that PRF and TE are also functions of detention basin design characteristics. Curtis and McCuen (1977) identify storage volume, basin length and detention time as significant predictor variables.

The regression equations formulated by Davis et al. were used in a model to simulate runoff, sediment and pollutant discharge from a watershed, and from the detention basin system. The model was used to test the effects of various retention basin designs on sediment trap efficiency and flow reduction. The basin riser characteristics (outlet pipe design) were found to be important for stormwater runoff control, but did not affect trap efficiencies. Retention time and flow length were identified as critical design criteria with respect to sediment and related pollutant trap efficiencies.

McCuen (1980) subjected the data of Davis et al. (1978) to further analysis. Equations provided by these authors for PRF, TE and inflow pollutant loads were used by McCuen to estimate specific pollutant loading and trap efficiencies for the same retention basin for different design storms.

TE was found to range from 2% to 98%. The highest values of TE occurred during smaller storm events. As volume of flow increases (larger return periods or greater storm duration) the TE decreases because detention time decreases.

In addition, McCuen found a high correlation ($\rho = .82-.97$) between sediment and water quality transport of specific pollutants indicating that either a physical relationship exists such that the water quality parameters are transported by sediment or that there is a common variation of both water quality and sediment with flow rate.

Oliver et al. (1981) investigated the use of a small urban lake to control storm-generated pollution in Rolla, Missouri. This study differs from the previously mentioned studies in that detention times in the lake are much greater than those in small retention facilities designed to service small urban or suburban catchments. The average residence time during the study was 28 days. Oliver found an average reduction in mass of runoff pollutants of 22, 54, 65 and 88 percent, respectively for organic nitrogen, COD, total phosphorus, and total suspended solids. Mechanisms attributed to reduction of pollutant load include dilution with incoming base flow, sedimentation of suspended matter and biological utilization of soluble organics, and nutrients by bacteria and algae.

Ferrara and Smith (1982) determined concentrations associated with three separate particle size ranges for COD, total phosphorus, total Kjeldahl nitrogen and total suspended solids samples collected at inflow and outflow locations of a retention pond. A relationship between particle size distribution, settling velocity and trap efficiency was determined.

2. Laboratory Studies

Laboratory determinations of grain size and fall velocity in still water have been correlated with sediment trap efficiency of detention basins (Ward, 1977; Chen, 1974; Bondurant, 1975). More recently, Whipple and Hunter (1981) attempted to quantify settleability of different pollutants in a laboratory water column using stormwater samples collected at five urban/suburban locations. They concluded that 32 hours settlement in undisturbed water six feet deep removes approximately 60 to 70 percent of common runoff pollutants. Lead and hydrocarbons exhibited removal characteristics most similar to total suspended solids; these parameters required only 16 hours for sedimentation. Zinc settled more slowly than the other metals tested. Many researchers assume that pollutants will settle at rates proportional to their particulate concentrations. Whipple and Hunter could not support this assumption with their data. The results obtained in this study varied considerably from site to site, therefore, similar studies would be required in various regions before retention basin settling time policies could be determined. A further limitation in these studies is that field properties will differ from the laboratory results, where the water is undisturbed in a settling column. For example, Oliver and Grigoropoulos (1981) performed a field study in an urban lake. Average residence times for settling was 28 days versus Whipple's findings of 32 hours in lab experiments.

Randall et al. (1982) conducted a similar investigation to determine the efficiency of sedimentation for specific pollutants found in urban runoff from commercial shopping mall parking lots in Northern Virginia. A 48 hour settling period removed 90, 86, and 64 percent of TSS, lead and BOD, respectively.

Although many urban runoff pollutants are believed to have a high affinity for adsorption on suspended particles (phosphorus, heavy metals, and petroleum based organics), traditional studies concerning trap efficiency of detention basins for sediment cannot be translated into pollutant settleability results. This is due to differing specific gravities of various particles.

Randall et al. and Whipple and Hunter provide the only known attempts to define the association of several pollutants with particulates found in a specific region, and their settling velocities. The characteristic particle size in urban runoff was found to be less than 15 microns. Pollutant removal rates did not correlate well with TSS removal rates because particles in this size range behave as flocculant suspended solids (coagulated suspended particles) rather than total suspended solids.

The variablility in pollutant settling from region to region can be further exemplified by the results of NURP (National Urban Runoff Program) monitoring programs which indicate ranges between 0.5 and 20 feet per hour for TSS settling (Driscoll 1982). Once the settling velocity of a particular pollutant is quantified, the removal due to sedimentation in a dynamic (flow through) system was expressed by Driscoll as:

$$R = 1 - \left(1 + \frac{1}{n} \times \frac{V_s}{Q/A}\right)^{-n}$$

Where

R = fraction of initial solids (or pollutant) removed

V_s = settling velocity of particles or pollutant

Q/A = overflow velocity

n = a parameter providing a measure of the degree of turbulence or short circuiting in the pond.

The V_s term must be determined for specific pollutants as Whipple and Hunter, and Randall et al. have done in their studies. Rinella and McKenzie (1982) have also suggested a method to relate suspended-chemical concentrations to suspended-sediment particle size classes.

3. Assessment of Previous Studies

Much of the existing data concerning the use of stormwater retention basins for both flood protection and water quality control is quite site-specific. It is difficult to compare results due to variations in basin design, storm events, catchment size, and land use characteristics. In many studies, an average detention time was not calculated, and where it was calculated, short circuiting through the pond is likely, though difficult to quantify, and actual detention time is unknown. Laboratory settling studies cannot be correlated directly with field studies for this reason.

There is a great need for normalization of field data to reduce site dependence of the results. General comparisons between regions would be beneficial to many stormwater planners; it is not feasible to undertake data collection efforts at each site. Comparable pollutant loading estimation methods would be useful in determining if stormwater detention for water quality purposes is feasible.

Several of the models described in the next section are adaptable to general estimation of trap efficiencies, or proper detention pond design characteristics for maximum efficiency. Unfortunately, most models require site specific monitoring (flow and water quality) data, an expensive endeavor.

C. Detention System Modeling

Many hydraulic and hydrologic models have been formulated to predict runoff-generated pollutant loads and to examine the effect of stormwater detention on sediment and other pollutant loads (Davis et al., 1978; Kamedulski and McCuen, 1979; Ferrara and Smith, 1982; Smith and Bedient, 1980; Amandes and Bedient, 1980; Curtis and McCuen, 1977; Mays and Bedient, 1982; Ditoro and Small, 1979). These models typically simulate runoff, sediment and pollutant discharge into and out of a retention basin. The most complex models use a kinematic wave approximation to simulate overland flow (Kamedulski and McCuen, 1979; Davis et al., 1978). The less complex models use either the rational method or the Soil Conservation Service method of translating rainfall into runoff. Channel routing is accomplished by Mannings equation or the Muskingham Method (Whipple et al., 1983).

Detention basin routing is typically simulated using time variable conservation of mass for the volume of water in the pond. Basin sedimentation is usually simulated using classical settling principles based on the settling velocity of sediment particles or of a particular pollutant. These models are clearly susceptible to errors due to the violation of assumptions required by Camp's (1945) principles of sedimentation. These assumptions are:

1. The material is not resuspended once it has reached the bottom of the basin.

2. The particles and their velocity vectors are distributed equally over the basin cross-section.
3. The fluid moves as an ideal slug (ie. no short circuiting, total mixing).

Pollutant buildup on the land surface during dry periods was treated by the early models as a linear function of time of dry period. More recently it has been found that the rate of build up of pollutants decreases with time (Sartor et al, 1974).

Most models assume a first order decay process for pollutant washoff to simulate first flush, although Ferrara and Smith (1982) assumed constant influent concentrations throughout each storm event. If the storm event is of low intensity, the exponential washoff equation can be modified by including an additional availability factor, A, which ranges from .75 to 1.0. In this case, the change of pollutant load being washed off with time is:

$$dP/dt=-kRPA$$

P = mass load of pollutant

k = empirical coefficient based on decay time

R = runoff rate

A = availability factor

In addition to physical modeling attempts, Mays and Bedient (1982) have constructed an optimization model to determine minumum cost, size and location of detention basins in urban watersheds. The model uses a dynamic programming scheme which can simulate a network of detention basin locations and sizes.

Most models are able to test pollutant removal efficiencies and flood protection capabilities for a variety of catchments, hydrologic characteristics and precipitation inputs, as well as different retention basin design strategies. Davis et al. (1978) have developed a model that illustrates the difference in design criteria for stormwater flow rate control and water pollution control. Where riser characteristics dictate flow control, flow length and retention time are important for pollution control. In addition, flood damage occurs during occasional large storms, whereas urban pollution problems are caused by smaller storm discharges which occur more frequently. Due to the first flush phenomena, small floods have a disproportionately high mass loading of pollutants. These models have helped show the contrasting requirements for dual purpose use of retention ponds. In general, prolonged retention of small floods is desirable for pollution control, while large storage capacity with a quick release capability is desirable for protection against flooding. These requirements need not be incompatible. A small retention outlet at the bottom of a detention basin can be used to provide slow release of runoff from smaller storms, with the main outlets, designed for flood control, placed at a higher elevation in the pond (Whipple, 1981). The viability of such strategies is dependent on provision of sufficient storage.

CHAPTER THREE

STUDY AREA DESCRIPTION

A. Site Selection

Two retention facilities were selected to represent contrasting land uses. One pond is located at the Municipality of Metropolitan Seattle (METRO) East base transit storage and maintenance facility in Bellevue, Washington (Figure 3.1). This pond provides 6800 cubic feet of temporary storage for runoff from 15 acres of land used for bus parking and maintenance sheds (Figure 3.2). The site is located in an area characterized by light industrial land use. The pond storage discharges directly into the West tributary of Kelsey Creek. The second site serves approximately 76 acres of a single family residential area south of Bellevue in King County, Washington (Figure 3.2). Unlike the Metro facility, a small creek runs directly through this detention facility, which is dry except when the creek flow (including stormwater runoff) exceeds about 0.5 cfs. The pond provides approximately 15,000 cubic feet of stormwater storage capacity (Figures 3.3 and 3.4). The pond outlet enters the Vasa Creek drainage system, which terminates in Lake Sammamish. Table 3.1 provides a summary of study site characteristics.

Site selection was based on simplicity of the detention pond design, ease of equipment installation, accessibility, and low vandalism risk. Over 50 sites were considered initially in the selection process, however few ponds inspected had a single inlet and single outlet device, an important requirement. This fact immediately

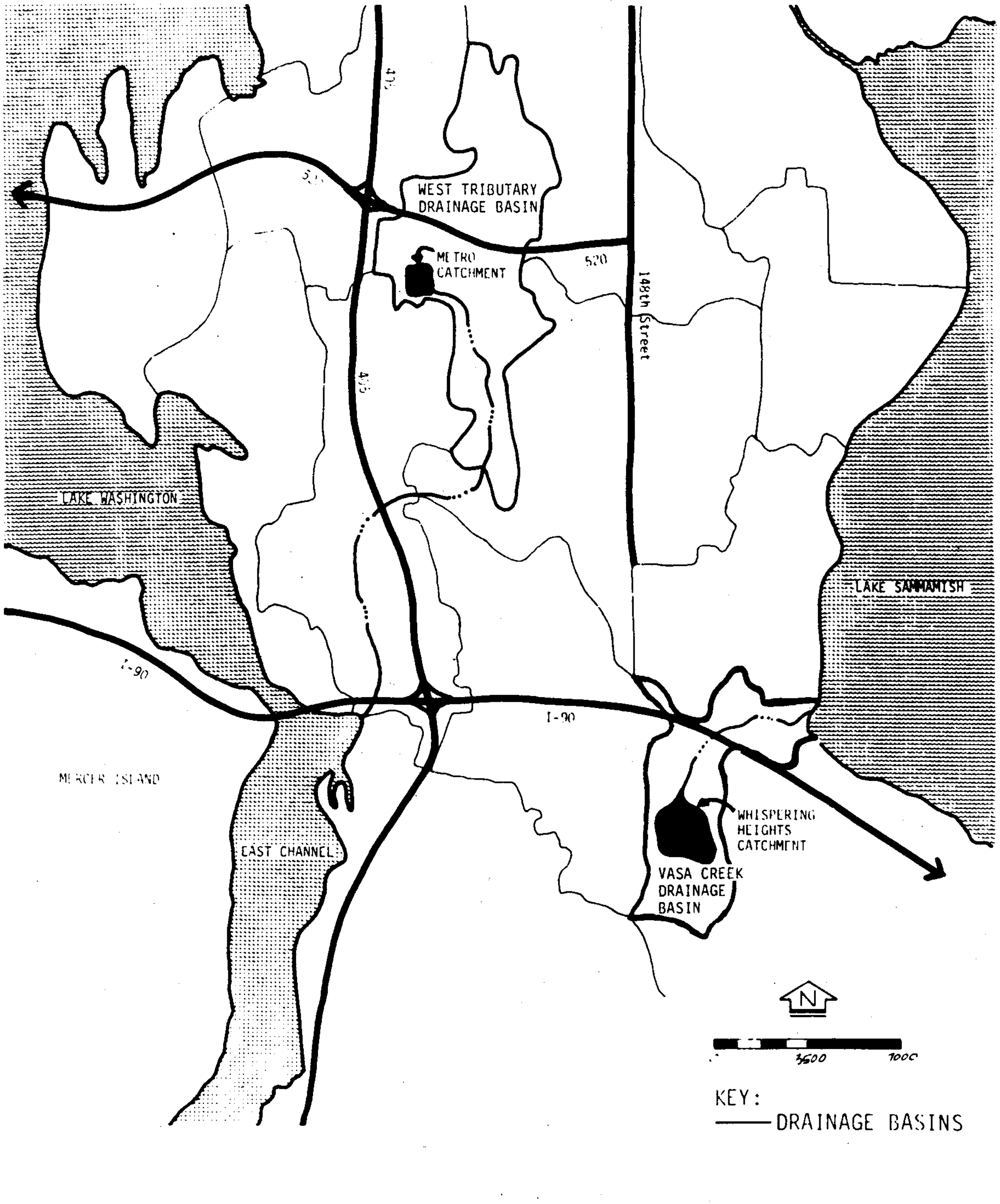


Figure 3.1 Site Location and Drainage Basin Boundaries.

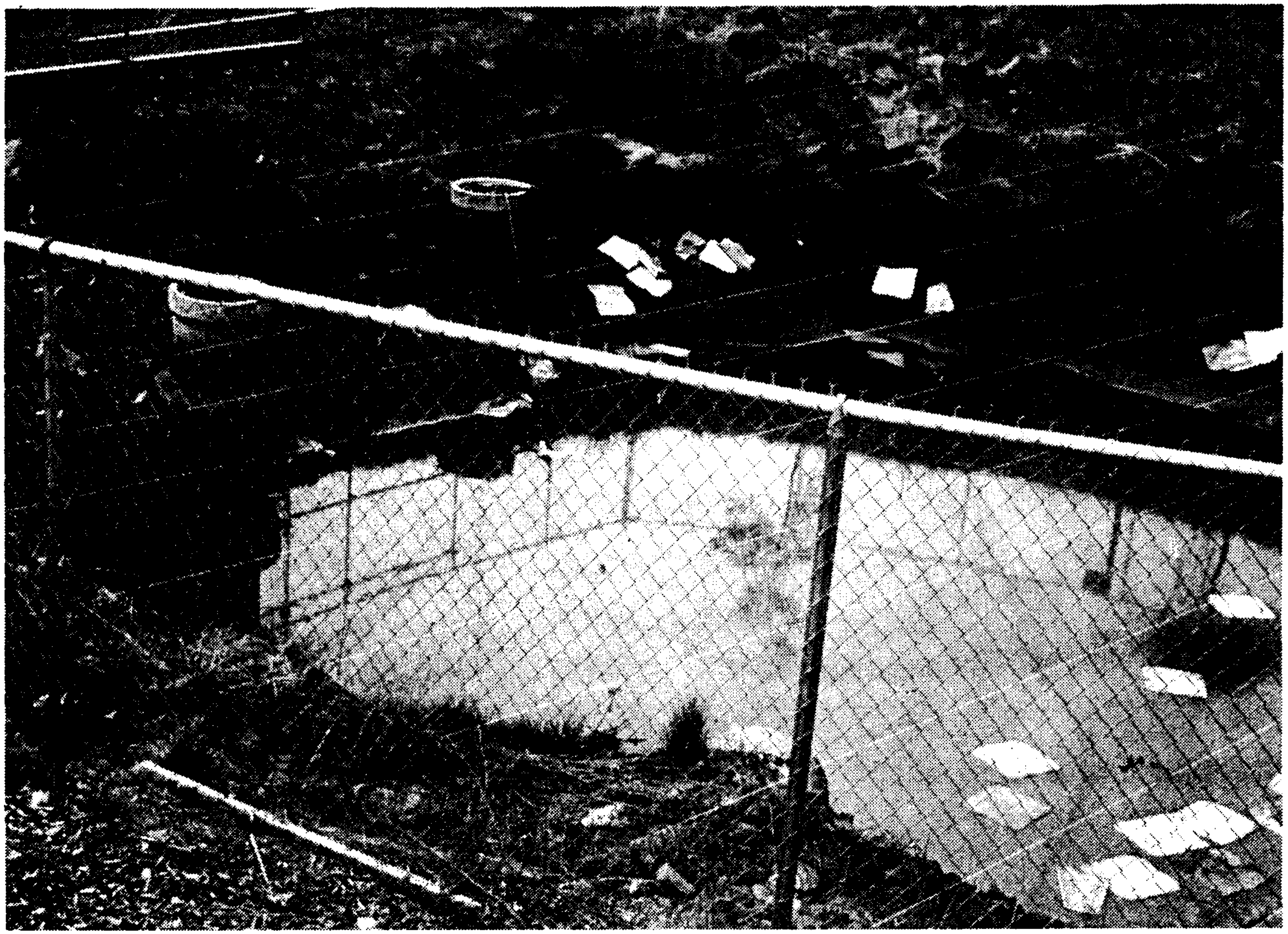


Figure 3.2 METRO Retention Pond

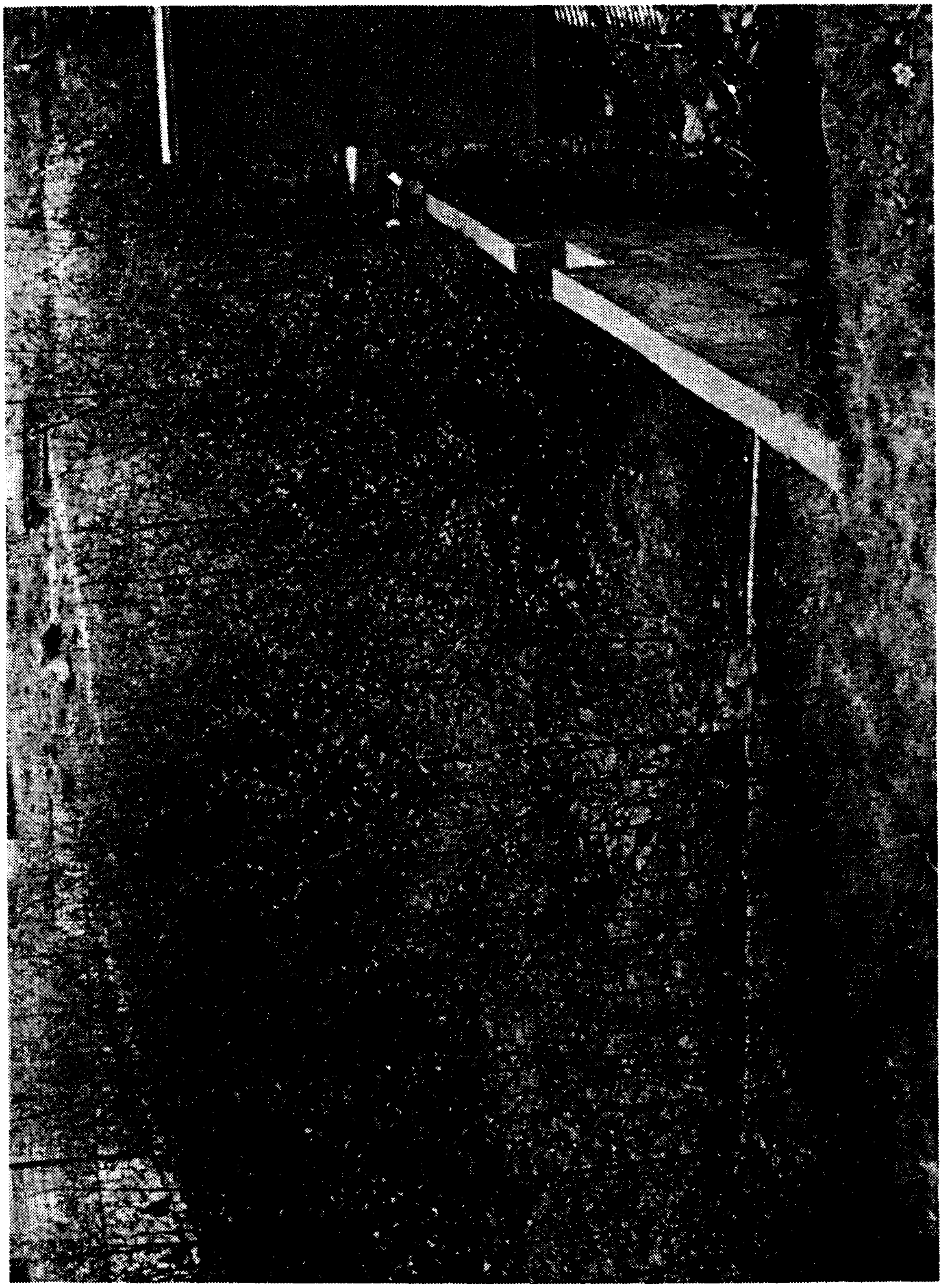


Figure 3.3 Whispering Heights Detention Pond and Outlet Structure

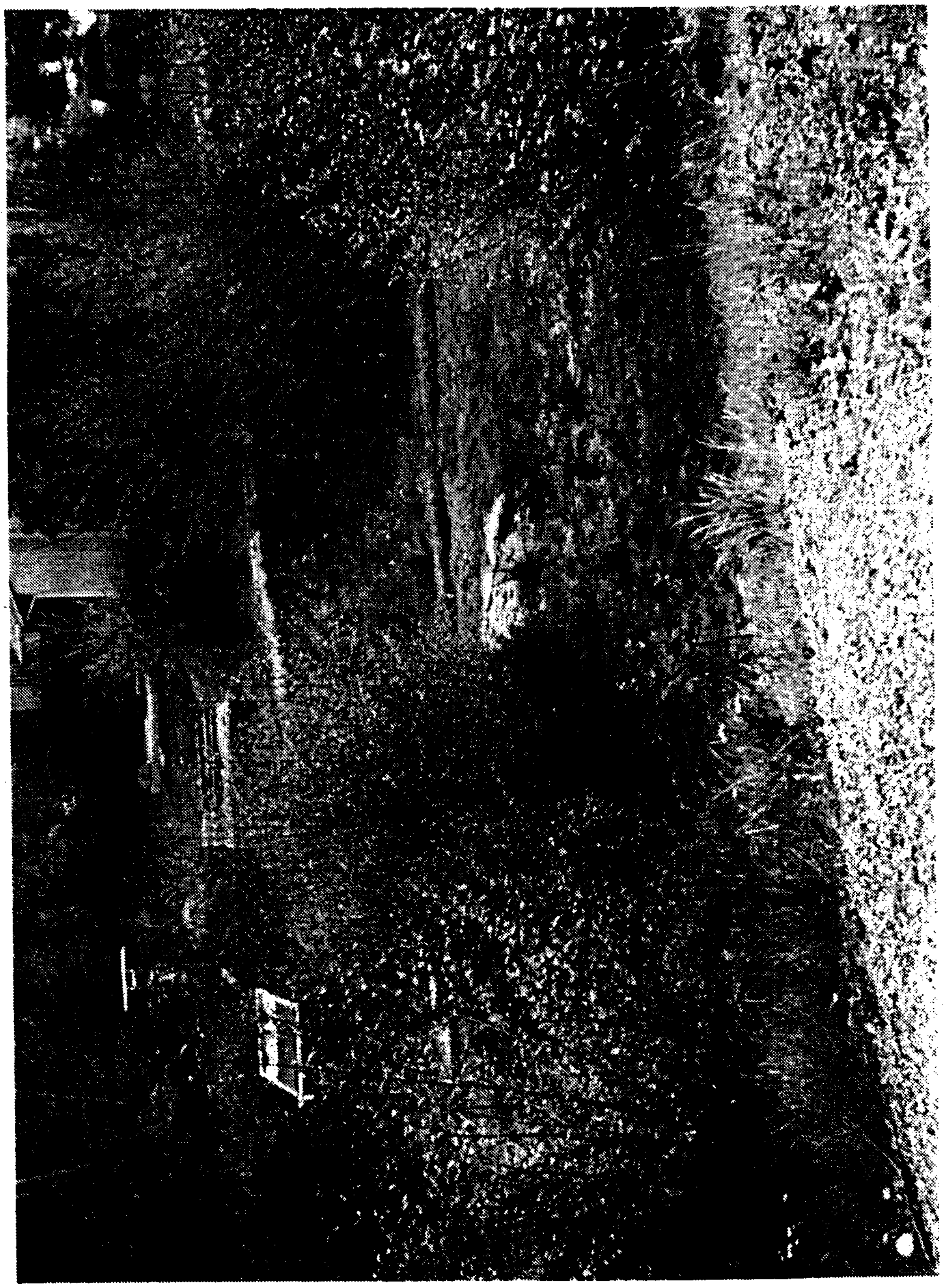


Figure 3.4 Whispering Heights Detention Pond, Side View

TABLE 3.1
Study Site Characteristics

Study Site	Land Use	Size of Catchment (Acres)	Percent Imperviousness	Receiving Water	Name of Drainage Basin
Whispering Heights	Single Family Residential	76	20-30%	Vasa Creek/ Lake Sammamish	Vasa Creek
METRO	Light Industrial	15	90%	Kelsey Creek/ Lake Washington	West Tributary

narrowed the choice of experimental sites. Access on private land further limited the availability of sites. The sites chosen represent typical land uses in the Bellevue area. Figure 3.1 shows the sample sites and study catchments.

B. Existing Pond Design

1. METRO Site

Site plans for the METRO retention facility and surrounding drainage system are given in Figure 3.5. Stormwater enters the pond through two inflow pipes; a low flow 8 inch diameter concrete pipe and a high flow (overflow) 24 inch diameter concrete pipe. A dry weather flow oil-water separator is located on the 8 inch inlet pipe (Figure 3.6). Two outlet structures are provided. The 10 inch overflow outflow pipe is used when pond volume exceeds approximately 6000 cubic feet (elevation: 62 inches). A large oil separation tank treats water discharged through the regular outflow only (Figure 3.7). It was apparently assumed in designing the pond that the dilution during high flows would reduce grease and oil concentrations to levels acceptable for discharge to the receiving waters.

As a part of this research project, a concrete pond was constructed to collect all outflow and to divert the flow through a V-notch flume for purposes of flow measurement (Figure 3.8).

The Metro facility plans indicate the pond is capable of storing 25,000 cubic feet of stormwater runoff, which is much larger than the active storage capacity of the pond. Therefore, an additional topographical survey was conducted to determine accurate pond stage/pond

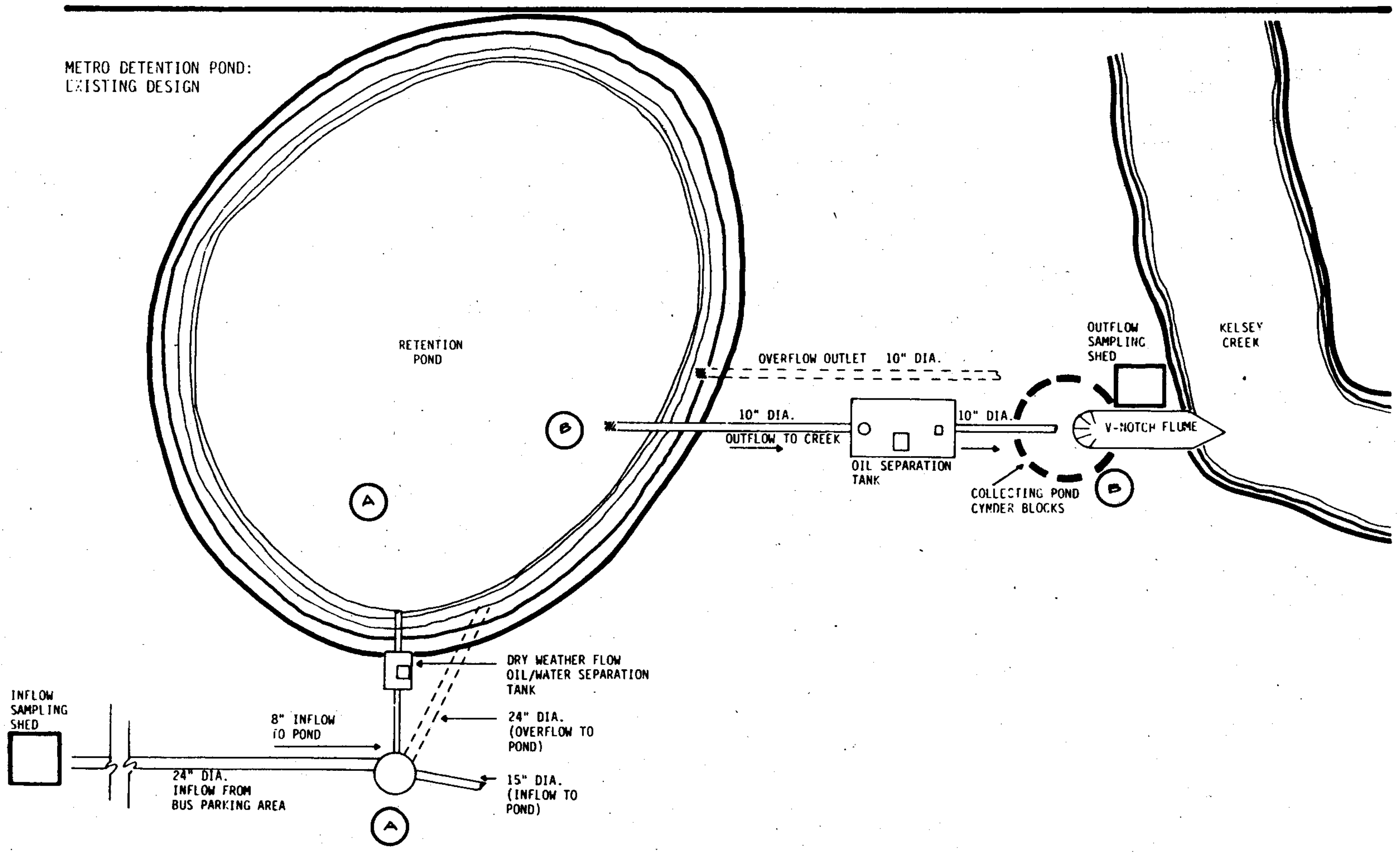


Figure 3.5 METRO Retention Pond and Surrounding Drainage System Site Plans. (Sections AA and BB refer to Figures 3.6 and 3.7).

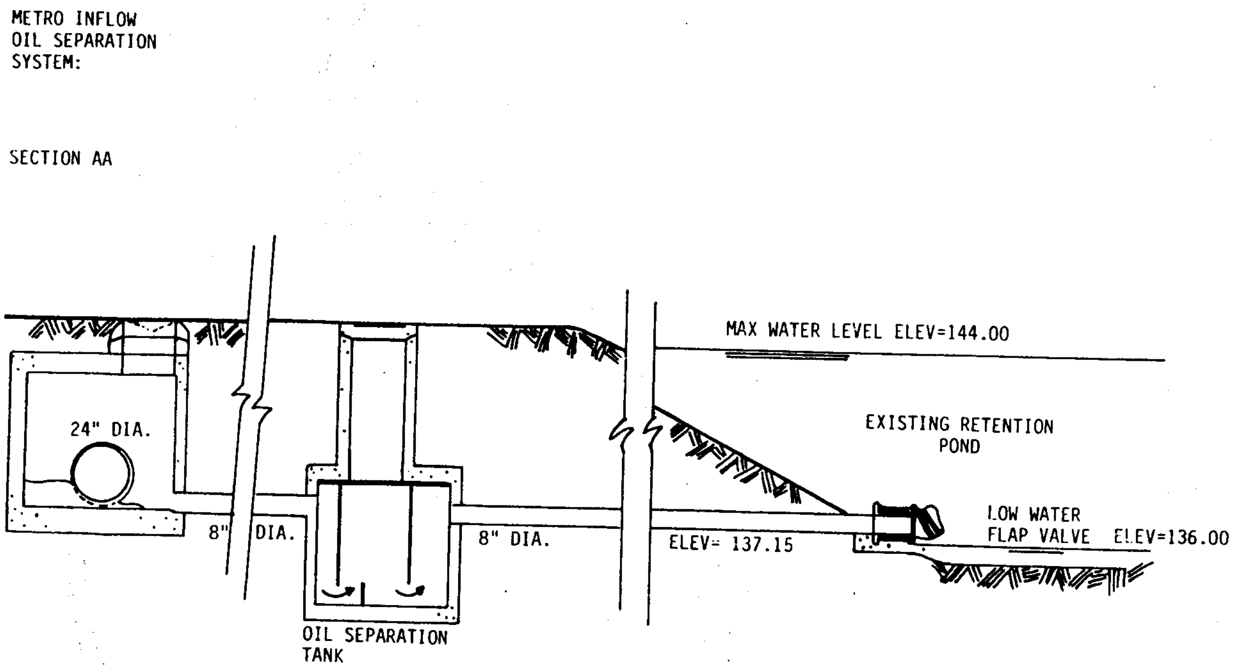


Figure 3.6 METRO Inflow Oil Separation System (Section AA of Figure 3.5).

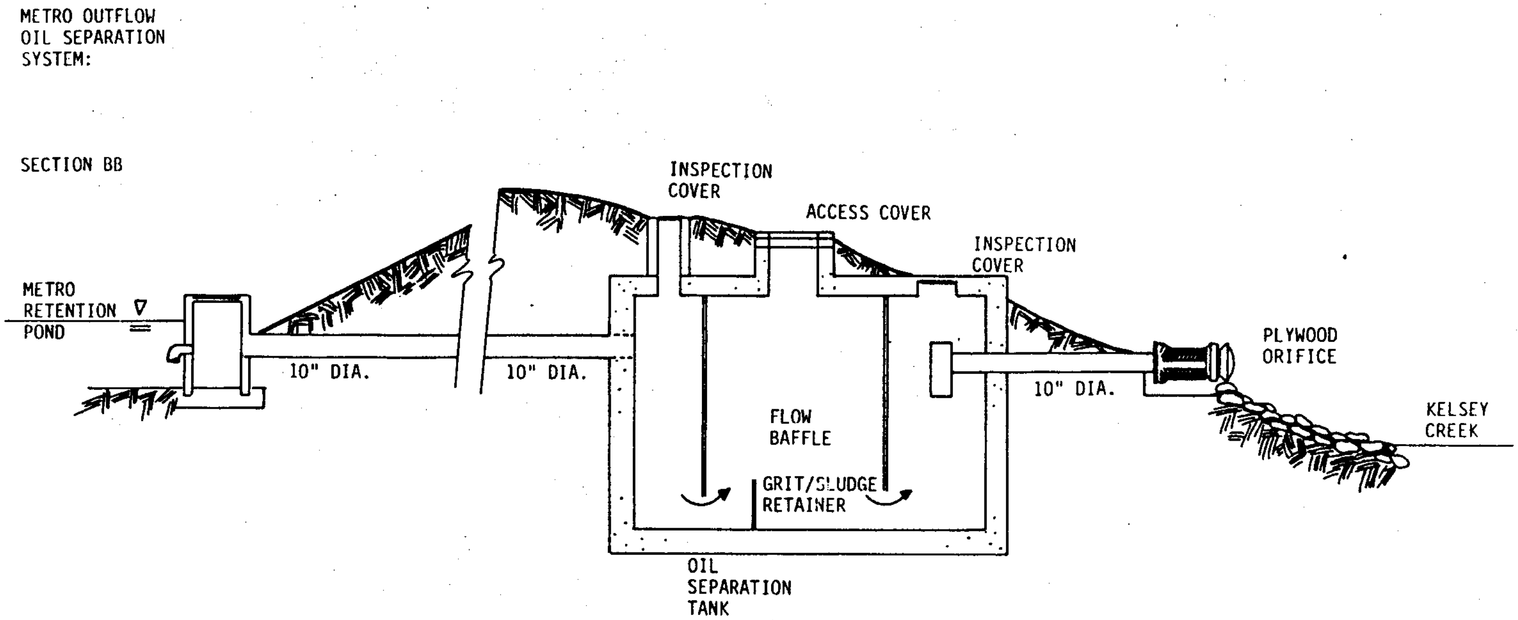


Figure 3.7 METRO Outflow Oil Separation System (Section BB of Figure 3.5).

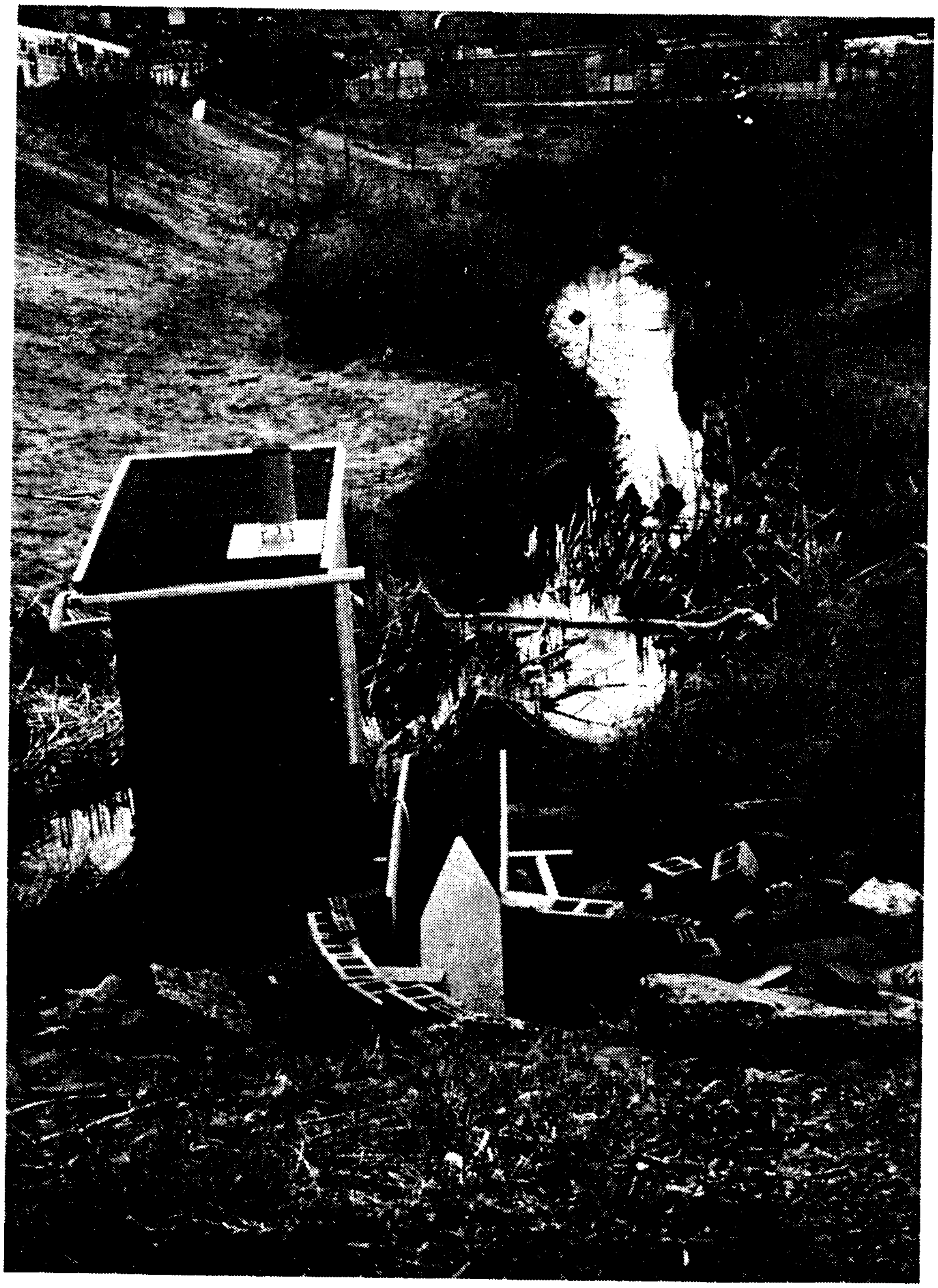


Figure 3.8 Collecting Pond, V-Notch Flume and Outflow Sampling Shed at the METRO Site. Discharge Enters the West Tributary of Kelsey Creek.

volume relationships. This survey indicated that storage of this magnitude would require water levels to exceed the invert elevation of the overflow outlet pipe by four feet, and the top grate of the outlet structure by two feet. Water levels of this magnitude were never observed at the site during the history of the project; the maximum storage ever observed in the pond was 6800 cubic feet. The Metro facility is a wet pond; water levels at the deepest point never drop below approximately 18 inches.

2. Whispering Heights Residential Site

The residential retention pond selected is very simple in its design (Figure 3.9). A single 30 inch Corrugated Metal Pipe (CMP) delivers storm drainage to the pond via a natural stream (Figure 3.10). In contrast to the METRO facility, this residential site supports grass and alder growth during drier months (Figure 3.3). During these dry periods, a small ephemeral stream (typical width one foot) runs through the pond. The outlet structure is a concrete dam with a rectangular spillway (Figure 3.11). A six inch orifice is located at the bottom of the dam to provide slow water release during storm periods (Figure 3.12). This facility does not include any pollution control devices such as oil separators; minimal treatment is achieved by settling of pollutants bound to sediment particles.

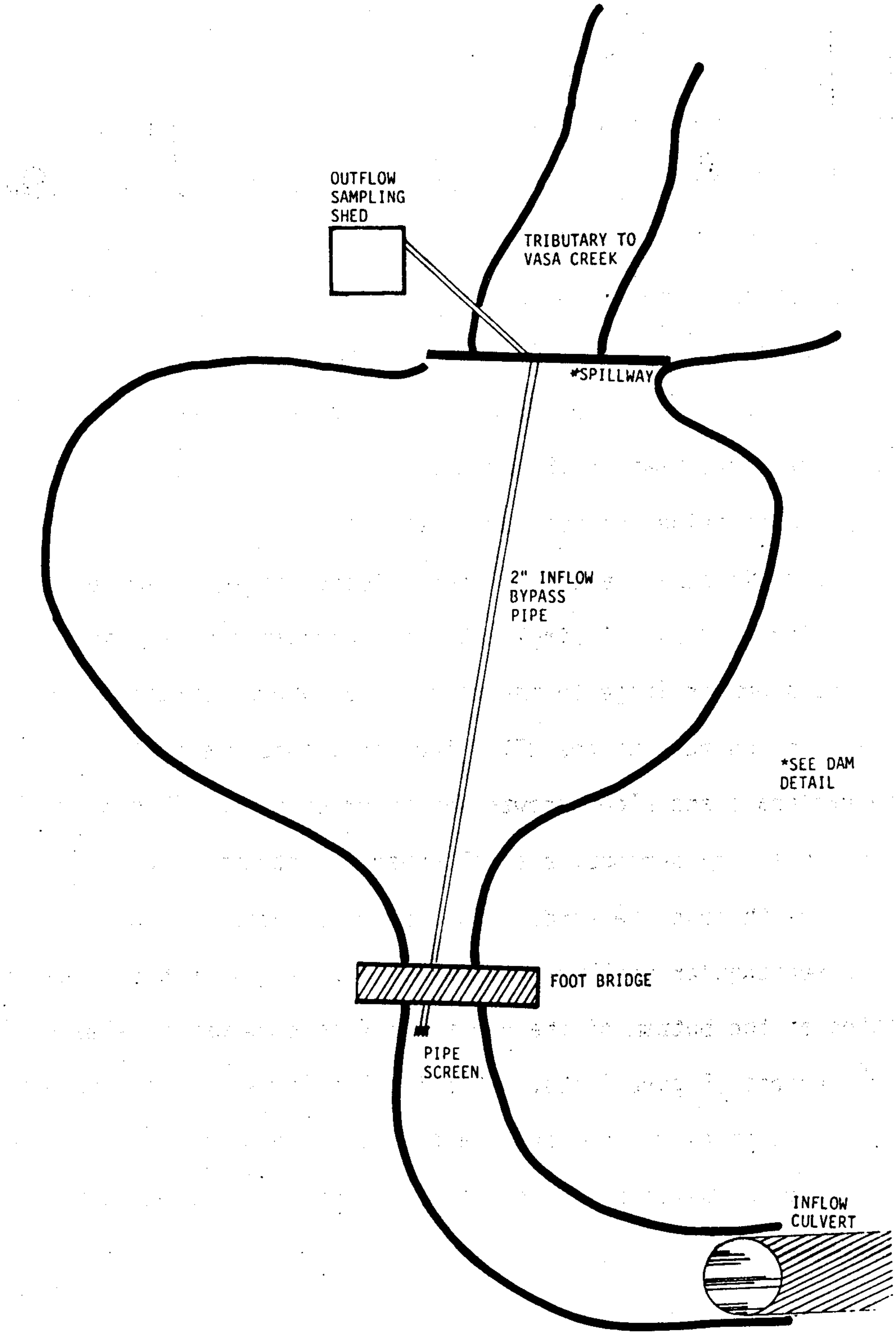


Figure 3.9 Plan View of Whispering Heights Detention Facility

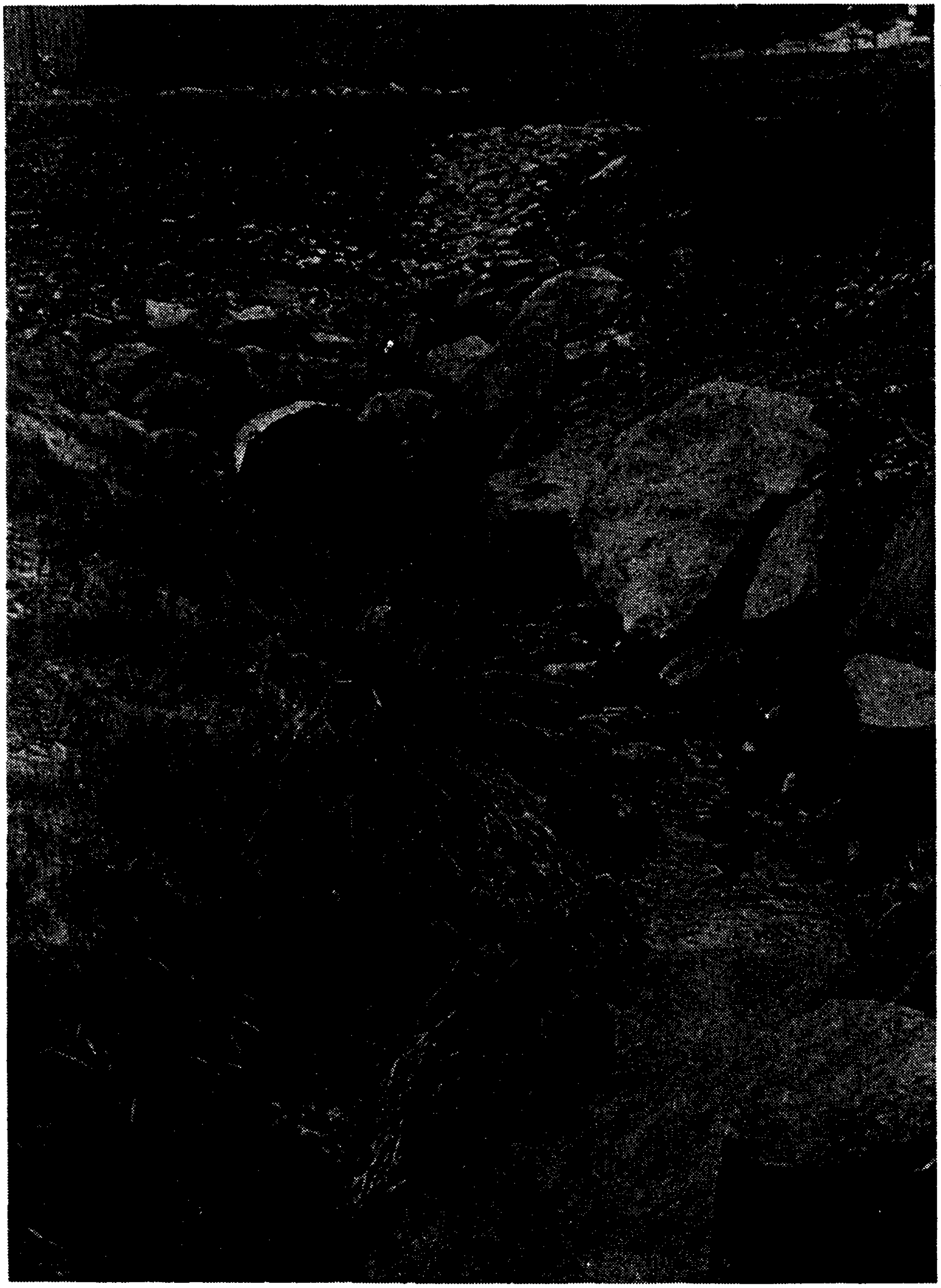


Figure 3.10. Whispering Heights Detention Pond Inflow Pipe

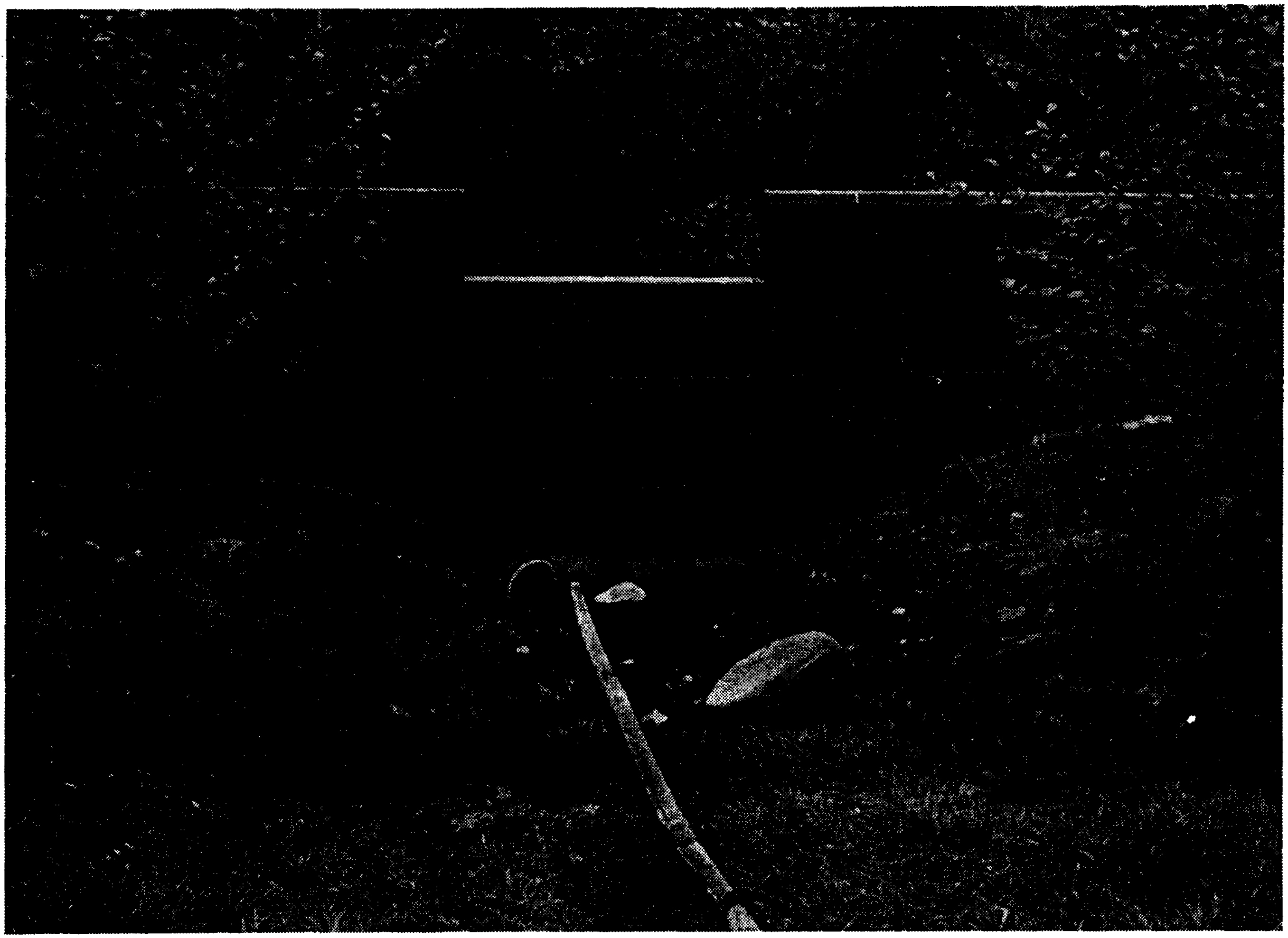


Figure 3.11 Whispering Heights Outlet Structure. Concrete Dam with a Rectangular Spillway and Circular Orifice.

WHISPERING HEIGHTS
SPILLWAY DETAIL
SCALE 1/2"=1'

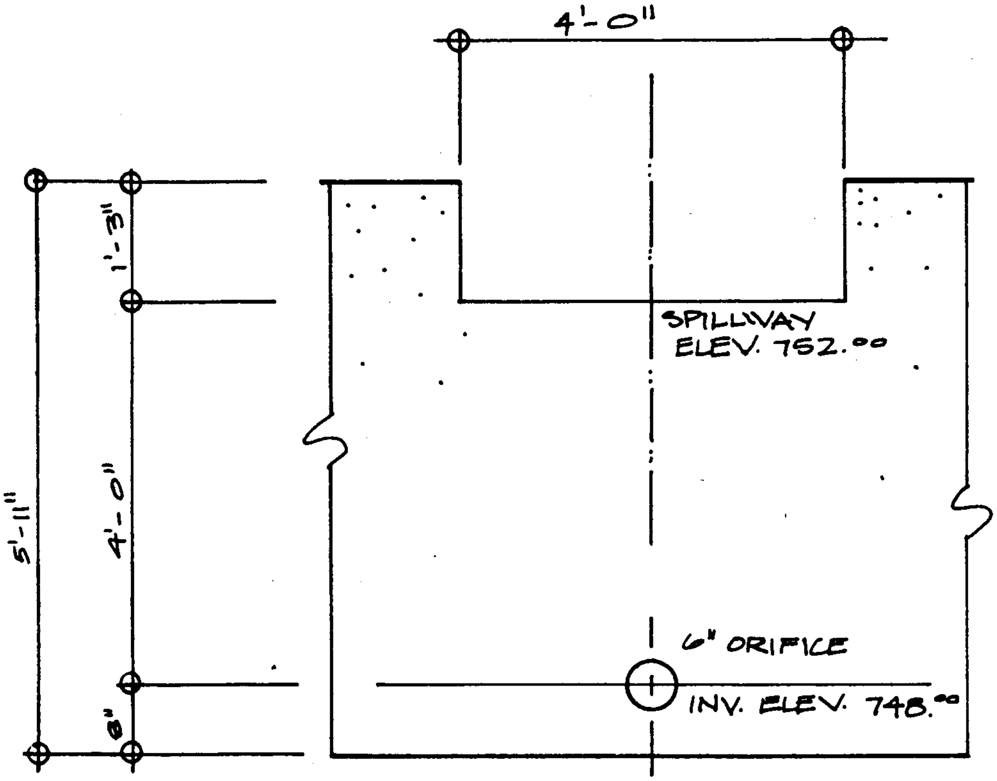


Figure 3.13 Whispering Heights Dam Detail.

CHAPTER FOUR

EXPERIMENTAL METHODS AND DESIGN

A. Field Equipment and Operation

1. METRO Site

Instrumentation was required to provide a continuous rainfall record and a means of measuring pond inflow and outflow, as well as time-discrete water quality samples at relatively small time increments. To accomodate the outflow measuement requirement, a V-notch flume was constructed (Figure 4.1). In addition, the primary outlet control device was replaced by one of several resin-sealed plywood covers with circular orifices. The covers were made with varying orifice sizes, and were used to control pond discharge rate, and subsequently, retention time.

A field shed was constructed near the outlet of the detention pond (Figure 4.2). This shed housed a Weathermeasure Corp. tipping bucket rain gauge, in addition to an Arcon level recorder, which measured pond height using nitrogen gas pressure differential.

A Stevens A-35 water level recorder and stilling well were installed to record flume stage. The stage/discharge relationship for the outflow flume was determined using a half scale hydraulic model (Chapter Five). A Manning 4040 discrete water quality sampler was installed, and used to sample discharge in the flume (Figure 4.2). Samples taken here represent the quality of the retention pond outflow, which enters the West tributary of Kelsey Creek. An identical sampler is stationed in a catch basin just above the

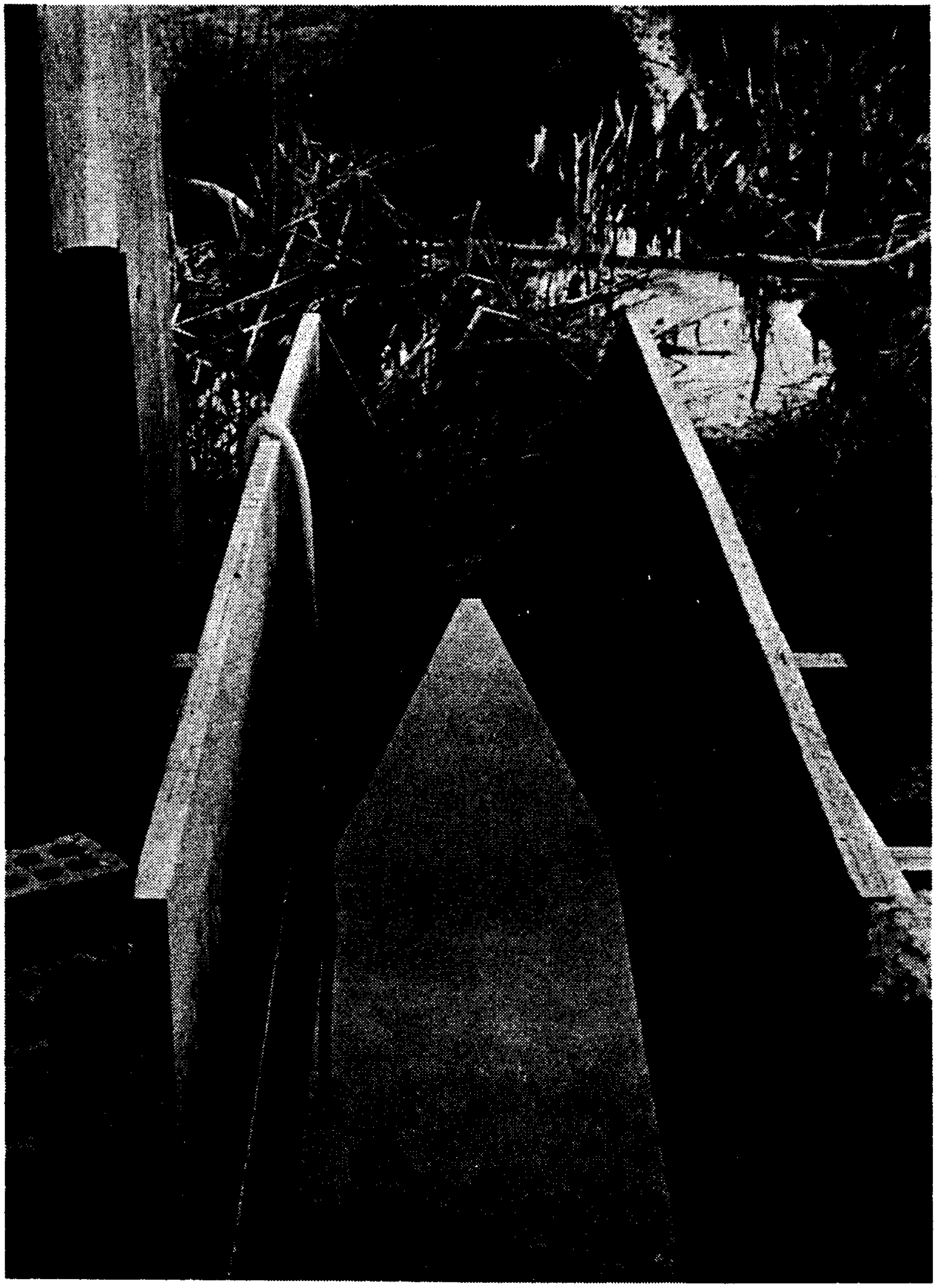


Figure 4.1 V-Notch Flume Containing Discharge from the METRO site.

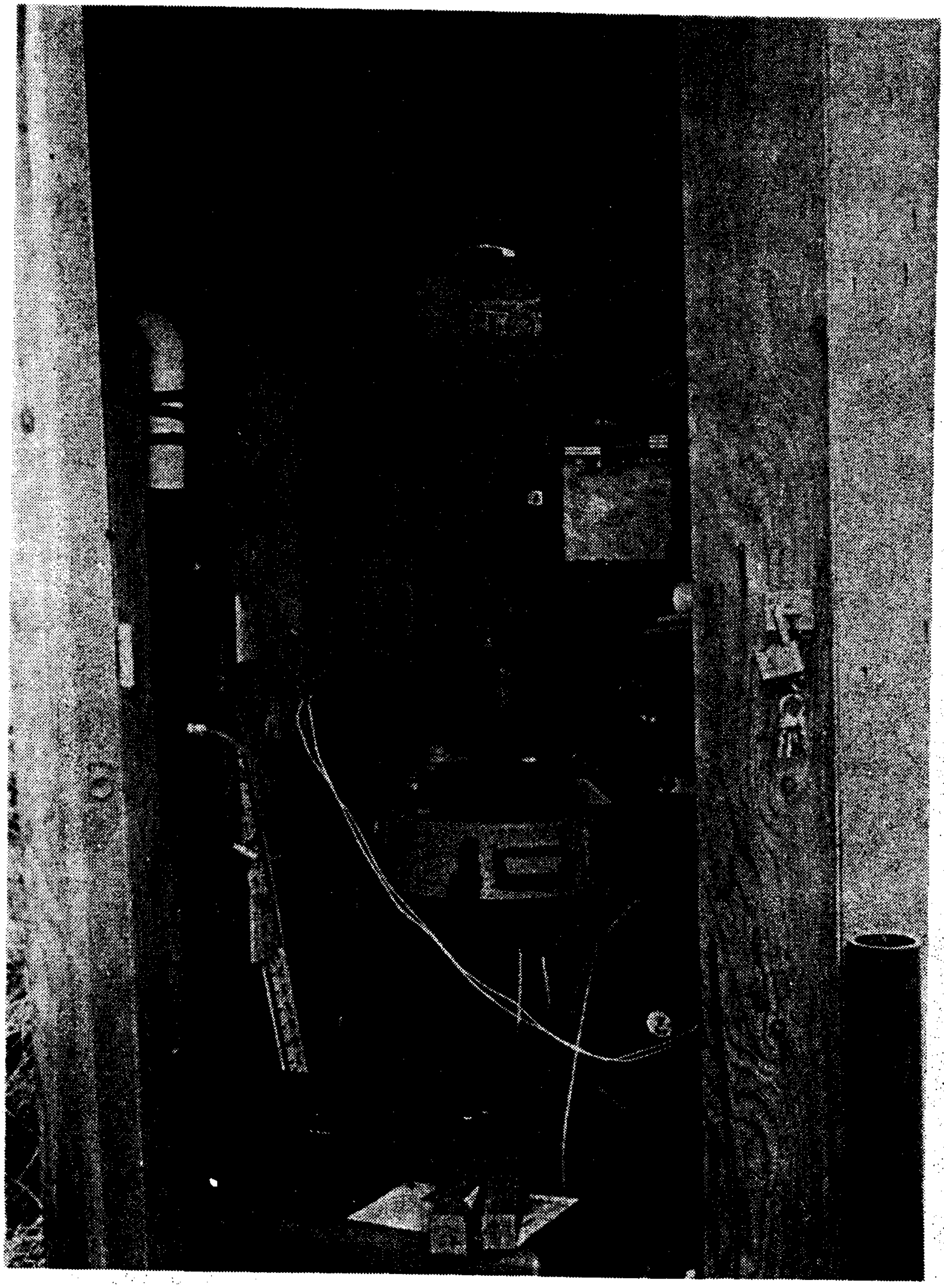


Figure 4.2 METRO Site Sampling Shed

retention pond. Samples taken here represent inflow quality of the runoff from the entire 15 acre site. The Manning water quality samplers use a 12 volt DC power source; an 84 amp-hour battery connected to a 110 volt AC automotive battery charger was used for this purpose. The samplers are capable of taking 24 one liter samples at varying time increments. After storm event number 7 was monitored the inflow sampler was moved to a catch basin higher in the catchment to avoid sampling standing pond water which was present due to backwater effects from the pond at high pond stage.

2. Whispering Heights Residential Site

An equipment shelter similar to that used at the METRO facility was constructed on the downstream side of the outlet dam at the Whispering Heights (WH) detention facility (Figure 4.3). A 12 inch diameter stilling well (Figure 4.4), constructed so that it fit through the floor of the shed, was used in conjunction with a Stevens A-35 float type water level recorder to measure the water level in the pond. The pond level measurement alone provides adequate data for discharge calculations at this site because the orifice size and spillway size are known, and the orifice flow/stage relationships were determined via lab scale model. Therefore, inflow to the pond can be calculated as the difference of outflow and storage change using only the pond height measurement (seepage was assumed to be negligible). A plywood plate with a 6 inch diameter orifice was installed at the original outlet to control the discharge rate and to provide longer retention time for sedimentation.

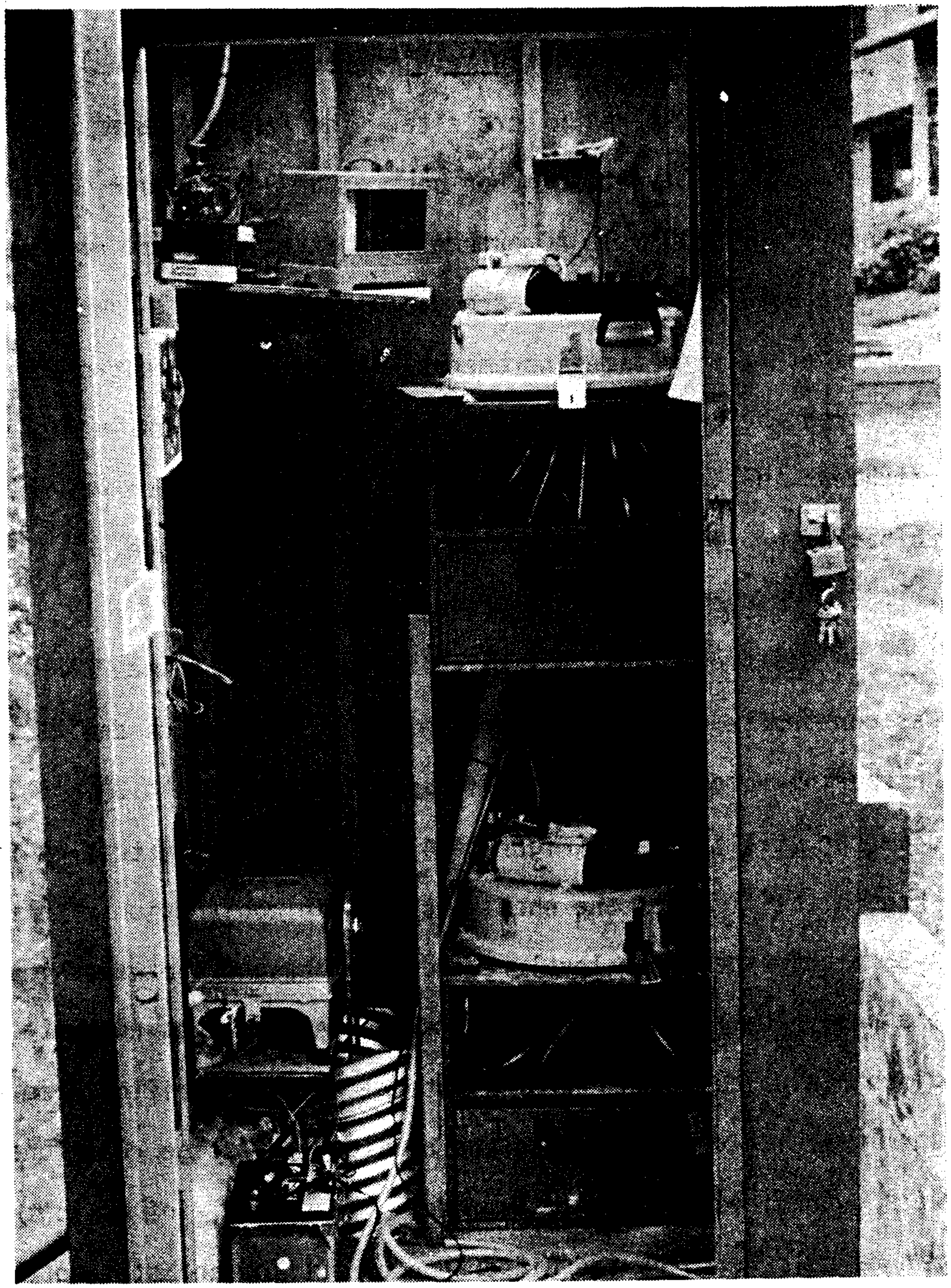


Figure 4.3 Whispering Heights Site Sampling Shed.

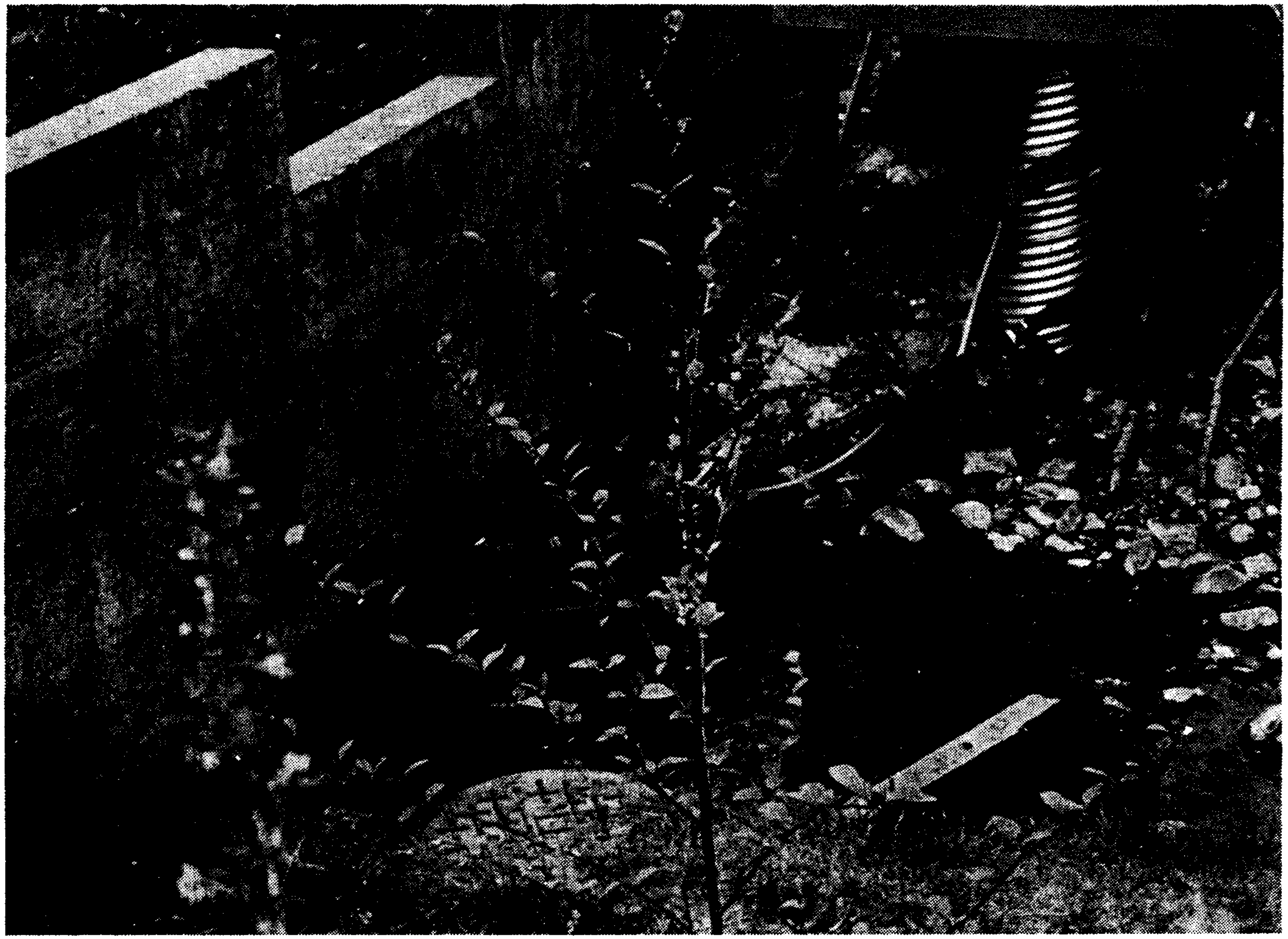


Figure 4.4 Stilling Well Constructed for Stage Measurements at the Whispering Heights Site.

Two Manning 4040 discrete automatic samplers with adjusted one liter intake capacities were used at this site. Both inflow and outflow samplers were housed in the shed at the pond outlet. Outflow samples were collected directly upstream of the circular discharge orifice. In the initial experiments, stormwater for inflow samples was diverted from the 24 inch inflow culvert upstream of the pond through a one inch pipe to a plastic pail at the shed where it was sampled. After several storms, a review of the inflow quality data suggested that the one inch pipe may have been filtering some sediment from the samples. To mitigate this problem, the diversion pipe was increased in size to two inches. A screen mesh was placed over the entrance to the pipe to avoid clogging of the diversion structure. This arrangement worked well, and no further problems were encountered with the inflow sampling setup.

Since no AC power source was available at this site, power was provided by an 84 amp-hour 12 volt battery. This battery was switched with a fully charged backup unit at the completion of each sampling cycle (24 one liter samples).

B. Field Data Collection

The data collection goal for this project was to measure accurately both mass and concentration of specific parameters describing the quality of the water entering and leaving the detention facilities over time. These measurements allow the calculation of both pollutant loadings into and out of the detention facilities, and the overall efficiency of the ponds in reducing pollutant loads and flood peaks.

"Catching a storm" is not a trivial task. To accurately estimate total storm loadings, samples must be taken from the onset of precipitation (especially if runoff travel times are short). If samples are not taken during the first minutes of stormwater runoff sampling, it is likely that the first flush phenomenon, if it exists at the site (see Chapter Two), will be missed, with the result that the total storm pollutant load may be substantially underestimated.

A major difficulty was the logistical complication of triggering the samplers. Rainfall patterns differ between Bellevue and the University of Washington campus (Seattle) which are separated by approximately 10 miles; therefore, the rain recorded in Seattle is not a good indicator of rainfall at either of the study sites. A trigger system was designed at both sites to avoid delay in sampling the beginning of each storm event. The samplers were triggered to take the first sample when the cumulative rainfall intercepting the equipment shed roof reached a predetermined amount. The volume of precipitation was routed through a gutter to a holding pipe. A pressure switch was used to detect the increased water level in the holding pipe, and upon reaching the threshold, complete the circuit to the battery, sampler and clock via a relay mechanism. If the rainfall did not continue, the system had to be reset manually. Unfortunately, the trigger systems could not be depended upon, particularly for short storms. At times they worked properly, however, often they triggered after a delay and samples representative of first flush concentrations were not obtained. The difficulties with the trigger mechanism were apparently related to the sensitivity of the pressure switch.

Both the measurement strategy for determining pond inflow and outflow rates, as well as the specific water quality parameters to be investigated were different for the two experimental sites. Measurements of precipitation, runoff quantity and runoff quality were taken at each site on a discrete (time incremental) basis throughout the entire storm. Outflow stage and pond height were sampled until the pond height returned to approximately pre-storm levels. This criterion, which defined the end of a storm, resulted in some very long storms; especially for low intensity, high frequency events which are typical occurences during the winter months in the Pacific Northwest. This sampling criterion was used to assure that all pollutant loads into and out of the pond were accounted for. In addition, estimate of pond pollutant removal efficiency requires that flow and pollutant concentration measurements be taken at small time increments throughout the storm and during any following storms which occur before the pond level recedes; this was the basis for selection of the sampling intervals.

All storms monitored at the residential site were real storm events. Storm events monitored at the Metro site were of two types: natural and simulated. The first simulated sampling experiments at the Metro site took place in August 1982. Because relatively few storm events occur during the dry season (convective storms are uncommon in the Seattle area) fire hydrants were opened to provide flow rates similar to those generated by storm runoff. Two fire hydrants at the opposing extremities of the catchment were opened, and flows from the hydrants were regulated so that the delivery of water to the catchment would be similar to a storm event of specified frequency. The first synthetic storm experiment simulated a 1.5 year frequency event with rainfall intensity 0.3 inches/hour and duration 35 minutes. The second and third experiments simulated a storm with an intensity of 0.2 inches/hour and duration of 45 minutes.

A total of eight storm events were monitored at the Whispering Heights site. Four natural storms and three simulated storms were monitored on a discrete sampling basis at the Metro facility. Table 4.1 summarizes the location and dates of storm events that were monitored during the project.

Simulated storm events at the Metro site resulted in three well-controlled experiments. The first inflow samples were taken immediately upon arrival of the hydrograph at the inflow sampling location, and pond and flume stages were monitored manually to provide a check on all stage recorder measurements and clock times.

Grab samples of the receiving water at the Metro site (West Tributary of Kelsey Creek) were taken during many of the storm events. Since the receiving water is the actual outflow from the pond at the residential site no additional receiving water sampling was required.

TABLE 4.1
Date and Location of Storm Events Monitored

Site	Date	Storm Number
METRO	08/05/82	2 (simulated storm)
METRO	09/22/82	3 (simulated storm)
METRO	10/6/82	7
METRO	10/16/82	8
METRO	01/19/83	9
METRO	02/06/83	11
WH	10/27/81	2
WH	11/21/81	4
WH	12/18/81	5
WH	01/29/82	7
WH	01/31/82-02/01/82	8/9
WH	02/12/82-02/18/82	11/15

C. Laboratory Procedures

Pollutograph sampling requires collection of a large number of samples during each storm event. Different water quality parameters were analyzed for the two sites, since the pollutants associated with the Metro catchment are quite different than those associated with the residential site. The water quality parameters to be analyzed for each site was based on the composition of preliminary grab samples collected in 1981. The WH residential site storm samples were initially tested for total suspended solids (TSS), trace metals (cadmium, zinc, lead and chromium) and Chemical Oxygen Demand (COD). Low metal concentrations in samples from the first storm resulted in these analyses being discontinued. The COD analysis was performed for two storms, and subsequently the same conclusion was resolved. The majority of the WH residential site samples were analyzed for TSS only. In addition, a particle size analysis was performed on samples collected from one storm at this site.

The Metro Site storm samples were analyzed for the following parameters; TSS, exchangeable and soluble metals (Zn, Pb, Cd, Cr, Ni, As, Cu), total phosphorus, orthophosphate (selected samples only), grease and oil, and turbidity. This site generated much higher levels of selected metals and grease and oil, as well as phosphorus, than did the residential site.

TSS, COD, exchangeable and soluble metals, and turbidity analyses were conducted in the water quality laboratory of the University of Washingon Civil Engineering Department. The METRO water quality laboratory performed all total phosphorus, orthophosphate and grease and oil analyses, and selected cadmium analyses.

Methods

Total suspended solids analysis was performed in accordance with standards established by the American Public Health Association (1980). Samples were filtered onto pre-ashed and pre-weighed (Whatman type AE) 1.2 micron glass fiber filters. Filters were dried for 1 hour at 105° C, cooled in a dessicator and reweighed at room temperature.

Total retrievable (also called exchangeable) zinc, lead, cadmium, chromium, copper, nickel and arsenic samples were acidified to a pH of 2.0 with redistilled nitric acid. Samples were shaken for 48 hours to allow metal ions to come into solution. Soluble metal samples were acidified and shaken similarly <u>after</u> being filtered through 1.2 micron ashed, glass fiber Whatman type AE filters. Therefore, all soluble metals concentrations in this study include soluble metals plus those metals associated with particulates smaller than 1.2 microns. A retrievable metals analysis was performed instead of a total acid digestion because it is these exchangeable metals that are available in the environment. Both soluble and particulate portions of the metal sample were determined to investigate the association of the metals with total solids, to determine if retention pond removal of metals involved only metals in the particulate fraction, and to determine which fraction of the sample contained the largest proportions of heavy metals.

Emission spectroscopy with inductively coupled plasma (ICP) was used to analyze all metal samples. Wang (1981) compared detection limits and precision of emission spectroscopic and atomic absorption methods. The ICP method was chosen because it analyzes all metals required simultaneously and it gives lower detection limits that the flameless AA method for the concentrations typically found in urban stormwater runoff. Any samples that exhibited cadmium concentrations below detection on the ICP (less than 1 ppb) were analyzed using Atomic Absorption units fitted with graphite furnaces by the METRO water quality laboratory.

Turbidity was measured with a Hach model 2100A turbidimeter in accordance with the American Public Health Association Standards (1980). COD was determined after dichromate refluxing by the ampule method. This method involves spectrophotometric measurement of a color reaction producing chromate (VI) ion (Oceanography International Corporation, 1980). COD analysis was performed only for two storm sampling events at the residential site.

The METRO water quality laboratory analyzed samples from the Metro site for grease and oil, total phosphorus and orthophosphate. Total recoverable grease and oil content was analyzed by serial extraction with Freon (see Appendix B for methodology). Total phosphorus concentration was determined by digestion with ammonium persulfate and colorimetric means. Orthophosphate concentrations were determined manually by colorimetric means. Appendix B includes details of the methodology for all phosphorus tests.

Storage and Preservation

It was impossible to analyze the samples for all of the water quality parameters immediately after sample collection due to the large number of samples involved. Therefore, all samples were stored at 4° C until time was available for analysis. Total suspended solids analysis was performed within 48 hours of each storm event. Grease and oil samples, collected in acid washed glass one liter containers, were acidified with HCl to a pH of 2.0 before transport to METRO water quality labs where samples were stored at 4° C until analyzed. Metal samples were acidified with redistilled nitric acid to a pH of 2.0 and stored at 4° C until analysis. All metal samples were stored in polyethylene bottles washed with ultra-pure water to avoid contamination.

Orthophosphate samples were taken directly to METRO labs following the storm and analyzed within 24 hours. Total phosphorus samples were acidified with sulfuric acid to a pH less than 2.0 and stored at 4° C until analysis. Concentration data were stored on computer systems at both METRO Labs and University of Washington.

CHAPTER FIVE

DATA ANALYSIS

A. Flow Calculations and Hydraulic Modeling

1. METRO Site

Field data used in flow calculations at the METRO site include continuous recordings of pond height and flume height for the duration of each storm. Initially, a standard stage-discharge relationship for a V-notch flume (Rantz et al, 1982; Leupold and Stevens, Inc., 1978) was used to calculate outflow from the detention pond. Upon further investigation it was determined that none of the published empirical rating curves for a V-notch flume would apply to a flume with the V cut to the bottom of the channel, as it is at the experimental site (Figure 4.1). The published V-notch equations assume a sufficient depth of water below the flume notch to eliminate the drag effects of the bottom of the flume. Therefore, laboratory calibration of the flume used at the METRO site was required.

Hydraulic Model

A half scale hydraulic model of the flume was constructed at the University of Washington's Harris Hydraulic Laboratory to determine an accurate stage-discharge relationship. For each water level tested, the flow was calculated by weighing the volume of water discharged over a predetermined time interval. In general, it is expected that the logarithms of the stage and discharge should be linearly related. Therefore, the following linear regression equation was developed:

$$\log_{10} Q_m = 0.1444 + 2.665 \log_{10} H_m \qquad (1)$$

which is equivalent to:

$$Q_m = 1.3944\ H_m^{2.665} \qquad (2)$$

using Froude Law scaling factors where

$$\frac{Q_p}{Q_m} = \left(\frac{L_p}{L_m}\right)^{5/2}$$

$$Q_p = (2)^{5/2} \times Q_m = 2^{5/2} \times 1.3944\ H_m^{2.665} \qquad (3)$$

where:

Q_p = actual field flows
Q_m = laboratory determined flows (half scale)
H_p = actual flume stage
H_m = model or laboratory flume stage (half scale)

The correlation between true half scale flows and calculated half scale flows is .9907. This indicates a good fit of half scale model flows. Error statistics are not available for comparison of actual full scale flows and those predicted by equation 3, however the large scale ratio (one-half) suggests that scaling errors should be small.

Methods of Solution

Once outflow was calculated, pond stages were used to compute the storage in the retention pond at each time step. The pond was surveyed to determine a stage-volume relationship. A continuity equation which derives outflow from inflow can be used to calculate inflow from the change in storage in the pond and outflow for each time step. Several numerical methods were considered for determining inflow:

1. Level Pool Routing (Backwards in time)

$$\frac{I(J) + I(J+1)}{2} - \frac{O(J) + O(J+1)}{2} = \frac{S(J+1) - S(J)}{\Delta t} \tag{4}$$

Moving backwards in time and solving for I at time step J=1:

$$I(J) = \frac{2S(J+1)}{\Delta t} - \frac{2S(J)}{\Delta t} + O(J) + O(J+1) - I(J+1) \tag{5}$$

which yields an explicit method of solution, where:

I(J) = Inflow at time step J

O(J) = Outflow at time step J

S(J) = Storage at time step J

A progressive oscillation of calculated inflow values was found to occur when this method was used. This is due to the fact that I(J) is dependent on a previous calculated inflow I(J+1), which is as significant as the change in storage and O(J) and O(J+1) terms. Inflow and storage changes are based on different field measurements, and discrepancies in time or magnitude of these independent data cause oscillation in the storage dependent value of inflow.

2. Central Finite Difference

A second method which proved most successful was an explicit central difference solution where:

$$I(J) = O(J) + \Delta S(J) \tag{6}$$

$$= O(J) + \frac{VOL(J+1) - VOL(J-1)}{2\Delta t} \tag{7}$$

A calibration parameter, α, can be introduced to correct errors in relating storage changes to outflow. This results in a modified central difference equation:

$$I(J) = O(J) + \alpha \left[\frac{VOL(J+1) - VOL(J-1)}{\Delta t}\right] \tag{8}$$

This modification is necessary because outflow and storage are not functions of the same stage measurement. Field equipment errors and time lags associated with the different gauges may cause inconsistancy between outflows and changes in storage. The parameter can be determined once inflow has stopped, when outflow must be equal to the rate of change in storage volume. This method was used to calculate inflows at the METRO site.

A computer program was developed to calculate outflow, change in storage and inflow using equations 6 and 7 and a stage-volume relationship assuming an incrementally trapezoidal pond. Field data were entered in 15 minute increments and linearly interpolated to time steps of 3.75 minutes. For situations where flows were increasing and decreasing rapidly over time, an option was constructed to enter field data at smaller time steps before interpolation. The source code used for all calculations is listed in Appendix C.

3. Whispering Heights Residential Site

Pond heights are the only data used for flow calculations at this site. When the stage is below the spillway, the outflow is a function of the pressure head above the orifice and a theoretical coefficient of contraction. When pond stage reaches the spillway level, outflow is a function of both the parameters controlling flow through the orifice, and the parameters controlling flow over a broad crested weir.

Using the Bernoulli equation, flow through the six inch orifice is

$$Q = \sqrt{2gH}\, AC_c \tag{9}$$

where C_c is the coefficient of contraction (.61 for a sharp edged orifice), and H is the water level measured from the center of the orifice, A is the cross-sectional area, and g is the gravitational constant. When water levels reach spillway elevation, the additional term for flow over the broad-crested weir (Henderson, 1966) is:

$$Q = 2/3\ H\sqrt{2/3\ gH}\ C^*$$

where

$$C^* = 1 + 0.069\left[\frac{L}{H} - \frac{1 + 2.84\ R_e^{0.25}}{R_e^{0.2}}\right]^{0.8} \tag{10}$$

and Re = Reynolds number = $\frac{V_1 H}{\nu}$

ν = kinematic viscosity of water

$$V_1 = \sqrt{2/3\ gH}$$

Hydraulic Model

The theoretical equations (9 and 10) are subject to some restrictions. The orifice equation is limited to situations with a minimum head of about five times the orifice diameter (Vennard, 1954). Many times, pond levels were just above the orifice; in these cases the flow would probably be overestimated by equation 9. Therefore, both half scale and full scale models were constructed to determine an empirical rating curve for this site. The same procedure was used as for determining a stage discharge relationship for the METRO flume. The V-notch plate located at the end of the model flume was replaced by a plate with a three inch diameter orifice (half scale). This orifice was used to determine a stage discharge relationship at higher pond levels, and a full scale, six inch diameter orifice was used to determine the rating curve at low water levels and when water surface elevations were below the top of the orifice.

The logarithm of the flow through an orifice is not expected to be a simple linear function of the logarithm of the stage. This is demonstrated by the data obtained by the hydraulic tests which are plotted on log-log paper in Figures 5.1 and 5.2. A piecewise continuous polynomial regression and spline fit was performed to avoid discontinuity at the points in the curve that initiate a change in slope. Four different equations were developed using this technique:

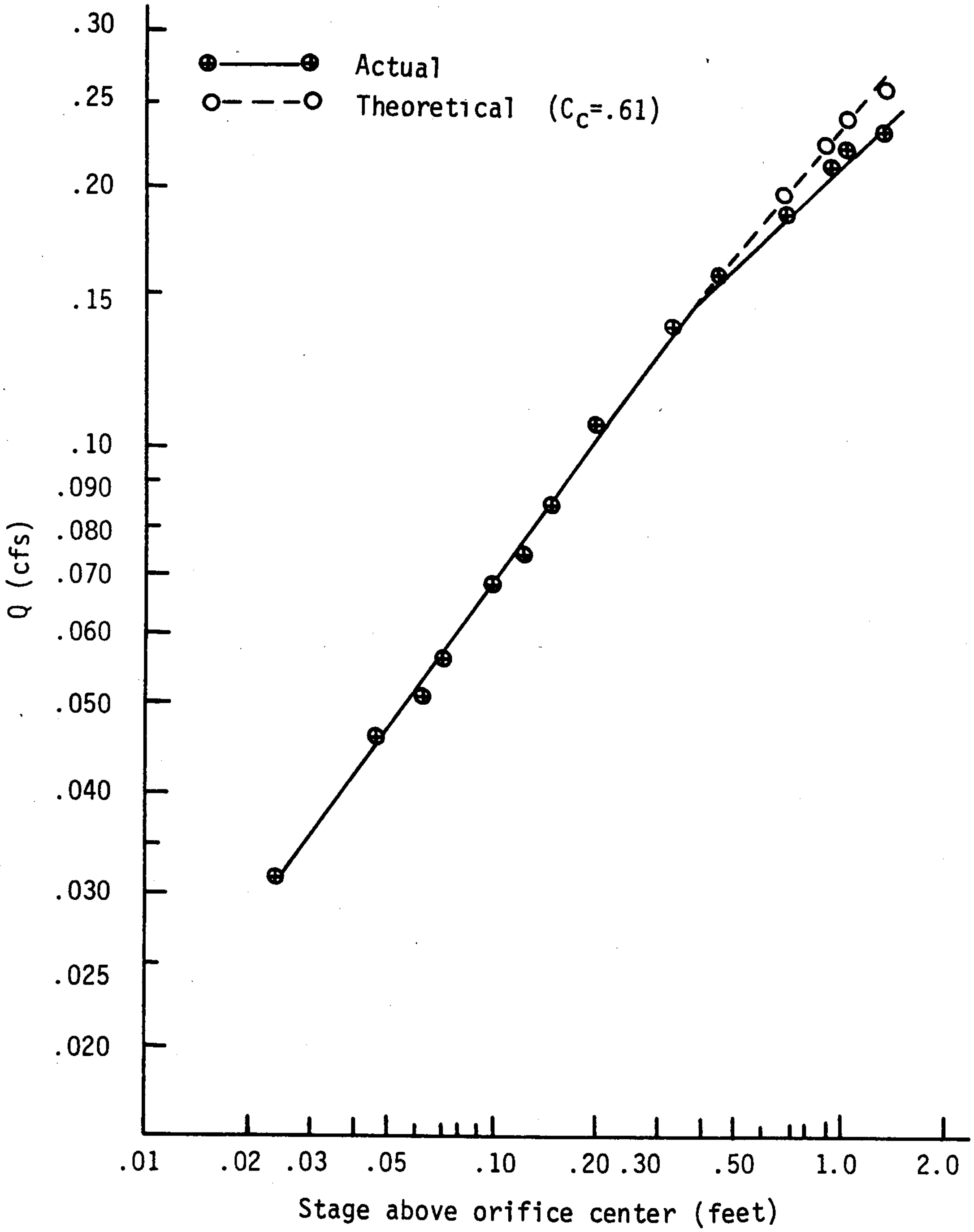


Figure 5.1 Theoretical and Actual Half Scale Model Stage-Discharge Relationship for Flow Through an Orifice.

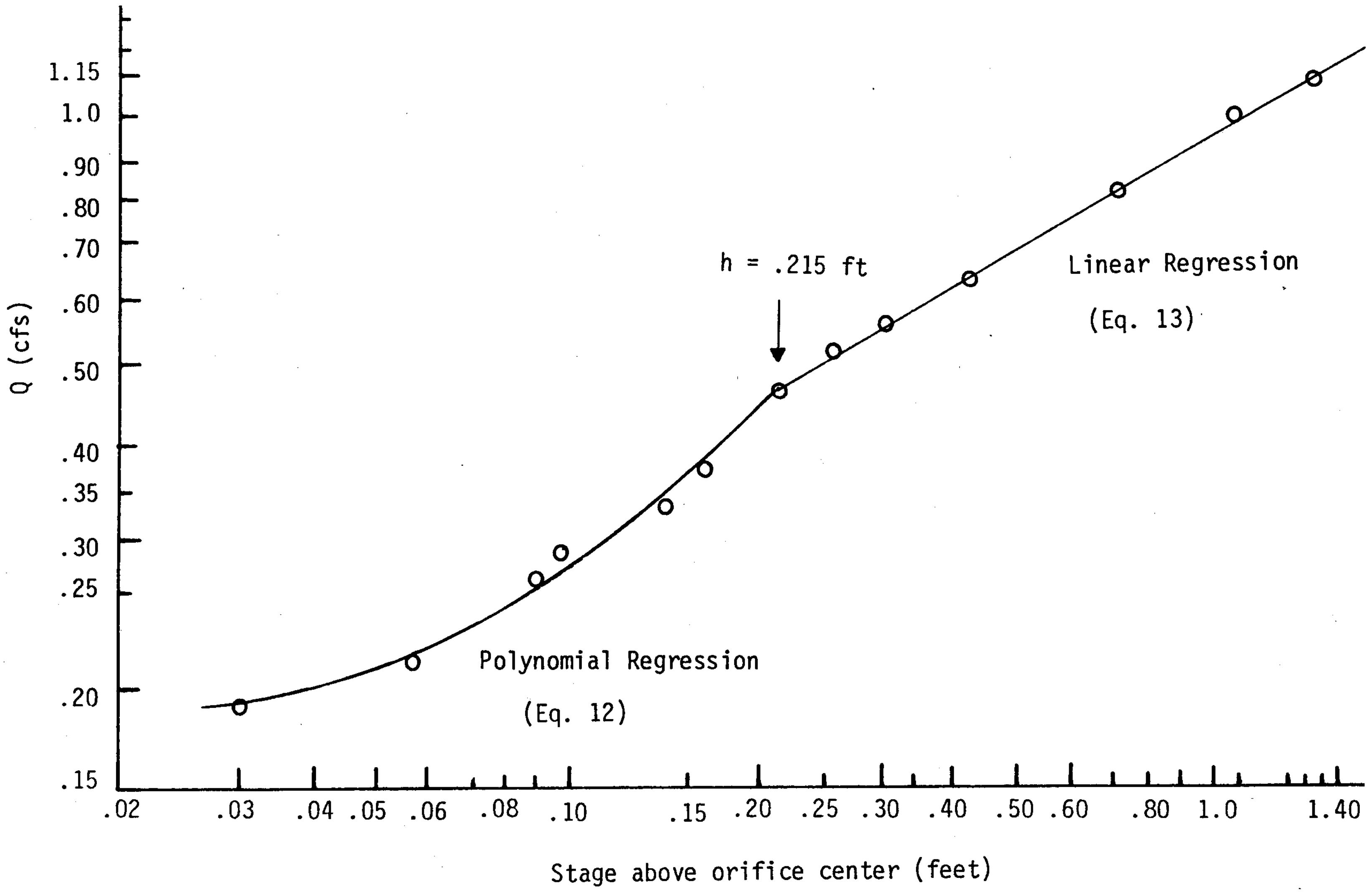


Figure 5.2 Full Scale Stage - Discharge Relationship for Whispering Heights

1. Stage below the center of the orifice. In this case no logarithmic scale was involved. Full scale model data were used, ($H_p = H_m$) resulting in:

$$Q_p = -0.0548 + 0.784\ (H_p + 0.25) \tag{11}$$

2. Stage between orifice center and top lip of orifice. The full scale model data were also used here:

$$\begin{aligned} Z = \log_{10} Q_p \cong\ & -0.02309 + 0.4579 \log_{10} H_p \\ & + .1120 \log_{10}(.215 - H_p) \\ & + 0.04821\ (\log_{10}(.215 - H_p))^2 \end{aligned} \tag{12}$$

and

$$Q_p = 10^Z$$

3. Stage between top of orifice and 0.866 feet above the center of the orifice. The full scale model data were used here as well:

$$X = \log_{10}Q_p = -0.02309 + 0.4579 \log_{10}H_p \tag{13}$$

and

$$Q_p = 10^X$$

Equations 11 through 13 were developed using spline fitting techniques. No discontinuity of flow will result from use of these equations. A fourth equation was developed using the half scale orifice model to determine flow at higher water elevations (water levels greater than .866 feet).

4. Stage between .866 feet and the broad crested weir. The half scale model data were used:

$$Y = \log_{10} Q_m = -0.6561 + 0.4121 \log_{10} H_m \qquad (14)$$

$$Q_m = 10^Y$$

$$Q_p = (2)^{5/2}\ Q_m$$

There is a slight discontinuity at water surface elevation 0.866 feet between equations 13 and 14, due to the use of data on two different scales. The discontinuity is equal to about 0.38 percent of the predicted discharge.

Figure 5.1 illustrates the difference between the theoretical orifice flow calculation (coefficient of contraction equal to 0.61) and the empirically tested flow values in log space. As expected, the theoretical equation overestimates the flows. Therefore, all hydraulic calculations were made with the empirically derived equations.

A central difference formulation of a mass balance equation was also used at the residential site to determine inflow from calculated outflow and change in pond storage. No storage adjustment factor was used at this site because both storage and outflow were derived from the same gauge measurement. The computer code used to compute flow and perform data analysis to interpolate input data to small time increments, and calculate flows is included in Appendix C.

The correlation coefficient relating the true full scale model flows and the calculated flows at this site was .9991. The calculation of correlation coefficient does not consider equation 14, which is derived from the half scale model data. Independently, the half scale calculated flows are correlated to half scale model flows with a correlation coefficient of .997. All correlations were calculated in real space after transformation.

B. Loading Calculations

Total mass loading of pollutants was determined by analyzing each sample discretely and multiplying the concentrations with flow calculated for the time period in which the sample was taken. Because all flow calculations were performed upon completion of the storm, sampling intervals were based on time and not on volume. Constant time interval sampling characterizes the tails of the runoff events fairly well, but tends to underestimate pollutant loads over the entire storm because important peak periods of the runoff may be missed. For example, the first flush phenomenon may last as little as five minutes, and the sampling time interval was usually fifteen minutes. Shortening sampling time intervals was not possible due to the large number of samples requiring laboratory analysis. The inflow sampling interval for the shorter duration synthetic storms was only 3.75 minutes, therefore; this problem is less severe for these storms.

Flows corresponding to the water quality sampling times were estimated by linear interpolation as explained in the previous section. A pollutograph can be constructed by multiplying the concentration of a specific water quality parameter by the corresponding flow rate to obtain an instantaneous mass loading rate. The instantaneous mass loading rate is expressed in units of pounds per day throughout this work. Integration of the inflow and outflow pollutographs over time yields the total mass of pollutant entering and leaving the pond. The ratio of the total mass entering to that leaving the pond is the pollutant removal efficiency of the pond. Although loadings are expressed in pounds per day, it should be emphasized that this is an instantaneous loading and does not represent the total mass flux for a day.

C. Error Estimation for Mass Loading

Errors in flow estimates, laboratory analyses and field measurement contribute to the total error in the pollutant loading estimates. The statistics of errors associated with laboratory procedures were provided by METRO water quality laboratory personnel for water quality parameters analyzed by METRO. These statistics (expressed as percentages) are specific for different concentration ranges; therefore, concentration errors will vary over the pollutograph. Errors associated with University of Washington laboratory analysis techniques were calculated from replicate analyses performed on composite samples. Table 5.1 contains concentration error statistics for pollutant concentration ranges found in urban runoff.

Flow error statistics are not as easily estimated as concentration error statistics. Two sources of error contribute to outflow calculations at each site: error in gauging or field measurement of the pond, and flume height (the latter at the METRO site only), and; the error associated with the linear regression (METRO Site) and polynomial regression with spline fit (WH Site) which were the basis for the stage-discharge relationships for each site. The regression errors reflect the discrepancy between actual hydraulic model flows and calculated scale model flows. Errors due to scaling effects were assumed to be negligible for both sites, due to the modest (2:1) scaling factor. Appendix F contains the calculations for regression error and field measurement error at the METRO site for both inflow and outflow. Flow errors are summarized in Table 5.2.

The error in loading at any one point in the pollutograph can be determined once coefficients of variation have been estimated for both flow and concentration measurements.

$$IL = I \times C \times K$$

where $K = 5.39 \ \frac{\text{lb-liter-sec}}{\text{mg-ft}^3\text{- day}}$

and

$$OL = O \times C \times K$$

where IL = Inflow loading

I = Inflow

OL = Outflow loading

O = Outflow

C = Concentration

A first order analysis provides the following relationship:

$$\sigma^2_{IL} = \sigma^2_I (KC)^2 + \sigma^2_C (IK)^2$$

$$\sigma^2_{OL} = \sigma^2_O (KC)^2 + \sigma^2_C (OK)^2$$

where σ^2_{IL} = variance in inflow load

σ^2_I = variance in inflow

σ^2_O = variance in the outflow,

σ^2_{OL} = variance in the outflow load

which can be represented as coefficients of variation by dividing both sides by the square of the respective loading and taking the square root:

$$\frac{\sigma_{IL}}{IL} = \sqrt{\frac{\sigma^2_I}{I^2} + \frac{\sigma^2_C}{C^2}}$$

$$\frac{\sigma_{OL}}{OL} = \sqrt{\frac{\sigma^2_O}{O^2} + \frac{\sigma^2_C}{C^2}}$$

These coefficients of variation can be used to place error bounds on pollutographs. The bounds are a function of stage and concentration at each point in time. The scope of this project does not include determination of error bounds for each time increment for

TABLE 5.1

Laboratory Error Statistics

Water Quality Parameter	Percent Error $\frac{\sigma}{\bar{x}}$ x 100	Standard Deviation (ppb)
TSS	5.18 %	
Pb (ICP Analysis)	5.30	
Zn (ICP Analysis)	1.30	
Cd (Furnace)		[*].14
Grease α Oil	[**]18.00	
Total Phosphorus	29.40	

[*] METRO's lab duplicate study reports precision as the mean absolute difference between duplicate analysis for samples low in concentration (less than ten times the limit of detection (LOD)). This average difference is related to the standard deviation by the following formula $= \bar{D}/1.13$.

[**] Error statistics for grease and oil are not available from METRO. The percent error reported was estimated using replicate values from composite samples.

TABLE 5.2

Flow Error at the METRO Site

Type of Error	Variance, σ^2 (cfs^2)
Outflow Regression Error	0.0039
Outflow Field Measurement Error	$.00475\ H_f^{3.33}$
Total Outflow Error	$0.0039 + .00475\ H_f^{\ 3.33}$
Change in Storage Error	$(0.01\ H_p)^2$
Total Inflow Error	$.0039 + .00475\ H_f^{3.3}$ $+ (.01\ H_p)^2$

where H_f = flume stage
H_p = pond stage

TABLE 5.3

Reference Level Error Analaysis for Inflow Loading at METRO. Storm Event 7.

Water Quality Parameter	Avg. Inflow Conc. (mg/l)	Reference Pond Height (ft)	Reference Flume Stage (ft)	Reference Outflow (cfs)	Reference Inflow (cfs)	Instantaneous Inflow Load (lbs/day)
TSS	184	4.83	0.63	0.37	0.726	720
Soluble Zinc	9.29×10^{-2}	4.83	0.63	0.37	0.726	3.64×10^{-1}
Grease & Oil	10	4.83	0.63	0.37	0.726	39

	I	C	IL	$\frac{\sigma_{IL}}{IL}$ (In percent)
TSS	.0854	9.53	92.4	12.8%
Soluble Zinc	.0854	1.2077×10^{-3}	4.3×10^{-2}	11.8%
Grease & Oil	.0854	1.8	7.2	18.4%

each pollutograph. However, an average concentration and reference stage measurement can be used to illustrate the significance of the instantaneous loading error. Table 5.3 presents the standard deviation and percent error in inflow loading for three water quality parameters (TSS, zinc, and grease and oil) at the METRO site for a reference pond and flume stage and an average storm concentration for storm 7. Error statistics were not calculated for the Whispering Heights site; however, TSS loading errors estimated for the METRO site will give an indication of the error bounds on Whispering Heights pollutographs.

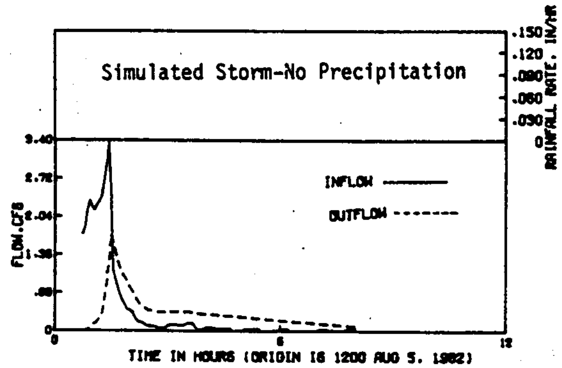
CHAPTER SIX

DISCUSSION OF RESULTS: METRO SITE

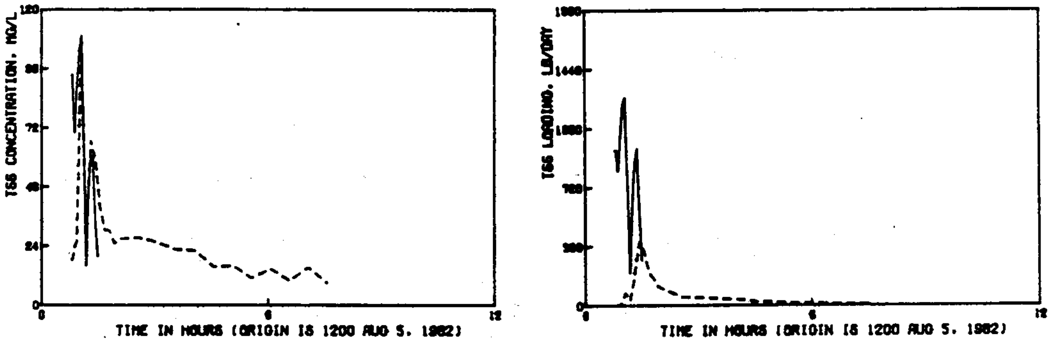
Storm events were monitored at the METRO site between August 1982 and February 1983. Runoff was sampled from artificial events (flooding from hydrants) as well as natural storms. All storms for which data are presented were monitored on a discrete basis to obtain time histories of concentration and mass loading. Composite sampling and a trace organics study is presently being conducted at the site.

Precipitation, retention pond inflow and outflow hydrographs, concentrations and pollutant mass loadings are displayed as a function of time for each of the storm events monitored at the METRO site in Figures 6.1 through 6.6. Flow, concentration and loading data are also given in tabular form in Appendix D.

Comparison of the inflow and outflow hydrographs illustrates the efficiency with which the pond reduces storm peak discharge entering Kelsey Creek. Storm event 2 (August 5, 1982) and Storm event 3 (September 22, 1982) hydrographs exhibit the highest magnitude and shortest duration inflows of all events monitored because they are a result of runoff generated by the release of water from fire hydrants. Synthetic inflow hydrographs (Figures 6.1a and 6.2a) indicate a squarer wave form than a typical, rising and falling limb of precipitation induced stormwater runoff. Peak flow reduction and flood peak attenuation were greatest for the artificial storms due to the magnitudes of the inflows (2.9 and 3.4 cfs, respectively). The rising limb of the outflow hydrograph exhibits two distinct maxima

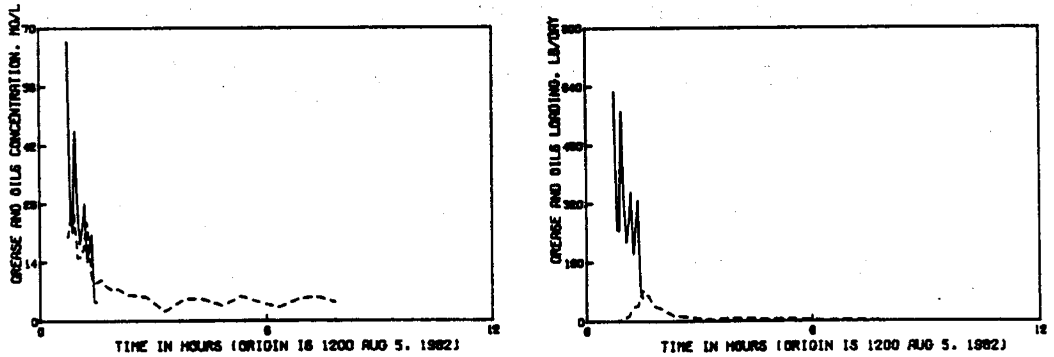


a.) Storm Hydrograph and Precipitation



b.) TSS Concentration

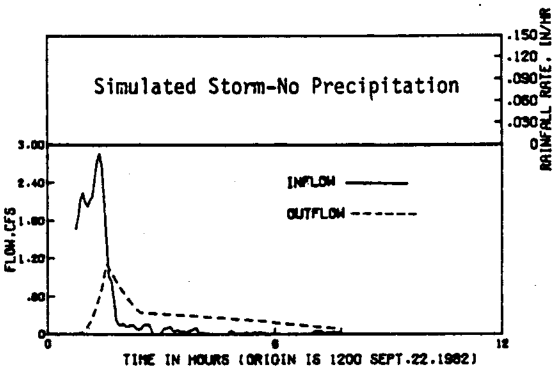
c.) TSS Mass Loading



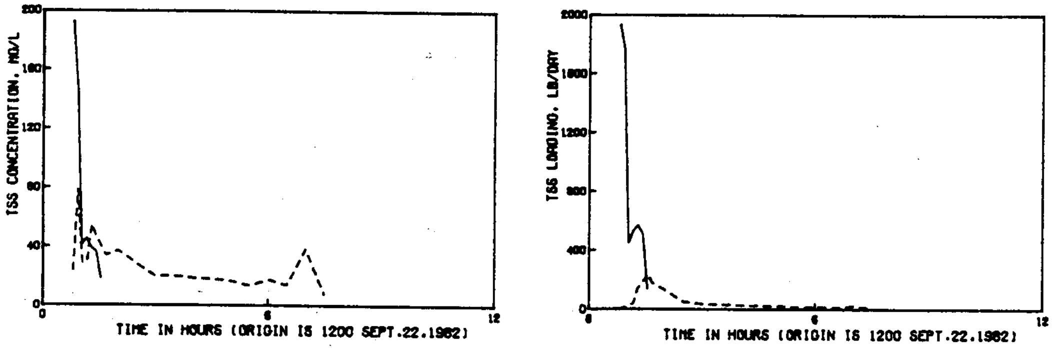
d.) Grease & Oil Concentration

e.)Grease & Oil Loading

Figure 6.1 a-e Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs for Storm 2: August 5, 1982.

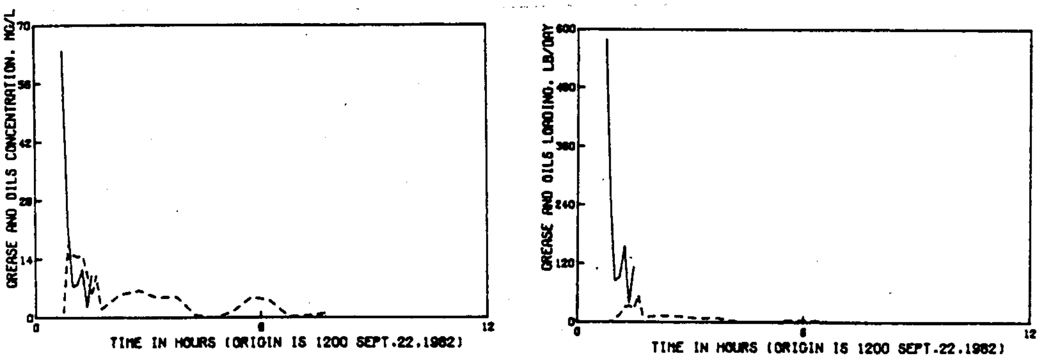


a.) Storm Hydrograph and Precipitation



b.) TSS Concentration

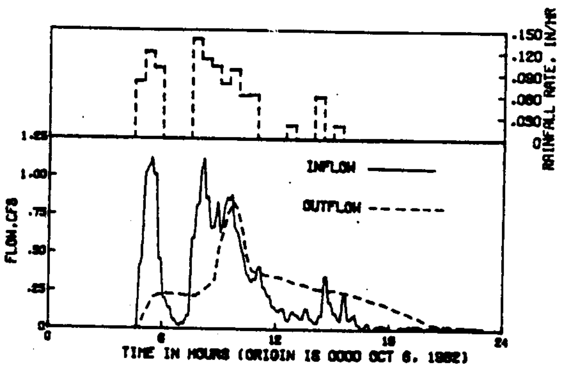
c.) TSS Mass Loading



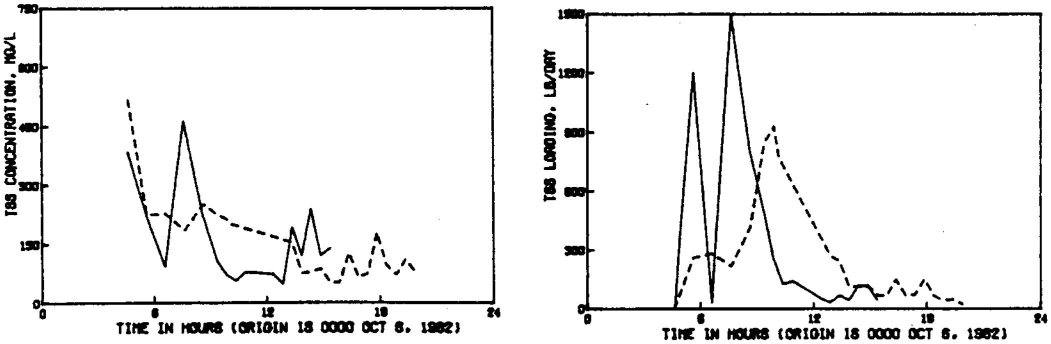
d.) Grease & Oil Concentration

e.) Grease & Oil Loading

Figure 6.2 a-e Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs for Storm 3: September 22, 1982.

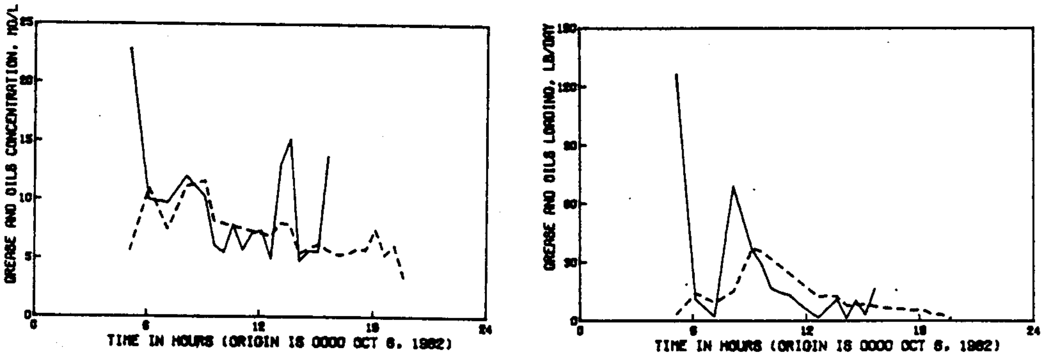


a.) Storm Hydrograph and Precipitation



b.) TSS Concentration

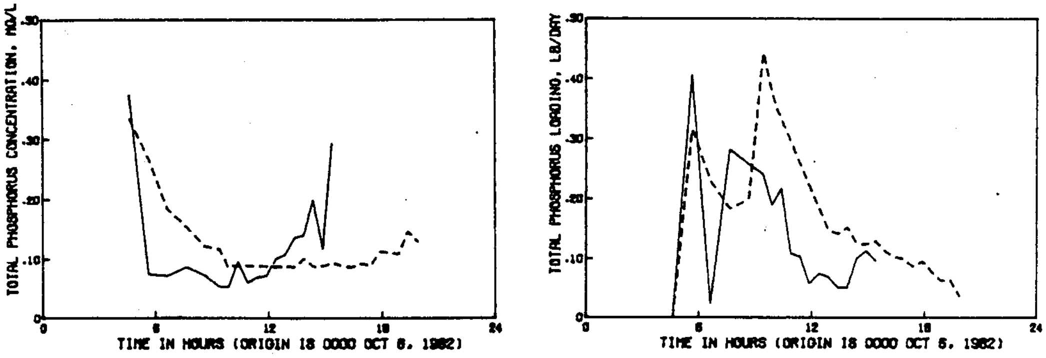
c.) TSS Mass Loading



d.) Grease & Oil Concentration

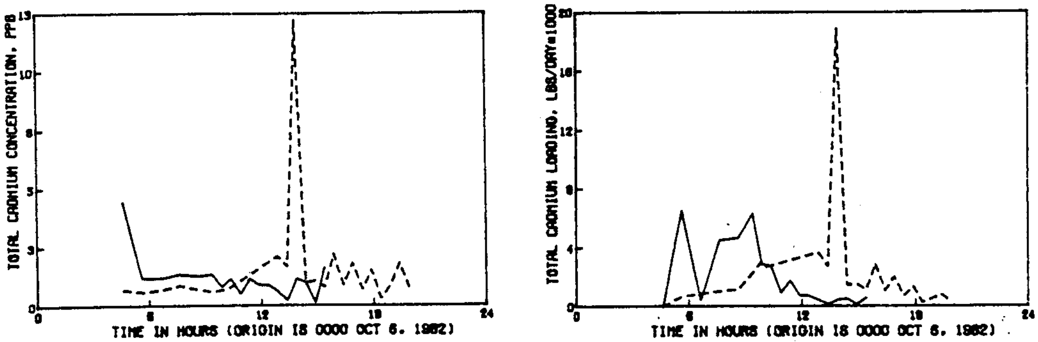
e.) Grease & Oil Mass Loading

Figure 6.3 a-e Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs for Storm 7: October 6, 1982.



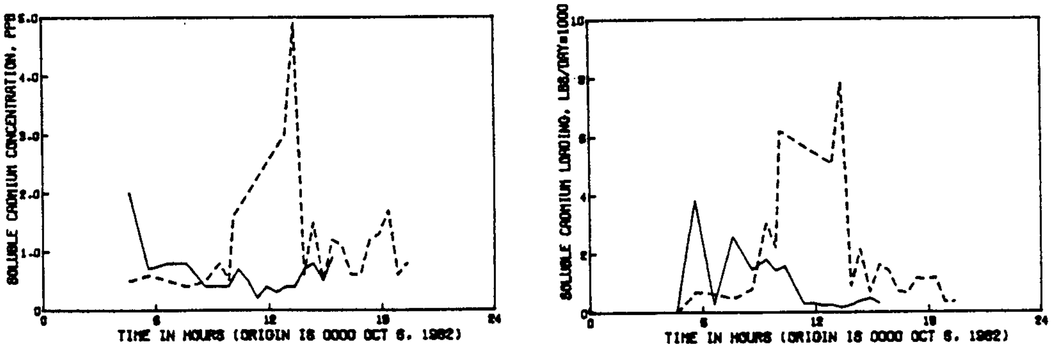
f.) Total Phosphorus Concentration

g.) Total Phosphorus Mass Loading



h.) Total Cadmium Concentration

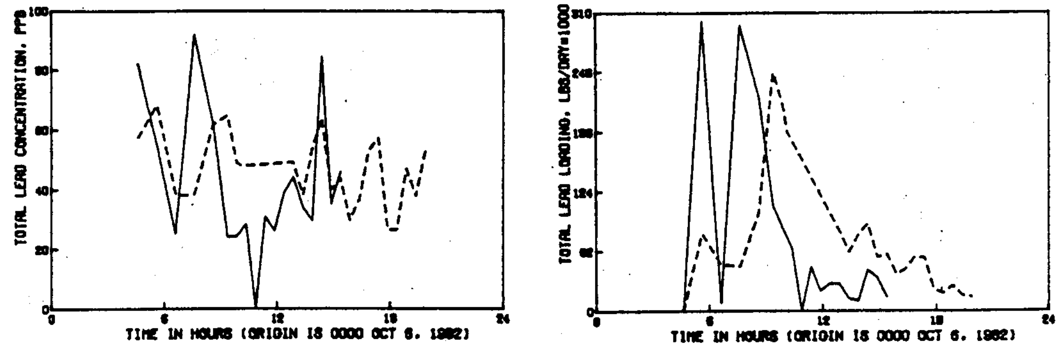
i.) Total Cadmium Mass Loading



j.) Soluble Cadmium Concentration

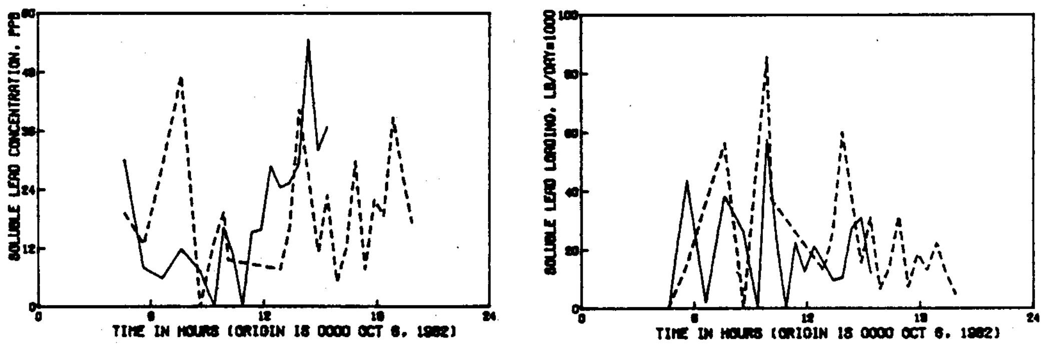
k.) Soluble Cadmium Mass Loading

Figure 6.3 f-k (Cont.)



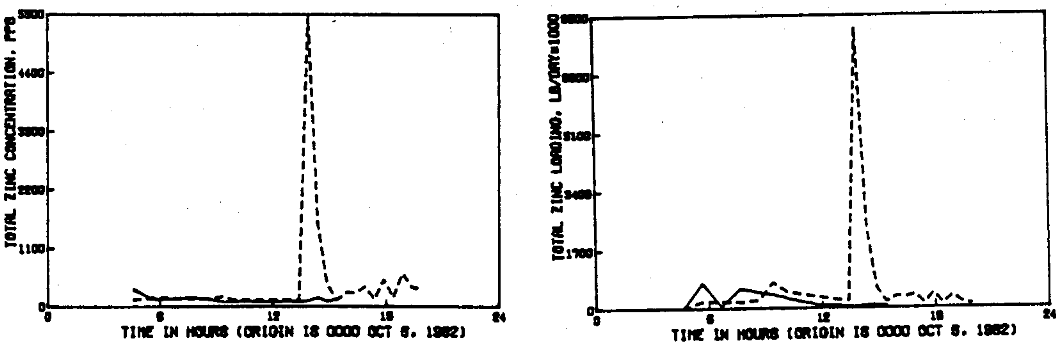
l.) Total Lead Concentration

m.) Total Lead Mass Loading



n.) Soluble Lead Concentration

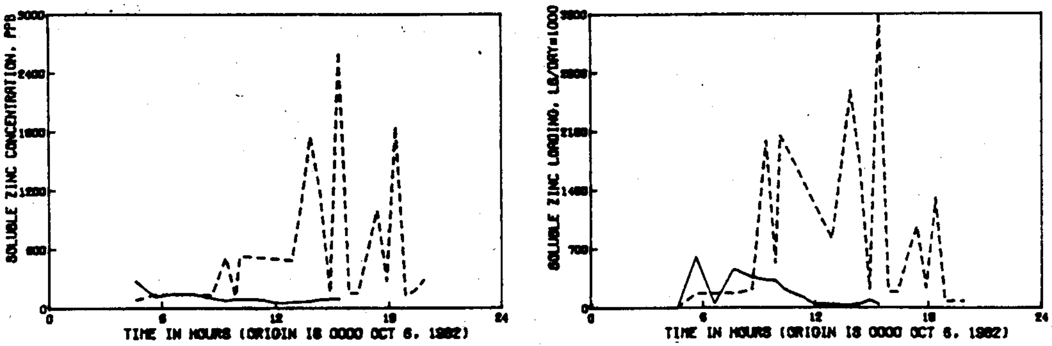
o.) Soluble Lead Mass Loading



p.) Total Zinc Concentration

q.) Total Zinc Mass Loading

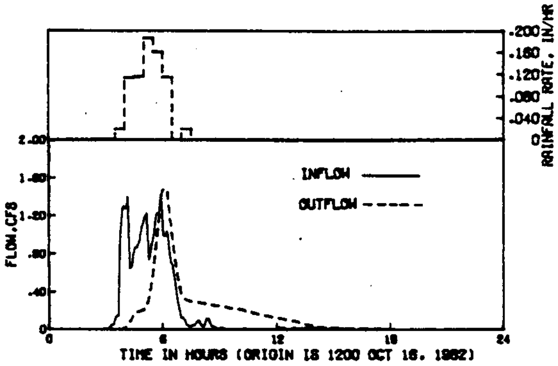
Figure 6.3 l-q (Cont.)



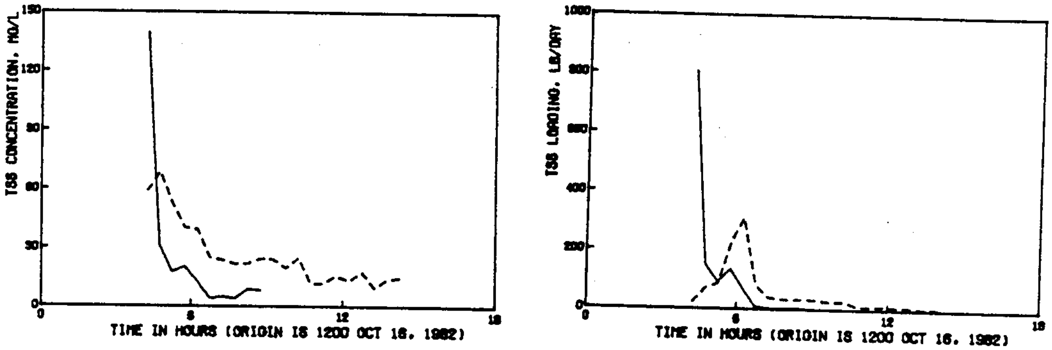
r.) Soluble Zinc Concentration

s.) Soluble Zinc Mass Loading

Figure 6.3 r-s (Cont.)

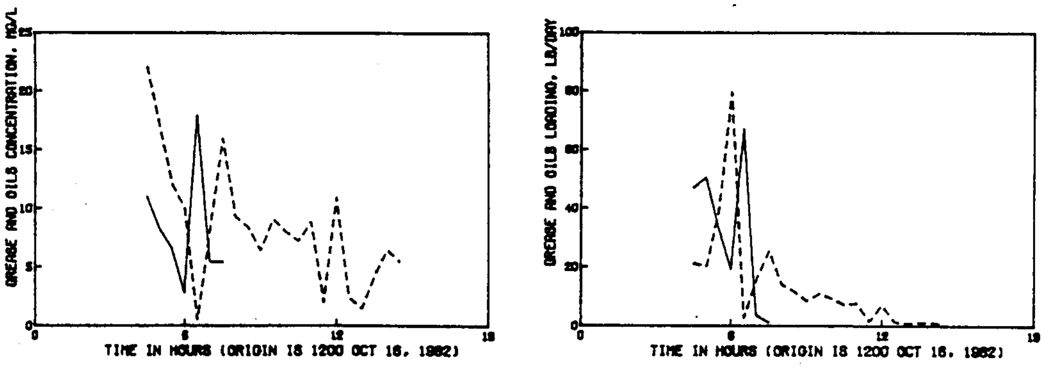


a.) Storm Hydrograph and Precipitation



b.) TSS Concentration

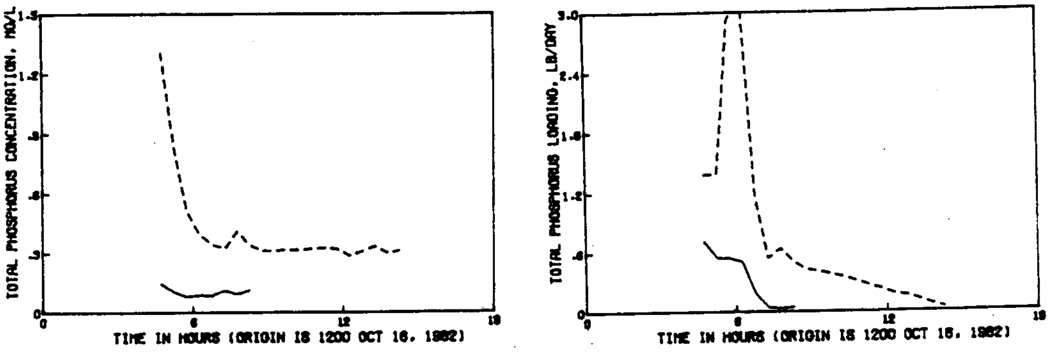
c.) TSS Mass Loading



d.) Grease & Oil Concentration

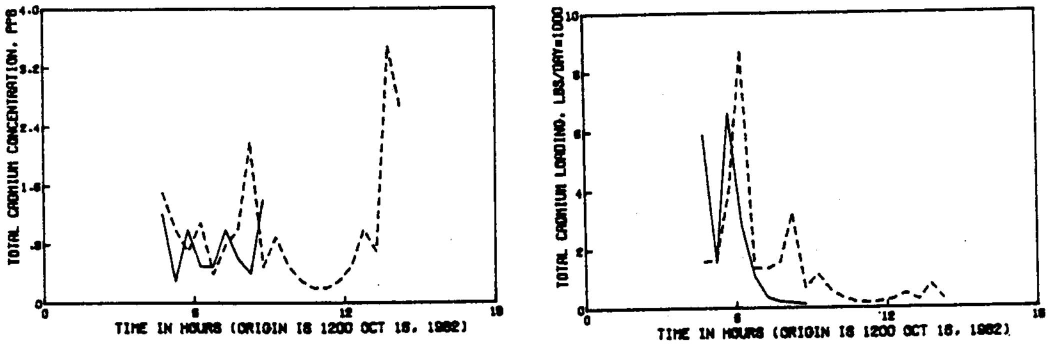
e.) Grease & Oil Mass Loading

Figure 6.4 a-e Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs for Storm 8: October 16, 1982.



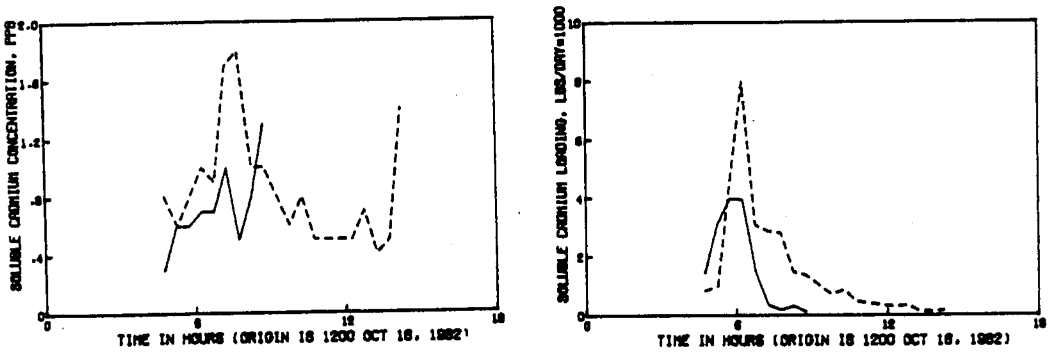
f.) Total Phosphorus Concentration

g.) Total Phosphorus Mass Loading



h.) Total Cadmium Concentration

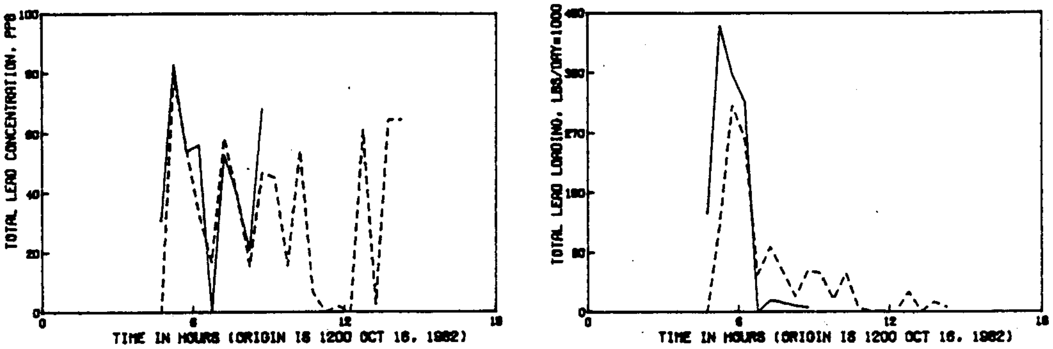
i.) Total Cadmium Mass Loading



j.) Soluble Cadmium Concentration

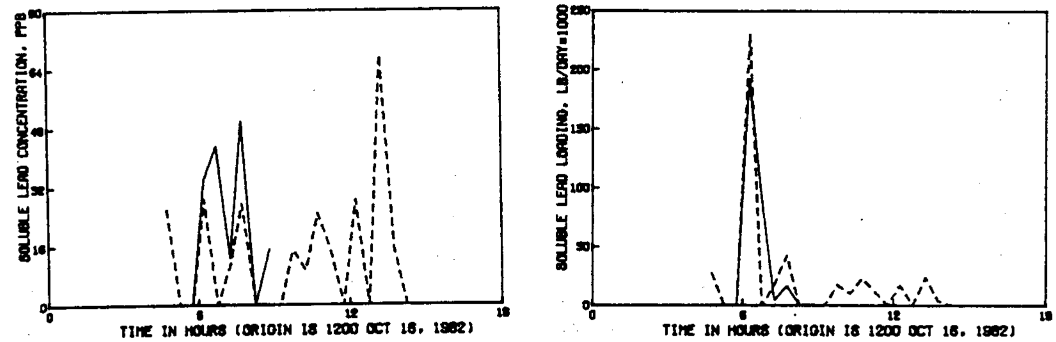
k.) Soluble Cadmium Mass Loading

Figure 6.4 f-k (Cont.)



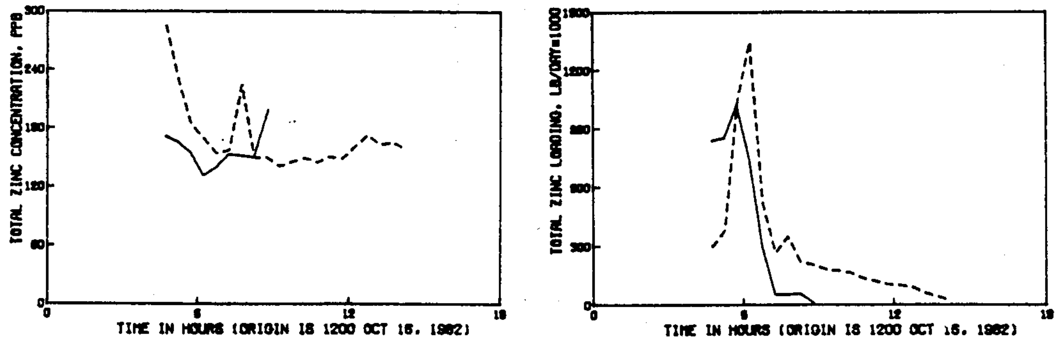
l.) Total Lead Concentration

m.) Total Lead Mass Loading



n.) Soluble Lead Concentration

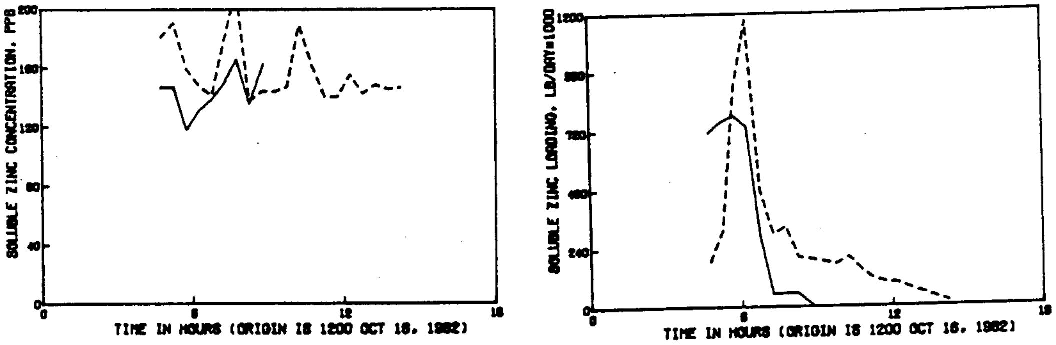
o.) Soluble Lead Mass Loading



p.) Total Zinc Concentration

q.) Total Zinc Mass Loading

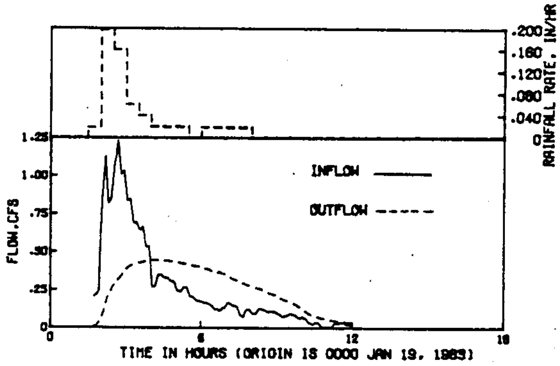
Figure 6.4 l-q (Cont.)



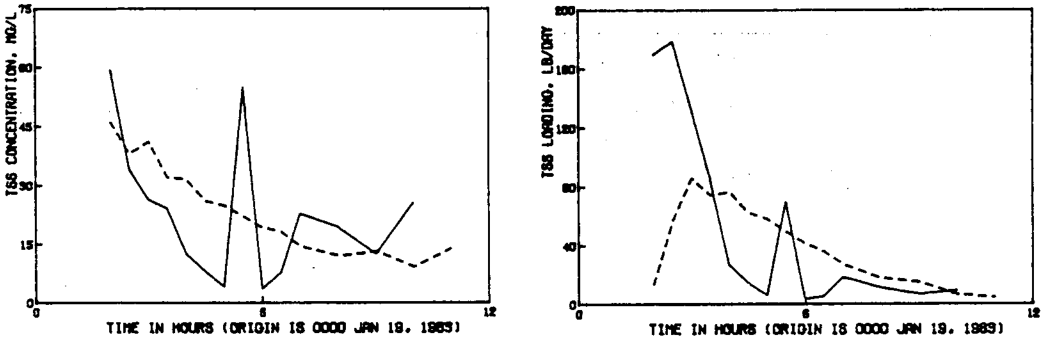
r.) Soluble Zinc Concentration

s.) Soluble Zinc Mass Loading

Figure 6.4 r-s (Cont.)

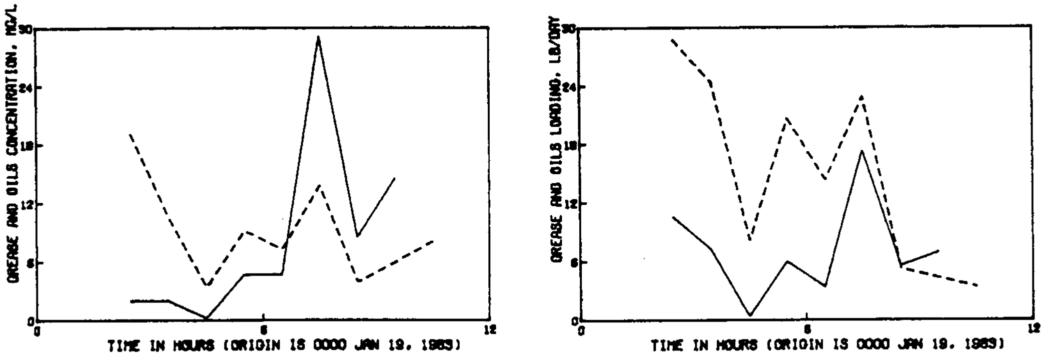


a.) Storm Hydrograph and Precipitation



b.) TSS Concentration

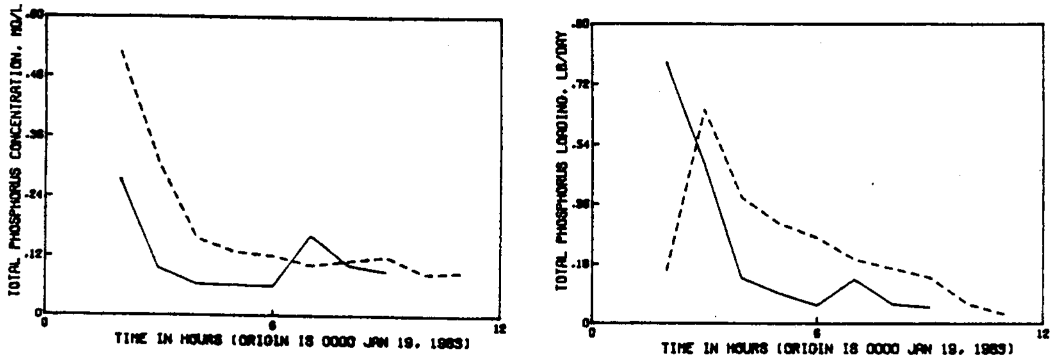
c.) TSS Mass Loading



d.) Grease & Oil Concentration

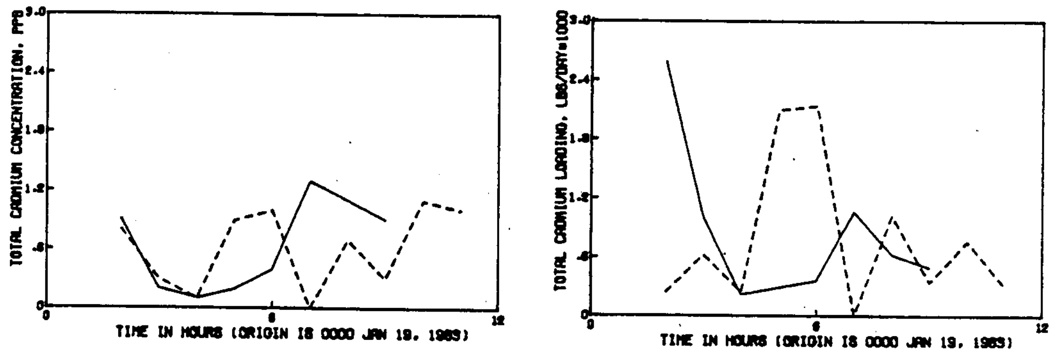
e.) Grease & Oil Mass Loading

Figure 6.5 a-e Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs for Storm 9: January 19, 1983.



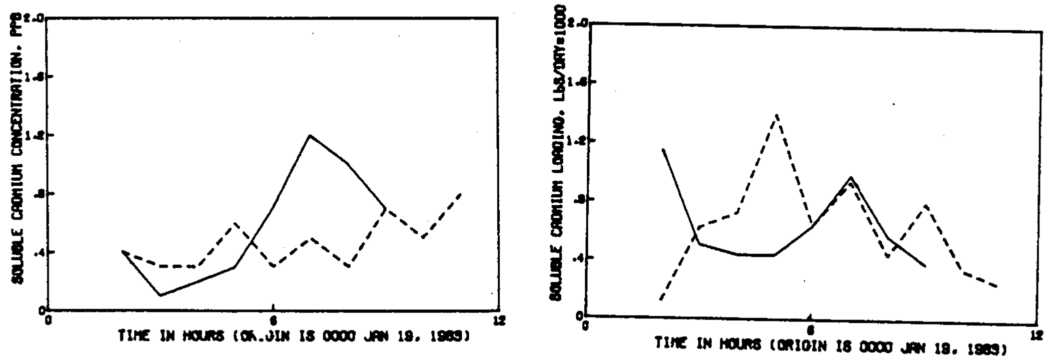
f.) Total Phosphorus Concentration

g.) Total Phosphorus Mass Loading



h.) Total Cadmium Concentration

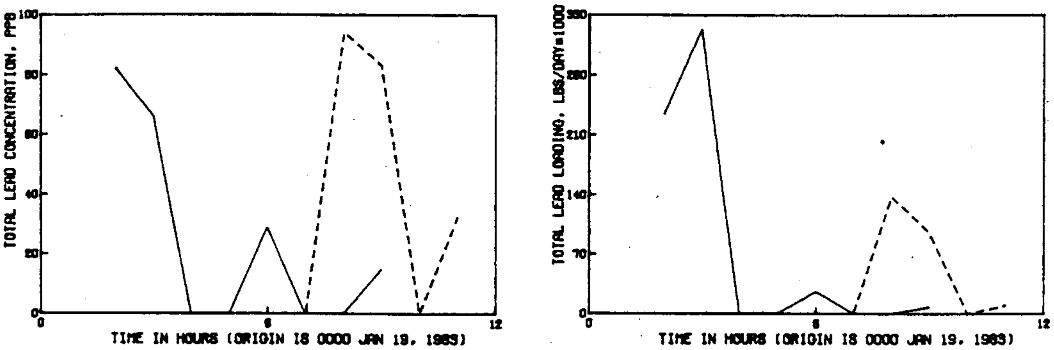
i.) Total Cadmium Loading



j.) Soluble Cadmium Concentration

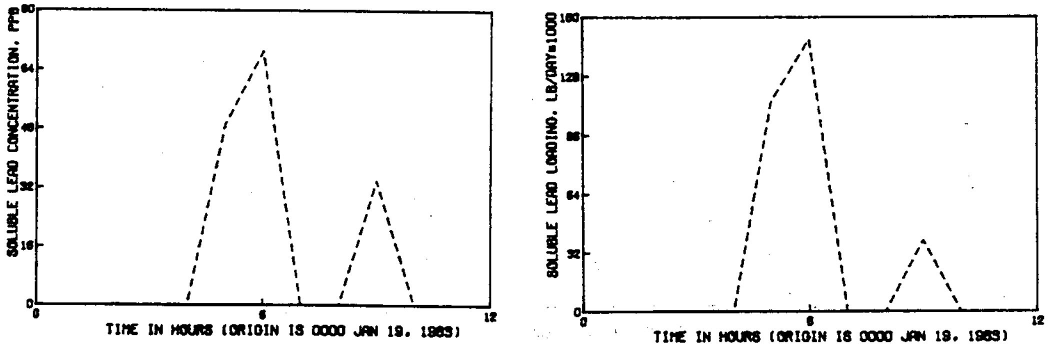
k.) Soluble Cadmium Mass Loading

Figure 6.5 f-k (Cont.)



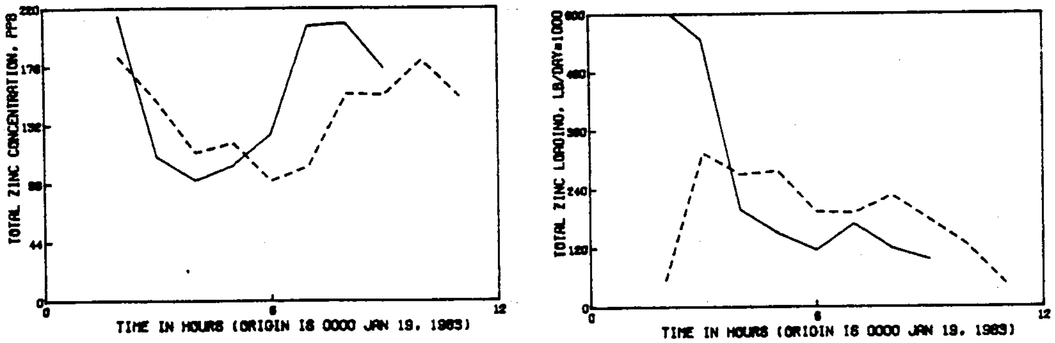
l.) Total Lead Concentration

m.) Total Lead Mass Loading



n.) Soluble Lead Concentration

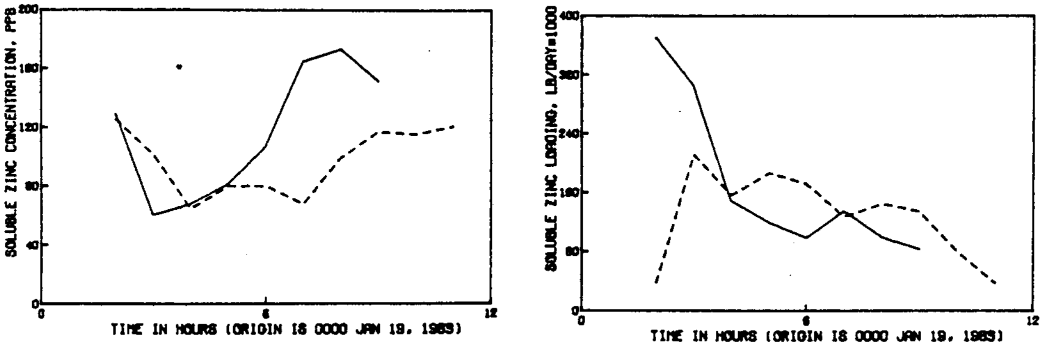
o.) Soluble Lead Mass Loading



p.) Total Zinc Concentration

q.) Total Zinc Mass Loading

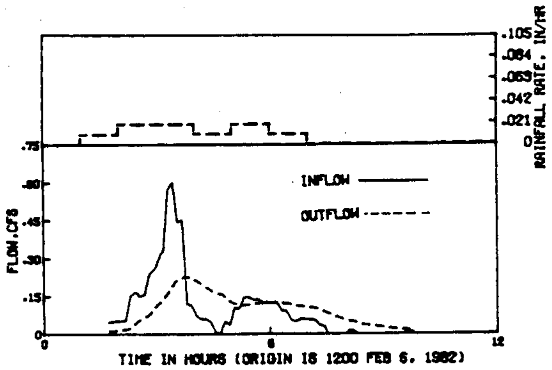
Figure 6.5 l-q (Cont.)



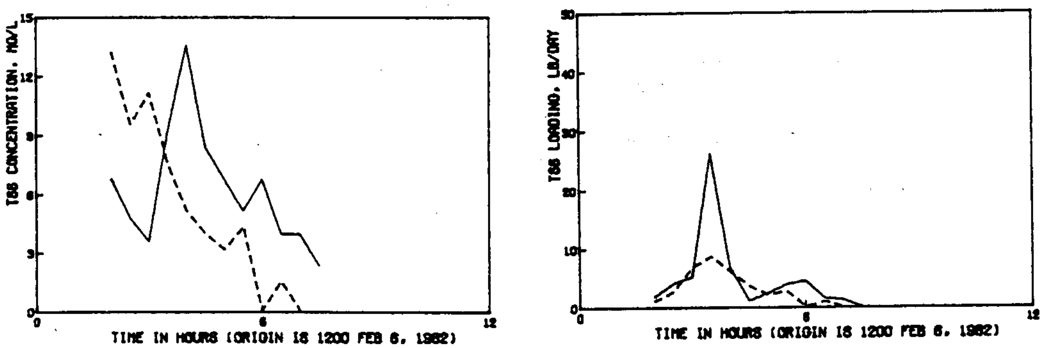
r.) Soluble Zinc Concentration

s.) Soluble Zinc Mass Loading

Figure 6.5 r-s (Cont.)

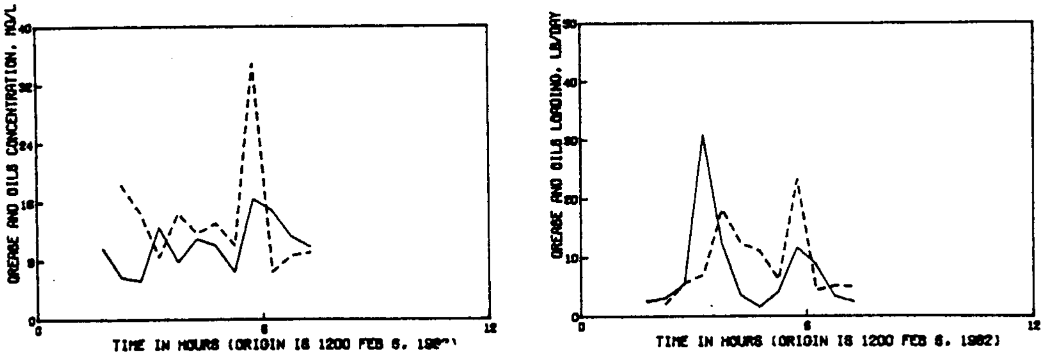


a.) Storm Hydrograph and Precipitation



b.) TSS Concentration

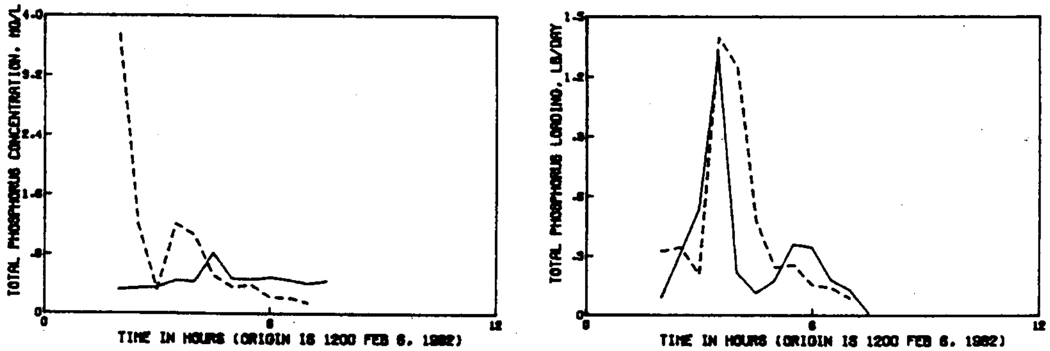
c.) TSS Mass Loading



d.) Grease & Oil Concentration

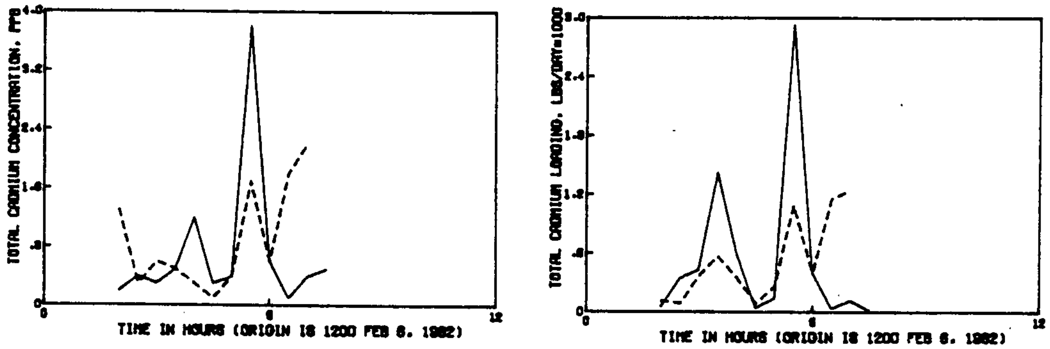
e.) Grease & Oil Mass Loading

Figure 6.6 a-e Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs for Storm 11: February 6, 1983.



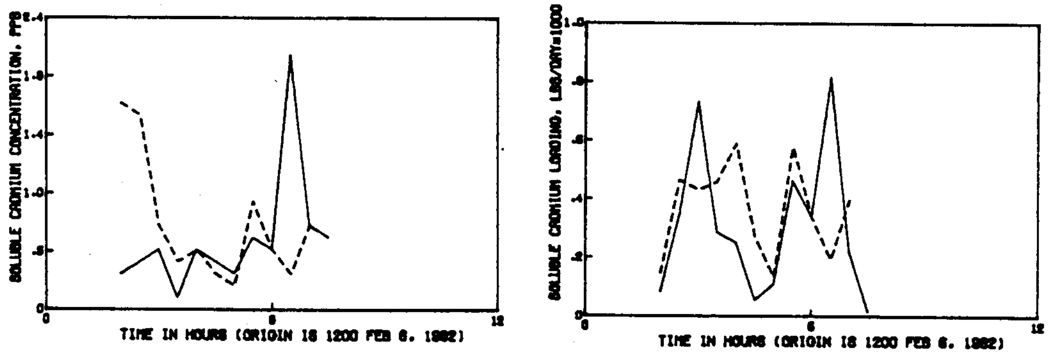
f.) Total Phosphorus Concentration

g.) Total Phosphorus Mass Loading



h.) Total Cadmium Concentration

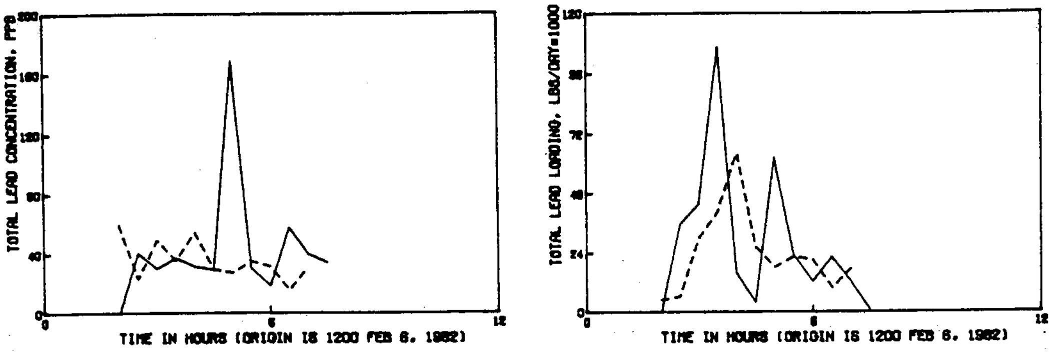
i.) Total Cadmium Mass Loading



j.) Soluble Cadmium Concentration

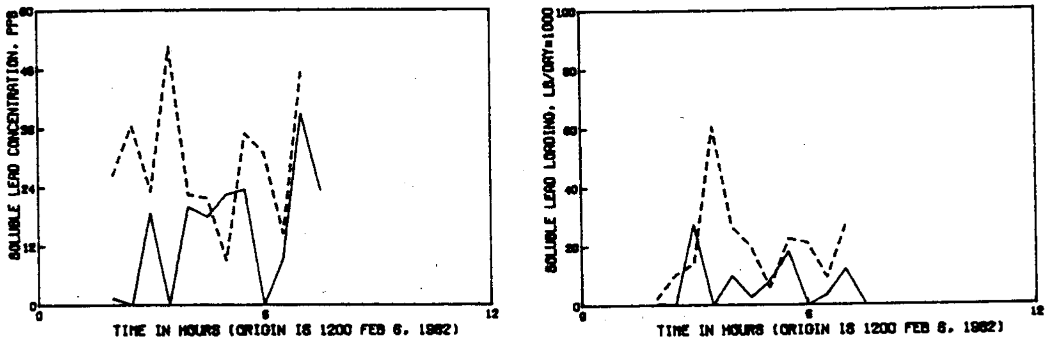
k.) Soluble Cadmium Mass Loading

Figure 6.6 f-k (Cont.)



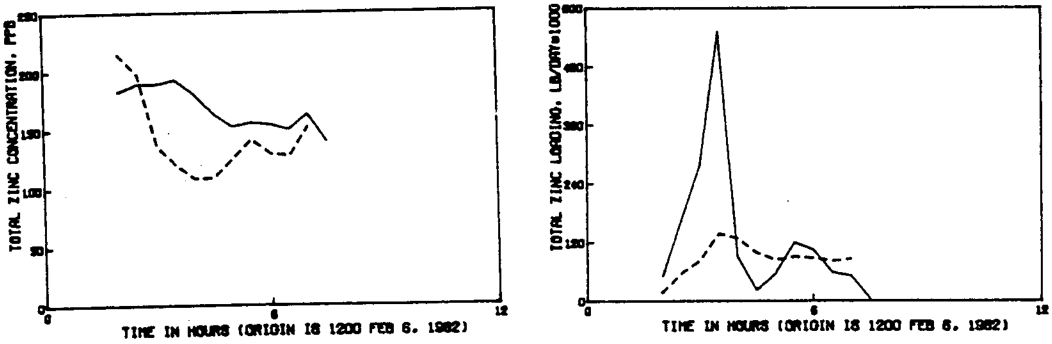
l.) Total Lead Concentration

m.) Total Lead Mass Loading



n.) Soluble Lead Concentration

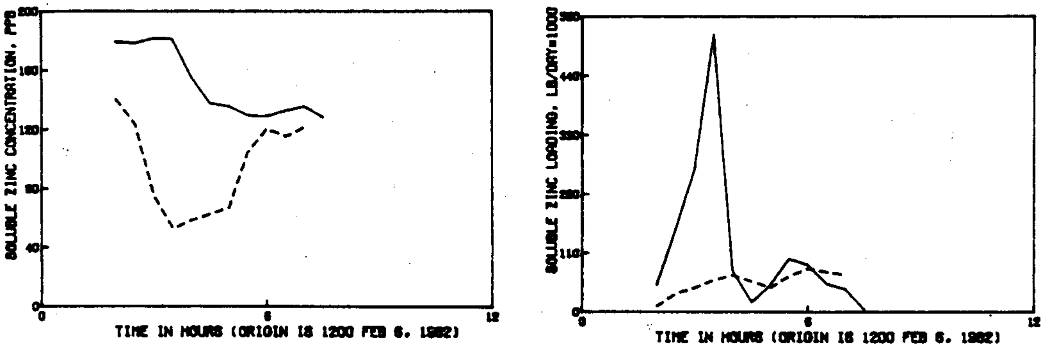
o.) Soluble Lead Mass Loading



p.) Total Zinc Concentration

q.) Total Zinc Mass Loading

Figure 6.6 l-q (Cont.)



r.) Soluble Zinc Concentration

s.) Soluble Zinc Mass Loading

Figure 6.6 r-s (Cont.)

for every storm monitored except Storm events 9 and 11. The first curve indicates that water levels in the pond did not rise to the elevation of the overflow pipe. The steeper curve is a result of discharge from both the regular outflow structure and the overflow structure. Discharge through the overflow pipe did not occur during storm events 9 and 11 (January 19 and February 6, 1983) due to their small magnitude and intensity, therefore, the outflow hydrographs for these storms are unimodal.

Pollutant Concentrations

The shape of the inflow hydrograph greatly influences the shape of the pollutograph. Graphs of pollutant concentration versus time and pollutant loading versus time are presented for total suspended solids (TSS) and grease and oil for all storms (Figures 6.1 through 6.6). In addition, Storm events 7,8 9,and 11 (all precipitation driven) include data for total phosphorus (TP), total cadmium, zinc and lead (TCd, TZn, and TPb), and soluble cadmium, zinc and lead (SCd, SZn, and SPb) (Figures 6.3 through 6.6). Preliminary grab sampling conducted in this study, as well as studies by Helsel et al. (1979) and Randall (1979) determined that zinc and lead are present in urban stormwater in concentrations greatly exceeding water quality criteria (USEPA, 1980). Stormwater samples were also analyzed for cadmium because of its acute toxicity (Galvin and Moore, 1982; USEPA, 1980). Sources of cadmium include alloys, paints, vulcanization of rubber and road induced breakdown of rubber. Lead enters the environment from tire abrasion, paint and primer pigments, as well as decomposition of auto emissions. Weathering and abrasion of galvanized iron and steel, lubricating oils, and asphalt are major sources of zinc at the METRO site.

Current maximum receiving water standards for aquatic life, established by the Environmental Protection Agency (USEPA, 1980) are 7.4 ppb (Pb), 180 ppb (Zn), and 0.15 ppb (Cd). Wilber and Hunter (1975) found secondary treatment effluent to contain average metal concentrations of 200 ppb (Pb) and 80 ppb (Zn). Although the stormwater runoff metal concentrations are highly variable over the length of a storm and between storms, the levels observed in the inflow and outflow (Tables 6.1a and 6.1b) are generally much higher than standards set for aquatic life, and are quite comparable to concentrations found in secondary treatment effluent. Although stormwater concentrations for total Cd, Pb, and Zn did exceed chronic water quality criteria during several storm events and during low flow, dry period discharge, interpretation of these results with regard to toxicity in the natural environment may be misleading. It is actually the free metallic ions (soluble form) that are lethal to sensitive aquatic organisms (Sittig, 1980). The EPA standards are for total metal concentration and do not indicate the concentrations at which the soluble form of a metal is toxic.

Analytical methods for determining soluble metals yield widely varying results. Difference in filter size, which determines the maximum size particle to be considered part of the soluble phase, lead to vast differences in results and great difficulty in comparing concentrations. In this study, a soluble metal was defined as any metal associated with particulates smaller than 1.2 microns in size.

TABLE 6.1a

Range of Pollutant Concentrations In INFLOW

Storm #	Date	TSS (mg/L)	G&O (mg/L)	TP (mg/L)	TCd (ppb)	SCd (ppb)	TPb (ppb)	SPb (ppb)	TZn (ppb)	SZn (ppb)
Storm 2	08/05/83	16-109	4.5-66.7	-	-	-	-	-	-	-
Storm 3	09/22/83	18-192	2.5-63.7	-	-	-	-	-	-	-
Storm 7	10/06/82	48-384	4.8-22.8	0.05-.37	0.1-4.6	0.2-2.0	24.6-92.0	*0-54.6	85.7-180.5	46.5-273.3.
Storm 8	10/16/82	4-139	2.8-18	0.08-.15	0.3-1.5	0.3-1.3	*0-83.1	*0-50.3	140-171	177-166
Storm 9	01/19/83	3.6-59.2	0.2-29.1	0.06-.27	0.1-1.3	0.1-1.2	*0-82.1	*0	90.5-208.9	60.4-173.7
Storm 11	02/06/83	2.4-13.6	6.5-16.5	0.33-0.83	0.1-3.8	0.1-2.1	*0-168.4	*0-39.0	139-193	

0 = below detection

TABLE 6.1b
Range of Pollutant Concentrations in OUTFLOW

Storm #	Date	TSS (mg/L)	G&O (mg/L)	TP (mg/L)	TCd (ppb)	SCd (ppb)	TPb (ppb)	SPb (ppb)	TZn (ppb)	SZn (ppb)
Storm 2	08/05/82	9-109	3.2-29.0	-	-	-	-	-	-	-
Storm 3	09/22/82	7-78	0.1-17.5	-	-	-	-	-	-	-
Storm 7	10/06/82	52-516	3.4-11.6	0.09-.33	0.3-12.7	0.5-4.9	26.6-68.6	*0-47.5	120-5463	86.8-2618.0
Storm 8	10/16/82	9.5-68.5	0.5-22	0.30-1.3	0.2-3.5	0.4-1.8	*0-79.3	*0-67.8	140-284	137-213
Storm 9	01/19/83	9.2-46.0	3.4-19.0	0.09-0.53	*0-1.1	0.3-0.8	*0-94.0	*0-69.0	90.2-183.1	64.4-125.1
Storm 11	02/06/83	0.1-13.2	6.5-35.0	.15-3.74	0.1-2.2	0.2-1.7	15.3-59.2	9-52.7	108-214	53-140

*0 - below detection

Zinc concentrations in stormwater entering and leaving the METRO retention pond are high. Total zinc concentrations range from 85 to 210 ppb in the inflow, and from 90 to 5460 ppb in the outflow. Soluble zinc concentrations range from 46 to 273 ppb in the inflow, and from 53 to 2620 ppb in the outflow. Although comparisons with EPA standards and past studies regarding secondary effluent are difficult due to analytical differences, it is apparent that the concentrations of soluble zinc being discharged into the West Tributary of Kelsey Creek should be of major concern; some of the observed concentrations are higher than total zinc concentrations which are considered acutely toxic, and higher than total zinc concentrations found in secondary treatment effluent. In addition, grab samples taken of low flow, dry period discharge during 1982 from the pond into the West Tributary of Kelsey Creek had concentrations of approximately 150 ppb (TZn) and 120 ppb (SZn). Although the dry period discharge is small (approximately 0.003 cfs), on an annual basis, the total dry period load of zinc discharged into the receiving water can be significant.

Table 6.2 lists the amount of pollutant (in pounds) discharged into Kelsey Creek per storm event and an estimate of the total pollutant discharged annually during low flow, dry periods. Low flow data are based on grab samples of dry period discharge from the METRO retention pond, and an average low flow of 0.003 cfs. Annual low flow loading may be underestimated, since the base flow in many inter-storm periods is probably higher. Additional loads caused by concentrated runoff from washsheds and solvent and fuel spills cannot

TABLE 6.2
Estimated Pollutant Load Delivered to Kelsey Creek (in lbs)

	TSS	G&O	TP	TCd (x10^3)	SCd (x10^3)	TPb (x10^3)	SPb (x10^3)	TZn (x10^3)	SZn (x10^3)
Storm 2	14.9	3.73							
Storm 3	12.8	2.21							
Storm 7	178.4	8.25	0.12	1.42	1.36	51.21	16.63	391.69	551.57
Storm 8	22.3	5.77	0.29	0.58	0.63	25.09	8.65	117.63	108.18
Storm 9	14.0	4.82	0.09	0.31	0.25	9.9	12.56	76.26	52.14
Storm 11	0.7	2.03	0.10	0.11	0.08	5.25	4.28	18.83	12.09
Dry Period, Low Flow Discharge Integrated over 1 year	118.	41.3	1.94-22	4.13	2.95	649.2	88.5	885	708

be determined, but would increase annual loads of grease and oil, heavy metals and total phosphate.

Concentrations for total and soluble lead were also greater than EPA acute toxic values, but are similar to event mean concentrations found in urban runoff in sites studied in the National Urban Runoff Program (NURP). NURP values range from 0.1 to 14 ppb (TCd), 10 to 2400 ppb (TZn), and 6 to 460 ppb (TPb) (Dave Galvin, personal communication, 1983). These ranges are quite similar to those found in Tables 6.1a and 6.1b.

The magnitude of pollutant loading at any instant in time is obtained by multiplying the instantaneous flow by the measured pollutant concentration. It is assumed that the concentration determined for a runoff sample taken at a given time is representative of water quality throughout the entire half-interval between adjacent samples. Sampling intervals ranged from 3.75 minutes for synthetic storm events, to 15 and 30 minutes for actual storm events. If concentrations change rapidly over time, this assumption may not be justified and pollutant loadings cannot be accurately determined.

Pollutant Removal Efficiency

The total mass of a pollutant entering and leaving the pond is represented by the area under the pollutograph, obtained by integrating the pollutant load over the storm duration. The ratio of the total mass of a pollutant leaving the retention pond to the mass of pollutant entering the pond indicates the percent removal or pond efficiency for each pollutant monitored. The efficiency of the METRO retention facility in reducing the pollutant mass in stormwater runoff for the pollutant parameters measured is compared for each storm in Table 6.3. Although percent removals were negative in many cases (i.e., pollutants were flushed from the detention facility), direct comparison indicates that TSS, lead and petroleum hydrocarbons are most effectively removed by sedimentation. These results are supported by several other studies using both field and laboratory settling experiments (Whipple, 1979; Whipple and Hunter, 1981; Randall et al., 1982), indicating the strong affinity of lead and petroleum based hydrocarbons for particulates.

Not all pollutants settle in proportion to their presence in particulate form. Percent removals exhibited for total zinc and total cadmium were generally much smaller (or more negative), and total phosphorus was found to have the lowest removal rates. Whipple and Hunter, (1981) and Randall et al. (1982) have also found that zinc settleability is lower than other heavy metals. However, in contrast to this study, Whipples's results indicate that total phosphorus has higher settleability than zinc. Soluble forms of the heavy metals were found to have lower percent removals due to smaller particle weight and subsequently, lower settling velocities. However, removal of total zinc and soluble zinc were very similar, indicating that zinc exists primarily in the soluble form in stormwater runoff from the site. In contrast, lead is primarily particulate-bound in the inflow.

A nation-wide metals analysis conducted through the NURP program also found lead to be the most particulate-associated metal (an average of only 11 percent was in the dissolved state using a 0.45

TABLE 6.3
Retention Pond Pollutant Removal Efficiency

Storm	Date	TSS	G&O	Total P	Cd (total)	Cd (dissolved)	Pb (T)	Pb (D)	Zn (T)	Zn (D)
Storm 2	08/05/82	+ 36%	+ 58%							
Storm 3	09/22/83	+ 50%	+ 56%							
Storm 7	10/06/82	+ 17%	+ 16%	- 71%	- 35%	- 167%	- 16%	- 76%	- 250%	- 506%
Storm 8	10/16/82	- 23%	- 40%	- 480%	- 76%	- 117%	- + 1%	- 36%	- 61%	- 67%
Storm 9	01/19/83	+ 2%	- 139%	- 50%	- 48%	- 39%	+ 50%	- 0	- 11%	- 10%
Storm 11	02/06/83	+ 40%	- 10%	- 25%	+ 21%	0%	26%	- 147%	+ 41%	+ 58.4%

$$\% \text{ Removal} = [1 - \frac{\text{output load}}{\text{input load}}] * 100$$

micron filter). The same study found 43 percent of the zinc in urban runoff to be soluble. Table 6.4 reports the percent of zinc, lead and cadmium in the soluble and particulate phases in both inflow and outflow. The larger percentages of dissoved metals, as compared to the NURP findings, can be attributed to the larger pore size filter used for analysis of the soluble phase. It can be seen that there is a substantial transformation of cadmium and lead from particulate to soluble form between inflow and outflow during most storms. This increase in free metallic ions occuring within the pond can have a negative impact upon the biota of the receiving water, as it is in this dissolved, ionic form that these metals are biologically available. The percent of soluble zinc does not appear to increase between inflow and outflow locations; however, an average of 85 percent of the zinc present in the inflow is already in the soluble phase.

Pond Dynamics

The tendency for negative removal rates for all metals except lead, and for total phosphorus can be explained by the design of the METRO detention facility. The pond is a wet pond, and is therefore capable of storing high concentrations of pollutants during dry periods. Low flow, dry period inflow to the pond (typically wastewater from bus washing and maintenance which includes high concentrations of heavy metals and phosphorus in various forms) is concentrated in the pond until the next storm. As discussed above, it is possible that low flow, high concentration discharge from the

TABLE 6.4
Percentage of Total Metal Load in Particulate and Dissolved Phase in Inflow and Outflow

INFLOW LOAD

Storm	CADMIUM		LEAD		ZINC	
	% Particulate	% Soluble	% Particulate	% Soluble	% Particulate	% Soluble
7	51	49	79	21	19	81
8	11	89	75	25	11	89
9	14	86	100	0	31	69
11	43	57	75	25	9	91

OUTFLOW LOAD

Storm	CADMIUM		LEAD		ZINC	
	% Particulate	% Soluble	% Particulate	% Soluble	% Particulate	% Soluble
7	4	96	68	32	-	> 100*
8	-	> 100*	65	35	8	92
9	19	81	-	> 100*	32	68
11	27	73	18	82	26	64

* - Soluble metal load was greater than total metal load due to analytical error

pond during dry periods integrated over the entire year represents a pollutant mass load on the same order of magnitude as storm loading.

The pond also appears to act as a chemical reactor, wherein metals which were originally adsorbed to particulates in the inflow undergo a partial digestion, and become available in the dissolved or ionic form in the outflow. Such a process would explain larger concentrations of soluble metals in the outflow. Metals associated with particulates that have settled in the pond during previous storm events are also available for chemical digestion. In addition, pollutants associated with dry period, low flow discharges from bus maintenance activities will not be accounted for in the inflow sampling of a storm event, however, if these pollutants are discharged during a storm event, a flushing process results, and the outflow loadings appear to be higher than the inflow loadings. This explanation appears more plausible than does any substantial chemical transformation during the relatively short period over which stormwater is detained in the pond. Unfortunately, monitoring of low flows into the pond during dry periods, which would complete the mass balance, was beyond the scope of this project.

Apparent negative efficiencies could also result if inflow sampling is delayed due to a faulty trigger system or malfunctioning of the sampling equipment. If the first portion of the storm event is not sampled, a disporportionately high mass inflow load of pollutant may not be included in the analysis. This was the situation in storm event 8 (October, 16, 1982), which is the only storm event exhibiting a negative TSS removal efficiency. The negative removal efficiency for TSS was quite likely due to a lack of inflow sampling during the first 25 minutes of the storm. Due to first flush effects (especially important for this storm which occurred after a lengthy dry period), a large portion of the solids loading into the pond was neglected; therefore, removal efficiencies for pollutant parameters in this event are, almost certainly less negative than the estimated values.

Negative grease and oil removal efficiencies may also be attributed to the underdesign and lack of sufficient cleaning of the two baffle system oil/water separators incorporated into the pond design. High flows cause the oil/water separators to overflow, thereby releasing petroleum hydrocarbons that have accumulated from both the current storm, and past storms and dry periods. Overflow of the oil/water separator associated with the low flow inflow pipe was observed during synthetic storm event 2. The retention pond itself also contains oil during dry periods (see Chapter Three) which is released during storms.

Increased pollutant removal efficiencies could be obtained by increasing detention time in the pond. Sedimentation removal rates are a function of the horizontal flow velocity which, in turn, is affected by the floor, or surface area of the pond. Rate of removal of sediment is entirely independent of the depth of the pond. Detention time of a particle and associated pollutants varies significantly over the course of a storm due to the transient nature of the inflow. The shortest detention times occur when the overflow discharge pipe is in operation, the longest detention times occur during the receding limb of the outflow hydrograph.

Retention times will vary even more drastically if the assumption of a well mixed pond is not valid; the actual performance of this basin was observed to depart from that of an ideal basin in several storms sampled, where short circuiting was clearly taking place. Short circuiting and resuspension of previously settled particulates make it difficult to determine an average settling time for a particle. The general effect of short-circuiting is to reduce the effective residence time of a large portion of the flow.

Retention times can be controlled by increasing the floor area or surface area, and by proper design of outlet structures; however, tradeoffs between retaining water for pollution control and providing empty storage for flood control should be identified before final design specifications are issued. Retention times of 24 to 36 hours are required for maximum potential settling of pollutants according to Kropp (1982). However, Oliver and Grigoropoulos (1981) reports detention times of 28 days for maximum removal. The retention times at the METRO detention pond are, on the average, approximately one to three hours, which are not nearly long enough to allow adequate settling. Short detention time is probably the most critical factor limiting pollutant removal efficiency.

First Flush

An understanding of the temporal concentration profile of pollutants occurring in stormwater is necessary before design of retention basins for water quality control can take place. As

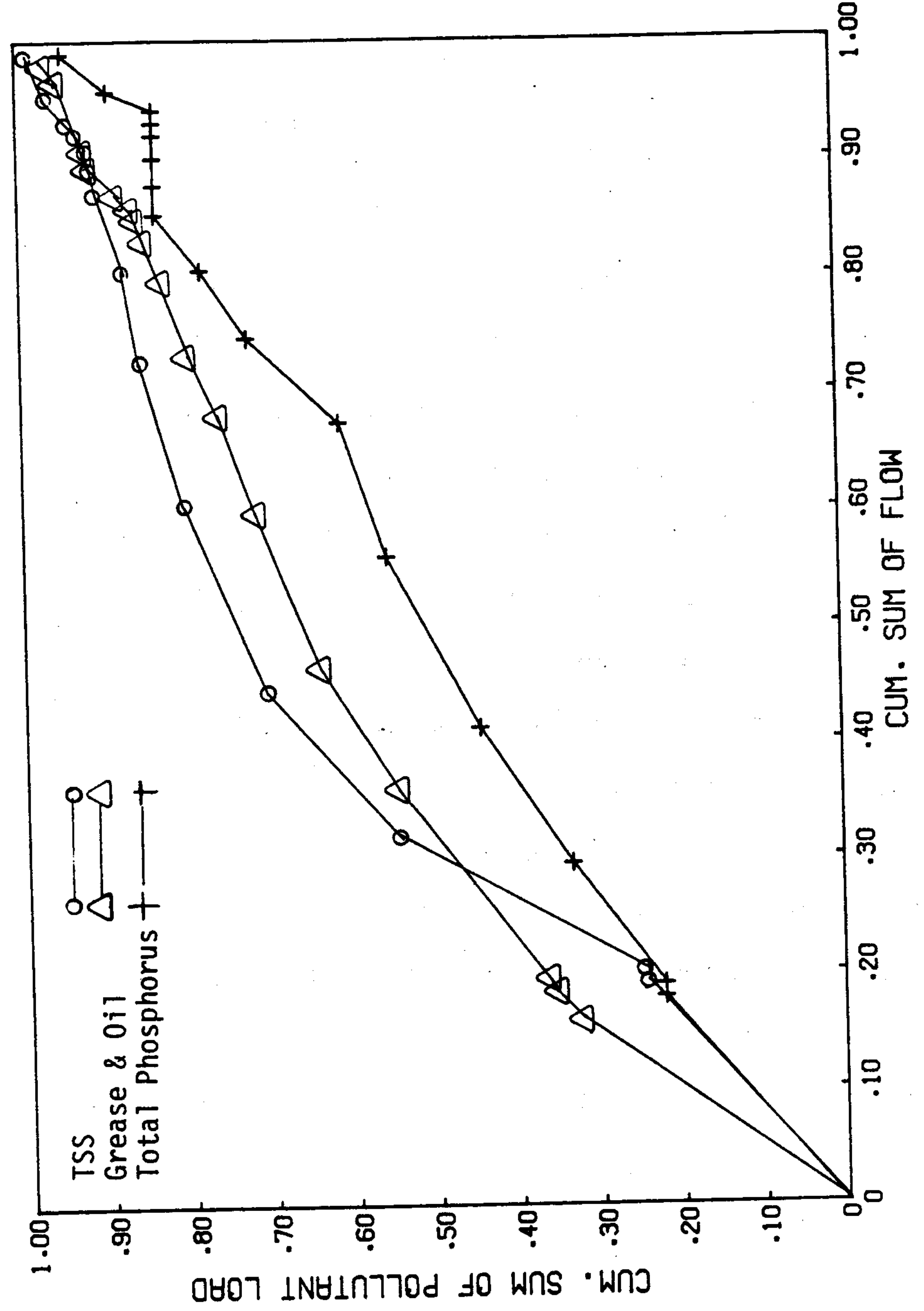


Figure 6.7 Double Mass Curve of Loading and Flow for TSS, Grease and Oil, and Total Phosphorus. METRO Site. Storm 7: October 6,1982.

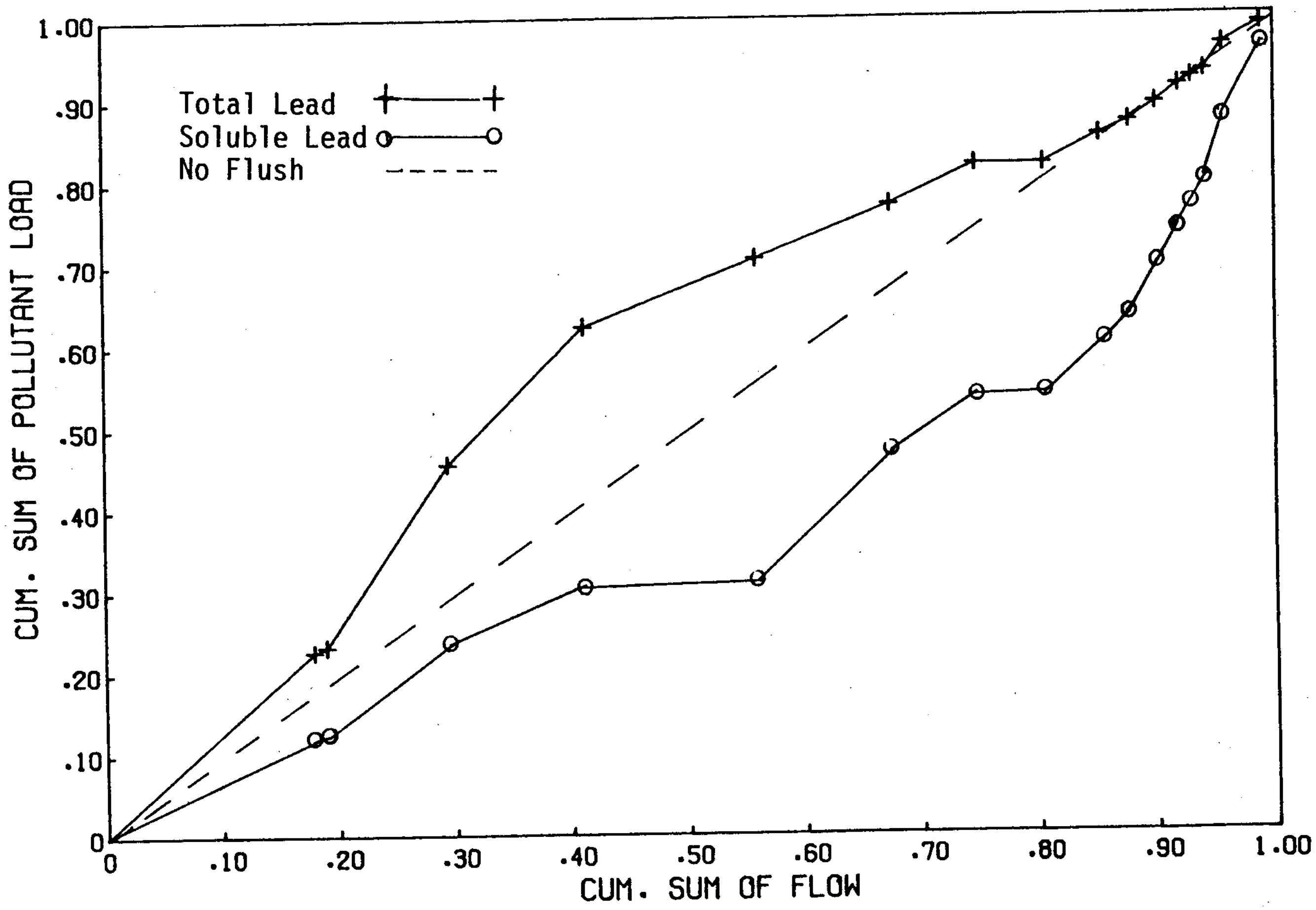


Figure 6.8 Double Mass Curve of Loading and Flow for Total and Dissolved Lead. METRO Site. Storm 7: October 6, 1982.

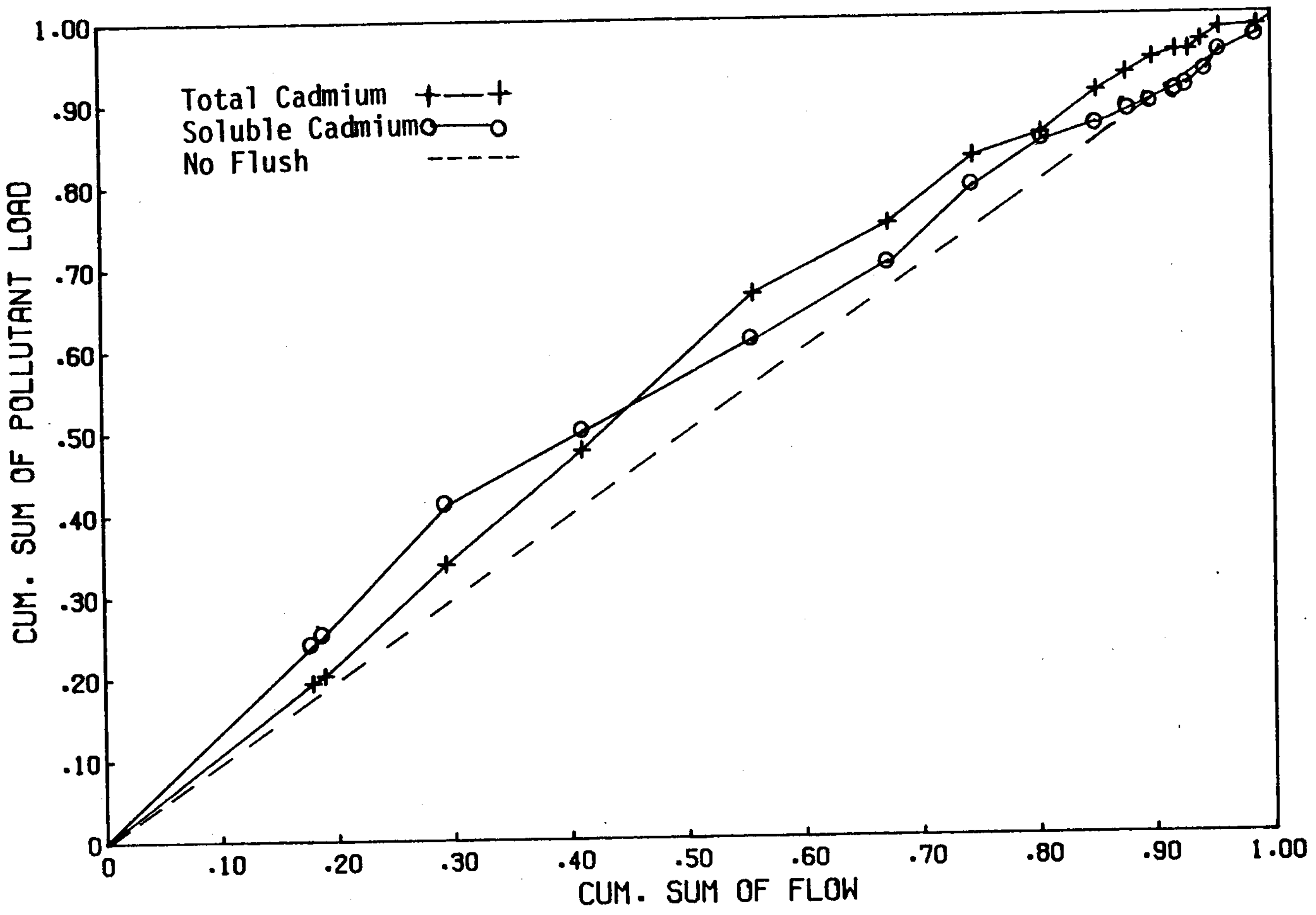


Figure 6.9 Double Mass Curve of Loading and Flow for Total and Dissolved Cadmium. METRO Site. Storm 7: October 6, 1982

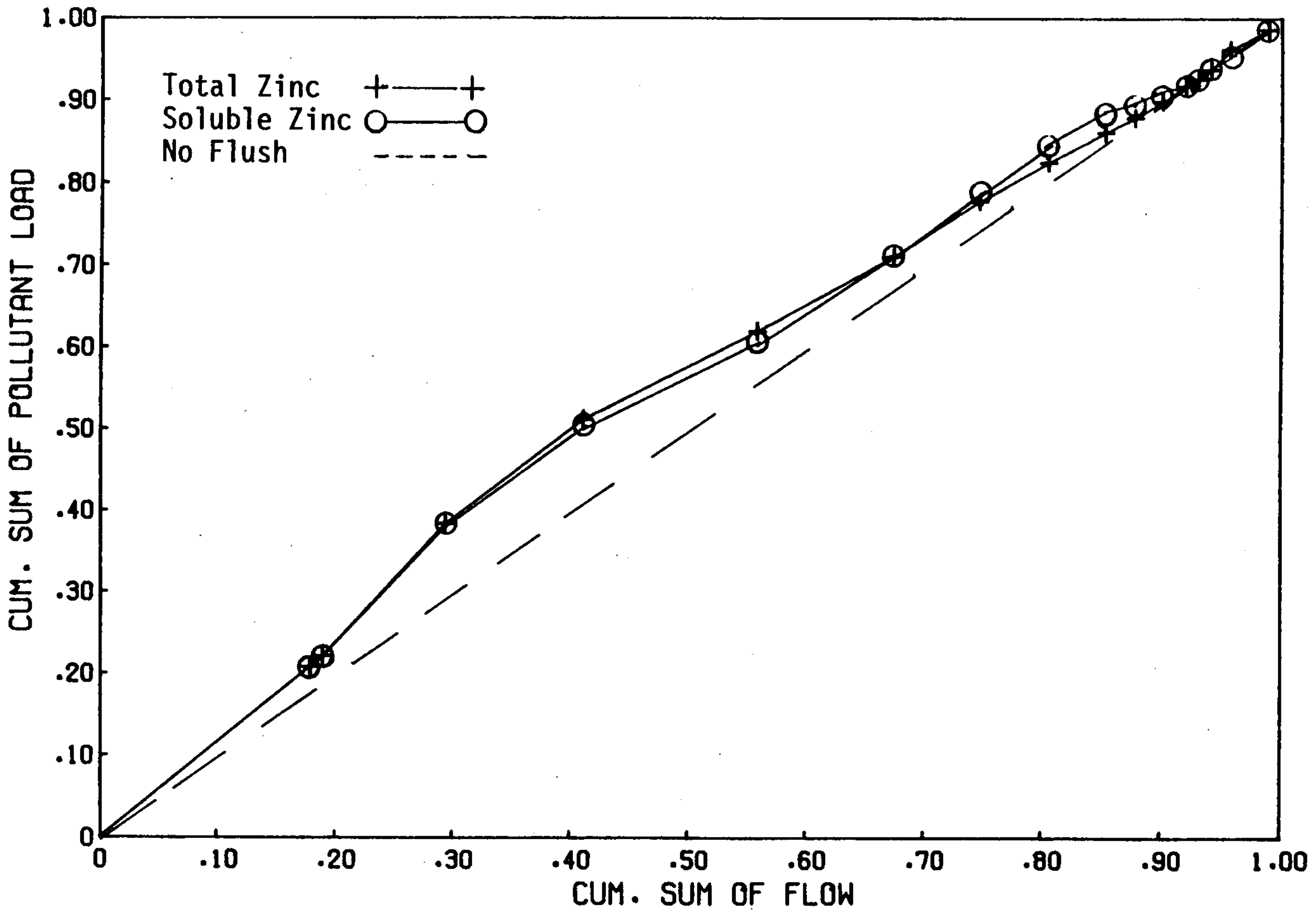


Figure 6.10 Double Mass Curve of Loading and Flow for Total and Dissolved Zinc. METRO Site. Sotrm 7: October 6, 1982.

discussed in Chapter Two, a first order decay process for pollutant washoff is often observed due to the first flush phenomenon. Figures 6.7 through 6.10 illustrate, using the double mass curve technique described in Chapter Two, the occurrence of first flush for a number of water quality parameters during storm event 7. The first flush effect is greatest for TSS, Grease and Oil, and total lead (Figure 6.7 and 6.8). The shape of the cumulative sum of the flow versus cumulative sum of the load curves are the same for total lead and TSS, indicating similar removal mechanisms for both pollutants. A comparison of double mass curves for total lead and soluble lead (Figure 6.8) indicates that first flush occurs only for total lead (which includes 80 percent particulate and 20 percent soluble lead). The removal mechanism for soluble lead appears to be almost the opposite of first flush removal, as a greater portion of soluble lead mass load is found to occur in the later discharge. In contrast, curves for total and soluble zinc and total and soluble cadmium show removal mechanisms that exhibit a slight first flush. Similar curves for total and soluble metals do not necessarily indicate similar removal mechanisms for particulate and soluble forms of the metals as it did for lead. In this case, 20 percent of the total zinc concentration was comprised of particulate zinc while 80 percent was comprised of soluble zinc, therefore one expects to see similar curves. Similarly, 50 percent of the total cadmium was of the ionic, soluble form. Total phosphorus did not exhibit a first flush characteristic removal.

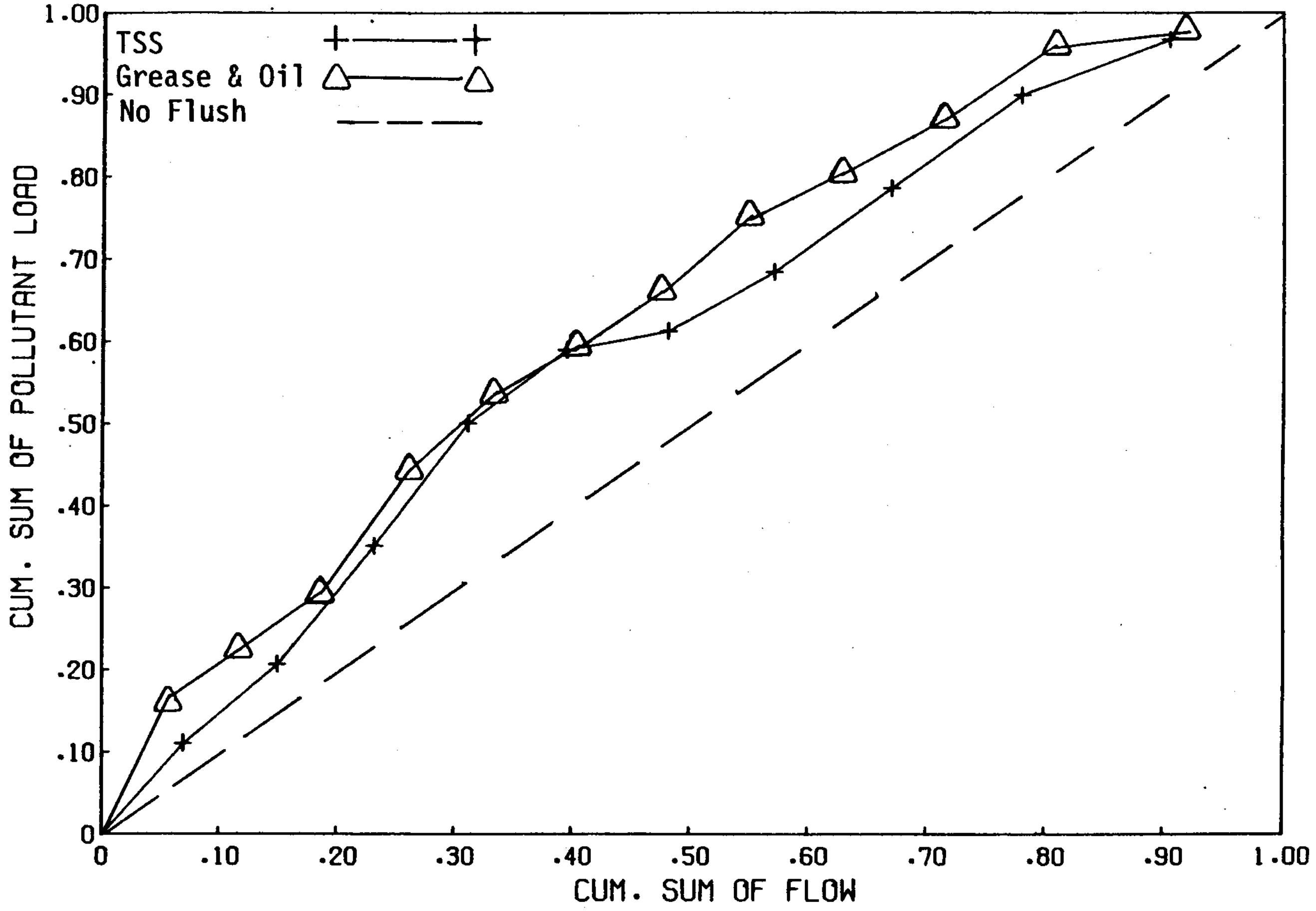


Figure 6.11 Double Mass Curve of Loading and Flow for TSS and Grease & Oil. METRO Site. Storm 2:August 5, 1982.

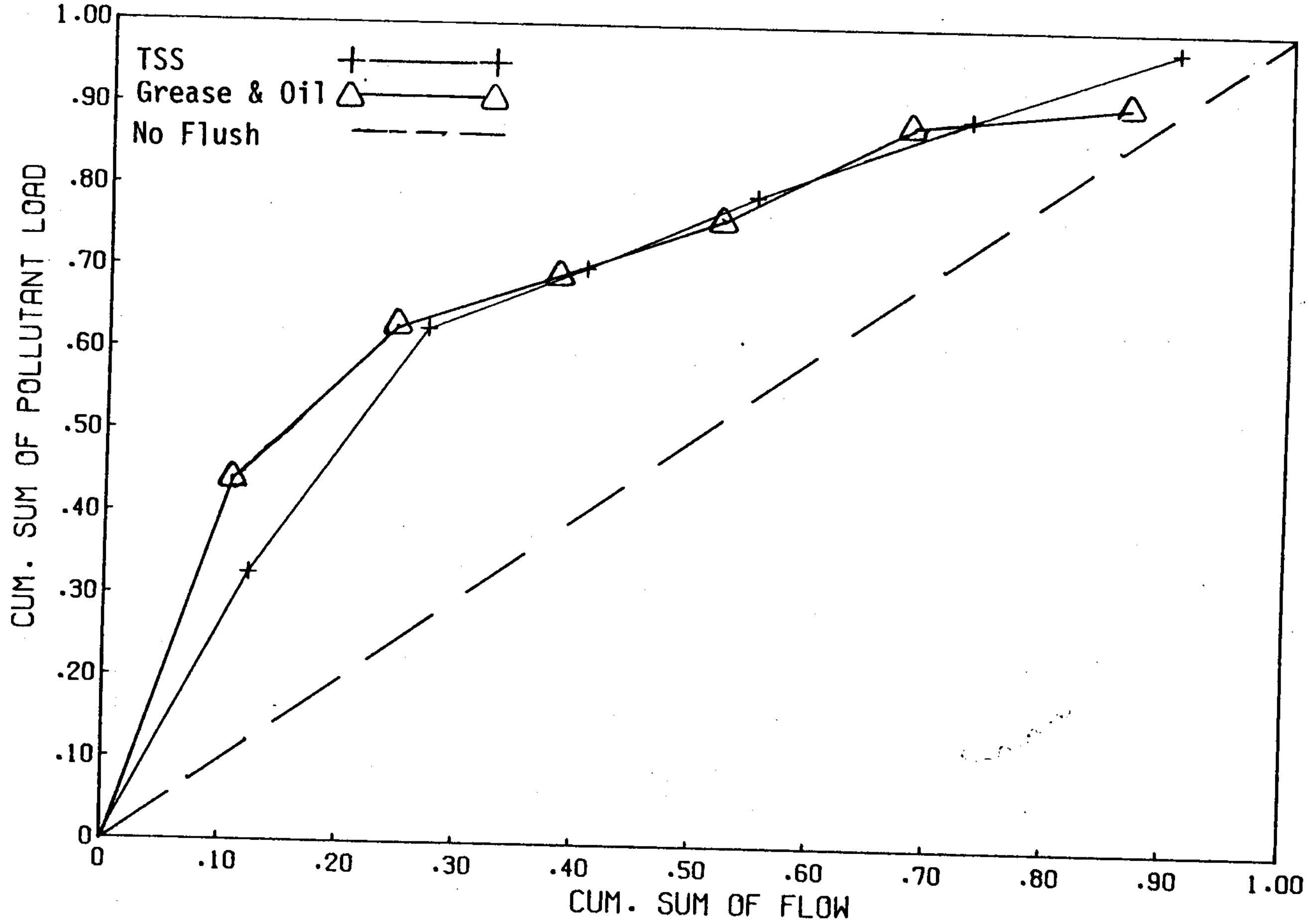


Figure 6.12 Double Mass Curve of Loading and Flow for TSS and Grease & Oil METRO Site. Storm 3: September 22, 1982.

Figures 6.11 and 6.12 illustrate the occurrence of first flush for TSS and grease and oil during storm events 2 and 3 (synthetic storm events). Both grease and oil and TSS exhibit similar removal mechanisms, and the magnitude of first flush is greater for both of these synthetic storms than for storm event 7 (a rainfall-generated storm event). Differences in the magnitude of first flush between synthetic storms and rainfall-based storm events may be due to the fact that pavement washoff is insignificant during simulated storms. Instead, pipe flushing is the main contributor to the first flush effect seen for synthetic storm events. Plots of inflow concentration versus time for each storm event (Figures 6.1 to 6.6b, d, f, h, j, i, l, p, and r) also indicate the magnitude of first flush, and support the representation of an exponential washoff curve for those pollutant parameters exhibiting first flush removal tendencies (Figures 6.1-6.6b,d,f, and l).

Predictor Variables

The length of the antecedent dry period (number of dry days preceding the storm event) which should be a major determinant of pollutant washoff potential, correlated poorly with average and maximum concentrations found in stormwater runoff from the transit base (Tables 6.5 and 6.6). Average concentration is represented as the total inflow pollutant load per total volume of storm runoff and is expressed in lbs/cubic ft. It is possible that the poor correlation is a result of the criterion used to define antecedent dry period. In this case, any event consisting of at least 0.02 inches of rain prior to the storm event monitored defined the extent of the dry period. An index of intensity of preceding storm events might help in determining actual antecedent dry period effects on stormwater runoff concentrations. Maximum rainfall intensity and traffic volumes also correlated poorly with maximum concentrations observed in the inflow (Table 6.5). These relationships were investigated to determine predictor variables for maximum pollutant concentration and loading. No significant relationships were found.

TABLE 6.5
Traffic Volume, Antecedent Dry Conditions, Rainfall Intensity and Maximum Concentrations in Stormwater Runoff at the METRO Site

Storm	Date	No. of Bus Trips	No. of Day/Hours Since Preceding Storm	Intensity (inches/hr)	TSS (mg/L)	G&O (mg/L)	TP (mg/L)	TCd (µg/L)	SCd (µg/L)	TPb (µg/L)	SPb (µg/L)	TZn (µg/L)	SZn (µg/L)
2	08/05/82	4	213.0	-	109.5	66.7	-	-	-	-	-	-	-
3	09/22/82	3	52.5	-	192.4	63.7	-	-	-	-	-	-	-
7	10/06/82	401	72.5	0.13	464.0	22.82	0.375	4.6	2.0	92	55	180	*273
8	10/16/82	9	188.5	0.18	139.0	18.0	0.145	1.4	1.3	83	50	199	166
9	01/19/83	360	7.0	0.20	59.2	29.1	0.270	1.3	1.2	82	0	209	174
11	02/06/83	11	169.5	0.02	13.6	16.5	0.830	3.8	2.1	168	39	193	182

* - soluble zinc was higher than total zinc in first inflow sample of storm #7.

TABLE 6.6

Traffic Volume, Antecedent Dry Conditions, and Average Concentrations in Stormwater Runoff at the METRO Site

Storm	Date	Total Volume Runoff $(\times 10^{-3})$ (ft^3)	No. of Bus Trips	Number of Dry Hours Preceding Storm Event	Average Concentration (lbs/ft^3) TSS $(\times 10^4)$	G&O $(\times 10^4)$	TP $(\times 10^6)$	TCd $(\times 10^{11})$	SCd $(\times 10^{11})$	TPb $(\times 10^9)$	SPb $(\times 10^{10})$	TZn $(\times 10^9)$	SZn $(\times 10^9)$ *
2	08/05/82	9.2	4	213	2.54	9.81	-	-	-	-	-	-	-
3	09/22/82	8.1	3	52.5	31.5	-	-	-	-	-	-	-	-
7	10/06/82	15.7	401	72.5	115.0	6.27	4.56	6.69	3.26	2.82	6.02	7.13	5.8
8	10/16/82	11.4	9	188.5	15.8	3.6	4.38	2.88	2.53	2.22	5.57	63.7	5.64
9	01/19/83	10.0	360	7.0	14.2	2.01	5.97	2.09	1.79	2.0	0	6.85	4.7
11	02/06/83	2.854	11	169.5	4.3	6.45	28.0	4.9	2.80	2.48	6.06	1.11	10.2

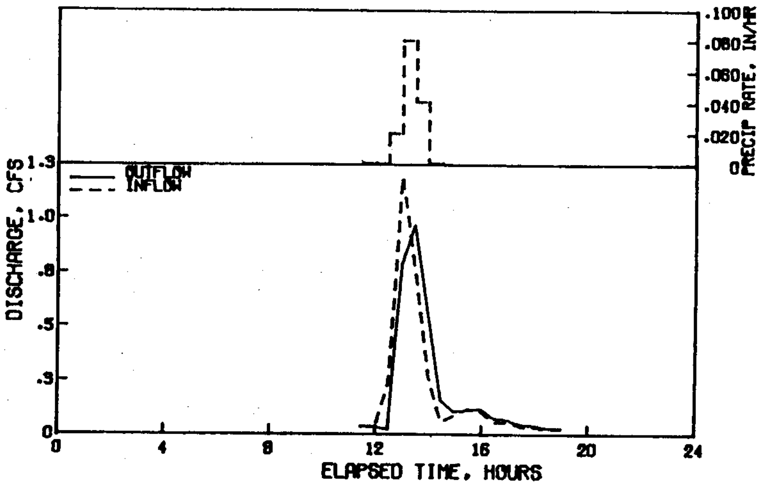
* Average Concentration is $5.8 * 10^{-9}$ lbs/ft^3 for soluble zinc

CHAPTER SEVEN

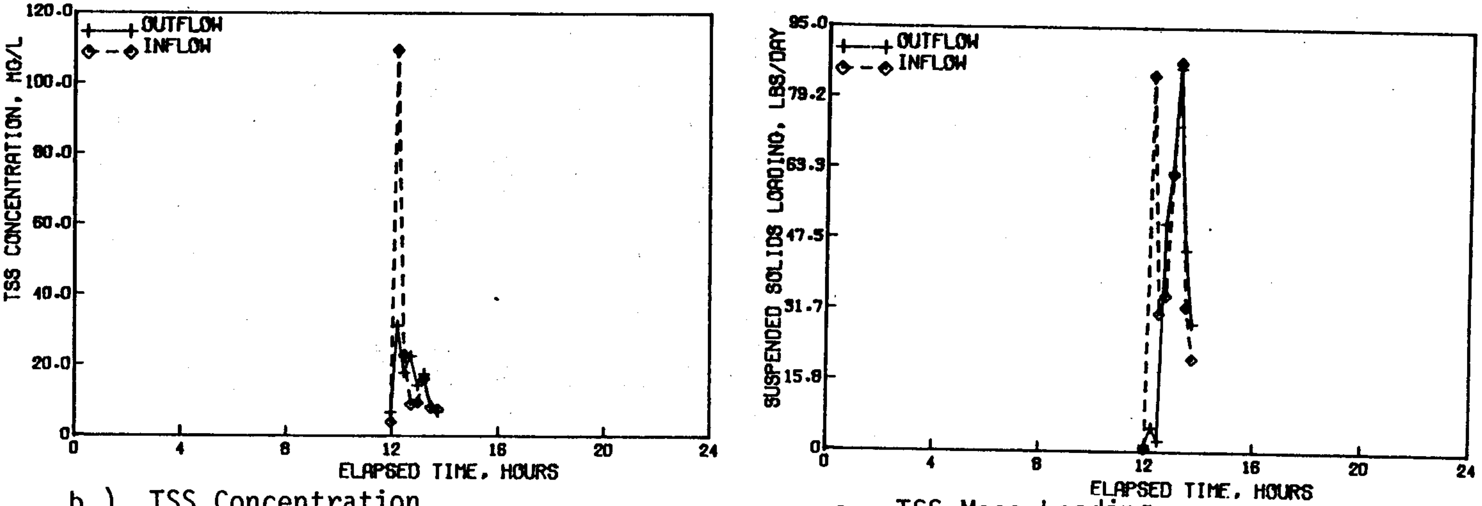
DISCUSSION OF RESULTS: WHISPERING HEIGHTS SITE

Storms were sampled at the Whispering Heights site between October, 1981 and February, 1982. Monitoring occurred one year prior to the onstart of the METRO stormwater sampling program. Samples were taken on a discrete basis, and unlike the METRO site, no supplemental composite sampling of storm events was performed. A sub-catchment sampling program was conducted in November 1982 to identify the source of sudden increases in sediment loading to the pond.

Precipitation, detention pond inflow and outflow hydrographs, concentrations and pollutant mass loadings are plotted for each of the storm events monitored at the Whispering Heights (WH) site in Figures 7.1 through 7.6. Flow rates and volumes, total suspended solids concentration, and loading data are also presented in tabular form in Appendix E. Comparison of the inflow and outflow hydrographs indicate the efficiency with which the pond reduces storm peak discharge entering the Vasa Creek drainage. Although the pond was designed specifically for attenuating flood peaks, the average reduction of flow by the detention facility is only 0.1 to 0.2 cfs (aproximately 5 to 10 percent). The peak outflow is displaced slightly in time from the peak inflow, as expected for any retaining structure. The hydrographs presented in Figures 7.1a to 7.6a suggest the extent to which the pond is underdesigned. Once the pond level reaches 42 inches, inflow is essentially equal to outflow through the



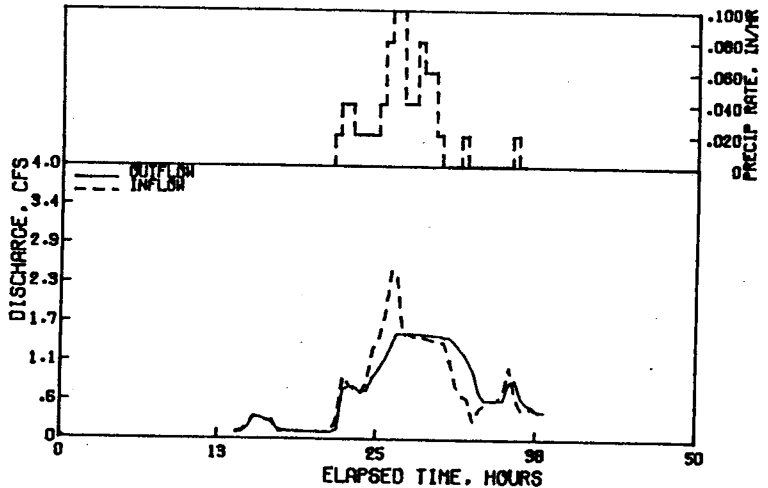
a.) Storm Hydrograph and Precipitation



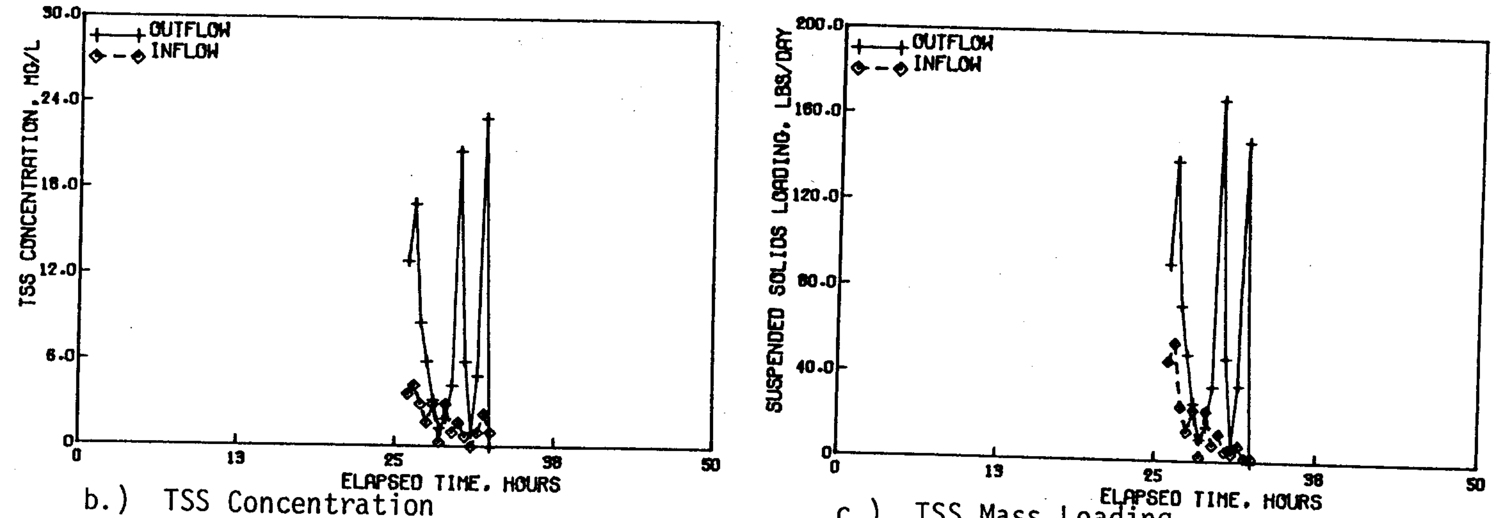
b.) TSS Concentration

c. TSS Mass Loading

Figure 7.1 Inflow and Outflow Hydrographs, TSS Concentration Graphs and Pollutographs. Storm 2. Whispering Heights. October 27, 1981.



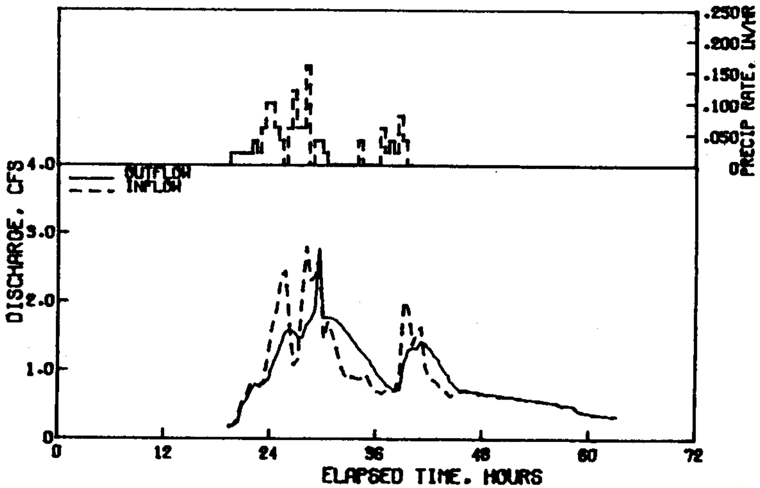
a.) Storm Hydrograph and Precipitation



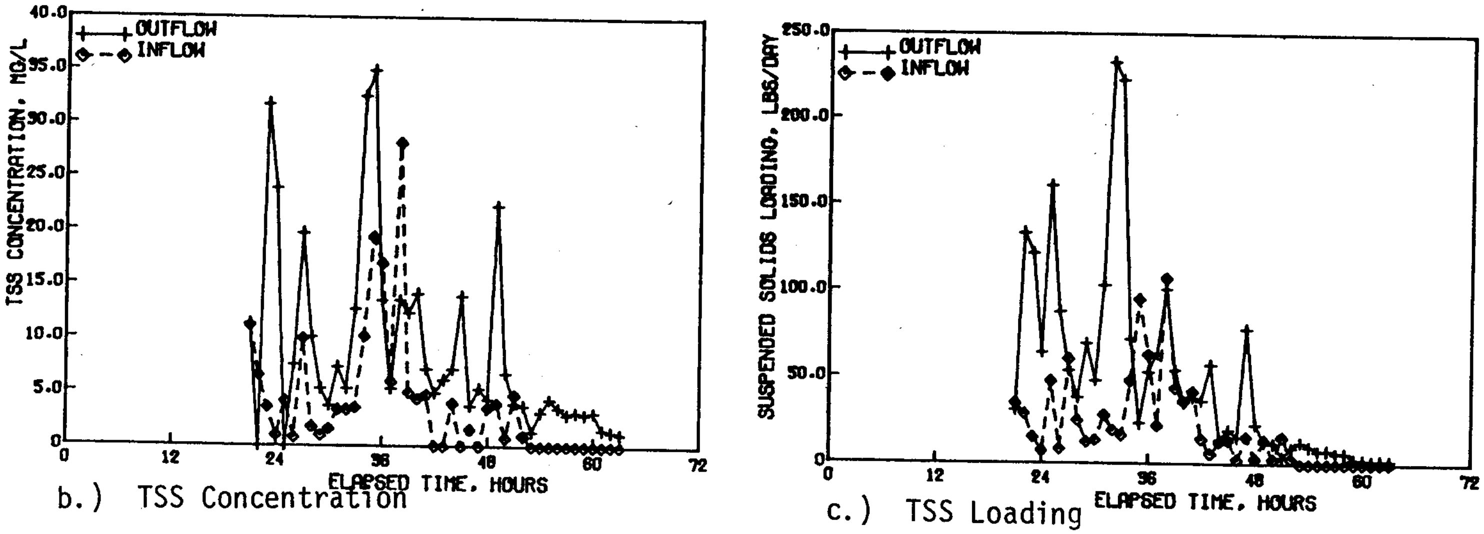
b.) TSS Concentration

c.) TSS Mass Loading

Figure 7.2 Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs. Storm 4. Whispering Heights. November 21, 1981.



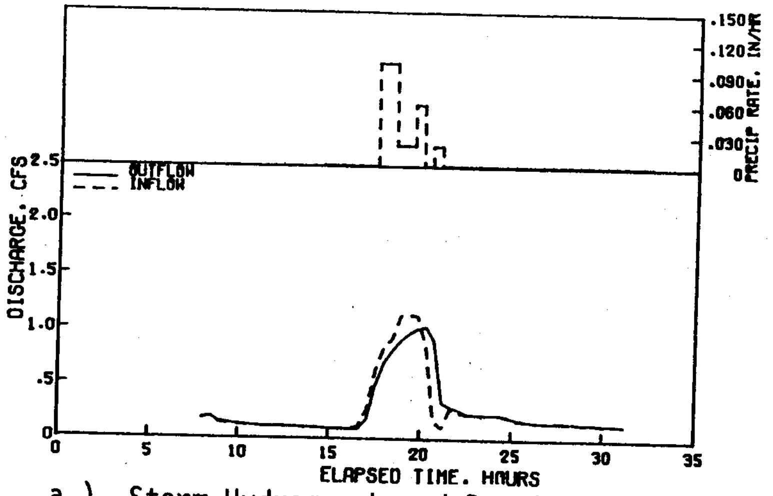
a.) Storm Hydrograph and Precipitation



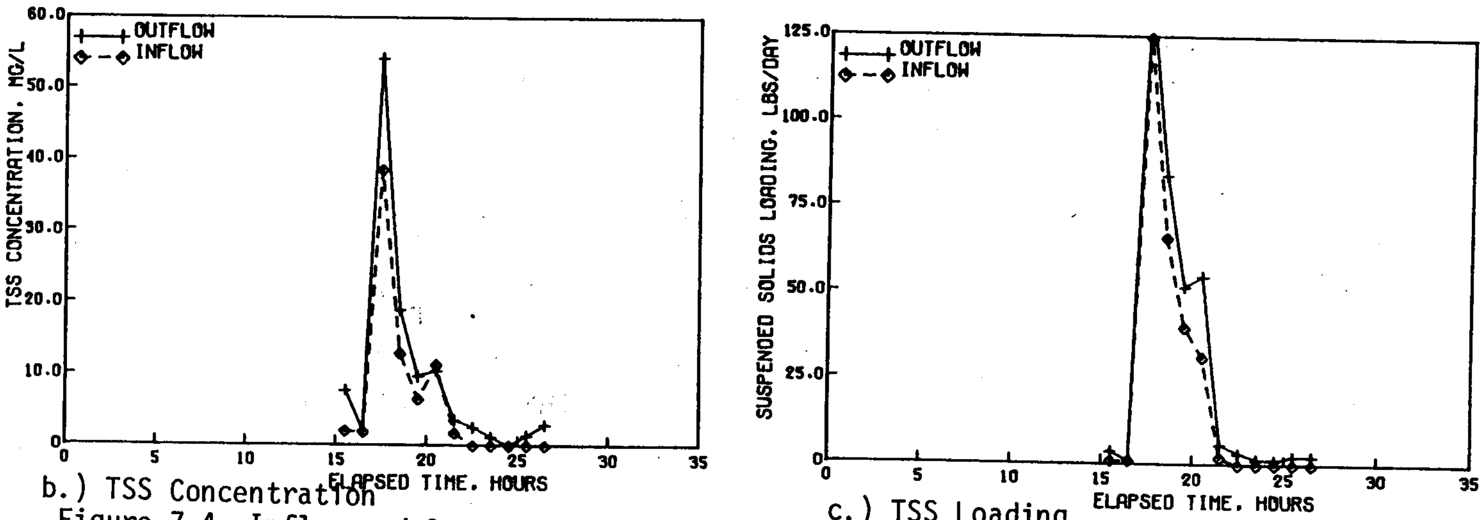
b.) TSS Concentration

c.) TSS Loading

Figure 7.3 Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs. Storm 5 Whispering Heights. December 18, 1981.



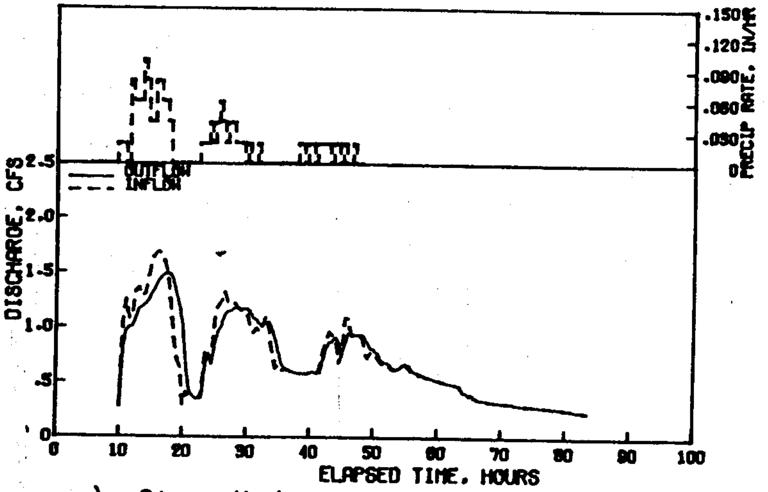
a.) Storm Hydrograph and Precipitation



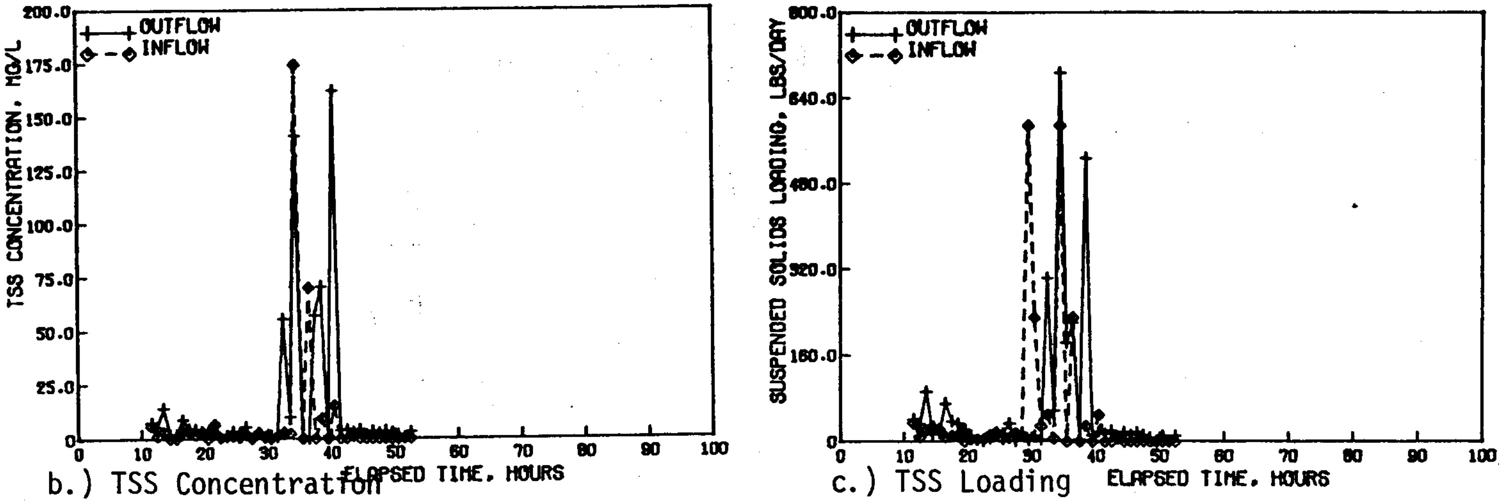
b.) TSS Concentration

c.) TSS Loading

Figure 7.4 Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs. Storm 7. Whispering Heights. January 29, 1982.



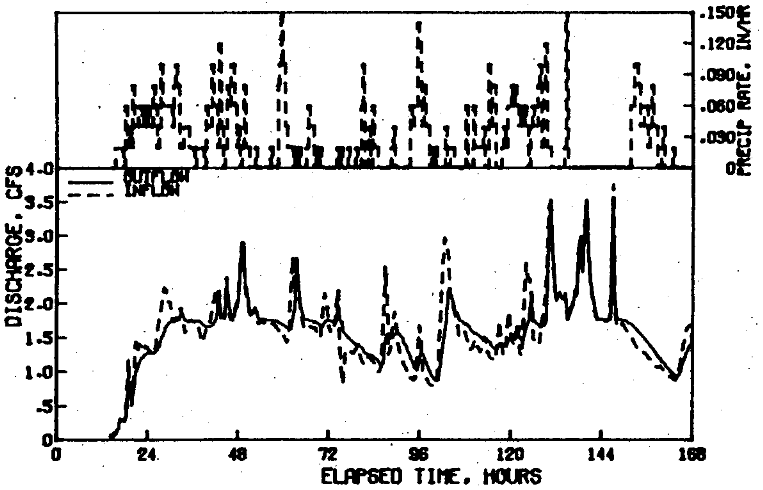
a.) Storm Hydrograph and Precipitation



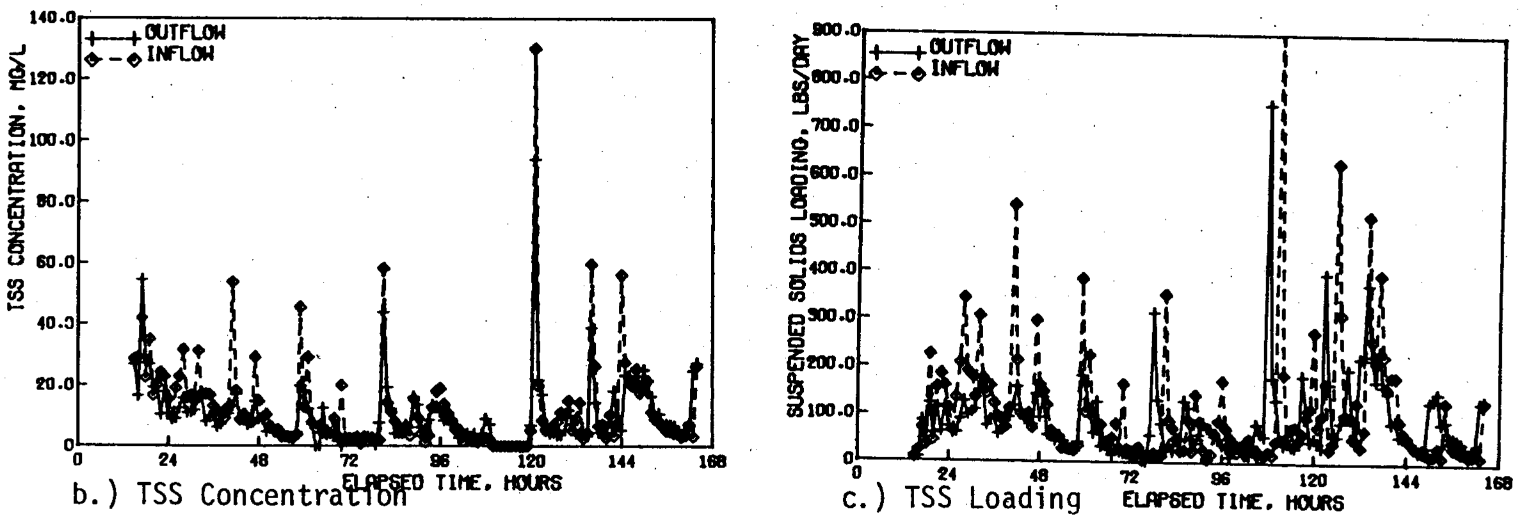
b.) TSS Concentration

c.) TSS Loading

Figure 7.5 Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs. Storm 8/9. Whispering Heights. January 31, 1982.



a.) Storm Hydrograph and Precipitation



b.) TSS Concentration

c.) TSS Loading

Figure 7.6 Inflow and Outflow Hydrographs, Concentration Graphs and Pollutographs. Storm 10/15. Whispering Heights. February 12, 1982 - February 18,1982.

spillway. The pond was originally designed to accomodate runoff from a single-family residential development. Since that time, additional subdivisions have been developed in the catchment, resulting in much greater volumes of stormwater runoff. The highest flow rates observed at the WH site occurred during the longest storm monitored, storm event 10/15 (February 1982), and were approximately 3.5 cfs (Figure 7.6a).

Total suspended solids (TSS) concentration data were collected at both inflow and outflow sampling locations for the duration of the storms monitored. Figures 7.1b through 7.6b present TSS concentration as a function of time. Quite often, TSS concentrations were higher in the outflow than in the incoming stormwater, indicating that particulate settling occurring in the pond was negligible, and that scouring of the sediment on the bottom of the pond was occurring. The design of the pond also accounts for the observation of greater pollutant loads in the outflow because the six inch outflow orifice is located at the bottom of the dam where much of the heavy sediment is trapped. Subsequently, turbulence near the orifice resuspends particulates which are then released from the pond and sampled in the outflow.

First Flush

Concentration graphs also illustrate the extent to which first flush occurs during each storm event. Inflow concentrations during storm events 2 and 7 exhibit a notable peak during the beginning of the storm and a subsequent decay (Figures 7.1b and 7.4b). These two storms were the shortest storms monitored, and were the result of one distinct event as compared to longer storms (events 4, 5, 8/9, and 10/15) which consisted of many sub-storms and short dry periods. These storms exhibited multiple peaks in the concentration graphs (Figures 7.2b, 7.3b, 7.5b, and 7.6b). The multiple peaks indicate that the first flush effect is not present, and because they seem to correlate well with the peak flows, suggest that pollutant concentration in stormwater is actually a function of the rainfall intensity and flow rate, and not a function of the time since storm initiation.

The first flush concentration patterns noted in storm events 2 and 7 may also be due to the characteristics of the events in question, which had a sudden initial peak flow followed by a gradual decline. As discussed in Chapter Two, the fact that pollutant concentration and mass flux rates remain approximately proportional to the flow rate for storms of low intensity suggests that some minimum flow may be required for complete flushing to occur. Storms 2 and 7 were of smaller magnitude and duration than the storms exhibiting multiple concentration peaks, and may not have been intense enough to initiate flushing.

To quantify the occurrence of first flush further, the double mass curve technique described in Chapter Two was used to relate the runoff pollutant load to the volume of runoff which has occurred at any point in the storm event. Figures 7.7 through 7.10 illustrate whether the first flush phenomenon is technically occurring during storm events 2, 5, 8/9, and 10/15, respectively. Storm event 2 (10/27/81) is the only storm analyzed that clearly exhibits first

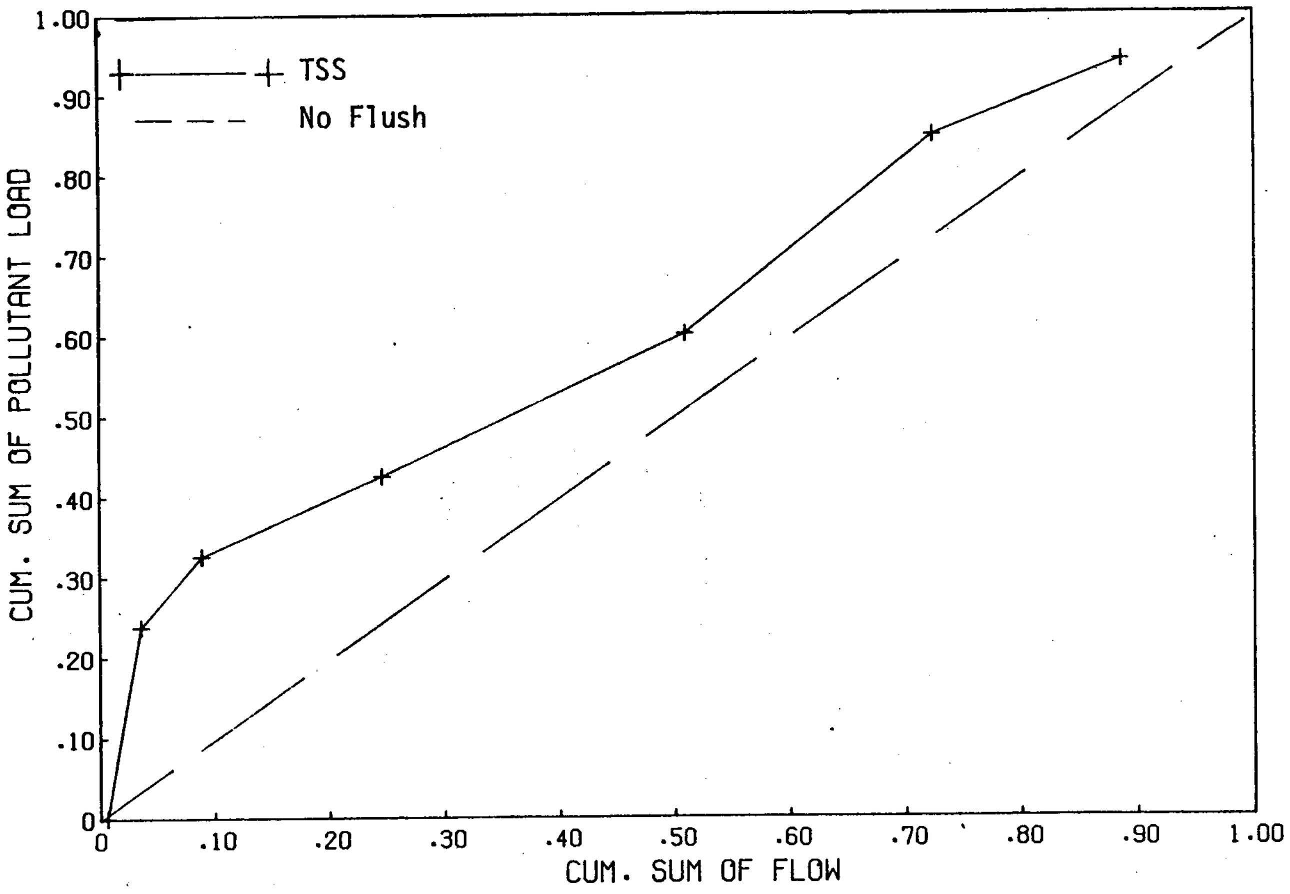


Figure 7.7 Double Mass Curve Indicating First Flush for TSS. Storm 2. Whispering Heights. October 27, 1981.

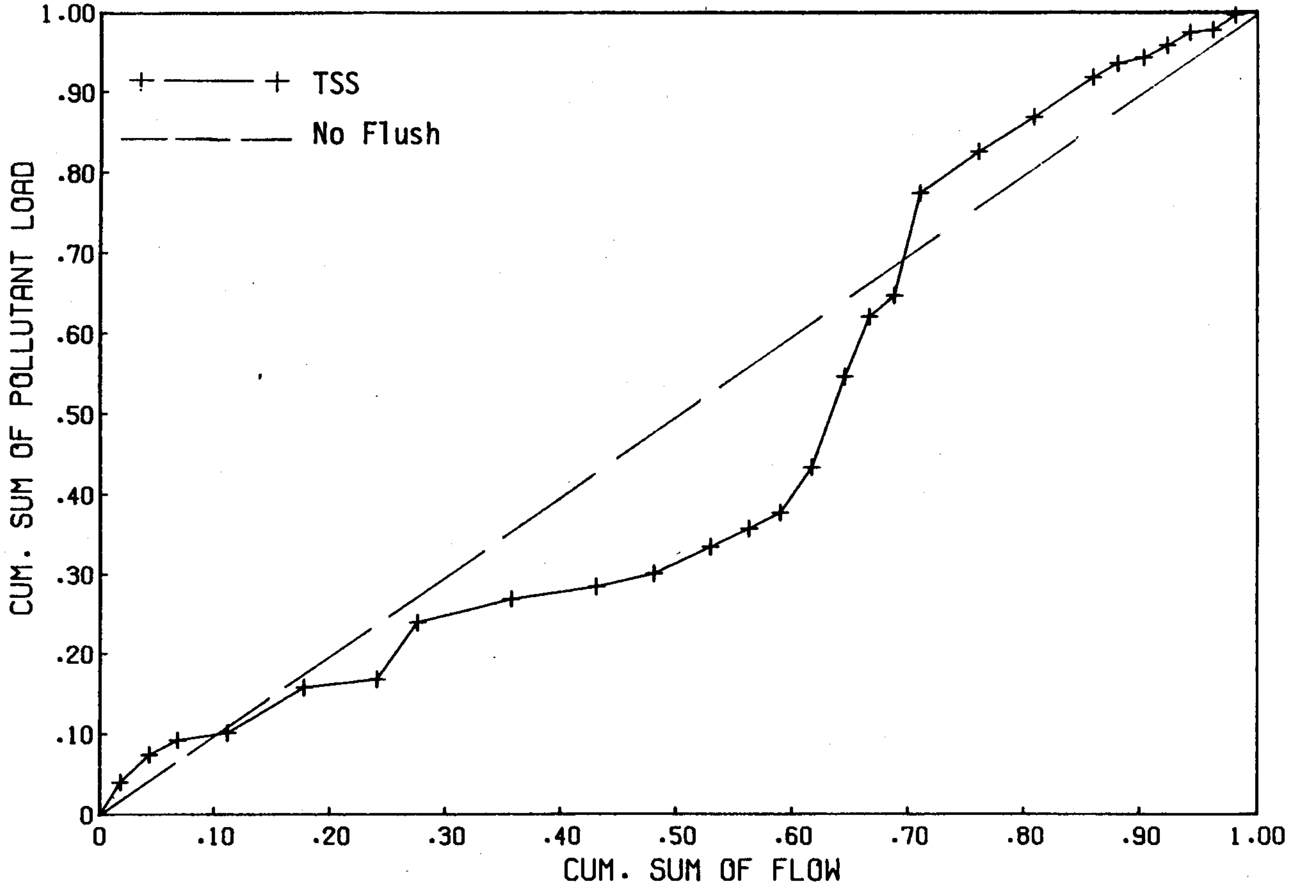


Figure 7.8 Double Mass Curve for TSS. Storm 5. Whispering Heights. January 29, 1982.

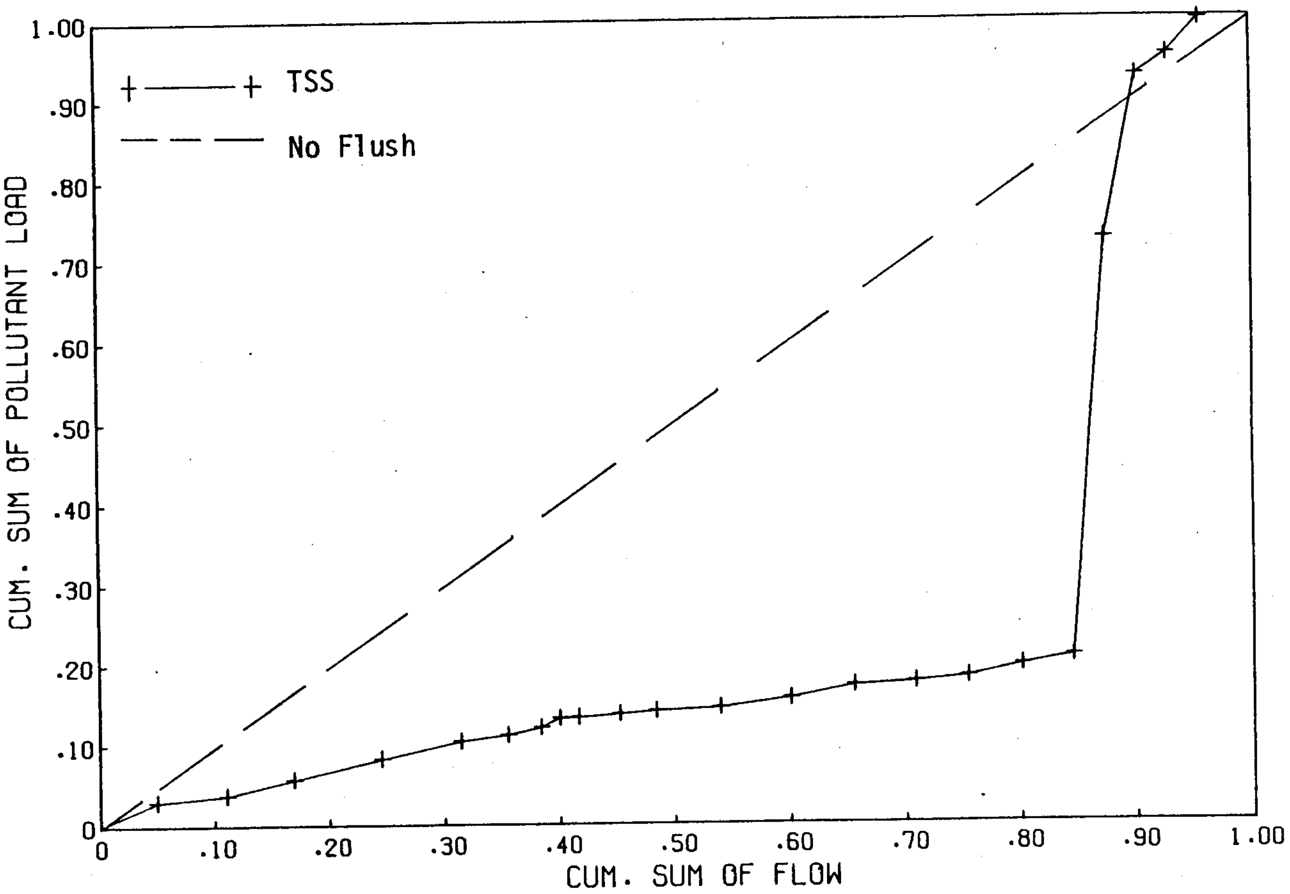


Figure 7.9 Double Mass Curve Indicating 'Last Flush' for TSS. Storm 8/9. Whispering Heights. January 31 to February 1, 1982.

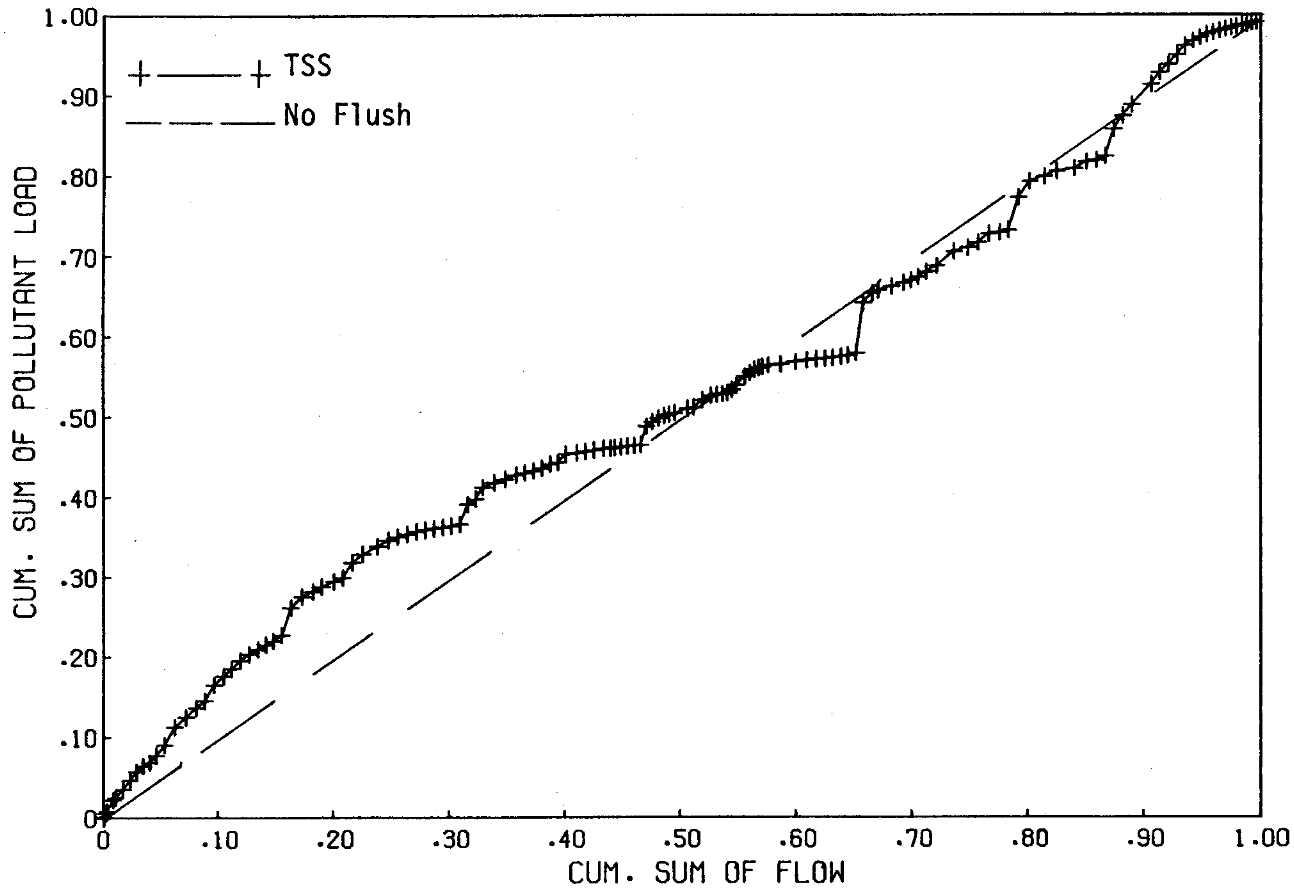


Figure 7.10 Double Mass Curve for TSS. Storm 10/15. Whispering Heights. February 12 to 18, 1982.

TABLE 7.1
Relationships Between Antecedent Dry Conditions, Rainfall Intensity and Maximum and Average TSS Concentrations in Stormwater Runoff at Whispering Heights

Storm	Date	Antecedent Dry Conditions*	Maximum Rainfall Intensity ("/hr)	Maximum Inflow TSS Conc. (mg/L)	Average TSS Conc. $(lbs/ft^3)(10^3)$
2	10/17/81	432	.08	109	0.60
4	11/21/81	6.5	.14	4.3	0.06
5	12/18/81	6.5	.12	28.2	0.25
7	01/29/82	9	.10	38.5	0.44
8/9	01/31/82- 02/01/82	32	.10	174.2	0.42
10/15	02/12/82- 02/18/82	19	.22	130	0.74

---

* Hours since last rain greater than 0.02 inches/hour

flush tendencies clearly (Figure 7.7). First flush in storm 2 may result from the long antecedent dry period (Table 7.1) and the short, continuous character of the associated precipitation. Double mass curves for storm events 5 and 10/15 (Figures 7.9 and 7.11) are quite similar to the case where no flush occurs. Figure 7.10 indicates a "last flush" effect for storm 8/9. The shape of this curve is due to the large concentrations of TSS observed in the later portion of the storm.

The multiple peaks in inflow TSS concentration occurring later in storm event 8/9 (Figure 7.5c) do not correlate well with peaks in rainfall intensity or inflow rate. It is possible that during a storm of this length, a soil moisture saturation threshold is reached, resulting in a much higher contribution of hillslope erosion to stormwater sediment loads. The WH catchment has steep slopes, and some construction activity was in progress at the time the storm was monitored. In an effort to identify possible causes of the multiple TSS concentration peaks found in stormwater throughout the course of the longer duration storms, a number of catch basins were sampled to determine whether areas could be identified that were the source of sudden increases in TSS concentrations monitored downstream at the retention pond.

Catch Basin Sampling

The results of the multi-catch basin sampling effort are presented in Table 7.2. Four catch basins located within the stormwater drainage system associated with the detention pond were sampled at approximately the same time (several minutes apart). This

TABLE 7.2
Results of Multi-Catch Basin Sampling Scheme: 11/17/82

Interval #	Time of Sampling	TSS Concentration (mg/L) in Catch Basin #1	#2	#3	#4
1	12:27 - 12:36 AM	97.4	7.4	6.2	12.0
2	12:42 - 12:47 AM	4.8	6.0	5.0	5.8
3	12:53 - 12:59 AM	5.6	6.0	5.0	3.6
4	1:15 - 1:21 AM	5.0	7.4	7.4	0.4
5	1:25 - 1:32 AM	5.8	11.6	3.2	9.8
6	1:35 - 1:42 AM	2.8	8.6	2.4	7.2

procedure was followed six times, at intervals of 15 minutes during the storm of November 17,1982. Rainfall had occured for six to seven hours preceding the time of sampling. Results show that apart from the first sample taken at catch basin 1, all TSS concentrations found in stormwater at various locations in the catchment were of similar magnitude. A concentration of 97 mg/l was found in the first sample taken in catchbasin 1. This catch basin is located in a steep portion of the catchment where some construction was taking place during previous storms, and it was during this first sampling interval that the most intense rainfall occurred. Although it cannot be proven that this sub-catchment is the sole source of multiple peaks in particulate concentration, the data suggest that the high sediment loads may have been related to construction activity.

Pollutant Removal Efficiency

The shape of the hydrograph greatly influences the shape of the pollutograph. Graphs of pollutant loading versus time (pollutographs) are presented for total suspended solids for all storms monitored at the Whispering Heights site (Figures 7.1c to 7.6c). The magnitude of pollutant loading at any instant is obtained by multiplying the instantaneous flow by the measured pollutant concentration for the time interval of interest. The total mass of a pollutant entering and leaving the pond is represented by the area under the pollutograph, obtained by integrating the pollutant load over the storm duration.

The mass of TSS leaving the pond is greater than that entering the pond for storm events 4, 5, 7, and 8/9 because outflow concentrations were higher than inflow concentrations due to scouring (Figures 7.2c to 7.5c). The ratio of the total mass of a pollutant leaving the detention pond to the mass of pollutant entering the pond indicates the percent removal or pond efficiency for total suspended solids. The total mass of TSS in stormwater entering and leaving the pond, and the efficiency of the Whispering Heights facility in reducing the pollutant mass is compared for each storm in Table 7.3. The total runoff volume is also reported. The negative removal efficiencies observed have been reported for other studies involving dry basins designed for short-term flood control detention (USEPA, 1982). Scouring in dry detention basins is a common problem. One of the first storms of the season (storm event 2) exhibited positive removal efficiency, probably due to the fact that previous storms had not occurred that would deposit sediments for future scouring, and because grass grows up higher than the sediment in the early fall which prevents scouring.

Predictor Variables

The length of the antecedent dry period (number of dry hours preceding the storm event) which should be a major determinant of pollutant washoff potential, correlated poorly with average and maximum concentrations found in stormwater runoff from the Whispering Heights catchment (Table 7.1). Storm event 2 (10/27/81) was the only storm that exhibited fairly high peak and average concentrations and also had a long antecedent dry period. This was also the only storm that exhibited a first flush removal mechanism. The criterion used to define the end of an antecedent dry period was any event consis-

TABLE 7.3
Whispering Heights Detention Pond Pollutant Removal

Storm	Date	Total TSS Load In (lbs)	Total TSS Load Out (lbs)	Efficiency[a] (Percent)	Total Runoff Volume (ft^3x10^{-3})
2	10/27/81	3.58	2.79	+ 22%	5.94
4	11/21/82	4.39	15.31	- 249%	11.62
5	12/18/81	37.77	96.87	- 156%	68.04
7	01/29/82	11.02	14.36	- 30%	24.77
8/9	01/31/82- 02/1/82	76.63	145.30	- 90%	183.50
10/15	02/12/82- 02/18/82	661.1	539.7	+ 18%	889.66

[a] efficiency = $\left[1 - \frac{\text{Output Load}}{\text{Input Load}}\right] \times 100$

ting of at least 0.02 inches of rain prior to the storm event monitored. The volume of precipitation used to define the antecedent dry condition will have some effect on the relationship between TSS concentration in stormwater and antecedent dry conditions.

Maximum rainfall intensity showed no apparent relationship to average and maximum concentrations observed in the inflow (Table 7.1) with the exception of storm event 10/15 which exhibited the highest precipitation intensities and the highest average TSS concentration in the inflow. The average TSS concentration is assumed to be the total inflow pollutant load per total volume of storm runoff, and is expressed in lbs/cubic foot.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate the extent to which each of the detention ponds analyzed reduces peak flows and the mass of pollutants entering the associated receiving water. Concentration and loading data indicate the severity of sediment and related pollutant mass loading at each site. Grease and oil, soluble zinc, soluble cadmium and total phosphorus are discharged from the METRO site at concentrations that could be harmful to the biota in Kelsey Creek. However, a better understanding of the effects of urban pollutant concentrations on receiving waters and associated biota is needed to assess these urban runoff related impacts properly. Total suspended solids appears to be the only stormwater pollutant present in concentrations that warrant monitoring at the Whispering Heights site. Suspended solids are detrimental to channel stability and erosion at the WH site but are not a concern in terms of toxicity as are the pollutants present at the METRO site.

In addition, this study provides an understanding of the stormwater pollutant generating process, which will help to determine dual purpose detention basin design criteria. The conclusions drawn from this study are summarized below.

A. Conclusions

1. METRO Site

a. First flush effects are quite apparent for total suspended solids, grease and oil and lead. First flush does not occur for total phosphorus, zinc or cadmium. Generally, particulate pollutants show the most characteristic first flush removal patterns. Soluble metals and total phosphorus do not exhibit an exponential wash-off decay.

b. Particulate pollutant removal efficiencies were greatest during storms which exhibited the most distinct first flush characteristics. Removal efficiencies were largest for specific pollutants which had the greatest tendency towards first flush removal (lead, grease and oil, and total suspended solids). There is some indication that these pollutants may actually be settling out in the pond at a relatively high removal rate; low removal efficiencies could be due to resuspension of particulates which have settled during previous storms.

c. Pond dynamics tend to be such that metals entering in particulate or exchangeable form are undergoing a transformation into a more soluble form. The corresponding percentage of total metals in the pond outflow is less than that in the inflow, while the percentage of soluble metals in the outflow is much greater than that in the inflow. This dissolution process is most significant for cadmium, and next, for lead. The percent of soluble zinc does not appear to increase in the pond. This is because the majority of the zinc entering the pond is already in the soluble phase. (It should be noted that the soluble phase includes metals associated with particles less than 1.2 microns in size). A current study of trace organics present in stormwater at the METRO site may provide further explanation of the chemical processes occurring within the pond and the mechanisms responsible for the apparent increase in soluble metals discharged to the West Tributary of Kelsey Creek.

d. Comparison of synthetic storm event runoff concentrations and loadings with those of true storm events indicate the relative contribution of pipe flushing to total stormwater runoff pollution. Runoff from synthetic storm events exhibited higher concentrations of total suspended solids and grease and oil (analysis for heavy metal concentrations was not performed for synthetic events) suggesting that during high intensity storms, pipe flushing may be the major source of urban runoff pollution. During smaller storm events, pavement wash-off contributes a more significant portion of runoff pollution. A current composite sampling program indicates that lead concentrations also increase significantly (approximately ten fold) when pipe flow is great enough to induce pipe flushing of pollutants.

e. No direct relationships were found between average or maximum pollutant concentrations and traffic volume or antecedent (dry days preceding a storm) conditions.

f. Stormwater concentrations of the metals analyzed exceeded both chronic and acute federal water quality criteria for ambient receiving waters. However, concentrations of these pollutants in Kelsey Creek are expected to be lower than in un-diluted stormwater. A dual purpose retention basin which provides pollutant control as well as peak flow reduction is necessary at this site to reduce impacts from particulate pollutant loading during storm events.

g. High concentrations of grease and oil, total and soluble cadmium, lead and zinc, total phosphorus and total suspended solids have been found in baseline (dry weather) discharge from the METRO pond. Annual loadings of pollutants in dry period discharge are significant, and could be as high as the cumulative pollutant loadings from all storm events within the year.

h. High intensity precipitation (as simulated by the synthetic storm events) can cause overflow of the oil/water separation system resulting in discharge of high concentrations of grease and oil which have accumulated over past small storms. An oil/water separator capable of storing larger volumes of runoff or a better bypass system is required.

i. Hydrographs for storms occurring at the METRO catchment are not smooth and exhibit a very flashy response due to the small and impervious nature of the catchment.

2. Whispering Heights Site

a. Small storms exhibit a smooth hydrograph and pollutograph. Multiple peaks in concentration and loading did not occur during small storm events. First flush removal patterns were only apparent for one small storm which occurred early in the season, and had a long antecedent dry period.

b. Long storm events sampled at the Whispering Heights site exhibited sporadic peaks in the pollutographs and concentration graphs. A subcatchment sampling program appeared to support the hypothesis that construction activities were responsible for the high concentrations of total suspended solids observed towards the end of longer storms.

c. Negative pollutant removal efficiencies result from of resuspension of sediment which is caught in the tall grass growing in the pond and near the discharge orifice. The first storm of the sampling season exhibited positive sediment removal efficiencies. This is probably because little or no sediment was available for scouring. Particulates which were removed during this early storm were probably resuspended later in the season. A wet detention pond would help to alleviate this problem.

d. Preliminary analysis of stormwater for heavy metals, grease and oil, total phosphorus and chemical oxygen demand indicated that they were either present in very low concentrations or in concentrations below detection. Suspended solids are detrimental in terms of channel stabalization and erosion, rather than toxicity as was the case at the METRO site.

e. The "last flush" effect which is characterized by large pollutant loadings occurring late in the storm, may be a result of soil saturation and resulting sediment generation. This phenomenon was observed for one storm only.

B. Recommendations

Current practice for analysis of detention basin water quality performance involves the use of predictive models to estimate pollutant loadings from stormwater runoff, and prescribed efficiencies of detention facilities in removing particulate pollutants. However, the quantity of a pollutant flushed from a catchment during a storm event and the resulting impacts upon the biota of the receiving water are quite site specific. Contrasting conditions between basins introduce a data variety which exceeds the scope of a general model. Determination of the potential impacts of urban runoff pollution requires some type of field data collection effort. Obviously, a study of this magnitude is not an economically feasible method for determining design criteria for every retention facility required by public law. However, some stormwater analysis should be performed, at least on a regional basis, to determine whether there is a need for pollutant reduction and under what conditions. Stormwater quality should determine the criteria for design. A dual purpose detention facility for peak flow reduction and water quality control should be required only when sediment loading and/or pollutant toxicity is a potential problem.

Retention facilities designed for flood control differ from those designed for efficient removal of particulates and associated pollutants. Flood damages occur from infrequent large storm events (e.g. 10-100 year frequency), whereas most of the runoff pollutant load in receiving waters occurs from more frequent small storm events. The disproportionately high concentration of pollutants from small storm events can be attributed to the first flush phenomenon. Water quality design criteria require that discharge from a small frequency event (defined as a settleability design storm) be retained for 24-36 hours. In contrast, flood control design requires storage for large volumes of runoff which can be released soon after the inflow rate falls below some predetermined limit.

Dual purpose stormwater management can be achieved by providing a small retention outlet at the bottom of the detention basin, designed for slow release of runoff from relatively small storms. Main outlet structures (typically a rectangular spillway) for flood control should be located at a higher elevation. The retention outlet should not be placed so close to the bottom of the pond that sediment that has settled near the outlet is resuspended by the higher velocity flow. In addition, a wet pond is preferable to a dry pond because scouring of sediments on the bottom of the pond is avoided. However, in industrial areas, a wet basin may actually promote dissolution of heavy metals which increases toxicity impacts in the receiving waters.

Detention storage should reduce the post development maximum flow for a specified storm frequency event to be less than the pre-development maximum flow from the same storm. At the same time, the runoff should be retained for at least 24-36 hours for partial removal of hydrocarbons, lead and total suspended solids. Detention basins designed to control peak flow for a variety of storm events (2, 10, and 100 year events) require more storage, but are more effective at reducing flood peaks both at the site and downstream. The larger volume ponds also provide longer detention times for particulate settling. When larger storms pass through the detention basin through flood control outlets, the same volume of runoff will be retained for particulate settling, however, it would not include the first flush.

Oil and grease removal systems are essential for detention ponds which service industrial or commercial land uses. Separator systems should be designed to hold runoff volumes equivalent to those produced by larger frequency storm events. In addition, if separator systems are used, separator maintenance should be performed on a regular basis, preferably between each major storm event, to avoid large loadings associated with overflow. If oil and grease separators are properly designed for the runoff volumes which they treat, the dual baffle system which removes floatables is effective. In situations where very high concentrations of grease and oil are being discharged, an expensive alternative, a coalescing plate separator (originally used in industrial pretreatment) can be used to coalesce small oil and grease droplets, at least 7 microns in size, into larger droplets greater than 20 microns in size which will float more readily. These larger floatables are more easily removed. Alternative grease and oil removal processes should be explored before requiring a specific type of removal system. It is possible that coating of the sides of the pond and flume, and subsequent weathering and oxidation will provide a low cost method of removal.

After detailed analysis of data from this field study of two detention ponds in the Bellevue, King County area, it is recommended that the retention pond at the METRO site be redesigned to promote more efficient settling of pollutants and removal of grease and oil. This will entail providing a larger storage volume for runoff and a small retention outlet for slow release of small storms which contain high concentrations of pollutants. A larger capacity oil and grease separator should be installed in the outflow pipe or an alternative method of grease and oil removal should be employed. High concentrations of grease and oil (60 mg/l) and observed overflow of an existing separator indicate a possible need for an industrial coalescing plate separator. In contrast, the pollutant concentrations in stormwater at the Whispering Heights residential site are not significant. The pond is underdesigned from a flood peak reduction standpoint due to additional residential development which occurred after the pond was constructed. A larger storage volume and smaller diameter orifice would be beneficial in terms of particulate settleability; however, the pollutant loadings from this site are not large enough to justify large scale redesign on the basis of water quality. Channel protection is a much larger issue at the Whispering Heights site.

Incorporation of dual purpose detention basins into stormwater management planning provides an opportunity for controlling non-point source pollution. However, detention requirements should be flexible enough to avoid unnecessary design for water quality control where water quality is not an issue. In addition, maintenance responsibility should be designated within legislation to assure that settled particulates and associated pollutants are disposed of properly. If these facilities are not maintained, they will not function properly.

REFERENCES

Amandes, C.B. and P.B. Bedient, Stormwater detention in developing watersheds, Journal Environmental Engineering Division, ASCE, 106(EE2), Proc. paper 15335, 403-410, 1980.

American Public Health Assoc., Standard Methods for the Examination of Water and Wastewater, 15th ed., Washington, D.C., 1980.

Bedient, P.B., D.A. Harned and W.G. Characklis, Stormwater analysis and prediction in Houston, Journal of the Environmental Engineering Division, ASCE, 104(EE6), Proc. paper 14237, 1087-1100, 1978.

Bedient, P.B., J.C. Lambert and N.K. Springer, Stormwater pollutant load-runoff relationships, Journal of Water Pollution Control Federation, 52(9), 2396-2404, 1980.

Bondurant, J.A. et al., Some aspects of sedimentation pond design, paper presented at the International Symposium on Urban Hydrology and Sediment Control, Univ. of Kentucky, Lexington, KY, 1975.

Camp, T.R., Sedimentation and the design of settling tanks, Transactions, ASCE, 71(2285), 445-486, 1945.

Chen, C., Design of sediment retention basins, paper presented at the International Symposium on Urban Hydrology and Sediment Control, Univ. of Kentucky, Lexington, KY, 1974.

Curtis, D.C. and R.H. McCuen, Design efficiency of stormwater detention basins, Journal of the Water Resources Planning and Management Division, ASCE, 103(WR1), Proc. paper 12938, 125-140, May, 1977.

Davis, W.J., R.H. McCuen and G.E. Kamedulski, The effect of stormwater detention on water quality, paper presented at the International Symposium on Urban Stormwater Management, University of Kentucky, Lexington, KY, July, 1978.

Dendrou, S.A. and J.W. Delleur, Watershed-wide planning of detention basins, paper presented at Conference on Stormwater Detention Facilities, New England College, Henniker, NH, Aug., 1982.

DiToro, D.M. and M.H. Small, Stormwater interception and storage, Journal of the Environmental Engineering Division, ASCE, 105(EE1), Proc. paper 14368, 43-54, Feb., 1979.

Driscoll, E.B., Analysis of detention basins in EPA NVRP program, paper presented at Conference on Stormwater Detention Facilities, New England College, Henniker, NH, Aug., 1982.

Farris, G.D., J.M. Buffo, K.L. Clark, D.S. Sturgill, and R.I. Matsuda, Urban drainage stormwater monitoring program, Municipality of Metroplitan Seattle, Seattle, WA, 1979.

Ferrara, R.A. and A. Hildick-Smith, A modeling approach for storm water quantity and quality control via detention basins, Water Resources Bulletin, 18(6), 975-981, 1982.

Galvin, D.V., Project Manager, Municipality of Metropolitan Seattle, Water Quality Division, Personal Communication, May, 1983.

Galvin, D.V. and R.K. Moore, Toxicants in Urban Runoff, METRO Toxicant Program Report #2, Municipality of Metropolitan Seattle, Seattle, WA, December, 1982.

Griffin, D.M., T.J. Grizzard and C.W. Randall, An examination of nonpoint pollution export from various land use types, paper presented at International Symposium on Urban Stormwater Management, Lexington, KY, July, 1978.

Helsel, D.R., J.I. Kim, T.J. Grizzard, C.W. Randall and R.C. Hoehn, Land use influences on metals in storm drainage, Journal Water Pollution Control Federation, 51(4), 709-717, 1979.

Henderson, F.M., Open Channel Flow, The MacMillian Co., New York, 1966.

Hey, D.L., Lake Ellyn and stormwater treatment, paper presented at Conference on Stormwater Detention Facilities, New England College, Henniker, NH, August, 1982.

Jewell, T.K., D.D. Adrian and F.A. DiGiano, Urban stormwater pollutant loadings, Water Resources Research Center, University of Massachusetts, Amherst, Massachusetts, 1980.

Kamedulski, G.E. and R.H. McCuen, Evaluation of alternative stormwater detention policies, Journal of the Water Resources Planning and Management Division, ASCE, 105(WR2), Proc. paper 14806, 171-186, Sept., 1979.

Kropp, K.H., Water quality enhancement design techniques, paper presented at Conference on Stormwater Detention Facilities, New England College, Henniker, NH, August, 1982.

Leupold and Stevens, Inc., Stevens Water Resources Data Book, Leupold and Stevens, Inc., Beaverton, Oregon, 1978.

Little, L.M., Model calibration and probability distributiosn for Washington State highway runoff quality, Master's thesis, University of Washington, Seattle, WA, 1982.

Mays, L.W. and P.B. Bedient, Model for optimal size and location of detention, Journal of the Water Resources Planning and Management Division, ASCE, 108(WR3), Proc. paper 17429, 270-285, October, 1982.

McCuen, R.H., Water quality trap efficiency of storm water management basins, Water Resources Bulletin, 16(1), 15-21, 1980.

Medina, M.A., Jr., Discussion of 'Water quality trap efficiency o stormwater management basins," by R.H. McCuen, Water Resources Bulletin, 17(1), 147-149, 1981.

Northern Virginia Planning District Commission and Virginia Polytechnic Institute and State Univ., Occoquan/four mile run nonpoint source correlation study - final report, 1978.

Oceanography International Corporation, EPA Approved Ampule Method COD Procedure Outline, April, 1980.

Oliver, L.J. and S.G. Grigoropoulos, Control of storm-generated pollutants using a small urban lake, Journal Water Pollution Control Federation, 53(5), 594-603, 1981.

Randall, C.W., Characterization of urban runoff in Northern Virginia, Water Resources Center, Virginia Polytechnic Institute and State University, Blacksburg, VA, 1979.

Randall, C.W., K. Ellis, T.J. Grizzard and W.R. Knocke, Urban runoff pollutant removal by sedimentation, paper presented at Conference on Stormwater Detention Facilities, New England College, Henniker, NH, August, 1982.

Rantz, et al., Measurement and computation of streamflow, Vols. 1 and 2, USGS Water Supply paper 2175, 1982.

Rinella, J.F. and S.W. McKenzie, Determining the settling of suspended chemicals, paper presented at Conference on Stormwater Detention Facilities, New England College, Henniker, NH, August, 1982.

Sartor, J.D., G.B. Bard and F.J. Agardy, Water pollution aspects of street surface to contaminants, Journal of Water Pollution Control Federation, 46(3), 458-467, 1974.

Sittig, M. (ed.) Priority Toxic Pollutants -- Health impacts and Allowable Limits, Noyes Data Corporation, Park Ridge, NJ, 370 pp., 1980.

Smiley, J. and C.T. Haan, The dam problem of urban hydrology, paper presented at National Symposium of Urban Hydrology, Hydraulics and Sediment Control, Univ. of Kentucky, Lexington, KY, July, 1976.

Smith, D.P. and P.B. Bedient, Detention storage for urban flood control, Journal of the Water Resources Planning and Management Division, ASCE, 106(WR2), Proc. paper 15555, 413-424, 1980.

U.S. Environmental Protection Agency, Water Quality Standards: 1980 Criteria, Federal Register, 45(231), Nov., 1980.

Wakeham, S.G., A characterization of the sources of petroleum hydrocarbons in Lake Washington, Journal of Water Pollution Control Federation, 49, 1680-1687, 1977.

Wanielista, M.P., Y.A. Yousef and W.M. McLellon, Nonpoint source effects on water quality, Journal of Water Pollution Control Federation, 49, 441-451, 1977.

Wang, T-Z, A study of heavy metals from highway source and its mitigating strategies, Master's Thesis, University of Washington, Seattle, WA, 1981.

Ward, A.J., et al., Simulation of the sedimentology of sediment detention basins, Univ. of Kentucky, Lexington, KY, 1977.

Whipple, W. Jr., Dual purpose detention basins in stormwater management. Water Resources Bulletin, 17(4), 642-650, 1981.

Whipple, W., Jr., Dual purpose detention basins, Journal of Water Resources Planning and Managment Division, ASCE, 105(WR2), 403-410, 1979.

Whipple, W., J.V. Hunter, and S.L. Yu, Unrecorded pollution from urban runoff, Journal of Water Pollution Control Federation, 46, 873-879, 1974.

Whipple, W. and J.V. Hunter, Nonpoint sources and planning for water pollution control, Journal of Water Pollution Control Federation, 49(1), 15-23, 1977a.

Whipple, W., B.B. Berger, C.D. Gales, R.M. Ragan and C.W. Randall, Characterization of urban runoff, Water Resources Research, 14(2), 370-372, 1978.

Whipple, W., Jr., and J.V. Hunter, Petroleum hydrocarbons in urban runoff, Water Resources Bulletin, 15(4), 1096-1104, 1979.

Whipple, W. and J.V. Hunter, Settleability of urban runoff pollution, Journal of Water Pollution Control Federation, 53(12), 1726-1731, 1981.

Whipple, W., N.S. Grigg, T. Grizzard, C.W. Randall, R.P. Shubinski and L.S. Tucker, Stormwater Management in Urbanizing Areas, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1983.

Wilber, W.G. and J.V. Hunter, Contributions of metals resulting from storm water runoff and precipitation in Lodi, NJ, in Urbanization and Water Quality Control, edited by W. Whipple, American Water Works Association, Minneapolis, MN, 45-54, 1975.

IX. APPENDICES

APPENDIX A.

Bellevue and King County Retention Pond Ordinances

Section 4.04

Runoff Control Policies.

A. Runoff Diversion: Off-site surface water entering areas of new roadway construction, plats, and commercial developments shall be received and discharged at the existing locations with adequate energy dissipators to minimize downstream damage. There shall be no diversion at either of these points. In subdivisions and commercial developments, this rule shall apply to the total property, by division in the case of plats, and not just to proposed right of way.

B. Peak Discharge Control:

1. The peak discharge from the road right of way or from the total subdivided property shall not exceed 0.2 cfs per acre , and

2. Stormwater detention facilities acceptable to the Engineer shall be provided in order to handle all surface water in excess of the peak discharge as per Section 4.05 of these Standards.

C. Oil Separation Devices: Whenever contamination of runoff by oil, grease or other pollutants is anticipated and deemed significant by the Engineer, an oil/grease separation device shall be installed as shown in Drawing No. 4-31, Drawing No. 4-32 and 4-33 or Drawing No. 34. It shall be located at a point where it can be maintained and where it will intercept floating contaminants flowing off road right of ways and other sources of pollutants.Selection of oil separation device type shall be subject to approval of the Engineer.

D. Erosion and Siltation Control: In addition to catch basins as provided in Section 4.03, measures such as the following shall be taken as necessary during and after construction to prevent erosion and to prevent silt'from being carried off-site and/or into receiving bodies of water.

1. Excavation and grading shall be done in a manner to maintain controlled drainage of the worksite and minimize exposure of unprotected slopes to the action of precipitation surface water or flowing ground water.

2. Whenever possible, existing natural vegetation shall be left intact.

3. When completed, exposed slopes shall be given appropriate permanent protection as soon as is practical, e.g., grass or other ground cover, riprap, rockeries, or retaining walls.

4. The provisions of Chapter 2, Land Alteration, shall apply. This shall include the submittal of an effective temporary erosion/sedimentation control plan to be approved by the Engineer prior to beginning any clearing and grubbing or other earthwork.

4.05 Stormwater Detention.

A. General Requirements.

1. All storm water runoff originating from and/or draining to any proposed development shall be controlled and/or conveyed in accordance with all City standards and policies based on Ordinance 2799 and as described in these Standards. When existing conditions make stormwater detention impossible for a portion of a site, in lieu of providing detention for such an area, at the discretion of the Engineer, compensatory storage volume may be provided on another portion of the site, provided the total site area is tributary to one drainage basin both prior to and after development. In no case shall the runoff from the total site exceed the allowable release rate.

2. The stormwater detention requirement may be waived at the discretion of the Engineer when a "tightline" discharge (in conjunction with oil separation) to a major receiving body (Lake Washington or Lake Sammamish) is provided. Said control or conveyance of storm water runoffs shall be the basis of a drainage plan which shall be prepared by the developer's licensed engineer and shall be submitted for review and approval.

3. Said drainage plans shall incorporate, among other data, the best topographical map available to clearly define:

    a. The proposed development

    b. All areas, improved or unimproved, lying upstream and draining to and through the proposed development

    c. Drainage courses natural or manmade to which the proposed development shall drain

4. The drainage plan shall be accompanied by all calculations for determination of the required size of the storm sewer system and storm water detention facility.

   Storm drain pipe sizes may be selected by nomograph or calculated based on the Manning Formula.

5. The stormwater detention storage requirement may be waived (See Section 4.01B) at the discretion of the Engineer when the volume calculated for that storage is less than two hundred fifty (250) cubic feet (see paragraph C. this section). Collection systems shall be either gravity pipe systems, open drainage swales or open channels, or a combination of the three.

6. Detention facilities shall be open basins or ponds, roof top storage, parking lot ponding, underground storage (pipe/chamber), gravel filled trench storage or infiltration trenches or combinations of any of the above.

7. Drainage plans shall include a plan profile of the facilities. The profile requirement for private drainage systems may be waived at the discretion of the Engineer when sufficient data is provided on the plan in a clear and concise manner including the following as minimum data: all hydraulic and physical data such as grades, bottom elevations of ditches, channels, ponds and swales, parking lots and recharge trenches, inverts of pipes, inverts and tops of all structures such as manholes, catch basins, chambers or similar structures, as well as size, length and slope of all pipes or other detention or conveyance facilities, including the invert elevations of the existing or any other storm drainage system that the subject drainage proposes to discharge (tie) into. The design volume of all detention ponds shall also be shown on the plan as well as a note indicating that ponds shall be inspected prior to paving and/or landscaping.

8. The on-site drainage system including conveyance, flow restriction, detention, oil separation and emergency overflow elements must be properly designed to handle on-site precipitation and conveyance through the site of off-site runoff when the on-site system is not so designed to detain off-site runoff. Designers should conceptualize how water will move into, through, and out of the system, looking for potential problems, flow impediments, construction difficulties, future maintenance problems, and soil erosion potential.

9. All aspects of public health and safety must be carefully reviewed in every drainage control system plan. Protective measures are often necessary and shall be required whenever appropriate. The protective measures themselves shall be designed so as not to constitute hazards or nuisances.

10. Off-site stormwater flows passing through the site must be conveyed in an adequate system, with appropriate easements provided. The conveyance system shall not be used as a part of the on-site detention, excpet where one detention system may flow into another using a multi-orifice restrictor as per paragraph H. of this section of the standards and when no other discharge point is available. The on-site system shall be consistent with all connecting off-site elements, such as the element to which the on-site system releases. In the case of an open stream conveyance system passing through a site, consideration should be given to flow elevations during flood conditions of a 100 year event storm to prevent backing water into the on-site system.

11. The designer should consider system reliability in terms of layout, specification of materials and methods of installation, and the influence of other activities in the area both during and after construction.

12. The impact of a system failure should be analyzed both in terms of on-site and off-site effects. The impacts may be to adjacent properties or to elements of the public drainage system or other private systems.

13. The frequency and difficulty of future maintenance can be minimized by thorough consideration during design of what could possibly go wrong in the system and what would be required to correct the problem. Design adjustments to ease maintenance should be a major consideration.

14. The designer should consider other planned uses in the same area as elements of the drainage system. This multiple use may require compromise, but no adjustments to usual policy will be made which would impact the system to the degree that risk of failure or impact of system failure is increased.

15. The use of the site should be evaluated to determine if hazardous materials or other pollutants are likely to be present, and if extraordinary design considerations are necessary.

16. The visual impact and other potential problems (mosquito breeding, smell, etc.) should be considered. Concerns will vary with the site environment, but aesthetics should always be of concern to the designer.

17. It is important that runoff from rooftops pass through the detention system - the design should clearly indicate how roof runoff moves through the system.

18. Access to all control structures by appropriate equipment shall be provided.

B. Allowable Rate of Release.

The allowable rate of release is 0.2 cfs/acre (which is equal to 0.2 inches per hour) for the portion of the subject site tributary to the point of release.

C. Storage Requirements.

The storage requirement performance criteria is given below. In calculating the storage volume provided, do not include "dead storage", i.e. that volume of water which must be assumed to be present in the detention system at the commencement of the design storm. Any volume at a level below that of the outfall invert must be presumed to be dead storage, e.g. catchments.

1. Impervious Area.

One (1) inch coverage of water is required to be stored for the area which is impervious. (Compacted areas surfaced with gravel or other material are assumed to be impervious.) This is easily calculated by dividing the square footage of impervious area by 12, which expresses storage required for the impervious area in cubic feet.

2. Pervious Area.

Because of poor infiltration conditions which predominante in the City, storage may be required for pervious as well as impervious areas. Unless it can be otherwise demonstrated by an infiltration (perc) test (See Paragraph F), it is assumed that individual properties allow infiltration at a sustained rate of .2 inches per hour on the pervious surface. The sustained rate is that which occurs after 2 hours of continuous infiltration and is maintained thereafter. Storage is required for the pervious area whenever the infiltration rate is less than .5 inches per hour.

Section 4.05 G

G. Sizing of Control Orifice.

1. Sharp edged circular orifices shall be used for discharge restriction where $Q = Ac\sqrt{2gH}$ and "c" = 0.62. "H" shall be the vertical distance between the maximum water surface and the outfall invert in feet.

2. The derived equation:

$$\left(\sqrt{\frac{4Q}{(.62)\ \sqrt{(H)\ 64.4}}}\right) 12 = \text{DIA. in inches}$$

shall be used in sizing the control orifice.

The control orifice size shown on the plans shall be rounded to the nearest lower 1/8" and shall be specified as a "drilled" orifice to achieve the circular and sharp edged qualities required. See Drawing No. 4-36.

3. Where the allowable release rate exceeds 1 cfs, a multiple orifice control shall be used having orifices at various elevations, with the lowest orifice being sized to pass 25% of the allowable Q or being one inch in diameter, whichever is greater. The remaining orifices, from lower to highest, shall be sized so as to release 25% of the allowable Q. In the case where the lowest orifice must release more than 25% of the Q allowable due to the one inch miniumum orifice size, the highest of the orifices may discharge at a rate greater than 25% of the allowable release rate. Where the orifice sizes are limited by the overflow standpipe size, each higher orifice may pass more or less than 25% of the allowable Q and there may be more or less than four orifices. (See Drawing No. 4-37, 4-38, & 4-39). <u>The minimum control orifice size shall be one inch in diameter</u>.

B. Surface Ponds Other Than Parking Lot Ponds.

1. Slopes on all interiors of surface ponds shall not exceed three feet horizontal to one foot vertical for all detention ponds in plats. Ponds in commercial developments which are to remain under private ownership and maintenance shall have at least one interior slope not exceeding three feet horizontal to one foot vertical with all other interiors exceeding three to one to be retaining walls designed by a licensed structural engineer or rockwalls designed by a licensed engineer experienced in soils mechanics. Slopes on pond exteriors shall not exceed two horizontal to one vertical.

2. The bottom of all ponds less than three feet deep shall have six feet as a minimum dimension. The bottom of all ponds three feet or more deep shall have 15 feet as a minimum dimension. Maximum water depth in all ponds shall be five feet.

3. Ponds suited to multiple use are encouraged. Examples of multiple uses are sport courts, play areas, neighborhood parks, and picnic areas. Such ponds may be designed with engineered walls (with slopes exceeding 3 to 1) as approved by the Engineer on a case by case basis.

4. All ponds shall be landscaped so as to provide slope stability and pleasant appearance by utilizing sodding, seeding, and planting of trees and shrubbery etc. (See Section 2.04 of these Standards). Under no circumstances shall use of easily floatable or erodable materials (such as "beauty bark") be permitted in pond interiors.

5. Maintenance of surface ponds in commercial developments shall be the responsibility of the property owner, or Owner's Association. Maintenance of surface pond

landscaping in single family residential areas shall be the responsibility of the adjacent property owners or homeowners association except in the case of multiple use ponds accepted for maintenance by the City. Maintenance of landscaping and facilities of multiple use ponds in single family residential developments shall be the responsibility of an owner's association or community club and shall be so stated on the face of the plat unless accepted for maintenance by the City.

6. Where berms are to be constructed as banks of detention ponds, the following requirements as regards to soils shall be met and attainment of these specifications and that the pond (earth dam) is safe for the intended use shall be certified by an experienced independent soils engineer. Notes to the effect of the above shall be shown on the approved plan.

   a. Berm soils shall consist of material capable of placement in maximum six (6) to eight (8) inch lifts.

   b. Berm soils shall be capable of permeability (k) of no more than 3 x 10^{-5} cm/sec.

   c. Berm soils shall consist of material conforming to the following gradation:

Sieve Size	% Passing
3"	100%
#4	65 - 90%
#200	12 - 20%

   d. Berm soils shall be compacted in-place to a minimum of 95 percent (ASTM D-1557)

   e. Berm soils shall be placed and compacted at or up to 3 percent below optimum moisture.

   f. Berm soils shall be placed and compacted over a prepared subgrade free of organic or other deleterious materials; preferably into natural soils.

   g. Berm soils placed around structures in the berm shall be placed in four (4) inch maximum lifts and compacted to 98 percent of ASTM D-1557. Anti-seep collars shall be placed on all pipes and trenches within the berm.

   h. Vegetation on the berm soils shall be limited to shallow rooted varieties and/or placed into top soil above or adjacent to the engineered berm soils.

i. Designs having specifications varying from those in 6. above may be approved by the Engineer on a case-by-case basis when said design is by a licensed engineer experienced in soil mechanics.

7. All detention pond control structures in single family residential developments not abutting a public right of way shall be accessible to the City of Bellevue for maintenance and operation. Access shall be provided in access easements and shall accommodate vehicular traffic.

8. A vehicular access must be provided to the bottom of the retention/detention pond when the bottom width of the pond is 20 feet or greater and/or when the height of the pond interior wall exceeds five feet.

9. The access grade into the proposed retention/detention pond shall be no steeper than 5 feet horizontal to 1 foot vertical.

10. All detention ponds other than those in parking lots shall have a minimum of one foot of freeboard above the maximum design water surface.

11. Any embankment for a detention pond in excess of 3 feet must be approved by a qualified soils engineer and the Department of Public Works. The minimum top width of this berm shall be 15 feet, unless otherwise approved by a qualified, licensed engineer and the Department of Public Works. The soils engineer experienced in soils mechanics, shall inspect and certify the construction of any such berm.

12. Any embankment less than 3 feet, including 1 foot of freeboard, in depth forming one or more sides of a retention/detention pond shall have a minimum 6 foot wide berm with a back slope not to exceed 2 horizontal to 1 vertical unless otherwise approved by the Engineer and designed by and with construction being certified by a licensed engineer experienced in soils mechanics.

13. All constructed and graded retention/detention ponds shall be sloped no flatter than 0.005 ft./ft. (1/2%) towards the outlets, for drainage.

    EXCEPTION: This requirement need not apply to natural ponds, which exist, and are utilized for storm water detention.

14. Use of "flow through" detention ponds shall be approved for construction by the Engineer on a case-by-case basis where the Engineer deems such a design appropriate. All "flow through" detention ponds shall have a well defined low flow channel to contain runoff of lesser storms. Any low flow channel shall be designed so as to enhance the pond landscaping and overall pond appearance.

15. Outlets of all detention ponds shall be provided with suitable debris barriers designed to protect the outlet from blockage or plugging.

16. The maximum design water depth in all detention ponds other than those in parking lots shall be five feet.

17. The design volume of the detention pond shall be shown on the plan and the pond volume inspected prior to landscaping (a note to this effect shall be shown on the plans).

18. All ponds shall have a landscape plan and shall be landscaped so as to provide a pleasing appearance, stability, and ease of maintenance per Section 2.03 and 2.04 of these Standards.

19. Storm retention/detention ponds may be utilized as Interim Drainage Facilities if approved by the Engineer.

20. See Drawing No. 4-42 for a typical surface pond sketch.

C. Closed Detention Systems.

1. Maintenance of closed detention systems such as underground pipes, gravel filled trenches, and both underground and surface vaults in private commercial developments shall be the responsibility of the property owner or Owners Association. Maintenance of closed detention facilities in plats shall be the responsibility of the City and said facilities shall be deeded to the City unless otherwise approved with the dedication of the plat.

2. Adequate access to closed detention systems shall be required with access structures at each end of the facility and vehicular access to those structures suitable for travel by a vactor, jet-rodder, and other maintenance equipment. See Drawings No. 4-43 and No. 4-44.

3. All closed detention facilities constructed above ground shall be provided with suitable screening as per Section 3.27 of these Standards.

KING COUNTY DRAINAGE CODE

Chapter 20.50 Surface Water Runoff Policy (page 754)

20.50.050 Drainage plan - Mandatory requirements. A. Surface water entering the subject property shall be received at the naturally occurring location and surface water exiting the subject property shall be discharged at the natural location with adequate energy dissipators to minimize downstream damage and with no diversion at any of these points.

B. The peak discharge from the subject property for the design frequency storm may not be increased due to the proposed development.

C. Retention/detention facilities or other drainage facilities must be provided in order to handle all surface water in excess of the peak discharge.

D. Open retention/detention ponds and infiltration facilities shall not be located in dedicated public road right-of-way areas unless specifically waived by the department.

E. An emergency overflow system is required for all retention/detention facilities.

F. The drainage course for a minimum distance of one-fourth mile downstream from the development must be evaluated for its capacity to pass the design storm flow after completion of the development.

Variances from any or all of the foregoing requirements may be permitted only after a determination by the department employing the following criteria:

1. Capacity of downstream facilities;
2. Acceptability of receiving bodies of water;
3. Possibility of adverse effects of retention;
4. Utility of regional retention facilities; and
5. Capability of maintaining the system. (Ord. 4938 § 5, 1980: Ord. 2812 § 3, 1976: Ord. 2281 § 5, 1975).

Chapter 20.50, page 757.

20.50.110 Maintenance of subdivision retention/detention facilities. King County shall assume the maintenance of all subdivision retention/detention facilities which fully comply with the requirements of this section. Until all the conditions of this section have been met, maintenance shall remain the responsibility of the person required to construct the retention/detention facility. Prior to final plat recording or the release of bonds posted to guarantee satisfactory completion, whichever occurs last, the following conditions must be met by the person required to construct the retention/detention facility pursuant to this chapter.

A. All of the requirements of Section 20.50.100 have been fully complied with.

B. The retention/detention facility and other drainage facilities have been constructed according to plan, applicable specifications and standards, and approved by the department following a comprehensive inspection conducted for the purpose of County assumption of maintenance without regard to any prior inspections or approvals.

C. All required improvements have been completed and have been inspected and approved by King County.

D. All necessary easements entitling the County to properly maintain the retention/detention facility have been conveyed to the county.

E. The fee as specified by the director based upon the fee schedule adopted by the Council has been paid.

Only after all of the above conditions have been met shall King County assume maintenance of the subdivision retention/detention facility.

EXCEPTION: A retention/detention facility located within and servicing only an individual lot shall not be accepted by the county for maintenance and will remain the responsibility of persons holding title to the property within which the facility is located. (Ord. 5824 § 5, 1982: Ord. 4938 § 9, 1980: Ord. 2812 § 7, 1976: Ord. 2281 § 8, 1975).

20.50.120 Maintenance of multifamily/commercial facilities. A. Any person or persons holding title to the property for which a facility was required shall be responsible for the continual operation and maintenance of the facility in accordance with standards and requirements of the department. Prior to the issuance of any of the permits and/or approvals listed in Section 20.50.030 the person or persons holding title to the subject property for which a retention/detention facility was required shall record the declaration of covenant set forth in Appendix A to Ordinance 4938. The restrictions set forth in such convenant shall be included in any instrument of conveyance of the subject property and shall be recorded with the King County Records Division.

B. The county shall enforce the restrictions set forth in Appendix A of Ordinance 4938.

C. Prior to the issuance of any of the permits and/or approvals contained in Section 20.50.030 or the release of bonds posted to guarantee satisfactory completion, the person or persons holding title to the subject property for which a retention/detention facility was required shall pay a fee established by the director to reasonably compensate the county for costs relating to inspection of the facility to ensure that it has been constructed according to plan and applicable specifications and standards. Fees shall be established by the director in accordance with the County Administrative Code. Such fees may be updated as needed to reflect actual costs.

D. Any person or persons holding title to the subject property for which a facility was required shall pay, upon receipt of an annual statement, a fee established by the county council to reasonably compensate the county for costs incurred by the periodic inspection of commercial facilities to ensure that maintenance is being carried out in accordance with standards and requirements of the department. This maintenance checking fee shall apply to all facilities which have been or are required to be constructed as a condition of approval regardless of the date of approval or completion.

E. The duties specified in this section of maintenance and payment of inspection and maintenance checking fees shall be enforced against the person or persons holding title to the property for which the retention/detention facility was required. (Ord. 5824 § 9, 1982: Ord. 4938 § 10, 1980).

storm drainage design

section b

INTRODUCTION:

All storm waters originating on any proposed land development, roads, and all areas draining thereto shall be estimated as to rate of precipitation and to percentage of overland runoff in accordance with criteria hereinafter stated. Said estimates of precipitation and run-off shall be the basis of a drainage plan which shall be prepared by a Professional Civil Engineer and which shall be submitted to the King County Department of Public Works for review and approval. Said drainage plan shall incorporate, among other data, the best available topographical maps to clearly define: (1) the proposed development; (2) all areas, improved or unimproved, lying upstream and draining to and through the proposed development; and (3) drainage courses, natural or otherwise, to which the proposed development shall drain. Under no circumstances shall drainage be diverted in the proposed development to points of discharge other than those points receiving drainage prior to the proposed development.

Unless specifically approved otherwise by the Department of Public Works, the rate of storm water run-off from any proposed land development to any natural or manmade point of discharge downstream, such as storm sewers or ditches, shall not exceed the peak rate of runoff for the design storm occurring prior to the proposed land development, all in accordance with King County Code Chapter 20.50. In the event that waters from this development drain into a critical flood, drainage, and/or erosion problem area, the quantity of water from this site may be restricted to the existing quantity leaving this site prior to development. In the event that run-off from a proposed land development has in the past discharged directly into a relatively large body of water such as a lake or river or has or could discharge to such bodies of water via ditch or pipeline sized to accommodate anticipated increased run-off from the proposed land development, then it shall be the sole decision of the Department of Public Works to permit or not permit such increased run-off to said bodies of water from the proposed land development.

Run-off rates can be determined by the rational formula:

$$Q = C\ I\ A$$

Q = Run-off in cfs
C = Runoff coefficient
I = Rainfall intensity in inches per hour
A = Contributing area in acres

The run-off coefficient (C) should be based on Table 1. The rainfall intensity (I) will be based on the Rainfall Intensity-Duration Curves, prepared by the U. S. Weather Bureau for the area. The curve that is the closest to the plat will be used (see pages 36 to 43). Where other data of the same nature is used, the engineer should submit the curve along with the design analysis. For drainage areas less than 50 acres or producing a runoff of less than 20 cfs, a 10-year design frequency may be used. For areas greater than 50 acres or producing a run-off greater than 20 cfs, a 25-year design frequency will be used regardless of the size of the plat. The outlet flow may be further restricted if the downstream drainage basin is presently subject to serious flooding.

APPENDIX B.

Laboratory Methods

APPENDIX B.
LAB METHODS

Method 755 -- Oil and Grease -- Water and Wastewater

PURPOSE

This procedure determines total recoverable oil and grease of water and wastewater by serial extraction with Freon.

EQUIPMENT AND MATERIALS REQUIRED

1. Separatory funnel, 2000 ml, teflon stopcock, glass stopper.
2. Separatory funnel, 250 or 500 ml, teflon stopcock, glass stopper.
3. Glass funnel.
4. Filter paper, Whatman No. 40, 11 cm.
5. Erlenmeyer flask, 125 ml, ground glass joint (24/40).
6. Rotary Evaporator.
7. Constant temperature water bath, 70 degrees C.
8. Constant temperature oven, 70 degrees C.
9. Desiccator.
10. Freon.
11. Hydrochloric acid, 1:1.
12. Anhydrous sodium sulfate.
13. Beakers.

SAMPLE PRESERVATION

1. If the volume of the sample is unknown, mark the meniscus for later determination of the volume.
2. Add 5 ml of 1:1 HCl to the sample and check the pH with pH paper. If the pH is not below 2, add more HCl.
3. Samples preserved in this manner may be stored at 4 degrees C for 28 days.

PROCEDURE

1. Clean 125 ml flasks are stored in desiccators. Take out one for each sample and blank, and weigh them immediately. To clean a flask, wash it thoroughly with detergent, rinse it with deionized water, wipe down the outside with a Kimwipe soaked with Freon, rinse the inside with Freon, dry it in an oven at 70 degrees C and store it in a desiccator.

   (NOTE: Make sure the dessicant has not been expended.)

2. Preheat the constant temperature water bath to 70 degrees C. Preheat the oven to 70 degrees C also.

3. Pour the sample into a 2000 ml separatory funnel.

4. Pour 30 ml of Freon into the sample jar and swirl it around to rinse down the sides.

5. Pour this Freon into the 2000 ml separatory funnel. Shake it vigorously for 2 minutes, and allow the layers to separate.

6. Drain the separated Freon through a Whatman No. 40 filter cone containing 1 gm anhydrous sodium sulfate. Capture the filtered Freon in a tared 125 ml flask.

7. If an emulsion forms, drain it into a clean beaker.

8. Repeat steps 4 through 7 two more times, using fresh solvent each time.

9. Freeze the emulsion in the beaker with a glass stirring rod set in it. When frozen use the glass stirring rod to break up the ice. Filter the released Freon into the small separatory funnel. Rinse the slush left from the emulsion with Freon, and filter the Freon into the smaller separatory funnel.

10. Rinse the filter paper and filter with 10-20 ml of Freon, and add this Freon to the smaller separatory funnel.

11. Drain the solvent from the smaller separatory funnel through the Whatman no. 40 filter cone (containing 1 gram anhydrous sodium sulfate) into the tared 125 ml flask, leaving any water behind. Add 10 ml Freon to the separatory funnel, swirl gently (allow the layers to separate if water is present) and filter the solvent into the flask.

12. Rinse the filter containing the sodium sulfate with 10-20 ml Freon, and drain it into the flask.

13. Connect the 125 ml flask to the Rotary Evaporator and place in the 70 degree bath. Place a piece of tape over the opening at

the lower end of the condenser. Rotate at speed 2-3 until the flask appears dry and no more solvent is condensing into the collection flask. Remove the tape from the opening and, while the flask is still in the water bath, blow air through the flask for 5 minutes.

14. Remove the flask from the Rotary Evaporator, wipe the outside clean with Kimwipes wetted with Freon, place it in the 70 degree oven for 15 minutes, remove it, and immediately lay on its side in a desiccator. Weigh it after 30 minutes.

    (NOTE: Make sure the dessicant has not been expended.)

15. Run a solvent blank by putting 120 ml Freon in a tared 125 ml flask and proceeding with steps 13 and 14.

16. If the sample volume is not known, fill the sample container to the marked meniscus level with water, and measure the volume of the water.

CALCULATION

$$\text{Total recoverable Oil and Grease (mg/L)} = \frac{A - B - C}{D} \times 1{,}000{,}000$$

Where A = Weight of flask + oil and grease (gm)

B = Weight of flask (gm)

C = Weight solvent blank (gm)

D = Volume of sample (ml)

Method 290 -- Manual Orthophosphate Analysis

INTRODUCTION

Orthophosphate in water results from fertilizers, leaching from rocks and soils, and from industrial effluents. It stimulates algae growth which may cause problems in public water supplies. This procedure determines orthophosphate concentration in the sample by colorimetric means.

EQUIPMENT AND MATERIALS REQUIRED

1. 125 ml Erlenmeyer flasks.
2. 5 ml Automatic Pipettor.
3. 50 ml Graduated Cylinder
4. Beckman Model 26 Spectrophotometer.
5. Stock Phosphate Solution.

   Dry KH_2PO_4 (potassium dihydrogen phosphate) in an oven at 105 degrees C for one hour and desiccate for one hour. Dissolve 0.4394 grams KH_2PO_4 in deionized water. Dilute to 1000 ml with deionized water. concentration = 100 mg/L.

6. Intermediate Phosphate Solution.

   Dilute 10.0 ml of the Stock Phosphate Solution to 1000 ml total volume with deionized water. Remake every month. Concentration = 1.0 mg/L.

7. Phenolphthalein Solution.

   Dissolve one gram Phenolphthalein in 100 ml reagent grade alcohol (denatured). Add 100 ml deionized water.

8. Sulfuric Acid Solution (2.5 N).

   To about 400 ml deionized water, slowly add 70 ml concentrated H_2SO_4 (sulfuric acid). Stir and cool solution. After cooling, dilute to 1000ml with deionized water.

9. Stock Color Reagent.

   In 700 ml deionized water, dissolve 0.210 grams of Antimony Potassium Tartrate. Dissolve 9.20 grams of Ammonium Molybdate into the first solution. Slowly add 107.3 ml of concentrated H_2SO_4 (sulfuric acid). USE A FACE MASK. Stir and cool to room temperature. Dilute to one liter with deionized water.

10. Combined Color Reagent.

Weigh out a prescribed amount of Ascorbic Acid and dissolve with Stock Color Reagent (No. 9). The volume required should be sufficient for 5 ml of dissolved reagent per flask. Make fresh daily.

Volume of Reagent (ml)	Grams of Ascorbic Acid
100	0.808
200	1.62
250	2.02
500	4.04
1000	8.08

PROCEDURE

Color Development

1. Obtain a clean 125 ml Erlenmeyer flask for each sample. Obtain six additional flasks for blanks and standards.

2. Rinse the inside of each flask three times with deionized water. Shake out the last bit of water.

3. Add 50 ml deionized water to each of three Erlenmeyer flasks for reagent blanks.

4. To three other flasks add the following amounts of Intermediate Phosphate Solution and deionized water to make these standards:

0.100 mg/L	5.00 ml	Intermediate Solution	+ 45.0 ml water
0.200 mg/L	10.00 ml	" "	+ 40.0 ml water
0.300 mg/L	15.00 ml	" "	+ 35.0 ml water

5. Pour 50. ml of sample into a flask.

6. Add one drop of Phenophthalein Solution to each blank, standard and sample. Neutralize to a clear color with Sulfuric Acid Solution if necessary.

7. Pipette 5.00 ml Combined Color Reagent to each blank, standard and sample.

8. Allow flasks to develop at least 30 minutes, but not more than 2 hours.

Measurement

1. Turn on the spectrophotometer and select the CONC mode.

2. Turn the "CONC CALIB" knob all the way clock-wise.

3. Set the wavelength to 650 nm and the slit to NORMAL.

4. Make sure the 1-cm flow-cell installed.

   (NOTE: When filling the 1 cm cell, set the "FILL TIME" knob to "7" and push the "FILL" button twice.)

5. Fill the cell with deionized water. Using the "BASELINE ADJUST" knob, adjust the readout to "0000."

6. Fill the cell with each of the three blanks and record the readings of all three blanks on the data sheet.

7. Read the 0.100, 0.200 and 0.300 mg/L standards, in that order, and record the results on the data sheet.

8. Fill the cell with deionized water and set the baseline to zero again.

9. Read each sample, recording the reading for each one on the data sheet in the order they were read.

10. When all the samples are read, fill the cell with deionized water and record the reading.

    (NOTE: If a large number of samples are being analyzed, read the deionized water baseline after every 20-25 samples, recording the reading and then re-adjusting to '0000.'

CALCULATION

1. Average the readings of the three blanks and subtract this value from the standard and sample readings.

2. Calculate the calibration factor for each standard by dividing the actual concentration of the standard by the corrected reading from the spectrophotometer. Average the three calibration factors of the standards.

3. To calculate the concentration of a sample, multiply the corrected spectrophotometer reading of the sample by the average calibration factor.

4. If the sample was diluted, multiply the concentration obtained in step 3 by the dilution factor for that sample.

Method 295 -- Total Phosphorus -- Water and Wastewater

INTRODUCTION

This procedure determines total phosphorous concentration in the sample by digestion with ammonium persulfate and colorimetric means.

EQUIPMENT AND MATERIALS REQUIRED

1. 125 ml Erlenmeyer flasks.
2. 100 ml volumetric flasks.
3. Plastic funnels.
4. Boiling stones.
5. Whatman filter paper #40 or # 42.
6. 9 ml automatic pipettor.
7. 100 ml graduated cylinder.
8. Beckman model 26 spectrophotometer.
9. Stock Phosphate Solution (100 mg/L).

   Dry KH2PO4 (potassium dihydrogen phosphate) in an oven at 105 degrees C for one hour and desiccate for one hour. Dissolve 0.4394 grams KH2PO4 in deionized water. Dilute to 1000 ml with deionized water. Concentration = 100 mg/L PO4-P. Remake every six month.

10. Intermediate Phosphate Solution

    Dilute 10.0 ml of the Stock Phosphate Solution to 1000 ml total volume with deionized water. Remake every month. Concentration = 1.00 mg/L.

11. Strong Acid Solution (10.8 N)

    To 600 ml deionized water Add 300 ml reagent grade H2SO4 (sulfuric acid). Stir, cool and dilute to one liter.

12. Ammonium Persulfate Solution

    Weigh out a prescribed amount of reagent grade (NH4)2S2O8 (ammonium persulfate) and dissolve with deionized water. The volume required should be sufficient for 5 ml of dissolved reagent per flask.

Volume of Reagent (ml)	Grams of Ammonium Persulfate
75	10
125	20
250	40
500	80
1000	160

13. Phenolphthalein Solution

Dissolve one gram Phenolphthalein in 100 ml reagent grade alcohol (denatured). Add 100 ml deionized water.

14. Sodium Hydroxide Solution (6 N)

In 750 ml of deionized water dissolve 240 grams of NAOH (sodium hydroxide) under the hood and with a face mask on. Cool and dilute to one liter.

15. Sulfuric Acid Solution (2.5 N)

To about 400 ml deionized water (under the hood and with a fask mask on), slowly add 70 ml concentrated H2SO4 (sulfuric acid). Stir and cool solution. After cooling dilute to 1000 ml with deionized water.

16. Stock Color Reagent

In 700 ml deionized water, dissolve 0.210 grams of Antimony Potassmium Tartrate. Dissolve 9.20 grams of Ammonium Molybdate into the first solution. Slowly add 107.3 ml concentrated H2SO4 (sulfuric acid). USE A FASK MASK. Stir and cool to room temperature. Dilute to one liter with deionzied water.

17. Combined Color Reagent

Weigh out a prescribed amount of Ascorbic Acid and dissolve with Stock Color Reagent (#16). The volume required should be sufficient for 9 ml of the dissolved reagent per each flask. Make fresh daily.

Volume of Reagent	Grams of Ascorbic Acid
100	0.808
200	1.62
250	2.02
500	4.04
1000	8.08

PROCEDURE

Digestion

1. Obtain a clean 125 ml Erlenmeyer flask, a clean 100 ml volumetric flask, and a clean plastic funnel for each sample. Obtain 6 additional set-ups for blanks and standards.

2. Rinse each Erlenmeyer flask, volumetric flask, and funnel three times with deionized water.

3. Add 100 ml deionized water to each of the three Erlenmeyer flasks for reagent blanks.

4. To three other Erlenmeyer flasks add the following amounts of Intermediate Phosphate Solution and deionized water to make these standards:

0.100	10.0 ml	Intermediate	Solution	+ 90 ml water
0.200	20.0 ml	"	"	+ 80 ml water
0.300	30.0 ml	"	"	+ 70 ml water

5. Pour 100 ml of each sample into its own Erlenmeyer flask.

6. Add 5.0 ml of Ammonium Persulfate Solution to each blank, standard, and sample.

7. Add boiling stones and 2.0 ml of Strong Acid Solution to each Erlenmeyer flask.

8. Boil each flask down to 20 ml.

9. Allow flasks to cool and rinse down sides of flasks with deionized water.

Color Development

1. Filter samples into 100 ml volumetric flasks, rinsing filters three times with deionized water.

2. Add one drop Phenolphthalein Solution to each volumetric flask.

3. Add Sodium Hydroxide Solution until mixture turns pink.

4. Dilute to about 85 ml with deionized water.

5. Add Sulfuric Acid Solution until pink color disappears.

6. Add 9.0 ml of Combined Color Reagent and dilute to 100 ml with deionized water. Mix thoroughly.

7. Allow color to develop for at least 30 minutes, but not more than 2 hours.

Measurement

1. Turn on the spectrophotometer and select the CONC mode.
2. Turn the "CONC CALIB" knob all the way clock-wise.
3. Set the wavelength to 650 nm and the slit to NORMAL.
4. Make sure the 1-cm flow-cell is installed.

   (NOTE: When filling the 1 cm cell, set the "FILL TIME" knob to "7" and push the "FILL" button twice.)

5. Adjust the cell with deionized water. Using the "BASELINE ADJUST" knob, adjust the readout to "0000."
6. Fill the cell with each of the three blanks and record the readings of all three blanks on the data sheet.
7. Read the 0.100, 0.200 and 0.300 mg/L standards, in that order, and record the results on the data sheet.
8. Fill the cell with deionized water and set the baseline to zero again.
9. Read each sample, recording the reading for each one on the data sheet in the order they were read.
10. When all the samples are read, fill the cell with deionized water and record the reading.

    NOTE: If a large number of samples are being analyzed, read the deionized water baseline after every 20-25 samples, recording the reading and then re-adjusting to '0000.'

CALCULATION

1. Average the readings of the three blanks and subtract this value from the standard and sample readings.
2. Calculate the calibration factor for each standard by dividing the actual concentration of the standard by the corrected reading from the spectrophotometer. Average the three calibration factors of the standards.
3. To calculate the concentration of a sample, multiply the corrected spectrophotometer reading of the sample by the average calibration factor.

4. If the sample was diluted, multiply the concentration obtained in step 3 by the dilution factor for that sample.

Computerized

1. Directions for using the computer program to calculate Total Phosphorus concentrations are found in Method 820 in this manual.

APPENDIX C.

Fortran Source Codes

METRO Data Analysis
Computer Program

```
      PROGRAM LOAD(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE10,
     &TAPE11,TAPE12,TAPE13,TAPE15)
      DIMENSION IQC(500), IQL(500),OQC(500),OQL(500),
     &FLUHT(150),PONDHT(150),FLUSTA(500),PONDSTA(500),QIN(500),
     &QOUT(500),TIME1(500),TIME2(500),DELST(500),
     &DQOUT(500),DQIN(500),RAIN(100)
      DIMENSION NTIME(5),LABQC(5),LABQL(5)
      REAL IQC,IQL
C --  PROGRAM TO COMPUTE INFLOW HYDROGRAPH AND INFLOW AND OUTFLOW
C --  LOADINGS FOR METRO EAST BASE
C --  INFLOW IS COMPUTED BY DIFFERENCE USING FLUME STAGE HEIGHT
C --  AND RESULTS OF LABORATORY SCALE MODEL TESTS TO COMPUTE
C --  POND DISCHARGE, AND POND STAGE AND SURVEYED ELEVATION
C --  VOLUME RELATIONSHIP TO COMPUTE STORAGE CHANGE.
C --  INPUT VARIABLES ARE:
C --    M = NUMBER OF INFLOW QUALITY SAMPLES (SAMPLING INTERVAL
C --      SPECIFIED BY DELTQ)
C --    MM = NUMBER OF OUTFLOW QUALITY SAMPLES (SAMPLING INTERVAL
C --      SPECIFIED BY DELTQ)
C --    KHT = NUMBER OF POND HEIGHT AND FLUME HEIGHT READINGS
C --    NR = NUMBER OF RAINFALL DATA
C --    RAINFALL DATA ARE ASSUMED TO BE ON 30 MINUTE TIME INTERVAL
C --    IPFLOW = INITIAL PERIOD (IN NUMBER OF DELT'S) FOR FLUME HEIGHT
C --      AND POND STAGE DATA
C --    IPQUAL = INITIAL PERIOD (IN NUMBER OF DELTQ'S) FOR QUALITY DATA
C --    IPRAIN = INITIAL PERIOD (IN HALF HOURS) FOR RAINFALL DATA
C --    IPLOT IS PLOT OPTION , 1 FOR PRINTER PLOTS, 2 FOR CALCOMP-
C --      COMPATIBLE.  FOR IPLOT = 2, APPROPRIATE JCL MUST BE ADDED,
C --      AND IN ALL CASES GRAFTN LIBRARY MUST BE MADE LOCAL
C --    ICOMP IS DIFFERENCING OPTION FOR INFLOW COMPUTATION
C --      1 USES BACKWARD DIFFERENCE
C --      2 USES CENTRAL DIFFERENCE
C --      3 USES FORWARD DIFFERENCE
C --    NVAR IS NUMBER OF WATER QUALITY VARIABLES PLOTTED
C --    DELT = SAMPLING INTERVAL FOR POND AND FLUME HEIGHT.  DEFAULT
C --      IS 15 MINUTES, 3.75
C --      MINUTES CAN ALSO BE USED.  ANY OTHER VALUE WILL CAUSE EXIT
C --      FROM PROGRAM
C --    DELTQ = QUALITY SAMPLING TIME INTERVAL (MUST BE 3.75 OR
C --      15 MINUTES)
C --    XFAC = MULTIPLIER TO ADJUST FOR STORAGE CHANGE-OUTFLOW
C --      INCOMPATIBILITIES.  THIS FACTOR IS USED TO ADJUST ALPHA
C --      IN CENTRAL DIFFERENCE EQUATION FOR INFLOW COMPUTATION, AND
C --      IS CALIBRATED USING RECESSION LIMB OF POND OUTFLOW HYDRO-
C --      GRAPH.  NOMINAL VALUE IS 1.0.
C --    DELH IS ADDITIVE ADJUSTMENT TO FLUME HEIGHT (NOMINAL VALUE
C --      IS 0.02)
C --    NTIME IS TIME AXIS LABEL FOR PLOTS (MAXIMUM 50 CHARACTERS)
C --    LABQC,LABQL ARE AXIS LABELS FOR PLOTS,
C --      MAXIMUM 50 CHARACTERS
C --    FMAX IS MAXIMUM FLOW (CFS)
```

```
C --    RMAX IS MAXIMUM RAINFALL RATE (IN/HR)
C --    YMQ IS PLOTTING MAXIMUM FOR CONCENTRATION (MG/L)
C  --   YLQ IS PLOTTING MAXIMUM FOR LOADING (LBS/DAY)
C --  INPUT FILES ARE:
C --    5  PROGRAM OPTION VARIABLES
C --    10 POND HEIGHT
C --    11 FLUME HEIGHT
C --    12 INFLOW QUALITY DATA (ONE HEADER CARD ASSUMED AT BEGINNING
C --      OF EACH RECORD
C --    13 OUTFLOW QUALITY DATA (ONE HEADER CARD ASSUMED AT BEGINNING
C --      OF EACH RECORD
C --    15 PRECIPITATION
      READ(5,206) M, MM, KHT, NR,IPLOT,ICOMP,IPFLOW,IPQUAL,
     $IPRAIN,NVAR
      READ(5,207) DELT,DELTQ,XFAC,DELH,FMAX,RMAX
      READ(5,208) NTIME
      EPS1 = ABS(DELT-15.)
      EPS2 = ABS(DELT-3.75)
      EPS = EPS1
      IF(EPS2 .LT. EPS) EPS = EPS2
      IF(EPS .GT. 1.E-06) GO TO 999
206   FORMAT(16I5)
207   FORMAT(8F10.3)
208   FORMAT(8A10)
      WRITE(6,400)
400   FORMAT(1H1,10X,*ECHO PRINT OF INPUT DATA*,//)
      WRITE(6,401) M, MM, KHT, NR, IPLOT, ICOMP,IPFLOW,IPQUAL,
     $IPRAIN,NVAR
401   FORMAT(1H ,16I5)
      WRITE(6,402) DELT,DELTQ,XFAC,DELH,FMAX,RMAX
402   FORMAT(1H ,8F10.4)
403   FORMAT(1H ,8A10)
      WRITE(6,403) NTIME
      NN = KHT
CCC   READ(     )(RR(I),I=1,N)
      GO TO (21,22), IPLOT
21    CALL PRNTON
      GO TO 23
22    CALL STCCON(48H
     $                                            )
23    CONTINUE
      READ(15,411)
      READ(15,417) (RAIN(J),J=1,NR)
417   FORMAT(20X,12F4.0)
      READ(11,412)(FLUHT(I),I=1,KHT)
      READ(10,412)(PONDHT(I),I=1,KHT)
      WRITE(6,414)
414   FORMAT(//,10X,*FLUHT*,/)
      WRITE(6,420) (FLUHT(I), I=1,KHT)
      WRITE(6,415)
415   FORMAT(//,10X,*PONDHT*,/)
```

```
      WRITE(6,420) (PONDHT(I), I=1,KHT)
      WRITE(6,418)
418   FORMAT(//,10X,*RAINFALL*,/)
      WRITE(6,420) (RAIN(I),I=1,NR)
      NN=KHT
      DO 95 J=1,KHT
      PONDSTA(J)=PONDHT(J)
      FLUSTA(J)=FLUHT(J)
95    CONTINUE
      IF(DELT .EQ. 3.75) GO TO 10
CC    INTERPOLATE FLUME AND POND HEIGHTS FROM 15 TO 3.75 MIN INC.
      CALL INTERP(FLUHT,KHT,FLUSTA)
      CALL INTERP(PONDHT,KHT,PONDSTA)
      NN=4*(KHT-1)+1
CC    CALCULATE OUTFLOW VIA STAGE-DISCHARGE RELATIONSHIP
10    DO 100 J=1,NN
      FLUSTA(J)=FLUSTA(J)+DELH
  100 QOUT(J)=5.65685*(10**(0.1444+2.665*ALOG10((FLUSTA(J)/2.))))
      GO TO (11,12,13), ICOMP
11    CONTINUE
CC    CALCULATE INFLOW FROM STORAGE AND OUTFLOW--BACKWARDS STORAGE
CC    ROUTING USING A FORWARD DIFFERENCE APPROXIMATION
      DO 110 I=1,NN
      J = NN-I+1
110   QIN(J)=2.*VOL(PONDSTA(J+1))/(3.75*60.)+QOUT(J+1)+
     &QOUT(J)-QIN(J+1)-2*VOL(PONDSTA(J))/(3.75*60.)
      GO TO 15
12    CONTINUE
C     CALCULATE INFLOW FROM CENTRAL DIFFERENCE APPROXIMATION USING
C     STORAGE AND OUTFLOW.  THE FIRST INFLOW VALUE IS CALCULATED
C     USING FORWARD DIFFERENCE.
CC    CALIBRATION OF MODEL THROUGH ALPHA WHICH AFFECTS CHANGES IN
CC    STORAGE.  BEFORE CALIBRATION ALPHA = .5 FOR CENTRAL DIFFERENCE.
      ALPHA = .5*XFAC
      PONDSTA(NN+1) = PONDSTA(NN)
      DO 111 I=2,NN
      J = NN-I+2
  111 QIN(J)=ALPHA*(VOL(PONDSTA(J+1))-VOL(PONDSTA(J-1)))/(3.75*60.)
     &+QOUT(J)
      QIN(1)=(VOL(PONDSTA(2))-VOL(PONDSTA(1)))/(3.75*60.)+QOUT(1)
      GO TO 15
13    CONTINUE
C     CALCULATE INFLOW FROM BACKWARDS DIFFERENCE.
      DO 112 I=2,NN
      J = NN-I+2
112   QIN(J)=(VOL(PONDSTA(J))-VOL(PONDSTA(J-1)))/(3.75*60)
     &+(QOUT(J-1)+QOUT(J))/2.
      QIN(1)=(VOL(PONDSTA(2))-VOL(PONDSTA(1)))/(3.75*60.)+QOUT(1)
15    QO=0.
      CALL VPLOT(NN,QIN,QOUT,NR,RAIN,IPFLOW,IPRAIN,FMAX,RMAX,NTIME,
     $DELT)
```

```
      WRITE(6,399)
      DELST(1)=0
      MMM=NN-1
      DO 699 J=2,MMM
  699 DELST(J)=(VOL(PONDSTA(J+1))-VOL(PONDSTA(J-1)))*ALPHA
      DO 700 J=1,NN
      QO=QO+QOUT(J)*3.75*60./1000.
  700 WRITE(6,500)J,QOUT(J),VOL(PONDSTA(J)),PONDSTA(J),FLUSTA(J),
     &DELST(J)
      WRITE(6,501)QO
  399 FORMAT(///,3X,'J',4X,'QOUT',4X,'VOL(J)',8X,'PONDHT',2X,'FLUMEHT',
     &1X,'DELTA STORAGE',/)
500   FORMAT(1X,I3,1X,F7.2,1X,F12.1,1X,F10.2,1X,F7.2,1X,F7.1)
      WRITE(6,503)
      Q=0.
      DO 701 J=1,NN
      Q=Q+QIN(J)*3.75*60./1000.
  701 WRITE(6,502)J,QIN(J)
      WRITE(6,501)Q
501   FORMAT(///,1X,'TOTAL FLOW = ',F10.3,2X,'CUBIC FEET/1000'///)
502   FORMAT(1X,I3,1X,F7.4)
503   FORMAT(///,3X,'J',4X,'QIN',/)
CC    ALSO NOTE THAT THIS EQUATION IS FOR 3.75 MIN TIME INCREMENTS
CC    ONLY!!!!!
CC
      DO 600 KK = 1,NVAR
      READ(5,208) ICLAB,ILLAB,OCLAB,OLLAB
      READ(5,208) LABQC
      READ(5,208) LABQL
      READ(5,207) YMC,YML
      READ(12,411)
      READ(13,411)
411   FORMAT(1H )
      READ(12,412) (IQC(J),J=1,M)
      READ(13,412) (OQC(J),J=1,MM)
412   FORMAT(12F6.0)
420   FORMAT(1H ,12F6.2)
      WRITE(6,413) ICLAB
413   FORMAT(///,10X,*ECHO PRINT OF INFLOW DATA FOR *,A10,//)
      WRITE(6,420) (IQC(J),J=1,M)
      WRITE(6,416) OCLAB
416   FORMAT(///,10X,*ECHO PRINT OF OUTFLOW DATA FOR *,A10,//)
      WRITE(6,420) (OQC(J), J=1,MM)
CC    CALCULATE INFLOW POLLUTANT LOADING
      DO 130 J=1,M
  130 IQL(J)=IQC(J)*QIN(J)*5.39254
CC    INFLOW AND OUTFLOW LOADING UNITS ARE NOW IN LBS/DAY
CC    CALCULATE OUTFLOW POLLUTANT LOADING
CC    USE NN FOR OUTFLOW LOADING DO LOOP IF IT IS LESS THAN MM
      IF(NN.LT.MM)MM=NN
      DO 140 J=1,MM
```

```
140   OQL(J) = OQC(J)*QOUT(J)*5.39254
      CALL NOZER(IQC,IQL,DQIN,QIN,TIME1,M,NK)
      CALL NOZER(OQC,OQL,DQOUT,QOUT,TIME2,MM,NL)
      WRITE(6,305) ICLAB
      WRITE(6,306)(TIME1(J),DQIN(J),IQC(J),IQL(J),J=1,NK)
      CALL TOTLOAD(IQL,NK,TIME1,TOTLD)
      WRITE(6,3077)ILLAB,TOTLD
      WRITE(6,310) OCLAB
      WRITE(6,306)(TIME2(J),DQOUT(J),OQC(J),OQL(J),J=1,NL)
      CALL TOTLOAD(OQL,NL,TIME2,TOTLD)
      WRITE(6,311)OLLAB,TOTLD
      CALL PLOTC(TIME1,IQC,NK,TIME2,OQC,NL,IPQUAL,DELTQ,YMC,
     $NTIME,LABQC)
      CALL PLOTC(TIME1,IQL,NK,TIME2,OQL,NL,IPQUAL,DELTQ,YML,
     $NTIME,LABQL)
600   CONTINUE
  305 FORMAT(1X,/////,20X,'INFLOW DATA FOR ',A10,//,5X,
     &'TIME',8X,'INFLOW',7X,'CONCENTRATION',8X,'LOADING',/,
     &5X,'(MIN)',7X,'(CFS)',11X,'(MG/L)',10X,'(LBS/DAY)',/)
  306 FORMAT(1X,F7.2,8X,F6.3,10X,F8.2,8X,F10.2)
  310 FORMAT(1X,///,20X,'OUTFLOW DATA FOR ',A10,//,5X,
     &'TIME',8X,'OUTFLOW',6X,'CONCENTRATION',8X,'LOADING',/,
     &5X,'(MIN)',7X,'(CFS)',11X,'(MG/L)',10X,'(LBS/DAY)',/)
  307 FORMAT(1X,///,10X,'THE TOTAL ',A10,'LOAD = ',
     &F12.2,2X,'LBS')
  311 FORMAT(1X,///,10X,'THE TOTAL ',A10,'OUTPUT LOAD = ',
     &F12.2,2X,'LBS')
      CALL EXITPL
      STOP
999   WRITE(6,998) DELT
      CALL EXITPL
998   FORMAT(//,10X,*DELT = *, F5.2, * ONLY VALUES OF 3.75 OR 15 MIN*,
     $*UTES ARE ADMISSABLE, PROGRAM TERMINATED*)
      END
      SUBROUTINE VPLOT(NN,QIN,QOUT,NR,RAIN,IPFLOW,IPRAIN,FMAX,
     $RMAX,NTIME,DELT)
      DIMENSION X(2), Y(2), W(2), Z(2), TF(500), TR(100),QIN(500),
     $QOUT(500),NTIME(5),RAIN(100)
      CALL STS20B(1.,4.3,1.,2.4)
      DO 10 I = 1,NN
10    TF(I) = IPFLOW*DELT/60. + (I-1)*3.75/60.
      NRP1 = NR + 1
      DO 20 I = 1,NRP1
20    TR(I) = IPRAIN*.5 + (I-1)*.5
      XP = TF(NN)/6.
      NP = XP
      XPP = XP-NP
      NPP = NP + 1
      IF(XPP .GT. .9) NPP = NP + 2
      TMAX = NPP*6.
      CALL STSUBJ(0.,TMAX,0.,FMAX)
```

```
CALL STNDIV(1,1)
CALL GDLILI
CALL STNDIV(NPP,5)
CALL AXLILI
CALL STNDEC(2)
CALL STCHSZ(.057)
CALL NODLIL
CALL STNDEC(0)
CALL NODLIB
CALL STNCHR(50)
CALL STCHSZ(.070)
CALL TITLEB(NTIME)
CALL STNCHR(10)
CALL TITLEL(10HFLOW,CFS   )
CALL STNPTS(NN)
CALL STTXTR(4)
CALL SLLILI(TF,QOUT)
CALL STTXTR(1)
CALL SLLILI(TF,QIN)
XOBJ1 = 7.0
XOBJ2 = 7.5
XOBJ3 = 7.7
XOBJ4 = 7.4
CALL STNPTS(2)
YOBJ = 3.5
X(1) = OSLIX(XOBJ4)
X(2) = OSLIX(XOBJ2)
Y(1) = OSLIY(YOBJ+.5)
Y(2) = OSLIY(YOBJ+.8)
X(1) = OSLIX(XOBJ1)
X(2) = OSLIX(XOBJ2)
Y(1) = Y(2) = OSLIY(YOBJ)
CALL STTXTR(1)
CALL SLLILI(X,Y)
CALL OBLNST(XOBJ3,YOBJ)
CALL TITLEG(10HINFLOW        )
YOBJ = 3.0
Y(1) = Y(2) = OSLIY(YOBJ)
CALL STTXTR(4)
CALL SLLILI(X,Y)
CALL OBLNST(XOBJ3,YOBJ)
CALL TITLEG(10HOUTFLOW      )
CALL STS2OB(1.,4.3,2.4,3.2)
CALL STNDIV(1,1)
CALL GDLILI
CALL STSUBJ(0.,TMAX,0.,RMAX)
CALL STNDEC(3)
CALL STNDIV(1,5)
CALL AXLIR
CALL NODLIR
CALL STNCHR(20)
```

```
      CALL TITLER(20HRAINFALL RATE, IN/HR        )
      CALL STNPTS(2)
      X(1) = TR(1)
      X(2) = X(1)
      Y(1) = 0.
      Y(2) = 2.*RAIN(1)/100.
      CALL SLLILI(X,Y)
      NRM1 = NR - 1
      DO 30 I = 1,NRM1
      X(1) = TR(I)
      X(2) = TR(I+1)
      Y(1) = 2.*RAIN(I)/100.
      Y(2) = Y(1)
      CALL SLLILI(X,Y)
      Y(2) = 2.*RAIN(I+1)/100.
      X(1) = X(2)
30    CALL SLLILI(X,Y)
      X(1) = TR(NR)
      X(2) = TR(NR+1)
      Y(1) = 2.*RAIN(NR)/100.
      Y(2) = Y(1)
      CALL SLLILI(X,Y)
      X(1) = X(2)
      Y(2) = 0.
      CALL SLLILI(X,Y)
      CALL ADVANC(999.,999.)
      RETURN
      END
      SUBROUTINE PLOTC(T1,CI,NI,T2,CO,NO,IP,DELT,YMAX,NTIME,LABEL)
      DIMENSION T1(500),T2(500),CI(500),CO(500),NTIME(5),LABEL(5)
     $,T(500),X(2),Y(2)
      CALL STS20B(1.,4.3,1.,3.2)
      NDEC = 0
      IF(YMAX .LT. 10.) NDEC = 1
      IF(YMAX .LT. 1.) NDEC = 2
      IM = (DELT+1.E-06)/3.75
      DO 10 I = 1,NO
10    T(I) = (IP*3.75*IM)/60. + T2(I)/60.
C --  MAKE TOTAL AXIS LENGTH AN EVEN MULTIPLE OF 6 HOURS
      XP = T(NO)/6.
      NP = XP
      XPP = XP-NP
      NPP = NP + 1
      IF(XPP .GT. .9) NPP = NP + 2
      TMAX = NPP*6
      CALL STSUBJ(0.,TMAX,0.,YMAX)
      CALL STNDIV(1,1)
      CALL GDLILI
      CALL STNDIV(NPP,5)
      CALL AXLILI
      CALL STNDEC(NDEC)
```

```
      CALL STCHSZ(.057)
      CALL NODLIL
      CALL STNDEC(0)
      CALL NODLIB
      CALL STNCHR(50)
      CALL STCHSZ(.070)
      CALL TITLEB(NTIME)
      CALL TITLEL(LABEL)
      CALL STNPTS(NO)
      CALL STTXTR(4)
      CALL SLLILI(T,CO)
      CALL STNPTS(NI)
      DO 11 I = 1,NI
11    T(I) = IP*IM*3.75/60. +T1(I)/60.
      CALL STTXTR(1)
      CALL SLLILI(T,CI)
      XOBJ1 = 7.0
      XOBJ2 = 7.5
      XOBJ3 = 7.7
      CALL STNPTS(2)
      YOBJ = 6.0
      X(1) = OSLIX(XOBJ1)
      X(2) = OSLIX(XOBJ2)
      Y(1) = Y(2) = OSLIY(YOBJ)
      CALL STTXTR(1)
      CALL SLLILI(X,Y)
      CALL OBLNST(XOBJ3,YOBJ)
      CALL STNCHR(10)
      CALL TITLEG(10HINFLOW    )
      YOBJ = 5.5
      Y(1) = Y(2) = OSLIY(YOBJ)
      CALL STTXTR(4)
      CALL SLLILI(X,Y)
      CALL OBLNST(XOBJ3,YOBJ)
      CALL TITLEG(10HOUTFLOW   )
      CALL ADVANC(999.,999.)
      RETURN
      END
      SUBROUTINE NOZER(XC,XL,DQ,Q,T,M,N)
      DIMENSION XC(500),XL(500),DQ(500),Q(500),T(500)
      IC = 0
      DO 10 J = 1,M
      IF(XC(J) .EQ. 0.) GO TO 10
      IC = IC + 1
      XC(IC) = XC(J)
      XL(IC) = XL(J)
      DQ(IC) = Q(J)
      T(IC) = (J-1)*3.75
10    CONTINUE
      N = IC
      RETURN
```

```
      END
      SUBROUTINE INTERP(HT,K,STAGEI)
      DIMENSION HT(100),STAGEI(500)
      NN=K-1
      DO 10 I=1,NN
      DO 10 J=1,4
   10 STAGEI((I-1)*4+J)=HT(I)*(1.-(J-1)/4.)+HT(I+1)*(J-1)/4.
      STAGEI(4*NN+1)=HT(K)
      RETURN
      END
      SUBROUTINE TOTLOAD(TILP,N,TIME,TOTLD)
CC
CC
CC    THIS SUBROUTINE INTEGRATES THE POLLUTANT LOADINGS
CC    OVER TIME TO SOLVE FOR THE TOTAL POLLUTANT LOAD IN AND OUT
CC    OF THE POND OVER THE LENGTH OF THE STORM.
CC
CC
      DIMENSION TILP(100),TIME(100)
      TOTLD=0
      NM=N-1
      DO 5 J=1,NM
      IF(TILP(J).GT.TILP(J+1))TOT=(1/1440.)*(TIME(J+1)-TIME(J))*
     &(((TILP(J)-TILP(J+1))*.5)+TILP(J+1))
      IF(TILP(J).LE.TILP(J+1))TOT=(1/1440.)*(TIME(J+1)-TIME(J))*
     &(((TILP(J+1)-TILP(J))*.5)+TILP(J))
    5 TOTLD=TOT+TOTLD
      RETURN
      END
      FUNCTION VOL(PONDHT)
CC
CC
CC    THE FOLLOWING FUNCTION SUBPROGRAM COMPUTES VOLUME OF
CC    WATER IN THE POND (IN CUBIC FEET) FROM STAGE DATA
      IPONDHT=PONDHT+1.7
      GO TO (1,2,3,4,5,6),IPONDHT
    1 VOL=PONDHT*107.4+0.
      RETURN
    2 RES=PONDHT-0.3
      VOL=RES*575.9+(1.-RES)*32.2
      RETURN
    3 RES=PONDHT-1.3
      VOL=RES*1656.1+(1.-RES)*575.93
      RETURN
    4 RES=PONDHT-2.3
      VOL=RES*3076.2+(1.-RES)*1656.1
      RETURN
    5 RES=PONDHT-3.3
      VOL=RES*4780.1+(1.-RES)*3076.2
      RETURN
    6 RES=PONDHT-4.3
```

```
VOL=RES*6800.4+(1.-RES)*4780.1
RETURN
END
```

Whispering Heights Data Analysis
Computer Program

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1)
      DIMENSION QI(4000),Q(500),STAGE(500),SI(4000),TIME(150)
      DIMENSION T(500),TEXTB(4),TEXTL(4),LAB1(2),LAB2(2),
     $QUALI(400),IF(4000),QUALO(400),TEXTL1(4),TEXTL2(4),TT(500)
     $,QLI(400),QLO(400),PCP(500),ZI(400),ZO(400)
      DATA (TEXTL1(J),J=1,4)/40H         TSS CONCENTRATION, MG/L
     $          /
      DATA (TEXTL2(J),J=1,4)/40H   SUSPENDED SOLIDS LOADING, LBS/DAY
     $              /
      DATA CONVT/5.39/
      REAL IF,LMAX
C --  PROGRAM TO COMPUTE INFLOW AND OUTFLOW FROM WHISPERING
C --  HEIGHTS DETENTION FACILITY GIVEN POND STAGE HEIGHT,
C --  AND TO PLOT INFLOW, OUTFLOW, INFLOW AND OUTFLOW QUALITY
C --  CONCENTRATIONS AND LOADINGS AS FUNCTION OF TIME
C --  IFERF = INITIAL PERIOD FOR FLOW MINUS ONE (HALF HOURS)
C --  NPERF = NUMBER OF PERIODS FOR FLOW (HALF HOURS)
C --  NPERQ = NUMBER OF PERIODS FOR QUALITY (UNITS DEPEND ON TINT)
C --  NDIVX = NUMBER OF X AXIS DIVISIONS
C --  NYQ = NUMBER OF Y AXIS DIVISIONS FOR FLOW
C --  NYL = NUMBER OF Y AXIS DIVISIONS FOR LOADING
C --  ITP = STORAGE EQUATION SOLUTION METHOD FOR INFLOW: = 1
C --  USES BACKWARD DIFFERENCE, = 2 USES CENTRAL DIFFERENCE
C --  FAC = STAGE LEVEL TIME CORRECTION FACTOR
C --  FMAX = MAXIMUM FLOW FOR AXIS (CFS)
C --  QMAX = MAXIMUM QUALITY CONCENTRATION (MG/L)
C --  LMAX = MAXIMUM QUALITY LOADING (LBS/DAY)
C --  TMAX = MAXIMUM TIME (2*HRS)
C --  TPERQ = INITIAL PERIOD FOR QUALITY MINUS ONE (HALF HOURS)
C --  STAGE = STAGE HEIGTH IN FT/2
C --  QUALI = INFLOW QUALITY, MG/L
C --  QUALO = OUTFLOW QUALITY, MG/L
C --  TEXTL = LEFT AXIS LABEL
C --  TEXTB = BOTTOM AXIS LABEL
C --  TINT IS QUALITY DATA COLLECTION INTERVAL (HOURS)
C --  IPERP IS INITIAL PERIOD MINUS ONE FOR PRECIPITATION (HALF
C --    HOURS)
C --  NPERP IS NUMBER OF PERIODS FOR PRECIPITATION (HALF HOURS)
C --  PMAX IS PRECIPITATION SCALE MAXIMUM (SHOULD BE DIVISIBLE BY 5)
      READ(5,1) IPERF,NPERF,NPERQ,NDIVX,NDIVY,NYQ,NYL,ITP,
     $FAC,FMAX,QMAX,LMAX,TMAX,TPERQ,TINT,PMAX
      READ(5,1) IPERP, NPERP
      WRITE(6,100)
100   FORMAT(1H1)
      WRITE(6,101)  IPERF,NPERF,NPERQ,NDIVX,NDIVY,NYQ,NYL,ITP,
     $FAC,FMAX,QMAX,LMAX,TMAX,TPERQ,TINT,PMAX
      WRITE(6,101) IPERP, NPERP
101   FORMAT(1H ,8I5,8F10.2)
1     FORMAT(8I5,8F5.0)
      READ(1,5)
5     FORMAT(1H )
```

```
      NPP = NPERP + IPERP
      READ(1,4) (PCP(J),J=1,NPP)
      WRITE(6,102) (PCP(J),J=1,NPP)
4     FORMAT(20X,12F5.0)
      NREADF = IPERF + NPERF
      READ(5,2) (STAGE(J),J=1,NREADF)
      WRITE(6,102) (STAGE(J),J=1,NREADF)
102   FORMAT(1H ,12F10.2)
2     FORMAT(20X,12F5.0)
      READ(5,2) (QUALI(J),J=1,NPERQ)
      WRITE(6,102) (QUALI(J),J=1,NPERQ)
      READ(5,2) (QUALO(J),J=1,NPERQ)
      WRITE(6,102) (QUALO(J),J=1,NPERQ)
      READ(5,3) (TEXTL(J),J=1,4)
      READ(5,3) (TEXTB(J),J=1,4)
      WRITE(6,103) (TEXTL(J),J=1,4)
      WRITE(6,103) (TEXTB(J),J=1,4)
103   FORMAT(1H ,4A10)
3     FORMAT(4A10)
      DO 10 J = 1,NPERF
10    STAGE(J) = STAGE(J+IPERF)/10./2.
      DO 20 J = 1,NPERF
20    CALL OUTFLOW(STAGE(J),Q(J))
      NN = 10*(NPERF -1) + 1
      MM=10*(IPERP-1)+1
      PRINT*,"Q(J),J=1,NPERF", (Q(J),J=1,NPERF)
      CALL INTERP(Q,NPERF,QI)
C     PRINT*,"QI(J),J=1,NN",(QI(J),J=1,NN)
C     PRINT*,"STAGE(J),J=1,NPERF",(STAGE(J),J=1,NPERF)
      CALL INTERP(STAGE,NPERF,SI)
C     PRINT*,"SI(J),J=1,NN",(SI(J),J=1,NN)
      CALL INFLOW(QI,NN,SI,IF,FAC,ITP)
C     PRINT*,"IF(J),J=1,NN",(IF(J),J=1,NN)
      QII=0
      QO=0
      DO 110 J=1,NN
      QO=QO+QI(J)*3.*60./1000.
      QII=QII+IF(J)*3.*60./1000.
110   CONTINUE
      WRITE(6,150)QII,QO
150   FORMAT(///,1X,'TOTAL VOLUME OF INFLOW =',F10.3,'CUBIC FEET/1000',
     &///,1X,'TOTAL VOLUME OF OUTFLOW =',F10.3,'CUBIC FEET/1000')
      CALL STCCON(48H
     $                                                )
      DO 30 I = 1,NPERF
30    IF(I) = IF(1+(I-1)*10)
      PRINT*,"IF(J),J=1,NPERF",(IF(J),J=1,NPERF)
      DO 35 J = 1,NPERF
35    TT(J) = IPERF +1 + (J-1)*FAC
      PRINT*,"TT(J),J=1,NPERF",(TT(J),J=1,NPERF)
      ENCODE(20,201,LAB1)
```

```
201   FORMAT(20HOUTFLOW                             )
      ENCODE(20,202,LAB2)
202   FORMAT(20HINFLOW                              )
      CALL DPLOT1(Q,IF,TT,FMAX,TMAX,TEXTB,TEXTL,4,0,NDIVX,NDIVY
     $,NPERF,LAB1,LAB2,IPERP,NPERP,PMAX,PCP)
      ENCODE(20,203,LAB1)
203   FORMAT(20HOUTFLOW                             )
      ENCODE(20,204,LAB2)
204   FORMAT(20HINFLOW                              )
      DO 45 J = 1,NPERQ
45    T(J) = TPERQ + 1.0 + (J-1)*2.*TINT
      CALL DPLOT2(QUALO,QUALI,T,QMAX,TMAX,TEXTB,TEXTL1,
     $4,1,NDIVX,NYQ,NPERQ,LAB1,LAB2)
      PRINT*,"T(J),J=1,NPERQ",(T(J),J=1,NPERQ)
      DO 60 I = 1,NPERQ
      DO 55 J = 1,NPERF
      JC = J
55    IF(TT(J) .GE. T(I)) GO TO 58
58    DEN = TT(JC) -TT(JC-1)
      FAC1 = (T(I)-TT(JC-1))/DEN
      FAC2 = (TT(JC)-T(I))/DEN
      QLI(I) = (FAC2*IF(JC-1) + FAC1*IF(JC))*QUALI(I)*CONVT
      QLO(I) = (FAC2*Q(JC-1) + FAC1*Q(JC))*QUALO(I)*CONVT
      ZI(I)=(FAC2*IF(JC-1)+FAC1*IF(JC))
      ZO(I)=(FAC2*Q(JC-1)+FAC1*Q(JC))
      PRINT*,"QLI(I),QLO(I)",QLI(I),QLO(I)
60    CONTINUE
      N=0
      DO 300 J=1,NPERQ
      IF(QUALI(J).EQ.0)GO TO 300
      N=N+1
      QUALI(N)=QUALI(J)
      QLI(N)=QLI(J)
      ZI(N)=ZI(J)
      TIME(N)=(J-1)*60.*TINT
300   CONTINUE
      NL=N
      WRITE(6,115)
      WRITE(6,116)(TIME(J),ZI(J),QUALI(J),QLI(J),J=1,NL)
      CALL TOTLOAD(QLI,NL,TIME,TOTLD)
      WRITE(6,120)TOTLD
      N=0
      DO 310 J=1,NPERQ
      IF(QUALO(J).EQ.0)GO TO 310
      N=N+1
      QUALO(N)=QUALO(J)
      QLO(N)=QLO(J)
      ZO(N)=ZO(J)
      TIME(N)=(J-1)*60.*TINT
310   CONTINUE
      NL=N
```

```
      WRITE(6,117)
      WRITE(6,116)(TIME(J),ZO(J),QUALO(J),QLO(J),J=1,NL)
      CALL TOTLOAD(QLO,NL,TIME,TOTLD)
      WRITE(6,121)TOTLD
115   FORMAT(1X,/////,20X,'INFLOW DATA FOR TSS',//,5X,'TIME',8X,'INFLOW',
     &7X,'CONCENTRATION',8X,'LOADING',/,5X,'(MIN)',7X,'(CFS)',11X,'(M
     &G/L)',14X,'(LBS/DAY)',/)
116   FORMAT(1X,F7.2,8X,F6.3,10X,F8.3,8X,F10.4)
117   FORMAT(1X,///,20X,'OUTFLOW DATA FOR TSS',//,5X,'TIME',8X,'OUTFLOW',
     &6X,'CONCENTRATION',8X,'LOADING',/,5X,'(MIN)',7X,'(CFS)',11X,'(MG
     &/L)',14X,'(LBS/DAY)',/)
120   FORMAT(1X,///,10X,'THE TOTAL TSS INPUT LOAD =',F12.4,2X,'LBS')
121   FORMAT(1X,///,10X,'THE TOTAL TSS OUTPUT LOAD =',F12.4,2X,'LBS')
      CALL DPLOT2(QLO,QLI,T,LMAX,TMAX,TEXTB,TEXTL2,4,1,NDIVX,NYL,
     $NPERQ,LAB1,LAB2)
      CALL EXITPL
      END
      SUBROUTINE TOTLOAD(TILP,N,TIME,TOTLD)
      DIMENSION TILP(100),TIME(100)
      TOTLD=0
      NM=N-1
      DO 5 J=1,NM
      IF(TILP(J).GT.TILP(J+1))TOT=(1/1440.)*(TIME(J+1)-TIME(J))*
     &(((TILP(J)-TILP(J+1))*.5)+TILP(J+1))
      IF(TILP(J).LE.TILP(J+1))TOT=(1/1440.)*(TIME(J+1)-TIME(J))*
     &(((TILP(J+1)-TILP(J))*.5)+TILP(J))
5     TOTLD=TOT+TOTLD
      RETURN
      END
      SUBROUTINE BCREST(H,QS,L1,B,HMAX,VISC)
      REAL L1,MAXQ,MAXH
C
C  BROAD CREST WEIR DISCHARGE -- REFERENCE: HENDERSON "OPEN CHANNEL FLOW"
      V=SQRT(2.*32.174/3.*H)
      RE=V*H/VISC
      CL = 1.-0.069*(L1/H-1. +2.84*RE**.25)**.8/RE**.2
      CB=1. - 4.*H*(1.-CL)/3./B
      C=CL*CB
      QS = B*C*3.0876*H**1.5
      RETURN
      END
      SUBROUTINE INFLOW(QI,N,SI,IF,FAC,ITP)
      DIMENSION QI(4000),SI(4000),IF(4000)
      REAL IF
      IF(ITP .EQ. 2) GO TO 10
      IF(1) = QI(1)
C --  CENTRAL DIFFERENCE FORMULATION
      NN = N-1
      DO 100 J = 2,NN
100   IF(J) = .5*(VOL(SI(J+1))- VOL(SI(J-1)))/(3.0*FAC*60.) + QI(J)
      IF(N) = QI(N)
```

```
      RETURN
10    IF(1) = QI(1)
      DO 200 J = 2,N
200   IF(J) = (VOL(SI(J))-VOL(SI(J-1)))/(3.0*FAC*60.) + QI(J)
      RETURN
      END
      FUNCTION VOL(STAGE)
      ISTAGE = STAGE + 1
      GO TO (1,2,3,4,5,6),ISTAGE
1     VOL = STAGE*963. + (1.-STAGE)*0.
      RETURN
2     RES = STAGE - 1.
      VOL = RES*3171. + (1.-RES)*963.
      RETURN
3     RES = STAGE - 2.
      VOL = RES*5983. + (1.-RES)*3171.
      RETURN
4     RES = STAGE - 3.
      VOL = RES*9463. + (1.-RES)*5983.
      RETURN
5     RES = STAGE - 4.
      VOL = RES*13846. + (1.-RES)*9463.
      RETURN
6     RES = (STAGE-5.)/.25
      VOL = RES*15114. + (1.-RES)*13846.
      RETURN
      END
      SUBROUTINE DISCH(D,Q)
C     PI = 2.*ASIN(1.)
C --     COMPUTES DISCHARGE THROUGH PARTIALLY FILLED SHARP-
C --     EDGED CIRCULAR ORIFICE
C --     NUMERICALLY INTEGRATES DISCHARGE EQUATION, USING 200
C --     INCREMENTS, AND COEFFICIENT OF CONTRACTION OF 0.40
C     IF(D .LE. .25) GO TO 11
C     IF(D .GT. .25 .AND. D .LE. .50) GO TO 12
C     PHI = PI
C     GO TO 2
C11   PHI = PI/2. -  ASIN((.25-D)/.25)
C     GO TO 2
C12   PHI = PI/2. + ASIN((D-.25)/.25)
C2    DELPHI = PHI/200.
C     Q = 0.
C     IF(D .GT. .25) GO TO 150
C     DO 100 J = 1,200
C     XPHI = DELPHI*J
C     DY = .25*COS(XPHI-DELPHI) - .25*COS(XPHI)
C     W = 2.*.25*(SIN(XPHI)+SIN(XPHI-DELPHI))/2.
C     Y = (.25*COS(XPHI) + .25*COS(XPHI-DELPHI))/2. - (.25-D)
C     IF(Y .LT. 0.) PRINT*,"D,J,XPHI,Y", D,J,XPHI,Y
C     DQ = SQRT(2.*32.17*Y)*W*DY*.6
C100  Q = Q + DQ
```

```
C       RETURN
C150    DO 200 J = 1,200
C       XPHI = DELPHI*J
C       DY = .25*COS(XPHI-DELPHI) - .25*COS(XPHI)
C       W = 2.*.25*(SIN(XPHI)+SIN(XPHI-DELPHI))/2.
C       Y = D-.25 + (.25*COS(XPHI) + .25*COS(XPHI-DELPHI))/2.
C       IF(Y .LT. 0.) PRINT*,"D,J,XPHI,Y", D,J,XPHI,Y
C       DQ = SQRT(2.*32.17*Y)*W*DY*.6
C200    Q = Q + DQ
C --      COMPUTES DISCHARGE USING CURVES COMPUTED FROM BOTH
C --      HALF SCALE AND FULL SCALE MODELS.
        H=D-.25
        IF(H.LT..03)GO TO 11
        IF(H.GE..03.AND.H.LT..215) GO TO 12
        Z1=-0.02309+0.4579*ALOG10(H)
        Q=10**Z1
        GO TO 2
     12 Z2=-0.02309+0.4579*ALOG10(H)+0.1120*(ALOG10(.215-H))+
       &0.04821*((ALOG10(.215-H))**2)
        Q=10**Z2
        GO TO 2
     11 Q=-0.05483+D*0.7841
      2 RETURN
        END
        SUBROUTINE OUTFLOW(STAGE,FLOW)
        CALL DISCH(STAGE,OFLOW)
        FLOW = OFLOW
        IF(STAGE .LT. 50./12.) RETURN
        H = STAGE - 50./12.
        XL = 10./12.
        CALL BCREST(H,WEIRQ,XL,4.0,1.167,1.664E-05)
        FLOW = OFLOW + WEIRQ
        RETURN
        END
        SUBROUTINE INTERP(Q,N,QI)
        DIMENSION Q(500),QI(4000)
        NN = N-1
        DO 10 I = 1,NN
        DO 10 J = 1,10
10      QI((I-1)*10+J) = Q(I)*(1.-(J-1)/10.) + Q(I+1)*(J-1)/10.
        QI(10*NN+1) = Q(N)
        RETURN
        END
        SUBROUTINE DPLOT1(QI,IF,T,FMAX,TMAX,TEXTB,TEXTL,NTXTR,IPOINT,
       $NDIVX,NDIVY,N,LAB1,LAB2,IPERP,NPERP,PMAX,PCP)
        DIMENSION QI(400) ,IF(400) ,T(500),TEXTL(4),TEXTB(4),
       $LAB1(2),LAB2(2),X(2),Y(2),PCP(500),TPCP(500)
        REAL IF
        CALL STTXTR(1)
        CALL STS2OB(1.,4.3,1.,2.4)
        TMAX1 = TMAX/2.
```

```
      CALL STSUBJ(0.,TMAX1,0.,FMAX)
      CALL STNDIV(1,1)
      CALL GDLILI
      CALL STNDIV(NDIVX,NDIVY)
      CALL STCHSZ(.057)
      CALL AXLILI
      CALL STNDEC(1)
      CALL NODLIL
      CALL STNDEC(0)
      CALL NODLIB
      CALL STSUBJ(0.,TMAX,0.,FMAX)
      CALL STNPTS(N)
      CALL SLLILI(T,QI)
      CALL STTXTR(NTXTR)
      CALL SLLILI(T,IF)
      CALL STTXTR(1)
      IF(IPOINT .EQ. 0) GO TO 10
      CALL STSYMB(3)
      CALL PSLILI(T,QI)
      CALL STSYMB(5)
      CALL PSLILI(T,IF)
10    CALL STNCHR(40)
      CALL STCHSZ(.070)
      CALL TITLEL(TEXTL)
      CALL TITLEB(TEXTB)
      X(1) = TMAX/50.
      X(2) = X(1) + TMAX/15.
      Y(1) = Y(2) = .95*FMAX
      CALL STNPTS(2)
      CALL STNCHR(20)
      CALL SLLILI(X,Y)
      CALL STSYMB(3)
      IF(IPOINT .NE. 0) CALL PSLILI(X,Y)
      XX = X(2) + TMAX/50.
      CALL STLNST(XX,Y(1))
      CALL STCHSZ(.057)
      CALL TITLEG(LAB1)
      Y(1) = Y(2) = .90*FMAX
      CALL STTXTR(NTXTR)
      CALL SLLILI(X,Y)
      CALL STSYMB(5)
      IF(IPOINT .NE. 0) CALL PSLILI(X,Y)
      CALL STLNST(XX,Y(1))
      CALL TITLEG(LAB2)
      CALL STS2OB(1.,4.3,2.4,3.2)
      CALL STSUBJ(0.,TMAX1,0.,PMAX)
      NNN=NPERP+1
      DO 20 I = 1,NNN
20    TPCP(I) = (IPERP+I)/2.
      DO 21 I = 1,NPERP
21    PCP(I) = 2.*PCP(I+IPERP)/100.
```

```
      PRINT*, "PCP", (PCP(J),J=1,NPERP)
      CALL STNDIV(1,1)
      CALL GDLILI
      CALL STNDIV(NDIVX,5)
      CALL AXLIR
      CALL STNDEC(3)
      CALL NODLIR
      CALL TITLER(20HPRECIP RATE, IN/HR    )
      CALL STTXTR(4)
      X(1) = TPCP(1)
      X(2) = X(1)
      Y(1) = 0.
      Y(2) = PCP(1)
      CALL STNPTS(2)
      CALL SLLILI(X,Y)
      NRM1 = NPERP - 1
      DO 30 I = 1,NRM1
      X(1) = TPCP(I)
      X(2) = TPCP(I+1)
      Y(1) = PCP(I)
      Y(2) = Y(1)
      CALL SLLILI(X,Y)
      Y(2) = PCP(I+1)
      X(1) = X(2)
30    CALL SLLILI(X,Y)
      X(1) = TPCP(NPERP)
      X(2) = TPCP(NPERP + 1)
      Y(1) = PCP(NPERP)
      Y(2) = Y(1)
      CALL SLLILI(X,Y)
      X(1) = X(2)
      Y(2) = 0.
      CALL SLLILI(X,Y)
      CALL ADVANC(999.,999.)
      RETURN
      END
      SUBROUTINE DPLOT2(QI,IF,T,FMAX,TMAX,TEXTB,TEXTL,NTXTR,IPOINT,
     $NDIVX,NDIVY,N,LAB1,LAB2)
      DIMENSION QI(400) ,IF(400) ,T(500),TEXTL(4),TEXTB(4),
     $LAB1(2),LAB2(2),X(2),Y(2)
      REAL IF
      CALL STTXTR(1)
      CALL STS2OB(1.,4.3,1.,3.2)
      TMAX1 = TMAX/2.
      CALL STSUBJ(0.,TMAX1,0.,FMAX)
      CALL STNDIV(1,1)
      CALL GDLILI
      CALL STNDIV(NDIVX,NDIVY)
      CALL STCHSZ(.057)
      CALL AXLILI
      CALL STNDEC(1)
```

```
      CALL NODLIL
      CALL STNDEC(0)
      CALL NODLIB
      CALL STSUBJ(0.,TMAX,0.,FMAX)
      CALL STNPTS(N)
      CALL SLLILI(T,QI)
      CALL STTXTR(NTXTR)
      CALL SLLILI(T,IF)
      CALL STTXTR(1)
      IF(IPOINT .EQ. 0) GO TO 10
      CALL STSYMB(3)
      CALL PSLILI(T,QI)
      CALL STSYMB(5)
      CALL PSLILI(T,IF)
10    CALL STNCHR(40)
      CALL STCHSZ(.070)
      CALL TITLEL(TEXTL)
      CALL TITLEB(TEXTB)
      X(1) = TMAX/50.
      X(2) = X(1) + TMAX/15.
      Y(1) = Y(2) = .95*FMAX
      CALL STNPTS(2)
      CALL STNCHR(20)
      CALL SLLILI(X,Y)
      CALL STSYMB(3)
      IF(IPOINT .NE. 0) CALL PSLILI(X,Y)
      XX = X(2) + TMAX/50.
      CALL STLNST(XX,Y(1))
      CALL STCHSZ(.070)
      CALL TITLEG(LAB1)
      Y(1) = Y(2) = .90*FMAX
      CALL STTXTR(NTXTR)
      CALL SLLILI(X,Y)
      CALL STSYMB(5)
      IF(IPOINT .NE. 0) CALL PSLILI(X,Y)
      CALL STLNST(XX,Y(1))
      CALL TITLEG(LAB2)
      CALL ADVANC(999.,999.)
      RETURN
      END
```

APPENDIX D.

METRO Site Flow, Concentration and Pollutant Loading Data

(METRO STORMS 2, 3, 7, 8, 9, & 11)

Note: A concentration of .00 means <u>below detection</u> for lead, cadmium and zinc.

STORM: #2
DATE: 8/5/82
SITE: METRO
TOTAL OUTFLOW = 8.696 * 1000 CUBIC FEET
TOTAL INFLOW = 9.162 * 1000 CUBIC FEET

INFLOW DATA FOR GREASE AND OIL

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	1.743	66.70	626.79
3.75	1.883	24.50	248.77
7.50	2.174	21.00	246.14
11.25	2.343	45.50	574.86
15.00	2.218	29.20	349.23
18.75	2.154	18.40	213.76
22.50	2.265	22.10	269.97
26.25	2.323	28.20	353.21
30.00	2.415	14.10	183.63
33.75	2.664	17.70	254.30
37.50	2.970	20.60	329.90
41.25	3.366	4.54	82.42
45.00	2.561	4.60	63.53

THE TOTAL GREASE AND OIL INPUT LOAD = 8.99 LBS

OUTFLOW DATA FOR GREASE AND OIL

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.002	20.10	.25
7.50	.027	29.10	4.28
15.00	.096	15.10	7.79
22.50	.183	15.60	15.38
30.00	.308	23.70	39.31
37.50	.837	9.90	44.70
45.00	1.731	9.14	85.30
52.50	1.388	10.00	74.84
60.00	1.091	8.30	48.83
67.50	.931	7.60	38.15
75.00	.786	8.10	34.35
93.75	.453	6.30	15.39
123.75	.338	5.74	10.45
153.75	.349	2.34	4.40
183.75	.312	5.39	9.06

213.75	.289	5.30	8.25
243.75	.264	3.70	5.27
273.75	.233	6.00	7.55
303.75	.205	4.44	4.90
333.75	.174	3.22	3.02
363.75	.146	5.28	4.17
393.75	.120	5.87	3.80
423.75	.097	4.44	2.32

THE TOTAL GREASE AND OIL OUTPUT LOAD = 3.73 LBS

INFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
3.75	1.883	93.50	949.40
7.50	2.174	70.00	820.48
15.00	2.218	103.00	1231.88
18.75	2.154	109.50	1272.12
22.50	2.265	62.00	757.39
26.25	2.323	16.00	200.40
30.00	2.415	47.00	612.11
33.75	2.664	60.50	869.23
37.50	2.970	60.00	960.88
41.25	3.366	32.00	580.90
45.00	2.561	20.00	276.24

THE TSS INPUT LOAD = 23.29 LBS

OUTFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
3.75	.011	18.50	1.05
11.25	.055	26.50	7.86
18.75	.135	109.50	79.65
26.25	.240	27.00	34.97
33.75	.532	67.00	192.13
41.25	1.234	59.00	392.55
48.75	1.553	39.50	330.88
56.25	1.234	30.50	202.93
63.75	1.009	30.00	163.22
71.25	.857	25.00	115.51
78.75	.702	27.00	102.26
108.75	.358	27.50	53.16
138.75	.343	25.50	47.23
168.75	.343	22.50	41.58
198.75	.300	22.00	35.63
228.75	.277	15.50	23.19
258.75	.249	16.00	21.47
288.75	.219	11.00	12.98
318.75	.189	15.00	15.30
348.75	.160	10.00	8.63
378.75	.133	15.50	11.10
408.75	.107	9.00	5.22

THE TSS OUTPUT LOAD = 14.93 LBS

STORM: 3
DATE: 9/22/82
SITE: METRO

TOTAL INFLOW = 7.506 * 1000 CUBIC FEET
TOTAL OUTFLOW = 8.063 * 1000 CUBIC FEET

INFLOW DATA FOR GREASE AND OIL

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	1.683	63.70	578.10
7.50	2.138	21.89	252.41
15.00	2.101	7.44	84.31
22.50	2.134	8.11	93.31
30.00	2.466	11.77	156.54
37.50	2.865	2.56	39.54
45.00	2.090	10.10	113.82

THE TOTAL GREASE AND OIL INPUT LOAD = 5.06 LBS

OUTFLOW DATA FOR GREASE AND OIL

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.003	1.33	.02
7.50	.020	17.44	1.87
15.00	.094	15.00	7.63
22.50	.202	14.44	15.76
30.00	.395	15.00	31.92
37.50	.620	10.67	35.66
45.00	.967	5.33	27.80
52.50	1.049	10.22	57.80
60.00	.912	2.11	10.37
90.00	.468	5.70	14.39
20.00	.330	6.60	11.75
50.00	.315	4.70	7.97
80.00	.295	5.10	8.12
10.00	.272	.65	.95
40.00	.250	.01	.01
70.00	.227	1.50	1.83
00.00	.202	5.11	5.58
30.00	.167	4.10	3.70
60.00	.135	.11	.08
90.00	.107	.56	.32
20.00	.081	1.11	.49

THE TOTAL GREASE AND OIL OUTPUT LOAD = 2.21 LBS

INFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
3.75	1.863	192.40	1932.86
11.25	2.246	146.40	1773.06
18.75	2.018	41.20	448.37
26.25	2.178	45.60	535.53
33.75	2.747	38.80	574.70
41.25	2.643	36.00	513.01
48.75	1.439	18.00	139.69

THE TSS INPUT LOAD = 25.42 LBS

OUTFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
3.75	.009	24.00	1.16
11.25	.037	78.40	15.58
18.75	.131	28.40	20.09
26.25	.285	30.00	46.04
33.75	.499	54.80	147.54
41.25	.757	46.00	187.77
48.75	1.125	40.00	242.63
56.25	.979	33.60	177.33
75.00	.668	37.20	134.02
05.00	.345	28.00	52.08
35.00	.322	19.60	33.99
65.00	.305	19.60	32.22
95.00	.283	18.40	28.11
25.00	.260	17.60	24.70
55.00	.237	16.40	20.98
85.00	.215	13.20	15.34
15.00	.184	17.60	17.45
45.00	.151	13.60	11.06
75.00	.120	38.70	25.07
05.00	.094	7.70	3.89

THE TSS OUTPUT LOAD = 12.80 LBS

STORM: 7
DATE: 10/6/82
SITE: METRO

TOTAL OUTFLOW = 15.654 * 1000 CUBIC FEET
TOTAL INFLOW = 15.697 * 1000 CUBIC FEET

INFLOW DATA FOR GREASE AND OILS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
37.50	1.026	22.82	126.20
97.50	.199	10.00	10.75
157.50	.037	9.70	1.96
217.50	1.069	12.00	69.20
277.50	.662	10.20	36.40
307.50	.869	6.11	28.63
337.50	.559	5.45	16.43
367.50	.335	7.89	14.24
397.50	.416	5.70	12.80
427.50	.220	7.16	8.49
457.50	.120	7.40	4.78
487.50	.058	4.94	1.54
517.50	.094	13.00	6.58
547.50	.137	15.22	11.25
577.50	.041	4.78	1.05
607.50	.354	5.67	10.81
637.50	.105	5.56	3.15
667.50	.223	13.78	16.57

THE TOTAL GREASE AND OIL OUTPUT LOAD = 9.85 LBS

OUTFLOW DATA FOR GREASE AND OILS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
37.50	.110	5.68	3.38
97.50	.237	11.05	14.13
157.50	.227	7.44	9.10
217.50	.255	11.14	15.33
277.50	.594	11.62	37.24
307.50	.802	8.14	35.18
487.50	.327	6.88	12.15
517.50	.302	8.00	13.03
547.50	.289	7.85	12.22

577.50	.268	5.42	7.83
611.25	.258	5.97	8.30
637.50	.257	6.24	8.63
667.50	.242	5.68	7.41
697.50	.228	5.30	6.51
727.50	.209	5.39	6.09
757.50	.186	5.81	5.82
787.50	.169	5.78	5.27
817.50	.144	7.53	5.85
847.50	.117	5.30	3.35
877.50	.093	6.11	3.08
907.50	.069	3.40	1.27

THE TOTAL GREASE AND OIL OUTPUT LOAD = 8.25 LBS

INFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
7.50	.002	384.00	3.39
67.50	1.014	220.00	1202.95
127.50	.060	92.00	29.96
187.50	.599	464.00	1497.76
247.50	.665	224.00	803.72
292.50	.839	108.00	488.83
322.50	.657	72.00	255.10
352.50	.419	56.00	126.47
382.50	.335	80.00	144.31
472.50	.138	72.00	53.47
502.50	.119	48.00	30.78
532.50	.069	192.00	71.90
562.50	.067	120.00	43.49
592.50	.094	240.00	121.13
622.50	.181	120.00	116.98
652.50	.061	140.00	46.09

THE TSS INPUT LOAD = 180.56 LBS

OUTFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
7.50	.002	516.00	4.56
67.50	.219	224.00	264.33
127.50	.231	228.00	283.74
187.50	.220	184.00	218.24
247.50	.306	252.00	416.11
292.50	.705	224.00	851.18
322.50	.814	212.00	930.76
337.50	.716	200.00	772.58
502.50	.312	160.00	268.99
532.50	.297	152.00	243.14
562.50	.275	76.00	112.90
592.50	.264	80.00	113.88
622.50	.257	88.00	121.72
652.50	.250	52.00	70.21
682.50	.236	52.00	66.18
712.50	.218	128.00	150.66
742.50	.197	64.00	68.04
772.50	.179	76.00	73.29
802.50	.157	180.00	152.86

```
832.50          .130          96.00          67.50
862.50          .107          72.00          41.45
892.50          .081         112.00          48.80
922.50          .052          80.00          22.27

        THE TSS OUTPUT LOAD = 178.36 LBS
```

INFLOW DATA FOR TOTAL PHOSPHORUS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
7.50	.002	.37	.00
67.50	1.014	.07	.41
127.50	.060	.07	.02
187.50	.599	.09	.28
247.50	.665	.07	.26
292.50	.839	.05	.24
322.50	.657	.05	.19
352.50	.419	.10	.22
382.50	.335	.06	.11
412.50	.272	.07	.10
442.50	.147	.07	.06
472.50	.138	.10	.08
502.50	.119	.11	.07
532.50	.069	.14	.05
562.50	.067	.14	.05
592.50	.094	.20	.10
622.50	.181	.12	.11
652.50	.061	.29	.10

THE TOTAL PHOSPHORUS INPUT LOAD = .07 LBS

OUTFLOW DATA FOR TOTAL PHOSPHORUS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
7.50	.002	.33	.00
67.50	.219	.27	.32
127.50	.231	.18	.23
187.50	.220	.15	.18
247.50	.306	.12	.20
292.50	.705	.12	.44
322.50	.814	.09	.38
337.50	.716	.09	.35
502.50	.312	.09	.15
532.50	.297	.09	.14
562.50	.275	.10	.15
592.50	.264	.09	.12
622.50	.257	.09	.12
652.50	.250	.10	.13
682.50	.236	.09	.11
712.50	.218	.09	.10
742.50	.197	.09	.10

772.50	.179	.09	.09
802.50	.157	.11	.10
832.50	.130	.11	.08
862.50	.107	.11	.06
892.50	.081	.15	.06
922.50	.052	.13	.04

THE TOTAL PHOSPHORUS OUTPUT LOAD = .12 LBS

INFLOW DATA FOR TOTAL CADMIUM

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	4.60	.04
67.50	1.014	1.20	6.56
127.50	.060	1.20	.39
187.50	.599	1.40	4.52
247.50	.665	1.30	4.66
292.50	.839	1.40	6.34
322.50	.657	.80	2.83
352.50	.419	1.20	2.71
382.50	.335	.50	.90
412.50	.272	1.20	1.76
442.50	.147	.90	.72
472.50	.138	.90	.67
502.50	.119	.60	.38
532.50	.069	.20	.07
562.50	.067	1.20	.43
592.50	.094	1.00	.50
622.50	.181	.10	.10
652.50	.061	1.70	.56

THE TOTAL CADMIUM INPUT LOAD = 1.05/1000 LBS

OUTFLOW DATA FOR TOTAL CADMIUM

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	.70	.01
67.50	.219	.60	.71
127.50	.231	.70	.87
187.50	.220	.90	1.07
247.50	.306	.70	1.16
292.50	.705	.60	2.28
322.50	.814	.70	3.07
337.50	.716	.70	2.70
502.50	.312	2.20	3.70
532.50	.297	1.70	2.72
562.50	.275	12.70	18.87
592.50	.264	1.00	1.42
622.50	.257	1.10	1.52
652.50	.250	.80	1.08
682.50	.236	2.30	2.93
712.50	.218	.90	1.06
742.50	.197	1.90	2.02
772.50	.179	.70	.68

802.50	.157	1.60	1.36
832.50	.130	.30	.21
862.50	.107	.90	.52
892.50	.081	1.90	.83
922.50	.052	.80	.22

THE TOTAL CADMIUM OUTPUT LOAD = 1.42/1000 LBS

INFLOW DATA FOR SOLUBLE CADMIUM

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	2.00	.02
67.50	1.014	.70	3.83
127.50	.060	.80	.26
187.50	.599	.80	2.58
247.50	.665	.40	1.44
292.50	.839	.40	1.81
322.50	.657	.40	1.42
352.50	.419	.70	1.58
382.50	.335	.50	.90
412.50	.272	.20	.29
442.50	.147	.40	.32
472.50	.138	.30	.22
502.50	.119	.40	.26
532.50	.069	.40	.15
562.50	.067	.70	.25
592.50	.094	.80	.40
622.50	.181	.50	.49
652.50	.061	.90	.30

THE SOLUBLE CADMIUM INPUT LOAD = .51/1000 LBS

OUTFLOW DATA FOR SOLUBLE CADMIUM

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	.50	.00
67.50	.219	.60	.71
127.50	.231	.50	.62
187.50	.220	.40	.47
247.50	.306	.50	.83
292.50	.705	.80	3.04
322.50	.814	.50	2.20
337.50	.716	1.60	6.18
502.50	.312	3.00	5.04
532.50	.297	4.90	7.84
562.50	.275	.60	.89
592.50	.264	1.50	2.14
622.50	.257	.50	.69
652.50	.250	1.20	1.62
682.50	.236	1.10	1.40
712.50	.218	.60	.71
742.50	.197	.60	.64

772.50	.179	1.20	1.16
802.50	.157	1.30	1.10
832.50	.130	1.70	1.20
862.50	.107	.60	.35
892.50	.081	.80	.35

THE SOLUBLE CADMIUM OUTPUT LOAD = 1.36/1000 LBS

INFLOW DATA FOR TOTAL LEAD

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	82.10	.72
67.50	1.014	55.10	301.28
127.50	.060	25.20	8.21
187.50	.599	92.00	296.97
247.50	.665	62.00	222.46
292.50	.839	24.10	109.08
322.50	.657	24.50	86.80
352.50	.419	28.70	64.81
382.50	.335	.00	.00
412.50	.272	31.20	45.85
442.50	.147	26.20	20.82
472.50	.138	39.20	29.11
502.50	.119	44.40	28.47
532.50	.069	34.00	12.73
562.50	.067	29.60	10.73
592.50	.094	84.60	42.70
622.50	.181	35.30	34.41
652.50	.061	46.10	15.18

THE TOTAL LEAD INPUT LOAD = 44.24/1000 LBS

OUTFLOW DATA FOR TOTAL LEAD

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	57.70	.51
67.50	.219	68.60	80.95
127.50	.231	38.20	47.54
187.50	.220	38.60	45.78
247.50	.306	62.20	102.71
292.50	.705	65.10	247.37
322.50	.814	48.90	214.69
337.50	.716	48.00	185.42
502.50	.312	49.40	83.05
532.50	.297	38.20	61.10
562.50	.275	53.80	79.92
592.50	.264	64.20	91.39
622.50	.257	40.10	55.47
652.50	.250	44.00	59.41
682.50	.236	29.80	37.93
712.50	.218	37.00	43.55
742.50	.197	53.40	56.77

772.50	.179	57.40	55.35
802.50	.157	26.60	22.59
832.50	.130	26.60	18.70
862.50	.107	47.00	27.06
892.50	.081	37.80	16.47
922.50	.052	53.00	14.75

THE TOTAL LEAD OUTPUT LOAD = 51.21/1000 LBS

INFLOW DATA FOR SOLUBLE LEAD

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	30.00	.26
67.50	1.014	8.00	43.74
127.50	.060	5.80	1.89
187.50	.599	11.90	38.41
247.50	.665	7.30	26.19
292.50	.839	.00	.00
322.50	.657	16.30	57.75
352.50	.419	10.80	24.39
382.50	.335	.00	.00
412.50	.272	15.40	22.63
442.50	.147	15.90	12.64
472.50	.138	28.80	21.39
502.50	.119	24.40	15.65
532.50	.069	25.40	9.51
562.50	.067	29.30	10.62
592.50	.094	54.60	27.56
622.50	.181	31.90	31.10
652.50	.061	36.90	12.15

THE SOLUBLE LEAD INPUT LOAD = 9.45/1000 LBS

OUTFLOW DATA FOR SOLUBLE LEAD

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	19.20	.17
67.50	.219	12.90	15.22
127.50	.231	28.90	35.97
187.50	.220	47.50	56.34
247.50	.306	.00	.00
292.50	.705	13.80	52.44
322.50	.814	19.50	85.61
337.50	.716	9.60	37.08
502.50	.312	7.70	12.94
532.50	.297	16.70	26.71
562.50	.275	40.50	60.16
592.50	.264	26.70	38.01
622.50	.257	11.30	15.63
652.50	.250	23.00	31.05
682.50	.236	5.10	6.49
712.50	.218	12.00	14.12
742.50	.197	29.80	31.68

772.50	.179	7.70	7.43
802.50	.157	22.10	18.77
832.50	.130	18.60	13.08
862.50	.107	38.80	22.34
892.50	.081	27.30	11.90
922.50	.052	17.30	4.82

THE SOLUBLE LEAD OUTPUT LOAD = 16.63/1000 LBS

INFLOW DATA FOR TOTAL ZINC

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	322.30	2.85
67.50	1.014	136.30	745.28
127.50	.060	142.90	46.54
187.50	.599	180.50	582.64
247.50	.665	127.90	458.91
292.50	.839	85.70	387.90
322.50	.657	92.00	325.96
352.50	.419	106.40	240.29
382.50	.335	93.90	169.38
412.50	.272	88.40	129.90
442.50	.147	80.00	63.57
472.50	.138	95.80	71.14
502.50	.119	103.50	66.37
532.50	.069	78.80	29.51
562.50	.067	117.20	42.48
592.50	.094	170.20	85.90
622.50	.181	89.30	87.05
652.50	.061	151.40	49.84

THE TOTAL ZINC INPUT LOAD = 112.00/1000 LBS

OUTFLOW DATA FOR TOTAL ZINC

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	137.20	1.21
67.50	.219	179.60	211.93
127.50	.231	161.60	201.11
187.50	.220	159.60	189.30
247.50	.306	153.90	254.12
292.50	.705	197.50	750.48
322.50	.814	127.00	557.58
337.50	.716	120.90	467.03
502.50	.312	132.00	221.91
532.50	.297	132.30	211.63
562.50	.275	5463.00	8115.08
592.50	.264	1598.00	2274.85
622.50	.257	415.60	574.86
652.50	.250	126.80	171.20
682.50	.236	270.20	343.90
712.50	.218	265.70	312.73
742.50	.197	381.20	405.27

772.50	.179	142.80	137.71
802.50	.157	513.60	436.17
832.50	.130	168.50	118.47
862.50	.107	635.80	366.04
892.50	.081	361.10	157.35
922.50	.052	334.10	92.99

THE TOTAL ZINC OUTPUT LOAD = 391.69/1000 LBS

INFLOW DATA FOR SOLUBLE ZINC

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	273.30	2.41
67.50	1.014	111.10	607.49
127.50	.060	149.50	48.68
187.50	.599	142.50	459.98
247.50	.665	98.00	351.63
292.50	.839	71.70	324.53
322.50	.657	88.70	314.27
352.50	.419	93.30	210.70
382.50	.335	87.80	158.38
412.50	.272	78.50	115.35
442.50	.147	53.00	42.12
472.50	.138	46.50	34.53
502.50	.119	56.00	35.91
532.50	.069	62.40	23.37
562.50	.067	70.60	25.59
592.50	.094	91.30	46.08
622.50	.181	94.60	92.22
652.50	.061	93.80	30.88

THE SOLUBLE ZINC INPUT LOAD = 91.04/1000 LBS

OUTFLOW DATA FOR SOLUBLE ZINC

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
7.50	.002	86.80	.77
67.50	.219	148.40	175.12
127.50	.231	143.20	178.21
187.50	.220	145.80	172.93
247.50	.306	131.80	217.63
292.50	.705	522.20	1984.32
322.50	.814	118.80	521.58
337.50	.716	531.50	2053.14
502.50	.312	482.40	810.99
532.50	.297	1051.00	1681.19
562.50	.275	1747.00	2595.10
592.50	.264	1176.00	1674.11
622.50	.257	155.20	214.67
652.50	.250	2618.00	3534.62
682.50	.236	150.30	191.30
712.50	.218	155.50	183.03
742.50	.197	568.10	603.97

772.50	.179	1002.00	966.30
802.50	.157	275.10	233.63
832.50	.130	1854.00	1303.56
862.50	.107	128.50	73.98
892.50	.081	180.50	78.65
922.50	.052	289.10	80.47

THE SOLUBLE ZINC OUTPUT LOAD = 51.57/1000 LBS

STORM: 8
DATE: 10/16/82
SITE: METRO

TOTAL OUTFLOW = 11.381 * 1000 CUBIC FEET
TOTAL INFLOW = 11.446 * 1000 CUBIC FEET

INFLOW DATA FOR GREASE AND OIL

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
90.00	.794	11.00	47.11
120.00	1.129	8.30	50.54
150.00	.939	6.60	33.41
180.00	1.265	2.80	19.10
210.00	.694	18.00	67.37
240.00	.124	5.40	3.61
270.00	.038	5.40	1.09

THE TOTAL GREASE AND OIL INPUT LOAD = 4.13 LBS

OUTFLOW DATA FOR GREASE AND OIL

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
90.00	.179	22.00	21.22
120.00	.220	17.00	20.16
150.00	.613	12.00	39.69
180.00	1.478	10.00	79.72
210.00	.997	.50	2.69
240.00	.360	8.20	15.90
270.00	.296	16.00	25.51
300.00	.281	9.30	14.09
330.00	.260	8.40	11.77
360.00	.246	6.40	8.49
390.00	.227	9.10	11.12
420.00	.214	8.00	9.23
450.00	.185	7.20	7.17
480.00	.163	8.90	7.83
510.00	.143	2.00	1.54
540.00	.121	11.00	7.16
570.00	.100	2.40	1.30
600.00	.082	1.50	.67
630.00	.053	4.20	1.20
660.00	.029	6.50	1.02
690.00	.018	5.50	.54

THE TOTAL GREASE AND OIL OUTPUT LOAD = 5.77 LBS

INFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
75.00	1.073	139.00	804.54
105.00	.906	31.00	151.47
135.00	.961	17.50	90.72
165.00	1.231	20.50	136.11
195.00	1.041	12.50	70.15
225.00	.393	4.00	8.47
255.00	.064	5.00	1.73
285.00	.063	4.00	1.36
315.00	.075	9.00	3.64
345.00	.016	8.00	.70

THE TSS INPUT LOAD = 18.05 LBS

OUTFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
75.00	.075	59.00	23.75
105.00	.196	68.50	72.44
135.00	.310	52.50	87.87
165.00	1.052	40.00	226.85
195.00	1.478	39.00	310.92
225.00	.629	24.50	83.05
255.00	.311	23.50	39.40
285.00	.288	21.50	33.43
315.00	.274	22.00	32.48
345.00	.253	24.50	33.40
375.00	.239	24.00	30.99
405.00	.220	19.50	23.15
435.00	.202	25.00	27.23
465.00	.174	11.50	10.77
495.00	.148	12.00	9.58
525.00	.129	16.00	11.17
555.00	.112	13.00	7.87
585.00	.093	18.00	9.02
615.00	.067	9.50	3.41
645.00	.043	14.00	3.26
675.00	.021	15.00	1.71

THE TSS OUTPUT LOAD = 22.27 LBS

INFLOW DATA FOR TOTAL PHOSPHORUS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
105.00	.906	.15	.71
135.00	.961	.11	.55
165.00	1.231	.08	.55
195.00	1.041	.09	.51
225.00	.393	.09	.19
255.00	.064	.11	.04
285.00	.063	.09	.03
315.00	.075	.12	.05

THE TOTAL PHOSPHORUS INPUT LOAD = .05 LBS

OUTFLOW DATA FOR TOTAL PHOSPHORUS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
105.00	.196	1.30	1.38
135.00	.310	.83	1.39
165.00	1.052	.51	2.92
195.00	1.478	.40	3.18
225.00	.629	.35	1.17
255.00	.311	.32	.54
285.00	.288	.41	.64
315.00	.274	.34	.51
345.00	.253	.31	.43
375.00	.239	.31	.41
405.00	.220	.32	.38
435.00	.202	.32	.35
465.00	.174	.33	.31
495.00	.148	.33	.26
525.00	.129	.32	.23
555.00	.112	.29	.17
585.00	.093	.31	.16
615.00	.067	.34	.12
645.00	.043	.30	.07
675.00	.021	.31	.04

THE TOTAL PHOSPHORUS OUTPUT LOAD = .29 LBS

INFLOW DATA FOR TOTAL CADMIUM

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.906	1.20	5.86
135.00	.961	.30	1.56
165.00	1.231	1.00	6.64
195.00	1.041	.50	2.81
225.00	.393	.50	1.06
255.00	.064	1.00	.35
285.00	.063	.60	.20
315.00	.075	.40	.16
345.00	.016	1.40	.12

THE TOTAL CADMIUM INPUT LOAD = .33/1000 LBS

OUTFLOW DATA FOR TOTAL CADMIUM

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.196	1.50	1.59
135.00	.310	1.00	1.67
165.00	1.052	.70	3.97
195.00	1.478	1.10	8.77
225.00	.629	.40	1.36
255.00	.311	.80	1.34
285.00	.288	1.00	1.55
315.00	.274	2.20	3.25
345.00	.253	.50	.68
375.00	.239	.90	1.16
405.00	.220	.50	.59
435.00	.202	.30	.33
465.00	.174	.20	.19
495.00	.148	.20	.16
525.00	.129	.30	.21
555.00	.112	.50	.30
585.00	.093	1.00	.50
615.00	.067	.70	.25
645.00	.043	3.50	.81
675.00	.021	2.60	.30

THE TOTAL PHOSPHORUS OUTPUT LOAD = .58/1000 LBS

INFLOW DATA FOR SOLUBLE CADMIUM

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.906	.30	1.47
135.00	.961	.60	3.11
165.00	1.231	.60	3.98
195.00	1.041	.70	3.93
225.00	.393	.70	1.48
155.00	.064	1.00	.35
285.00	.063	.50	.17
315.00	.075	.80	.32
345.00	.016	1.30	.11

THE SOLUBLE CADMIUM INPUT LOAD = .29/1000 LBS

OUTFLOW DATA FOR SOLUBLE CADMIUM

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.196	.80	.85
135.00	.310	.60	1.00
165.00	1.052	.80	4.54
195.00	1.478	1.00	7.97
225.00	.629	.90	3.05
255.00	.311	1.70	2.85
285.00	.288	1.80	2.80
315.00	.274	1.00	1.48
345.00	.253	1.00	1.36
375.00	.239	.80	1.03
405.00	.220	.60	.71
435.00	.202	.80	.87
465.00	.174	.50	.47
495.00	.148	.50	.40
525.00	.129	.50	.35
555.00	.112	.50	.30
585.00	.093	.70	.35
615.00	.067	.40	.14
645.00	.043	.50	.12
675.00	.021	1.40	.16

THE SOLUBLE CADMIUM OUTPUT LOAD =.63/1000 LBS

INFLOW DATA FOR TOTAL LEAD

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.906	30.60	149.51
135.00	.961	83.10	430.80
165.00	1.231	53.70	356.55
195.00	1.041	56.30	315.94
225.00	.393	.00	.00
255.00	.064	53.00	18.29
285.00	.063	39.50	13.45
315.00	.075	20.80	8.41
345.00	.016	68.40	5.96

THE TOTAL LEAD INPUT LOAD = 25.44/1000 LBS

OUTFLOW DATA FOR TOTAL LEAD

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.196	.00	.00
135.00	.310	79.30	132.72
165.00	1.052	55.00	311.92
195.00	1.478	32.80	261.49
225.00	.629	16.80	56.95
255.00	.311	58.80	98.59
285.00	.288	39.60	61.57
315.00	.274	15.50	22.88
345.00	.253	46.90	63.94
375.00	.239	45.10	58.23
405.00	.220	15.60	18.52
435.00	.202	54.50	59.37
465.00	.174	6.70	6.28
495.00	.148	.00	.00
525.00	.129	2.00	1.40
555.00	.112	.00	.00
585.00	.093	61.30	30.72
615.00	.067	2.50	.90
645.00	.043	64.70	15.05
675.00	.021	64.60	7.36

THE TOTAL LEAD OUTPUT LOAD = 25.09/1000 LBS

INFLOW DATA FOR SOLUBLE LEAD

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.906	.00	.00
135.00	.961	.00	.01
165.00	1.231	.00	.01
195.00	1.041	34.30	192.48
225.00	.393	43.40	91.95
255.00	.064	12.70	4.38
285.00	.063	50.30	17.13
315.00	.075	.00	.00
348.75	.005	15.30	.41

THE SOLUBLE LEAD INPUT LOAD = 6.38/1000 LBS

OUTFLOW DATA FOR SOLUBLE LEAD

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.196	26.00	27.49
135.00	.310	.00	.00
165.00	1.052	.00	.01
195.00	1.478	29.00	231.20
225.00	.629	.00	.00
255.00	.311	11.00	18.44
285.00	.288	27.70	43.07
315.00	.274	.00	.00
345.00	.253	.00	.00
375.00	.239	.00	.00
405.00	.220	15.00	17.81
435.00	.202	9.40	10.24
465.00	.174	25.10	23.52
495.00	.148	14.80	11.82
525.00	.129	.00	.00
555.00	.112	28.70	17.38
585.00	.093	.00	.00
615.00	.067	67.80	24.33
645.00	.043	15.50	3.61
675.00	.021	.00	.00

THE SOLUBLE OUTPUT LOAD = 8.65/1000 LBS

INFLOW DATA FOR TOTAL ZINC

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.906	171.60	838.43
135.00	.961	165.00	855.38
165.00	1.231	154.10	1023.17
195.00	1.041	131.20	736.26
225.00	.393	140.10	296.83
255.00	.064	153.00	52.80
285.00	.063	151.30	51.53
315.00	.075	149.40	60.42
348.75	.005	198.80	5.34

THE TOTAL ZINC INPUT LOAD = 72.97/1000 LBS

OUTFLOW DATA FOR TOTAL ZINC

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.196	284.30	300.65
135.00	.310	229.10	383.43
165.00	1.052	183.40	1040.10
195.00	1.478	169.00	1347.31
225.00	.629	153.70	521.00
255.00	.311	157.60	264.24
285.00	.288	224.90	349.66
315.00	.274	149.00	219.99
345.00	.253	149.50	203.81
375.00	.239	140.40	181.28
405.00	.220	145.30	172.51
435.00	.202	149.20	162.53
465.00	.174	144.60	135.48
495.00	.148	150.80	120.43
525.00	.129	148.50	103.63
555.00	.112	161.50	97.79
585.00	.093	173.10	86.74
615.00	.067	162.50	58.31
645.00	.043	165.90	38.60
675.00	.021	158.10	18.01

THE TOTAL ZINC OUTPUT LOAD = 117.63/1000 LBS

INFLOW DATA FOR SOLUBLE ZINC

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.906	146.80	717.26
135.00	.961	146.60	759.99
165.00	1.231	117.90	782.81
195.00	1.041	131.20	736.26
225.00	.393	138.70	293.87
255.00	.064	149.80	51.70
285.00	.063	166.20	56.61
315.00	.075	135.40	54.76
348.75	.005	163.00	4.38

THE SOLUBLE ZINC INPUT LOAD = 64.59/1000 LBS

OUTFLOW DATA FOR SOLUBLE ZINC

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
105.00	.196	180.80	191.20
135.00	.310	190.60	319.00
165.00	1.052	159.20	902.86
195.00	1.478	147.50	1175.91
225.00	.629	141.00	477.95
255.00	.311	178.90	299.95
285.00	.288	213.30	331.63
315.00	.274	137.10	202.42
345.00	.253	144.40	196.86
375.00	.239	144.00	185.93
405.00	.220	147.50	175.13
435.00	.202	189.50	206.43
465.00	.174	161.90	151.69
495.00	.148	140.40	112.12
525.00	.129	140.10	97.77
555.00	.112	155.60	94.21
585.00	.093	142.50	71.41
615.00	.067	148.70	53.36
645.00	.043	145.40	33.83
675.00	.021	146.90	16.73

THE SOLUBLE ZINC OUTPUT LOAD = 108.18/1000 LBS

STORM: 9
DATE: 1/19/83
SITE: METRO
TOTAL OUTFLOW = 9.961 * 1000 CUBIC FEET
TOTAL INFLOW = 10.049 * 1000 CUBIC FEET

INFLOW DATA FOR GREASE AND OIL

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
45.00	.974	2.00	10.50
105.00	.666	2.00	7.18
165.00	.339	.20	.37
225.00	.236	4.70	5.98
285.00	.131	4.70	3.32
345.00	.110	29.10	17.32
405.00	.121	8.50	5.52
465.00	.089	14.50	6.96

THE TOTAL GREASE AND OIL INPUT LOAD = 2.02 LBS

OUTFLOW DATA FOR GREASE AND OIL

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
45.00	.279	19.00	28.62
105.00	.429	10.50	24.32
165.00	.443	3.40	8.13
225.00	.416	9.20	20.64
285.00	.368	7.20	14.28
345.00	.308	13.80	22.89
405.00	.247	3.90	5.19
525.00	.077	8.10	3.36

THE TOTAL GREASE AND OIL OUTPUT LOAD = 4.82 LBS

INFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
15.00	.531	59.20	169.62
45.00	.974	34.00	178.51
75.00	.937	26.40	133.42
105.00	.666	24.00	86.21
135.00	.405	12.40	27.11
165.00	.339	8.00	14.63
195.00	.272	4.00	5.87
225.00	.236	55.00	70.03
255.00	.171	3.60	3.31
285.00	.131	8.00	5.65
315.00	.152	22.80	18.71
375.00	.106	19.20	10.97
435.00	.102	12.40	6.80
495.00	.069	25.60	9.49

THE TSS INPUT LOAD = 14.22 LBS

OUTFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
15.00	.057	46.00	14.20
45.00	.279	38.00	57.25
75.00	.388	41.20	86.24
105.00	.429	32.00	74.11
135.00	.450	31.60	76.73
165.00	.443	26.00	62.15
195.00	.433	24.80	57.89
225.00	.416	22.00	49.35
255.00	.398	19.20	41.19
285.00	.368	18.00	35.69
315.00	.349	14.40	27.13
375.00	.272	12.00	17.58
435.00	.212	13.20	15.10
495.00	.129	9.20	6.39
555.00	.057	14.00	4.32

THE TSS OUTPUT LOAD = 13.98 LBS

INFLOW DATA FOR TOTAL PHOSPHORUS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
15.00	.531	.27	.78
75.00	.937	.10	.48
135.00	.405	.06	.14
195.00	.272	.06	.09
255.00	.171	.06	.05
315.00	.152	.16	.13
375.00	.106	.10	.06
435.00	.102	.09	.05

THE TOTAL PHOSPHORUS INPUT LOAD = .06 LBS

OUTFLOW DATA FOR TOTAL PHOSPHORUS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
15.00	.057	.53	.16
75.00	.388	.31	.65
135.00	.450	.16	.38
195.00	.433	.13	.30
255.00	.398	.12	.26
315.00	.349	.10	.19
375.00	.272	.11	.16
435.00	.212	.12	.14
495.00	.129	.09	.06
555.00	.057	.09	.03

THE TOTAL PHOSPHORUS OUTPUT LOAD = .09 LBS

INFLOW DATA FOR TOTAL CADMIUM

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.531	.90	2.58
75.00	.937	.20	1.01
135.00	.405	.10	.22
195.00	.272	.20	.29
255.00	.171	.40	.37
315.00	.152	1.30	1.07
375.00	.106	1.10	.63
435.00	.102	.90	.49

THE TOTAL CADMIUM INPUT LOAD = .21/1000 LBS

OUTFLOW DATA FOR TOTAL CADMIUM

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.057	.80	.25
75.00	.388	.30	.63
135.00	.450	.10	.24
195.00	.433	.90	2.10
255.00	.398	1.00	2.15
315.00	.349	.00	.00
375.00	.272	.70	1.03
435.00	.212	.30	.34
495.00	.129	1.10	.76
555.00	.057	1.00	.31

THE TOTAL CADMIUM OUTPUT LOAD = .31/1000 LBS

INFLOW DATA FOR SOLUBLE CADMIUM

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.531	.40	1.15
75.00	.937	.10	.51
135.00	.405	.20	.44
195.00	.272	.30	.44
255.00	.171	.70	.64
315.00	.152	1.20	.98
375.00	.106	1.00	.57
435.00	.102	.70	.38

THE SOLUBLE CADMIUM INPUT LOAD = .18/1000 LBS

OUTFLOW DATA FOR SOLUBLE CADMIUM

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.057	.40	.12
75.00	.388	.30	.63
135.00	.450	.30	.73
195.00	.433	.60	1.40
255.00	.398	.30	.64
315.00	.349	.50	.94
375.00	.272	.30	.44
435.00	.212	.70	.80
495.00	.129	.50	.35
555.00	.057	.80	.25

THE SOLUBLE CADMIUM OUTPUT LOAD = .25/1000 LBS

INFLOW DATA FOR TOTAL LEAD

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.531	82.10	235.23
75.00	.937	65.90	333.05
135.00	.405	.00	.00
195.00	.272	.00	.00
255.00	.171	29.00	26.69
315.00	.152	.00	.00
375.00	.106	.00	.00
435.00	.102	15.00	8.23

THE TOTAL LEAD INPUT LOAD = 20.06/1000 LBS

OUTFLOW DATA FOR TOTAL LEAD

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.057	.00	.00
75.00	.388	.00	.00
135.00	.450	.00	.00
195.00	.433	.00	.00
255.00	.398	.00	.00
315.00	.349	.00	.00
375.00	.272	94.00	137.68
435.00	.212	83.00	94.97
495.00	.129	.00	.00
555.00	.057	32.60	10.06

THE TOTAL LEAD OUTPUT LOAD = 9.90/1000 LBS

INFLOW DATA FOR SOLUBLE LEAD

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.531	.00	.00
75.00	.937	.00	.01
135.00	.405	.00	.00
195.00	.272	.00	.00
255.00	.171	.00	.00
315.00	.152	.00	.00
375.00	.106	.00	.00
435.00	.102	.00	.00

THE SOLUBLE LEAD INPUT LOAD = .00/1000 LBS

OUTFLOW DATA FOR SOLUBLE LEAD

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.057	.00	.00
75.00	.388	.00	.00
135.00	.450	.00	.00
195.00	.433	49.00	114.39
255.00	.398	69.00	148.03
315.00	.349	.00	.00
375.00	.272	.00	.00
435.00	.212	34.00	38.90
495.00	.129	.00	.00
555.00	.057	.00	.00

THE SOLUBLE LEAD OUTPUT LOAD = 12.56/1000 LBS

INFLOW DATA FOR TOTAL ZINC

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.531	213.60	612.00
75.00	.937	108.10	546.32
135.00	.405	90.50	197.83
195.00	.272	102.00	149.60
255.00	.171	125.00	115.03
315.00	.152	206.80	169.69
375.00	.106	208.90	119.33
435.00	.102	174.80	95.89

THE TOTAL ZINC INPUT LOAD = 68.82/1000 LBS

OUTFLOW DATA FOR TOTAL ZINC

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.057	183.10	56.52
75.00	.388	150.30	314.59
135.00	.450	111.50	270.73
195.00	.433	119.00	277.80
255.00	.398	90.20	193.51
315.00	.349	101.20	190.67
375.00	.272	156.00	228.48
435.00	.212	154.70	177.00
495.00	.129	180.90	125.62
555.00	.057	153.30	47.32

THE TOTAL ZINC OUTPUT LOAD = 76.26/1000 LBS

INFLOW DATA FOR SOLUBLE ZINC

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.531	129.10	369.89
75.00	.937	60.40	305.25
135.00	.405	68.10	148.86
195.00	.272	81.40	119.39
255.00	.171	107.00	98.46
315.00	.152	165.10	135.47
375.00	.106	173.70	99.22
435.00	.102	151.50	83.11

THE SOLUBLE ZINC INPUT LOAD = 47.21/1000 LBS

OUTFLOW DATA FOR SOLUBLE ZINC

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.057	125.10	38.62
75.00	.388	101.20	211.82
135.00	.450	64.40	156.37
195.00	.433	80.00	186.76
255.00	.398	80.00	171.63
315.00	.349	67.50	127.18
375.00	.272	99.30	145.44
435.00	.212	117.20	134.10
495.00	.129	115.20	80.00
555.00	.057	120.90	37.32

THE SOLUBLE ZINC OUTPUT LOAD = 52.14/1000 LBS

STORM: 11
DATE: 2/6/83
SITE: METRO

TOTAL OUTFLOW = 2.849 * 1000 CUBIC FEET
TOTAL INFLOW = 2.854 * 1000 CUBIC FEET

INFLOW DATA FOR GREASE AND OIL

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.050	9.70	2.59
30.00	.103	5.80	3.21
60.00	.197	5.30	5.63
90.00	.453	12.70	31.00
120.00	.289	7.90	12.33
150.00	.060	11.10	3.59
180.00	.029	10.10	1.58
210.00	.122	6.50	4.27
240.00	.132	16.50	11.74
270.00	.110	14.90	8.82
300.00	.055	11.40	3.39
330.00	.046	9.90	2.46

THE TOTAL GREASE AND OIL INPUT LOAD = 1.84 LBS

OUTFLOW DATA FOR GREASE AND OIL

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
30.00	.022	18.40	2.21
60.00	.074	14.60	5.79
90.00	.155	8.60	7.20
120.00	.233	14.60	18.31
150.00	.194	11.80	12.35
180.00	.155	13.20	11.05
210.00	.114	10.10	6.21
240.00	.124	35.00	23.40
270.00	.126	6.50	4.40
300.00	.110	8.80	5.24
330.00	.100	9.20	4.95

THE TOTAL GREASE AND OIL OUTPUT LOAD = 2.03 LBS

INFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
15.00	.053	6.80	1.94
45.00	.162	4.80	4.19
75.00	.272	3.60	5.27
105.00	.529	9.20	26.24
135.00	.093	13.60	6.79
165.00	.025	8.40	1.14
195.00	.069	6.80	2.52
225.00	.143	5.20	4.01
255.00	.126	6.80	4.60
285.00	.072	4.00	1.55
315.00	.058	4.00	1.25
345.00	.005	2.40	.06

THE TSS INPUT LOAD = 1.22 LBS

OUTFLOW DATA FOR TOTAL SUSPENDED SOLIDS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
15.00	.016	13.20	1.15
45.00	.054	9.60	2.79
75.00	.114	11.20	6.89
105.00	.213	7.60	8.74
135.00	.219	5.20	6.14
165.00	.167	4.00	3.61
195.00	.124	3.20	2.14
225.00	.119	4.40	2.83
255.00	.126	.10	.07
285.00	.119	1.60	1.03
315.00	.105	.10	.06

THE TSS OUTPUT LOAD = .73 LBS

INFLOW DATA FOR TOTAL PHOSPHORUS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
15.00	.053	.33	.09
45.00	.162	.36	.31
75.00	.272	.37	.54
105.00	.529	.46	1.32
135.00	.093	.44	.22
165.00	.025	.83	.11
195.00	.069	.48	.18
225.00	.143	.47	.36
255.00	.126	.50	.34
285.00	.072	.46	.18
315.00	.058	.41	.13
345.00	.005	.46	.01

THE TOTAL PHOSPHORUS INPUT LOAD = .08 LBS

OUTFLOW DATA FOR TOTAL PHOSPHORUS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
15.00	.016	3.74	.33
45.00	.054	1.19	.35
75.00	.114	.34	.21
105.00	.213	1.21	1.40
135.00	.219	1.06	1.25
165.00	.167	.53	.48
195.00	.124	.37	.25
225.00	.119	.40	.26
255.00	.126	.23	.15
285.00	.119	.22	.14
315.00	.105	.15	.09

THE TOTAL PHOSPHORUS OUTPUT LOAD = .10 LBS

INFLOW DATA FOR TOTAL CADMIUM

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.053	.20	.06
45.00	.162	.40	.35
75.00	.272	.30	.44
105.00	.529	.50	1.43
135.00	.093	1.20	.60
165.00	.025	.30	.04
195.00	.069	.40	.15
225.00	.143	3.80	2.93
255.00	.126	.60	.41
285.00	.072	.10	.04
315.00	.058	.40	.13
345.00	.005	.50	.01

THE TOTAL CADMIUM INPUT LOAD = .14/1000 LBS

OUTFLOW DATA FOR TOTAL CADMIUM

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.016	1.30	.11
45.00	.054	.30	.09
75.00	.114	.60	.37
105.00	.213	.50	.58
135.00	.219	.30	.35
165.00	.167	.10	.09
195.00	.124	.40	.27
225.00	.119	1.70	1.09
255.00	.126	.60	.41
285.00	.119	1.80	1.16
315.00	.105	2.20	1.25

THE TOTAL CADMIUM OUTPUT LOAD = .11/1000 LBS

INFLOW DATA FOR SOLUBLE CADMIUM

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.053	.30	.09
45.00	.162	.40	.35
75.00	.272	.50	.73
105.00	.529	.10	.29
135.00	.093	.50	.25
165.00	.025	.40	.05
195.00	.069	.30	.11
225.00	.143	.60	.46
255.00	.126	.50	.34
285.00	.072	2.10	.82
315.00	.058	.70	.22
345.00	.005	.60	.02

THE SOLUBLE CADMIUM INPUT LOAD = .08/1000 LBS

OUTFLOW DATA FOR SOLUBLE CADMIUM

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.016	1.70	.15
45.00	.054	1.60	.47
75.00	.114	.70	.43
105.00	.213	.40	.46
135.00	.219	.50	.59
165.00	.167	.30	.27
195.00	.124	.20	.13
225.00	.119	.90	.58
255.00	.126	.50	.34
285.00	.119	.30	.19
315.00	.105	.70	.40

THE SOLUBLE CADMIUM OUTPUT LOAD = .08/1000 LBS

INFLOW DATA FOR TOTAL LEAD

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.053	.00	.00
45.00	.162	40.80	35.63
75.00	.272	30.00	43.94
105.00	.529	37.40	106.66
135.00	.093	31.50	15.73
165.00	.025	29.20	3.97
195.00	.069	168.40	62.46
225.00	.143	30.10	23.21
255.00	.126	18.20	12.33
285.00	.072	57.80	22.45
315.00	.058	39.90	12.48
345.00	.005	34.00	.90

THE TOTAL LEAD INPUT LOAD = 7.07/1000 LBS

OUTFLOW DATA FOR TOTAL LEAD

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.016	59.20	5.16
45.00	.054	23.10	6.72
75.00	.114	49.20	30.26
105.00	.213	35.50	40.83
135.00	.219	54.50	64.31
165.00	.167	29.50	26.60
195.00	.124	27.20	18.19
225.00	.119	35.20	22.65
255.00	.126	31.30	21.20
285.00	.119	15.30	9.85
315.00	.105	31.30	17.78

THE TOTAL LEAD OUTPUT LOAD = 5.25/1000 LBS

INFLOW DATA FOR SOLUBLE LEAD

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.053	1.30	.37
45.00	.162	.00	.00
75.00	.272	18.80	27.54
105.00	.529	.00	.00
135.00	.093	20.00	9.99
165.00	.025	17.90	2.44
195.00	.069	22.60	8.38
225.00	.143	23.60	18.20
255.00	.126	.00	.00
285.00	.072	9.40	3.65
315.00	.058	39.00	12.20
345.00	.005	23.40	.62

THE SOLUBLE LEAD INPUT LOAD = 1.73/1000 LBS

OUTFLOW DATA FOR SOLUBLE LEAD

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.016	26.70	2.33
45.00	.054	36.70	10.67
75.00	.114	23.20	14.27
105.00	.213	52.70	60.61
135.00	.219	22.50	26.55
165.00	.167	21.80	19.66
195.00	.124	9.00	6.02
225.00	.119	35.00	22.53
255.00	.126	31.00	20.99
285.00	.119	14.50	9.33
315.00	.105	47.40	26.93

THE SOLUBLE LEAD OUTPUT LOAD = 4.28/1000 LBS

INFLOW DATA FOR TOTAL ZINC

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.053	183.40	52.19
45.00	.162	189.90	165.83
75.00	.272	189.70	277.84
105.00	.529	193.40	551.55
135.00	.093	181.00	90.38
165.00	.025	163.80	22.28
195.00	.069	152.50	56.56
225.00	.143	156.20	120.47
255.00	.126	154.00	104.29
285.00	.072	149.70	58.13
315.00	.058	163.20	51.05
345.00	.005	139.40	3.69

THE TOTAL ZINC INPUT LOAD = 31.80/1000 LBS

OUTFLOW DATA FOR TOTAL ZINC

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.016	214.80	18.72
45.00	.054	198.20	57.63
75.00	.114	136.90	84.20
105.00	.213	120.40	138.47
135.00	.219	108.40	127.92
165.00	.167	109.40	98.66
195.00	.124	125.50	83.92
225.00	.119	141.60	91.13
255.00	.126	129.40	87.63
285.00	.119	127.20	81.87
315.00	.105	152.20	86.46

THE TOTAL ZINC OUTPUT LOAD = 18.83/1000 LBS

INFLOW DATA FOR SOLUBLE ZINC

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.053	179.30	51.02
45.00	.162	178.30	155.70
75.00	.272	181.90	266.42
105.00	.529	181.30	517.04
135.00	.093	155.60	77.70
165.00	.025	137.70	18.73
195.00	.069	135.90	50.40
225.00	.143	129.60	99.95
255.00	.126	129.30	87.56
285.00	.072	133.50	51.84
315.00	.058	136.20	42.60
345.00	.005	128.40	3.40

THE SOLUBLE ZINC INPUT LOAD = 29.07/1000 LBS

OUTFLOW DATA FOR SOLUBLE ZINC

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (PPB)	LOADING (LBS/DAY)*1000
15.00	.016	140.20	12.22
45.00	.054	123.50	35.91
75.00	.114	75.30	46.32
105.00	.213	53.00	60.96
135.00	.219	59.00	69.62
165.00	.167	63.20	57.00
195.00	.124	67.70	45.27
225.00	.119	105.60	67.96
255.00	.126	121.00	81.94
285.00	.119	115.80	74.53
315.00	.105	122.10	69.36

THE SOLUBLE ZINC OUTPUT LOAD = 12.09/1000 LBS

APPENDIX E.

Whispering Heights Site Flow, Concentration and Pollutant Loading Data

(WH STORMS 2, 4, 5, 7, 8/9, and 10/15)

STORM #2
DATE: 10/27/81
SITE: WHISPERING HEIGHTS
TOTAL VOLUME OF INFLOW = 5.94 CUBIC FEET/1000
TOTAL VOLUME OF OUTFLOW = 5.96 CUBIC FEET/1000

INFLOW DATA FOR TSS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.033	3.700	.6630
15.00	.143	109.000	84.2705
30.00	.254	22.800	31.1691
45.00	.749	8.700	35.1329
60.00	1.245	9.300	62.3981
75.00	1.011	16.000	87.2155
90.00	.778	7.800	32.7012
105.00	.532	7.300	20.9434

THE TOTAL TSS INPUT LOAD = 3.5801 LBS

OUTFLOW DATA FOR TSS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.039	6.500	1.3755
15.00	.031	31.200	5.2840
30.00	.024	17.800	2.2623
45.00	.422	22.500	51.2112
60.00	.821	14.200	62.8351
75.00	.916	17.400	85.9012
90.00	1.011	8.300	45.2241
105.00	.799	6.700	28.8401

THE TOTAL TSS OUTPUT LOAD = 2.7899 LBS

STORM: #4
DATE: 11/21/81
SITE: WHISPERING HEIGHTS
TOTAL VOLUME OF INFLOW = 68.87 CUBIC FEET/1000
TOTAL VOLUME OF OUTFLOW = 68.62 CUBIC FEET/1000

INFLOW DATA FOR TSS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	2.346	3.700	46.7910
30.00	2.383	4.300	55.2298
60.00	1.579	3.000	25.5308
90.00	1.526	1.700	13.9782
120.00	1.496	3.000	24.1902
150.00	1.494	.300	2.4166
180.00	1.468	3.000	23.7425
210.00	1.444	1.000	7.7821
240.00	1.426	1.700	13.0703
270.00	1.290	.700	4.8679
330.00	.701	1.000	3.7772
360.00	.616	2.300	7.6313
390.00	.340	1.000	1.8333

THE TOTAL TSS INPUT LOAD = 4.3927 LBS

OUTFLOW DATA FOR TSS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	1.315	13.000	92.1268
30.00	1.530	17.000	140.2304
60.00	1.554	8.700	72.8599
90.00	1.552	6.000	50.2023
120.00	1.547	3.300	27.5138
150.00	1.540	1.300	10.7899
180.00	1.535	2.000	16.5440
210.00	1.524	4.300	35.3102
240.00	1.514	20.700	168.8943
270.00	1.499	6.000	48.4748
300.00	1.442	1.000	7.7707
330.00	1.332	5.000	35.8916
360.00	1.206	23.000	149.4817

THE TOTAL TSS OUTPUT LOAD = 15.3185 LBS

STORM: #5
DATE: 12/18/81
SITE: WHISPERING HEIGHTS
TOTAL VOLUME OF INFLOW = 152.13 CUBIC FEET/1000
TOTAL VOLUME OF OUTFLOW = 152.03 CUBIC FEET/1000

INFLOW DATA FOR TSS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.585	11.200	35.2902
60.00	.816	6.600	29.0346
120.00	.795	3.600	15.4180
180.00	1.409	1.000	7.5963
240.00	2.116	4.200	47.8917
300.00	2.014	.800	8.6834
360.00	1.127	10.000	60.7684
420.00	2.602	1.800	25.2428
480.00	2.363	1.000	12.7354
540.00	1.605	1.600	13.8429
600.00	1.553	3.400	28.4578
660.00	1.067	3.400	19.5612
720.00	.861	3.600	16.7064
780.00	.878	10.200	48.2484
840.00	.914	19.400	95.5311
900.00	.689	17.000	63.1268
960.00	.690	6.000	22.3219
1020.00	.708	28.200	107.6308
1080.00	1.629	5.000	43.8967
1140.00	1.527	4.400	36.2235
1200.00	1.623	4.800	41.9800
1380.00	.681	4.000	14.6851
1500.00	.703	1.600	6.0640
1620.00	.657	3.600	12.7488
1680.00	.647	4.000	13.9449
1740.00	.624	.800	2.6914
1800.00	.611	4.800	15.7970
1860.00	.595	1.000	3.2075

THE TOTAL TSS INPUT LOAD = 37.7718 LBS

OUTFLOW DATA FOR TSS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.512	11.400	31.4367
120.00	.781	31.800	133.9383
180.00	.943	24.000	122.0043
300.00	1.583	7.600	64.8283
360.00	1.514	19.800	161.5361
420.00	1.610	10.200	88.5224
480.00	1.857	5.400	54.0365
540.00	1.891	3.800	38.7296
600.00	1.756	7.400	70.0257
660.00	1.667	5.400	48.5062
720.00	1.506	12.800	103.8940
780.00	1.328	32.600	233.4353
840.00	1.181	35.000	222.8581
900.00	.992	13.600	72.6886
960.00	.825	5.400	24.0141
1020.00	.729	13.600	53.4262
1080.00	.961	12.400	64.2442
1140.00	1.328	14.200	101.6390
1200.00	1.403	7.200	54.4607
1260.00	1.323	5.000	35.6526
1320.00	1.158	6.200	38.6845
1380.00	.948	7.200	36.8028
1440.00	.764	14.000	57.6208
1500.00	.713	3.800	14.6078
1560.00	.688	5.400	20.0393
1620.00	.667	4.400	15.8215
1680.00	.651	22.400	78.6278
1740.00	.632	6.800	23.1813
1800.00	.616	4.000	13.2881
1860.00	.601	3.800	12.3027
1920.00	.581	1.400	4.3812
1980.00	.567	3.200	9.7841
2040.00	.551	4.400	13.0642
2100.00	.534	3.600	10.3521
2160.00	.494	3.000	7.9814
2220.00	.485	3.200	8.3596
2280.00	.405	3.000	6.5565
2340.00	.378	3.200	6.5147
2400.00	.359	1.600	3.0938
2460.00	.342	1.400	2.5810
2520.00	.336	1.200	2.1701

THE TOTAL TSS OUTPUT LOAD = 96.8747 LBS

STORM: #7
DATE: 1/30/82
SITE: WHISPERING HEIGHTS
TOTAL VOLUME OF INFLOW = 24.77 CUBIC FEET/1000
TOTAL VOLUME OF OUTFLOW = 24.81 CUBIC FEET/1000

INFLOW DATA FOR TSS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.093	2.000	1.0030
60.00	.113	1.870	1.1404
120.00	.600	38.500	124.4632
180.00	.949	12.900	66.0135
240.00	1.142	6.500	40.0120
300.00	.515	11.300	31.3953
360.00	.229	1.750	2.1585

THE TOTAL TSS INPUT LOAD = 11.0252 LBS

OUTFLOW DATA FOR TSS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.094	7.750	3.9328
60.00	.092	2.120	1.0534
120.00	.464	54.200	135.4467
180.00	.823	19.000	84.2745
240.00	.986	9.750	51.8178
300.00	.971	10.500	54.9377
360.00	.310	3.620	6.0445
420.00	.240	2.620	3.3849
480.00	.229	1.250	1.5405
600.00	.179	1.500	1.4483
660.00	.161	3.000	2.6095

STORM: #8/9
DATE: 1/31/82 TO 2/1/82
SITE: WHISPERING HEIGHTS
TOTAL VOLUME OF INFLOW = 183.50 CUBIC FEET/1000
TOTAL VOLUME OF OUTFLOW = 183.56 CUBIC FEET/1000

INFLOW DATA FOR TSS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	1.070	6.000	34.6105
60.00	1.339	1.200	8.6626
120.00	1.274	3.200	21.9696
300.00	1.659	3.200	28.6104
360.00	1.497	3.000	24.2136
420.00	.895	1.800	8.6804
480.00	.627	3.200	10.8142
600.00	.359	6.800	13.1725
660.00	.352	.400	.7584
720.00	.784	1.000	4.2234
780.00	.691	1.200	4.4690
840.00	1.204	.600	3.8948
900.00	1.332	1.800	12.9189
1020.00	1.183	2.800	17.8608
1080.00	1.156	.800	4.9849
1200.00	.999	1.200	6.4598
1260.00	1.022	3.000	16.5273
1320.00	.968	2.400	12.5247
1380.00	.628	174.200	589.2412
1500.00	.610	70.200	230.8631
1620.00	.580	9.400	29.3797
1740.00	.605	15.400	50.2306
1920.00	.930	1.000	5.0126

THE TOTAL TSS INPUT LOAD = 76.6324 LBS

OUTFLOW DATA FOR TSS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	1.009	7.800	42.4151
60.00	1.079	5.800	33.7201
120.00	1.191	14.600	93.7204
180.00	1.241	2.200	14.7167
240.00	1.357	2.400	17.5538
300.00	1.456	9.200	72.1841

360.00	1.497	4.800	38.7418
420.00	1.406	4.600	34.8685
480.00	1.176	3.800	24.0851
540.00	.658	3.400	12.0555
600.00	.373	1.800	3.6166
660.00	.350	.800	1.5110
720.00	.658	1.600	5.6732
780.00	.660	3.600	12.7970
840.00	.959	3.000	15.5071
900.00	1.106	5.800	34.5811
960.00	1.156	.200	1.2456
1020.00	1.183	2.600	16.5850
1080.00	1.168	.600	3.7783
1140.00	1.149	1.800	11.1523
1200.00	1.069	.800	4.6107
1260.00	1.013	55.800	304.6416
1320.00	1.054	10.200	57.9507
1380.00	.904	141.200	687.6716
1560.00	.594	57.400	183.7560
1620.00	.581	70.800	221.5405
1680.00	.579	1.200	3.7423
1740.00	.605	162.200	529.0522
1800.00	.588	4.000	12.6824
1860.00	.803	4.400	19.0369
1920.00	.878	3.200	15.1411
1980.00	.868	4.400	20.5919
2040.00	.850	2.000	9.1627
2100.00	.948	3.600	18.3993
2160.00	.932	2.600	13.0578
2220.00	.926	3.600	17.9722
2280.00	.811	2.800	12.2334
2340.00	.772	1.800	7.4859
2400.00	.681	.600	2.2017
2460.00	.668	3.200	11.5180

STORM: #10/15
DATE: 2/12/82 TO 2/18/82
SITE: WHISPERING HEIGHTS
TOTAL VOLUME OF INFLOW = 889.65 CUBIC FEET/1000
TOTAL VOLUME OF OUTFLOW = 884.59 CUBIC FEET/1000

INFLOW DATA FOR TSS

TIME (MIN)	INFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.062	28.600	9.5967
60.00	.150	29.200	23.6631
120.00	.319	42.000	72.2024
180.00	.287	22.400	34.6616
240.00	1.197	35.000	225.7201
300.00	.500	16.600	44.7732
360.00	1.452	20.000	156.5315
420.00	1.419	24.200	185.1491
480.00	1.304	22.800	160.2335
540.00	1.357	15.400	112.6612
600.00	1.289	9.400	65.3269
660.00	1.319	19.000	135.0413
720.00	1.695	22.800	208.2749
780.00	2.027	31.600	345.3168
840.00	2.211	16.000	190.6668
900.00	2.022	16.600	180.9414
960.00	1.728	14.600	135.9990
1020.00	1.828	31.200	307.4491
1080.00	1.933	17.000	177.1112
1140.00	1.564	17.000	143.3373
1200.00	1.767	16.800	160.0170
1260.00	1.746	13.000	122.3746
1320.00	1.752	10.000	94.4563
1380.00	1.559	10.800	90.7518
1440.00	1.466	9.200	72.7137
1500.00	1.637	12.800	112.9418
1560.00	1.866	53.800	541.1105
1620.00	2.184	18.200	214.2063
1680.00	2.188	8.600	101.4162
1740.00	1.724	10.400	96.6411
1800.00	2.393	8.000	103.1864
1860.00	1.759	7.600	72.0404
1920.00	1.894	29.200	298.1653
1980.00	2.049	14.800	163.4680
2040.00	2.933	9.400	148.6042
2100.00	2.145	10.400	120.2343
2160.00	1.867	6.600	66.4012
2220.00	1.882	5.200	52.7536
2280.00	1.813	5.400	52.7570

2340.00	1.720	3.000	27.8061
2400.00	1.713	3.200	29.5522
2460.00	1.743	2.800	26.2990
2520.00	1.697	2.600	23.7792
2580.00	1.661	3.800	34.0289
2640.00	1.571	45.600	386.1294
2700.00	1.555	12.600	105.6032
2760.00	1.424	29.300	224.9331
2820.00	2.256	7.800	94.8294
2880.00	2.172	5.800	67.9067
2940.00	2.160	6.800	79.1725
3000.00	1.761	4.200	39.8602
3060.00	1.689	4.200	38.2360
3120.00	1.673	5.800	52.3107
3180.00	1.645	9.200	81.5770
3240.00	1.561	3.400	28.6123
3300.00	1.524	20.000	164.3069
3360.00	2.160	2.400	27.9436
3420.00	1.698	2.600	23.7917
3480.00	1.667	2.400	21.5581
3540.00	1.959	3.000	31.6728
3600.00	1.383	.600	4.4740
3660.00	.807	3.000	13.0459
3720.00	1.268	1.600	10.9336
3780.00	1.300	2.800	19.6211
3840.00	1.304	1.800	12.6553
3900.00	1.314	2.000	14.1606
3960.00	1.124	58.400	353.7758
4020.00	1.159	14.200	88.7158
4080.00	1.206	11.200	72.7768
4140.00	1.130	8.000	48.7102
4200.00	1.046	4.200	23.6794
4260.00	1.081	4.400	25.6478
4320.00	2.547	6.600	90.6093
4380.00	1.247	3.400	22.8446
4440.00	1.717	15.400	142.5126
4500.00	1.652	9.600	85.4789
4560.00	1.227	4.000	26.4592
4620.00	1.085	1.200	7.0207
4680.00	.952	3.600	18.4730
4740.00	.916	12.600	62.2311
4800.00	.904	18.000	87.6751
4860.00	1.680	19.000	172.0696
4920.00	.972	13.800	72.2692
4980.00	.895	11.000	53.0425
5040.00	.799	8.400	36.1601
5100.00	.785	5.200	22.0160
5160.00	1.186	5.400	34.5210
5220.00	2.447	1.400	18.4657
5280.00	2.919	3.200	50.3499
5340.00	2.154	2.200	25.5467

```
5400.00          1.929          2.600         27.0277
5460.00          1.710          1.200         11.0598
5520.00          1.531          2.000         16.5008
5580.00          1.584          2.800         23.9033
5640.00          1.352          2.400         17.4945
6300.00          1.627          5.200         45.6098
6360.00          1.398        130.200        981.1551
6420.00          1.732         20.000        186.7484
6480.00          1.228          8.600         56.9457
6540.00          2.608          5.200         73.0940
6600.00          2.354          6.000         76.1404
6660.00          1.467          6.000         47.4371
6720.00          1.406          8.200         62.1239
6780.00          1.606         11.200         96.9304
6840.00          2.019         10.600        115.3509
6900.00          3.411         15.000        275.7752
6960.00          2.730          5.200         76.5144
7020.00          2.006          9.200         99.4507
7080.00          2.164         14.400        167.9233
7140.00          2.082          2.600         29.1715
7200.00          1.756          4.600         43.5279
7260.00          1.959         59.800        631.3505
7320.00          2.206         26.400        313.9230
7380.00          2.878          6.600        102.3660
7440.00          2.450          7.400         97.7066
7500.00          3.520          2.800         53.1200
7560.00          2.303         10.400        129.0917
7620.00          1.945          3.400         35.6529
7680.00          1.739          7.600         71.2564
7740.00          1.724         56.200        522.1373
7800.00          1.740         27.600        258.8199
7860.00          1.765         22.400        213.1021
7920.00          3.767         19.600        397.9246
7980.00          1.660         25.400        227.2330
8040.00          1.686         17.400        158.1127
8100.00          1.681         20.200        183.0775
8160.00          1.572         21.600        182.9635
8220.00          1.507         11.200         90.9651
8280.00          1.394          8.800         66.1136
8340.00          1.336          8.000         57.6087
8400.00          1.267          6.400         43.6993
8460.00          1.245          5.000         33.5634
8520.00          1.173          4.800         30.3597
8580.00          1.113          4.200         25.1982
8640.00          1.054          4.000         22.7290
8700.00          1.055          3.000         17.0569
8760.00           .977          3.600         18.9670
8820.00           .933          7.200         36.1943
8880.00           .890          3.200         15.3509
8940.00           .921         26.400        131.0572

          THE TOTAL TSS INPUT LOAD =     661.1053  LBS
```

OUTFLOW DATA FOR TSS

TIME (MIN)	OUTFLOW (CFS)	CONCENTRATION (MG/L)	LOADING (LBS/DAY)
0	.057	26.800	8.2199
60.00	.122	16.600	10.8794
120.00	.298	54.600	87.7621
180.00	.273	27.200	40.0302
240.00	.856	27.000	124.5912
300.00	.577	19.400	60.2972
360.00	.991	21.400	114.2526
420.00	1.137	10.400	63.7529
480.00	1.224	17.800	117.4685
540.00	1.275	10.800	74.2348
600.00	1.287	8.800	61.0644
660.00	1.274	9.200	63.1612
720.00	1.349	12.500	90.8982
780.00	1.507	15.800	128.3294
840.00	1.670	11.000	98.9878
900.00	1.739	11.200	105.0092
960.00	1.750	11.800	111.2721
1020.00	1.752	16.000	151.1039
1080.00	1.854	16.600	165.8631
1140.00	1.765	8.200	78.0180
1200.00	1.746	9.600	90.3358
1260.00	1.750	10.000	94.2984
1320.00	1.746	6.400	60.2421
1380.00	1.736	7.200	67.3826
1440.00	1.672	10.900	98.2183
1500.00	1.661	10.600	94.9107
1560.00	1.675	13.200	119.1798
1620.00	1.745	17.000	159.9214
1680.00	2.176	9.200	107.8881
1740.00	1.809	9.200	89.7164
1800.00	2.259	7.000	85.2351
1860.00	1.862	8.000	80.2944
1920.00	1.809	14.800	144.3263
1980.00	1.958	9.000	94.9767
2040.00	2.833	9.000	137.4081
2100.00	2.288	4.800	59.1939
2160.00	1.958	5.600	59.0966
2220.00	1.846	4.600	45.7611
2280.00	1.880	5.600	56.7322
2340.00	1.768	4.800	45.7497
2400.00	1.762	3.000	28.4927
2460.00	1.755	3.000	28.3744

2520.00	1.752	2.600	24.5470
2580.00	1.741	4.600	43.1550
2640.00	1.716	19.800	183.1361
2700.00	1.681	18.200	164.8656
2760.00	1.637	12.400	109.4073
2820.00	1.615	7.200	62.6815
3000.00	1.889	12.600	128.2626
3060.00	1.762	3.600	34.1912
3120.00	1.746	4.000	37.6513
3180.00	1.727	3.000	27.9298
3240.00	1.706	1.800	16.5545
3360.00	1.715	3.000	27.7392
3420.00	1.765	2.400	22.8278
3480.00	1.734	2.200	20.5639
3540.00	1.712	2.200	20.3038
3600.00	1.755	1.200	11.3497
3660.00	1.575	1.400	11.8872
3720.00	1.512	3.000	24.4473
3780.00	1.454	2.800	21.9493
3840.00	1.398	.400	3.0144
3900.00	1.388	7.800	58.3462
3960.00	1.329	44.100	315.8874
4020.00	1.257	19.400	131.4130
4080.00	1.243	12.200	81.7146
4140.00	1.216	4.200	27.5167
4200.00	1.164	6.200	38.9008
4260.00	1.086	4.200	24.5861
4320.00	1.387	7.000	52.3358
4380.00	1.532	6.200	51.1875
4440.00	1.494	16.200	130.4774
4500.00	1.579	13.600	115.7805
4560.00	1.532	6.200	51.1875
4620.00	1.425	5.400	41.4830
4680.00	1.311	8.600	60.7855
4740.00	1.171	13.400	84.5662
4800.00	1.039	13.000	72.7757
4860.00	1.193	11.200	71.9951
4920.00	1.241	8.400	56.1911
4980.00	1.117	8.600	51.7757
5040.00	.978	7.400	39.0108
5100.00	.879	7.000	33.1659
5160.00	.878	2.800	13.2484
5220.00	1.295	3.800	26.5230
5280.00	1.704	4.200	38.5658
5340.00	2.176	3.200	37.5263
5400.00	2.002	4.200	45.3138
5460.00	1.862	1.800	18.0662
5520.00	1.737	4.200	39.3185
5580.00	1.705	9.000	82.6937
5640.00	1.654	7.200	64.2067
6300.00	1.509	7.000	56.9494

```
   6360.00        1.488        94.000       753.8730
   6420.00        1.534        21.800       180.2707
   6480.00        1.467        17.000       134.3970
   6540.00        1.598         6.000        51.6704
   6600.00        1.755         4.200        39.7241
   6660.00        1.762         4.600        43.6887
   6720.00        1.710         3.800        35.0259
   6780.00        1.644         3.800        33.6791
   6840.00        1.681         5.400        48.9162
   6900.00        2.851        12.000       184.3961
   6960.00        2.906         7.200       112.7941
   7020.00        2.073         4.200        46.9173
   7080.00        2.176         4.600        53.9440
   7140.00        2.060         4.000        44.4198
   7200.00        1.862         3.400        34.1251
   7260.00        1.898        39.000       398.9538
   7320.00        2.176        14.400       168.8683
   7380.00        2.707         4.600        67.1198
   7440.00        2.456         4.400        58.2402
   7500.00        3.529         4.600        87.4949
   7560.00        2.440         8.000       105.2074
   7620.00        2.025        18.200       198.6110
   7680.00        1.791        10.000        96.5475
   7740.00        1.769         5.400        51.4986
   7800.00        1.764        23.400       222.5055
   7860.00        1.759        23.200       219.9517
   7920.00        3.572        19.600       377.3452
   7980.00        1.830        23.200       228.8658
   8040.00        1.759        18.400       174.4444
   8100.00        1.748        25.200       237.4891
   8160.00        1.726        17.600       163.7537
   8220.00        1.691        16.400       149.4342
   8280.00        1.640         9.800        86.6471
   8340.00        1.578        10.800        91.8397
   8400.00        1.518         7.200        58.9155
   8460.00        1.450         7.200        56.2886
   8520.00        1.375         7.000        51.8634
   8580.00        1.308         6.600        46.5439
   8640.00        1.230         5.200        34.4736
   8700.00        1.168         4.000        25.1889
   8760.00        1.097         5.600        33.1143
   8820.00        1.031         6.800        37.7802
   8880.00         .973        25.000       131.0861
   8940.00         .919        27.400       135.7951

        THE TOTAL TSS OUPUT LOAD= 539.7276 LBS
```

APPENDIX F.

ERROR STATISTIC CALCULATIONS

APPENDIX F

FLOW ERROR STATISTICS FOR THE METRO SITE

I. Outflow Error Calculations

Two factors contributed to the error associated with outflow estimation: regression error from the determination of a stage discharge relationship in the flume, and field measurement error.

A. Regression Error

Calculated in $\log_{10}$ space:

$Q = x$

$\log_{10} Q = y$

$$\log_{10} Q_m = .1444 + 2.665 \log_{10} H_m$$

$$\sum \text{residuals} = -0.0005510 = \sum (y_i - y)$$

$$\sum (\text{residuals})^2 = \sum_{i=1}^{24} (y_i - y)^2 = .1768$$

$$\hat{\sigma}_y{}^2 = \frac{1}{n-2} \sum_{i=1}^{24} (y_i - y)^2 = .008037 \quad = (\text{std. error})^2$$

Transforming to real space:

$$\hat{\sigma}_x^2 = (10^{\hat{\sigma}_y{}^2} - 1)\, 10^{(\hat{\sigma}_y{}^2 + 2\mu_y)} = (.0187)(.00653) = .000122$$

Scaling up to full scale:

$$\sigma^2_{Q_{P_1}} = [(2)^{5/2}]^2 \sigma_x{}^2 = \underline{\underline{.0039}} \qquad \longleftarrow$$

$\sigma^2_{Q_{P_1}}$ due to regression error

B. Field Measurement Error

H_p = stage in the flume. It can be read accurately to

1/4" = ± .02083'

allow σ_x = .02083'. For the 1/2 scale stage, H_m,

$$\sigma_{H_m} = \sqrt{\frac{.0208^2}{(2)^2}}$$

$$\sigma_{H_m} = .0104$$

in real space

$$Q_p = (2)^{5/2}\, Q_m = (2)^{5/2}\,(1.3944)\, H_m^{\,2.665}$$

$$\sigma^2_{Q_{P_2}} \cong \left[\frac{\partial}{\partial H}(7.888\; H_m^{2.665})\right]^2 \sigma^2_{H_m}$$

$$\sigma^2_{Q_{P_2}} \cong [(7.888)(2.665)H_m^{\,1.665}]^2\;(.0104)^2$$

$$\sigma^2_{Q_{P_2}} \cong .0478 H_m^{\,3.33} \qquad \longleftarrow$$

$$\cong .0478\;\left[\frac{Hp}{2}\right]^{3.33}$$

$$\sigma^2_{Q_{P_2}} \cong .00475\; H_p^{\,3.33} \qquad \longleftarrow$$

The total outflow error (assuming regression and field errors are independent) is:

$$\sigma^2_{Q_{P_1}} + \sigma^2_{Q_{P_2}} = .0039 + .00475\; H_p^{\,3.3}$$

Therefore, outflow and pollutant mass loading errors are both a function of flume stage.

II. Inflow Error Calculations

Additional error is introduced in calculating inflow from outflow and pond height.

Inflow is calculated at both sites using the following equation:

$$I(J) = O(J) + \frac{S(J+1) - S(J-1)}{\Delta T}$$

Errors in calculating inflow include error in pond height readings, error in pond height - pond volume relationships and time lag error caused by reading data charts with very small scales. First order uncertainty analysis can be performed to estimate the variance of inflow estimates. Outflow and storage estimates are independent at the METRO site because different stage recorders monitor pond height (storage determination) and flume height (outflow determination). Using the relationship:

$$I(J) = O(J) + \frac{\Delta S}{\Delta t}$$

and assuming the outflow and storage change are independent events, then

$$\sigma^2_{\text{inflow}} = \sigma^2_{\text{outflow}} + \sigma^2_{\text{storage change}}$$

The standard deviation of the storage measurement is a function of pond height.

$$\sigma_{\text{storage}} = \frac{\Delta S}{\Delta t} = \frac{10\ H_p}{(15\ \text{min})(60\ \frac{\text{sec}}{\text{min}})} = .01\ H_p\ \text{cfs}$$

$$\sigma^2_{\text{storage}} = (.01\ H_p)^2$$

Therefore:

$$\sigma^2_{\text{inflow}} = .0039 + .00475\ H_f^{3.3} + (.01\ H_p)^2$$