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Research Report 103

SIMULATION OF THE SEDIMENTOLOGY OF SEDIMENT DETENTION BASINS

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Preface

This research report results from work on a research project entitled "Evaluation of Detention Basins for Controlling Urban Runoff and Sedimentation." The work on which this report is based was supported in part by the Kentucky Agricultural Experiment Station and by funds provided by the Office of Water Research and Technology, The United States Department of the Interior as authorized under the Water Resources Act of 1964, Public Law 88-379, as amended.

ABSTRACT

Sediment detention basins are a widely used means of controlling downstream sediment pollution resulting from stripmining and construction activities. A mathematical model for describing the sedimentation characteristics of detention basins has been developed. This model requires as inputs the inflow hydrograph, inflow sediment graph, sediment particle size distribution, detention basin stage-area relationship and detention basin stage-discharge relationship. Based on this information the model routes the water and sediment through the basin. In this routing process the outflow sediment concentration graph, the pattern of sediment deposition in the basin and the sediment trapping efficiency are estimated. Comparison of predicted results with measured sediment basin performance indicates the model accurately represents the sedimentation process in detention basins.

This report details the model, illustrates its use in design, explains how to process the model on a digital computer and presents a program listing of the model.

Descriptors: Detention basin, sediment, urban hydrology

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TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES--Continued

CHAPTER I

INTRODUCTION

In 1966 the annual cost of damages associated with waterborne sediment was estimated to be $262 million (EPA, 1976a). One of the major causes of increased sedimentation is the removal of the natural vegetative cover of soils. The rate of erosion from construction sites and strip mining areas has been estimated as two thousand times that from a forest area (EPA, 1973). Loss of storage space in reservoirs and an increased emphasis on water quality and pollution control has led to much legislation and research on the control of erosion and sedimentation.

Soil erosion from denuded areas occurs due to the detachment and transport of soil particles by the energy of wind and water. The rate of removal is dependent on the susceptibility of the soil particles to detachment and the erosive energy of the wind or water. In construction and strip mining areas, therefore, sediment transport may be reduced by stabilizing the denuded soil and controlling the runoff.

Erosion due to rainfall is the most frequently encountered problem and occurs as either sheet, rill or gully erosion (USDA, 1975). Stream channel erosion may also occur. The most frequently used onsite sediment control measures are outlined below (EPA, 1976a):

1) Soil Stabilization. Stabilization is achieved by the use of chemical bonds, mulching, revegetation, stone surfacing or the replacement of the original cover with impervious surfaces such as roads, pavements and parking lots in urban areas.
2) Runoff Control. Detached particles may be controlled by the use of vegetative filters and by terracing and reduction of slope steepness. Small sediment pits and ditches are also frequently employed.
3) Site Practices. Construction or mining activities may be carefully controlled to disturb a minimum area at any one time. Construction activities may also be planned for periods of low rainfall and/or quick germination of seeding.

Onsite sediment control practices are usually not successful in removing all sediment from the runoff. Recent legislation in many states requires provision of a sediment detention structure downstream of mining and construction activities (EPA, 1976). Sediment detention basins are small reservoirs designed specifically to trap sediment. In urban areas sediment storage is sometimes provided in flood detention basin so that they may serve the dual purpose of both a flood control structure and a sediment basin.

Current legislation normally specifies a minimum size for the basin and limits the sediment concentrations in the effluent. Design guidelines are limited and theory on the performance of sediment basins is scant.

Tables 1 and 2 give the basin size requirements for strip mining detention basins in several states and the effluent quality standards in those states (EPA, 1976). Sediment basin design usually requires the use of a riser outlet as the principal spillway. The riser may have perforations along part of its length but the design of these perforations is very restricted, by state codes, and at present they are not designed to provide a specific sediment concentration in the effluent. A typical riser design requirement for strip mines in Kentucky is shown in Figure 1 (SCS, 1977).

The purpose of this research was to review the methods that have been developed to predict sediment deposition in reservoirs and to develop a mathematical model which simulates sedimentation in sediment detention basins. The model which has been developed also simulates the change in geometry of the basin due to sediment deposition. The model is not restricted to any specific basin geometry or spillway design and may be utilized in the design of any reservoir. The performance of the model has been compared on several sediment basins studied by the Environmental Protection Agency (EPA, 1976). The model predicts a performance in close agreement to those observed in these sediment basins. The results of this comparison and a study of

TABLE 1

DESIGN STORAGE CAPACITY REQUIREMENTS

State	Requirement
SCS (Maryland)	Site should be selected to provide adequate storage for not less than 0.5 in. per acre of drainage area. Volume for trap efficiency calculations shall be the volume below the emergency spillway crest or pipe spillway crest if there is no emergency spillway.
Kentucky	Sediment pool shall have a minimum capacity (from the lowest elevation in the reservoir of the crest of the principal spillway) of 0.2 acre-ft per acre of disturbed area in the watershed. The disturbed area includes all land affected by previous operations that are not presently stabilized and all land that will be affected throughout the life of the structure.
Pennsylvania	V = (AIC) + (AIC/3) V = volume in cu ft A = maximum area draining to the pit in sq ft I = rainfall (in.) per 24 hr detention time (hr) C = constant = % of rainfall not absorbed by soils (runoff)
West Virginia	The sediment pool shall have a minimum capacity (from the lowest elevation in the reservoir to the crest of the principal spillway) to store 0.125 acre-ft per acre of disturbed area in the watershed. The disturbed area includes all land affected by previous operations that is not presently stabilized and all land that will be affected during surface mining and reclamation work.

TABLE 2

EFFLUENT STANDARDS FOR THE SURFACE MINING INDUSTRY

State	Turbidity or Suspended Solids	pH	Total Iron	Alkalinity	Toxic Materials
Federal	30-100 mg/1	6.0-9.0	4.0-7.0 mg/1	Greater than acidity	[1]
Kentucky	150 JTU's [2]	6.0-9.0	7.0 mg/1 or less	Greater than acidity	---
Pennsylvania	[3]	6.0-9.0	7.0 mg/1 or less	---	---
West Virginia	1000 JTU's or less [4]	5.5-9.0	10 mg/1 or less	---	---

[1] No toxic or hazardous material as designated under the provisions of Section 12 of the Federal Water Pollution Control Act or known to be hazardous or toxic by the permittee except with the approval of the Regional Administrator (WPA) or his authorized representative.

[2] The discharge shall contain no settleable matter, nor shall it contain suspended matter in excess of 150 Jackson Turbidity Units, except during a precipitation event, which the operator must show to have occurred, in which case 1000 Jackson Turbidity Units may not be exceeded.

[3] No silt, coal mine solids, rock debris, dirt, and clay shall be washed, conveyed, or otherwise deposited into the waters of the Commonwealth.

[4] Turbidity - not more than 1000 Jackson Units (JU) of turbidity 4 hours following a major precipitation event and not more than 200 JU after 24 hours (major precipitation event = ½ inch of rainfall in 30 minutes).

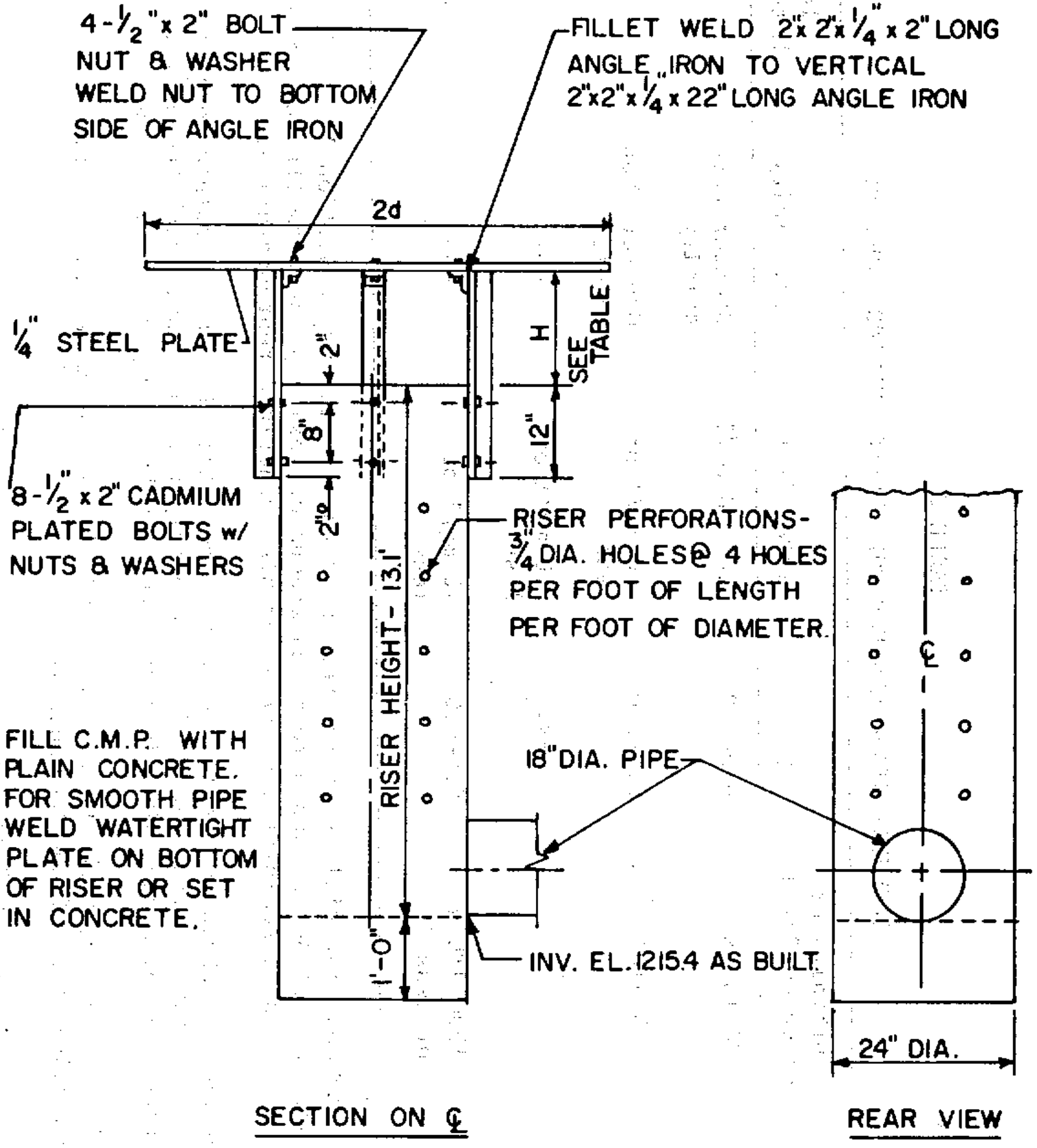


Figure 1: Detail of Riser

the factors affecting sedimentation in a reservoir are contained in the report. A listing of the computer program and a guide to its use is provided in the appendices.

CHAPTER II

LITERATURE REVIEW

The control of waterborne sediment is not a recent concern of mankind; settling basins were probably first employed by the Romans (Brown, 1943):

> The intake of New Anio is on the Sublacesion Way at the forty-second milestone, in the Simbiunum, and from the river; which flows muddy and discolored even without the effects of rainstorms, and, as a result, loose banks, for this reason a settling reservoir was built upstream from the intake, so that in it and between the river and the conduit the water might come to rest and clarify itself.

Our knowledge of Roman techniques is, however, very limited and it is not until the 1400's that any significant theory was developed. Leonardo da Vinci (1452) was one of the earliest researchers in the field of hydraulics but perhaps the most significant early research was presented by Brahms (1753), Chezy (1775), and duBuat (1796). The early research by most of these famous Europeans was mainly concerned with river and channel flow.

In 1889 Seddon (1889) presented a paper on the St. Louis Settling Basins and in 1904 Hazen developed the first real theory on the trap efficiency of a reservoir (Hazen, 1904). Hazen considered the settling of soil particles under different hydraulic conditions and obtained the trap efficiency based on detention time, fall velocity, particle size and the prevailing conditions. His research has become the base upon which several of the more widely used concepts were developed and does not appear to receive the credit it deserves.

Brown (1943) developed a curve relating the trap efficiency to the capacity-watershed ratio (C/W). His curve was based on data collected from over twenty five reservoirs and is represented by the equation:

$$Ct=100\ (1.0-1.0/(1.0+C/10W)) \qquad (1)$$

where Ct = reservoir trap efficiency (%), and C/W = reservoir capacity (acre-feet per square mile of drainage area). Brown's curve plus some additional data plotted by Brune is shown in Figure 2 (Brune, 1953). There is considerable scatter in the points, indicating that there is very little correlation between the capacity-watershed ratio and trap efficiency. The method saw very little use as several other methods were being developed in the 40's and 50's. The most notable contributions being made by Camp, Borland, Churchill and Brune. In Brune's excellent paper "Trap Efficiency of Reservoirs" he describes some of the more notable methods and develops a series of empirical curves which are still widely used today (Brune, 1953).

Brune's trap efficiency curves were based on data collected from forty-four reservoirs. He related trap efficiency to the capacity-inflow ratio (a term first used by Hazen in 1914). Brune's curves are shown in Figure 3 (Brune, 1953). The reservoirs were located in twenty different states and the results gave a much better

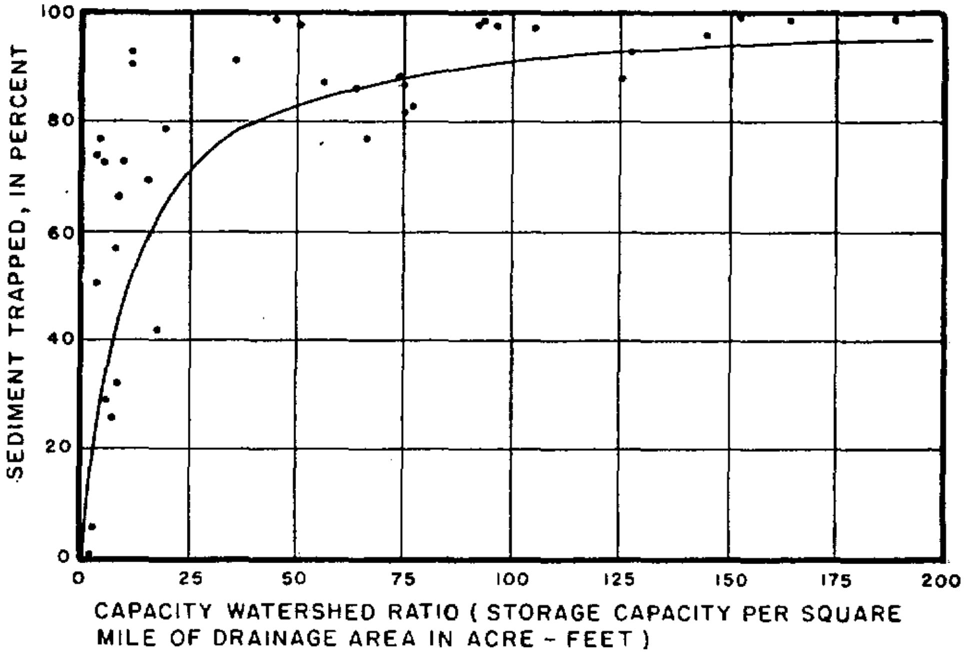


Figure 2: Trap efficiency as related to capacity-watershed ratio

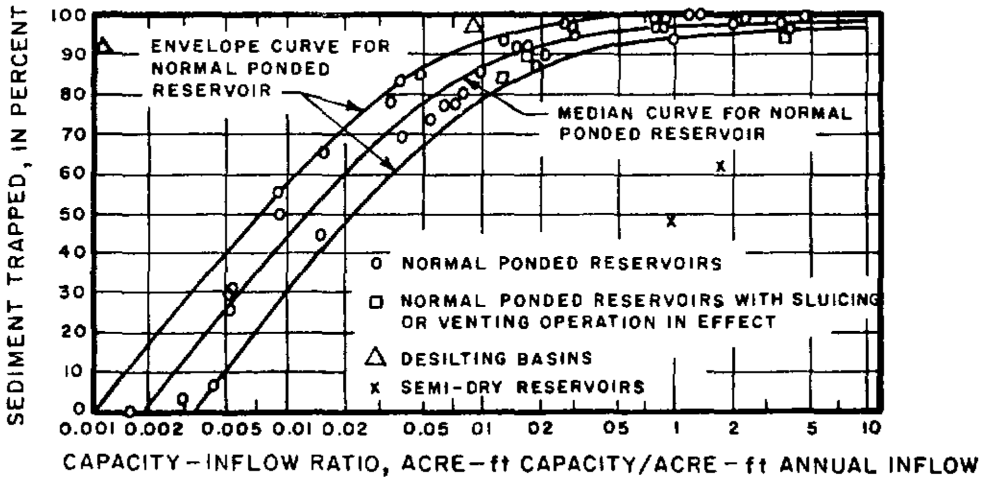


Figure 3: Trap efficiency as related to capacity-inflow ratio, type of reservoir, and method of operation

correlation with trap efficiency than the C/W ratio proposed by Brown. There is, however, still considerable scatter in the points and there appears to be no correlation for semi-dry reservoirs. The shortcomings of both the C/W and C/I ratios can best be exemplified by first amplifying on the mechanics of sediment deposition.

Stokes (1880) studied the drag on small spheres falling freely in a fluid and found by neglecting inertia forces that

$$F = 3\pi\mu dv \qquad (2)$$

where F is the drag force, μ the dynamic viscosity, v the fall velocity of the particle, and d the particle diameter. In the region of viscous settling the drag coefficient is 24/R, where R is the Reynolds number. Later research has shown Stokes' Law to be valid for values of R from 10^{-4} to about 0.5 (Camp, 1945). At higher Reynolds numbers inertia forces cannot be ignored. Stokes only studied the motion of an isolated sphere. Later research has found that the concentration of particles and their shape influence the fall velocity. Clay particles have been found to be disc shaped and based on studies by Pettyjohn and Christiansen (1948) and McNown and Malaiki (1951) equation 2 should be:

$$F = K(3\pi\mu dv) \qquad (3)$$

where the correction factor K varies from 0.5-1.0. A further correction of $(1 - C)^{-m}$ has been proposed by Durand (1972) and by Maude and Whitemore (1958) to account for the hinderance of several particles falling in close proximity. C is the sediment concentration and m varies from 2.2 to 4.5 depending on the flow conditions and Reynolds number.

It can be seen that the deposition of sediment in reservoirs will be dependent on the soil characteristics, the detention time in the basin, the depth of fall and the sediment concentration of the flow. The detention time and depth of flow in the basin are dependent on the geometry of the basin, the inflow and outlet design and the inflow hydrograph. The sediment concentration variation with flow is dependent on the intensity of the rainfall, the vegetative cover on the watershed, the permeability and characteristics of the soil, and the slopes and distances of transport on the watershed. Turbulence will tend to keep particles in suspension or will resuspend them by removal from the reservoir bed (Sayre, 1969). Turbulence will occur depending on the inflow geometry and design and the shape of the basin.

The C/W and C/I ratios used by Brown and Brune, respectively, give only a limited account of the watershed hydrology and basin geometry, and are independent of soil characteristics. Brune appears to have been very aware of the shortcomings of his curves and perhaps if his paper had been more carefully read these curves would have seen less extensive use. Brune's curves have been modified by the U. S. Soil Conservation Service to account for the particle characteristics and have been used extensively in the design of the sediment storage capacity required in small reservoirs (Geiger, 1963).

Churchill (1948) developed a method of relating the trap efficiency to the sedimentation index of a reservoir. The sedimentation index is the detention time divided by the mean velocity. The curve was based on results obtained from several TVA reservoirs and is shown in Figure 4 (Brune, 1953). The method has little use in design as the detention time and mean velocity of flow are difficult to determine and no account is made of the sediment characteristics. An attempt however, has been made to modify the curves to allow for the particle characteristics as shown in Figure 5. It can be seen that because the detention time and mean velocity are dependent on the reservoir geometry, the inflow and outflow rates and the watershed hydrology, there is very little scatter in the points and a high correlation between trap efficiency and sedimentation index results.

Borland (1951) presented a method which can probably be best used to help predict sediment accumulations based on monitoring the performance of the basin after construction. He plotted a curve of trap efficiency with detention time for Imperial Dam Reservoir in Arizona. Brune (1953) in his paper "Trap Efficiency of Reservoirs" made the following comment on the curve:

> Such curves are quite satisfactory for specific reservoirs, since other factors such as sediment characteristics, shape the reservoir, and method of operation tend to remain constant.

This statement is only true for very large reservoirs and dams in which the volume of deposited sediment is small and the land uses on the reservoir remain essentially the same during the life of the reservoir. Imperial Dam Reservoir's capacity was reduced by two thirds between 1938-1947, a very clear demonstration of how the reservoir shape will change with time. The sediment characteristics are dependent on the intensity of the rainfall, bedscour and the watershed land

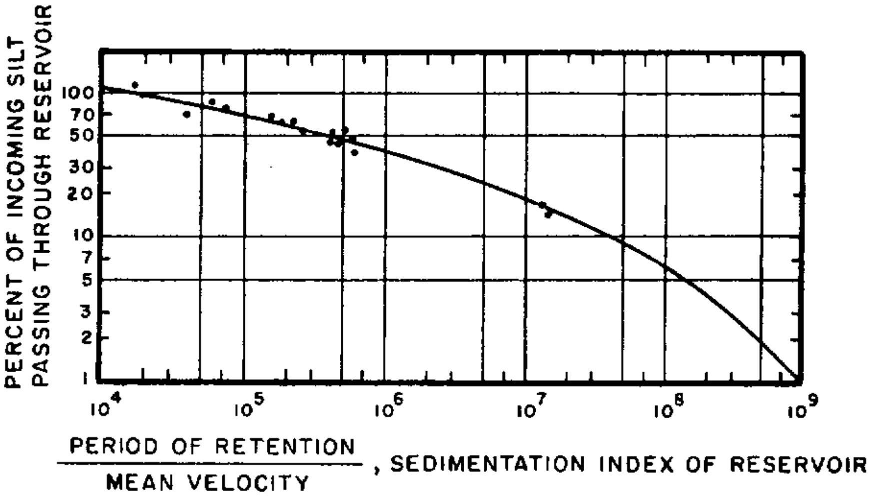


Figure 4: Percent of incoming silt passing through reservoir as related to sedimentation index, TVA reservoirs

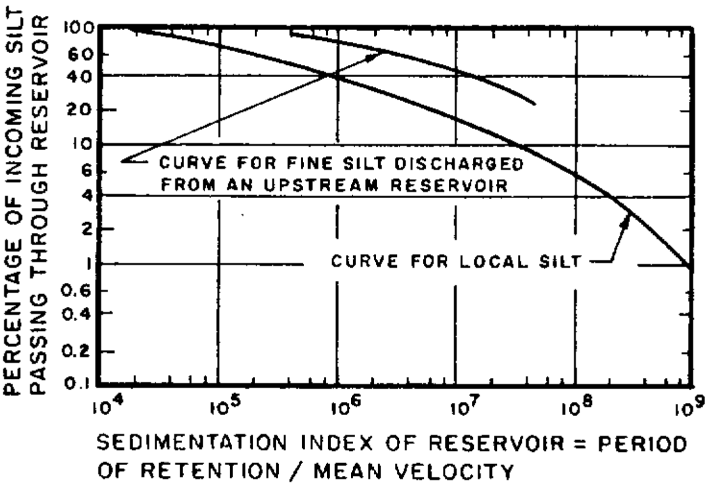


Figure 5: Churchill's Trap Efficiency Curves

uses. All these factors are likely to change with time. It is even questionable whether the method of operation remains the same during the life of a reservoir. The curve developed by Borland (1951) is shown in Figure 6.

While Borland, Churchill, Brown and Brune were developing their respective ideas on the trap efficiency of reservoirs Dobbins (1944), was studying the effect of turbulence on sedimentation and Camp (1945) was developing a method which was suitable for the design of settling tanks. With the exception of some of Hazen's ideas, all the methods mentioned have been of an empirical nature. During the same era considerable theory was developed on sediment transport. As with the early theory of Brahm, the theory was developed primarily for flow in channels, pipes and rivers. Dupuit (1865), Einstein (1950), Schoklitsch (1933), Meyer-Peter and Muller (1969), duBoys (1879) and Vanoni (1946), are but a few of the major contributors in this field. Although much of this theory would be applicable in developing a method to determine trap efficiency of large reservoirs located on large well established rivers, very little research was done on mathematical methods of determining trap efficiency. Camp, however, did develop a method based on Stokes' Law of Settling.

Camp (1945) states in his paper that Stokes' law is valid for values of Reynolds number between 10^{-4} and about 0.5 and that in this range

$$v = (g/18\nu)(s-1)d^2 \tag{4}$$

where v is the terminal settling velocity, s the specific gravity of the particle, g the acceleration due to gravity and ν the kinematic viscosity of water. Camp made a very thorough study of the factors affecting sedimentation. He considered irregularities in shape, hindered settling due to particles settling in close proximity, bed-load movement scour, turbulence, short-circuiting and flocculation.

His development is fairly lengthy and will only be discussed here in part. It should be noted however that much of the theory upon which it was based is still widely used today. In part he incorporated some of Hazen's (1904) concepts with Shields' theory of bed-load movement, (Vanoni, 1946), Nikuradse's (1939) theory of mixing in pipes, von Karman's velocity distribution and Dobbin's (1944) theory on turbulent flow and incorporated them in modifications of settling in ideal basins. Camp defined an ideal basin in the following way.

> Since an 'ideal basin' has been defined as a hypothetical settling tank in which settling takes place in exactly the same manner as in quiescent settling container of the same depth, an "ideal rectangular continuous flow basin' for unhindered settling has the following characteristics:
> 1. The direction of flow is horizontal and the velocity is the same in all parts of the settling zone (hence, each particle of water is assumed to remain in the settling zone for a time equal to the detention period--namely, the volume of the settling zone divided by the discharge rate);
> 2. The concentration of suspended particles of each size is the same at all points in the vertical cross section at the inlet end of the settling zone; and
> 3. A particle is removed from suspension when it reaches the bottom of the settling zone.

Camp showed that the trap efficiency, E, of all particles having settling velocity, v, is:

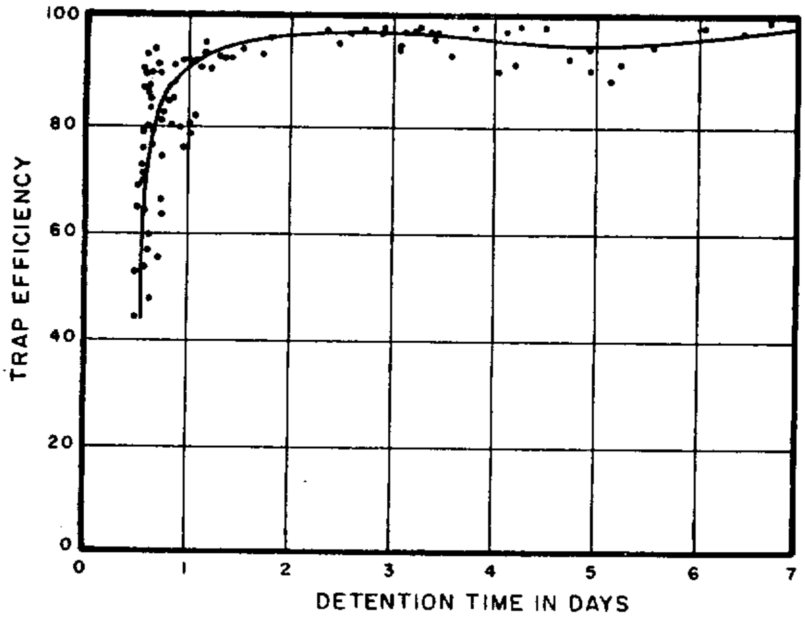


Figure 6: Trap efficiency as related to detention time, Imperial Dam Reservoir, Yuma, Arizona

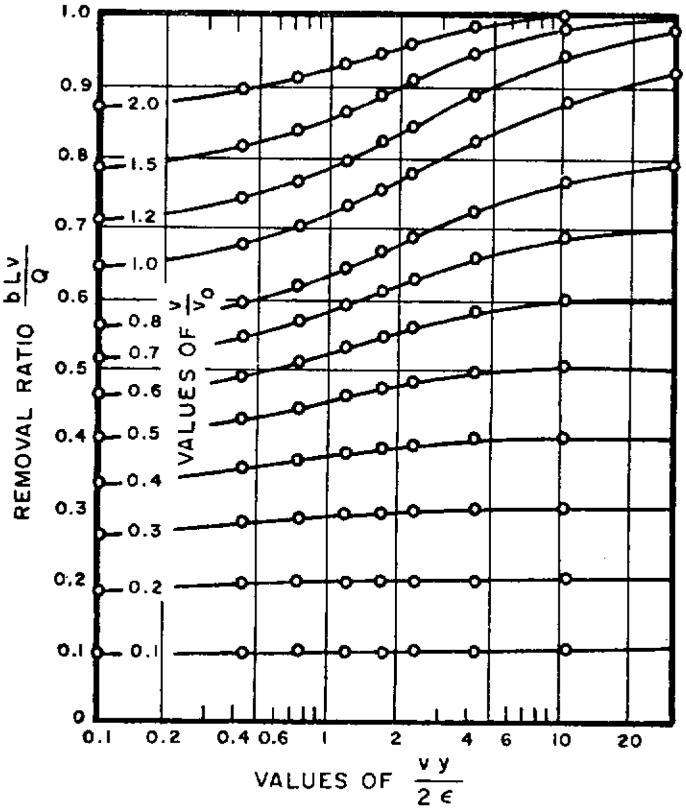


Figure 7: Camp's Trap Efficiency Curves

$$E = vA/Q \tag{5}$$

where A is the surface area of the basin (width, B, times the length, L) and Q is the discharge rate. This result was first obtained by Hazen. Q/A is known as the overflow velocity or "surface loading" of a basin. All particles having settling velocities less than the overflow rate will not be trapped. This method has been modified slightly by making A the wetted surface area of a reservoir and is one method currently employed by the EPA (1976a). Although simple in appearance, the method is very difficult to use because the discharge rate and wetted area tend to vary considerably during storm events, particularly in small reservoirs and sediment detention basins.

Based upon the assumption that the fluid velocity is uniform in the basin, and that the mixing coefficient, e, is the same at every point in the basin, Camp and Dobbins developed an analytical relation between E (vA/Q) and vy/2e where y is the depth of the basin. This relationship is shown in Figure 7. A modification of this method by Brown is shown in Figure 8 (Brown, 1950). Figure 8 demonstrates the effect of turbulence on reducing trap efficiency. It should also be noted that trap efficiency has now become dependent on the basin depth which was not the case in quiescent settling. Although the effect of the basin depth is small, it becomes significant if the basin is made too shallow and bed scour occurs. Camp showed that the critical non scour mean velocity, Vc, is given by;

$$Vc = [(8\beta/f)(s-1)gd]^{\frac{1}{2}} \qquad (6)$$

where β is the Shield's critical shear stress parameter and f the Darcy-Weisbach friction factor. For uniform sand β ranges from 0.04 to 0.06 and tends to be higher for sticky and flocculent material.

When high turbulent flow conditions occur, the trap efficiency can be related to vA/Q by the equation;

$$E = 1-\exp(-vA/Q) \qquad (7)$$

This relation was used by the Bureau of Reclamation for the design of the settling basins of the All-American Canal project (Vetter, 1940). As illustrated by this description of the All-American Canal at Imperial Dam (Brown, 1943), the curve seems well suited to the design of settling basins.

> . . .these desilting works consist of 6 settling basins arranged in pairs. Each basin is approximately 269 feet wide, 769 feet long and has an average depth of 12.5 feet. The basins are set at an angle of 60° with the inflow channels. Each basin has a rated flow capacity of 2000 second-feet . . . . The maximum flow across the channel is 0.22 foot per second. At this velocity the detention period is 21 minutes. It is estimated that with this velocity approximately 80 percent of the maximum income sediment will be deposited on the floor of the basin. The design of the basin is based on a total inflow of 12,000 second-feet, or 80 percent of the capacity of the canal. The average sediment load for a flow of 12,000 second-feet was estimated to be 60,000 tons dry weight per day.

Figure 9 shows a plot of the curve for high turbulent flow and for quiescent flow as plotted by Chen (1975). He recommends that Brown's plot be used for flow conditions between high turbulence and quiescent flow. However, Brown's plot has the same pitfalls as the equation for quiescent flow in that the overflow rate is not a constant

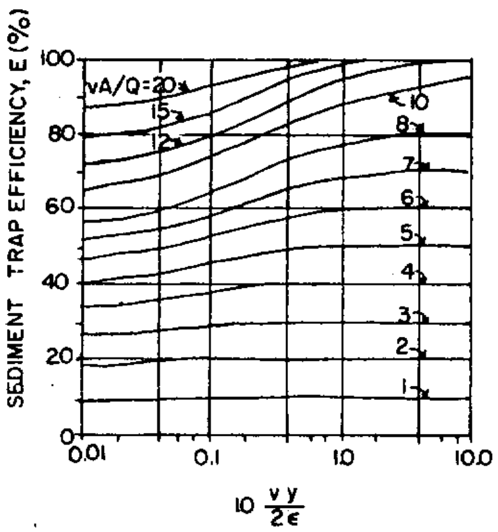


Figure 8: Camp's Trap Efficiency Curves

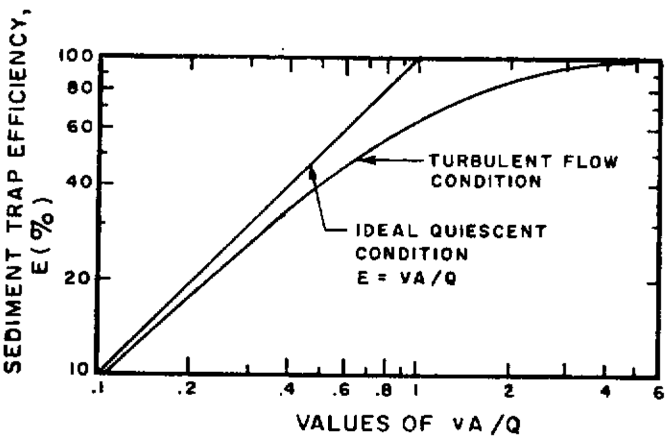


Figure 9: Trap Efficiency versus Ratio of Settling to Overflow Velocity

for a given basin. A is also a poor indicator of the effect of the basin geometry and is not readily defined for non linear geometric shapes. Some account of these limitations is made both by the EPA and Bureau of Reclamation by using Q as the peak discharge and A as the wetted surface area at this peak discharge. The assumption is made that the basin will be as efficient or more efficient at lower flow rates.

During the past twenty years much of the research has been focused on determining the nature of the soil erosion on a watershed, predicting the sediment yield to a reservoir and modeling the hydrology of the watershed. In a study conducted by Glymph (1954) on data compiled from 113 watersheds varying in size from sixty-four acres to 300,000 acres, it was found that the dominent source of erosion was sheet erosion. The watersheds were located primarily in humid agricultural areas and in seventy-three of the watersheds sheet erosion accounted for more than seventh-five percent of the sediment. Predictive equations such as those developed by Graf (1971), Bagnold (1966) and Einstein (1950), for determining the total load in a stream do not account for the washload and cannot therefore be used to determine sediment yields to most reservoirs. In 1947 Musgrave (1947) developed an equation for predicting the sediment yield from sheet and rill erosion on a watershed. His equation was widely used until the early 1960's when Wischmeier and Smith (1965) developed what is now known as the Universal Soil-Loss Equation (USLE). The USLE was originally developed for use on agricultural watersheds but has been widely adopted for use on urban watersheds. The USLE and many of the predictive equations based on it tend to give very poor estimates of the sediment yield to a downstream point on the watershed. The USLE was developed to give the sediment movement from a single watershed slope. In order to obtain the sediment yield downstream a delivery ratio is required. Much of the detached sediment may be redeposited before it reaches the control structure. Kuo (1975), for example, found in an urban development study at Cedar Hill, Virginia, that the USLE, in a modified form, over-predicted the sediment yield to a downstream point on the watershed by 5-200 times. One of the biggest problems today in determining the performance of sediment detention structures is the difficulty in determining the amount of sediment entering the structure.

Several researchers have studied the relationship between the amount of effective precipitation and the sediment discharge. Herrero (1974), has developed a method of estimating the washload on a storm basis for small watersheds. He found that the shape of the sediment concentration-time curve was very similar to that of the hydrograph for the watershed. This result has been substantiated by several other researchers. An example of this relationship is shown in Figures 10 and 11. It can be seen from Curtis's (1976) curves (Figure 11) that the intensity of the storm and its duration are major factors in establishing the sediment discharge.

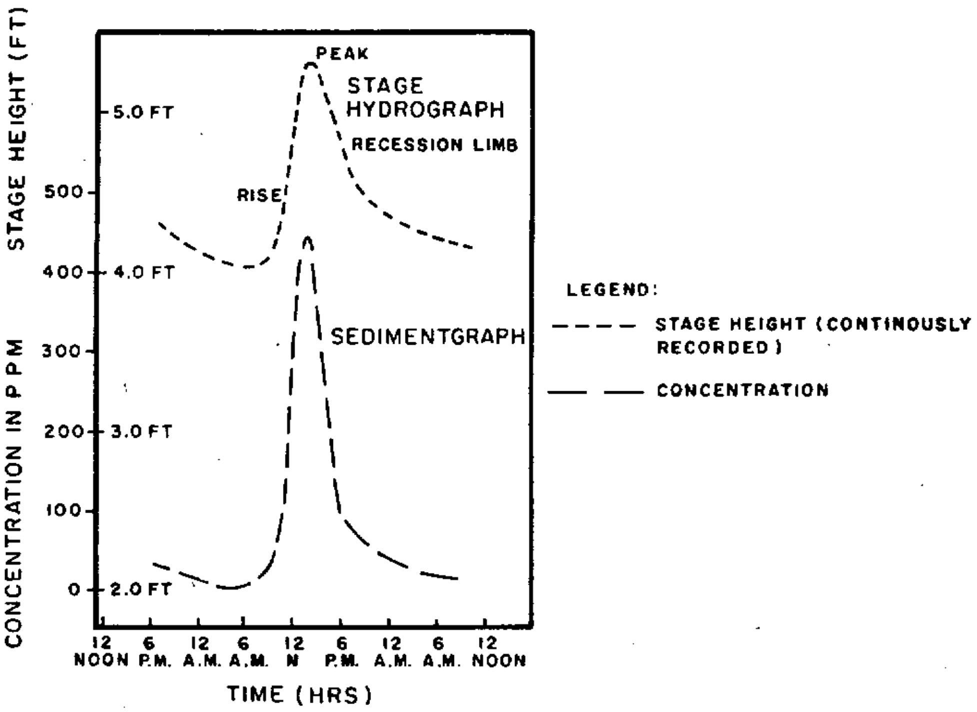


Figure 10: Typical stage Hydrograph and Sedimentgraph

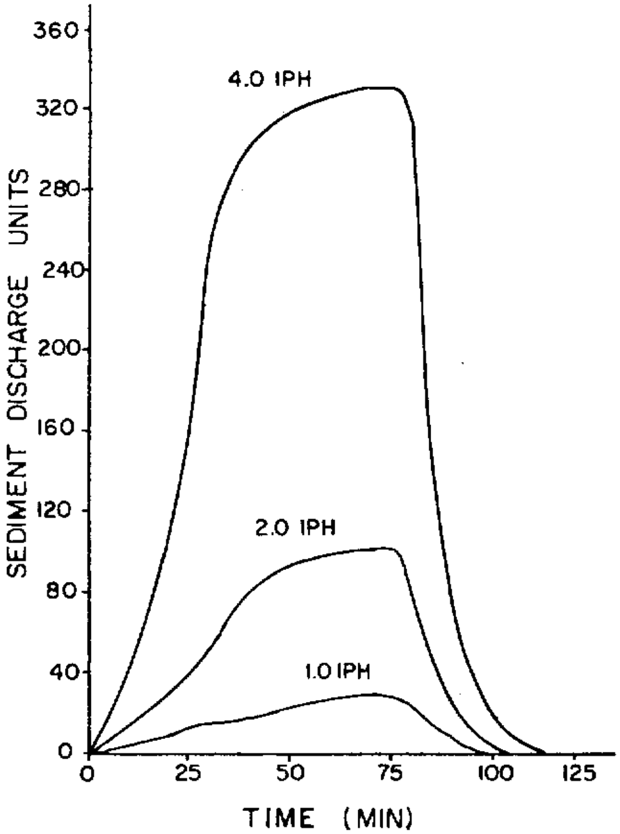


Figure 11: Sedimentgraph developed by Curtis

Since Brune developed his trap efficiency curves, very few trap efficiency methods of note have been developed. In 1953 Fair and Geyer (1954) developed a method which has seen occasional use in water treatment facilities and Wolman (1966) developed a method for determining the trap efficiency of weir ponds (USDA, 1972):

$$TE = \Sigma\ RS \tag{8}$$

where TE = trap efficiency in percent, R is the decimal fraction of the material size range that is trapped. R = 1 if r is not 1.0; R = 0.5 if r = 1.0; R = 0.0 if r = 0.0 where

$$r = \frac{\text{percent of material trapped in weir pond}}{\text{percent of material in deposits downstream}}$$

and s is the percent of the material trapped in the weir pond that is in the size range considered. The method has not been widely used and is not suitable as a design method. It is also restricted to use in very small control structures. Some of the more prominent work on trap efficiency methods and mathematical modeling of these methods was done by Chen, C. (1975), and Chen, Y. (1976) respectively.

Figure 12 shows a plot Chen, C. (1975) developed for comparing the methods of Brune and Churchill to that of Camp for high turbulent flow. Although this is hardly a valid comparison of the different methods, as high turbulent flow is not the typical flow situation in sediment detention basins, it does illustrate several valid points. The curves indicate as Chen noted, that Churchill's and Brune's curves overestimate the trap efficiency for finer sediments and underestimate the trap efficiency for coarser material. The entrapment of clay size

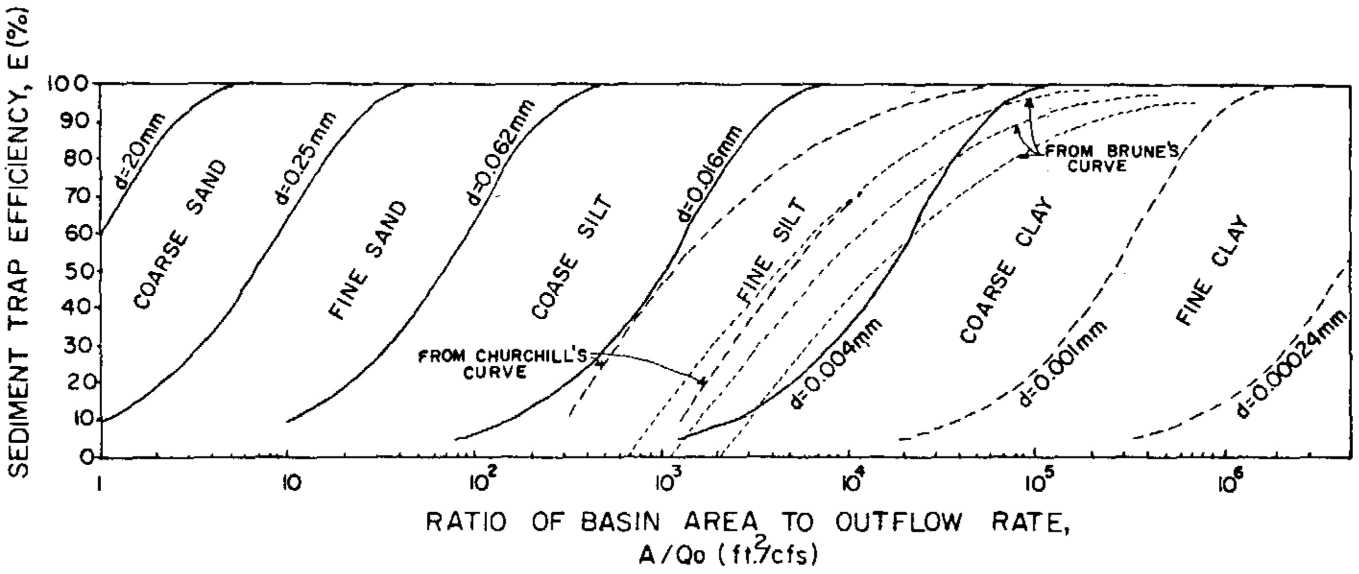


Figure 12: Trap efficiency versus ratio of basin area to outflow rate

particles can usually only be obtained by chemical flocculants or basins with large dimensions. It is felt, however, that this last observation is not strictly true. Removal of clay particles may be obtained in small basins if the outlet design provides for a severe restriction in discharge and hence gives a long detention time in the basin. Size and nature of the outlet are, however, very dependent on the hydrology and size of the watershed.

Chen (1976) has done considerable research into mathematical modelling of sediment transport in rivers and reservoirs. He has attempted to develop solutions to the three basic equations determining sediment transport:

Sediment continuity equation:

$$\frac{\partial Q_s}{\partial x} + p\frac{\partial A_d}{\partial t} + \frac{\partial AC_s}{\partial t} - q_s = 0 \tag{9}$$

Flow continuity equation:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} + \frac{\partial A_d}{\partial t} - q_\ell = 0 \tag{10}$$

Flow momentum equation:

$$\frac{\partial \rho Q}{\partial t} + \frac{\partial B\rho QV}{\partial x} + gA\frac{\partial \rho y}{\partial x} = \rho gA \quad (S_o - S_f + D_\ell) \tag{11}$$

where:

x = horizontal distance along the channel

t = time

Q_s = sediment discharge

ρ = Volume of sediment in a unit volume of bed layer given by ρ_b/ρ_s

ρ_b = bulk density of sediment forming the bed

ρ_s = density of sediment

A_d = volume of sediment deposited on channel bed per unit of length of channel, the value is negative for bed erosion

A = water cross-sectional area

C_s = mean sediment concentration on a volume basis given by A_s/Q

Q = flow discharge

q_s = lateral sediment flow per unit length of channel, a positive quantity indicates inflow

q_w = lateral water flow per unit length of channel, a positive quantity indicates inflow

q_ℓ = lateral flow per unit length of channel, given by $q_s + q_w$

ρ = density of sediment-laden water given by $p_w + C_s (\rho_s - \rho_w)$

β = momentum coefficient

V = mean flow velocity

y = flow depth

g = acceleration of gravity

S_o = bed slope

s_f = friction slope

D_ℓ = dynamic contribution of lateral discharge given by $q\ell V\ell/Ag$

V_ℓ = velocity component of lateral inflow in the main flow direction

ρ_w = density of water

Chen's solutions have been incorporated into a watershed model developed by the Colorado State University to simulate the hydrology and water-sediment movement on small watersheds. Extensive knowledge of the basin geometry, land uses and soil types, infiltration rates, hydrology, etc., are required to utilize the model.

Several other models of note have been developed in recent years. The Corps of Engineers, Hydrologic Engineering Center (1967 and 1968) have developed models for predicting sediment deposition, trap efficiency and delta sedimentation in reservoirs. The models, however, cannot be used as design criteria. They require extensive collection of suspended sediment concentrations and flow rates in the reservoir following construction. The main value of the models is in the monitoring of the performance of a reservoir during its life.

A plug flow model has recently been developed by Pennell and Larson (1976) at the University of Minnesota. The model assumes an ideal basin, the Universal Soil Loss Equation, a 100% delivery ratio, complete mixing and instantaneous inflow and discharge. The model provides a useful tool in evaluating some of the factors affecting trap efficiency but its application is very limited. Several models have been developed on delta sedimentation but they give little insight into simulation techniques for sediment laden flow.

It can be seen from the preceeding review of some of the literature pertaining to reservoir sedimentation that although extensve research has been conducted, many questions remain unanswered. No single trap efficiency method has been developed which is suitable in the design of reservoirs and sediment detention basins. Most of the methods in fact can only be utilized following construction and do not give good results. One of the biggest problems in developing better design methods has been a lack of data on the performance of sediment basins.

Sedimentation surveys have been conducted by many state and federal authorities during the past 100 years (Ohio State Department of Natural Resources, 1948 and 1955). Unfortunately the nature of the surveys has provided researchers very little data of value in developing better design methods. Most sedimentation surveys are done by the range method and only determine the volume of sediment deposited over a period of several months or years. The type of surveys that are required should include monitoring of suspended sediment concentration variations with time, inflow and outflow variations with time and riser stage, and collection of inflow soil size characteristics. A few studies of this nature have been conducted by Hittman Associates (1974 and 1976) for the Environmental Protection Agency.

In one study (Hittman, 1976) nine sediment detention basins in either Pennsylvania, Kentucky or West Virginia, were monitored during a storm event and a baseline condition. Although these studies are probably the best that have been conducted, they are still inadequate in several ways. Only part of each storm event was monitored and the data on inflow rates are incomplete. The initial stage at the riser and the variation in stage depth during the storm events were not recorded. In future studies of this nature it would be advantageous if more than one storm event was monitored. Determining the actual trap efficiency of a basin during a storm event is not easy and it is felt that the method employed in the Hittman studies is not completely correct.

The actual trap efficiency was determined by using the mass balance equation (Mallory and Nawrocki, 1974):

$$R \text{ (\% solids removed)} = \left[1 - \frac{\dfrac{10^6}{C_1} - 1}{\dfrac{10^6}{C_2} - 1} \right] 100 \qquad (12)$$

where C_1 is the solids concentration of influent (mg/l) and C_2 is the solids concentration of the effluent (mg/l). Influent and effluent readings however were taken simultaneously over a short period of time. Their use in equation 12 implies instantaneous flow through the basin. There is a time lag approximately equal to the average detention time between corresponding influent and effluent readings. If the entire storm event had been monitored the average influent and effluent readings could have been used in equation 12.

A better conceptual knowledge of the entire sedimentation process is needed before a good understanding of inlet and outlet designs, particle flocculation and aggregation can be obtained to maximize sediment trap efficiencies in detention structures. Flocculating agents are frequently used in waste water treatment facilities to remove colloidal particles (Weber, 1972). Their use on a large scale in sediment basins would prove to be very costly but with a better understanding of the sedimentation process, selective use may prove very beneficial. Strip mine sediment basins are frequently poorly sized due to the natural aggregation and flocculation on strip mine watersheds. Monitoring of the chemical composition of the influent might show that a small change in the electrokinetic balance could greatly increase deposition.

Many of the ideas expressed in this review have been incorporated in the conceptual model described in this report. Although the focus of the research is on sediment detention basins the concepts discussed and developed within the report are also applicable to the design of sediment storage space in large reservoirs.

CHAPTER III

DESCRIPTION OF THE DEPOSITS MODEL

Introduction

As has been noted, the severe problems associated with the transport of sediment by water has led to the construction of small control reservoirs designed specifically to trap sediment. The mechanics of sediment laden flow is very complex, but the major factors governing the efficiency of sediment retention basins are the geometry of the basin, the inflow hydrograph, the inflow sediment graph, the outlet design, the hydraulic behavior of the flow within the basin, the characteristics of the sediment and the settling behavior of the suspended sediment particles. Most trap efficiency methods discussed previously are based only on a few of the above factors. If a mathematical model can be developed that considers these governing parameters, a better description of basin performance and design methods can be obtained.

The following is a description of a model for describing sediment basin performance. The model is named DEPOSITS, which is an abbreviation for DEposition Performance Of Sediment In Trap Structures. The model estimates basin trapping efficiency, concentration of sediment in the water discharging from the basin, and the change in basin geometry due to sediment accumulation in the basin.

Basic Concepts

In order to develop a model sufficiently general to be applicable to most sediment detention basins, the flow within the basin was idealized by the PLUG flow concept. Plug flow assumes no mixing between plugs and routes the flow on a first in, first out basis. Although this type of flow does not allow for turbulence or short circuiting, provision for a correction factor has been incorporated in the model. As most sediment basins are designed to contain runoff for periods of less than 1-5 days, the effects of temperature fluctuations are considered to be insignificant.

Settling of the sediment particles is described by Stokes' Law of Settling and particles are considered "trapped" as soon as they reach the reservoir bed. The bed is considered a perfect absorber of sediment and resuspension or saltation of the particles is disregarded. The model accounts for the variation in sediment concentration with depth by subdividing each plug into four layers. Selective withdrawal, at the basin outlet, from these layers is provided for in the model.

The basic inputs are few and are typical of those required for the design of any hydraulic structure to detain sediment:

1) Stage-area curve for the basin.
2) Inflow hydrograph.

3) Particle size distribution and specific gravity of suspended sediment.
4) Stage-discharge curve for the basin.
5) Sediment inflow graph.
6) Viscosity of the fluid.
7) Stage-discharge distribution curve.

The basin geometry is completely defined by the stage-area curve. The stage is defined in the model as the depth of water at the riser. Such factors as the basin length, slope, width or cross-sections along the basin's length are not required.

If a stage-discharge distribution curve is not specified, the model assumes that the outflow rate is uniform with depth. Normally the outflow rate for a given stage varies with the depth of the outflow surface, For example, if there is two feet of water above a six foot drop inlet it might be assumed that most of the outflow is drawn from the two feet of water at the surface. For a riser pipe with uniform perforations along its length the outflow is dependent on the head of water above each perforation. The outflow rates through the lower perforations will be greater than the rates through the perforations near the surface.

If a sedimentgraph is not available for the basin inflow, sediment concentration is taken as proportional to the water inflow rate. The total mass of sediment entering the basin during the design storm event or the inflow sediment graph must be specified if effluent sediment concentrations are required as an output. The model can also determine changes in basin geometry due to deposition provided the total mass of sediment in the inflow is known.

As has been indicated the model is capable of predicting the sediment concentration of the effluent and the sediment deposition pattern in the reservoir. The model determines the volume of sediment deposited in each plug layer and makes a corresponding adjustment in the stage-area curve. If this option is desired, the specific weight of the sediment deposits is required. The model assumes the same unit weight of deposits throughout the basin and does not provide for later consolidation of the deposits. If consolidation is a design criteria an adjustment to the initial specific weight should be made. A listing of the program and a glossary of terms used are contained in the Appendices.

Model Theory and Mathematics

Basin Geometry

The basin geometry is defined by the input of a stage-area curve. The capacity and average depth for each stage point is determined from the stage-area curve. The stage is defined in the model as the depth of water at the outlet structure. If the deposition option is employed, the stage is defined as the height of flow, above the initial basin bed, at the riser. As the basin bed is redefined due to deposition the depth of flow at the riser is redefined in the model as the depth. The capacity of the basin at any given stage point is determined by the trapezoidal method described by:

$$\mathrm{CAPAC(N)} = \sum_{J=1}^{N} \mathrm{(AREA(J)+AREA(J-1))(STAGE(J)-STAGE(J-1))/2} \quad (13)$$

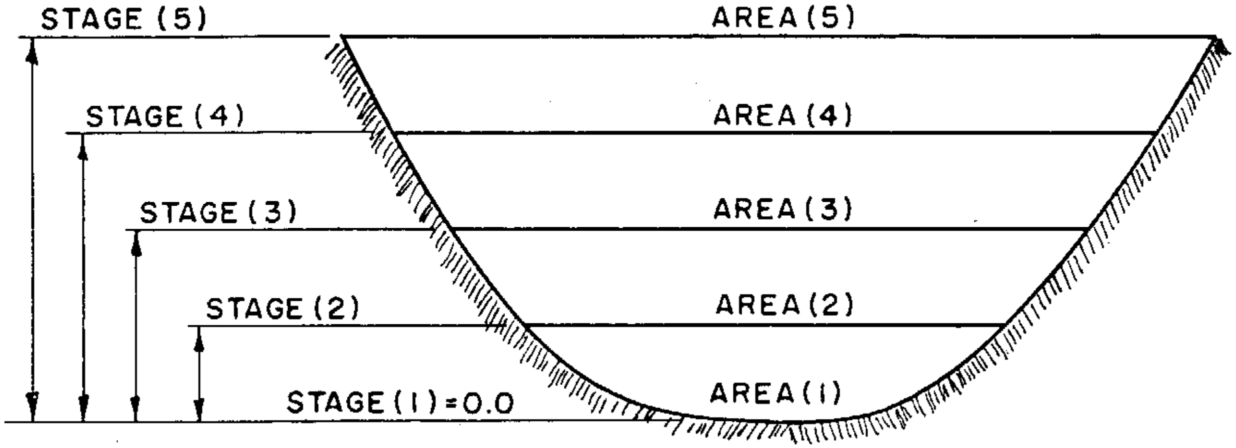
Where CAPAC(J) is the capacity, in acre-feet, and AREA(J) is the surface area, in acres, at the stage point (J). This method is illustrated in Figure 13, Stage-area determinations are usually made from topographic maps or from field measurements. It was felt that the accuracy of these methods did not warrant the use of some of the more sophisticated conic procedures for arriving at the stage-area relationship.

The average depth of water is defined as the average depth of the water surface from the reservoir bed. It is a volume weighted average of the water depth throughout the basin. The average depth for each stage point is given by:

$$\mathrm{AVDPTH(I)} = \frac{\sum_{J=2}^{J=I} \mathrm{DEPO}^{2.0} \mathrm{*(AREA(J)-AREA(J-1))}}{\sum_{J=2}^{J=I} \mathrm{DEPO * (AREA(J)-AREA(J-1))}} \quad (14)$$

where DEPO = STAGE(I)-(STAGE(J) + STAGE(J-1))/2.0

This procedure is shown in Figures 15 and 16. Equation 14 may not be used in situations where there is no increase in surface area with depth. In practice this is only likely to occur in the design of a retangular settling tank. The model contains an alternative method of computation which gives good results for any shape of basin.



$$\text{CAPAC}(5) = \sum_{J=2}^{5} \Big(\text{AREA}(J) + \text{AREA}(J-1)\Big)\Big(\text{STAGE}(J) - \text{STAGE}(J-1)\Big)/2 \quad \text{....} 13$$

Figure 13: Determination of the basin capacity

$$\text{AVDPTH(J)} = (\text{STAGE(J)} - \text{AVDEP(J)})*2.0 \qquad (15)$$

where

$$\text{AVDEP(J)} = (\text{CAPAC(J-1)} * \text{AVDEP(J-1)} + \frac{(\text{CAPAC(J)}-\text{CAPAC(J-1)})(\text{STAGE(J)}-\text{STAGE(J-1)})}{2.0*\text{CAPAC(J)}}$$

The mathematical validity of equation (15) has not been determined and it is only used when two consecutive areas on the stage-area curve are the same.

Inflow Routing

The inflow of water to the basin is defined by an inflow hydrograph. The number of inflow points and the time increment between points must be specified. If the inflow hydrograph is not known, there are many methods available to simulate a given design hydrograph. In simulation runs in this study the procedure described by Mynear and Haan (1977) was used for developing inflow hydrographs.

The flow was routed through the reservoir by a computer method based on Kao's (1975) Four-Quadrant Graph-Method.

The change in storage for each increment of time is given by the equation:

$$(S_2 + O_2 \Delta t/2) - (S_1 - O_1 \Delta t/2) = (I_2 + I_1) \Delta t/2 \; \ldots.(16)$$

where S_1 and S_2 are the basin capacities at times one and two respectively. I_1 and I_2 are the inflows rates and O_1 and O_2 are the outflow rates at times one and two. Δt is the time increment between times one and two. In the model the stage-capacity curve is

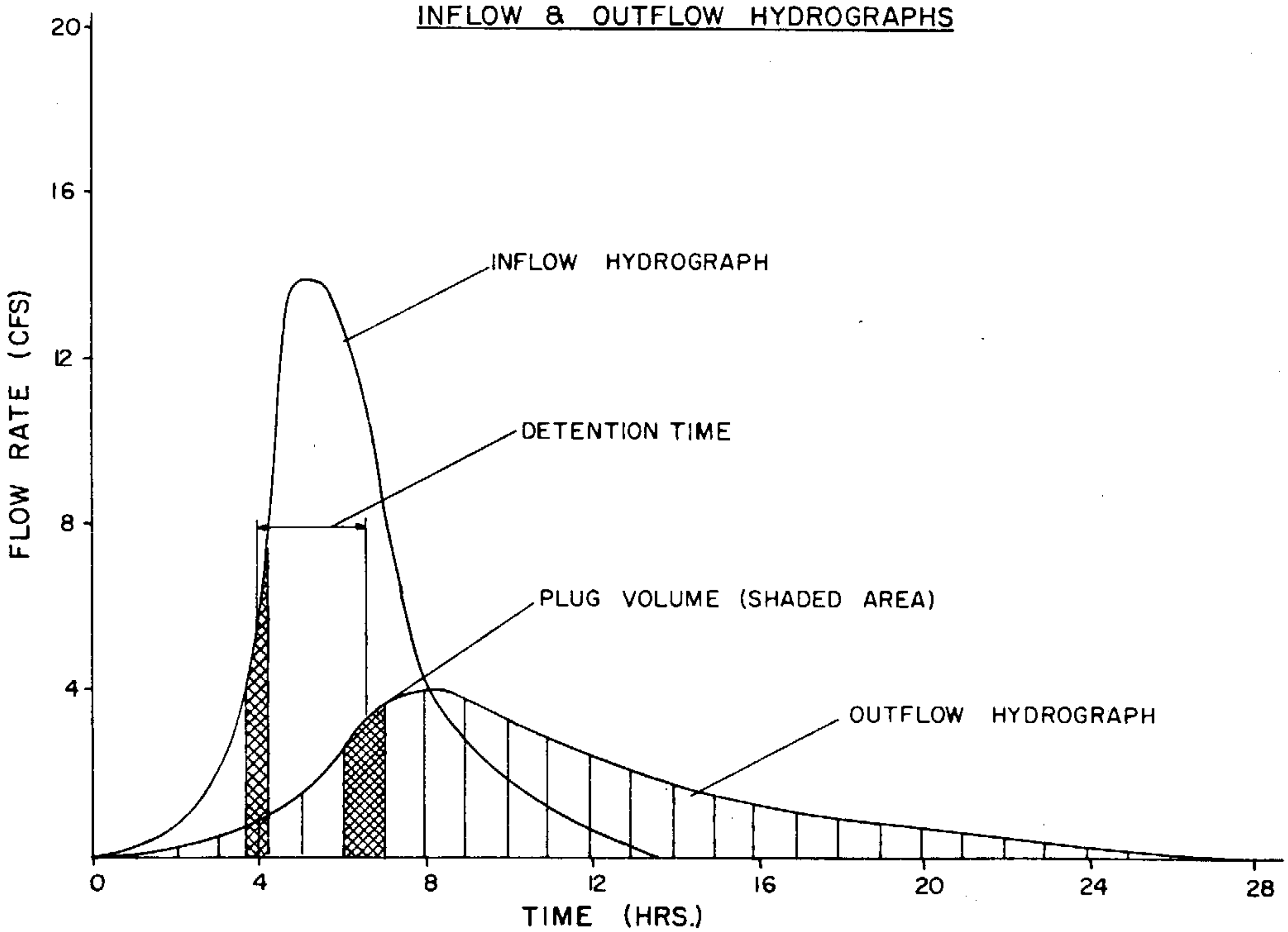


Figure 14: Inflow and outflow hydrographs

computed from the stage-area curve of the basin. The stage-discharge curve must be defined at the same stage points as the stage-area curve. The accuracy of the routing method is dependent on the time increment between successive inflow points and the height increment between successive stage points. To adequately represent the inflow hydrograph, the increment should not exceed one quarter of the time to peak of the hydrograph. The increment between stage points does not have to be constant and its magnitude depends on the basin size. For basins with a capacity less than thirty acre-feet, the stage increment should not exceed two feet. If the deposition buildup in the basin is required, it is desirable to make the stage increment constant.

Sediment Concentration

As previously indicated, the sediment concentration variation may either be specified as an input or estimated by the program. If specified, the concentrations must be given for the same time points as the inflow hydrograph.

The volume of sediment inflow for each increment of time is determined by:

$$\text{SEDMNT}(J)=(\text{CONCED}(J)+\text{CONCED}(J-1))(\text{VOLUME}(J)/2000\text{SG}) \qquad (17)$$

where VOLUME (J) is the incremental inflow at time J, in acre-feet, CONCED(J) is the concentration (mg/l) and SG the specific gravity of the inflowing sediment particles. The concentration is specified in milligrams per liter and the equation is divided by 2000 to obtain the average volume of sediment in acre-feet during the time increment.

If the influent concentrations are not specified, the sediment concentration variation is assumed proportional to VOLUME(J) for each time increment. If the total mass of sediment inflow is specified, influent concentrations are determined by:

$$\mathrm{NFLNT(JS)} = \frac{\mathrm{SEDMNT(JS)*SG*MASS*735.48}}{\mathrm{VOLUME(JS)*SEDTOT(M)}} \qquad (18)$$

where NFLNT(JS) is the influent sediment concentration (mg/l) at time JS, SEDMNT(JS) = $\mathrm{VOLUME(JS)}^{2.0}$, MASS = mass of sediment in tons and SEDTOT(M) is the sum of the M values of SEDMNT(JS). M is the number of inflow points specified in the input of the inflow hydrograph. The equation is multiplied by 735.48 to convert the mass in tons and volume in acre-feet to a concentration in mg/l.

Several studies have shown a correlation between the inflow rate and the sediment concentration. Based on studies by Land and Koelzier (1963), Curtis (1976), Kuo (1975), Herrero (1974), Oscanyan (1975) and the USDA (1975), it appears that considering the sediment concentrations proportional to the flow rate gives a reasonable approximation for most small watersheds. The actual correlation is dependent on the rainfall intensity, the particle characteristics and watershed factors. It has also been shown that the peak of the sediment concentration curve may preceed the peak of the inflow hydrograph (Graf, 1971). On small watersheds with moderate slopes the peaks usually coincide.

Effluent concentrations are determined by:

$$\mathrm{EFLNT(NN)} = \mathrm{(SEDPLG(NN)/\ PLGVOL(NN))*MASS*7.3548} \qquad (19)$$

where EFLNT(NN) is the average effluent concentration for plug (NN), SEDPLG(NN) is the percent of the total sediment volume contained in the plug outflow and PLGVOL(NN) is the volume of the plug. The effluent concentration is determined only if the mass of sediment is specified either by the input of influent concentrations or a total mass of sediment. All influent and effluent values are in mg/l.

Plug Routing

The flow is subdivided into separate plugs of flow of equal time increment. The time length of the plug on the outflow hydrograph must be specified in the input and must be an integer multiple of the inflow hydrograph time increment. It is recommended that the plug time increment not exceed one hour or half the time to peak on the inflow hydrograph. The plug time increment is denoted by DELPLG, and must be specified in hours. Each plug is subsequently subdivided into four layers or strata of equal depth.

The following factors are determined for each plug:

1) The plug volume.
2) The fraction of the total sediment inflow initially contained in the plug.
3) The detention time.
4) The average stage during outflow.
5) The average depth of flow of the plug during detention.

A description of how each of these factors is determined will now be given.

Plug Volume

The initial routing of the inflow by the Four Quadrant method gives the discharge rate for each time increment DELTAT. The accumulated outflow is then given by:

ACOUT(L)=ACOUT(L-1)+(DISCHA(L-1)+DISCHA(L))*DELTAT*.0413 (20)

where ACOUT(L) is the accumulated outflow at time L and DISCHA(L) is the discharge at time L. The factor 0.04132 converts the average discharge in cfs and the time DELTAT in hours into an accumulated volume expressed in acre-feet.

The inflow and outflow points of each plug are determined from the initial outflow hydrograph points. The volume of each plug is:

PLGVOL(NN) = ACOUT(P) - ACOUT(P-LR) (21)

where LR=DELPLG/DELTAT, P=LR*(NN-1)+1 and the plug volume in acre-feet is PLGVOL(NN). Because the plug points P are multiples of the initial routing points MR, it is necessary for the ratio DELPLG/DELTAT to be an integer value. The number of plugs is MR where MR=MS/LR. MS is the number of outflow increments and must be selected as a multiple of LR not exceeding 400. MR may not exceed 100 and is the maximum value of NN. Higher values of MR and MS are permissible if the model arrays are redimensioned.

Initial Sediment Content of the Plug

The sediment content, average depth and detention time of each plug are dependent on the location of the plug on the inflow hydrograph. The initial point of entry to the basin of each plug is determined by first ascertaining the points at which the accumulated inflow is equal to the accumulated outflow on the respective hydrographs as shown in Figure 14. The times at which these points occur on the inflow hydrograph are determined by linear interpolation between the accumulated inflow points used in the initial routing. The sediment volumes at each of these points is determined by interpolation between the values found on the sediment volume curve described by equation 17. The average inflow time and the fraction of sediment in each plug is calculated from:

VOLTME(NN) = (TMEIN(NN) + TMEIN(NN - 1))/2.0 (22)

and

SEDOUT(NN) = (SEDT(NN) - SEDT(NN - 1))/SEDTOT(N) (23)

where VOLTME(NN) is the average time of inflow, TMEIN(NN - 1) is the initial inflow time and TMEIN(NN) is the final inflow time for plug (NN). SEDOUT(NN) is the fraction of the total sediment (for the entire storm event) contained in inflow plut (NN) and SEDT(NN) is the accumulated fraction, occurring up to time NN, of SEDTOT(M).

Detention Time

The average outflow is given by:

PLGCEN(NN) = (PLGTME(NN) + PLGTME(NN - 1))/2.0 (24)

where PLGTME(NN) = PLGTME(NN - 1) + DELPLG. PLGTME(1) = 0.0. The average detention time is then:

DETTME(NN) = PLGCEN(NN) - VOLTME(NN) (25)

where DETTME(NN) is the detention time of the plug (NN).

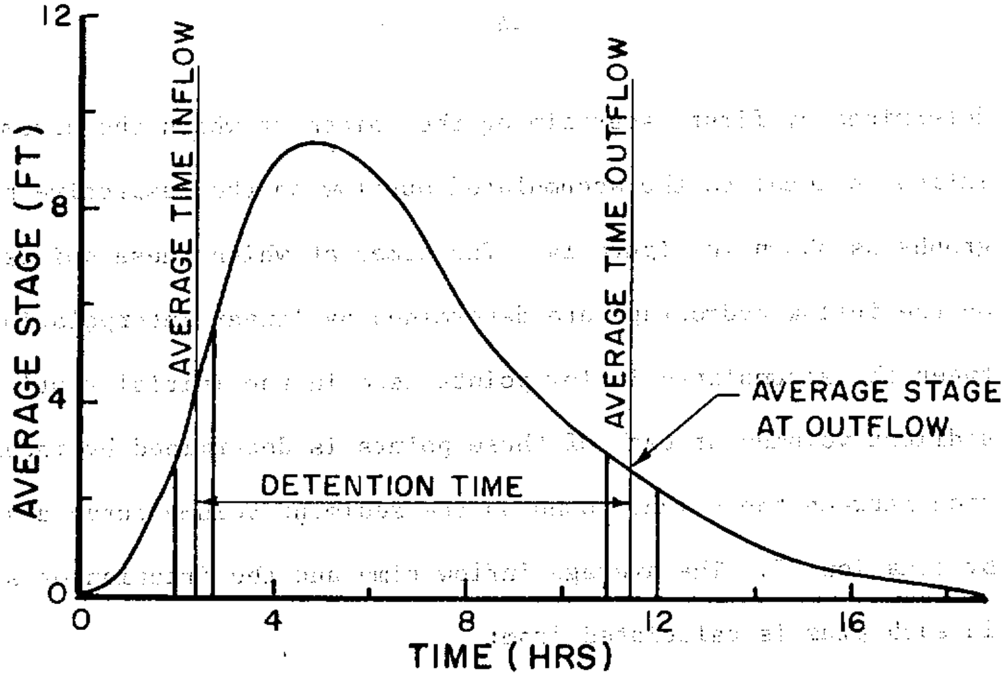


Figure 15: Stage-time curve

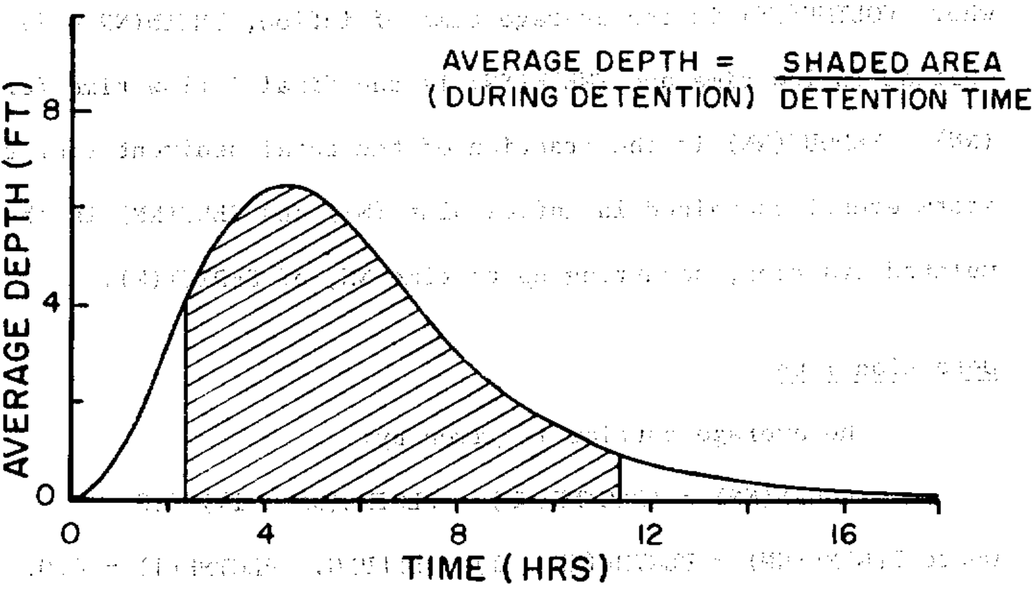


Figure 16: Average depth-time curve

Outflow Stage and Average Depth

Figure 16 illustrates how the stage in the basin varies with time. The average stage during the outflow of plug (NN) is determined as the stage at time PLGCEN(NN) by linear interpolation on the stage-time curve developed during computations based on the Four Quadrant Routing Method.

The average stage during the inflow of the plug (NN) is determined in a similar fashion at the time VOLTME(NN). The average depth, experienced by plug (NN) while in the basin is then computed by determining the area, under the average depth-time curve, contained between VOLTME(NN) and PLGCEN(NN) and then dividing this area by the detention time. The average depth-time curve is determined in the initial routing and gives a volume weighted average depth of the flow from the basin-bed during the storm event. The average depth-time curve is obtained by linear interpolation on the average depth-stage curve defined by equation 14.

$$\text{AVDPTH(I)} = \frac{\sum_{J=2}^{J=I} \text{DEPO}^{2.0} * (\text{AREA(J)} - \text{AREA(J-1)})}{\sum_{J=2}^{J=I} \text{DEPO} * (\text{AREA(J)} - \text{AREA(J-1)})} \tag{14}$$

where $\text{DEPO} = \text{STAGE(I)} - (\text{STAGE(J)} + \text{STAGE(J-1)})/2.0$.

Plug Stratification

Each plug is subdivided into four layers of equal depth as shown in Figure 17. The sediment remaining in suspension within each strata is computed and the percentage of the total outflow associated with each plug is calculated. The fraction of the initial sediment content that is removed by each plug is determined. The sum of these incremental sediment discharges gives the total removal during the storm event. The basis of these computations is described below.

Sediment Concentration Profile

The sediment distribution in each plug is assumed uniform when the flow first enters the basin. The amount of sediment remaining in suspension, in each layer, is calculated by Stokes' Law. The method of computation is outlined in the description accompanying Figure 17. The percent of particles that will fall 0.125, 0.375, 0.625 and 0.875 of the average depth (DEPTH) is calculated by determining the fall velocity required for the particles to fall each of these distances.

$$V_{fall} = \text{Fall distance}/(\text{detention time} \times (1\text{-}C)^{2.5}) \qquad (26)$$

where C is 50% of the initial sediment concentration expressed as a fraction. The factor $(1\text{-}C)^{2.5}$ accounts for hinderance due to several small particles falling in close proximity (Shen, 1972). The fall velocity V_{fall} is multiplied by a correction factor (FIX) to account for short-circuiting and flocculation. Once the fall velocity is determined, the particle size associated with this velocity is

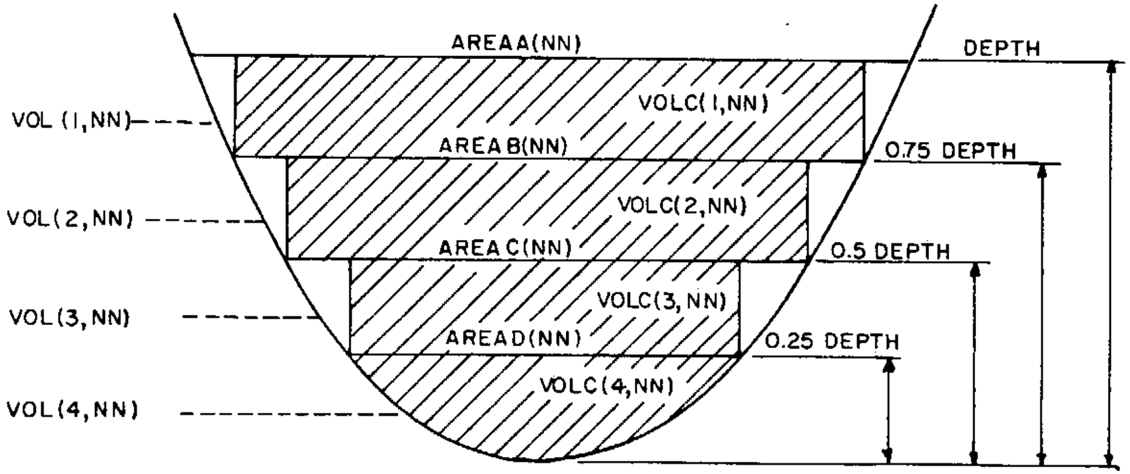


Figure 17: Layer sediment concentration determination

determined from Stokes' Law as:

$$D = [V \times \mu \ / (51.5 \times (SG-1))]^{1/2} \tag{27}$$

where D is the particle size (mm), V the corrected fall velocity (feet/hour), SG the particle specific gravity, μ the water viscosity (cm^2/sec) and the factor 51.5 is 0.8 times the acceleration due to gravity (32.2 ft/sec) times a conversion factor to account for the different units used in the equation. The factor 0.8 is used to correct for the non-spherical nature of clay and colloidal particles.

Stokes' Law is only valid for particles with a Reynolds number less than 1. The assumption is made that if some of the fine particles satisfying Stokes' Law are trapped, all the coarse particles will automatically be trapped. The concentration C was selected as half the original concentration because a large percent of the particles are usually coarse and settle very rapidly.

Figure 18 demonstrates the typical changes in sediment concentration with time as a function of the particle size distribution and the average depth. It can be seen that unless the percent of fines is very large, the values of C should probably be less than 50% of the original concentration. Hinderance, however, is unlikely to be a major factor unless the model is adopted for use in the design of settling tanks.

The percent of the initial concentration, PCT(I,NN), remaining in the Ith layer depends on how much sediment enters and leaves the layer. For the top layer, I=1, sediment must fall an average distance

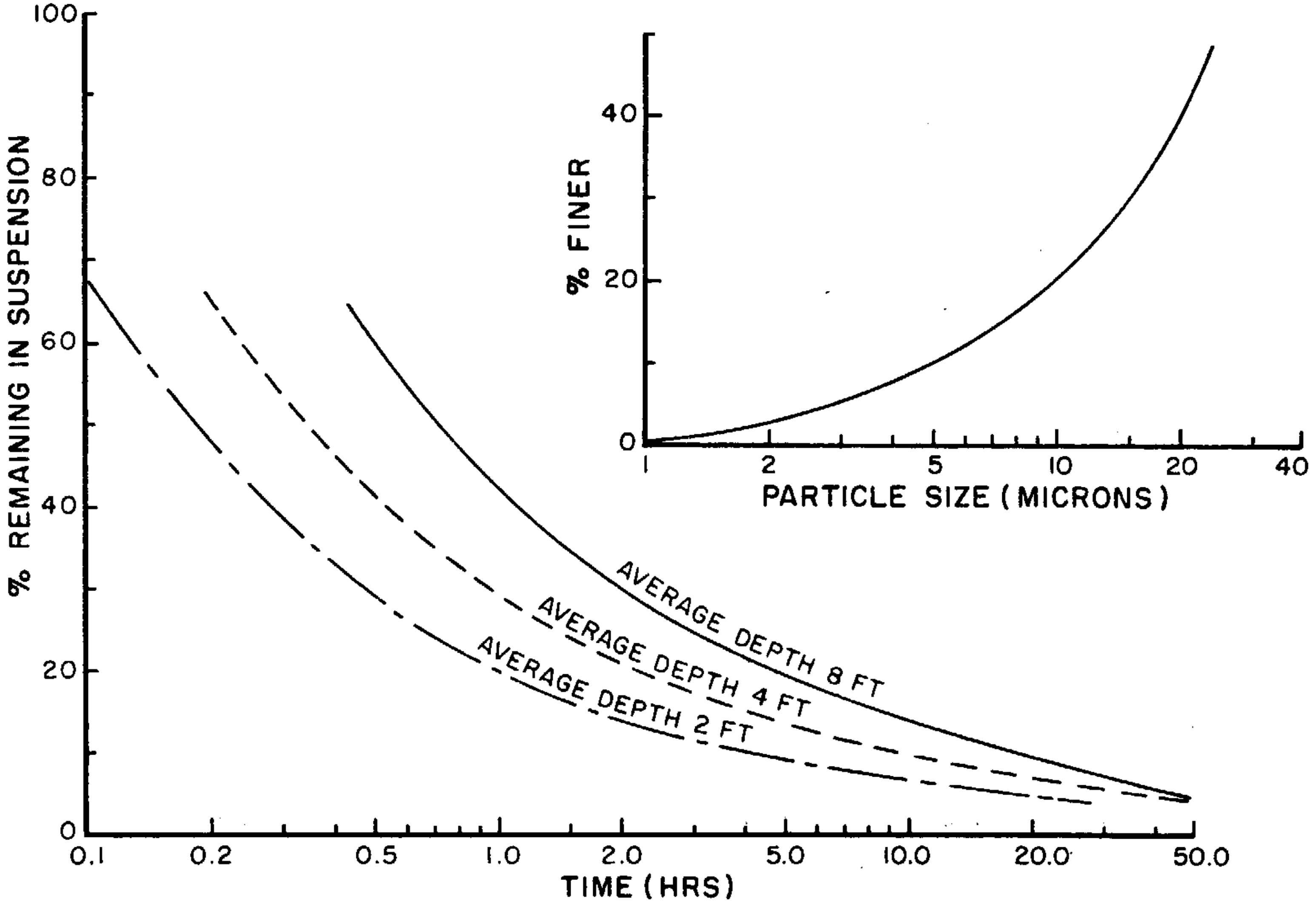


Figure 18: Sediment content variation with time

0.125 DEPTH to leave the layer and none enters. For the second layer, I=2, sediment must also fall an average distance of 0.125 DEPTH to leave the layer; however, sediment from layer 1 is meanwhile entering layer 2. For sediment from layer 1 to pass through layer 2, it must fall an average of 0.125 DEPTH + 0.250 DEPTH. The percent of particles falling 0.250 DEPTH is taken as the difference in those falling 0.125 DEPTH and those falling 0.375 DEPTH. Figure 18 indicates that not all particles in this latter category can fall through the second layer since some of the particles will strike the basin sides before falling the required distance. These particles are considered trapped. The percent of particles being trapped in this fashion is:

$$((\mathrm{VOL}(2,NN)-\mathrm{VOLC}(2,NN))/\mathrm{VOL}(2,NN))*(\mathrm{PERCT}(3,NN)-\mathrm{PERCT}(4,NN)) \tag{28}$$

This same process occurs in layers 3 and 4.

Therefore, the percent of the initial concentration remaining in the Ith layer, PCT(I,NN), is given by

<u>Top Layer</u>

$$\mathrm{PCT}(1,NN) = \mathrm{PERCT}(4,NN) \tag{29}$$

<u>Second Layer</u>

$$\begin{aligned}\mathrm{PCT}(2,NN) = {} & \mathrm{PERCT}(4,NN) + \mathrm{VOLC}(1,NN)*\ (\mathrm{PERCT}(3,NN) - \\ & \mathrm{PERCT}(4,NN))/\mathrm{VOL}(2,NN)\end{aligned} \tag{30}$$

<u>Third Layer</u>

$$\begin{aligned}\mathrm{PCT}(3,NN) = {} & \mathrm{PERCT}(4,NN) + \mathrm{VOLC}(2,NN)*\ (\mathrm{PERCT}(2,NN)- \\ & \mathrm{PERCT}(4,NN))/\mathrm{VOL}(3,NN)\end{aligned} \tag{31}$$

Bottom Layer

PCT(4,NN) = PERCT(4,NN) + VOLC(3,NN)* (PERCT(1,NN) - PERCT(4,NN))/VOL(4,NN) (32)

where:

PERCT(1,NN) = % finer with diameter of size smaller than those particles falling 0.875 DEPTH

PERCT(2,NN) = % finer with diameter smaller than those particles falling 0.625 DEPTH

PERCT(3,NN) = % finer with diameter smaller than particles falling 0.375 DEPTH

PERCT(4,NN) = % finer with diameter smaller than those particles falling 0.125 DEPTH

VOL(I,NN) = the volume of layer I.

The volumes VOLC(I,NN) I=1,4 are shown by the shaded areas on Figure 18 and are determined from

VOLC(1,NN) = VOL(1,NN)*(AREA B(NN)/AREA A(NN)) (33)

VOLC(2,NN) = VOL(2,NN)*(AREA C(NN)/AREA B(NN)) (34)

VOLC(3,NN) = VOL(3,NN)*(AREA D(NN)/AREA C(NN)) (35)

The values PCT(1,NN), PCT(2,NN), PCT(3,NN) and PCT(4,NN) determined in Figure 17 are the percent of the initial volume of sediment contained in the plug which remain suspended in each layer. The actual fraction of the total sediment volume that is discharged from each layer is given by the equation:

$$S_{dis} = P_{lay} * SED_{total} * Q_{lay} \quad (36)$$

where S_{dis} is the fraction of the total sediment volume associated with the storm event that is discharged by each layer of each plug,

P_{lay} is PCT(1,NN), PCT(2,NN) etc., SED_{total} is the fraction of the total sediment volume initially contained in the plug (the value SEDOUT(NN) that was described earlier), and Q_{lay} is the percent of the total discharge associated with each layer. Figures 19 and 19a give typical distributions of Q_{lay} for a drop outlet and a riser outlet. If Q_{lay} is not specified, it is assumed to be 25% for each strata. For a riser outlet with uniformly spaced perforations of a constant diameter, this assumption produces an error of less than 2% in the trap efficiency.

Sediment Deposition

Figure 17, used in the development of the sediment concentrations exiting in each layer at the time of outflow, gives a conceptual picture of the average parameters existing in each plug of flow during detention. The typical geometry of each plug will probably vary considerably as it flows through the basin. In the model the average depth geometry is employed only to determine the suspended sediment concentrations remaining at outflow. The volume of outflow associated with each layer is determined from the outflow distribution obtained from the average stage at the riser during outflow.

Equation 29 gives the fraction of the initial sediment concentration that is trapped on the sides of each layer. The volume of sediment actually deposited on the basin sides from each layer is:

$$DEP_{vol} = \frac{MASS \times .000736 \times (100-P_{lay}) \times SED_{total} \times Q_{lay}}{10000.0 \times DENSITY} \qquad (37)$$

TYPICAL OUTFLOW-DEPTH DISTRIBUTIONS

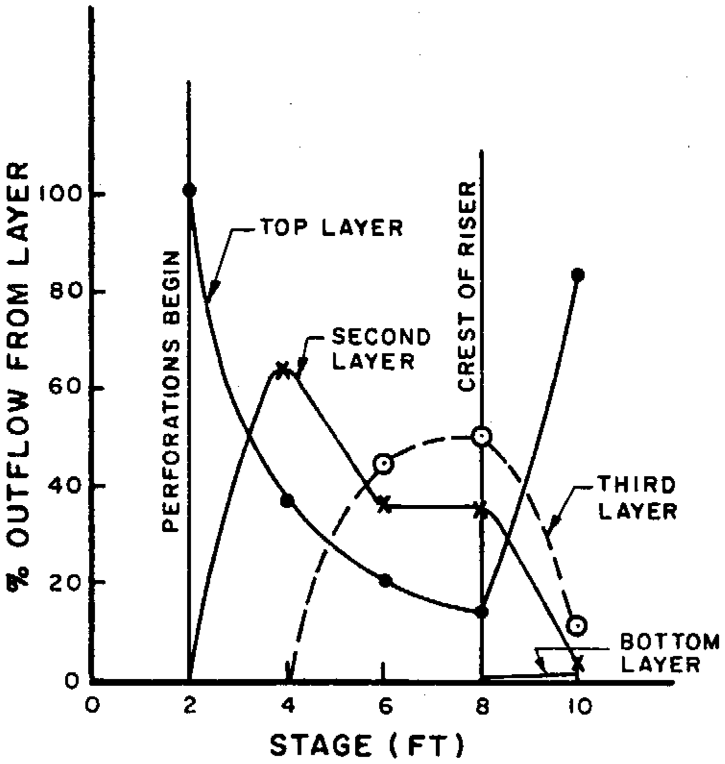


Figure 19: Perforated riser

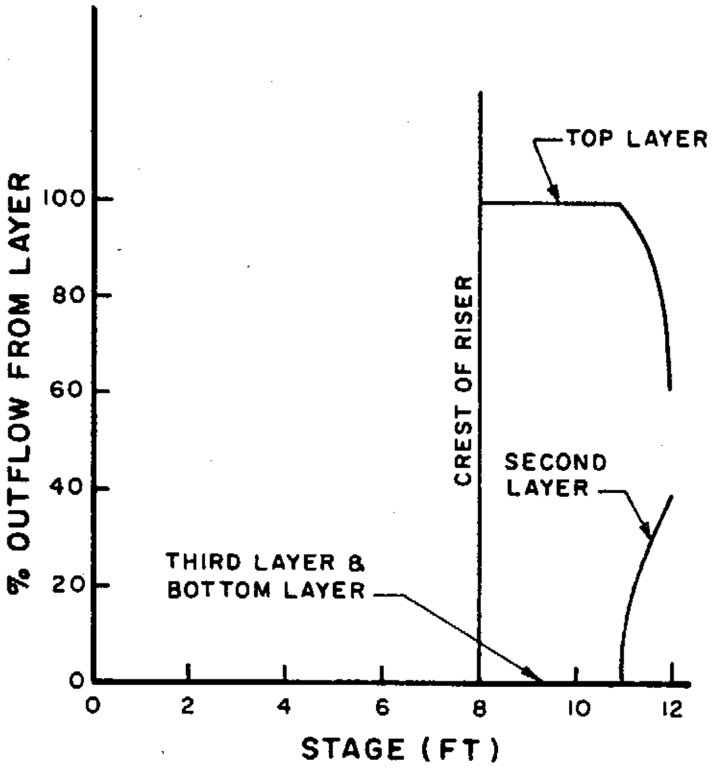


Figure 19a: Drop inlet

where DEP_{vol} is the volume of the sediment deposit, MASS is the total sediment mass (tons) during the storm event and DENSTY is the specific gravity of the sediment deposit.

The changes in volume and area due to deposition are calculated by assuming the sediment deposited as uniformly distributed in each layer. The capacity of the basin is reduced at each stage point corresponding to the average depth point at which the increment of deposition occurs. This accounting cycle is repeated for each plug. Physically this procedure does not give the actual location of deposition in the basin. It does however give a conceptual idea of how the capacity-stage and area-stage curves will be altered due to the deposition of sediment.

The area-stage curve is then determined from the new capacity-stage curve. The model is based upon the assumption that the area increases with an increase in stage. When the area-stage curve is determined numerically from the capacity-stage curve, this condition may be violated. If this occurs the area-stage curve is smoothed out by maintaining the criteria that the area increase with depth and that the new area at each stage will either be the same as that prior to deposition or will have been reduced by deposition. A further correction is then made to both curves to ensure that the "smoothing" has not altered the volume of deposition. It can be seen from the above assumptions on the basin geometry that the model may be applied to most normal situations but would not be applicable, for example, to a shape like a goldfish bowl where the area decreases with stage.

The specific gravity of the sediment deposits may be determined by a method obtained by Lara and Pemberton (1963):

$$W = W_c P_c + W_m P_m + W_s P_s \tag{38}$$

where W is the unit weight of the sediment, W_c, W_m, and W_s are the unit weights of clay, silt and sand respectively. Lara and Pemberton recommend that these values be selected as 60, 73, and 97 lb/ft^3. P_c, P_m, and P_s are the fractions of clay, silt and sand contained in the deposits. Although coarser material is likely to be deposited at the inlet, the model does not account for the physical location of the deposits. The fraction to be used in equation 38 should be the initial particle size distribution of the suspended sediment. For more accurate computations, a second calculation can be made after the trap efficiency has been determined. Further corrections to allow for compaction may be made by referring to the work of Miller (1953) and Heinemann (1962). The unit weight must be divided by the unit weight of water to obtain the specific weight. The choice of the values W_c, W_m, and W_s is dependent on the normal operating conditions of the reservoir. A list of suitable values is given in Table 3.

It is recommended that if the deposition option is used, that the stage points be defined every 0.5 feet in a shallow basin and every 1.0 feet in a deep basin (riser length greater than 10 feet). The stage interval should be kept constant for depths where deposition is likely to occur.

Trap Efficiency

The trap efficiency of the basin is determined from

$$\text{TRAP} = (100.0 - \text{SEDEND(NN-1)}) \tag{39}$$

where TRAP is the percent of sediment trapped by the basin and SEDEND(NN-1) is the percent of sediment flowing out of NN-1 plugs. Normally the amount of sediment not accounted for in the monitoring of the (NN-1) plugs is very small. The model has been programed to stop computations when 99.95% of the initial sediment content has been accounted for. This measure has been incorporated to reduce the cost of using the model program.

Short-circuiting and Turbulence

As mentioned earlier the plug flow concept does not allow for turbulence or short-circuiting of the flow. These factors will vary depending on the inflow rate, inflow structure and the basin geometry. It is expected that the effects of turbulence will be reduced by the design of a suitable inlet structure. Short-circuiting for uniform flow in a rectangular basin has been shown to be primarily a function of the basin geometry (EPA, 1976a). It is recommended that a value of 1.0 be used for the correction factor FIX although the values in Table 4 may be used with caution if short-circuiting is present.

TABLE 3

MODIFIED VALUES OF COEFFICIENTS IN EQUATION 38 FOR RESERVOIR TYPES

Type of Reservoir Operation	Observations	Values of Coefficients in Equation 38		
		W_c	W_m	W_s
	Number			
I	262	26	70	97
II	462	35	71	97
III	405	40	72	97
IV	187	60	73	97

I. Sediment always submerged or nearly submerged

II. Normally moderate to considerable drawdown

III. Reservoir normally empty

IV. Riverbed sediments

TABLE 4

SHORT CIRCUITING FOR SETTLING TANKS

Type of Tank	Short Circuiting Factor FIX
Radial flow circular	1.20
Wide rectangular (length = 2.4 x width)	1.08
Narrow rectangular (length = 17 x width)	1.11
Baffled mixing chamber (length - 528 x width)	1.01
Ideal basin	1.00

Flocculation and Aggregation

Aggregation is the physical cementing or binding of small particles into a larger particle. Aggregates are not dispersed by water and occur in suspension so that the effective particle diameters determined in a mechanical analysis will include those of the aggregates. Care should be taken in the laboratory testing not to transform the aggregated particles back into their primary composite particles.

Flocculation is a phenomenon which occurs due to the electrokinetic potential of the particles. It may occur by the chemical separation of a dispersed phase, by "flocculating agents" in the water and by the collision of rapidly settling particles with slower particles. The latter process always occurs and the degree to which it occurs depends primarily on the lattice structure and chemical composition of the clay fraction and the water.

The model does not account for these factors. Chemical flocculation may occur either by the introduction of flocculating agents or by the natural chemical composition of the runoff. Table 5 gives a list of chemicals that will induce flocculation. If flocculation is expected to occur to any high degree, the correction factor, FIX, may be reduced to account for this behavior. Laboratory experiments measuring the fall velocity of the suspended particles in the anticipated runoff would give the magnitude of the required reduction. It is envisioned that FIX will vary between 0.8 and 1.2 and a value of 1.0 should normally be used. Experimental data however is limited and the range of 0.8 - 1.2 for FIX is intuitive only.

TABLE 5

SETTLEMENT BY THE USE OF FLOCCULATING AGENTS

	Type of Suspension	Treatment[1]
1)	High Colloid Concentration Low Alkalinity	Easiest systems to treat Use positively hydroxometal at acidic pH levels 4-6.
2)	High Colloid Concentration High Alkalinity	Destabilization by adsorption at neutral and acid pH levels. Lower coagulant dosages (at lower pH) may be used if the alkalinity is reduced.
3)	Low Colloid Concentration High Alkalinity	Coagulation obtained with high dosage by enmeshment of Colloid particles in a "sweep floc".
4)	Low Colloid Concentration Low Alkalinity	Difficult to treat. Metal salts ineffective unless alkalinity is increased.

[1] Flocculating Agents:

Metal Salts $Al_2(SO_4)_3$ or $FeCl_3$

Metal Oxide or Hydroxide Lime (CaO or $Ca(OH)_2$) or soda ash (Na_2CO_3)

Model Output

An example of the model output is given in Appendix D. If the deposition pattern is not specified, the columns headed "DEPTH" and "NEW CAPACITY" are omitted. If the mass of sediment or the influent concentrations are not specified, the influent and efluent columns are omitted. All the inflow and outflow values are given for the time increment of the plugs. The time related output is terminated when 99.95% of the sediment has been accounted for by the outflow computations.

A listing of all the input variables is incorporated in the output. A definition of each of these terms is provided in a glossary of terms contained in Appendix A. The output has been arranged to give the variables that are of most value in determining the design of a sediment detention structure. Additional output may easily be obtained and a complete list of all the variables evaluated in the model is contained in the glossary.

CHAPTER IV

MODEL VERIFICATION

Introduction

Although many studies have been conducted on the performance of sediment detention structures very little data suitable for a simulation study are available. Through the kind cooperation of the Environmental Protection Agency (EPA) it was possible, however, to simulate the performance of several detention basins described in the EPA report "Effectiveness of Surface Mine Sedimentation Ponds" (1976a). The descriptions of the basins contained in this report are insufficient for simulation studies but the unpublished reports on each basin were made available by the EPA and provided enough information to make simulation studies. Despite the vast amount of information collected on each basin, several basic assumptions and approximations had to be made.

The results of the comparisons are presented in Table 6. A brief description of each basin and the assumptions made in obtaining the results in Table 6 are presented below. In general the drawbacks of the studies, conducted by Hittman Associates, were:

1) Only part of each storm event was monitored.

2) The period of monitoring of inflow and outflow conditions was usually only 2-4 hours.

3) Inflow rates were not obtained in all the basins.

4) The initial riser depth and subsequent changes in depth were not recorded.

5) Although soundings were taken to determine the buildup of sediment deposits in the basin the data were not sufficient to determine accurately the prevailing stage-area curve.

6) The actual condition of the riser was not available and the stage discharge curve could only be approximated by the discharge conditions described during the period monitored.

7) The method of determining the actual performance of the basin does not appear valid.

As noted in (7) above, the method used to determine the performance of the basin was probably in error. The mass balance equation (12) described earlier was used. In the Hittman studies utilization of this equation assumes instantaneous flow through the basin. An alternative method based on the smallest particles likely to be trapped is contained in Table 6. Based on the detention time and average depth of flow, the sizes of the smallest particle which will be completely trapped may be established. A similar procedure is followed to determine the largest size of particles which will not be trapped. The percent finer corresponding to these two values gives the likely range of the basin trap efficiency.

TABLE 6

RESULTS OF VERIFICATION STUDY

Location	Principal Spillway	Flow Condition	Trap Efficiency (Percent)		
			EPA Method 1)	DEPOSITS Model	Actual 2)
Breathitt Co. Kentucky (EPA Pond 4)	Perforated 14" diameter riser	Baseline 0.7 cfs	95	94	97.5 < 97 3)
Kanawaha Co. West Virginia (EPA Pond 8)	Drop Inlet 3 ft. square	Storm 0.47 cfs	97	95	92.3 < 97 3)
Monongalia Co. West Virginia (EPA Pond 7)	Perforated 24" diameter riser	Storm Peak 1.01 cfs	67 83	82	91.3 < 90 3)
Perry Co. Kentucky (EPA Pond 3)	Perforated 24" diameter riser	Baseline 0.99 cfs.	90	90	89.3 < 93 3)
Columbia Maryland 4)	15" Perforated riser & 42" diameter drop inlet.	Storm Peak 5.4 cfs	Not Measured	95	95+

1) Using equation 5
2) Using equation 12
3) Based on % finer of smallest particles trapped.
4) Source. Joint Construction Sediment Control Project. EPA-660/2-73-035.

Because of the necessity to make several assumptions, the sensitivity of the model to variations in these assumptions was tested. Based on these studies it is felt that model simulations of the trap efficiency are within 2% of the results that would have been obtained had no assumptions been necessary. The particle size distributions for each basin are shown in Figure 20.

EPA Pond 3

Pond 3 is a small strip-mining detention basin located in Kentucky. Considerable sediment accumulation had occurred during a year of operation and the basin geometry could only be approximated based on sediment accumulations measured at several places in the basin. Although the basin was monitored during a baseline and storm event, it was felt a valid simulation could only be made for the baseline condition. During the storm event there was flow through the emergency spillway and the survey indicates that considerable scour occurred on the spillway. A whirlpool action was also observed around the riser causing resuspension of deposited sediment.

The above factors did not occur during the baseline event making it suitable for a simulation comparison. No inflow rates were available and the simulation was made to conform with the outlet conditions. The influent and effluent concentrations were monitored every fifteen minutes over a two-hour period. Although most of the influent readings were fairly constant, two readings were considerably higher than the others. As the detention time of flow in the basin

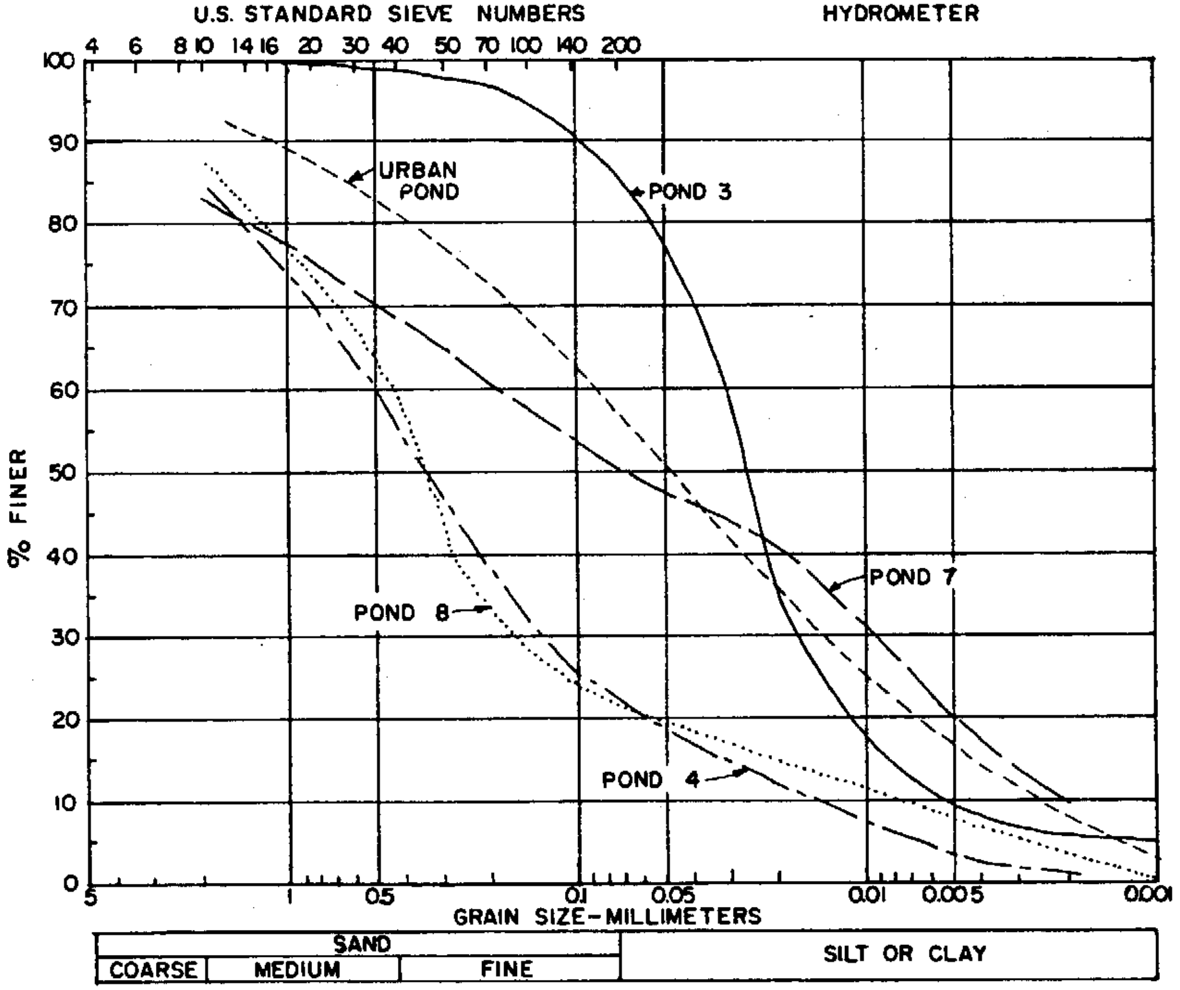


Figure 20: Particle size distributions for the basins used in the verification study

is longer than 10 hours these two high readings are not reflected in the effluent concentrations. The actual basin performance predicted by equation (12) may therefore be high although it is the opinion of the author that there is no correlation between the influent and the effluent readings observed during the two-hour period.

Because of the approximations necessary in simulating the basin geometry and inflow and outflow conditions several simulations were made. The trap efficiency varied between 88-91%. The simulation that appeared to most closely approximate the actual conditions gave a result of 90%. Based on the particle size distribution and the observed detention time the actual trap efficiency of the basin might be expected to be between 88-83%.

EPA Pond 4

Pond 4 is a very small structure located in Kentucky. Considerable deposition had occurred making simulation conditions similar to those in Pond 3. The pond was found to perform very poorly during storm events due to high inflow velocities and high outflow rates over the emergency spillway. Because of these factors, only the baseline event was simulated.

The baseline event which was monitored occurred shortly after a period of high rainfall. It appears that the effluent readings observed during a two-hour period reflect the high sediment concentration associated with a storm event while the influent readings reflect the low concentrations associated with the end of a storm event. The trap efficiency determined by equation 12 is therefore probably low.

Simulation results gave a trap efficiency of 93-96% and based on the particle size distribution and a detention time of 3 hours the actual efficiency is probably 94-97%.

EPA Pond 7

Pond 7 is a small detention structure located in West Virginia. Sediment depositions were fairly uniform and did not exceed 1.5 feet. It was possible therefore, to accurately simulate the basin geometry. Because of algae on the riser during the baseline event no valid results were collected for this event. During the storm event however, the algae was removed by the higher discharge rates and conditions were favorable for simulation. As well as recording inflow and outflow rates and concentrations over a four-hour period, an additional reading was made the following morning. This basin is probably the best documented and the event monitored most closely follows the pattern of a typical storm event.

The trap efficiency predicted by equation 12 for the four-hour period is 91.3%. This value is probably higher because the high concentrations associated with the influent take 8-11 hours to reach the outlet. A simulation was made for the entire 16 hour period and the model predicted an effluent reading, based on the observed influent readings, of 17 mg/l at 6.00 am on May 16. The actual reading recorded was 20 mg/l. Considering the lack of information on flow conditions between 6.00 p.m. and 6:00 a.m. it is felt that the model simulates the performance of the basin to a high degree.

The model predicts a trap efficiency of 82% and the particle size distribution indicates a performance between 79-90%. It may be observed that the results on this basin highlight the difficulty in using the EPA method based on Camp's (1945) trap efficiency method. The discharge during the storm event varied between 0.43-3.3 cfs and the EPA method gives a trap efficiency for the lowest discharge rate of 83% and an efficiency of 67% for the peak discharge rate. In the semi-dry detention structures normally found in urban areas the changing condition of a very low flow to a high flow is the normal operating event for these structures. A composite trap efficiency for the design storm is required and as indicated, is not readily available with the EPA method. DEPOSITS was used on several other storm events and the model method of predicting sediment concentrations were tested on this basin and gave trapping efficiencies between 79-84%.

EPA Pond 8

Pond 8 is located in West Virginia and is a larger structure than the other ponds described. It differs also in that it has a square drop inlet spillway. Sediment depositions were fairly uniform and did not exceed 1.0 foot in much of the basin. A valid comparison could not be made for the baseline event because pumping close to the outlet riser caused considerable disturbance of deposited sediment giving an observed negative trap efficiency. During the storm event no disturbance was observed.

The storm event was monitored for a period of 5 1/2 hours and both the influent and effluent concentrations were observed to be very low. Equation 12 predicted a trap efficiency of 92.3%. In simulation studies, a trap efficiency of 94-97% was predicted. Because of the nature of the outlet structure, an actual efficiency based on the particle size distribution cannot be obtained. The maximum efficiency however, will probably not exceed 97% as observations indicate continuous flow into the basin even during dry periods and a maximum detention time of 200 hours. Three percent of the particle have a grain size of two microns and require nearly 60 days to fall a depth of one foot. The average depth of flow was observed to be over 7.0 feet.

Urban Development Pond

This pond is located in Columbia, Maryland and is described in the EPA report "Joint Construction Sediment Control Project" (1973). The pond is different from those described earlier in that both the watershed and basin do not have steep slopes and the basin capacity is considerably larger. The strip-mine basins described earlier vary in capacity from 1-10 acre-feet while this basin has a maximum design capacity of nearly 14 acre-feet.

The principal spillway is comprised of a drop inlet and a perforated drawdown device. Although many storms were monitored, insufficient data is included in the report for valid simulations on each event. It is indicated in the report that the overall performance of the basin is probably 95%. A storm event was simulated using the drawdown device and a 95% efficiency was predicted. Simulation studies indicate that for baseline conditions or small storm events, the efficiency will exceed 95% and during very large storms the efficiency will be less than 90%. The report indicates that during several storm events efficiencies of 82-86% were observed. Unfortunately, no information is provided on these events. The pond includes a forebay area and the simulation studies were done on the combined structure.

Discussion

Although the model has only been compared to the performance of five basins, it appears to give a good prediction of the performance of sediment detention basins. The events used in the model verification provide a representative sample of the types of basin geometry, outlet structures, and flow events normally encountered. Results are comparable to those predicted by the EPA method for steady flow conditions (baseline events) and appear to present better predictions for events with widely varying flow conditions. In addition to determining the trap efficiency, the model also provides an estimate of the outflow sediment concentrations and the accumulation of sediment deposits in the basin.

It should be noted that in the EPA report "Effectiveness of Surface Mine Sedimentation Ponds", nine basins are described. Only those basins that would present a valid simulation comparison have been presented in this report. Pond 6, a large flood control and recreation structure, may also be suitable although it is indicated that considerable deposition occurs at the inlet due to the upstream vegetation. The model will be further tested as data on studies currently being conducted become available.

Model Application

Introduction

In addition to the simulation tests described earlier, a study was conducted to determine the importance of some of the parameters which effect the performance of sediment basins. The factors studied were:

1) Particle size.
2) Outlet design.
3) Basin geometry.
4) Magnitude of the storm event.

All of the studies were performed using the method described by Mynear and Haan (1977). A 100 acre watershed with a 6% slope and a curve number of 85 was used. All rainfall was simulated over a

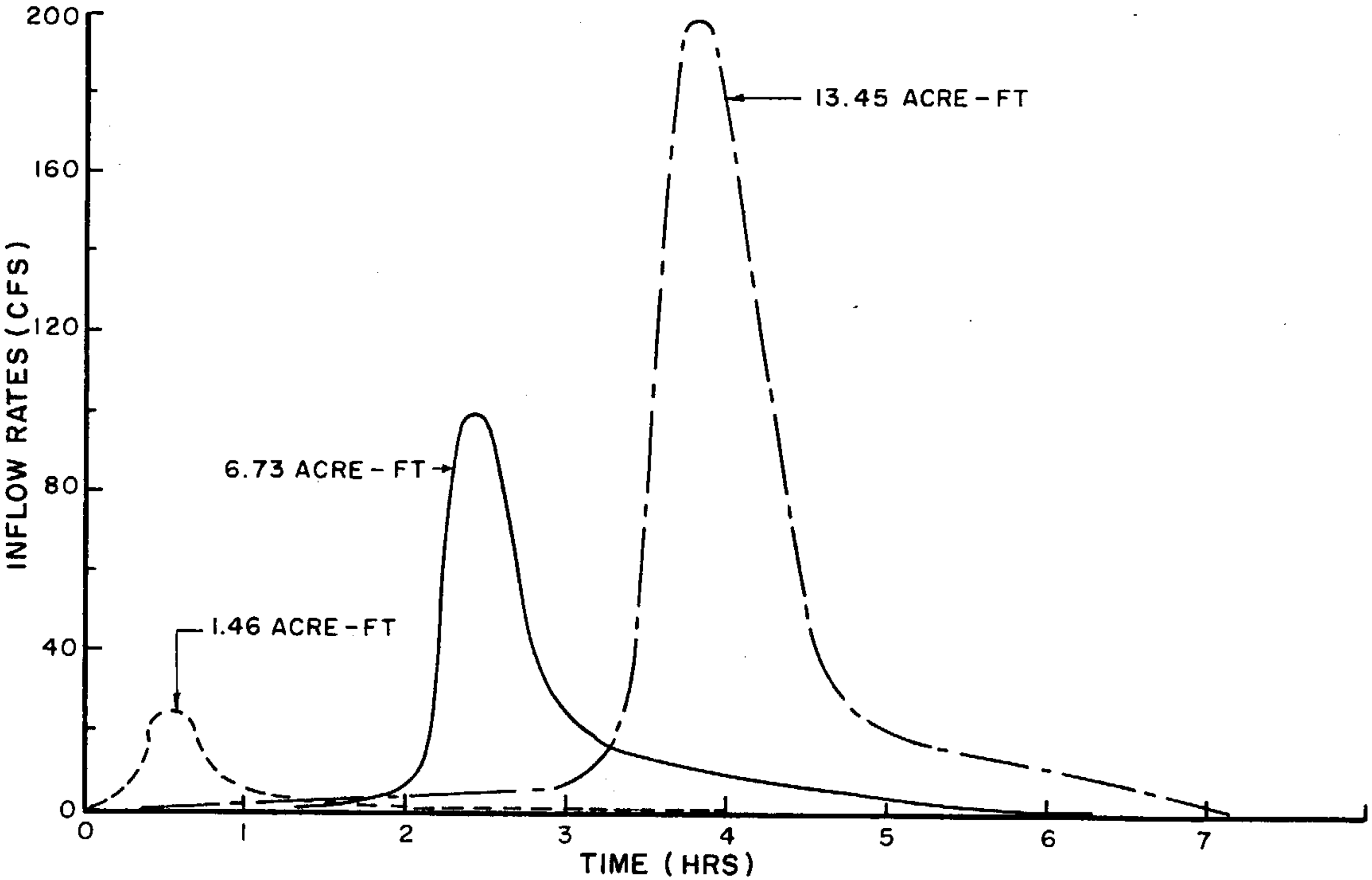


Figure 21: Typical hydrographs used in simulation studies

10-hour period. An example of some of the hydrographs used is given in Figure 21.

Particle Size

Figure 22 shows the results of simulation studies on the effect of particle size on trap efficiency with two basins. The same storm event was used in each test and both ponds had identical risers. It can be seen that by keeping all factors the same except the particle size distribution the trap efficiency is closely related to the particle size. The results also illustrate the effect of basin geometry on trap efficiency. The larger basin is less susceptible to variations in particle size and also has a much higher trap efficiency. In all studies conducted with the model it was found that the particle size distribution and specifically the percent finer than 20 microns were the most critical in determining the performance of a sediment basins. Except in cases where the inflow velocity is very high, the distribution above 20 microns has little effect on trap efficiency. This means that a standard hydrometer analysis is sufficient to give the particle size distributions.

In the tests performed to obtain Figure 22 the distribution below 20 microns was uniform when plotted on semi-log paper (as is customary for mechanical analysis results). Tests runs were performed for distributions with 20, 40, 60 and 80 percent by weight of the particles less than 20 microns.

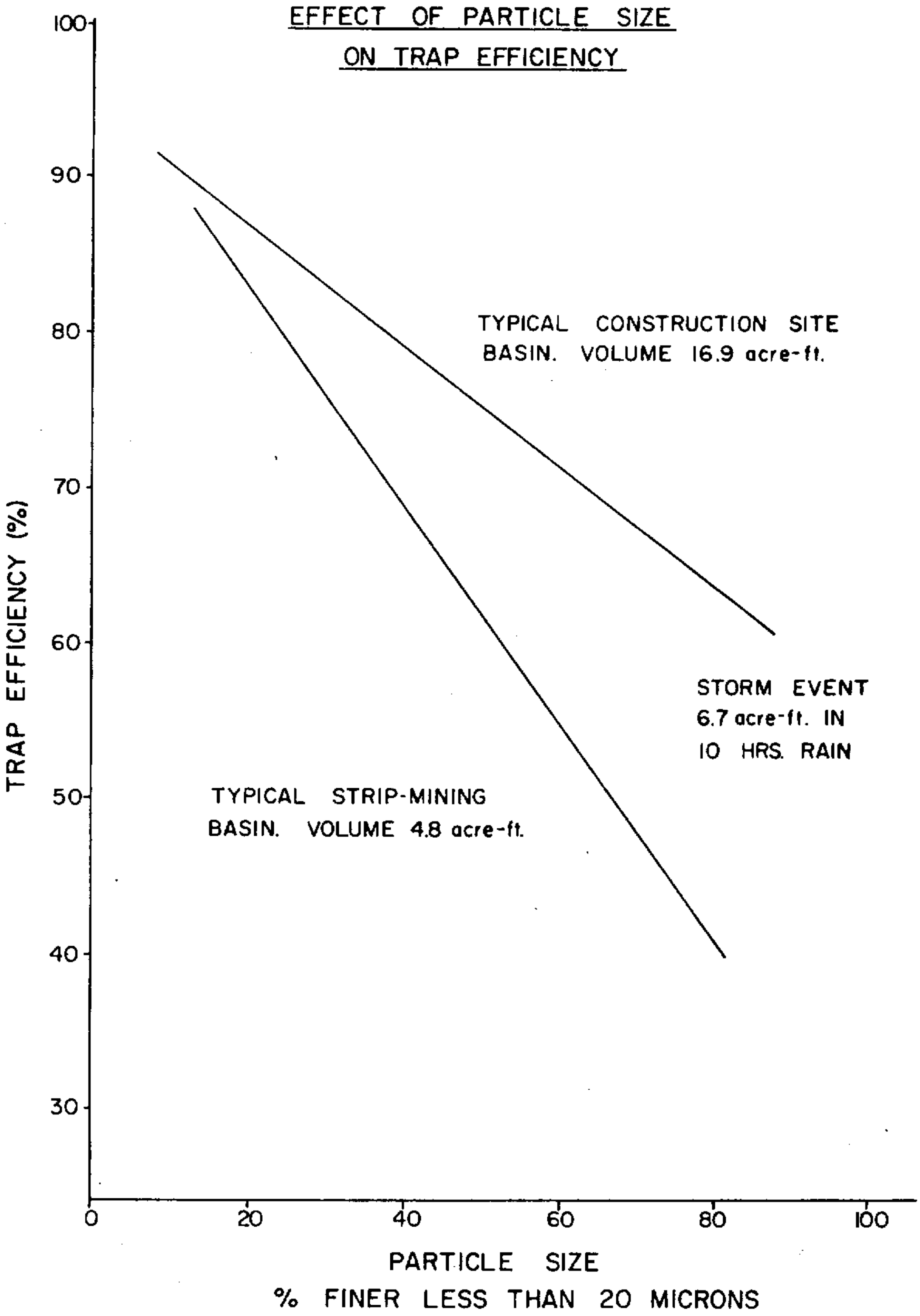


Figure 22: Effect of particle size on trap efficiency

In the large basin approximately 50% of the particles less than 20 microns were trapped. While in the small basin, only about 25% were trapped.

Basin Geometry and Storm Magnitude

Figure 23 shows the effect of storm magnitude and basin geometry on pond efficiency. An identical riser was used in each basin. The stage-discharge curve for this riser is shown in Figure 24 (curve A) and is the riser used in the particle size study. It should be noted that no attempt was made to make the riser conform to any particular state code. The trap efficiency has been plotted against the maximum stage at the riser during the storm events. Two storm events which were used in all the basins have also been plotted. The plots indicate that for a large basin the riser can be designed to give a fairly consistent performance which is independent of the storm event.

Basins are usually designed for a particular storm event. The criteria suggested by the EPA and several states is the 10-year, 24-hour storm (EPA, 1976). The performance of these basins during other storm events has seen little attention. If the storm corresponding to a maximum stage at the riser crest was considered the design storm for each basin, it can be seen that the two small bains are probably undersized. Studies have shown that most strip mining detention basins are undersized. They tend to fill up very quickly with sediment yet have poor trap efficiencies during storm events.

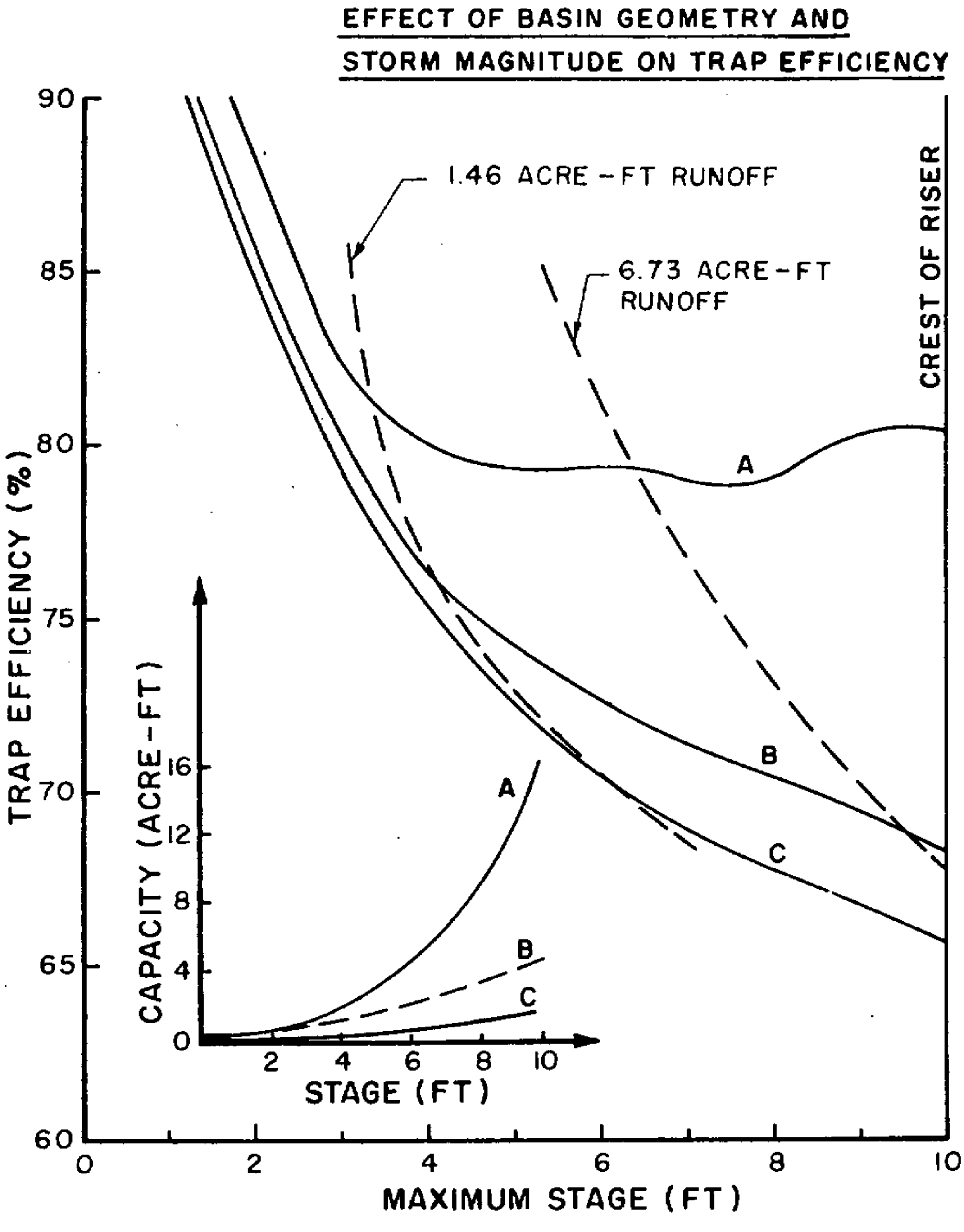


Figure 23: Effect of basin geometry and storm magnitude on trap efficiency

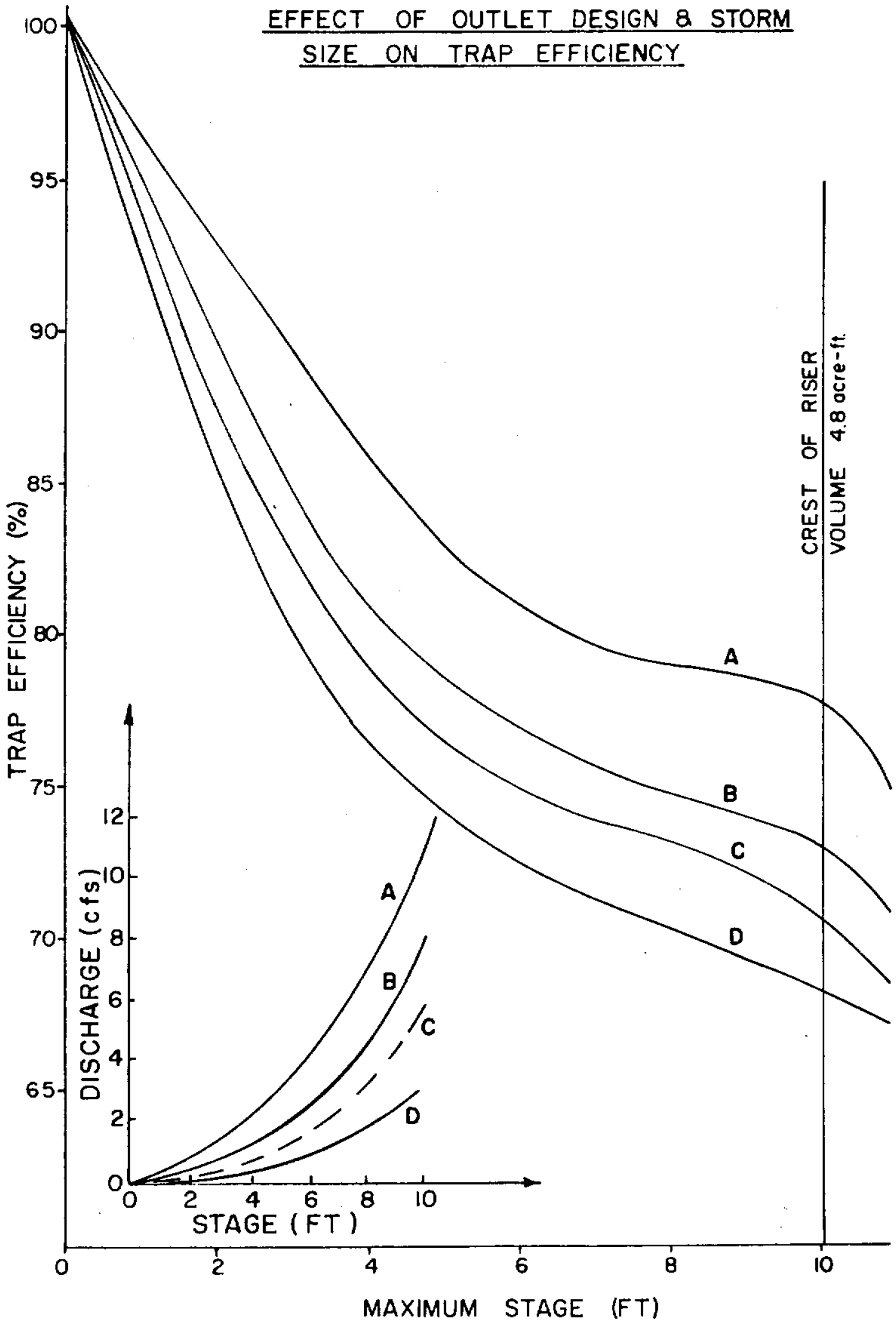


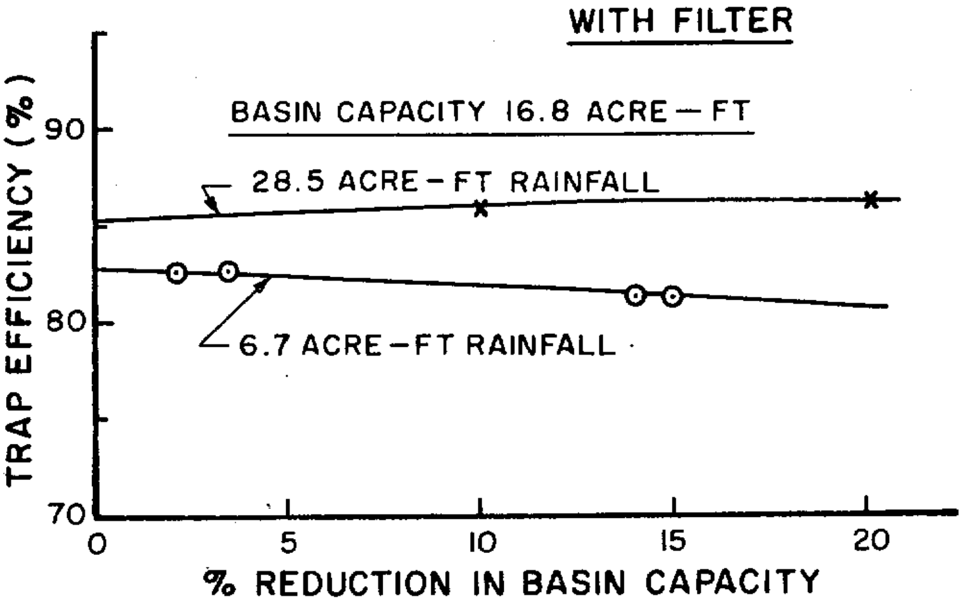
Figure 24: Effect of outlet design and storm size on trap efficiency

Outlet Design

The effect of changing the size of the outlet riser and the number of perforations in the riser is shown in Figures 25 and 26. It can be seen that on a small basin of this nature there is considerable variation in performance regardless of the riser design. The reason however, is not solely in the size of the basin, but in the nature of the stage-area curve. In small shallow basins, it was found that there was considerably less variation than in the steeply sloping strip mine basins used in the simulations. It should be noted that the small strip mine basins used in all these studies were based on the basins used in the verification studies. Their geometry is therefore not untypical. The construction site basin is similar to that found in the verification study as well.

Sediment Accumulation

The effect of loss in capacity due to sediment deposition is illustrated in Figure 25. Sediment accumulation was simulated by using three different sizes of storm events in a 21-storm cycle. A similar process was followed on the larger basin except four storms in a 32-storm cycle were used. The results on the small basin indicate a gradual decrease in efficiency with reduced capacity. This is probably typical of most small basins with steep slopes and indicates that the design criteria should be based on some future basin geometry rather than that existing at construction. Alternatively, the basin should be designed to initially give sediment concentrations lower than the maximum design concentrations.



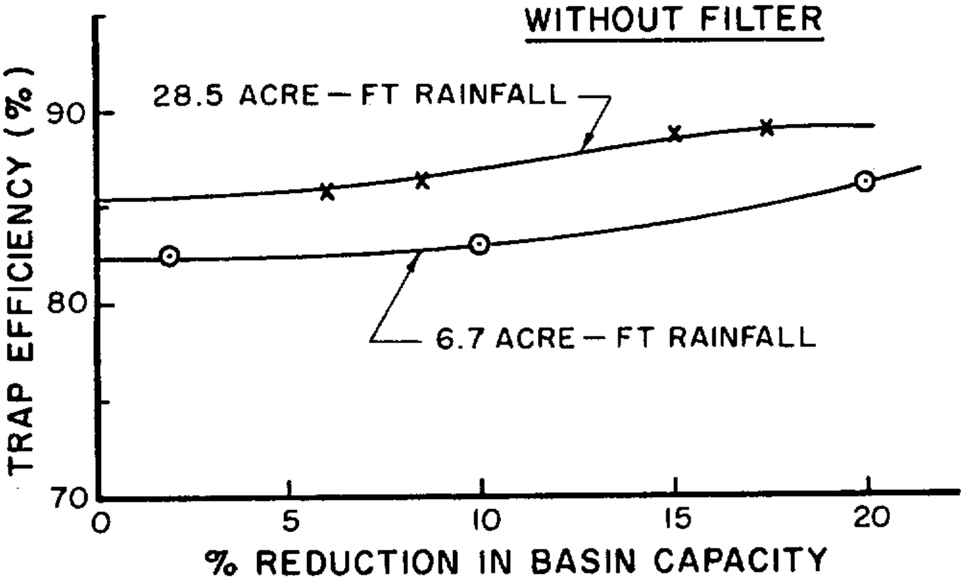


Figure 25: The effect of reduced basin capacity on trap efficiency

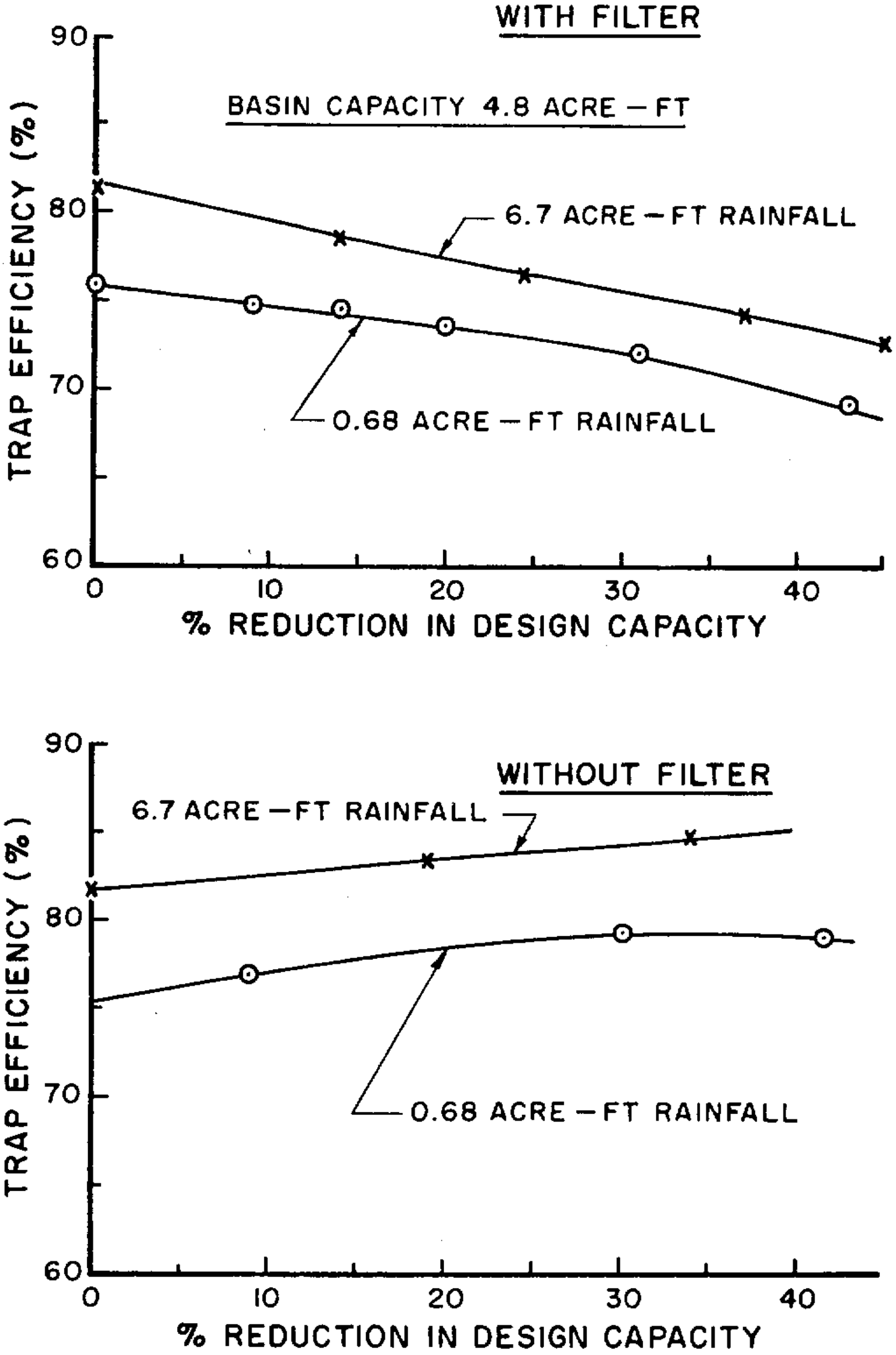


Figure 26: The effect of reduced basin capacity on trap efficiency

The large basin indicates a gradual increase in efficiency followed by a steady decrease in efficiency. The increase is due to the shallower depths required for the same storage as the basin "channel" is filled. However, as deposition continues the discharge rates for the same size storms are increased resulting in shorter detention times. A point is reached where the efficiency begins to decrease. One of the advantages of the model is that it can be used to indicate at which capacity the basin should be cleaned. The results described above assumed the use of a gravel filter around the riser preventing clogging of the riser perforations. Figures 25 and 26 also show the results obtained allowing for clogging as the sediment accumulated. It may appear at first glance that clogging is desirable; both basins show improved trap efficiency with sediment accumulations. This result however, is deceptive. In the smaller basin for example, safe passage of the 6.7 acre-ft storm event was possible through the principal spillway, after a 45% reduction in capacity, when using a filter. Without the use of a filter flow through the emergency spillway would have occurred after a 35% reduction in capacity. The improved trap efficiency is provided by the increased detention time obtained through the reduced hydraulic performance of the riser.

Figures 27 and 28 show the effect of sediment accumulation on the stage-area and stage-capacity curves. In this example sediment accumulation of nearly 4 feet have occurred at the bottom of the

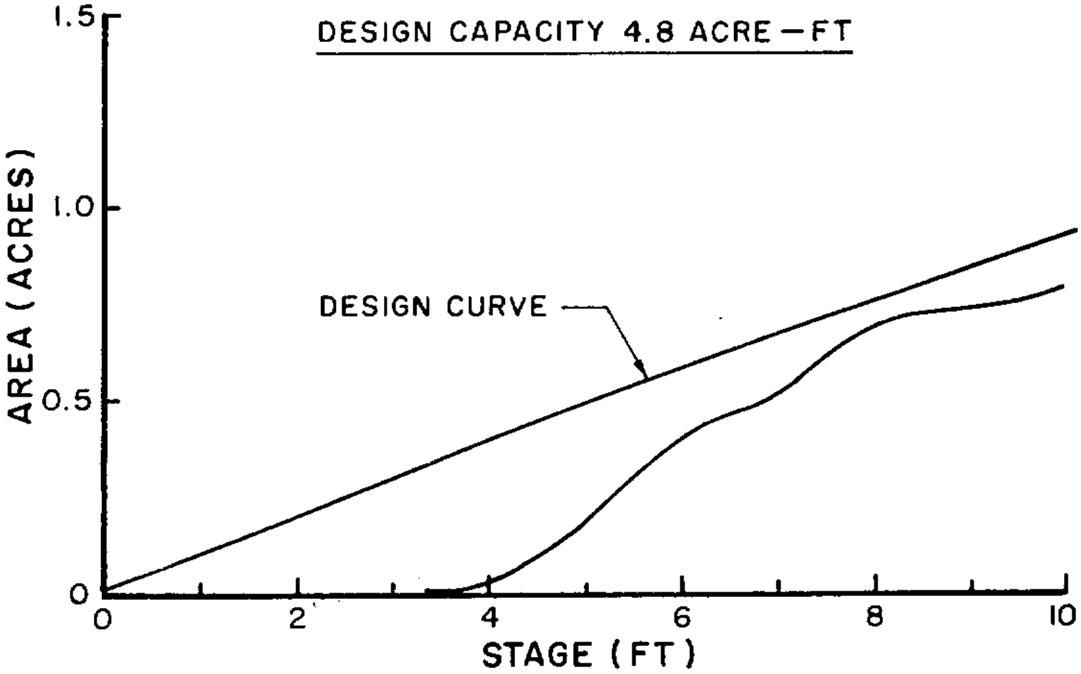


Figure 27: Change in stage-area curve due to sediment accumulation

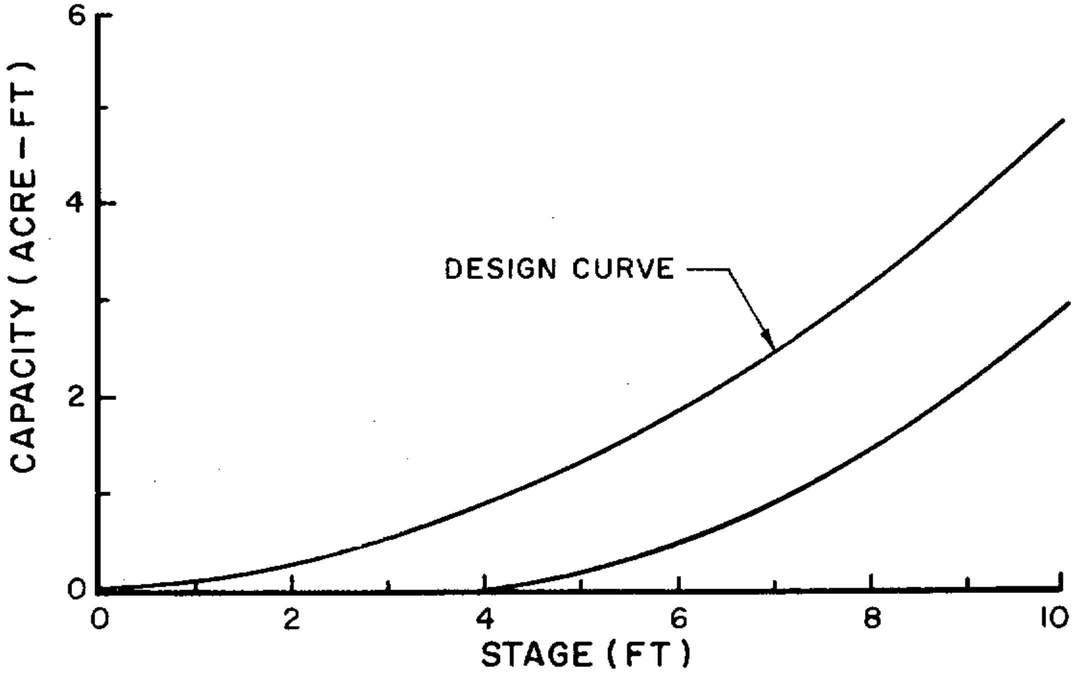


Figure 28: Change in capacity curve due to sediment accumulation

basin. The stage-area curved has been "smoothed" according to the criteria described in the model description. Deposition however, is not uniform across the basin-bed as indicated by the wavy nature of the stage-area curve. Three distinct areas of deposition are indicated and correspond to the three storms used in the deposition simulation. The model maintains the deposition pattern associated with each storm event within 3% of the incremental volume change predicted by the model in the trap efficiency and effluent concentration calculations. On the four sediment accumulation cycles described previously the volume of sediment deposited was within 1.0% of that predicted by the trap efficiency computations.

Influent and Effluent Sedimentgraphs.

Much of the current legislation associated with waterborne sediment transport is written in terms of allowable sediment concentrations. The DEPOSITS model provides for the prediction of effluent sediment concentrations. Figure 29 shows the inflow and outflow hydrographs of a typical storm routing and their associated sedimentgraphs. It should be noted that the model provides an average sediment concentration for each outflow routing increment. In the basic output this value at each plug time is given. Some smoothing due to the values not being instantaneous and not all being provided in the output is required. Normally the peak sediment concentrations rather than the actual shape of the curves are of importance. The curves however, do provide a guide to the use of chemical flocculating agents

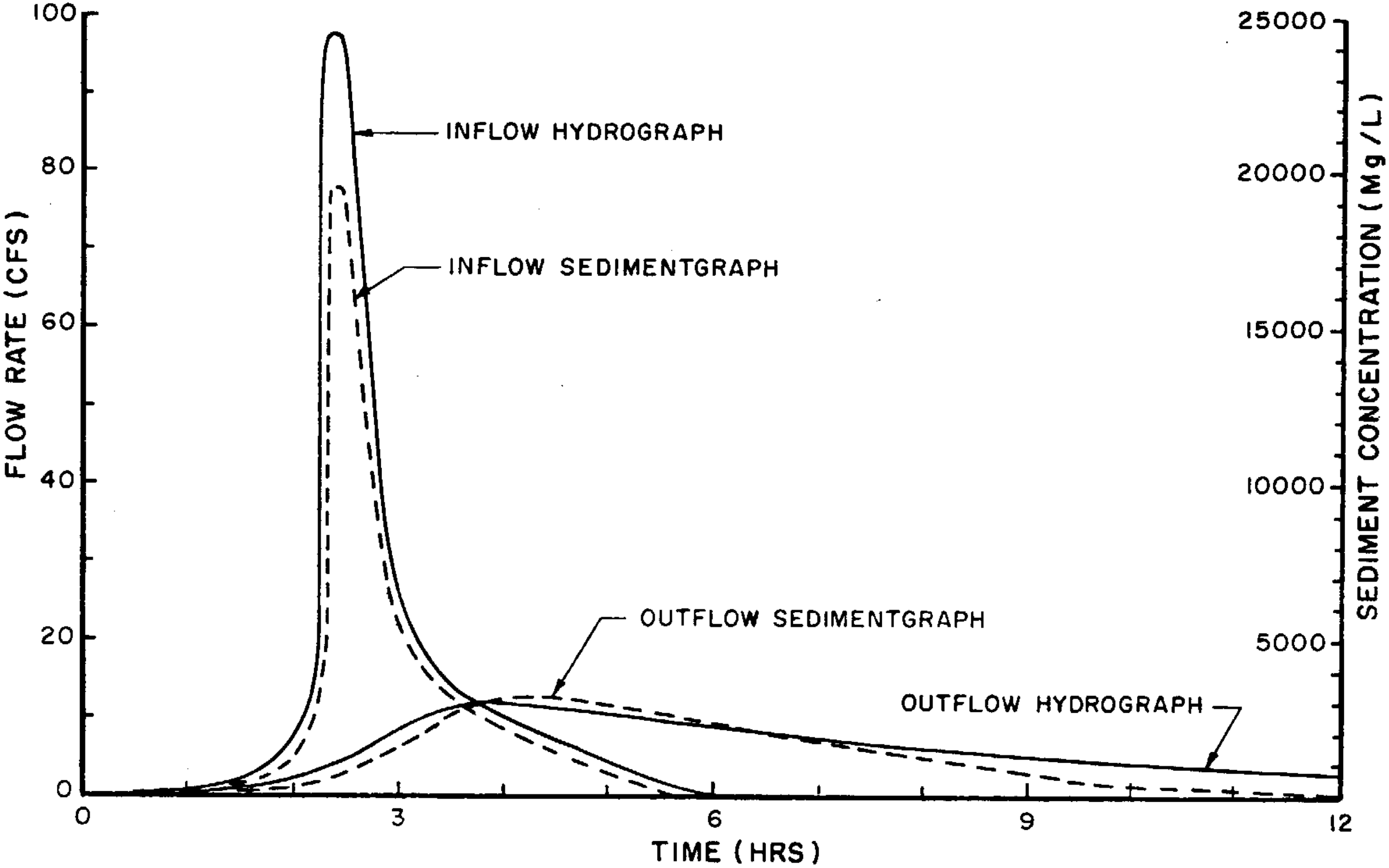


Figure 29: Inflow and outflow hydrograph and sedimentgraph

and drawdown devices. The rate of reduction in high concentrations is also of importance. High concentrations over a small time period may be acceptable but continuous high values indicate the need of a better design.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The study of the methods available to determine the efficiency of sediment detention structures indicated a need for a better method. Most of the methods available were either developed for large reservoirs or basins with steady flow rates. None of the current methods provide a knowledge of effluent sediment concentrations. Most of the current federal and state legislation pertaining to sediment pollution are written in terms of allowable sediment concentrations rather than trap efficiencies. The current methods are also unable to predict the variation of efficiency in sediment basins due to the loss of capacity resulting from sediment deposition. DEPOSITS, the conceptual model developed in this report, has the ability to ascertain the trap efficiency, sediment concentrations and the effect of sediment depositions on the basin performance.

Based on the available data, it appears that the model offers a good indicator of a basin's performance. The model will not work well for poorly designed basins with highly turbulent flow and short-circuiting. It is anticipated however, that most basins are designed to eliminate or greatly reduce these factors. The model is not limited by a particular basin geometry or outlet structure and accounts for the inflow sediment graph and the sediment particle characteristics.

Based on simulation tests with the model, the following factors were found to be important in the design of a sediment detention structure:

1) Basin geometry
2) Inflow hydrograph
3) Sedimentgraph
4) Particle characteristics
5) Discharge curve
6) Outlet design
7) Sediment accumulation.

As indicated in the report, these factors have been ascertained by other research but no method has been available to determine their importance. In predicting the performance of a basin, knowledge of the sediment faction less than 20 microns is essential.

When monitoring sediment basins, care should be taken in selecting sampling points. If samples are taken upstream of the structure, the course fraction will be considerably higher than that obtained near the inlet. Representative samples should be collected for a variety of storm conditions. On a given watershed the sediment concentrations and particle size distribution will vary with the intensity of the storm event.

Determining the size of sediment particles is very difficult. Aggregation and flocculation are both likely to occur. The degree to which they occur depends on the storm event, watershed conditions and the chemical composition of the inflow and the colloidal particles. If the flow contains a high amount of colloidal material, the viscosity of the flow is altered (Kao, 1976).

The performance of a basin can be altered considerably by the outlet design. Preliminary results indicate that for large basins an optimum discharge curve can be developed to give a constant trap efficiency for the basin. The riser is usually designed based on the magnitude of the design storm with little regard to the required water quality. Provision of a gravel envelop around the riser or redesign of the riser perforations can greatly improve the basin performance. Current legislation usually requires a uniform spacing of identically sized perforations. Preliminary studies indicate that the basin efficiency may be improved by 2-3% by altering the spacing or perforation sizes to allow more withdrawal from the cleaner surface flow. The model provides for selective withdrawal from four stratas with different sediment concentrations. Unless highly turbulent flow occurs, stratification normally takes place in a reservoir.

Although directed towards the design of sediment basins, the model may be applied to flood control and water supply reservoirs. In water supply and recreation facilities, the objectives, however, would be different. Normally, the main design criteria in these structures is to determine the minimum sediment storage required and to improve the design to reduce the trap efficiency. In such structures it may be desirable to allow selective withdrawal from near the basin bed. It is felt that the objectives of the research have been accomplished and that the conceptual model provides not only a means for studying the factors affecting a basin's performance, but is also a viable design method. Considerable research is still required as indicated in the following recommendations.

Recommendations

More studies similar to those conducted by Hittman Associates (EPA, 1976) are required. The basin needs to be monitored for longer periods (continuously if possible) and several storm events of different intensity need to be monitored. Knowledge of the volume of sediment reaching reservoirs and detention structures is still very limited and is probably the biggest drawback in developing a suitable design criteria. The Universal Soil Loss Equation (USDA, 1975) may be modified for local conditions but a considerable collection of data over a long period is required. More research is required in developing better predictive equations.

Sizing of sediment particles remains a major problem. The volume of sediment reaching a detention structure and the rate of settlement is dependent on the particle sizes, aggregation and flocculation. Considerable research is required in this area.

Research into the improvement of inlet and outlet structures is needed. Inlets should be designed to dissipate the flow thus reducing turbulence, bed scour and the likelihood of short-circuiting. Outlets need to be designed to provide selective withdrawal and to prevent clogging of the perforations. Algae often form on the riser and greatly affect the basin performance. Methods to control the development of algae are required. It appears that current regulations on riser design need to be made sufficiently flexible to allow for the control of sediment concentrations as well as the design hydraulics.

Further studies into the effect of the colloidal content of sediment flow are required. Perhaps a Theory of Colloidal Settling and Colloidal Flow needs to be developed. Chemical manipulation of sediment deposition on a mass scale appears economically unfeasible but further research may show that selective use of chemicals is economically beneficial.

The collection of data is of prime importance but experience indicates it is not an easy task. More research is required into better sampling methods. With better data, better methods can more readily be developed.

A better design method is still required. The model presented in this paper is of wider scope and presents a better design method than those methods currently available, but does not adequately describe the flow conditions within the basin. A model which allows for partial mixing within the basin is required. It is felt that development of such a model will be very difficult and will probably require extensive field studies on a number of basins.

APPENDIX A

Glossary of Terms

GLOSSARY OF TERM

ACOUT = ACCUMULATED DISCHARGE FROM THE RESERVOIR. (ACRE-FEET)

AREA = BASIN SURFACE AREA AT EACH STAGE POINT. (ACRES)

AREAS = DESIGN BASIN SURFACE AREA AT EACH STAGE POINT. (ACRES)

AREAA = SURFACE AREA OF EACH PLUG. (ACRES)

AREAB = SURFACE AREA OF SECOND PLUG LAYER. (ACRES)

AREAC = SURFACE AREA OF THIRD PLUG LAYER. (ACRES)

AREAD = SURFACE AREA OF BOTTOM PLUG LAYER. (ACRES)

AROLD = SURFACE AREA AT EACH STAGE POINT PRIOR TO DEPOSITION. (ACRES)

AVDPTH = AVERAGE DEPTH AT EACH STAGE POINT. (FEET)

AVSTG = AVERAGE DEPTH AT EACH INFLOW TIME. (FEET)

CAPACA = BASIN CAPACITY AT EACH INFLOW TIME. (ACRE-FEET)

CAPAC = DESIGN CAPACITY OF THE BASIN AT EACH STAGE VALUE. (ACRE-FEET)

CAPCO = DESIGN CAPACITY OF THE BASIN AT EACH STAGE VALUE. (ACRE-FEET)

CAPAC = BASIN CAPACITY AT THE BEGINNING OF EACH STORM EVENT. (ACRE-FT)

CAPNW = BASIN CAPACITY AFTER DEPOSITION. (ACRE-FEET)

CONSED = CONTROL VARIABLE DETERMINING THE INPUT OF A OUTFLOW DEPTH DISTRIBUTION

CONSED = CONTROL VARIABLE DETERMINING THE INPUT OF INFLUENT CONCENTRATIONS.

DELPLG = PLUG TIME INCREMENT. (HOURS)

DELTAT = INFLOW HYDROGRAPH TIME INCREMENT. (HOURS).

DENSTY = DENSITY OF THE SEDIMENT DEPOSITS.

DEPOST = CONTROL VARIABLE DETERMINING USE OF THE DEPOSITION OPTION.

DEPTH = AVERAGE DEPTH DURING DETENTION OF EACH PLUG. (FEET)

DEPTH1 = DEPTH OF THE SECOND PLUG LAYER. (FEET)

DEPTH2 = DEPTH OF THE THIRD PLUG LAYER. (FEET)

DEPTH3 = DEPTH OF THE BOTTOM PLUG LAYER. (FEET)

DETTME = DETENTION TIME OF EACH PLUG. (HOURS)

DISCH = DISCHARGE RATE AT EACH STAGE VALUE. (CFS)

DISCHA = DESIGN DISCHARGE RATE AT EACH STAGE VALUE, (CFS)

DIAMTR = PARTICLE SIZE WITH A FALL VELOCITY VELOC. (MM)

DPTH = DEPTH VALUES ON THE OUTFLOW DISTRIBUTION CURVE. (FEET)

EFLNT = EFFLUENT CONCENTRATION FOR EACH OUTFLOW INCREMENT. (MG/L)

FALL= REQUIRED DEPTH OF SETTLING. (FEET)

FILTER = CONTROL VARIABLE DETERMINING THE USE OF A FILTER ON THE OUTLET STRUCTURE

FIX = CORRECTION FACTOR TO ALLOW FOR SHORT-CIRCUITING AND FLOCCULATION.

FLOW = CONTROL VARIABLE DETERMINING THE INPUT OF A OUTFLOW DEPTH DISTRIBUTION.

INFLOW = INFLOW RATES AT EACH INFLOW TIME. (CFS)

M = NUMBER OF INFLOW VALUES

MASS = MASS OF SEDIMENT ENTERING THE BASIN. (TONS)

MP = NUMBER OF OUTFLOW DISTRIBUTION WITH DEPTH VALUES.

N = NUMBER OF STAGE VALUES.

MS = NUMBER OF OUTFLOW ROUTING VALUES.

NS = NUMBER OF PARTICLE SIZE DISTRIBUTION VALUES.

NFLNT = THE INFLUENT CONCENTRATIONS AT EACH INFLOW ROUTING POINT. (MG/L)

NSTORM = CONTROL VARIABLE DETERMINING THE NUMBER OF STORM EVENTS.

OUTFL1 = OUTFLOW DISTRIBUTION FOR THE TOP PLUG LAYER AT EACH DEPTH. (%)

OUTFL2 = OUTFLOW DISTRIBUTION FOR THE SECOND PLUG DEPTH. (%)

OUTFL3 = OUTFLOW DISTRIBUTION FOR THE THIRD PLUG LAYER, (%)

OUTFL4 = OUTFLOW DISTRIBUTION FOR THE BOTTOM PLUG LAYER. (%)

PCT = PERCENT OF SEDIMENT REMAINING IN SUSPENSION IN EACH LAYER, (%)

PEAKIN = PEAK INFLOW RATE. (CFS)

PERCNT = % FINER AT EACH PARTICLE SIZE DIAMTR. (%)

PERCT = PERCENT OF PARTICLES CAPABLE OF FALLING THE RESPECTIVE INDICATED DEPTH DURING THE PLUG DETENTION TIME.

PLGCEN = THE AVERAGE TIME DURING THE PLUG OUTFLOW. (HOURS)

PLGTME = THE TIME OF OUTFLOW FOR EACH PLUG. (HOURS)

PLGVOL = THE VOLUME OF EACH PLUG. (ACRE-FEET)

SED = PERCENT OF THE TOTAL SEDIMENT INFLOW CONTAINED IN EACH PLUG LAYER

SEDEND = TOTAL PERCENT OF SEDIMENT DISCHARGED AFTER EACH PLUG HAS BEEN DISCHARGED. (%)

SEDMNT = PROPORTION OF SEDIMENT ASSOCIATED WITH EACH INFLOW INCREMENT.

SEDOUT = FRACTION OF SEDIMENT CONTAINED IN EACH PLUG.

SEDPLG = PERCENT OF SEDIMENT DISCHARGED IN EACH PLUG. (%)

SEDTOT = ACCUMULATED VOLUME OF SEDIMENT FLOWING INTO THE RESERVOIR.

SEDT = ACCUMULATED VOLUME OF SEDIMENT ASSOCIATED WITH THE OUTFLOW.

SG = SPECIFIC GRAVITY OF THE SEDIMENT PARTICLES.

SIZE = PARTICLE SIZE. (MM)

STAGE = DEPTH OF FLOW AT THE RISER. (FEET)

STAGEA = STAGE AT EACH ROUTING TIME. (FEET)

STAGO = STAGE AT OUTFLOW . (FEET)

STAG = STAGE VALUES PRIOR TO EACH STORM EVENT. (FEET)

STAREA = AREA UNDER THE AVERAGE DEPTH-TIME CURVE.

STARTV = VOLUME OF INFLOW AT THE START OF THE ROUTING CYCLE. (ACRE-FEET)

STGIN = STAGE DURING INFLOW OF THE PLUG. (FEET)

STGOUT = STAGE DURING THE PLUG OUTFLOW. (FEET)

STGI = DESIGN STAGE VALUES. (FEET)

STP = ACCUMULATED VOLUME OF OUTFLOW. (ACRE-FEET)

STPV = ACCUMULATED INFLOW AT TIME T1. (ACRE-FEET)

TMEIN = TIME DURING INFLOW. (HOURS)

TRAP = TRAP EFFICIENCY. (%)

TRP = CONTROL VARIABLE SPECIFYING A DESIRED TRP EFFICIENCY. (%)

T1 = INFLOW TIME. (HOURS)

VELOC = FALL VELOCITY. (FEET/HOUR)

VISCOS = VISCOSITY OF THE FLOW. (CM. SQ./SEC)

VOL = VOLUME OF EACH PLUG LAYER. (ACRE-FEET)

VOLA = VOLUME OF EACH PLUG. (ACRE-FEET)

VOLB = VOLUME OF FLOW BELOW THE SECOND PLUG LAYER. (ACRE-FEET)

VOLE = VOLUME BELOW THE THIRD PLUG LAYER. (ACRE-FEET)

VOLC = VOLUME OF EACH LAYER ALLOWING SETTLING INTO THE NEXT LAYER.

VOLIN = VOLUME OF INFLOW ACCOUNTED FOR AFTER EACH PLUG DISCHARGE.

VOLOUT = FRACTION OF SEDIMENT ACCOUNTED FOR AFTER EACH PLUG DISCHARGE

VOLTME = AVERAGE TIME DURING INFLOW.

TMEIN = THE TIME OF INFLOW OF EACH PLUG. (HOURS)

VOLUME = VOLUME OF INFLOW DURING EACH INFLOW TIME INCREMENT. (ACRE-FEET)

```
X1(J)=CAPAC(J)-DISCH(J)/2.0*DELTAT*0.08264
X2(J)=CAPAC(J)+DISCH(J)/2.0*DELTAT*0.08264
```

APPENDIX B

User's Guide to the DEPOSITS Model

User's Guide to the DEPOSITS Computer Program

General

The purpose of this guide is to facilitate use of the DEPOSITS Model. With a view to meeting most design criteria, considerable flexibility has been incorporated into the use of the program. Options are made available to the user through the use of several control variables. A glossary of terms is contained in Appendix A and a listing of the program is given in Appendix C. An outline of each data card is provided in this section.

Card 1

The first data card contains most of the control variables required in the model. The following variables should be entered in the appropriate columns.

NSTORM (Columns 1-8)

NSTORM is the number of inflow events required. It has been incorporated into the model to provide for sediment accumulation in a basin through routing of multiple storm events. NSTORM is a real number and, if only one storm event is to be routed through the basin, a value of 1.0 should be entered in columns 1-8.

CONSED (Columns 9-16)

CONSED is a control variable determining the calculation of the inflow sediment concentrations. If the influent sediment concentrations are to be entered on data cards, a value of 2.0 should be entered in columns 9-17. If the concentrations are to be approximated by the model, a value other than 2.0 must be entered.

DEPOST (Columns 17-24)

DEPOST is the control variable determining the use of the deposition option. If the change in basin geometry due to sediment deposition is required, a value of 2.0 should be entered. The deposition option may only be selected if the mass of sediment entering the structure is entered in the input data.

MASS (Columns 25-32)

MASS is the total mass of sediment (tons) entering the basin during each storm event. If no estimate is known, a value of 0.0 may be entered. In this event the model cannot determine sediment accumulations and will only determine effluent concentrations if the influent concentrations are entered on the appropriate data cards.

FLOW (Columns 33-40)

FLOW is the control variable determining the desired outflow conditions. If the discharge distribution with depth is entered as an input on the appropriate data cards, a value of 2.0 should be entered for the FLOW value.

TRP (Columns 41-48)

TRP is a control variable providing simultaneous testing of several outlet structures. If a desired trap efficiency is required, it should be entered as the TRP value (%). If the model determines a trap efficiency less than this value, it will seek additional input data beginning with the discharge curve. The model will continue to seek such data until either the value of TRP is reached or until no further data are provided. If TRP has a value less than or equal to 1.0, it will not seek additional data. It should be noted that NSTORM and TRP may not exceed 1.0 simultaneously. If the performance of several outlet structures are to be tested, a value of 100.0 for TRP will automatically initiate reading of all data cards.

FILTER (Columns 49-56)

Deposition accumulations may be determined either by assuming clogging of riser perforations with sediment or else the use of a gravel filter. If a filter is used, a value of 2.0 should be entered. In this case the model assumes the initial stage-discharge curve is not affected by deposition. Entering of another value for FILTER will give a new stage-discharge curve dependent on the actual depth of water at the riser.

DENSTY (Columns 57-64)

The density of the sediment depositions should be entered for the value of DENSTY. A guide to the choice of a suitable value for the density of sediment deposits is contained in the Model description.

SG (Columns 65-72)

SG is the specific gravity of the sediment particles. The value of SG will usually range from 2.6 - 2.8.

VISCOS (Columns 72-80

VISCOS is the viscosity of the flow in cm^2/sec. All the values entered on this card are real and may be entered anywhere within the defined column range. If no value is specified for a control variable (CONSED, DEPOST, FLOW, TRP, FILTER) in the above description, any value may be chosen but it is recommended that the value 1.0 be employed.

Card 2

The second card contains the remaining control variables and the variables determining the input of the remaining data. Care should be taken in the entry of values on this card. The first five values are all integers and must be entered such that the last digit of each number is entered in the last column of the defined column range.

MP (Columns 1-8)

MP is the number of outflow distribution points. If no outflow distribution values are to be entered, MP should be made equal to N (the number of stage points).

M (Columns 9-16)

M is the number of inflow hydrograph values.

N (Columns 17-24)

N is the number of stage-area and stage-discharge points.

NS (Columns 25-32

NS is the number of particle size distribution points. NS may not exceed 12 for correct listing in the output.

MS (Columns 25-32)

MS is the number of outflow hydrograph points. The value of MS may not exceed 400.

DELTAT (Columns 33-40)

DELTAT is the time increment (hours) of the inflow values.

DELPLG (Columns 41-48)

DELPLG is the time increment of the outflow plug routing.

The following restrictions are placed on the selection of MS, DELTAT, and DELPLG:

1) MS less than 400.
2) DELPLG divided by DELTAT is an integer.
3) MS divided by the ratio given by (2) is also an integer.

FIX (Columns 49-56)

FIX is a correction factor to account for short-circuiting and flocculation. Normally a value of 1.0 should be entered. Choice of another value is described in the model description.

Card 3

Card 3 contains the input of the % finer values (PERCNT) determined from the particle size distribution. Entery of all subsequent input has the same input format and provides for entry of 10 values on each card. Each value may be entered in a field of 8 columns as described for the first two cards. All values however, are real. The order of input must be the same as that contained in this description. Because subsequent input of each variable may necessitate the use of several cards, input will no longer be described by the card number.

Particle Size (SIZE)

The particles sizes corresponding to the values of PERCNT are entered on the next card (or cards). Ten values may be contained on each card. Values are in millimeters.

Stage Values (STGI)

The stage values at the riser determining the stage-area and stage-discharge curves are entered on the next cards. Stage values are in feet and the smaller the stage interval the better the accuracy.

Area Values (AREA)

The area values (acres) corresponding to the stage values entered on the previous cards should now be entered.

Discharge Values (DISCHB)

The values of the outflow rates (cfs) corresponding to the defined stage points are entered. It should be remembered that a maximum of 10 values may be entered on each card.

Inflow Hydrograph Values (INFLOW)

Prior to entering the inflow values, cards 1 and 2 must be duplicated. The duplication is necessary because of the provision of the NSTORM option. When multiple storms are routed through the reservoir, some of the values on cards 1 and 2 may vary with each storm.

The inflow rates (cfs) should now be entered. The interval between each point has previously been specified by the value DELTAT.

The above description completes the entry of required input. The following input depends on the choice of the control variables previously described.

Influent Sediment Concentrations (CONCED)

If the control value CONSED is 2.0, values for the inflow sediment concentrations corresponding to each inflow point must be entered. Values must be given in mg/l.

Outflow Distribution with Depth (OUTFL)

If FLOW equals 2.0, values of the outflow distribution associated with each layer and the depths for which they are defined must be entered. The values of the depth (DEPTH) must be entered. The maximum and minimum values of the depth must be the same as the maximum and minimum value of the stage value.

The number of points, MP, has previously been entered on card 2. The order of entry of the outflow distributions is as follows:

1) OUTFL 1 - values for the top plug layer.
2) OUTFL 2 - values for the second plug layer.
3) OUTFL 3 - values for the third plug layer.
4) OUTFL 4 - values for the bottom layer.

A more detailed description of these variables may be found in the Model description.

If TRP has a value greater than 1.0, the required output cards starting with the discharge values (DISCHB) must be repeated using the desired input events. If NSTORM is greater than 1.0, only the desired input starting with the repetition of cards 1 and 2 is required. This procedure is probably better understood by studying the program listing.

A sample of the output is contained in Appendix D. Only those options which appeared most suitable in utilizing the DEPOSITS Model as a design method have been incorporated in the program. Additional output data and simulation of basin conditions can easily be obtained by the addition of appropriate logic statements in the program.

APPENDIX C

List of the DEPOSITS Computer Program

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C                     LIST OF THE DEPOSITS COMPUTER PROGRAM
C
C
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C       THE DEPOSITS COMPUTER PROGRAM IS A SIMULATION MODEL TO DETERMINE THE
C       PERFORMANCE OF A SEDIMENT DETENTION BASIN. THE MODEL WILL DETERMINE T
C       BASIN TRAP EFFICIENCY, SEDIMENT DEPOSITION PATTERN IN THE RESERVOIR
C       AND THE EFFLUENT SEDIMENT CONCENTRATIONS FOR A GIVEN STORM EVENT.
C
C
        DIMENSION PERCNT(100),X1(400),X2(400),SEDPLG(100)
        DIMENSION DEPTH1(100),DEPTH2(100),DEPTH3(100)
        DIMENSION AREA1(100),AROLD(100),CAPNW(100)
        DIMENSION STP(400),AVDEP(400),SEDT(400),SEDEND(100),DEPTH(400)
        DIMENSION ACINFL(400),VOLUME(400),STARTV(400),STPV(400),STAGEA(400)
       1),CAPACA(400),T1(400),DISCHA(400),STAGE(100),CAPAC(400),DISCH(400)
        DIMENSION NFLNT(400),EFLNT(100),AREAS(50),CAPCD(400),CONCED(400)
        DIMENSION AREAA(100),AREAB(100),AREAC(100),AREAD(100)
        DIMENSION VOL(4,100),SED(4,100),VELOC(4,100),FALL(4,100),VOLC(4,100
       10),DEP(4,100),PCT(4,100),PERCT(4,100)
        DIMENSION SIZE(50),OUTFL1(50),OUTFL2(50),OUTFL3(50),OUTFL4(50)
        DIMENSION STG1(50),DISCHB(50),AREA(50),DPTH(50),INFLOW(400),VELC(50
       10)
        DIMENSION AVDPTH(400),AVSTG(400),STGIN(400),STGOUT(400),STAGO(400),
        DIMENSION STAREA(400),STGAR(400),ACOUT(400),VOLOUT(400),PLGVOL(100
       1),PLGTME(100),VOLIN(100),TMEIN(100),DETTME(100),PLGCEN(100)
        DIMENSION VOLTME(100),SEDMNT(400),SEDTOT(400),SEDOUT(400)
        DIMENSION VOLA(100),VOLB(100),VOLE(100),VOLD(100)
        DIMENSION DIAMTR(4,100),STAG(100)
        REAL OUTFL1,OUTFL2,OUTFL3,OUTFL4
        REAL NFLNT,MASS,INFLOW,NSTORM
        READ(5,800)NSTORM,CONSED,DEPOST,MASS,FLOW,TRP,FILTER,DENSTY,SG,VIS
       1COS
        READ(5,751)MP,M,N,NS,MS,DELTAT,DELPLG,FIX
  751   FORMAT(5I8,3F8.0)
        READ(5,800)(PERCNT(NL),NL=1,NS)
        READ(5,800)(SIZE(NL),NL=1,NS)
        READ(5,800)(STG1(I),I=1,N)
        READ(5,800)(AREAS(I),I=1,N )
  50    READ(5,800)(DISCHB(I),I=1,N)
  800   FORMAT(10F8.0)
        DO 7 I=1,N
        AREA(I)=AREAS(I)
        DISCH(I)=DISCHB(I)
        STAGE(I)=STG1(I)
  7     CONTINUE
  91    NNN=NSTORM
        DO 777 IN=1,NNN
        READ(5,800)NSTORM,CONSED,DEPOST,MASS,FLOW,TRP,FILTER,DENSTY,SG,VIS
       1COS
        READ(5,751)MP,M,N,NS,MS,DELTAT,DELPLG,FIX
        READ(5,800)(INFLOW(I),I=1,M)
```

```
      DO 12 I=1,N
      AROLD(I)=AREA(I)
      STAG(I)=STAGE(I)
 12   CONTINUE
      CAPCO(1)=0.0
      IF(CONSED.EQ.2.0) GO TO 17
      GO TO 611
 17   READ(5,800)(CONCED(I),I=1,M)
 611  CONTINUE
      PEAKIN=0.0
      DO 8 J=1,M
      IF(INFLOW(J).GT.PEAKIN)PEAKIN=INFLOW(J)
 8    CONTINUE
      DO 11 I=1,N
      DPTH(I)=STG1(I)
 11   CONTINUE
      IF(FLOW.EQ.2.0) GO TO 34
      DO 6 I=1,MP
      OUTFL1(I)=25.0
      OUTFL2(I)=25.0
      OUTFL3(I)=25.0
      OUTFL4(I)=25.0
 6    CONTINUE
      GO TO 31
 34   CONTINUE
      READ(5,800)(DPTH(I),I=1,MP)
      READ(5,800)(OUTFL1(I),I=1,MP)
      READ(5,800)(OUTFL2(I),I=1,MP)
      READ(5,800)(OUTFL3(I),I=1,MP)
      READ(5,800)(OUTFL4(I),I=1,MP)
 31   CONTINUE
      AVDEP(1)=0.0
      X1(1)=0.0
      X2(1)=0.0
      CAPAC(1)=0.0
      CAPNW(1)=0.0
      AVDPTH(1)=0.0
      DO 10 J=2,N
      CAPAC(J)=(AREA(J)+AREA(J-1))*(STAGE(J)-STAGE(J-1))/2.0+CAPAC(J-1)
      CAPNW(J)=CAPAC(J)
C AVDPTH= AVERAGE DEPTH FOR A GIVEN STAGE.
      X1(J)=CAPAC(J)-(DISCH(J)/2.0)*DELTAT*.08264
      X2(J)=CAPAC(J)+(DISCH(J)/2.0)*DELTAT*.08264
      CAPCO(J)=(AREAS(J)+AREAS(J-1))*(STG1(J)-STG1(J-1))/2.0+CAPCO(J-1)
 10   CONTINUE
      AVSTG(1)=0.0
C SEDMNT= SEDEMENT CONCENTRATION FOR EACH TIME INCREMENT (VOLUMETRIC).
      SEDMNT(1)=0.0
      SEDTOT(1)=0.0
      SEDOUT(1)=0.0
      STP(1)=0.0
      ACINFL(1)=0.0
      NM=N+1
      DO 20 I=2,N
      SUM1=0.0
      SUM2=0.0
      DO 30 J=2,I
      IF(AREA(J).EQ.AREA(J-1)) GO TO 15
      DEPO=STAGE(I)-(STAGE(J)+STAGE(J-1))/2.0
      SUM1=DEPO**2.0*(AREA(J)-AREA(J-1))+SUM1
      SUM2=DEPO*(AREA(J)-AREA(J-1))+SUM2
```

```
30    CONTINUE
      IF(SUM2.LE.0.0) GO TO 63
      AVDPTH(I)=SUM1/SUM2
      GO TO 69
63    AVDPTH(I)=0.0
69    CONTINUE
20    CONTINUE
      GO TO 21
15    DO 16 J=2,N
      AVDEP(J)=(CAPAC(J-1)*AVDEP(J-1)+(CAPAC(J)-CAPAC(J-1))*(STAGE(J)+ST
     1AGE(J-1))/2.0)/CAPAC(J)
      AVDPTH(J)=(STAGE(J)-AVDEP(J))*2.0
16    CONTINUE
21    CONTINUE
      DO 99 I=MM,MS
      INFLOW(I)=0.0
99    CONTINUE
      VOLUME(1)=0.0
      DO 40 I=2,MS
      ACINFL(I)=ACINFL(I-1)+((INFLOW(I-1)+INFLOW(I))/2.0)*DELTAT*.08264
      VOLUME(I)=ACINFL(I)-ACINFL(I-1)
40    CONTINUE
      STAREA(1)=0.0
      STGAR(1)=0.0
      STARTV(1)=0.0
      STAGEA(1)=0.0
      CAPACA(1)=0.0
      DISCHA(1)=0.0
      T1(1)=0.0
      MR=(MS)/(DELPLG/DELTAT)
      PEAK=0.0
      DO 95 I=MM,MS
      CONCED(I)=0.0
95    CONTINUE
      DO 60 J=2,MS
      IF(CONSED.EQ.2.0) GO TO 632
      SEDMNT(J)=(VOLUME(J)**2.0)
      GO TO 23
632   SEDMNT(J)=(CONCED(J)+CONCED(J-1))*VOLUME(J)/(SG*2000.0)
23    CONTINUE
      SEDTOT(J)=SEDTOT(J-1)+SEDMNT(J)
      STP(J)=STP(J-1)+VOLUME(J)
      STPV(J-1)=STARTV(J-1)+VOLUME(J)
C  DO AN ITERATION TO FIND STAGE FROM STPV
      DO 70 K=2,N
      IF(STPV(J-1).LT.X2(K))GO TO 75
      IF(STPV(J-1).GT.X2(N)) GO TO 19
70    CONTINUE
75    STAGEA(J)=STAGE(K-1)+((STPV(J-1)-X2(K-1))/(X2(K)-X2(K-1)))*(STAGE(
     1K)-STAGE(K-1))
      AVSTG(J)=AVDPTH(K-1)+((STPV(J-1)-X2(K-1))/(X2(K)-X2(K-1)))*(AVDPTH
     1(K)-AVDPTH(K-1))
      CONTINUE
C  DO AN ITERATION TO FIND VOLUME FOR S-(Q/2)*DELTA T FROM STAGE FOUND FO
      DO 100 KK=2,N
      IF(STAGEA(J).LT.STAGE(KK)) GO TO 105
      IF(STAGEA(J-1).GT.STAGE(N) ) GO TO 19
100   CONTINUE
105   CAPACA(J)=X1(KK-1)+((STAGEA(J)-STAGE(KK-1))/(STAGE(KK)-STAGE(KK-1)
     1))*(X1(KK)-X1(KK-1))
C  DO AN ITERATION TO FIND DISCHARGE FOR STAGEA
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```
      DISCHA(J)=DISCH(KK-1)+((STAGEA(J)-STAGE(KK-1))/(STAGE(KK)-STAGE(KK
     1-1)))*(DISCH(KK)-DISCH(KK-1))
      IF(DISCHA(J).GT.PEAK)PEAK=DISCHA(J)
      CONTINUE
      STARTV(J)=CAPACA(J)
      IF(STARTV(J).LT.0.0) STARTV(J)=0.0
      T1(J)=(J-1)*DELTAT
      STAREA(J)=ABS((AVSTG(J)+AVSTG(J-1))*(DELTAT/2.0))
      STGAR(J)=STAREA(J)+STGAR(J-1)
C THIS PART OF THE PROGRAM DIVIDES THE OUTLET HYDROGRAPH INTO PLUGS OF EQUAL
C TIME INCREMENT DELPLG. THE PLUG IS THEN ROUTED THROUGH THE RESERVOIR AND
C THE DETENTION TIME,STAGE AT OUTFLOW, AVERAGE DEPTH AND THE VOLUME OF
C THE PLUG IS DETERMINED.
   60 CONTINUE
      IF(CONSED.EQ.2.0) GO TO 771
      DO 49 JS=2,M
      IF(VOLUME(JS).EQ.0.0) GO TO 784
      NFLNT(JS)=(SEDMNT(JS)*SG*MASS*735.48)/(VOLUME(JS)*SEDTOT(M))
      GO TO 785
784   NFLNT(JS)=0.0
785   CONTINUE
49    CONTINUE
      GO TO 883
771   DO 772 JS=1,M
      NFLNT(JS)=CONCED(JS)
772   CONTINUE
883   CONTINUE
      DO 766 JJ=MM,MS
      NFLNT(JJ)=0.0
766   CONTINUE
      DO 25 I=1,4
      J=1
      SED(I,J)=0.0
      DIAMTR(I,J)=0.0
      VELOC(I,J)=0.0
      FALL(I,J)=0.0
      VOL(I,J)=0.0
      PCT(I,J)=0.0
      VOLC(I,J)=0.0
25    CONTINUE
      SEDPLG(1)=0.0
      SEDEND(1)=0.0
      DEPTH(1)=0.0
      ACOUT(1) = 0.0
      PLGVOL(1)=0.0
      PLGTME(1)=0.0
      VOLOUT(1)=0.0
      VOLIN(1)=0.0
      TMEIN(1)=0.0
      SEDT(1)=0.0
      DETTME(1)=0.0
      PLGCEN(1)=0.0
      VOLTME(1)=0.0
      AREAA(1)=0.0
      AREAB(1)=0.0
      AREAC(1)=0.0
      AREAD(1)=0.0
      VOLA(1)=0.0
      VOLB(1)=0.0
      VOLF(1)=0.0
      VOLD(1)=0.0
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```
      DEPTH(1)=0.0
      DEPTH2(1)=0.0
      DEPTH3(1)=0.0
      DO 200 L=2,MS
      ACOUT(L)=ACOUT(L-1)+((DISCHA(L-1)+DISCHA(L))/2.0)*DELTAT*.08264
200   CONTINUE
      DO 300 NN=2,MR
      PLGTME(NN)=PLGTME(NN-1) + DELPLG
      LR=(DELPLG)/DELTAT
      P=LR*(NN-1)+1
      PLGVOL(NN)=ACOUT(P)-ACOUT(P-LR)
      VOLIN(NN) = VOLIN(NN-1) + PLGVOL(NN)
      PLGCEN(NN) = (PLGTME(NN) + PLGTME(NN-1))/2.0
C DO AN ITERATION TO FIND TMEIN FROM VOLIN
      DO 400 NP=2,M
      IF(VOLIN(NN).LT.STP(NP)) GO TO 500
400   CONTINUE
500   TMEIN(NN)=T1(NP-1)+((VOLIN(NN)-STP(NP-1))/(STP(NP)-STP(NP-1)))*DELT
     1TAT
      VOLTME(NN)=(TMEIN(NN)+TMEIN(NN-1))/2.0
      DETTME(NN)=PLGCEN(NN)-VOLTME(NN)
      IF(DETTME(NN).LT.0.0) DETTME(NN)=0.0
      IF(DETTME(NN).LT.0.0.AND.NN.GT.10) GO TO 312
      SEDT(NN)=SEDTOT(NP-1)+((VOLIN(NN)-STP(NP-1))/(STP(NP)-STP(NP-1)))
     1*(SEDTOT(NP)-SEDTOT(NP-1))
      SEDOUT(NN)=(SEDT(NN)-SEDT(NN-1))/SEDTOT(M)
      STGIN(1)=0.0
      STGOUT(1)=0.0
      STAGO(1)=0.0
      DO 710 II=2,MS
      IF(VOLTME(NN).LT.T1(II)) GO TO 750
      IF(VOLTME(NN).GE.T1(MS)) GO TO 321
C DO AN ITERATION TO FIND DEPTH FOR VOLTME
710   CONTINUE
750   STGIN(NN)=STGAR(II-1)+ABS(((VOLTME(NN)-T1(II-1))/(T1(II)-T1(II-1))
     1)*(STGAR(II)-STGAR(II-1)))
      CONTINUE
      DO 900 II=2,MS
      IF(PLGCEN(NN).LT.T1(II)) GO TO 760
C DO AN ITERATION TO FIND DEPTH FOR PLGTME
900   CONTINUE
760   STGOUT(NN)=STGAR(II-1)+((PLGCEN(NN)-T1(II-1))/(T1(II)-T1(II-1)))*(
     1STGAR(II)-STGAR(II-1))
      STAGO(NN)=STAGEA(II-1)+((PLGCEN(NN)-T1(II-1))/(T1(II)-T1(II-1)))*(
     1STAGEA(II)-STAGEA(II-1))
      IF(DETTME(NN).EQ.0.0) GO TO 381
      DEPTH(NN)=(STGOUT(NN)-STGIN(NN))/DETTME(NN)
      DEPTH1(NN)=0.75*DEPTH(NN)
      DEPTH2(NN)=0.5*DEPTH(NN)
      DEPTH3(NN)=0.25*DEPTH(NN)
      DO 1200 LM=2,N
      IF(DEPTH(NN).LT.STAGE(LM)) GO TO 1300
1200  CONTINUE
1300  VOLA(NN)= CAPAC(LM-1)+((DEPTH(NN)-STAGE(LM-1))/(STAGE(LM)-STAGE(LM-
     1-1)))*(CAPAC(LM)-CAPAC(LM-1))
      AREAA(NN)=AREA(LM-1)+((DEPTH(NN)-STAGE(LM-1))/(STAGE(LM)-STAGE(LM-
     11)))*(AREA(LM)-AREA(LM-1))
      CONTINUE
      DO 1400 LM=2,N
      IF(DEPTH1(NN).LT.STAGE(LM)) GO TO 1500
1400  CONTINUE
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      CONTINUE
 1500 VOLB(NN)=CAPAC(LM-1)+((DEPTH1(NN)-STAGE(LM-1))/(STAGE(LM)-STAGE(LM
     1-1)))*(CAPAC(LM)-CAPAC(LM-1))
      AREAB(NN)=AREA(LM-1)+((DEPTH1(NN)-STAGE(LM-1))/(STAGE(LM)-STAGE(LM-
     1-1)))*(AREA(LM)-AREA(LM-1))
      CONTINUE
      DO 1600 LM=2,N
      IF(DEPTH2(NN).LT.STAGE(LM)) GO TO 1700
 1600 CONTINUE
 1700 VOLE(NN)= CAPAC(LM-1)+((DEPTH2(NN)-STAGE(LM-1))/(STAGE(LM)-STAGE(L
     1M-1)))*(CAPAC(LM)-CAPAC(LM-1))
      AREAC(NN)=AREA(LM-1)+((DEPTH2(NN)-STAGE(LM-1))/(STAGE(LM)-STAGE(L
     1-1)))*(AREA(LM)-AREA(LM-1))
      CONTINUE
      DO 1800 LM=2,N
      IF(DEPTH3(NN).LT.STAGE(LM)) GO TO 1900
 1800 CONTINUE
 1900 VOLD(NN)= CAPAC(LM-1)+((DEPTH3(NN)-STAGE(LM-1))/(STAGE(LM)-STAGE(L
     1M-1)))*(CAPAC(LM)-CAPAC(LM-1))
      AREAD(NN)=AREA(LM-1)+((DEPTH3(NN)-STAGE(LM-1))/(STAGE(LM)-STAGE(L
     1-1)))*(AREA(LM)-AREA(LM-1))
      CONTINUE
      VOL(1,NN)=VOLA(NN)-VOLB(NN)
      VOL(2,NN)=VOLB(NN)-VOLE(NN)
      VOL(3,NN)=VOLE(NN)-VOLD(NN)
      VOL(4,NN)=VOLD(NN)
      FALL(1,NN)=0.875*DEPTH(NN)*FIX
      FALL(2,NN)=0.625*DEPTH(NN)*FIX
      FALL(3,NN)=0.375*DEPTH(NN)*FIX
      FALL(4,NN)=0.125*DEPTH(NN)*FIX
      IF(PLGVOL(NN).LT..001) GO TO 321
      VELOC(1,NN)=FALL(1,NN)/(DETTME(NN)*(1.0-(SEDOUT(NN)*MASS*0.000138
     1/PLGVOL(NN)))**2.5)
      VELOC(2,NN)=FALL(2,NN)/(DETTME(NN)*(1.0-(SEDOUT(NN)*MASS*0.000133
     1/PLGVOL(NN)))**2.5)
      VELOC(3,NN)=FALL(3,NN)/(DETTME(NN)*(1.0-(SEDOUT(NN)*MASS*0.000133
     1/PLGVOL(NN)))**2.5)
      VELOC(4,NN)=FALL(4,NN)/(DETTME(NN)*(1.0-(SEDOUT(NN)*MASS*0.000133
     1/PLGVOL(NN)))**2.5)
      DIAMTR(1,NN)=SQRT(VELOC(1,NN)*VISCOS/(51.5*(SG-1)))
      DIAMTR(2,NN)=SQRT(VELOC(2,NN)*VISCOS/(51.5*(SG-1)))
      DIAMTR(3,NN)=SQRT(VELOC(3,NN)*VISCOS/(51.5*(SG-1)))
      DIAMTR(4,NN)=SQRT(VELOC(4,NN)*VISCOS/(51.5*(SG-1)))
      CONTINUE
      DO 2000 LP=2,NS
      IF(DIAMTR(1,NN).LT.SIZE(LP)) GO TO 2100
 2000 CONTINUE
 2100 PERCT(1,NN)=PERCNT(LP-1)+((DIAMTR(1,NN)-SIZE(LP-1))/(SIZE(LP)-SIZE
     1(LP-1)))*(PERCNT(LP)-PERCNT(LP-1))
      DO 2200 LP=2,NS
      IF(DIAMTR(2,NN).LT.SIZE(LP)) GO TO 2300
 2200 CONTINUE
 2300 PERCT(2,NN)=PERCNT(LP-1)+((DIAMTR(2,NN)-SIZE(LP-1))/(SIZE(LP)-SIZE
     1(LP-1)))*(PERCNT(LP)-PERCNT(LP-1))
      DO 2350 LP=2,NS
      IF(DIAMTR(3,NN).LT.SIZE(LP)) GO TO 2400
 2350 CONTINUE
 2400 PERCT(3,NN)=PERCNT(LP-1)+((DIAMTR(3,NN)-SIZE(LP-1))/(SIZE(LP)-SIZE
     1(LP-1)))*(PERCNT(LP)-PERCNT(LP-1))
      DO 2450 LP=2,NS
      IF(DIAMTR(4,NN).LT.SIZE(LP)) GO TO 2600
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 2450 CONTINUE
 2600 PERCT(4,NN)=PERCNT(LP-1)+((DIAMTR(4,NN)-SIZE(LP-1))/(SIZE(LP)-SIZE
     1(LP-1)))*(PERCNT(LP)-PERCNT(LP-1))
      VOLC(1,NN)=VOL(1,NN)*AREAB(NN)/AREAA(NN)
      VOLC(2,NN)=VOL(2,NN)*AREAC(NN)/AREAB(NN)
      VOLC(3,NN)=VOL(3,NN)*AREAD(NN)/AREAC(NN)
      VOLC(4,NN)=VOL(4,NN)*AREA(2)/AREAD(NN)
      IF(VOL(2,NN).LE.0.0)  GO TO 321
      PCT(1,NN)=PERCT(4,NN)
      PCT(2,NN)=(VOL(2,NN)*PERCT(4,NN)+VOLC(1,NN)*(PERCT(3,NN)-PERCT(4,N
     1N)))/VOL(2,NN)
      PCT(3,NN)=(VOL(3,NN)*PERCT(4,NN)+VOLC(2,NN)*(PERCT(2,NN)-PERCT(4,N
     1N)))/VOL(3,NN)
      PCT(4,NN)=(VOL(4,NN)*PERCT(4,NN)+VOLC(3,NN)*(PERCT(1,NN)-PERCT(J,N
     1N)))/VOL(4,NN)
      DO 3600 LM=2,NS
      IF(STAGO(NN).LT.DPTH(LM)) GO TO 3700
 3600 CONTINUE
 3700 SED(1,NN)=PCT(1,NN)*SEDOUT(NN)*(OUTFL1(LM-1)+((STAGO(NN)-DPTH(LM-1
     1))/(DPTH(LM)-DPTH(LM-1)))*(OUTFL1(LM)-OUTFL1(LM-1)))
      SED(2,NN)=PCT(2,NN)*SEDOUT(NN)*(OUTFL2(LM-1)+((STAGO(NN)-DPTH(LM-1
     1))/(DPTH(LM)-DPTH(LM-1)))*(OUTFL2(LM)-OUTFL2(LM-1)))
      SED(3,NN)=PCT(3,NN)*SEDOUT(NN)*(OUTFL3(LM-1)+((STAGO(NN)-DPTH(LM-1
     1))/(DPTH(LM)-DPTH(LM-1)))*(OUTFL3(LM)-OUTFL3(LM-1)))
      SED(4,NN)=PCT(4,NN)*SEDOUT(NN)*(OUTFL4(LM-1)+((STAGO(NN)-DPTH(LM-1
     1))/(DPTH(LM)-DPTH(LM-1)))*(OUTFL4(LM)-OUTFL4(LM-1)))
      SEDPLG(NN)=(SED(1,NN)+SED(2,NN)+SED(3,NN)+SED(4,NN))/100.0
      GO TO 4352
  321 SEDPLG(NN)=0.0
      PCT(1,NN)=0.0
      PCT(2,NN)=0.0
      PCT(3,NN)=0.0
      PCT(4,NN)=0.0
 4352 CONTINUE
      GO TO 4451
  381 SEDPLG(NN)=100.0*SEDOUT(NN)
      PCT(1,NN)=100.0
      PCT(2,NN)=100.0
      PCT(3,NN)=100.0
      PCT(4,NN)=100.0
 4451 CONTINUE
      SEDEND(NN)=SEDEND(NN-1)+SEDPLG(NN)
      VOLOUT(NN)=SEDOUT(NN)+VOLOUT(NN-1)
      IF(VOLOUT(NN).GT.0.9995) GO TO 312
      IF(PLGVOL(NN).EQ.0.0) GO TO 1110
      EFLNT(NN)=(SEDPLG(NN)/PLGVOL(NN))*MASS*7.3548
      GO TO 1111
 1110 EFLNT(NN)=0.0
 1111 CONTINUE
      IF(DEPOST.NE.2.0) GO TO 300
      DEP(1,NN)=MASS*0.0007360*(100.0-PCT(1,NN))*SEDOUT(NN)*(OUTFL1(LM-1
     1)+((STAGO(NN)-DPTH(LM-1))/(DPTH(LM)-DPTH(LM-1))))*(OUTFL1(LM)-OUTFL
     11(LM-1))))/(10000.0*DENSTY)
      DEP(2,NN)=MASS*0.0007360*(100.0-PCT(2,NN))*SEDOUT(NN)*(OUTFL2(LM-1
     1)+((STAGO(NN)-DPTH(LM-1))/(DPTH(LM)-DPTH(LM-1))))*(OUTFL2(LM)-OUTFL
     12(LM-1))))/(10000.0*DENSTY)
      DEP(3,NN)=MASS*0.0007360*(100.0-PCT(3,NN))*SEDOUT(NN)*(OUTFL3(LM-1
     1)+((STAGO(NN)-DPTH(LM-1))/(DPTH(LM)-DPTH(LM-1))))*(OUTFL3(LM)-OUTFL
     13(LM-1))))/(10000.0*DENSTY)
      DEP(4,NN)=MASS*0.0007360*(100.0-PCT(4,NN))*SEDOUT(NN)*(OUTFL4(LM-1
     1)+((STAGO(NN)-DPTH(LM-1))/(DPTH(LM)-DPTH(LM-1))))*(OUTFL4(LM)-OUTFL
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     14(LM-1)))/(10000.0*DENSTY)
C     THIS PART OF THE PROGRAM DETERMINES THE CHANGE IN BASIN CAPACITY DUE
C     DEPOSITION
      DO 77 I=1,N
      IF(AVDPTH(I).LT.DEPTH3(NN)) GO TO 301
      IF(AVDPTH(I).LT.DEPTH2(NN)) GO TO 302
      IF(AVDPTH(I).LT.DEPTH1(NN)) GO TO 303
      IF(AVDPTH(I).LT.DEPTH (NN)) GO TO 304
      CAPNW(I)=CAPNW(I)-(DEP(4,NN)+DEP(3,NN)+DEP(2,NN)+DEP(1,NN))
      GO TO 77
301   CAPNW(I)=CAPNW(I)-DEP(4,NN)*AVDPTH(I)/DEPTH3(NN)
      GO TO 77
302   CAPNW(I)=CAPNW(I)-(DEP(4,NN)+DEP(3,NN)*(AVDPTH(I)-DEPTH3(NN))/DEPT
     1H2(NN))
      GO TO 77
303   CAPNW(I)=CAPNW(I)-(DEP(4,NN)+DEP(3,NN)+DEP(2,NN)+(DEP(2,NN)*(AVDPT
     1H(I)-DEPTH2(NN))/DEPTH1(NN)))
      GO TO 77
304   CAPNW(I)=CAPNW(I)-(DEP(4,NN)+DEP(3,NN)+DEP(2,NN)+(DEP(1,NN)*(AVDPT
     1H(I)-DEPTH1(NN))/DEPTH(NN)))
77    CONTINUE
300   CONTINUE
312   IF(DEPOST.NE.2.0) GO TO 841
      DEPCAP=CAPAC(N)-CAPNW(N)
      CAPMAX=CAPAC(N)
      DO 157 I=1,N
      CAPAC(I)=CAPNW(I)
157   CONTINUE
      NL=N-2.0
      DO 61 IK=1,NL
      AREA(N-IK-1)=2.0*(CAPAC(N-IK)-CAPAC(N-IK-1))/(STG1(N-IK)-STG1(N-IK
     1-1))-AREA(N-IK)
      CHECK=1.001*AROLD(N-IK-1.0)
      IF(AREA(N-IK-1.0).GT.CHECK) GO TO 203
      IF(AREA(N-IK-1.0).GT.AREA(N-IK)) GO TO 203
      IF(AREA(N-IK-1.0).LT.0.0) GO TO 209
      GO TO 311
203   AREA(N-IK-1)=0.995*AROLD(N-IK-1)
      IF((N-IK).EQ.2.0) GO TO 61
      CAPAC(N-IK-1.0)=CAPAC(N-IK)-(AREA(N-IK-1.0)+AREA(N-IK))*(STG1(N-IK
     1)-STG1(N-IK-1.0))/2.0
      CAPAC(N-IK-2.0)=CAPAC(N-IK-1.0)-(AREA(N-IK-2.0)+AREA(N-IK-1.0))*(S
     1TG1(N-IK-1.0)-STG1(N-IK-2.0))/2.0
311   CONTINUE
61    CONTINUE
      GO TO 208
209   AREA(N-IK-1.0)=0.0
      CAPAC(N-IK-1.0)=0.0
      AREA(N-IK)=0.9*AREA(N-IK)
      AREA(N-IK+1)=0.95*AREA(N-IK+1)
      IF(AREA(N-IK-1).GT.AREA(N-IK)) AREA(N-IK)=1.01*AREA(N-IK-1)
      CAPAC(N-IK)=CAPAC(N-IK+1.0)-(AREA(N-IK+1.0)+AREA(N-IK))*(STG1(N-IK
     1+1.0)-STG1(N-IK))/2.0
      IF(CAPAC(N-IK).LE.0.0) CAPAC(N-IK)=0.0
208   CONTINUE
      CAPAC(1)=0.0
      DO 351 IP=1,N
      IF(CAPAC(IP).EQ.0.0) MD=IP
      IF(CAPAC(IP).GT.0.0) GO TO 347
351   CONTINUE
347   DO 353 IM=1,N
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      STG2=STAGE(MD)
      STAGE(IM)=STAG(IM)-STG2
      IF(STAGF(IM).LT.0.0) STAGE(IM)=0.0
      IF(STAGE(IM).EQ.0.0) CAPAC(IM)=0.0
      IF(STAGE(IM).EQ.0.0.AND.IM.GT.1.0) GO TO 216
      GO TO 215
216   IF(STAGE(IM-1).EQ.0.0) AREA(IM-1)=0.0
215   CONTINUE
353   CONTINUE
      DO 463 MI=2,N
      IF(AREA(MI).LE.AREA(MI-1.0))GO TO 473
463   CONTINUE
      GO TO 471
473   AREA(MI)=0.99*AROLD(MI)
      AREA(MI-1)=0.99*AREA(MI-1)
      IF(MI.LE.2) GO TO 661
      IF(AREA(MI-1.0).LT.AREA(MI-2))GO TO 663
      GO TO 661
663   ARE=AREA(MI-1)
      AREA(MI-1)=AREA(MI-2)
      AREA(MI-2)=ARE
661   CONTINUE
      CAPAC(MI)=CAPAC(MI+1.0)-(AREA(MI+1.0)+AREA(MI))*(STG1(MI+1.0)-STG1
     1(MI))/2.0
      CAPAC(MI-1.0)=CAPAC(MI)-(AREA(MI)+AREA(MI-1.0))*(STG1(MI)-STG1(MI-
     11.0))/2.0
      IF(CAPAC(MI).LT.0.0) GO TO 783
      IF(CAPAC(MI-1.0).LT.0.0) GO TO 734
      GO TO 782
783   DO 348 IP=1,MI
      STG3=STAGE(MI)
      LS=MI
      ARC=AREA(MI)
      CAPAC(IP)=0.0
      STAGE(IP)=0.0
      AREA(IP)=0.0
      AREA(MI)=ARC
      IF(FILTER.EQ.2.0) GO TO 348
      DISCH(IP)=0.0
348   CONTINUE
      GO TO 551
734   MT=MI-1.0
      DO 344 IP=1,MT
      STG3=STAGE(MT)
      LS=MT
      ARC=AREA(MT)
      CAPAC(IP)=0.0
      STAGE(IP)=0.0
      AREA(IP)=0.0
      AREA(MT)=ARC
      IF(FILTER.EQ.2.0) GO TO 344
      DISCH(IP)=0.0
344   CONTINUE
551   CONTINUE
      DO 431 IS=1,N
      STAGE(IS)=STAGE(IS)-STG3
      IF(STAGE(IS).LT.0.0) STAGE(IS)=0.0
      IF(STAGE(IS).LT.0.0.AND.FILTER.NE.2.0) DISCH(IS)=0.0
      IF(FILTER.EQ.2.0) GO TO 431
      DISCH(LS-1+IS)=DISCHB(IS)
431   CONTINUE
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 782  CONTINUE
 471  CONTINUE
      IF(MI.GE.N) GO TO 808
      DO 583 ML=MI,N
      SMOOTH=3.0*AREA(ML)
      SMOTH2=1.5*AREA(ML)
      IF(SMOOTH.LT.AREA(ML-1)) GO TO 589
      IF(SMOTH2.LT.AREA(ML-1)) GO TO 587
      IF(AREA(ML).LT.AREA(ML-1)) GO TO 591
      IF(AREA(ML).EQ.AREA(ML-1)) AREA(ML-1)=0.95*AREA(ML-1)
      GO TO 583
 587  IF(ML .LE.(N-1)) AREA(ML+1)=0.9*AREA(ML+1)
      AREA(ML)=0.95*AREA(ML-1)
      AREA(ML-1)=0.8*AREA(ML-1)
      GO TO 583
 589  IF(ML.LE.(N-1)) AREA(ML+1)=0.8*AREA(ML+1)
      AREA(ML)=0.9*AREA(ML-1)
      AREA(ML-1)=0.8*AREA(ML-1)
      GO TO 583
 591  AR=AREA(ML)
      AREA(ML)=AREA(ML-1)
      AREA(ML-1)=AR
 583  CONTINUE
 808  DO 791 J=2,N
      CAPAC(J)=(AREA(J)+AREA(J-1))*(STAGE(J)-STAGE(J-1))/2.0+CAPAC(J-1)
 791  CONTINUE
      DO 3001 IT=1,10
      IF(IT.EQ.9) GO TO 3021
      CAPC=ABS((CAPMAX-CAPAC(N)) )
      CAPCH =ABS((CAPMAX-CAPAC(N))*1.03)
      DEPO=ABS(DEPCAP)
      DEPOC=1.03*DEPO
      DEPI=CAPAC(N)-CAPNW(N)
      IF(CAPC.GT.DEPOC) GO TO 3002
      IF(CAPCH.LT.DEPO) GO TO 3002
      GO TO 3011
3002  NO=N-2.0
      DO 3004 IJ=1,NO
      ARA=0.998*AROLD(N-IJ)
      IF(AREA(N-IJ).LT.ARA) GO TO 3005
3004  CONTINUE
      GO TO 3003
3005  NE=IJ
      COR=(CAPAC(N)/CAPAC(N-IJ+1))
      DO 3007 IS=NE,NO
      AREA(N-IS)=AREA(N-IS)*(1.0-(DEPI*COR)/CAPMAX)
3007  CONTINUE
3003  CONTINUE
      MD=1.0
      DO 3008 J=2,N
      CAPAC(J)=(AREA(J)+AREA(J-1))*(STG1(J)-STG1(J-1))/2.0+CAPAC(J-1)
      IF(STAGE(J).EQ.0.0) CAPAC(J)=0.0
      IF(STAGE(J).EQ.0.0) MD=J
3008  CONTINUE
      DO 383 IL=1,N
      STAGE(MD-1+IL)=STG1(IL)
      IF(FILTER.EQ.2.0) GO TO 383
      IF(STAGE(IL).EQ.0.0) DISCH(IL)=0.0
      DISCH(MD-1+IL)=DISCHB(IL)
 383  CONTINUE
3001  CONTINUE
```

```
 3011 CONTINUE
      CAPAC(1)=0.0
      GO TO 3300
 3021 ERROR=CAPAC(N)-CAPNW(N)
      WRITE(6,3220)ERROR
 3220 FORMAT(//,15X,'THE BASIN CAPACITY IS IN ERROR BY',3X,F10.3,5X,'ACR
     1E-FT')
 3300 CONTINUE
  841 NE=NN-1
      TRAP=(100.0-SEDEND(NN-1))
      WRITE(6,870)
  870 FORMAT(1H1)
      WRITE(6,930)STP(M)
  930 FORMAT(///,15X,'VOLUME INFLOW',3X,'=',F10.2,5X,'ACRE-FT')
      WRITE(6,940)PEAKIN
  940 FORMAT(// ,15X,'PEAK INFLOW',5X,'=',F10.2,5X,'CFS')
      WRITE(6,960)PEAK
  960 FORMAT( //,15X,'PEAK DISCHARGE = ',F10.2,5X,'CFS')
      WRITE(6,5000)TRAP
 5000 FORMAT(// ,15X,'TRAP EFFICIENCY = ',F10.2,5X,'%')
      WRITE(6,850)
  850 FORMAT(// ,15X,'MP',8X,'M',9X,'N',10X,'NS',7X,'MS',7X)
      WRITE(6,860)MP,M,N,NS,MS
  860 FORMAT(//,7X,5I10)
      WRITE(6,650)
  650 FORMAT(//,15X,'NSTORM',4X,'CONSED',4X,'DEPOST',4X,'FLOW',6X,'TRP',
     17X,'FILTER',4X,'FIX')
      WRITE(6,660)NSTORM,CONSED,DEPOST,FLOW,TRP,FILTER,FIX
  660 FORMAT(//,9X,7F10.1)
      WRITE(6,670)
  670 FORMAT(// ,15X,'MASS',7X,'VISCOS',5X,'DELTAT',4X,'DELPLG',4X,'DENS
     1TY',6X,'SG')
      WRITE(6,680)MASS,VISCOS,DELTAT,DELPLG,DENSTY,SG
  680 FORMAT(//,9X,F10.1,3X,F10.5,4F10.2)
      WRITE(6,4700)(SIZE(I),I=1,NS)
 4700 FORMAT(///,15X,'SIZE (MM)',10F8.4)
      WRITE(6,4750)(PERCNT(I),I=1,NS)
 4750 FORMAT(/  ,15X,'% FINER',1X,10F8.1)
      IF(DEPOST.EQ.2.0.AND.MASS.NE.0.0) GO TO 4100
      IF(MASS.NE.0.0) GO TO 9000
      WRITE(6,4500)
 4500 FORMAT(////,15X,'STAGE',10X,'AREA',7X,'AVERAGE DEPTH',5X,'DISCHARGE
     1E',7X,'CAPACITY')
      WRITE(6,4505)
 4505 FORMAT(/,16X,'(FT)',9X,'(ACRES)',10X,'(FT)',10X,'(CFS)',9X,'(ACRES
     1-FT)')
      DO 550 IL=1,N
      WRITE(6,450)STG1(IL),AREAS(IL),AVDPTH(IL),DISCHB(IL),CAPAC(IL)
  450 FORMAT(/ ,10X,F10.4, 5X,F10.2,5X,F10.2,5X,F10.2,5X,F10.3,5X)
  550 CONTINUE
      WRITE(6,4000)
 4000 FORMAT(////,8X,'TIME',8X,'INFLOW',7X,'DISCHARGE',6X,'DETENTION TIM
     1E',3X,'STAGE',8X,'DEPTH',8X,'SEDIMENT')
      WRITE(6,5600)
 5600 FORMAT(/,8X,'(HRS)',8X,'(CFS)',9X,'(CFS)',11X,'(HRS)',9X,'(FT)',9X
     1,'(FT)',11X,'(%)')
      DO 600 LL=2,NE
      JM=(DELPLG/DELTAT)*(LL-1)
      WRITE(6,5500)PLGTME(LL),INFLOW(JM),DISCHA(JM),DETTME(LL),STAGO(LL)
     1,DEPTH(LL),SEDEND(LL)
 5500 FORMAT(/,5X,F7.2,6X,F7.2,8X,F7.2,8X,F7.2,7X,F7.2,7X,F7.2,7X,F7.2)
```

```
600    CONTINUE
       GO TO 4110
4100   WRITE(6,4800)
4800   FORMAT(//,6X, 'STAGE', 9X,'DEPTH',6X,'DESIGN AREA',5X,'NEW AREA',
      15X,'AVERAGE DEPTH',5X,'DISCHARGE',3X,'DESIGN CAPACITY',3X,'NEW CAP
      1ACITY')
       WRITE(6,4850)
4850   FORMAT(/, 6X,'(FT)',11X,'(FT)',9X,'(ACRES)',8X,'(ACRES)',10X,'(FT)',1
      1',11X,'(CFS)',7X,'(ACRE-FT)', 7X,'(ACRE-FT)')
       DO 7200 IL=1,N
       WRITE(6,6000) STG1(IL),STAGE(IL),AREAS(IL),AREA(IL),AVDPTH(IL),DIS
      1CH(IL),CAPCO(IL),CAPAC(IL)
6000   FORMAT(      F10.2,5X,F10.2,5X,F10.2,5X,F10.2,5X,F10.2,5X,F10.2,5
      1X,F10.2,5X,F10.2)
7200   CONTINUE
       WRITE(6,4020)
4020   FORMAT(/,3X,'TIME',8X,'INFLOW',7X,'DISCHARGE',5X,'DETENTION TIME',
      14X,'STAGE',8X,'DEPTH',8X,'SEDIMENT',8X,'INFLUENT',7X,'EFFLUENT')
       WRITE(6,5650)
5650   FORMAT(/,3X,'(HRS)',8X,'(CFS)',9X,'(CFS)',11X,'(HRS)',9X,'(FT)',10
      1X,'(FT)',10X,'(%)',11X,'(MG/L)',9X,'(MG/L)')
       DO 8000 LL=2,NE
       JM=(DELPLG/DELTAT)*(LL-1)
       WRITE(6,7000)PLGTME(LL),INFLOW(JM),DISCHA(JM),DETTME(LL),STAGO(LL)
      1,DEPTH(LL),SEDEND(LL),NFLNT(JM),EFLNT(LL)
7000   FORMAT(     F7.2,6X,F7.2,8X,F7.2,8X,F7.2,7X,F7.2,7X,F7.2,7X,F7.2,9
      1X,F8.1,8X,F7.1)
8000   CONTINUE
4110   CONTINUE
       GO TO 4755
9000   WRITE(6,9200)
9200   FORMAT(//,15X,'STAGE',10X,'AREA',7X,'AVERAGE DEPTH',5X,'DISCHARGE'
      1,7X,'CAPACITY')
       WRITE(6,4510)
4510   FORMAT(/,16X,'(FT)',9X,'(ACRES)',10X,'(FT)',10X,'(CFS)',9X,'(ACRES
      1-FT)')
       DO 7300 IL=1,N
       WRITE(6,405)STG1(IL),AREAS(IL),AVDPTH(IL),DISCHB(IL),CAPAC(IL)
405    FORMAT(/ ,10X,F10.4, 5X,F10.2,5X,F10.2,5X,F10.2,5X,F10.3,5X)
7300   CONTINUE
       WRITE(6,4005)
4005   FORMAT(/,3X,'TIME',8X,'INFLOW',7X,'DISCHARGE',5X,'DETENTION TIME',
      14X,'STAGE',8X,'DEPTH',8X,'SEDIMENT',8X,'INFLUENT',7X,'EFFLUENT')
       WRITE(6,5670)
5670   FORMAT(/,3X,'(HRS)',8X,'(CFS)',9X,'(CFS)',11X,'(HRS)',9X,'(FT)',10
      1X,'(FT)',10X,'(%)',11X,'(MG/L)',9X,'(MG/L)')
       DO 8550 LL=2,NE
       JM=(DELPLG/DELTAT)*(LL-1)
       WRITE(6,7500)PLGTME(LL),INFLOW(JM),DISCHA(JM),DETTME(LL),STAGO(LL)
      1,DEPTH(LL),SEDEND(LL),NFLNT(JM),EFLNT(LL)
7500   FORMAT(/,    F7.2,6X,F7.2,8X,F7.2,8X,F7.2,7X,F7.2,7X,F7.2,7X,F7.2,8
      1X,F8.1,8X,F7.1)
8550   CONTINUE
4755   CONTINUE
       GO TO 43
19     WRITE(6,4900)
4900   FORMAT(///,20X,' THE RESERVOIR CAPACITY HAS BEEN EXCEEDED ')
43     CONTINUE
999    CONTINUE
777    CONTINUE
875    FORMAT(1H1)
```

```
          WRITE(6,875)
          IF(TRP.GT.1.0) GO TO 420
          GO TO 410
    420   IF(TRAP.GT.TRP) GO TO 50
    410   CONTINUE
          STOP
          END

    $ENTRY
```

APPENDIX D

Example of the DEPOSITS Computer Output

The first and last storm event
in a six event cycle is shown

```
VOLUME INFLOW   =       6.73     ACRE-FT

PEAK INFLOW     =      97.82     CFS .

PEAK DISCHARGE =       11.16     CFS

TRAP EFFICIENCY =       74.47     %

HP         M          N           NS        MS

25         30         25          8        200

NSTORM    CONSED     DEPOST    FLOW      TRP        FILTER    FIX

 6.0        1.0        2.0       1.0       1.0        2.0       1.0

MASS        VISCOS      DELTAT     DELPLG     DENSTY      SG

50.0       0.01140      0.20       0.40       1.20       2.70

SIZE (MM)  0.0025  0.0050  0.0060  0.0100  0.0120  0.0170  0.0200  0.1000
% FINER      10.0    16.0    20.0    28.0    32.0    36.0    40.0    80.0
```

STAGE (FT)	DEPTH (FT)	DESIGN AREA (ACRES)	NEW AREA (ACRES)	AVERAGE DEPTH (FT)	DISCHARGE (CFS)	DESIGN CAPACITY (ACRE-FT)	NEW CAPACITY (ACRE-FT)
0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00
0.50	0.50	0.06	0.05	0.25	0.11	0.02	0.02
1.00	1.00	0.10	0.10	0.62	0.22	0.06	0.06
1.50	1.50	0.15	0.15	0.95	0.37	0.12	0.12
2.00	2.00	0.20	0.20	1.27	0.53	0.21	0.20
2.50	2.50	0.25	0.25	1.59	0.92	0.32	0.32
3.00	3.00	0.30	0.30	1.92	1.35	0.46	0.45
3.50	3.50	0.35	0.34	2.25	1.84	0.62	0.61
4.00	4.00	0.40	0.40	2.57	2.39	0.81	0.80
4.50	4.50	0.45	0.45	2.90	2.95	1.02	1.01
5.00	5.00	0.50	0.50	3.23	3.60	1.26	1.25
5.50	5.50	0.55	0.55	3.56	4.30	1.52	1.51
6.00	6.00	0.60	0.60	3.89	5.00	1.81	1.80
6.50	6.50	0.64	0.64	4.23	5.72	2.12	2.11
7.00	7.00	0.68	0.68	4.57	6.50	2.45	2.44
7.50	7.50	0.72	0.72	4.92	7.20	2.80	2.79
8.00	8.00	0.75	0.75	5.28	8.10	3.17	3.15
8.50	8.50	0.79	0.79	5.64	9.00	3.55	3.54
9.00	9.00	0.83	0.82	5.99	10.00	3.96	3.94
9.50	9.50	0.87	0.87	6.35	10.90	4.38	4.36
10.00	10.00	0.92	0.92	6.70	12.00	4.83	4.81
10.50	10.50	0.96	0.96	7.05	20.00	5.30	5.28
11.00	11.00	1.00	1.00	7.40	30.00	5.79	5.77
11.50	11.50	1.03	1.03	7.75	34.00	6.30	6.28
12.00	12.00	1.07	1.07	8.10	40.00	6.82	6.80

TIME (HRS)	INFLOW (CFS)	DISCHARGE (CFS)	DETENTION TIME (HRS)	STAGE (FT)	DEPTH (FT)	SEDIMENT (%)	INFLUENT (MG/L)	EFFLUENT (MG/L)
0.40	0.20	0.01	0.18	0.05	0.01	0.00	38.5	0.0
0.80	0.68	0.09	0.45	0.41	0.09	0.00	177.7	2.7
1.20	1.53	0.19	0.66	0.36	0.26	0.00	395.3	6.0
1.60	2.45	0.32	0.87	1.24	0.49	0.00	618.9	10.8
2.00	7.64	0.61	1.02	2.10	0.78	0.00	1684.8	21.9
2.40	97.62	4.17	0.92	5.41	1.53	0.03	18368.7	71.7
2.80	41.03	9.97	0.79	8.98	3.59	0.46	20092.0	495.0
3.20	14.89	10.95	0.98	9.52	5.05	2.47	5295.8	2054.1
3.60	12.53	11.16	1.30	9.62	5.61	4.58	3895.2	2106.2
4.00	8.85	11.09	1.63	9.58	5.93	6.69	2738.9	2113.6
4.40	8.20	10.90	1.97	9.50	6.09	9.63	2516.9	3001.5
4.80	5.85	10.71	2.33	9.40	6.17	12.40	2248.9	2883.1
5.20	4.27	10.36	2.68	9.20	6.20	14.98	1513.1	2776.6
5.60	0.96	9.85	3.04	8.93	6.21	17.34	686.9	2664.0
6.00	0.01	9.10	3.40	8.55	6.19	19.17	16.3	2237.9
6.40	0.00	8.42	3.75	8.18	6.12	20.47	0.0	1718.2
6.80	0.00	7.78	4.10	7.82	6.05	21.62	0.0	1646.8
7.20	0.00	7.18	4.46	7.48	5.96	22.65	0.0	1590.1
7.60	0.00	6.72	4.82	7.16	5.87	23.58	0.0	1539.4
8.00	0.00	6.25	5.16	6.84	5.77	23.96	0.0	680.6
8.40	0.00	5.78	5.48	6.54	5.66	24.31	0.0	662.1
8.80	0.00	5.35	5.80	6.25	5.55	24.57	0.0	547.5
9.20	0.00	4.96	6.10	5.97	5.43	24.73	0.0	363.8
9.60	0.00	4.57	6.39	5.69	5.31	24.86	0.0	317.3
10.00	0.00	4.21	6.67	5.44	5.19	24.97	0.0	279.3
10.40	0.00	3.86	6.95	5.18	5.07	25.06	0.0	253.6
10.80	0.00	3.53	7.24	4.95	4.95	25.13	0.0	240.5
11.20	0.00	3.22	7.53	4.71	4.83	25.19	0.0	200.6
11.60	0.00	2.94	7.81	4.50	4.71	25.24	0.0	184.6
12.00	0.00	2.70	8.10	4.28	4.60	25.28	0.0	158.8
12.40	0.00	2.47	8.39	4.07	4.48	25.31	0.0	150.5
12.80	0.00	2.25	8.68	3.88	4.37	25.34	0.0	144.5
13.20	0.00	2.05	8.98	3.69	4.26	25.37	0.0	138.2
13.60	0.00	1.86	9.29	3.52	4.16	25.39	0.0	134.0
14.00	0.00	1.68	9.61	3.34	4.05	25.41	0.0	132.7
14.40	0.00	1.52	9.93	3.17	3.96	25.43	0.0	131.7
14.80	0.00	1.35	10.27	3.03	3.87	25.44	0.0	128.5
15.20	0.00	1.24	10.61	2.88	3.78	25.46	0.0	119.0
15.60	0.00	1.12	10.95	2.73	3.69	25.47	0.0	106.0

```
VOLUME INFLOW   =      0.68     ACRE-FT

PEAK INFLOW     =     11.05     CFS

PEAK DISCHARGE =       1.20     CFS

TRAP EFFICIENCY =      81.48     %

MP         M          N          NS        MS

25         16         25         8        200

NSTORM     CONSED     DEPOST     FLOW      TRP       FILTER     FIX

 1.0        1.0        2.0        1.0       1.0        2.0        1.0

MASS        VISCOS      DELTAT    DELPLG    DENSTY      SG

50.0       0.01140      0.20       0.40      1.20       2.70

SIZE (MM)  0.0025  0.0050  0.0060  0.0100  0.0120  0.0170  0.0200  0.1000
% FINER     10.0    16.0    20.0    28.0    32.0    36.0    40.0    80.0
```

STAGE (FT)	DEPTH (FT)	DESIGN AREA (ACRES)	NEW AREA (ACRES)	AVERAGE DEPTH (FT)	DISCHARGE (CFS)	DESIGN CAPACITY (ACRE-FT)	NEW CAPACITY (ACRE-FT)
0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
0.50	0.00	0.06	0.04	0.00	0.00	0.02	0.00
1.00	0.50	0.10	0.04	0.50	0.11	0.06	0.02
1.50	1.00	0.15	0.09	0.73	0.22	0.12	0.05
2.00	1.50	0.20	0.18	1.02	0.37	0.21	0.12
2.50	2.00	0.25	0.20	1.40	0.53	0.32	0.21
3.00	2.50	0.30	0.27	1.74	0.92	0.46	0.33
3.50	3.00	0.35	0.32	2.07	1.35	0.62	0.48
4.00	3.50	0.40	0.35	2.42	1.84	0.81	0.65
4.50	4.00	0.45	0.44	2.75	2.39	1.02	0.85
5.00	4.50	0.50	0.49	3.07	2.95	1.26	1.08
5.50	5.00	0.55	0.54	3.39	3.60	1.52	1.34
6.00	5.50	0.60	0.59	3.72	4.30	1.81	1.62
6.50	6.00	0.64	0.62	4.06	5.00	2.12	1.92
7.00	6.50	0.68	0.67	4.41	5.72	2.45	2.25
7.50	7.00	0.72	0.70	4.77	6.50	2.80	2.59
8.00	7.50	0.75	0.74	5.13	7.20	3.17	2.95
8.50	8.00	0.79	0.76	5.50	8.10	3.55	3.32
9.00	8.50	0.83	0.77	5.88	9.00	3.96	3.71
9.50	9.00	0.87	0.84	6.26	10.00	4.38	4.11
10.00	9.50	0.92	0.92	6.61	10.90	4.83	4.55
10.50	10.00	0.96	0.96	6.95	12.00	5.30	5.02
11.00	10.50	1.00	1.00	7.29	20.00	5.79	5.51
11.50	11.00	1.03	1.03	7.63	30.00	6.30	6.02
12.00	11.50	1.07	1.07	7.98	34.00	6.82	6.54

TIME (HRS)	INFLOW (CFS)	DISCHARGE (CFS)	DETENTION TIME (HRS)	STAGE (FT)	DEPTH (FT)	SEDIMENT (%)	INFLUENT (MG/L)	EFFLUENT (MG/L)
0.40	11.05	0.37	0.19	1.49	0.51	0.79	252846.1	25513.8
0.80	3.40	0.85	0.56	2.41	1.16	2.52	137137.8	23184.3
1.20	2.43	1.03	0.92	2.63	1.45	4.47	73593.4	21213.1
1.60	1.77	1.13	1.27	2.75	1.62	6.48	59554.5	19861.3
2.00	1.60	1.18	1.62	2.80	1.73	8.48	47288.9	18904.6
2.40	1.10	1.20	1.96	2.82	1.79	10.41	38422.2	17896.4
2.80	0.84	1.18	2.31	2.80	1.83	12.22	27191.1	17155.9
3.20	0.20	1.13	2.65	2.74	1.86	13.89	13743.3	16499.7
3.60	0.00	1.03	2.99	2.63	1.87	15.02	0.0	12093.3
4.00	0.00	0.94	3.31	2.52	1.87	15.71	0.0	9208.1
4.40	0.00	0.85	3.64	2.41	1.86	16.31	0.0	7878.3
4.80	0.00	0.76	3.95	2.30	1.84	16.65	0.0	4893.8
5.20	0.00	0.68	4.25	2.20	1.82	16.94	0.0	4711.7
5.60	0.00	0.62	4.56	2.11	1.79	17.15	0.0	3841.0
6.00	0.00	0.55	4.86	2.03	1.76	17.33	0.0	3640.6
6.40	0.00	0.51	5.18	1.94	1.73	17.48	0.0	3350.1
6.80	0.00	0.48	5.49	1.86	1.70	17.62	0.0	3182.0
7.20	0.00	0.46	5.81	1.78	1.67	17.74	0.0	2934.3
7.60	0.00	0.43	6.13	1.70	1.64	17.84	0.0	2578.1
8.00	0.00	0.41	6.44	1.62	1.60	17.94	0.0	2509.6
8.40	0.00	0.39	6.75	1.55	1.57	18.01	0.0	2048.4
8.80	0.00	0.37	7.07	1.49	1.53	18.07	0.0	1993.6
9.20	0.00	0.34	7.38	1.41	1.50	18.13	0.0	1874.2
9.60	0.00	0.32	7.70	1.34	1.47	18.18	0.0	1809.5
10.00	0.00	0.30	8.02	1.27	1.43	18.23	0.0	1760.2
10.40	0.00	0.28	8.34	1.21	1.40	18.27	0.0	1686.3
10.80	0.00	0.27	8.67	1.15	1.37	18.31	0.0	1656.4
11.20	0.00	0.25	9.00	1.10	1.34	18.35	0.0	1526.0
11.60	0.00	0.23	9.33	1.05	1.31	18.38	0.0	1340.7
12.00	0.00	0.22	9.66	0.99	1.28	18.40	0.0	1315.5
12.40	0.00	0.20	10.00	0.91	1.26	18.42	0.0	1167.3
12.80	0.00	0.18	10.33	0.84	1.23	18.44	0.0	1024.5
13.20	0.00	0.17	10.66	0.77	1.20	18.46	0.0	1007.2
13.60	0.00	0.16	11.00	0.71	1.18	18.47	0.0	923.9
14.00	0.00	0.14	11.33	0.65	1.15	18.48	0.0	854.2
14.40	0.00	0.13	11.67	0.60	1.13	18.49	0.0	841.4
14.80	0.00	0.12	12.02	0.55	1.10	18.50	0.0	810.6
15.20	0.00	0.11	12.36	0.50	1.08	18.51	0.0	697.7
15.60	0.00	0.09	12.71	0.42	1.06	18.51	0.0	688.4
16.00	0.00	0.08	13.07	0.35	1.03	18.52	0.0	679.3
16.40	0.00	0.06	13.43	0.29	1.01	18.52	0.0	670.7
16.80	0.00	0.05	13.80	0.24	0.99	18.52	0.0	557.3
17.20	0.00	0.04	14.16	0.20	0.96	18.52	0.0	388.9
17.60	0.00	0.04	14.52	0.17	0.94	18.52	0.0	385.0

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