

**DESIGN MANUAL FOR SEDIMENTATION CONTROL
THROUGH SEDIMENTATION PONDS AND
OTHER PHYSICAL/CHEMICAL TREATMENT**

**U.S. Department of the Interior
Office of Surface Mining**

By

**Simons, Li & Associates, Inc.
4105 East Florida Avenue
Suite 300
Denver, Colorado 80222**

November 1982

LIST OF CONTENTS

EXECUTIVE SUMMARY

- I. INTRODUCTION
- II. PRELIMINARY CONSIDERATIONS FOR APPLICATION AND USE OF SEDIMENTATION PONDS FOR SURFACE MINING
- III. SEDIMENT REMOVAL THROUGH SEDIMENTATION PONDS
- IV. SEDIMENTATION POND MODIFICATIONS
- V. MAINTENANCE FOR WATER QUALITY CONTROL
- VI. DESIGN PROCEDURES AND EXAMPLE
- VII. REFERENCES

EXECUTIVE SUMMARY

This report is a design manual to guide the design engineer and/or operator in the design and maintenance of sedimentation ponds for the control of sediment from surface mine operations.

The first chapter is an introduction presenting the present status of sedimentation pond application. The primary concern is that sedimentation ponds have been previously designed based on storage volume and specific detention time requirements. However, many ponds designed according to these criteria did not meet regulatory effluent requirements. The design methodologies presented in this manual address the meeting of effluent quality criteria.

Before attempting the design of a sedimentation pond, it is important to have an understanding of the watershed characteristics affecting soil erosion, location of sediment sources associated with surface mining, and the various types of sedimentation ponds used. The major watershed characteristics affecting soil erosion are climatology, geology, soils, vegetation, topography and hydrology. There are four main sources of sediment associated with surface mining: (1) haul and access roads, (2) areas of active mining, (3) areas being cleared for mining activities, and (4) areas in process of reclamation. There are various types and combinations of sedimentation ponds of which a dam embankment located on or off the main drainage is most common. Chapter II gives a discussion of the preliminary design considerations to sedimentation pond design.

Chapter III presents the design methodologies for meeting effluent water quality regulations. Design for the removal of sediment is mainly based on ideal settling. For ideal settling the main criteria is particle size or particle size distribution. Selection of a design particle size to be removed should be done carefully and conservatively. Although, the pond design is based on ideal settling several aspects of sedimentation ponds cause variations from ideal settling resulting in reduced pond efficiency. The main causes of variation from ideal settling are short circuiting, flow currents, turbulence, and scour and resuspension of settled sediments. These causes have been identified in studies evaluating the performance of sedimentation ponds. Several publications have identified and recommended measures to

control the various conditions of nonideal settling. These control methods are related to various components of the pond, entrance to the pond, spillway outlet, and pond configuration. Along with these methods, proper maintenance of sediment storage volume, inlets, and outlets is mandatory to maintain proper operating conditions. Chapters IV and V present various modifications to pond components and proper maintenance measures.

Although several methods to improve pond performance have been recommended by others and presented in this manual, there is a significant lack of information on their proven ability to increase the removal efficiency of the pond. Thus, there is a definite need for further investigation and research to evaluate the various pond components and modifications, specifically on a comparative basis, to enable a quantitative comparison of different methods for selection during sedimentation pond design.

The final chapter of the manual presents one possible step-by-step procedure for the design of sedimentation ponds. It should not be considered as the only method available but rather used as a guide. Again, even following the steps presented, meeting effluent quality regulations is not guaranteed. However, following these methods will help reduce the effects of surface mining and sedimentation on the hydrologic balance of the particular watershed being considered.

TABLE OF CONTENTS
CHAPTER I

	<u>Page</u>
I. INTRODUCTION	
1.1 <u>The Purpose</u>	1.1
1.2 <u>Application of Sedimentation Ponds</u>	1.1
1.3 <u>Scope</u>	1.2
1.4 <u>Design Manual Use</u>	1.3

I. INTRODUCTION

1.1 The Purpose

The need for control of sediment eroded from areas disturbed by coal mining operations has been well documented. Presently, several erosion and sedimentation control measures are available to the operator. Of these various methods, sedimentation ponds have been the most widely used and are required by federal regulations. Sedimentation ponds are typically the last treatment measure applied before runoff leaves the permit area. Therefore, it is paramount that sedimentation ponds be designed, constructed, and maintained to provide sediment removal to meet regulatory effluent limitations and maintain the hydrologic balance.

Previously, federal and state regulations have required design of sedimentation ponds for two general criteria: (1) to provide a specific storage capacity based on the amount of disturbed area and (2) provide a required storage capacity to retain the runoff from a design precipitation event for a specified period of time. Recent studies have shown that the sedimentation ponds designed to meet the above criteria do not necessarily meet applicable effluent limitations. This inconsistency is addressed by the regulations currently published by the Office of Surface Mining (OSM), whereby sedimentation ponds are required to meet effluent limitations and the selection of sedimentation pond design criteria such as storage volume, pond geometry, and detention time is left to the design engineer. Thus, the design of sedimentation ponds should be based on the pond's ability to achieve specific effluent limitations.

1.2 Application of Sedimentation Ponds

As stated previously, sedimentation ponds are the last treatment measure applied before the runoff leaves the permit area. However, it should be understood that sedimentation ponds are not the only means of sediment and erosion control, but simply an integral part of an overall plan. The need for a complete sediment and erosion control plan before, during, and after mining operations based on sound engineering knowledge is necessary to minimize potential environmental damage from surface mining activities. Further, it is essential that the designer realize that the drainage basin in the permit area is only one part of a larger, more complex drainage system. The drainage

network in the permit area interacts with other parts of the larger drainage system in a complex fashion. Over time this complicated system has established a state of balance or quasi-equilibrium. The mining operation, or any other large-scale disturbance, will affect this balance or equilibrium and can result in dynamic responses through the system. The designer must recognize this situation in order to restore the disturbed topography and drainage to a condition where it will again properly function as part of the larger system.

Sedimentation ponds as referred to in this manual are used for the removal of sediment due to erosion from disturbed areas during the active mining phase and during the reclamation phase until adequate revegetation has been established. Sedimentation ponds are used in all OSM regions, with all types of mining methods, on natural drainageways and in conjunction with diversions. The major controlling factor in the application of sedimentation ponds is topography of the specific site. Although mining in steep sloped terrain is normally associated with eastern mines in the Appalachian Mountain range, limited mining is conducted on steep sloped terrain in the Rocky Mountain states. There are also rolling and flat terrain areas in southeastern parts of the United States. Therefore, techniques for application and design of sedimentation ponds cannot be specified by region, but are very dependent on the topography of the site being analyzed.

1.3 Scope

The procedures presented in this manual are based on a comprehensive literature review and assessment of the best technology currently available. Selection criteria for inclusion in the design manual for the range of design methodologies available included consideration of the physical environment of surface mine operations, current design procedures employed, the problems with existing sedimentation ponds, and the level of effort required to provide compliance with effluent limitations. Modeling methods for design of sedimentation ponds are considered state-of-the-art procedures. However, based on the capabilities and present procedures used by most operators, modeling is not included in the manual. In contrast, many of the simplified procedures, including some methods in common use, are presented in this manual.

This manual addresses all aspects of the pond that affect the removal of suspended solids including, but not limited to, type of mining, topography, location soil types, pond geometry, inlet and outlet control, and maintenance. No attempt is made to present information on structural design.

To help meet the needs of designers and operators, contacts were made with appropriate agencies in states where significant active mining operations occur. Further, contacts were made with operators to develop a background of their capabilities, problems in sedimentation pond performance, innovative techniques, and present design procedures. This information provided insight for development of a useable design manual.

1.4 Design Manual Use

The methodologies and considerations in design of sedimentation ponds have been presented to provide the designer or operator with an understanding of the processes involved to remove suspended solids and what effects these processes have. In Chapter II, preliminary considerations of watershed characteristics and sources of sediment are discussed. In Chapter III, computational methods for water routing and removal efficiency are presented along with a discussion on the characteristics of sediment removal to meet effluent limitations. This chapter contains the data requirements and the methodologies that are used to design a sedimentation pond. An important discussion in this chapter is that pertaining to sediment data, specifically the particle size distribution. The design of ponds to meet effluent limitations is greatly dependent on the particle size distribution. Therefore, great care should be taken to develop an accurate representative size distribution. Chapter IV presents modifications that can be made to improve the performance of the sedimentation pond. Chapter V deals with maintenance and sediment removal. Maintenance of sedimentation ponds cannot be emphasized enough. Lack of pond maintenance is one of the major problems in the performance of existing sedimentation ponds and the development of a maintenance program is a significant part of pond design. Chapter VI presents how these sections are interrelated in the design process.

To bring the information and methodology together, the final chapter presents the procedural steps for design along with a comprehensive design

example. Users of the design manual are encouraged to carefully review the example presented in Chapter VI to better understand the design methodology. With a little practice, the complete design process will become familiar and straightforward.

TABLE OF CONTENTS
CHAPTER II

	<u>Page</u>
II. PRELIMINARY CONSIDERATIONS FOR APPLICATION AND USE OF SEDIMENTATION PONDS FOR SURFACE MINING	
2.1 <u>Office of Surface Mining Regulations and Environmental Protection Agency Water Quality Standards</u>	2.1
2.2 <u>Watershed Characteristics</u>	2.2
2.2.1 Climatology	2.2
2.2.2 Geology	2.3
2.2.3 Soils	2.3
2.2.4 Vegetation	2.4
2.2.5 Topography	2.4
2.2.6 Hydrology	2.6
2.3 <u>Location of Major Sources of Sediment</u>	2.6
2.3.1 Haul and Access Roads	2.7
2.3.2 Areas of Active Mining	2.7
2.3.3 Areas Being Cleared for Mining Activities	2.8
2.3.4 Areas in Process of Reclamation	2.8
2.4 <u>Types and Applications of Sedimentation Ponds</u>	2.9
2.4.1 Excavated Sedimentation Ponds	2.9
2.4.2 Embankment and Combination Embankment/ Excavated Sedimentation Ponds	2.10
2.4.3 Sedimentation Pond Spillway Type	2.11
2.4.4 Multiple Pond Systems	2.12
2.4.5 Physical/Chemical Treatment Ponds	2.12
2.4.6 Dry Basin versus Permanent Pool	2.13
2.5 <u>Summary of Preliminary Considerations</u>	2.14

LIST OF FIGURES
CHAPTER II

	<u>Page</u>
Figure 2.1. Example of rill and gully erosion	2.5

II. PRELIMINARY CONSIDERATIONS FOR APPLICATION AND USE OF SEDIMENTATION PONDS FOR SURFACE MINING

2.1 Office of Surface Mining Regulations and Environmental Protection Agency Water Quality Standards

Design criteria for sedimentation ponds are established through federal and state regulations. OSM sedimentation pond design criteria are intended to prevent, to the extent possible, additional contributions of suspended solids to stream flow or runoff outside the permit area and to achieve applicable federal and state water quality standards. These minimum water quality standards include effluent limitation guidelines for coal mining point sources established by the Environmental Protection Agency (EPA). Therefore, the requirements of the EPA are directly tied to the performance standards for the design criteria of sedimentation ponds.

OSM considers sedimentation ponds in conjunction with alternative control measures as the best practical technology (BPT) currently available, as established by the EPA, for the control of sediment. A sedimentation pond is specifically defined by OSM to include any barrier, dam, or excavated depression which slows water runoff allowing sediment to settle.

OSM sedimentation pond design criteria must enable compliance with the effluent limitations, water quality standards, and the safety requirements of state and federal governments. The determination of sedimentation pond design criteria is left up to the operators and the registered professional engineers designing the ponds and reviewed by the regulatory authorities.

Currently, the requirements of the EPA effluent limitations are the result of the Federal Water Pollution Control Act Amendments of 1972. In summary, point source water discharges are required to meet effluent limitations requiring the application BPT currently available by July 1, 1977, and best available technology (BAT) economically achievable by July 1, 1983. The Clean Water Act of 1977 revised the control program for nontoxic pollutants. For detailed discussion of applicable effluent limitations, see Section 3.3. Suggested design criteria for sedimentation ponds are based on the current effluent limits found in many states. Exact requirements for each agency vary; however, the state agency requirements must be taken into account by the design engineer.

2.2 Watershed Characteristics

The location, design, construction, and methods of treatment used in sedimentation ponds are dependent on the characteristics of the watershed where mining activity takes place. Preliminary consideration for the climatology, geology, soils, vegetation, topography, and hydrology of the watershed will help facilitate the design of efficient sedimentation ponds that meet water quality standards and regulations. These characteristics do vary on a watershed-by-watershed basis; proper consideration of this must be made in order to design sedimentation ponds properly.

2.2.1 Climatology

Climatological elements in sedimentation pond design include temperature and precipitation. In general, temperature can affect the amount of runoff to be treated as well as how effectively it is treated in a pond. Variation in ambient temperature changes the viscosity of water which changes the settling velocity of sediment particles. Consequently, the detention time required to settle out a waterborne particle of a given size changes. Ambient temperature also influences the magnitude and seasonal distribution of runoff. Precipitation in the form of snow causes little or no erosion. However, snow melting in the Spring on partially frozen ground is a source for higher rates of runoff and erosion. If low temperatures exist for a significant period of time, ice formations in sedimentation ponds may be a problem. If not taken into consideration in pond design, ice formations may cause failure of embankments or damage energy dissipators such as baffles or riprap. Low temperatures for a significant period of time may disrupt, damage, or halt chemical treatment processes that may be used as part of water treatment in sedimentation ponds.

Precipitation is the most important element of climate in determining the rate of erosion. The magnitude of annual precipitation, in addition to the frequency, intensity, duration, and seasonal distribution of precipitation events affect the magnitude of runoff and erosion. Precipitation characteristics also effect the type of outlet and operation of a sedimentation pond. For example, gated outlets are normally used to store all of the runoff from an event. The gates are opened to discharge the runoff after sediments have sufficiently settled to meet water quality standards. This would be

difficult to design for a pond on a watershed in the eastern region of the United States where annual precipitation is much greater and precipitation events that occur are characteristically of a longer duration, lower intensity, and more frequent. Gated outlets are much more suitable for ponds in the western region where annual precipitation and water yield are much lower and precipitation events are of high intensity but for a relatively short duration.

Seasonal distribution of precipitation results in a seasonal distribution of annual erosion potential. The erosion potential is greater during the high precipitation period such as Spring than it is during Winter. This is important in estimating the yield and concentration of sediment in the runoff. For further consideration of seasonal erosion potential refer to "Surface Water Hydrology and Sedimentology Manual" (OSM, 1982).

2.2.2 Geology

The geology of a watershed interacts somewhat with all hydrologic characteristics of the watershed. The geology has a significant effect on the topography. Topography is a major consideration in the location and shape of a sedimentation pond.

An important consideration of the geology is to evaluate the different types of overburden material that will be exposed during the mining process. Overburden erosion characteristics should be considered when estimating sediment yields and runoff concentrations.

2.2.3 Soils

Watershed soil characteristics depend to a large extent on the parent geologic materials and the predominant weathering processes. These soil characteristics of the watershed determine runoff and erosion from the watershed. The magnitude of runoff and erosion is a function of soil infiltration, soil permeability, moisture content, structure, texture, and content of organic matter.

The sediment size distribution of the runoff is the main design criteria in sizing a sedimentation pond. As the size of particle to be removed becomes smaller the size of a sediment pond required becomes larger. Often times, the size of pond is impractical and chemical treatment may be necessary to remove

the fine particles and alleviate the high cost of constructing a very large pond.

2.2.4 Vegetation

Vegetation plays an important role in the water balance and soil stability in a watershed. Through interception, transpiration, and evaporative processes, vegetation can substantially reduce water yield from a watershed. Vegetation plays an important part in protecting the soil from erosion. Vegetation can reduce the amount of erosion through: interception, reduced rainfall intensities by providing an energy-absorbing cover, reduced landslide hazards through binding and lowering soil water content, and reduced overland and channel erosion by providing added roughness which retards water velocity. Removal of vegetation exposes underlying soils to greatly increased erosive forces. Thus, one of the more critical periods during the mining process is when reclaimed area soils have not developed significant vegetation.

2.2.5 Topography

Topography, including land and channel slopes, aspect, and surface and channel geometry, is an expression of the morphological, geologic, and other erosive forces that have acted on the watershed. In turn, these factors are modified by the topography they have created. For example, channel slope governs water discharge rate and sediment transport rate. Conversely, the discharge rate and the sediment transport can alter the channel form to produce a new slope. Channel and surface geometry affect the depth and velocity of water flow, thus altering sediment transport. Primary topographic considerations in controlling erosion are slope and length of slope. An increase in slope increases the transport capacity of surface runoff, thus increasing erosion. An increase in length of slope allows for concentration of sheet flow. This concentration of sheet flow forms rills and gullies by erosion (see Figure 2.1).

The watershed shape or geometry can also be considered part of watershed topography. The geometry of the watershed determines the amount of area of the watershed where flow concentrates and the time required for flow concentration.

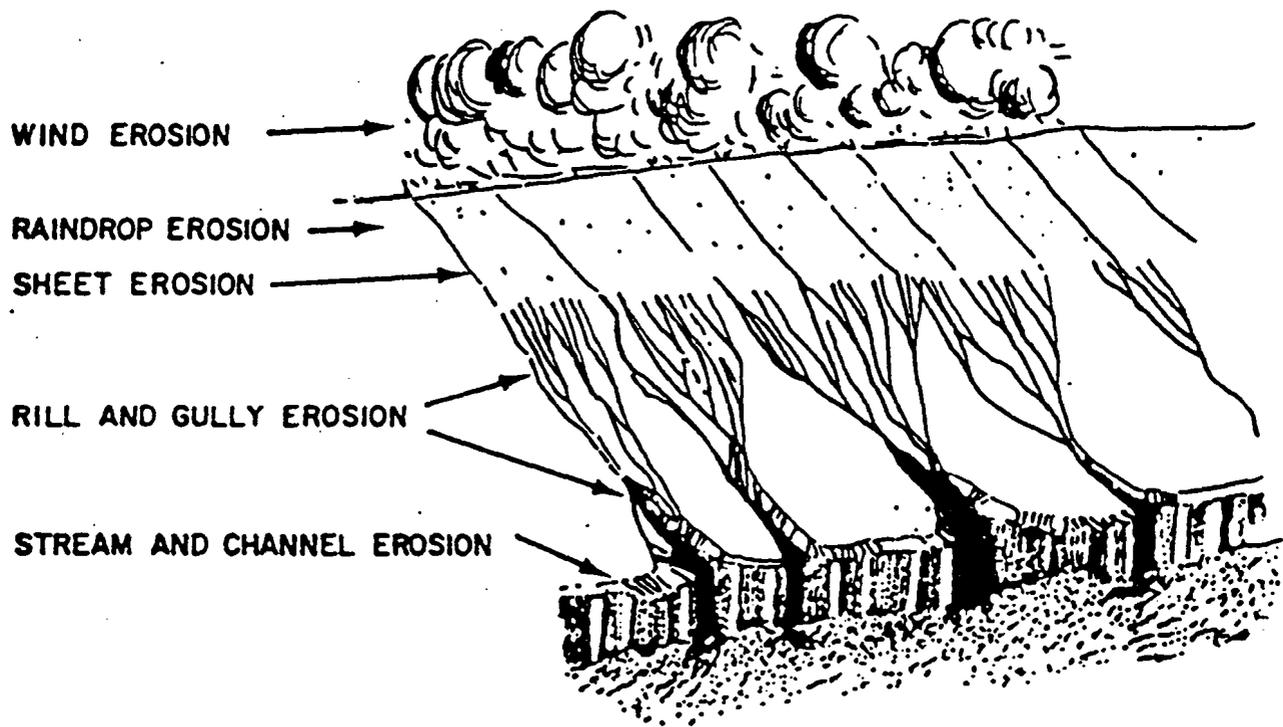


FIGURE 2.1 EXAMPLE OF RILL AND GULLY EROSION (SCS, 1980)

Many times topography controls the location of a sedimentation pond or the type of pond that is constructed. Regulations state that sedimentation ponds should be located as close to the source of sediment as possible. Normally the only factor that limits locating a pond is steep terrain; ponds are usually constructed in valleys or hollows a short distance downstream to facilitate construction.

2.2.6 Hydrology

Runoff that reaches a sedimentation pond is the result of complex interaction of all the previously discussed watershed characteristics; climatology, geology, soils, vegetation, and topography interact to make up the hydrologic process that includes runoff from a precipitation event. Climate includes the intensity, frequency, duration, distribution of precipitation events, and how that precipitation occurs, either in the form of snow or rain depending on temperature. Vegetative cover intercepts a fraction of this precipitation by evapotranspiration. The existence and degree of vegetative cover increases with favorable climate and soil conditions. Of the remaining fraction of precipitation, soil conditions determine what fraction will infiltrate and what fraction will become surface runoff. The remaining fraction that becomes surface runoff will concentrate in a watershed according to the geologic and topographic features of the watershed. In this manner the interaction of watershed characteristics governs the magnitude and distribution of runoff from precipitation and the sediment yield. Consequently, the quality of runoff from the disturbed area is affected by the dynamic equilibrium of the watershed.

2.3 Location of Major Sources of Sediment

There are four categories for sources of sediment from surface mining activities in a watershed. These are the unmined portion of the watershed, the mined or mining portion of the watershed, spoil banks or areas where spoil is stockpiled, and haul or access roads necessary for mining activities. Of these four categories, the unmined portion of the watershed generally yields the least amount of sediment and is not considered a major source of sediment yield. The remaining three categories are a direct consequence of mining operations. Of these three, haul or access roads and spoil banks commonly

generate the greatest sediment yield per unit area. For example, a study done on a monitored watershed in Appalachia (EPA, 1976) gave the following comparison for rates of erosion:

Area	Yield (tons/square mile)
Unmined watershed	28
Mined watershed	1,930
Spoil bank	27,000
Haul road	57,600

However, due to the much larger percentage of the total watershed covered by the mined or mining portion of the watershed, these areas generally yield the most sediment.

2.3.1 Haul and Access Roads

Both haul roads and access roads to mine sites constitute a major source of sediment. In addition, roadways generally remain as a main source throughout the life of the mine. Roadways yield larger amounts of sediment due to an increased rate of runoff resulting from a relatively impermeable surface, and steep cut or fill slopes associated with roadways. Roads intercept sheet runoff and act as a transport mechanism via roadside ditches. Roadways occasionally require clearing and steepening of side slopes which increase slope erosion. Other factors which contribute to a greater sediment yield from roadways include:

- Poor location of roads.
- Improper construction/maintenance of roads and side slopes.
- Improper planning/construction of road drainage systems.

2.3.2 Areas of Active Mining

The nature and extent of sediment yield from areas of active mining are dependent on the mining method or procedure utilized. Four common methods of surface mining are: area mining, contour mining, boxcut mining, and mountain

top removal. In general, area mining is a lesser source of sediment than contour mining due to containment of runoff on disturbed areas. Contour mines have a long, narrow geometry with more spoil and bench area potentiality, draining off the disturbed area directly into an off-site drainage system. In addition, the receiving waters are generally closer to the mining operations for contour mining than for area mining.

Boxcut mining is a form of contour mining used in steeper terrain that reduces spoil dumped downhill by moving it laterally along the boxcut and placing it in areas where coal has been removed. This facilitates maintaining the original grade of the hill. Boxcut mining falls somewhere between area and contour mining as a source of sediment.

Mountain top removal is another form of contour mining used when the economics of overburden removal and coal seam thickness facilitate removing the entire hilltop. Mountain top removal is also considered a lesser source of sediment than contour mining. This is due to the regional nature of, and the reduction in, relief due to mountain top removal. This generalization is true only if the surface drainage is controlled internally.

The mining methods could be ranked from the largest contributor of sediment to the least as contour mining, boxcut mining, mountain top removal, and area mining. This is an over generalization since the sediment yield from a mined area is site specific and is dependent on the amount of on-site erosion control measures that are taken.

2.3.3 Areas Being Cleared for Mining Activities

The areas being cleared and grubbed as pretreatment for surface mining activities are one of the major sources of sediment yield. Clearing and grubbing expose soil on steep slopes and can create a soil surface that impedes infiltration and/or concentrates runoff. Other factors that increase sediment yield are: failure to install perimeter control measures, overclearing or clearing too far ahead of the pit exposing the area for a longer period, and improper placement of the salvaged topsoil.

2.3.4 Areas in Process of Reclamation

This last major source occurs from the start of grading operations and lasts until stabilization of the soil occurs by vegetative and/or structural

measures. Other factors in the reclamation process that can increase sediment yield include constructing excessively steep, long slopes or structurally unstable drainage channels. Also, improper tillage practices, plant material selection, seedbed preparation, and maintenance can increase sediment yield from reclamation areas. The potential for erosion is greater just after reclamation than at any other time during mining operations; therefore, reclamation practices such as tilling, mulching, and revegetation are very important in the control of erosion.

2.4 Types and Applications of Sedimentation Ponds

Sedimentation ponds can be an effective way to control sediment from leaving the mine permit area. On-site erosion protection measures can be taken to reduce the sediment yield from the mine site, but such measures rarely control the sediment to the extent that effluent requirements can be met. Sedimentation ponds are typically the last sediment control measure that an operator uses before the runoff leaves the mine permit area and enters natural drainageways downstream. Improper control of the sediment leaving the mine permit area may cause severe off-site damages.

Sedimentation ponds are generally constructed with embankments, by excavation, or a combination of both. The sedimentation ponds presented in the following sections categorize the types of ponds that are currently used by the mining industry. However, several combinations of the various types ~~due~~ exist and may be used in the sediment control plan. There are many factors which must be considered at each site to determine which basic type of sedimentation pond, or variation, will provide the maximum control of sediment. The following sections give a description of the various types of sedimentation ponds and where their application is most practical.

2.4.1 Excavated Sedimentation Pond

Excavated sedimentation ponds are constructed by excavating a pit or "hole" in the ground with the use of a bulldozer or backhoe. Generally, these types of sedimentation ponds are limited to contain surface runoff from disturbed areas at surface mines located in rolling to flat terrain and from small drainage areas. Sedimentation ponds which are constructed strictly by excavation are not used in steep sloped terrain due to the large amount of

excavation that would be required to achieve the applicable storage volume requirements. These types of ponds are generally located off a natural drainageway.

The excavated sedimentation pond has been used in conjunction with the mine pit which serves as a preliminary settling basin. The runoff from disturbed areas within the mine site is directed into the mine pit where settling of the larger size particles occurs. From the pit, the mine drainage is pumped into the excavated sedimentation pond where final settling occurs. Using pumps to control the inflow into the excavated sedimentation pond allows control of the detention time within the sedimentation pond. Additionally, the storage volume within the pit can be utilized, thereby reducing the sedimentation pond storage requirements as long as the storage volume within the mine pit does not interfere with mining operations.

There are many disadvantages with the excavated sedimentation pond. It is limited to applications in relatively flat terrain and controlling surface runoff from small drainage areas. Installation of dewatering devices in these types of ponds is generally very expensive and therefore, they are rarely installed. This leads to the pond storing water for a long period of time thus reducing the available storage volume when a storm event occurs. The result of this will be decreased detention times and therefore, decreased effluent quality. In addition, it is difficult to provide separate principal and emergency spillways. For these reasons, applications of the excavated sedimentation pond are very limited.

2.4.2 Embankment and Combination Embankment/Excavated Sedimentation Ponds

An embankment sedimentation pond can be used in any type of terrain. Generally, these types of ponds are located on a drainageway. An embankment is constructed across the drainageway to form the sedimentation pond. When the drainageway bed is excavated upstream of the embankment, a combination embankment/excavated sedimentation pond is formed. Excavation upstream of the embankment provides additional storage volume capacity to an embankment sedimentation pond.

A variety of outlets may be used with the embankment and combination embankment/excavated sedimentation pond. The most common method is to use a pipe outlet for the principal spillway and a channel cut into the top of the embankment as the emergency spillway. Although, several other types of outlets are used and are presented in Section 3.9.

As previously mentioned, embankment sedimentation ponds are generally constructed on drainageways. The topography often dictates that this type of pond be constructed. However, this type of pond has some disadvantages. There is a possibility of embankment failure due to poor construction or the use of poor construction materials. Bank sloughing may occur that can decrease the sediment removal efficiency of the pond by adding sediment to the pond. Bank sloughing reduces the storage volume capacity and therefore, increases the maintenance requirements. The shape of the embankment sedimentation pond is generally controlled by topography.

The combination embankment/excavated sedimentation pond has the advantage of providing additional storage volume without increasing the height or size of the embankment. However, exposure of the side slopes due to upstream excavation may require that the slopes be stabilized.

2.4.3 Sedimentation Pond Spillway Type

Sedimentation ponds have often been classified according to the type of principal and emergency spillway used. OSM regulations require that a combination of principal and emergency spillways be provided to safely pass the runoff from a 25-year, 24-hour precipitation event or larger event specified by the regulatory authority. In addition, the elevation of the crest of the emergency spillway shall be at least one foot above the crest of the principal spillway. Therefore, separate outlets must be provided for the principal and emergency spillways.

Principal spillways are usually constructed by using some type of pipe outlet. Emergency spillways are generally constructed by excavating an exit channel through the embankment or natural ground. Other types of outlets may be used for the emergency spillway but due to the costs involved, the excavated exit channel is the most feasible. A complete discussion of spillways is presented in Section 3.9.

2.4.4 Multiple Pond Systems

A multiple pond system is considered to be the use of two or more sedimentation ponds in a series (one downstream of the other). The concept of multiple ponds is also accomplished through compartmentalization of a single pond. The concept of multiple ponds is the occurrence of staged settling. Solids with higher settling velocities will settle in the first pond or compartment and the finer sediments will be settled in the final pond or compartment. One particular advantage to this type of system is that most of the maintenance (i.e., sediment removal) is limited to the first settling pond or compartment. Also, field applications have shown that multiple sediment ponds in a series are more efficient in removing finer particles than a single pond of equal surface area. One disadvantage in the use of multiple ponds is that more area is disturbed due to the construction of additional ponds. A detailed discussion on the application and design of multiple pond systems is given in Section 4.3.

2.4.5 Physical/Chemical Treatment Ponds

Physical/chemical treatment identifies the process of adding chemicals to enhance the physical settling characteristics of the sediment particles to be removed by gravity settling. The chemicals added are generally referred to as coagulants or flocculant aids. Chemicals are added to the influent of the sedimentation pond, where proper mixing must occur, and then the sediment is flocculated and settled in the pond. Coal fines may not be flocculated when chemicals are added due to the electrical nature of the coal fines. Other treatment measures may be required to remove the coal fines.

Physical/chemical treatment is a standard practice in the treatment of water for domestic use. More recently it has been applied in the mining industry for the removal of sediment to meet effluent limitations. To meet the existing and proposed effluent limitations will sometimes require removal of very fine clay and silt sediments. The volume and surface area of a sedimentation pond required for removal of very fine sediments are unreasonably large. Therefore, physical/chemical treatment measures are required for removal of fine sediments.

Physical/chemical treatment measures have been used in the field in conjunction with multiple ponds in a series. In this type of application, the

large sediment is settled in the first pond, reducing the sediment load to the second pond where it is only used for settling of the finer sediments. The chemical dose required for settling is generally directly related to the concentration of solids. Therefore, by reducing the solids concentration in the first pond, the amount of chemical required is reduced below the amount that would be required using only one sedimentation pond. Detailed discussion on the actual physical/chemical treatment process and types of coagulants is given in Section 4.3.

Some disadvantages do exist in the application of physical/chemical treatment. The use of chemicals in settling solids adds to the volume of material settled in the sedimentation pond; therefore, consideration must be given to sediment storage volume and/or frequency of maintenance. Another consideration is final disposal of the settled sediment. It should be realized that the sediment contains the chemicals used for coagulation. The type and/or difficulty of final disposal will depend on the type of coagulation chemicals and flocculant aids used.

2.4.6 Dry Basin versus Permanent Pool

The dry basin is characterized as a basin which has a dewatering device such that the sedimentation pond does not store the water runoff from any one precipitation event indefinitely. Examples of dewatering devices include trickle tubes and perforated riser pipe outlets that dewater to the sediment storage level in the pond.

Dry basins may be located either on or off drainageways. For dry basin ponds, the dewatering device is designed to dewater the sediment pond at a rate which achieves and maintains the required detention time to achieve applicable effluent limitations. Between precipitation events this type of pond is either dewatering or dry.

The permanent pool sedimentation pond is designed to provide a permanent storage volume of water after the principal spillway has stopped discharging. The maximum permanent pool elevation is the elevation of the principal spillway crest. These types of ponds are often located on small drainageways and perennial streams when approval of the regulating authority is given. Permanent pool sedimentation ponds can also be located off drainageways.

The main difference between dry basins and permanent pool basins is that the permanent pool provides a constant storage volume for water while the dry basin does not. The advantages of the permanent pool basin are that it provides a water supply for dust control on haul and access roads during dry periods and the permanent pool helps minimize resuspension of sediment that has already settled. The disadvantage of the permanent pool basin is that it needs to be designed for the additional permanent storage volume of water.

The advantage of the dry basin pond is that it does not have to be designed for an additional storage volume and therefore, the entire storage volume of the basin can be utilized during large runoff events. The disadvantage of dry basins is that resuspension of the settled sediment may occur if control measures at the inlet are not taken.

2.5 Summary of Preliminary Considerations

Preliminary consideration for the application and use of a sedimentation pond in a surface mining operation is based on the pertinent regulations and standards that outline the level of performance required. With a working knowledge of the watershed characteristics, sediment transport mechanisms, and major sediment source locations, the type of sedimentation pond and its application can be chosen and designed to facilitate meeting regulations and standards for pond performance.

The criteria for design of sedimentation ponds is established federally through regulations by the Office of Surface Mining, Environmental Protection Agency, and the Mine Safety and Health Administration (MSHA). OSM design criteria are intended to prevent, to the extent possible, additional contributions of suspended solids outside of the permit area and achieve water quality standards. Sedimentation ponds are also required to meet inspection and large dam criteria of the MSHA (30 CFR 77.216) and requirements of state and local agencies with jurisdiction over the design, construction, or discharge of sedimentation ponds.

The climate, geology, soils, vegetation, topography, and resultant hydrology of a watershed affect the magnitude and rate of erosion and sediment transport that must be treated by a sedimentation pond. Climatological factors include the seasonal variation and range of temperature and the magnitude, intensity, frequency, duration, and seasonal distribution of

precipitation. Geological processes creating long- and short-term land surface adjustments affect watershed climate and hydrology. Erosion-resistant rocks, large-scale erosive forces, and bed structure dictate the general topography. Thus, the geology of a watershed is important because it affects all of the other watershed characteristics.

The magnitude of runoff and erosion is a function of soil permeability, moisture content, structure, texture, and content of organic matter. The amount of vegetative cover, which is a function of climate and soil characteristics, affects the stability of the soil and water yield from a watershed. Primary factors of topography are the length and steepness of slopes and the geometry of the watershed. The complex interaction of all these watershed characteristics determines the magnitude and distribution of runoff from a precipitation event, which is the element of the hydrologic process of concern.

There are four categories of sediment sources from surface mining activities in a watershed. These are the unmined portion of the watershed, the mined or mining portion of the watershed, spoil banks or areas where spoil is stockpiled, and haul or access roads necessary for mining activities. Of these four categories, the unmined portion of the watershed generally yields the least amount of sediment and is not considered a major source of sediment yield. The remaining three categories are a direct consequence of mining operations.

The type of pond can be classified into one of three general categories: excavated ponds; embankment ponds; and combination excavated/embankment ponds. The major factor in the selection of the type of pond is the topography of the proposed site.

When conditions for treatment of runoff from the disturbed area warrant, chemical treatment systems or multiple pond configurations are used. Normally, chemical treatment systems are utilized when high concentrations of colloidal size particles are present in runoff from the disturbed area and gravity-settling methods are not sufficient. Multiple ponds are normally used when the cost of constructing a single pond is high because of topographic constraints, or the gravity-settling method of treatment in a single pond is not sufficient to meet effluent limitations.

With sufficient knowledge of the preliminary considerations discussed previously, the type and application of a sedimentation pond which will be effective in sediment control can be selected.

TABLE OF CONTENTS
CHAPTER III

	<u>Page</u>
III. SEDIMENT REMOVAL THROUGH SEDIMENTATION PONDS	
3.1 <u>Site Selection</u>	3.1
3.1.1 General Considerations	3.1
3.1.2 Topography Considerations	3.2
3.1.2.1 <u>Steep Sloped Terrain</u>	3.2
3.1.2.2 <u>Mild Sloped Terrain</u>	3.3
3.1.3 Sedimentation Ponds Located on Main Drainageways	3.4
3.1.4 Sedimentation Ponds Located off Main Drainageways	3.4
3.1.5 Source of Sediment	3.5
3.1.6 Accessibility	3.5
3.1.7 Mining Considerations	3.6
3.1.8 Field Investigation	3.6
3.2 <u>Data Requirements</u>	3.8
3.2.1 Hydrology	3.8
3.2.2 Sediment Data	3.8
3.2.2.1 <u>Influent Sediment Size Distribution</u>	3.9
3.2.2.3 <u>Sediment Yield</u>	3.12
3.2.3 Inflow Suspended Solids Concentration	3.12
3.3 <u>Effluent Limitations</u>	3.13
3.3.1 Suspended Solids Limitation	3.13
3.3.2 Settleable Solids Limitation	3.13
3.4 <u>Trapping Efficiency</u>	3.16
3.5 <u>Settleable Solids Concentration</u>	3.20
3.6 <u>Storage Volume Requirement</u>	3.29
3.7 <u>Available Storage Volume</u>	3.30
3.8 <u>Sedimentation Pond Configuration</u>	3.36
3.8.1 Ideal Settling	3.36
3.8.2 Nonideal Settling	3.39
3.8.2.1 <u>Flow Currents</u>	3.39
3.8.2.2 <u>Delta Formation</u>	3.40

TABLE OF CONTENTS (continued)
CHAPTER III

	<u>Page</u>
3.8.2.3 <u>Short Circuiting and Turbulence</u>	3.40
3.8.2.4 <u>Scour and Resuspension</u>	3.40
3.8.3 Control of Nonideal Settling	3.40
3.8.3.1 <u>Short-Circuiting Factor</u>	3.43
3.8.3.2 <u>Length-to-Width Ratio</u>	3.43
3.8.3.3 <u>Permissible Inlet Velocity</u>	3.44
3.8.3.4 <u>Permissible Flow-Through Velocity</u>	3.44
3.9 <u>Sedimentation Pond Outlet Control Measures</u>	3.46
3.9.1 Principal Spillways	3.46
3.9.1.1 <u>Open Channel Spillways</u>	3.46
3.9.1.2 <u>Drop Inlet Spillways</u>	3.47
3.9.1.3 <u>Pipe Culvert Spillways</u>	3.47
3.9.1.4 <u>Efficiency of Principal Spillways</u>	3.50
3.9.2 Dewatering Devices	3.50
3.9.3 Principal Spillway Modifications	3.54
3.9.3.1 <u>Weir Troughs</u>	3.56
3.9.3.2 <u>Floating Discharge</u>	3.56
3.9.3.3 <u>Filtering</u>	3.58
3.9.3.4 <u>Gated Spillways</u>	3.58
3.9.3.5 <u>Anti-Vortex Devices</u>	3.60
3.9.4 Emergency Spillways	3.60
3.9.5 Erosion Control Below Spillways	3.65
3.9.5.1 <u>General</u>	3.65
3.9.5.2 <u>Riprap</u>	3.66
3.10 <u>Summary</u>	3.67

LIST OF TABLES
CHAPTER III

	<u>Page</u>
Table 3.1 Suggested Particle Size Distribution for Soil Textural Class	3.11
Table 3.2 Development of Settleable Solids Size Distribution	3.24
Table 3.3 Size Distribution for Particles Smaller than 0.011 mm	3.29
Table 3.4 Stage-Storage Relationship Development	3.36
Table 3.5 Permissible Velocities for Vegetated Spillways	3.63
Table 3.6 Permissible Spillway Velocities after Aging	3.64

LIST OF FIGURES
CHAPTER III

		<u>Page</u>
Figure 3.1	Imhoff cone test apparatus	3.15
Figure 3.2	Required trapping efficiency to meet various effluent limitations	3.18
Figure 3.3	Definition of trapping efficiency for various particle sizes	3.19
Figure 3.4	Influent sediment size distribution	3.21
Figure 3.5	Settleable solids size distribution	3.24
Figure 3.6	Definition of percentage intervals	3.27
Figure 3.7	Water routing curve, S/V versus T_b	3.31
Figure 3.8	Water routing curve, Q_I/Q_O versus T_b	3.32
Figure 3.9	Definition sketch to determine incremental storage volume	3.33
Figure 3.10	Particle size versus detention time for various depths	3.38
Figure 3.11	Schematic of delta formation	3.41
Figure 3.12	Sedimentation ponds with dead storage spaces	3.42
Figure 3.13	Typical drop inlet spillway	3.48
Figure 3.14	Typical pipe culvert spillway	3.49
Figure 3.15	Subsurface drain	3.52
Figure 3.16	Single perforation of riser barrel	3.53
Figure 3.17	Siphon dewatering methods	3.55
Figure 3.18	Weir trough	3.57
Figure 3.19	Floating weir	3.59
Figure 3.20	Anti-vortex device	3.61

III. SEDIMENT REMOVAL THROUGH SEDIMENTATION PONDS

The design of sedimentation ponds is based upon satisfying effluent limitations. These limitations are established for specified stream water quality criteria and design precipitation runoff event. Sedimentation ponds are usually designed in the preliminary stages of the mine plan and therefore, there is little or no available information on base flow conditions. Because of this, ponds are designed for the design precipitation runoff event and the pond effluent for base flow conditions is tested after the pond becomes operational. If base flow effluent limitations cannot be satisfied, modifications can be made to the pond. Generally, the design runoff event will control the sedimentation pond design unless sediment inflow for base flow conditions is composed of high concentrations of fine silts and clays.

The following sections describe the information that is required for designing a sedimentation pond to meet effluent limitations. The pond design is based upon ideal settling conditions with conservative factors incorporated into the design to account for nonideal settling conditions.

The design begins by selecting a particle size which must be removed in the pond such that effluent limitations are satisfied. Determining the pond configuration requires an interactive process which begins by assuming a depth. The required storage volume and the available storage volume are determined and compared to each other. When the required storage volume is larger than the available storage volume, a new depth is assumed and the design process is repeated. Once the available storage volume is adequate, the pond configuration is checked based upon nonideal settling conditions. The design procedure and example presented in Chapter VI show how the information presented in the following sections is used in sedimentation pond design.

3.1 Site Selection

3.1.1 General Considerations

Selecting a sedimentation pond location requires consideration of several factors. In all cases, sedimentation ponds must be constructed in locations where it will be possible to direct or divert all surface runoff from disturbed areas into sedimentation ponds throughout the life of mining operations. Other factors which are of primary importance and should be considered

in selecting a sedimentation pond location include the topography of the mine site, locating major sources of sediment, accessibility of the sedimentation pond, availability of construction materials, and the direction of mining. In many instances these factors will limit the number of viable locations that are available for sedimentation pond construction. In particular, availability of suitable sites for a sedimentation pond location will be controlled, to a large extent, by the topography of the mine site. In addition, ponds must be constructed prior to any disturbance of the mine area. Through careful planning practices and field investigation, the sedimentation pond locations which will meet this objective can be identified.

3.1.2 Topography Considerations

3.1.2.1 Steep Sloped Terrain

Throughout the United States surface mining operations are often located in steep sloped terrain. This is true for the Appalachian mining region, the Rocky Mountain, and parts of northern California and Washington. In the regions which are characterized by steep sloped terrain, the topography becomes the most important controlling factor in the site selection for a sedimentation pond location. The main problem in finding a suitable sedimentation pond location is to determine where an adequate storage volume can be provided.

Where surface mining operations are located in the upper part of a watershed, the topography is characterized by steep slopes and v-shaped drainageways. It is usually desirable to locate the sedimentation pond as close to the mining operation as possible; therefore, the only site that is often available for a sedimentation pond location is the v-shaped drainageway directly downstream of the surface mine operation. A sedimentation pond which incorporates the use of an embankment will have to be used. The storage volume of the sedimentation pond can be increased by excavating upstream of the embankment. Often times the storage capacity provided by the embankment including any upstream excavation does not provide the storage volume required to achieve effluent limitations. To overcome the problem of sedimentation pond location in steep sloping terrain, there are two alternatives available to the operator.

The first alternative is to construct a sedimentation pond at a location farther downstream within the watershed where the slope of the drainageway becomes milder and the shape of the drainageway becomes u-shaped. The disadvantage of this alternative is that runoff from a much larger area will need to be contained and treated, thereby requiring the construction of a much larger structure.

The second alternative is to construct a series of sedimentation ponds located in the steep, narrow drainageways where the runoff from the disturbed mining areas passes through each sedimentation pond (multiple sedimentation ponds).

It should be noted here that there are other alternatives to sedimentation ponds for sediment and erosion control. Depending on the size of the area, several devices and techniques have been used. Refer to "Design of Sediment Control Measures for Small Areas in Surface Coal Mining" (OSM, 1982) for further consideration of alternatives to sedimentation ponds.

3.1.2.2 Mild Sloped Terrain

There is much more flexibility in selecting a sedimentation pond location in mild sloped terrain. The physical constraints imposed by the topography are less than for steep sloped terrain and therefore, more attention may be directed toward the other primary factors considered in the selection of a sedimentation pond site.

Sedimentation ponds may be located on or off drainageways. Small drainageways are often selected for a sedimentation pond location where an embankment is used with or without excavation to provide the storage volume required. Due to the milder drainageway profile and milder slopes of the valley, the sedimentation pond located in the mild sloped terrain will normally have a greater length and width for any height of dam specified, thereby providing more storage capacity.

Off drainage locations are generally preferred when there is a suitable location available for sedimentation pond construction. Natural depression areas are good locations for sedimentation ponds. An embankment can be constructed across the downstream end of the depression area and the storage volume may be increased by excavation.

3.1.3 Sedimentation Ponds Located on Main Drainageways

Sedimentation ponds located on main drainageways are usually found in surface mining operations located in steep terrain. Due to topographic constraints, this may be the most cost-effective way to control sediment. The main drainageway may be either an ephemeral or perennial stream. The sedimentation pond located on a perennial stream will have a permanent pool, whereas sedimentation ponds located on main drainageways which are ephemeral may be either a dry basin or permanent pool.

The disadvantage of locating a sedimentation pond on a main drainageway is that the surface runoff from both disturbed and undisturbed areas will have to be detained long enough to achieve effluent limitations. This requires a much larger storage volume be provided and therefore, the construction of a much larger sedimentation pond structure. In addition, chances of a sedimentation pond being washed away during a major flood event are increased due to control of runoff from a larger drainage area. Sedimentation ponds located on drainageways which are perennial streams must be designed to meet base flow water quality limitations. When the sedimentation pond is removed, reclamation of the drainage channel will be required. The channel will have to be restored to its original shape, slope, and channel protection.

It is preferable to select a sedimentation pond location which will not be located in a main drainageway. However, the topographic constraints of the mine site area may be such that the main drainageway is the only possible site for a sedimentation pond location.

3.1.4 Sedimentation Ponds Located off Main Drainageways

Off main drainageways sedimentation ponds are generally used in rolling and mild terrain where the topography does not restrict the location to the extent as it does in steep sloped terrain. The types of sedimentation ponds used in off main drainageway locations are embankment or some combination of embankment and excavation. The sedimentation ponds may be constructed as either a permanent pool or dry basin.

The off main drainageway location has several advantages over the on main drainageway location. A sedimentation pond in an off main drainageway location can generally be constructed closer to the sediment source and therefore, designed for a smaller influent volume. This location avoids unnecessary

treatment of runoff from undisturbed areas. Essentially, the base flow is zero, therefore the pond is generally designed based on precipitation events.

Gated outlets can be used on sedimentation ponds located in an off main drainageway site to control the detention time between runoff events. Also, the chances of an embankment sedimentation pond failing during a major storm event are reduced since only the runoff from a much smaller area will have to be controlled. However, again topography will play an important role as to whether an off main drainageway location will be feasible for the operator to construct.

3.1.5 Source of Sediment

During the development of a mine plan, the locations that will be major sources of sediment in the surface mining operation should be identified. Major sediment sources include haul and access roads, areas being cleared, spoil piles, and areas being reclaimed. As mining progresses the locations of major sediment sources change. Thus, the location of sediment sources throughout the life of the mine should be considered during the planning stages.

Sedimentation ponds should be located as close to major sediment sources as possible. Locating sedimentation ponds in this manner has several advantages from both a sediment control and construction viewpoint. Controlling the sediment as close to the source as possible may require the construction of several smaller sedimentation ponds as opposed to one or two larger ponds. The smaller sedimentation ponds may be constructed directly downstream of the major sediment sources thus requiring sediment control of only the disturbed areas. The net effect of this is the influent volume is reduced by avoiding collection of runoff from undisturbed areas, thereby reducing the required storage volume to achieve effluent limitations.

3.1.6 Accessibility

Improper, or lack of, maintenance for sedimentation ponds is one of the major reasons for poor sediment removal efficiencies. Often the lack of maintenance is due to inaccessibility to the location of the sedimentation pond. Sedimentation ponds are often constructed in locations that are remote from the surface mining operation and therefore, access roads to the sedimentation

pond are given little regular attention and maintenance. The accessibility to a sedimentation pond should be a primary consideration in the planning and design of sedimentation ponds.

The access road should be designed considering the type of equipment which will use the road. Where possible, the access road should be designed such that the road drainage will be directed into the sedimentation pond. Other sediment control measures or the construction of another sedimentation pond will be required downstream of the access road to prevent off-site damage if road drainage into the sedimentation pond is not possible.

3.1.7 Mining Considerations

Throughout the life of the surface mining operations, the locations of the major sources of sediment will constantly change due to the progression of mining. Sedimentation pond locations should be selected considering the direction of mining so it will be possible to direct or divert all surface runoff from disturbed areas into the pond throughout the life of the mining operations. In all cases, time of exposure of cleared land should be kept to a minimum to avoid filling of the sedimentation pond prematurely.

3.1.8 Field Investigation

Field investigation is essential in the development of an effective sediment control plan. After the operator has an understanding of the factors that must be considered in selecting a sedimentation pond location, several preliminary sedimentation pond locations can be selected using the most recent topographic maps of the mine area. A field investigation should then be conducted to verify information from topographic maps, survey the physical features of each site, and identify any problems which may be encountered at each site.

There are several surface features that should be noted at each potential sedimentation pond location. These features include soil type, vegetative cover, profile and side slopes of the drainageway, channel shape, channel protection, and the capability of each site to provide the design storage volume.

The previously mentioned features are all interrelated in influencing the erosional potential of the site and the suitability of the site as a sedimentation pond location. An overview of each site should be conducted noting any

problems relating to unstable soils or erosion. These features will be evidenced by small landslides, bank sloughing, and gully or rill erosion.

The soil type and vegetative cover at the site should be investigated and noted. Vegetation reduces the erosion potential and tends to stabilize the soil. If a large area will be cleared for mining operations and the construction of the sedimentation pond, protective measures may be required to protect the barren soil. Where some type of excavation might be required, it is not desirable to disturb soils which would become unstable. This will happen for soils which have little cohesion and the problem is increased if the sedimentation pond is constructed in steep sloped terrain. Once unstable soils are disturbed, a continuous sloughing of the banks will occur which will reduce the sediment removal efficiency of the pond as well as threaten the stability of the embankment. However, sedimentation ponds located in soils which have a high clay content may pose a problem in achieving effluent limitations. Due to turbulence within the pond and wave action on the banks, high concentrations of colloidal particles could result and will require the addition of coagulants or flocculants under base flow conditions.

In steep sloped areas where sedimentation ponds are often constructed on drainageways, the drainageway channel shape and protection should be investigated. The drainageway channel protection should be noted since the channel will have to be restored after the removal of the embankment. The channel may have developed an armoring layer of a certain size particle or it may be protected only by vegetation. It can be expected that scouring will occur downstream of the sedimentation pond and the magnitude of scouring will be greater for the vegetation-lined drainageway than for the drainageway which has already developed an armoring layer.

Once in the field, the designer should verify the information on the topographic maps and survey the physical features at each site. After the field investigation, a review and comparison of the advantages and disadvantages of each site can be evaluated to select the best sedimentation pond location.

3.2 Data Requirements

Information that is required to design a sedimentation pond can be broken into three categories: hydrology, sediment data, and inflow suspended solids concentration. The following sections describe what specific information is required for sedimentation pond design.

3.2.1 Hydrology

Hydrologic information required to design a sedimentation pond includes the peak inflow rate and the runoff volume for the design storm event. In addition, where ponds receive the inflow from the mining pit, pumping, or are located on a perennial stream, the inflow rate for base flow conditions must be determined.

For the design storm event, an inflow hydrograph must be developed from which the peak inflow rate and runoff volume can be determined. There are several references available which describe inflow hydrograph development (OSM, 1982; Bureau of Reclamation, 1977; Barfield, 1981; Soil Conservation Service, 1975).

For sedimentation ponds which receive inflow by pumping, the designer will have to determine the inflow rate for base flow conditions. For ponds which are located on perennial streams, the designer can use historical data if available. However, this type of information may be very limited. Therefore, the inflow rate for base flow conditions or from pumping will generally have to be measured after the pond has been constructed.

3.2.2 Sediment Data

The sediment data required for pond design are the particle size distribution and total sediment yield during a runoff event. The design of a pond occurs during the planning stages before actual mining starts. Therefore, information on the particle size distribution of the sediment runoff from the disturbed area is not generally available for the specific site. The following sections discuss the methods of obtaining sediment size distribution and sediment yield.

3.2.2.1 Influent Sediment Size Distribution

The most important sediment data required to design a sedimentation pond to meet effluent limitations is the particle size distribution of the sediment influent. The particle size distribution should represent the worst condition during the life of the mine. From past and present experience, the worst condition occurs during the reclamation phase. Two conditions during the reclamation phase must be considered.

The first condition to be considered is before the topsoil or "A" horizon has been replaced. The soil which is eroded, and hence the influent particle size distribution, will be represented by the graded overburden. The second condition to be considered is after the topsoil or "A" horizon has been replaced. For this condition, the particle size distribution of the eroded soil will be represented by the topsoil. Whichever condition results in a particle size distribution with the highest percentage of particle sizes in the silt range (0.001 to 0.074 mm) will be selected for the design influent particle size distribution. The best way to estimate the particle size distribution is to obtain size distribution information from previous and nearby mining operations. When mining operations within the same area or areas with the same soil texture exist, determination of particle size distributions of sediment runoff from existing analysis can be used. Before a particle size distribution from a nearby site is used, several considerations and comparisons must be made so the information does represent the site under consideration.

1. Soil characteristics at both sites should be very similar including soil types below the surface which are disturbed during mining.
2. Slopes, drainage, and sediment transport characteristics of both sites should be evaluated and compared.
3. The type of mining and amount of area disturbed at both sites should be evaluated.
4. Data from as many samples and sites should be collected and evaluated to provide a good estimate.
5. The magnitude of the runoff event during which the sample was collected should be considered.

When these data do not exist, but nearby sites do exist, sampling and laboratory analysis should be conducted whenever possible.

Another method for developing particle size distribution information is based on the site specific soil textural class and physical properties. Generally, soil physical properties occurring at a specific site can be identified using information given in standard Soil Conservation Service (SCS) soil surveys. These investigations consist of classifying physical, chemical, and biological characteristics of soils extending to depths of up to six feet. The U.S. Department of Agriculture (USDA) publishes reports and maps of their soil surveys, usually on a county basis.

A procedure for determining particle size distribution based on soil textural class is presented for use with this manual. A textural class is simply a name given each soil which designates the ranges of sand, silt, and clay sizes it contains. This class can be obtained from SCS soil series descriptions, other soil survey data in the vicinity, soil data from the mine plan, field estimation by a soil scientist, or laboratory analysis. After determining the textural classification, the corresponding particle size groups are then determined from Table 3.1.

Where the mining area has several soil textural classifications within the drainage boundary, a composite size distribution can be developed. For each particular soil textural classification, the sediment size distribution given in Table 3.1 will be multiplied times the fraction of the disturbed area that each soil textural class covers. The values for each soil textural class are then added together to form a representative composite size distribution. An example of developing a representative composite size distribution is given in the design example in Chapter VI.

The sediment size distribution based on textural class is not recommended for use if more detailed soil data are available at the mine site. Also, it is important that the soil data describing the material below the surface (exposed during mining) be considered during development of the particle size distribution. The designer should realize that the design can be no better than the information on which it is based. To help eliminate significant changes and modifications to the pond after construction, the particle size distribution utilized should be a conservative estimate.

Table 3.1. Suggested Particle Size Distribution for Soil Textural Class.

Textural Class	Clay (< 0.002 mm) (%)	P ₁ Silt ($0.002-0.05$ mm) (%)	P ₂ Very Fine Sand ($0.05-0.01$ mm) (%)	P ₃ Fine, Medium Coarse Sand ($0.1-1.0$ mm) (%)	P ₄ Very Coarse Sand ($1.0-2.0$ mm) (%)
Sand	2	10	15	35	38
Loamy Sand	5	15	20	40	20
Sandy Loam	5	25	20	20	30
Loam	10	30	10	25	25
Silty Loam	20	60	5	15	--
Silt	5	90	5	--	--
Sandy Clay Loam	25	25	10	30	10
Clay Loam	30	40	10	10	10
Silty Clay Loam	35	55	5	--	5
Sandy Clay	55	5	5	10	25
Silty Clay	45	45	5	5	--
Clay	65	20	10	5	--

The size distribution for base flow conditions can be significantly different from the size distribution based upon the surface and overburden soils. Generally, the size distribution for base flow conditions will be composed of smaller particle sizes. Sampling of the base flow size distribution is recommended to accurately design for base flow effluent limitations.

For sedimentation ponds which receive inflow by pumping, the sediment size distribution is very difficult to predict. An initial estimate of the size distribution can be developed from the overburden soil. Once the pond is operational, the effluent will have to be tested and pond modifications may be required.

3.2.2.2 Sediment Yield

Sediment yield of the mining area is required to determine the sediment storage volume of the pond and calculate the average effluent concentration for the design storm event. The required sediment storage volume is dependent upon the annual sediment yield and the frequency of sediment removal. It is left to the designer to decide how often the sediment will be removed from the pond. The annual sediment yield can be determined using the Universal Soil Loss Equation (USLE). There are several references which are available which describe the use of the USLE (OSM, 1982; Barfield, 1981).

Sediment yield for the design storm event must be determined so the average effluent concentration can be calculated. The Modified Universal Soil Loss Equation (MUSLE) can be used to calculate the sediment yield from the design storm event. The previously mentioned references also describe the use of MUSLE.

3.2.3 Inflow Suspended Solids Concentration

The inflow suspended solids concentration is required for both base flow conditions and the design runoff event. For base flow conditions, the influent suspended solids concentration will have to be measured since it is very difficult to predict.

For the design runoff event, the average influent suspended solids concentration can be computed knowing the storm runoff volume and sediment yield. The average influent suspended solids concentration is computed as:

$$C_I = \frac{Y}{\gamma V} \times 10^6 \quad (3.1)$$

where, C_I = average influent suspended solids concentration (mg/l),

Y = storm sediment yield (lbs),

γ = unit weight of water (62.4 lb/ft³), and

V = storm runoff volume (ft³).

It should be recognized that this concentration is the average suspended solids concentration during the storm and higher suspended solids concentrations would be expected when the peak inflow rate occurs.

3.3 Effluent Limitations

Design procedures for sedimentation ponds developed in this manual are based on meeting solids effluent limitations. The operator should be aware that there are other effluent quality limitations on iron, manganese, and pH. It is assumed that the manual will be used for design of sedimentation ponds in the planning stages of mining and that the mining operation is controlled by New Source Performance Standards (NSPS). The NSPS solids effluent quality limitations are based on flow condition and the state of mining operation.

3.3.1 Suspended Solids Limitation

Solids effluent quality limitation during base flow for active surface mining, underground mining, and coal preparation areas is 35 mg/l total suspended solids (TSS) for the average of daily values for 30 consecutive days and a maximum of 70 mg/l TSS for any one day. For post-mining conditions, the discharge from underground mine drainage is also subject to these suspended solids limitations.

3.3.2 Settleable Solids Limitation

During any discharge or overflow resulting from a precipitation event less than or equal to the 10-year, 24-hour precipitation event, the discharge is subject to solids effluent quality limitations of 0.5 ml/l settleable solids (SS). During any discharge or overflow resulting from a precipitation event greater than the 10-year, 24-hour precipitation event the discharge is

not subject to a solids effluent quality limitation. These alternate limitations during precipitation events only apply if:

1. The treatment facility is designed, constructed, operated, and maintained to contain at a minimum the volume of water which would drain into the treatment facility from active mining areas and reclamation areas during the 10-year, 24-hour precipitation event (or snowmelt of equivalent volume);
2. The treatment facility is designed, constructed, operated, and maintained to consistently achieve the effluent limitations set by the regulatory agencies for all effluent quality limitations;

The volume of settleable solids in the effluent from a sedimentation pond is determined by a simple procedure known as the Imhoff cone test (see Figure 3.1). The Imhoff cones are filled to the one-liter mark with a thoroughly mixed sample. Settling is allowed to occur for 45 minutes, the sides of the cone are gently stirred with a rod to free any particles which may be clinging to the sides of the cone, and settling is allowed to occur for an additional 15 minutes. The volume of settleable solids in the cone is then recorded as milliliters per liter (from "Standard Methods for Examination of Water and Wastewater," 15th edition). The test is normally performed at room temperature 25°C, 77°F) or the results are adjusted to room temperature. It should be pointed out that some difficulty exists in reading the Imhoff cones. When dealing with fine particles such as silt, it requires practice in defining the volume of settleable solids. It is recommended that these readings be taken in the presence of persons who have experience in performing the Imhoff cone test.

Particle sizes smaller than one micron (0.001 mm) are assumed non-settleable under gravitational forces alone. Therefore, particle sizes smaller than one micron are not considered settleable solids in this manual.

A well-designed sedimentation pond will remove practically all of the sand-sized particles. Therefore, the settled volume in the bottom of the Imhoff cone will be composed primarily of silt.

The smallest particle which will settle through the entire height of the Imhoff cone during the test can be computed. Based upon Stoke's Law, test conditions, and assuming a specific gravity of the particle to be 2.65, this particle size is computed as 0.011 mm (d_0). Stokes's Law is based upon ideal settling and there are several references available which discuss Stoke's Law

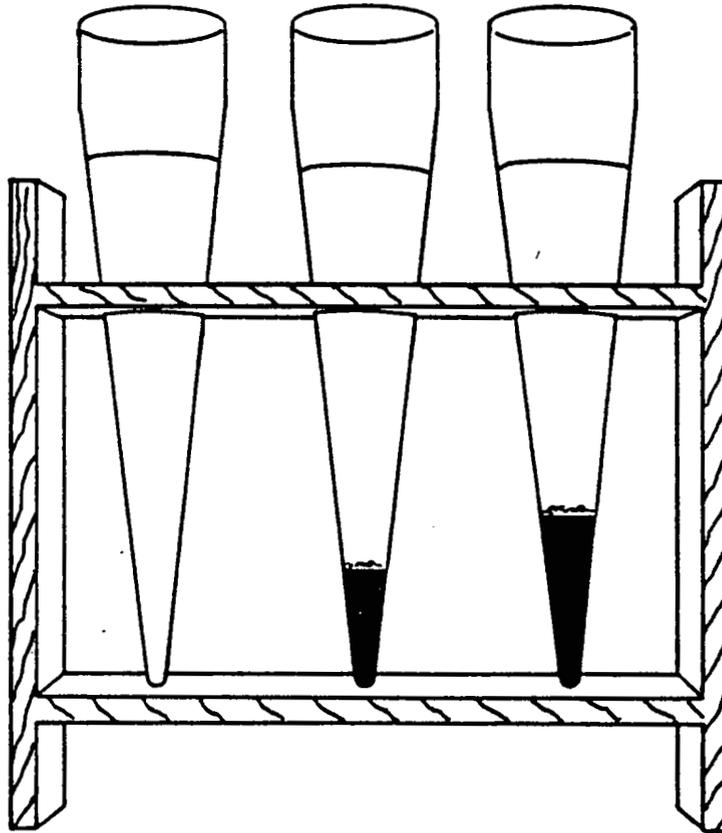


FIGURE 3.1 IMHOFF CONE TEST APPARATUS (SAWYER, 1978)

(Barfield, 1981; Shames, 1962). All particles larger than 0.011 mm would settle during the test. Only a percentage of the particles smaller than 0.011 mm would be expected to settle depending upon the concentration of each particle size within the sample. The objective of this design manual is to select a particle size of a particular size distribution that must be removed so that the settleable solids concentration meets effluent limitations when the sample is placed in the Imhoff cone.

3.4 Trapping Efficiency

To meet effluent limitations, sedimentation pond design must be based on sediment size distribution and TSS concentration of the base flow or design storm runoff entering the pond. Based on present state of the art, the most common method for developing the pond design criteria to meet a specified effluent limitation is by determining the percent of sediment removal required. The percent of sediment removal is called the trapping efficiency (E) and is equal to the weight of sediment flowing into the pond minus the weight of sediment leaving the pond divided by the weight of sediment flowing into the pond and then multiplied by 100 to obtain efficiency in percent. Thus, the trapping efficiency is given by:

$$E = \frac{W_I - W_O}{W_I} \times 100 \quad (3.2)$$

where, W_I = weight of sediment flowing into the pond,

W_O = weight of sediment flowing out of the pond,

During base flow, the sedimentation pond will be in a steady-state condition where the water inflow volume equals the water outflow volume. The water volume can be changed to a weight of water. Dividing the weight of sediment by the weight of water will yield a concentration of TSS. Therefore, the trapping efficiency becomes

$$E = \frac{C_I - C_O}{C_I} \times 100 \quad (3.3)$$

where, C_I = average sediment concentration into the pond,

C_O = average sediment concentration out of the pond.

For base flow, effluent limitations are stated as a concentration of TSS. Therefore, a relationship between the influent TSS concentration and the trapping efficiency can be developed if the effluent TSS concentration is known. Once the influent TSS concentration has been measured, the required trapping efficiency can be determined if the effluent TSS concentration is known. Figure 3.2 presents this relationship for a range of effluent concentration limitations. Knowing the influent TSS concentration, the required trapping efficiency to limit the effluent concentration to a standard can be determined from Figure 3.2.

During the design precipitation runoff event, the development of pond design criteria is more difficult. The condition during a storm runoff is dynamic in that the inflow to the pond is represented by a runoff hydrograph; the outflow is based on the water surface elevation in the pond and the discharge capacity of the outflow device. In addition, effluent limitations for the design precipitation runoff event are stated as a concentration of settleable sediment.

To design for the design runoff event requires that a practical approach be taken. The method used to route the inflow hydrograph through the sedimentation pond is based upon the inflow volume being equal to the outflow volume. (Water routing is discussed in Section 3.6.) Therefore, the trapping efficiency for the design runoff event can also be computed using Equation 3.3. However, for the design runoff event, the suspended solids concentration and the trapping efficiency are both unknown.

By definition, the trapping efficiency is the weight of sediment removed in the pond. The influent sediment is represented by the sediment concentration and size distribution. In addition, it is assumed that the influent sediment is evenly distributed in the water inflow. Therefore, when a sedimentation pond is designed to remove a certain particle size (d_1), the percent of sediment removal or trapping efficiency is equal to the percent of the size distribution that is larger than d_1 . Figure 3.3 presents the definition of the trapping efficiency for various particle sizes. This estimate of trapping efficiency is conservative since it assumes none of the particles

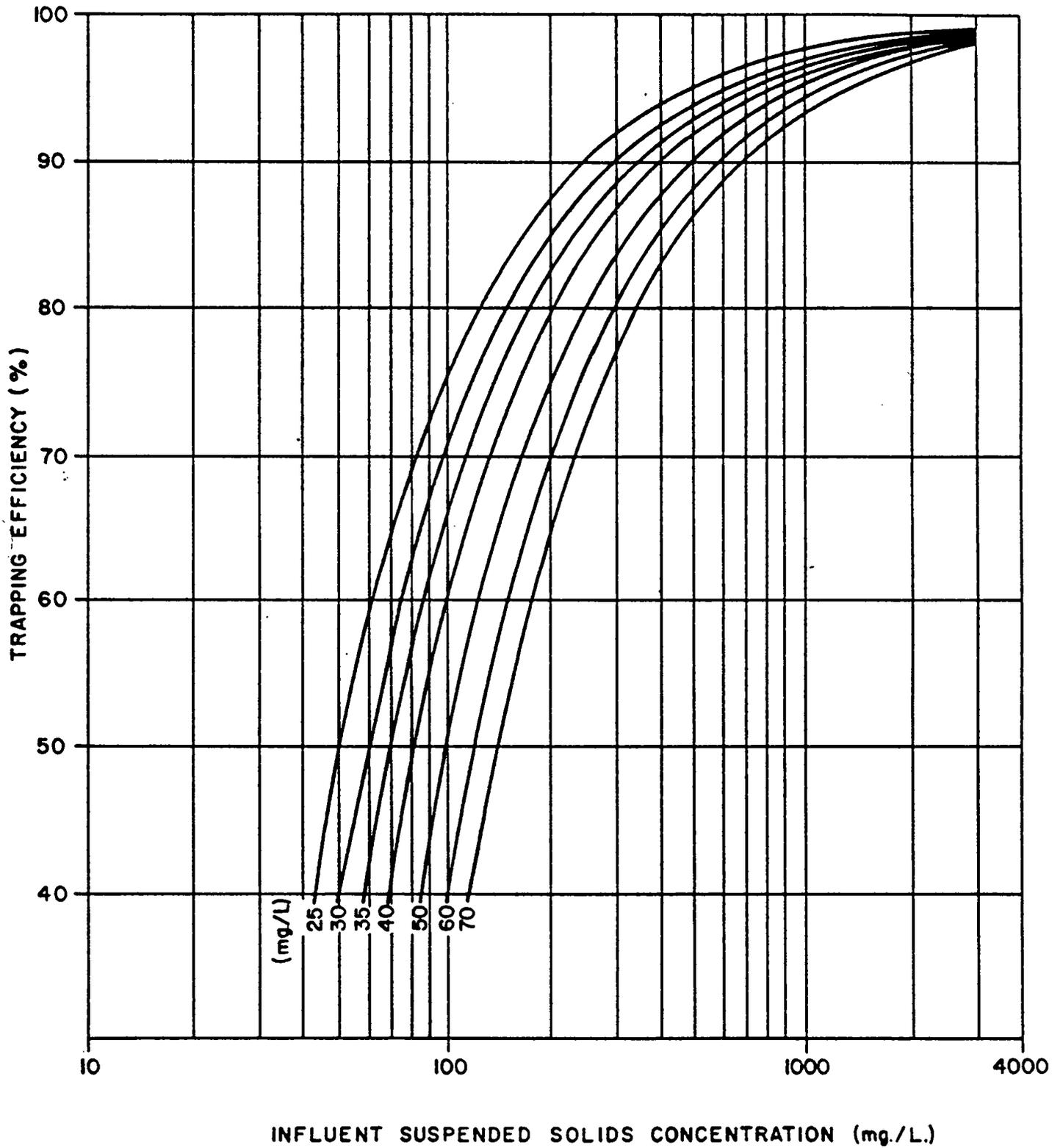


FIGURE 3.2 REQUIRED TRAPPING EFFICIENCY TO MEET VARIOUS EFFLUENT LIMITATIONS

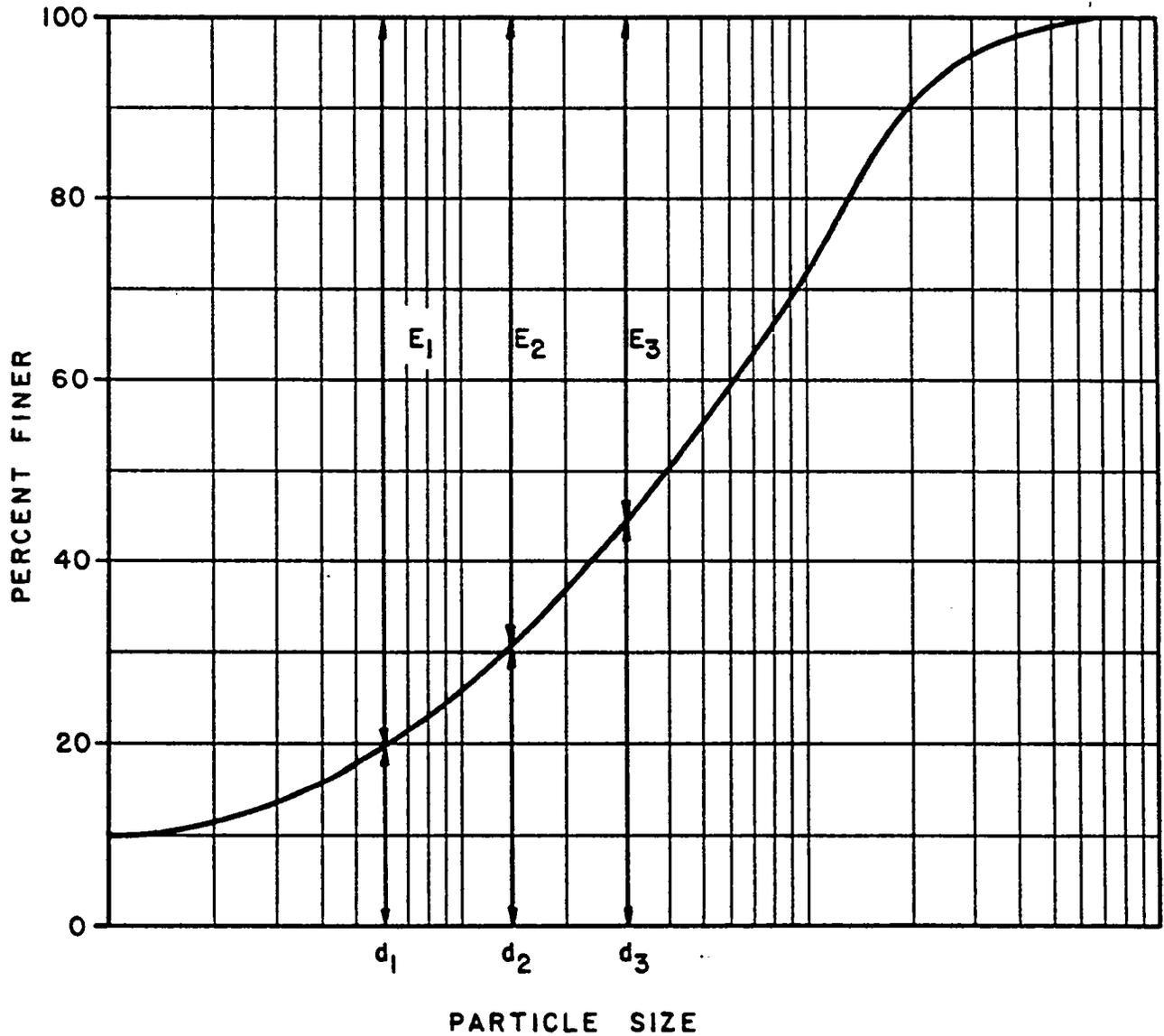


FIGURE 3.3 DEFINITION OF TRAPPING EFFICIENCY FOR VARIOUS PARTICLE SIZES

smaller than the selected particle size (d_i) will settle in the pond. Actually, a percentage of the particles smaller than d_i will settle. Therefore, for each particle size, a trapping efficiency can be determined from the influent size distribution, and the suspended solids concentration can be calculated by rearranging Equation 3.3.

$$C_0 = \left(1 - \frac{E}{100}\right) C_I \quad (3.4)$$

To determine whether the effluent requirements are satisfied, a relationship between the suspended solids concentration and the settleable solids concentration is required. This relationship is presented in the following section.

3.5 Settleable Solids Concentration

Effluent limitations during runoff events and post-mining reclamation are stated in terms of a volume of settleable solids per one liter of sample. To relate the settleable solids limitation to the design of sedimentation ponds, a relationship between settleable solids and total suspended solids must be considered. Settleable solids are defined as the volume of particles that settle in the bottom of an Imhoff cone in one hour of quiescent settling.

Knowing the influent sediment size distribution, a particle size to be settled in the pond is selected and the settleable solids concentration is determined. If the settleable solids concentration is larger than effluent limitations, a smaller particle size is selected and a new settleable solids concentration is computed. Likewise, if the settleable solids concentration is smaller than the effluent limitations, a larger particle size is selected and the new settleable solids concentration is computed. Therefore, an iterative process is required to determine the particle size that the sedimentation pond must remove so the pond effluent satisfies the settleable solids limitation.

The first step in computing the settleable solids concentration is to adjust the influent sediment size distribution by subtracting out the non-settleable sizes (< 0.001 mm). Given the size distribution in Figure 3.4, it can be seen that ten percent of the sediment is smaller than 0.001 mm. Therefore, the 90 percent of the size distribution which is settleable must be

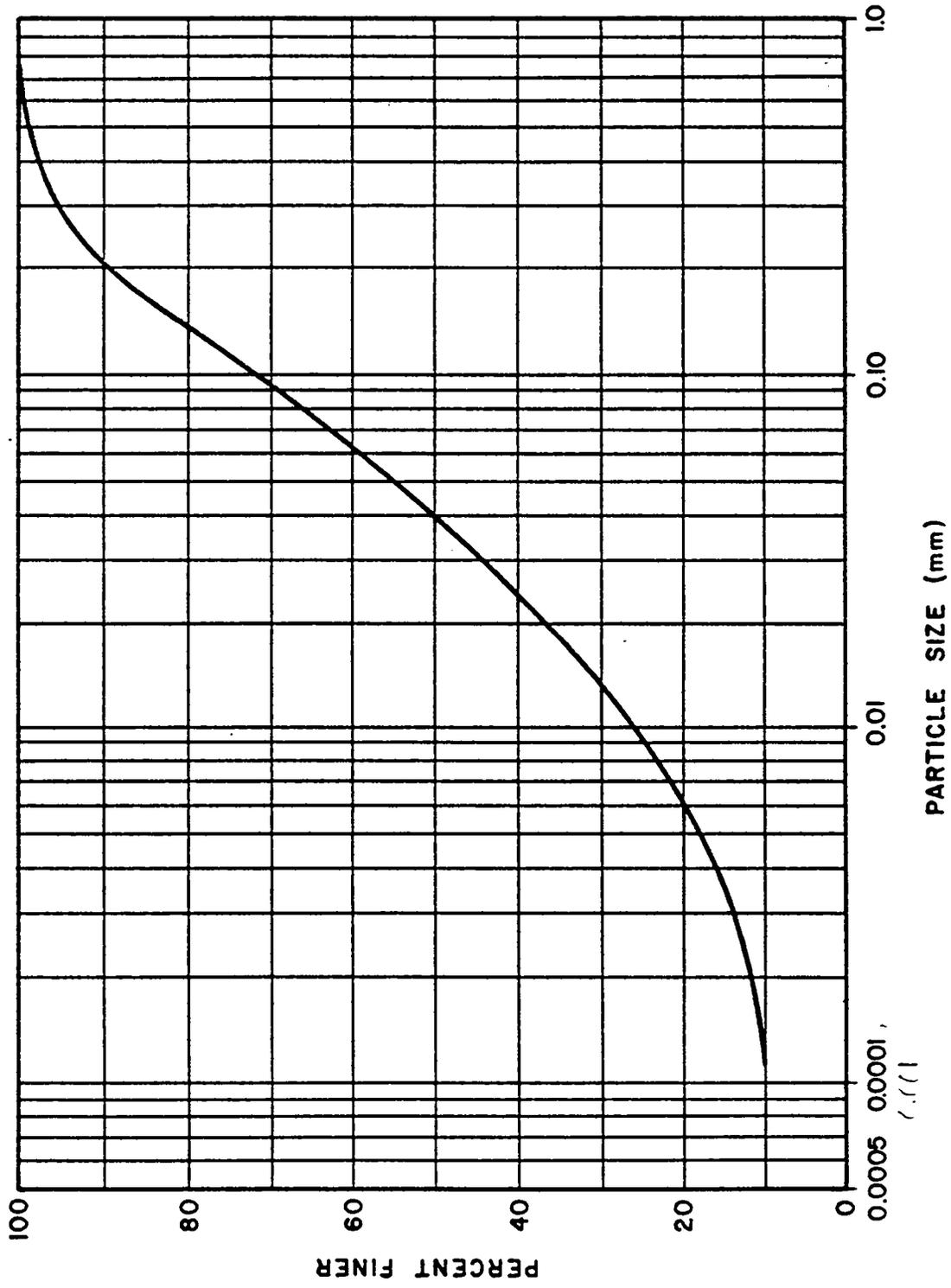


FIGURE 3.4 INFLUENT SEDIMENT SIZE DISTRIBUTION

redistributed so that it makes up 100 percent of the size distribution. Table 3.2 shows how to develop a size distribution in which all particle sizes are settleable. The settleable size distribution is presented in Figure 3.5.

A relationship between the effluent suspended solids concentration, the settleable particle size distribution, and the settleable solids concentration is required. Barfield (1981) developed an equation for the conversion of suspended solids concentration to settleable solids based on discrete particle settling and the geometry of the Imhoff cone. The volume of settleable solids is given by

$$SS = \frac{C^*}{W} \left[(1 - X_0) + \sum_{i=1}^{X_0} \left(\frac{d_i}{d_0} \right)^6 \Delta X_i \right] \quad (3.5)$$

where, SS = settleable solids concentration (mg/l),

C* = average effluent suspended solids concentration for the settleable sizes (mg/l),

W = dry bulk density of the settled solids (mg/ml),

X₀ = fraction of particles in the effluent distribution smaller than d₀ = 0.011 mm,

d₀ = smallest particle which will settle through the entire height of an Imhoff cone (0.011 mm),

d_i = mean particle size of the interval ΔX_i (mm), and

ΔX_i = fraction of effluent sediment size distribution which has a mean particle size of d_i.

The average effluent suspended solids concentration for the settleable sizes is given as

$$C^*_0 = (1 - E) C_I = (1 - E) \frac{kY}{\gamma V} \times 10 \quad (3.6)$$

where, E, γ, V, Y are as defined previously, and

k = fraction of the particles in the influent size distribution which are settleable.

In the previous example, k would equal 0.90 since 90 percent of the influent size distribution is settleable.

Table 3.2. Development of Settleable Solids Size Distribution.

Particle Size (mm) (1)	Influent Distribution (% finer) (2)	Column 2 - 10 (3)	Settleable Solids Size Distribution Column 3 x (100/90) (% finer) (4)
0.001	10	0	0.0
0.0042	16	6	6.7
0.01	26	16	17.8
0.04	50	40	44.4
0.10	72	62	68.9
0.20	90	80	88.9
0.66	100	90	100.0

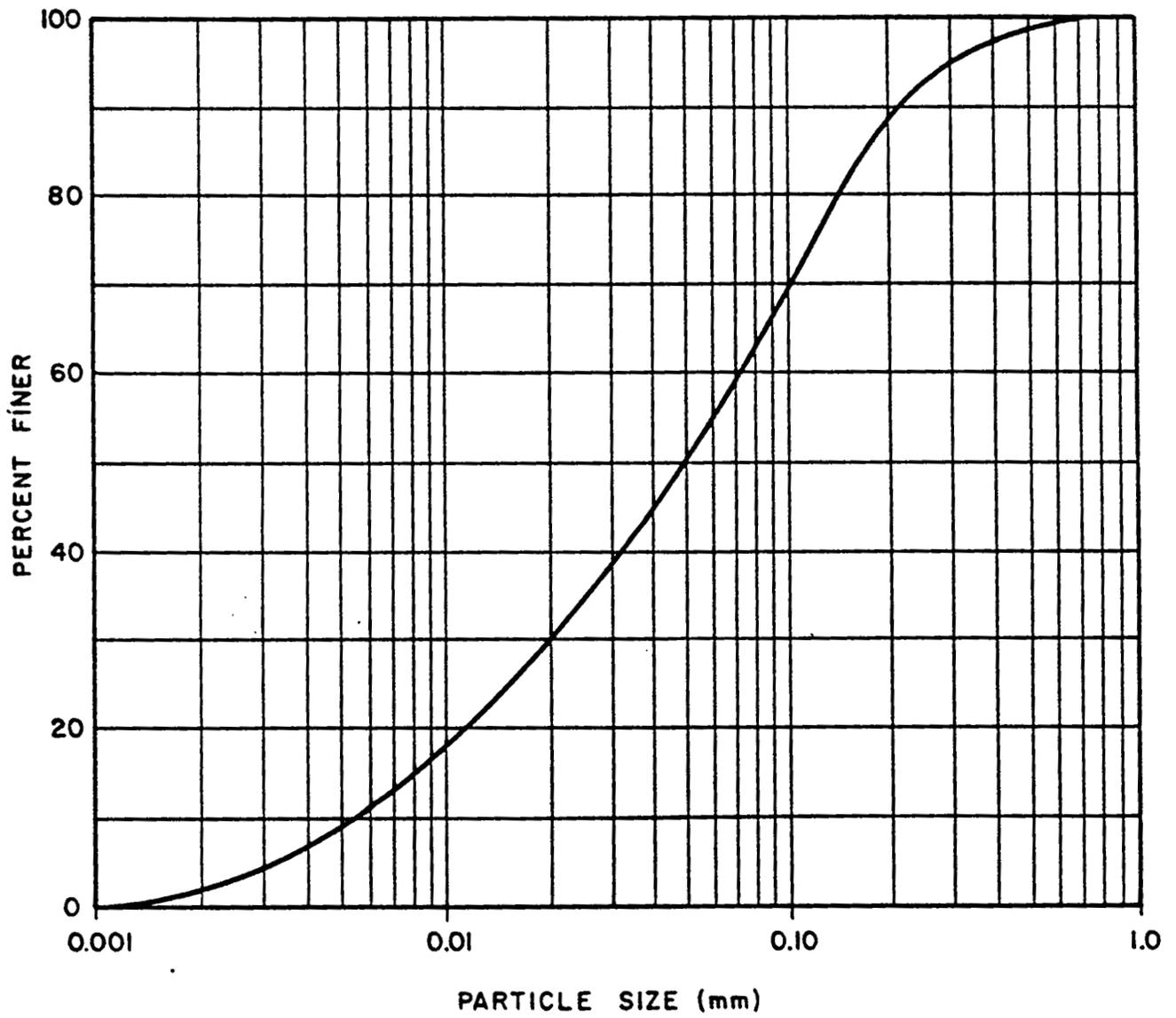


FIGURE 3.5 SETTLEABLE SOLIDS SIZE DISTRIBUTION

The dry bulk density of the settled solids (W) should be representative of settled silt since this is the size range that will settle during the Imhoff cone test. A representative value of W for settled silt is 70 lb/ft³ or approximately 1120 mg/l.

The fraction of the particles in the effluent size distribution which are smaller than d_0 (0.011 mm) is denoted as X_0 . When a particle size to be removed in a pond is equal to or smaller than 0.011 mm, X_0 will always be 1.0 and all of the particle sizes in the effluent are equal to or smaller than 0.011mm. All of the particle sizes which have a diameter of 0.011 mm or larger will settle in an Imhoff cone test. The second term in Equation 3.5 determines what percent of the particle sizes smaller than 0.011 will settle during the test.

When a particle size to be removed in the pond is larger than 0.011 mm, X_0 is equal to the percent of the effluent size distribution which is smaller than 0.011 mm. For this condition, the effluent will contain particle sizes greater than 0.011 mm. All particle sizes greater than 0.011 mm will settle in the Imhoff cone during the test. The first term in Equation 3.5 describes the percent of the effluent size distribution which is larger than 0.011 mm and therefore, will settle during the Imhoff cone test. For this condition, X_0 can be completed as

$$X_0 = \frac{\% \text{ of settleable size distribution smaller than } 0.011 \text{ mm}}{\% \text{ of settleable size distribution smaller than size to be removed in sedimentation pond}}$$

The design of a sedimentation pond to meet effluent limitations requires that a particle size to be removed be selected. A good starting point is to select a particle size of 0.011 mm. This makes X_0 in Equation 3.5 equal to 1.0. Therefore, the effluent size distribution is made up of particles smaller than 0.011 mm. To evaluate the second term in Equation 3.5, the particle sizes smaller than 0.011 mm must be redistributed into a size distribution in which the particle sizes smaller than 0.011 mm comprise the entire size distribution. Using the settleable size distribution presented in Figure 3.5, it can be seen that 19.5 percent of the settleable size distribution is smaller than 0.011 mm. This percentage of the settleable size distribution is then redistributed to be 100 percent.

This procedure starts by breaking up the settleable size distribution smaller than 0.011 mm into several percentage intervals. This is shown in Figure 3.6. The size range for each increment is then tabulated and the mean size (d_i) is determined. This procedure is shown in Table 3.3. In this example, percentage increments of 0.04 were chosen. There is no set value for the percent increments. However, smaller sized increments will yield a better result. The particle size range for each increment is then tabulated (column 1, Table 3.3). The particle size (d_i) in the middle of each increment is then tabulated in column 2 of Table 3.3 as mean size. The final step is to redistribute the size distribution smaller than 0.011 mm. This is accomplished by dividing each percent increment (column 3) by the sum of column 3. For this example, the first four entries in column 4 are found by dividing 0.04 by 0.195. Column 4 is the ΔX_i value used in Equation 3.5 corresponding to the d_i value (column 2). Knowing this information, the settleable solids concentration in the effluent can be determined from Equation 3.5.

If the settleable solids effluent limitations are not satisfied, a particle size smaller than 0.011 mm is chosen to be removed. The value of X_0 in Equation 3.5 will still be equal to 1.0. However, the particle size range in column 1, Table 3.3 will change. The particle size range will now have the upper limit of the selected particle size instead of 0.011 mm. Therefore, the trapping efficiency, effluent concentration, particle size range, increment size, and ΔX_i will have new values and the new settleable solids concentration can be computed.

When the computed settleable solids concentration is less than the effluent limitations, larger sized particles will be allowed in the effluent. Therefore, a particle size larger than 0.011 mm is selected to be removed in the pond. In Equation 3.5, the second term will remain the same as that which was computed for a particle size of 0.011 mm but will be reduced by a factor of X_0 . This is one of the main reasons for selecting 0.011 mm as a starting point. The value of X_0 will no longer be equal to 1.0. For this condition, X_0 can be computed as defined previously. With the new trapping efficiency, effluent concentration, and value of X_0 , the settleable solids concentration can be computed using Equation 3.5. The settleable solids concentration will increase rapidly as the particle size to be removed in the pond is increased

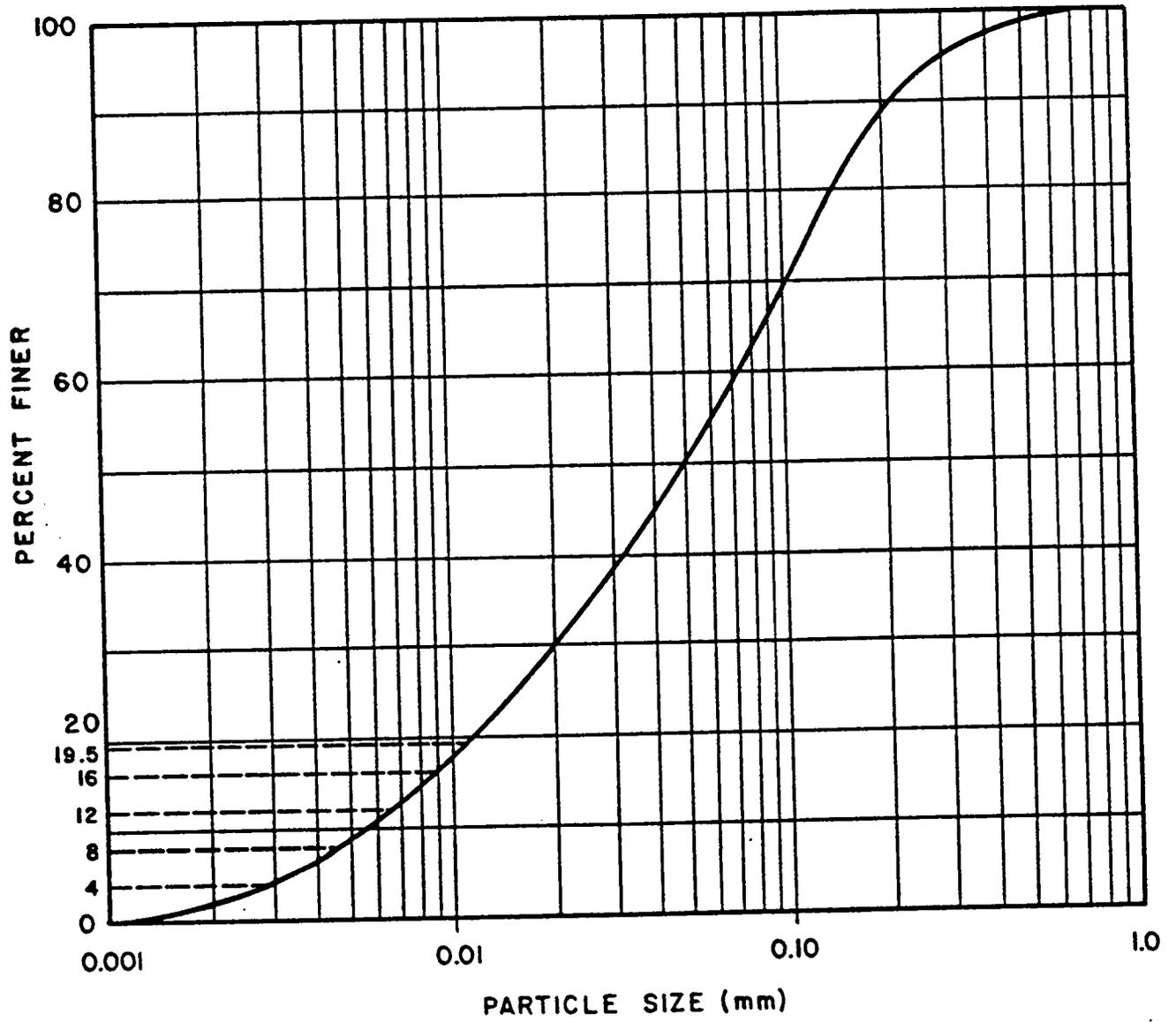


FIGURE 3.6 DEFINITION OF PERCENTAGE INTERVALS

Table 3.3. Size Distribution for Particles
Smaller than 0.011 mm.

(1) Particle Size Range	(2) Mean Size (d_i)	(3) Percent in Size Range of Settleable Size Distribution (X_i)	(4) $\Delta X_i = (X_i / \Sigma X_i)$
0.001 - 0.0023	0.0015	0.04	0.205
0.0023 - 0.0046	0.0035	0.04	0.205
0.0046 - 0.0064	0.0054	0.04	0.205
0.0064 - 0.0088	0.0075	0.04	0.205
0.0088 - 0.011	0.0100	<u>0.035</u>	<u>0.180</u>
Σ		0.195	1.0

since all particles larger than 0.011 mm will settle in an Imhoff cone. Therefore, when a new particle size is selected, a particle size in the range of 0.015 mm to 0.02 mm should be tried so the designer can understand how fast the settleable solids concentration increases.

When the designer has calculated the particle size which must be removed in the sedimentation pond to meet effluent limitations, criteria for the sedimentation pond design can be determined. The determination of the design particle size to meet effluent limitations may seem confusing. Following through the example given in Chapter VI will help the operator understand how to design a sedimentation pond to satisfy settleable solids effluent limitations.

3.6 Storage Volume Requirement

In the design process, there is an iteration procedure that is required between the information presented in Sections 3.6, 3.7 and 3.8. Knowing the particle size to be removed (Section 3.5), a depth is assumed and the corresponding required detention time is determined (Section 3.8). The available storage volume for the selected depth is determined (Section 3.7). The required storage volume is then determined (Section 3.6) and compared to the available storage volume. If the available storage volume is less than the required storage volume, the depth is increased and the iteration is repeated. When the available storage volume is greater than the required storage volume, the depth, detention time, storage volume, and outflow rate are established. The pond surface area, length, and width are then checked to ensure that the selected particle size is settled in the pond.

Flow routing through a sedimentation pond is determined by the rate of inflow, storage capacity of the pond, and outflow capacity for given reservoir levels. Numerous methods of reservoir routing have been developed which include the Modified Puls Method, Rippl Mass Curve, and several others. Descriptions of these methods can be found in hydrology texts and manuals.

A simplified method is used in this manual. The simplified routing method is used to determine the required storage volume and size the principal spillway to produce the required detention time so that effluent requirements are met. The simplified routing procedure requires that the peak inflow rate and runoff volume are known. The peak inflow rate and runoff volume can be determined from the inflow hydrograph. This method implies two assumptions,

the shape of the inflow and outflow hydrographs are triangular and the initial water surface elevation is at the elevation of the principal spillway crest. Therefore, the areas under the inflow and outflow hydrographs are equal.

Water routing through sedimentation ponds can be solved using Figures 3.7 and 3.8. Figure 3.7 is a graph showing the relationship between the time base of the inflow hydrograph (T_b) and the ratio of the required storage volume (S) to the runoff volume (V) for a range of detention times. Figure 3.8 presents the relationship between T_b and the ratio of the peak outflow rate (Q_o) to the peak inflow rate (Q_I) for a range of detention times. The time base of the inflow hydrograph is determined as:

$$T_b = \frac{V}{1800 Q_I} \quad (3.7)$$

where, T_b = time base of inflow hydrograph (hours),

V = water runoff volume (ft^3),

Q_I = peak inflow rate (cfs).

The time base can be computed based on the information from the inflow hydrograph. Knowing the time base of the inflow hydrograph and the required detention time for a selected particle size to be settled (Section 3.8.1), the required storage volume and peak outflow rate can be determined using Figures 3.7 and 3.8.

3.7 Available Storage Volume

The sedimentation pond storage volume should provide an adequate sediment storage volume and an adequate detention storage volume so effluent limitations are satisfied. At each sedimentation pond site, a relationship between the depth and the storage volume is required since the trapping efficiency depends on depth and storage volume of the pond.

The method utilized to develop the depth and storage volume relationship requires a topographic map of the location of the pool area and embankment of the sedimentation pond. An incremental value of storage volume between two pool elevations can be determined using a planimeter and the scaled topography map. For example, in Figure 3.9 the incremental storage volume between a pool at elevation E_2 and a pool at elevation E_3 is determined by measuring (with a

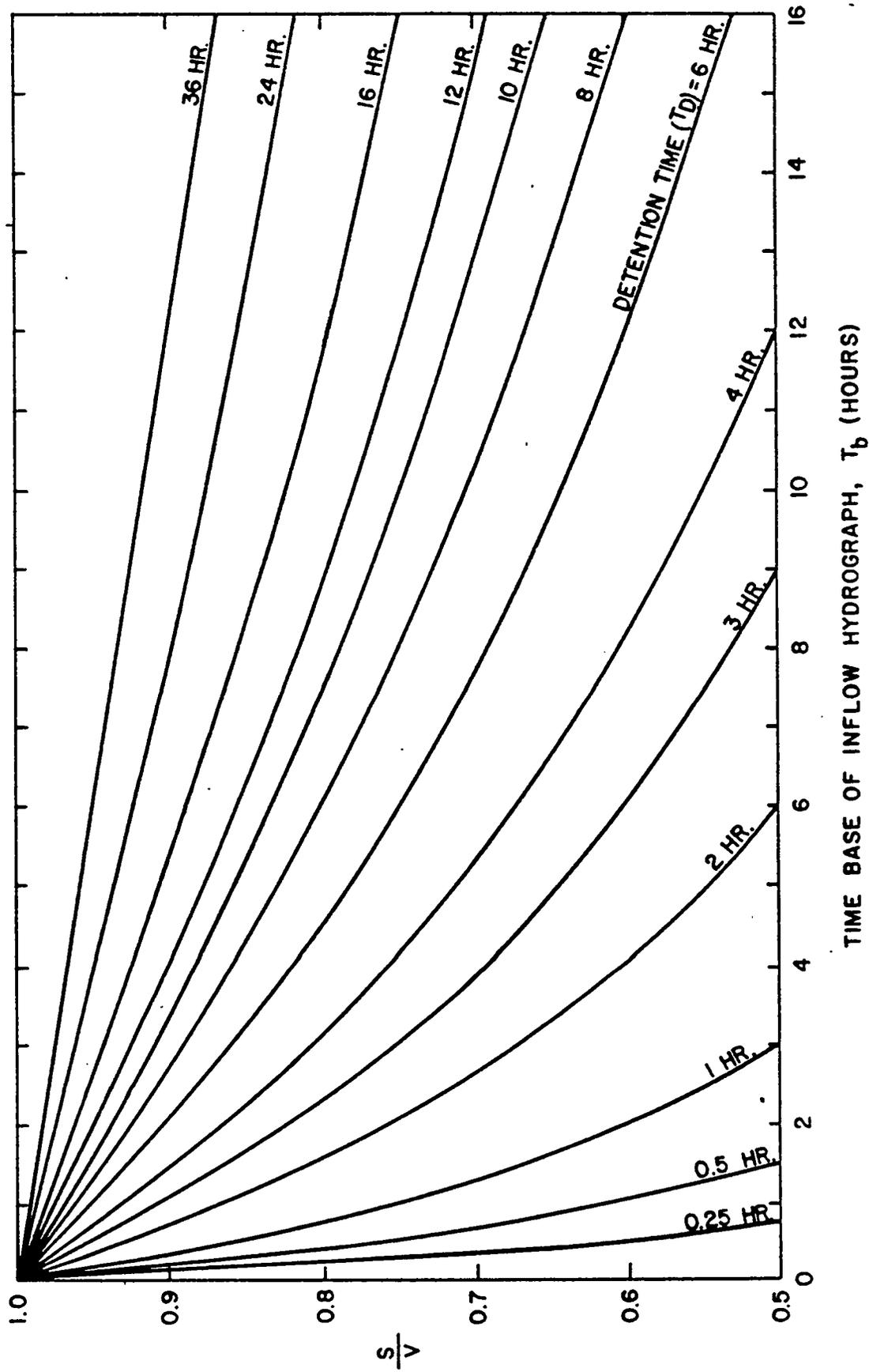


FIGURE 3.7 WATER ROUTING CURVE, S/V VERSUS T_b
(WARD, HAAN, TAPP, 1979)

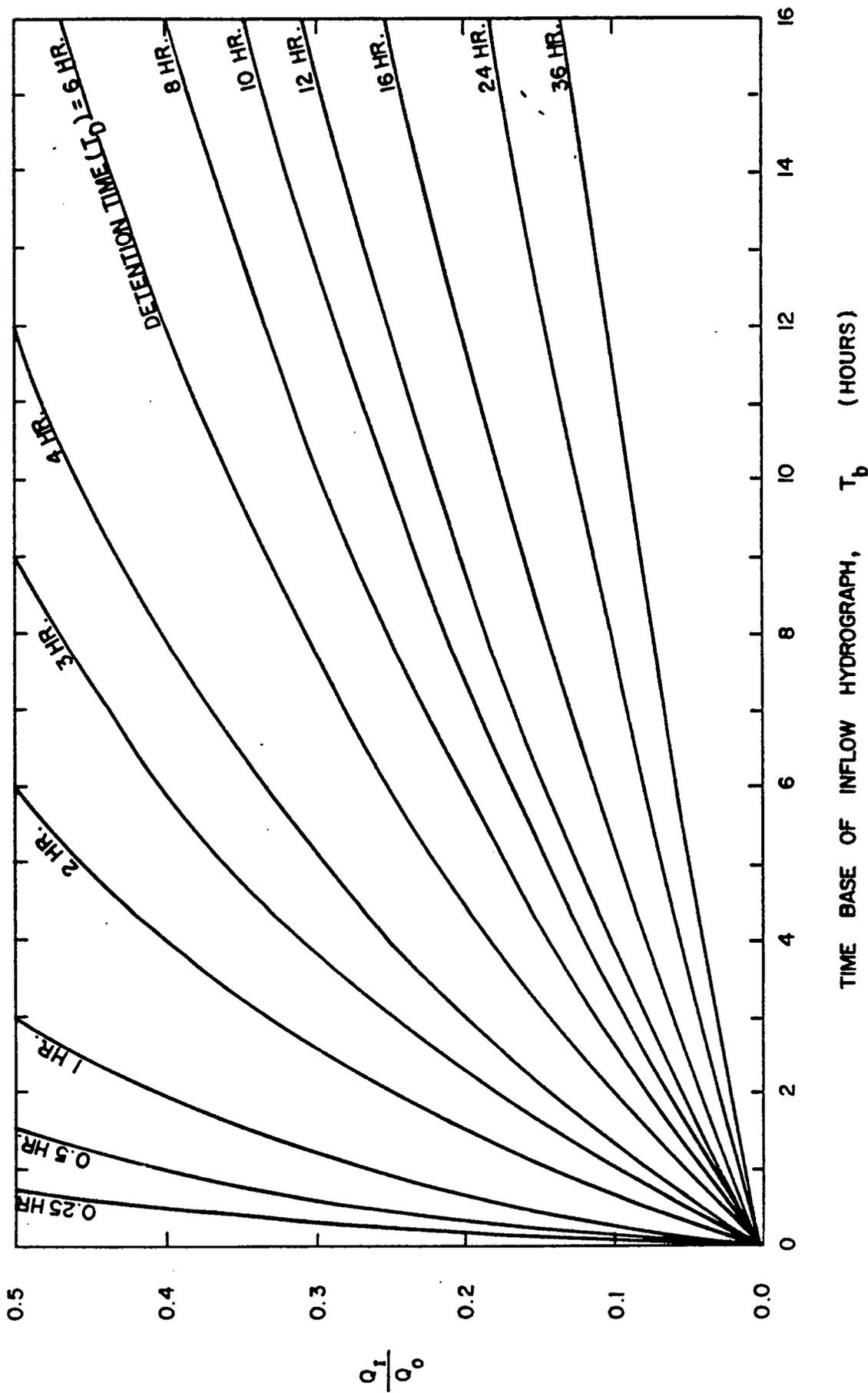


FIGURE 3.8 WATER ROUTING CURVE, Q_1/Q_0 VERSUS T_b
(WARD, HAAN, TAPP, 1979)

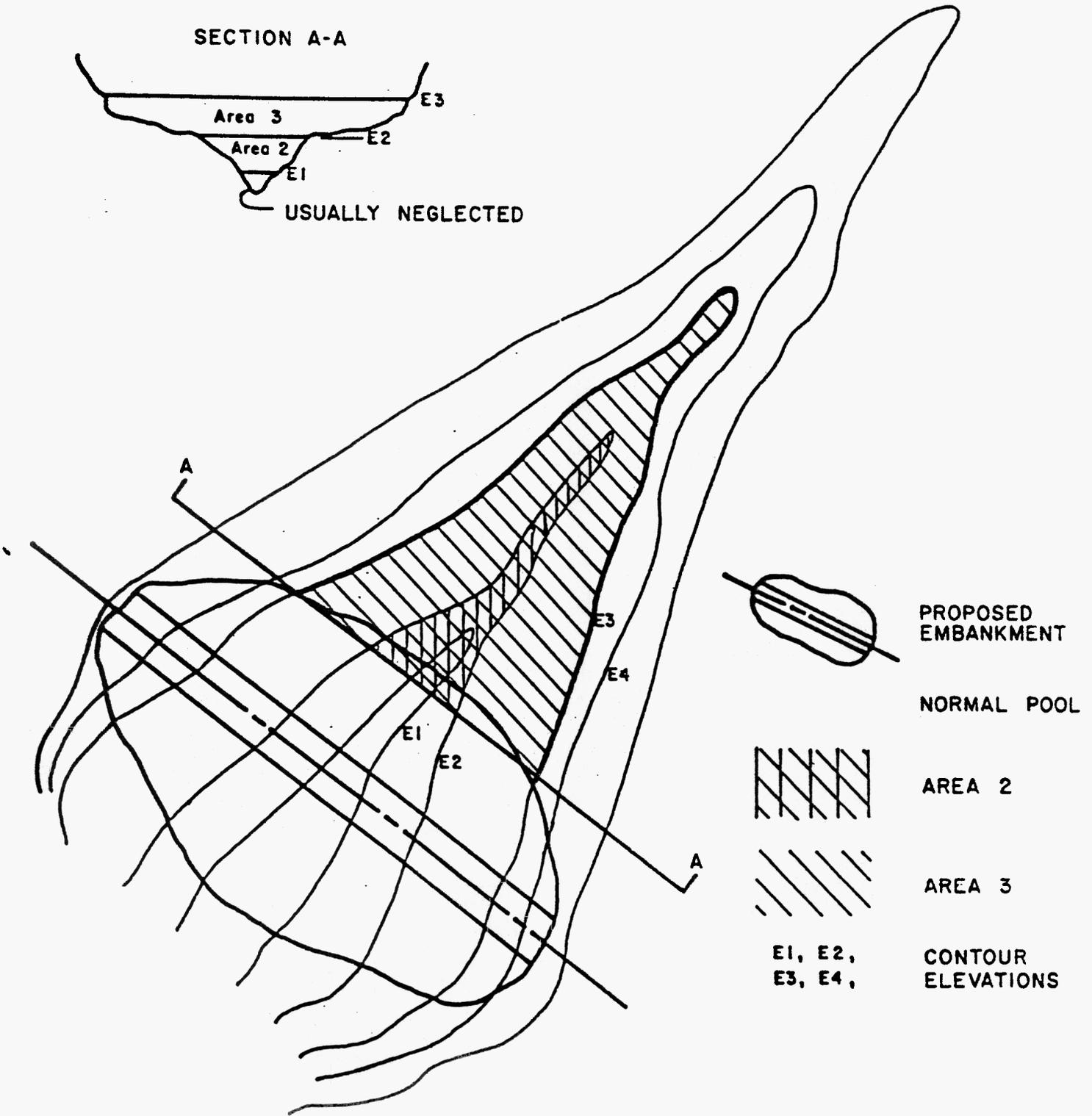


FIGURE 3.9 DEFINITION SKETCH TO DETERMINE INCREMENTAL STORAGE VOLUME

planimeter) the pool surface area at elevations E_2 and E_3 . The incremental storage volume is then calculated as the increase in elevation ($E_3 - E_2$) times the average surface area of the pool $[(A_{E_2} + A_{E_3})/2]$. Thus, a table relating storage to stage can be developed (see Table 3.4). A graph of the stage versus storage volume is then plotted.

It is left to the designer to decide how often sediment will be removed from the pond. The sediment yield during the time period between sediment removal can be computed using procedures described in Section 3.2.2.2. The sediment yield is converted to a storage volume by dividing the yield by the unit weight of the deposited sediment. Lara and Pemberton (1963) developed an equation to calculate the unit weight of the settled sediment based upon sediment size distribution and type of reservoir operation. This equation appears in several references (Barfield, 1981; Bureau of Reclamation, 1977) and the designer may consult these to compute the unit weight of the settled sediment. A unit weight of 70 lbs/ft^3 is suggested to simplify the design. Using this value of unit weight, the required sediment storage volume can be computed. The corresponding depth of the sediment in the pond can be found from the stage-storage curve.

The characteristics of sediment deposition are such that the large sized particles will settle near the inlet of the pond resulting in the formation of a delta. Delta formation is described in Section 3.8.2.2. Because the larger sized particles settle near the inlet, the sediment storage volume should be provided near the inlet of the pond. If the sediment storage volume is not provided at this location, accumulated sediment at the inlet will require frequent removal.

The detention storage volume is the storage volume required to produce the required detention time. This is the volume that is used in the water routing procedure presented in Section 3.6. The detention storage volume is determined from the stage-storage curve and is measured as the available storage volume above the elevation of the principal spillway crest. The elevation of the principal spillway crest is usually chosen as the maximum depth of the sediment storage volume unless a permanent pool is provided. When a permanent pool is provided, the permanent pool elevation will be at the elevation of the principal spillway crest.

Table 3.4. Stage-Storage Relationship Development.

Stage (feet)	Storage (feet ³)
E_1	0
E_2	$[(E_2 - E_1) \left(\frac{A_{E_1} + A_{E_2}}{2}\right)] = S_2$
E_3	$S_2 + [(E_3 - E_2) \left(\frac{A_{E_2} + A_{E_3}}{2}\right)] = S_3$
E_4	$S_3 + [(E_4 - E_3) \left(\frac{A_{E_3} + A_{E_4}}{2}\right)] = S_4$

3.8 Sedimentation Pond Configuration

The design of the sedimentation pond configuration is based upon ideal settling conditions. In actual field situations, ideal settling conditions are often difficult to reproduce. This necessitates the need to incorporate factors into the design which account for nonideal settling conditions. The following sections discuss the design of the pond configuration based upon ideal settling, factors which produce nonideal settling, and what factors are used to compensate for nonideal settling conditions.

3.8.1 Ideal Settling

Based upon ideal settling conditions, there is a direct relationship between the detention storage depth of the pond and the detention time. This relationship can be expressed as

$$V_s = \frac{D}{3600 T_D} \quad (3.8)$$

where, V_s = particle settling velocity (fps),

D = detention storage depth (ft), and

T_D = detention time (hours).

The particle settling velocity is defined by Stoke's Law and is dependent upon temperature of the water, particle size, and specific gravity of the particle. To determine the design particle size as presented in Section 3.5, the temperature of the water was assumed 77° F, since this is part of the Imhoff cone test and sets the criteria which must be satisfied. In the field, the temperature of the water runoff will be closer to 50° F. For the same particle size, settling will take longer in the water which is 50° F than in the water which is 77° F. Therefore, design of the sedimentation pond is based upon the water being 50° F. Assuming a water temperature of 50° F and the specific gravity of the particle to be 2.65, Stoke's Law may be written as

$$V_s = 2.254 d^2 \quad (3.9)$$

where, V_s = particle settling velocity (fps) and

d = particle diameter (mm).

The result of combining Equations 3.8 and 3.9 is

$$2.254 d^2 = \frac{D}{3600 T_D} \quad (3.10)$$

Figure 3.10 presents the relationship between the particle diameter and detention time for various depths using Equation 3.10. To settle any size particle, the required detention time for various depths can be found from Figure 3.10 or computed by Equation 3.10.

There is also a direct relationship between the flow length of the pond and the detention time. This relationship is represented as

$$V_H = \frac{L}{3600 T_D} \quad (3.11)$$

where, V_H = horizontal flow velocity through the pond (fps),

L = flow length of the pond (ft), and

T_D = detention time (hours).

The horizontal flow velocity through the pond can be computed as

$$V_H = \frac{Q_o}{WD_1} \quad (3.12)$$

where, Q_o = peak outflow rate (cfs),

W = average width of the pond (ft), and

D_1 = total depth of the pond (ft).

Combining Equations 3.11 and 3.12 results in

$$L = \frac{3600 T_{D_1} Q_o}{WD_1} \quad (3.13)$$

where, T_D , Q_o , W are as defined in Equation 3.11 and

D_1 = sediment storage depth plus detention storage depth, and

T_{D_1} = detention time for depth D_1 from Equation 3.10.

Equation 3.13 gives the required flow length of the pond to settle the design particle size. This equation is used as a check after the pond storage volume

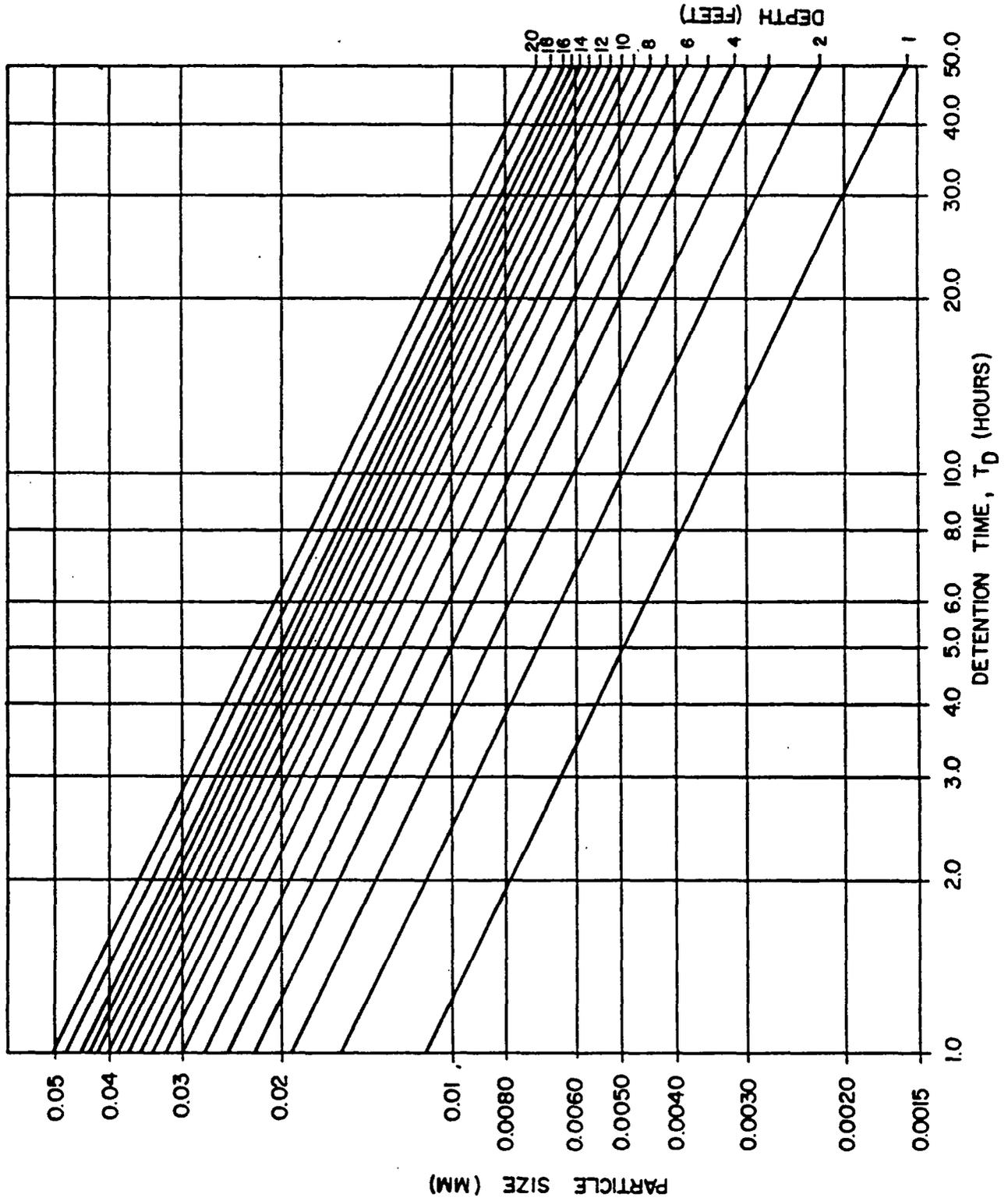


FIGURE 3.10 PARTICLE SIZE VERSUS DETENTION TIME FOR VARIOUS DEPTHS

and outflow rate have been established. The total depth is used in Equation 3.13 since the particle will be required to settle this depth just after the pond construction is completed. If the required flow length cannot be achieved, measures described in Section 4.2 can be taken to increase the flow length of the pond.

3.8.2 Nonideal Settling

As presented so far, the design of sedimentation ponds have been based on ideal settling conditions. However, in the field it is difficult and often impossible to provide ideal settling conditions. Variations from ideal settling are caused by several factors. These factors are not independent conditions; they are all interrelated and cause deviations from ideal settling reducing the efficiency of the sedimentation pond. The conditions causing variation from ideal settling are:

- Flow currents within the pond
- Reservoir deposition
- Short circuiting and turbulence
- Scour and resuspension

3.8.2.1 Flow Currents

Various types of flow currents can exist within sedimentation ponds. The most common being those caused by wind blowing over the surface of the pond. Convection currents can also exist due to significant differences of temperature within the pond.

Often during storm runoff events, the inflow to the pond is typically more dense due to high suspended solids concentrations. This results in a density current that flows along the bottom of the pond. This localized increase in flow can cause scour and resuspension of settled solids and significantly reduce the trap efficiency if the outlet to the pond is located near the bottom.

All types of currents transport suspended material throughout the pond both vertically and horizontally and distort the flow pattern from that assumed under ideal settling. The result is a reduction in the performance of the pond.

3.8.2.2 Delta Formation

As the sediment-laden inflow passes from the inlet channel to the sedimentation pond, the forward velocity of the flow is reduced due to increase in flow width and flow depth. This results in the larger sized particles being deposited almost immediately as flow enters the sedimentation pond. Deposition of the larger sized particles near the inlet of the pond will result in the formation of a delta. Figure 3.11 shows a delta formation near the inlet of the pond. The delta will continue to grow larger and will gradually migrate downstream within the pond. The consequence of a delta formation is reduced detention time. Therefore, small particle sizes are not given enough time to settle to the bottom of the pond.

3.8.2.3 Short Circuiting and Turbulence

Short circuiting is the flow of water through a sedimentation pond directly from the inlet to the outlet resulting in dead storage areas and reduced detention times. Figure 3.12 presents some typical sedimentation pond shapes which have short circuiting. Short circuiting and turbulence are caused by flow currents (as previously discussed), high inlet velocities, high outlet flow rates, sedimentation pond geometry, and improper location of inlets and outlets. When short circuiting occurs, the effective width of the flow area through the pond is reduced and the flow velocity through the pond is greater. This effect reduces the settling characteristics and increases potential for scour and resuspension of settled sediments.

3.8.2.4 Scour and Resuspension

Scour and resuspension is caused by density currents and high flow rates through the sedimentation pond. The scour velocity is defined as that velocity of flow required to initiate motion of a discrete particle. Resuspension of the design particle size will result in effluent limitations not being satisfied.

3.8.3 Control of Nonideal Settling

The significant factors which affect ideal settling are short circuiting, turbulence, and scouring of the settling sediment. In the following sections criteria are set to minimize these effects. These criteria are length-to-width

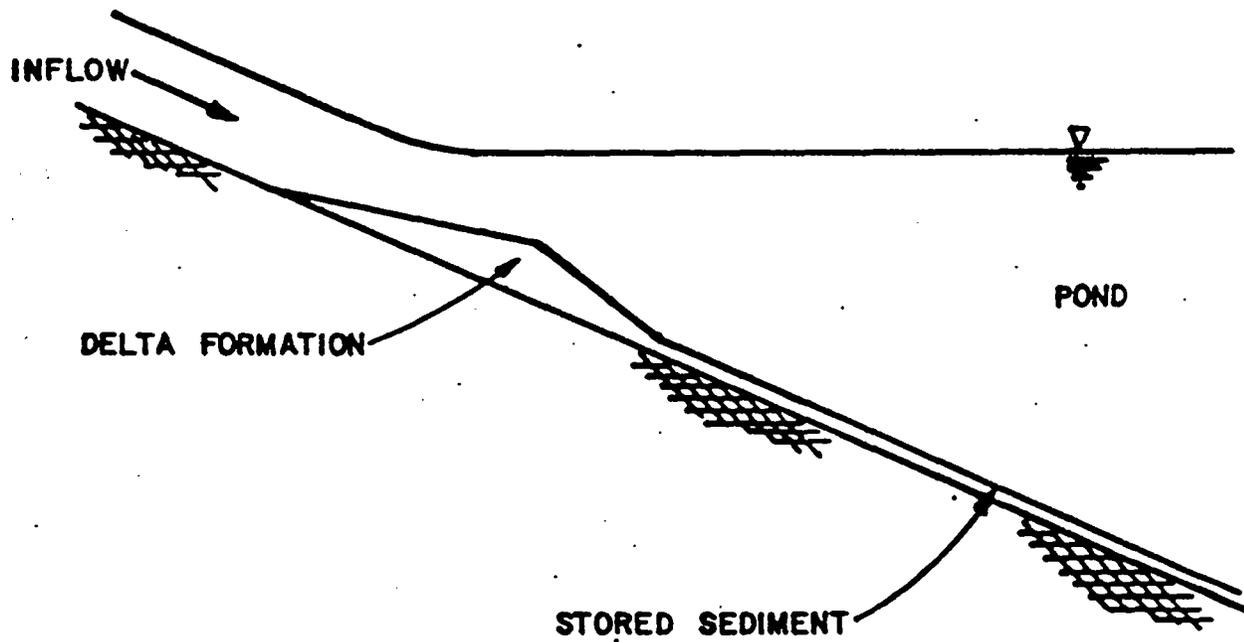


FIGURE 3. II SCHEMATIC OF DELTA FORMATION
(AFTER GRAF, 1974)

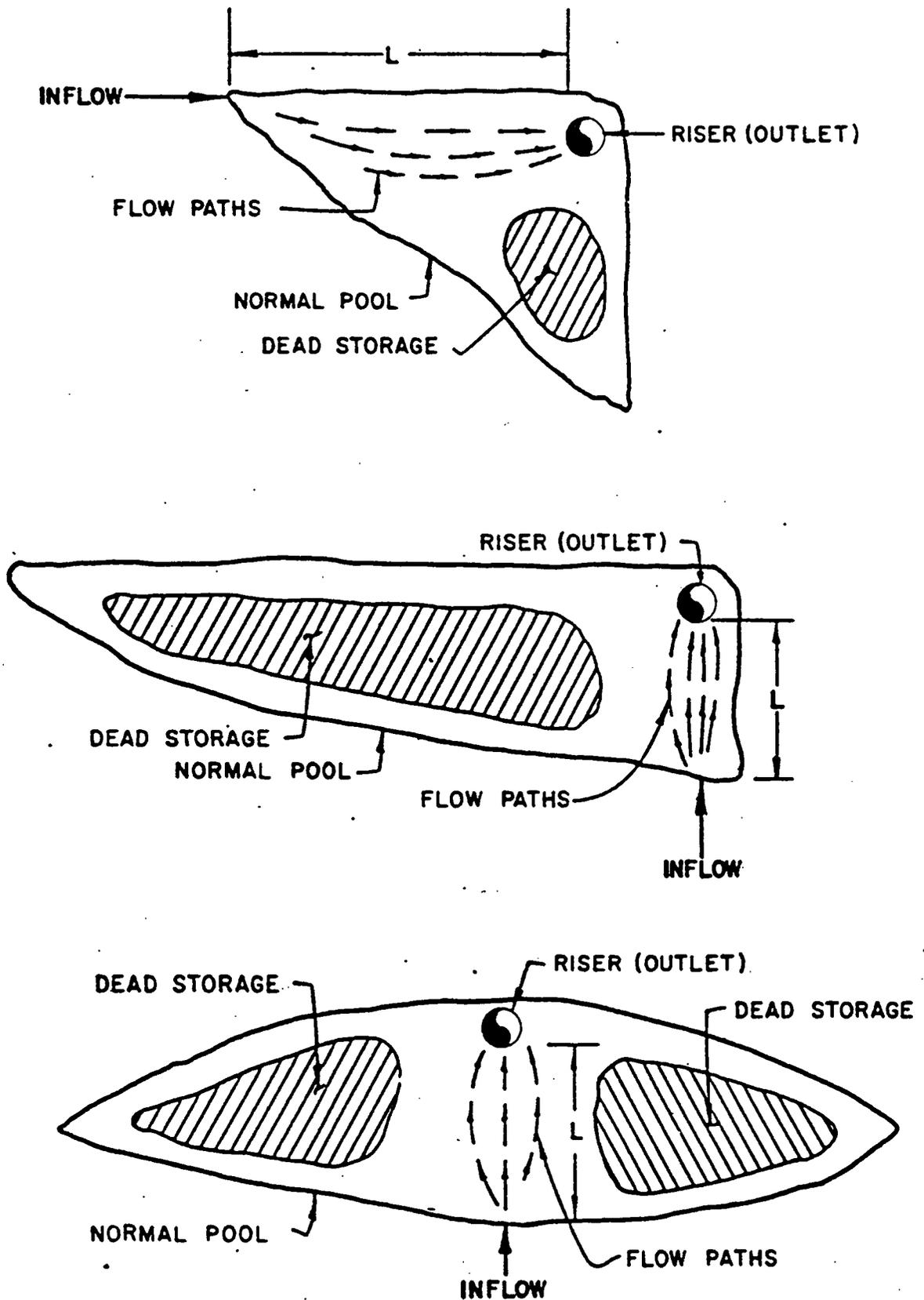


FIGURE 3.12 SEDIMENTATION PONDS WITH DEAD STORAGE SPACES (AFTER HAAN & BARFIELD, 1978)

ratio, short-circuiting factor, permissible inlet velocity, and permissible flow-through velocity. The sedimentation pond must meet these criteria to ensure that the desired sediment removal is attained.

3.8.3.1 Short-Circuiting Factor

Research by Camp (1946) on various types of settling basins has resulted in the development of a short-circuiting compensation factor based on the shape of the basin geometry. It has been recommended that the surface area of a settling basin be increased to account for nonideal settling conditions according to

$$A = \left(\text{FSC} \times \frac{Q_o}{V_s} \right) \quad (3.14)$$

where, A = surface area of the pond at the elevation of the principal spillway crest (ft^2),

FSC = short-circuiting factor,

Q_o = outflow rate (cfs), and

V_s = settling velocity of the design particle size (fps).

The value of FSC is generally 1.2. Equation 3.14 will yield the required surface area that is needed in the pond at the elevation of the principal spillway crest. There are three measures that can be taken if the pond surface area does not meet the requirement of Equation 3.14. The pond side slopes can be excavated, the elevation of the principal spillway crest can be raised, or application of multiple ponds.

3.8.3.2 Length-to-Width Ratio

The ratio between the flow length and the effective width of the sedimentation pond is used as a design aid to minimize short circuiting. Specifying a length-to-width ratio allows for utilization of the full surface area of the sedimentation pond and helps maintain a constant horizontal velocity through the sedimentation pond. The length that is used is the shortest distance that the water must flow from the inlet to the outlet of the pond. The width used in the computation is the effective width of the sedimentation pond. This is determined by dividing the surface area by the length from the inlet to the

outlet. The surface area of the pond is measured at the elevation of the principal spillway crest.

It is general practice to specify a minimum length-to-width ratio of 2:1. Larger length-to-width ratios will promote improved performance and values of up to 5:1 have been recommended. The length-to-width ratio is determined after the pond storage volume and outflow rate have been established. If this ratio cannot be satisfied, the flow length can be increased. Section 4.2 describes the measures that can be taken to increase the flow length.

Both the short-circuiting factor and the length-to-width ratio compensate for nonideal settling conditions. The short-circuiting factor determines only the required surface area, whereas the length-to-width ratio defines the shape of the surface area.

3.8.3.3 Permissible Inlet Velocity

For a sedimentation pond to be effective in sediment removal, the velocity of the flow into the pond must be small enough to prevent short circuiting. The criteria is used to limit the Froude number in the inlet channel to 1.0. The Froude number is defined as

$$F_r = \frac{V}{\sqrt{gD}} \quad (3.15)$$

where, F_r = Froude number,

V = velocity in the inlet channel (fps),

g = gravitational acceleration (32.2 ft/sec²), and

D = depth of flow in the inlet channel (ft).

If the Froude number in the inlet channel is greater than 1.0, inlet control measures will be required. These measures are discussed in Section 4.2.

3.8.3.4 Permissible Flow-Through Velocity

The horizontal flow velocity through the pond must be less than the scour velocity of the design particle size to avoid resuspension of the settled sediment. The scour velocity for a specific particle size is determined by

$$V_{sc} = \sqrt{\frac{8B}{F} g(S_s - 1) d} \quad (3.16)$$

where, V_{sc} = scour velocity,

B = Shields' critical shear stress parameter (0.047 for uniform sand),

g = gravitational acceleration (32.2 ft/sec²),

S_s = specific gravity of particle (usually 2.6 to 2.8),

d = diameter of spherical particle (ft),

F = Darcy-Weisbach friction factor (usually 0.02 to 0.03).

Assuming that Shields' critical shear stress parameter is equal to 0.05, the specific gravity of the particle is 2.65, and the Darcy-Weisbach friction factor is 0.025, Equation 3.16 can be reduced to

$$V_{sc} = 1.67 d^{1/2} \quad (3.17)$$

where, V_{sc} = scour velocity (fps) and

d = particle diameter (mm).

The horizontal velocity through the pond is

$$V_H = \frac{Q_o}{WD} \quad (3.18)$$

where, V_H = horizontal flow velocity (fps),

Q_o = outflow rate (cfs),

W = average width of sediment pond (ft), and

D = detention storage depth (ft).

If the horizontal velocity through the pond is greater than the scour velocity for the particle that must be settled, the depth can be increased to reduce the horizontal velocity which will also increase the width and decrease the outflow rate.

3.9 Sedimentation Pond Outlet Control Measures

Sedimentation ponds must provide a principal spillway and an emergency spillway. Principal spillways are designed to provide sufficient detention time during the design precipitation event to meet the effluent limitations and dewater the pond. Emergency spillways are designed to work in conjunction with the principal spillway and pond storage to safely discharge the peak runoff resulting from the design storm. The design procedure presented in Chapter VI develops the design discharge for sizing the principal spillway and the elevation above the bottom of the pond. Actual design of the outlet is not covered in this section. Several references provide design procedures for sizing standpipe and culvert-type spillways (U.S. Department of Transportation, 1965; Barfield 1981; Bureau of Reclamation, 1974; Soil Conservation Service, 1969). The following discussion presents important design considerations for principal and emergency spillways, various types and configurations, and effectiveness.

3.9.1 Principal Spillways

The principal spillway is sized to provide a discharge rate as determined through design of the sedimentation pond. Actual design should include evaluation of local drainage conditions, water rights, economics, land-use constraints, and requirements of local, state and federal regulations. Design of the principal spillway should not be independent of the design of the earth embankment and emergency spillway.

The types of principal spillways commonly used can be classified into three categories: open channel, drop inlet and pipe culverts. The type of spillway used is based on local site-specific conditions.

3.9.1.1 Open Channel Spillways

Open channel spillways should only be used when all other alternatives have been shown to be infeasible. This type of spillway provides no means of dewatering the pond. Typically open channel spillways are located on small drainage basins. Design of open channel spillways to meet effluent standards during base flow and design storm conditions is very difficult. When an open channel is used for the principal spillway it often is designed for the emergency capacity, or the emergency spillway is also an open channel. Open

channel spillways do not provide as much control of discharge or flexibility to modification as drop inlets or pipe culverts. Further discussion of open channel spillways is covered in Section 3.9.4 on emergency spillways.

3.9.1.2 Drop Inlet Spillways

Drop inlet spillways are one of the most common types of principal spillways used for sedimentation ponds. A drop inlet spillway is quite flexible in design, offers good control of discharge, and is well adapted to sedimentation ponds. A recommended minimum size for drop inlets is 12 inches in diameter. This minimum size provides accessibility for maintenance and cleaning. When the design discharge for meeting effluent requirements results in a spillway size smaller than 12 inches in diameter, a 12-inch pipe is used with an orifice of the required size opening affixed to the inflow end of the drop inlet.

Configuration of a typical drop inlet is shown in Figure 3.13. A drop inlet has two main features, the barrel and riser. The riser and barrel can be of concrete, reinforced concrete, polyvinyl chloride (PVC), corrugated or smooth metal pipe. The selection of the type of material used should consider site conditions and economics.

In designing drop inlets an important consideration is anchoring of the riser and barrel on the bottom of the pond, and seepage along the barrel. Failure of the riser to stay anchored is a common problem. Anchoring of risers should consider the size of the riser, local soil type, type of pond, and weather conditions. If the pond is a permanent pool it is susceptible to freezing, and the forces created by the forming ice should be considered.

Seepage along the barrel is often the cause of dam embankment failure. The problem generally occurs due to the lack of compaction around the barrel during construction of the embankment.

3.9.1.3 Pipe Culvert Spillways

Another type of principal spillway commonly used is the pipe culvert, also referred to as a "trickle tube." It consists of a pipe laid in the earth in such a manner that the entrance elevation of the pipe (at the upstream end) establishes the normal pool elevation in the pond. Figure 3.14 shows a typical pipe culvert arrangement. Pipe culvert spillways require the same con-

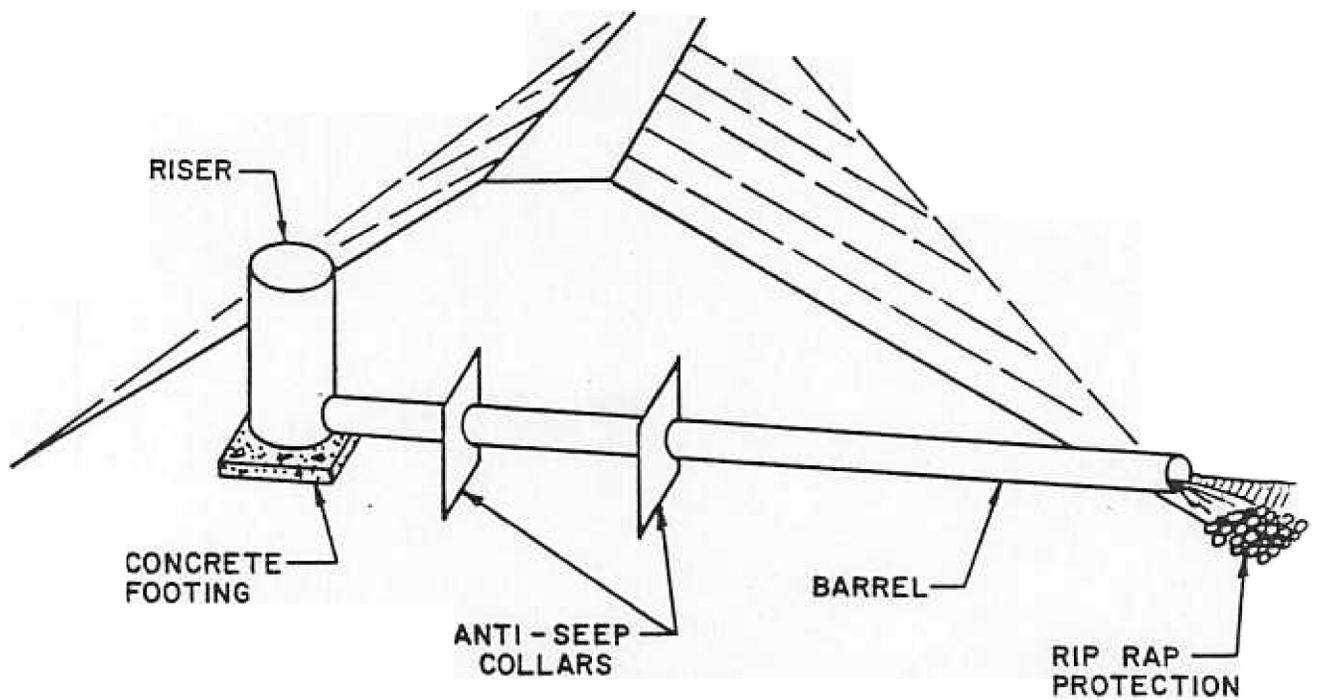


FIGURE 3.13 TYPICAL DROP INLET SPILLWAY

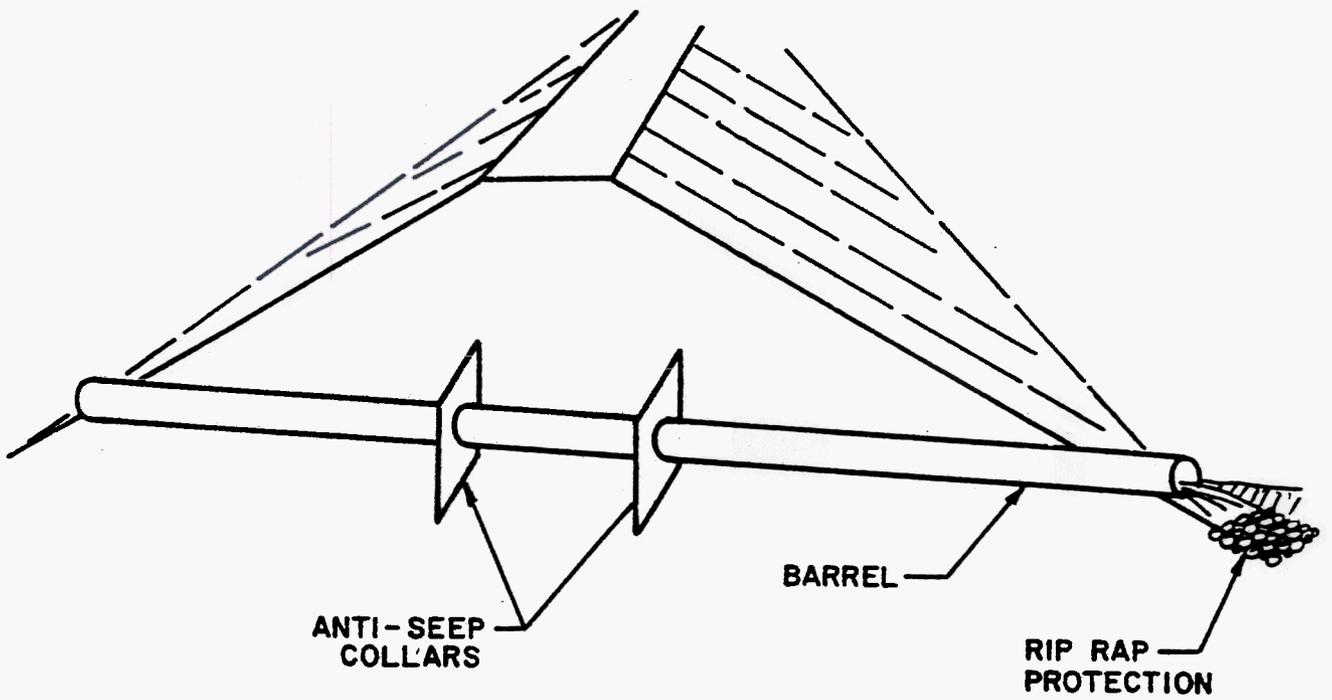


FIGURE 3.14 TYPICAL PIPE CULVERT SPILLWAY

sideration as drop inlet spillways do for seepage, minimum size and type of material.

3.9.1.4 Efficiency of Principal Spillways

In this section the efficiency of principal spillways is discussed in general. In Section 3.9.3 various modifications to principal spillways and their effect on discharge quality are presented. The size of the principal spillway is designed to convey the discharge required to achieve removal of sediment. The design discharge is determined during design of the sediment pond. Once the design discharge is properly determined, the effect of principal spillways on discharge quality is based on location, in relation to the geometry of the pond, and flow characteristics at the inlet end of the spillway.

The primary concerns in location of the principal spillway are an effective surface area and short circuiting. As discussed in Sections 3.8.2 and 3.8.3, the length-to-width ratio should be a minimum of 2:1, and a ratio of 5:1 is recommended. As the distance between the spillway and the pond inlet decreases, the effective surface area decreases. As the effective surface area decreases, the occurrence of short circuiting and turbulence is more likely, and the overall efficiency of the pond is reduced. The reduction in pond efficiency is variable and based on site-specific conditions. However, an estimate of the reduced efficiency can be based on the reduction in effective surface area of the pond.

The level at which the inlet of the principal spillway exists within the pond affects the efficiency of the pond. Because the sediment settles to the bottom of the pond, it is clear that there will be less sediment at the surface than near the bottom of the pond. Thus discharging from near the surface of the pond can improve the efficiency. This characteristic has been shown through use of floating weir devices and is discussed further in Section 3.9.3.2.

Due to the turbulent nature at the principal spillway inlet, scour and resuspension of settled sediment is likely. The amount of scour and resuspension around a spillway is related to the elevation of the settled sediment. As the level of settled sediment approaches the elevation of the inlet of the spillway, scour and resuspension increase. Scour and resuspension are often

associated with dewatering. When dewatering is required it is impossible to avoid some resuspension and scour at all times. Comparison of various dewatering methods is presented in the following section.

3.9.2 Dewatering Devices

Dewatering is usually required to drain the sediment pond between runoff storms so adequate storage volume within the pond is maintained. Dewatering devices are not necessary when draining below the principal spillway is not required. Several methods of dewatering are used, including perforated risers, subsurface drainage, a single perforation with associated use of a skimmer baffle or a type of gate valve, siphon arrangement attached to the riser and/or pumping.

The use of perforated standpipe or riser for dewatering is required by some states. However, sediment is carried out of the pond through the perforations because of resuspension of settled solids due to turbulence near the perforations or because sediment is allowed to accumulate too high along the riser barrel. Use of a perforated riser is not recommended.

In the subsurface drain arrangement, a (four-inch) perforated plastic pipe network is laid in a trench in the bottom of the pond and covered with a fabric filter and sand as shown in Figure 3.15. The pipe is connected to the riser and the pond is dewatered through the sand filter/perforated pipe arrangement by gravity.

There are two advantages of a subsurface drain arrangement: (1) complete dewatering of the settled sediment is possible to aid in removal and disposal, and (2) no turbulence or resuspension of settled sediment is associated with this method. However, major disadvantages are clogging of the sand filter and filter fabric due to the nature of the settled sediment, the permeability of the settled sediment could result in exceedingly long dewatering time, and the added expense of installing this type of pipe arrangement.

A single perforation at the sediment cleanout level with a skimmer-baffle is shown in Figure 3.16. The single perforation method is easy to construct and is capable of completely draining the pool to the sediment clean-out level. With a skimmer, the perforation is non-clogging, fairly easy to construct, and an efficient skimmer of surface debris. Some type of valve can also be used to gate the perforation which allows control over the desired

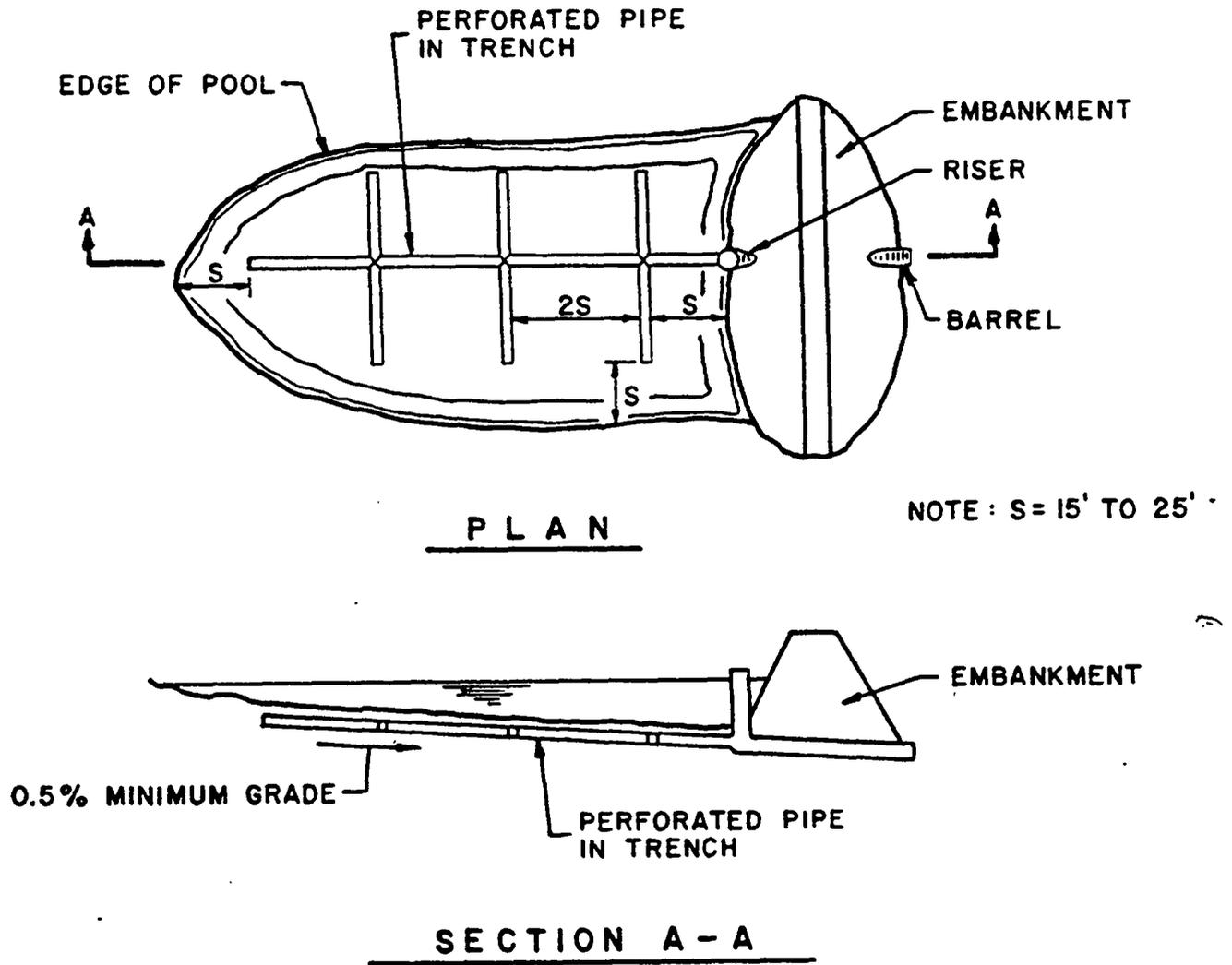
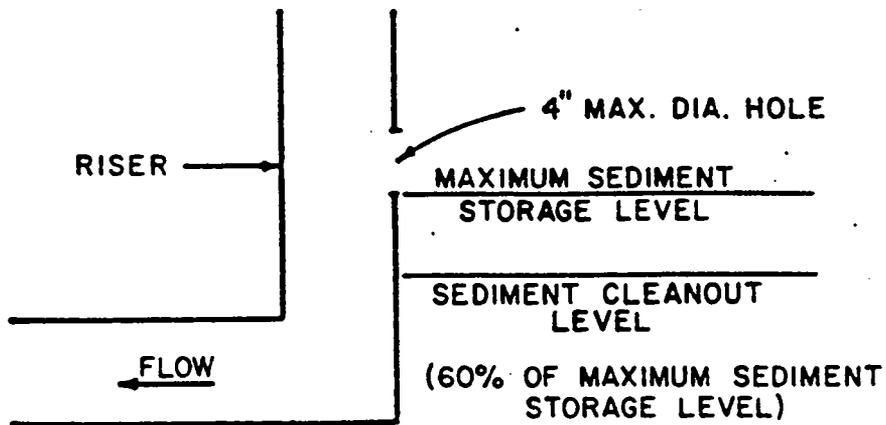
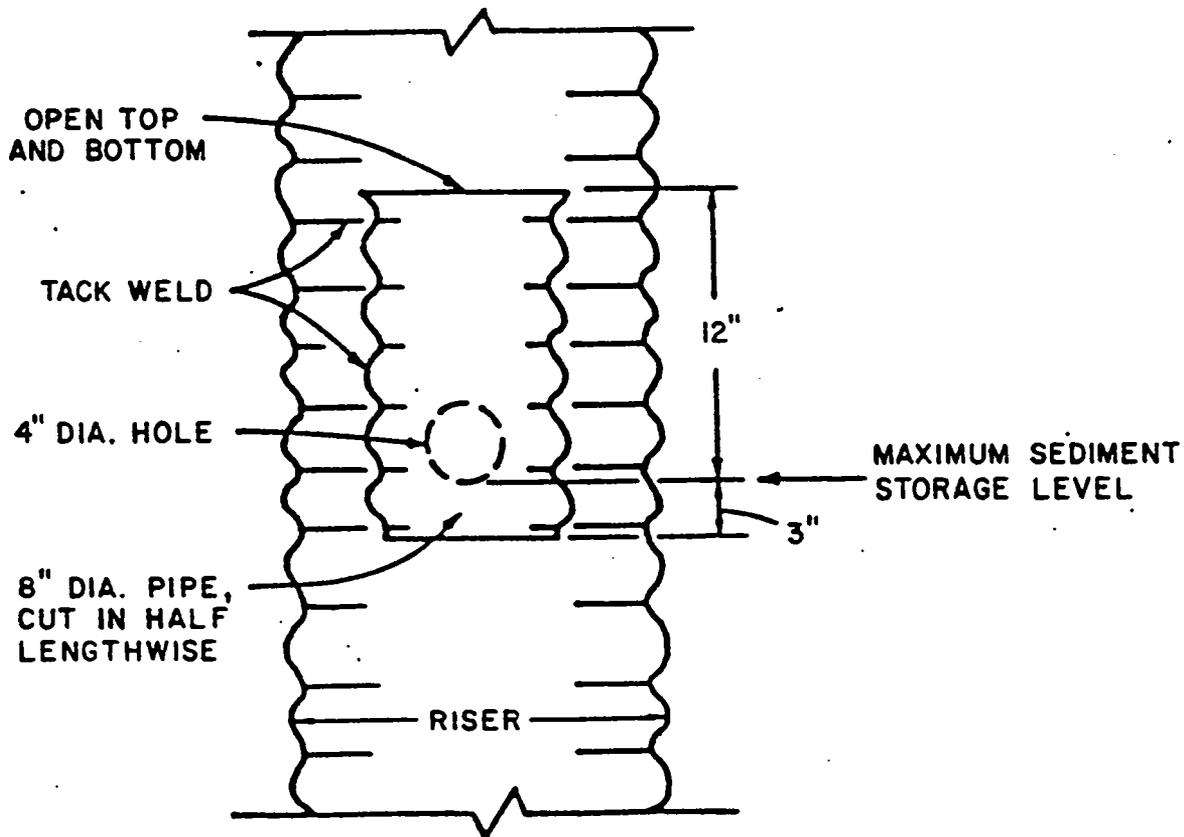


FIGURE 3.15 SUBSURFACE DRAIN (EPA, 1977)



**SINGLE PERFORATION
CROSS SECTION**



**SINGLE PERFORATION WITH SKIMMER
ELEVATION**

FIGURE 3.16 SINGLE PERFORATION OF RISER BARREL (EPA, 1977)

detention time before dewatering the pond. With the perforation, gated dewatering can be done after the runoff event is over and the required removal of sediment has occurred, thus reducing the amount of sediment discharged during dewatering.

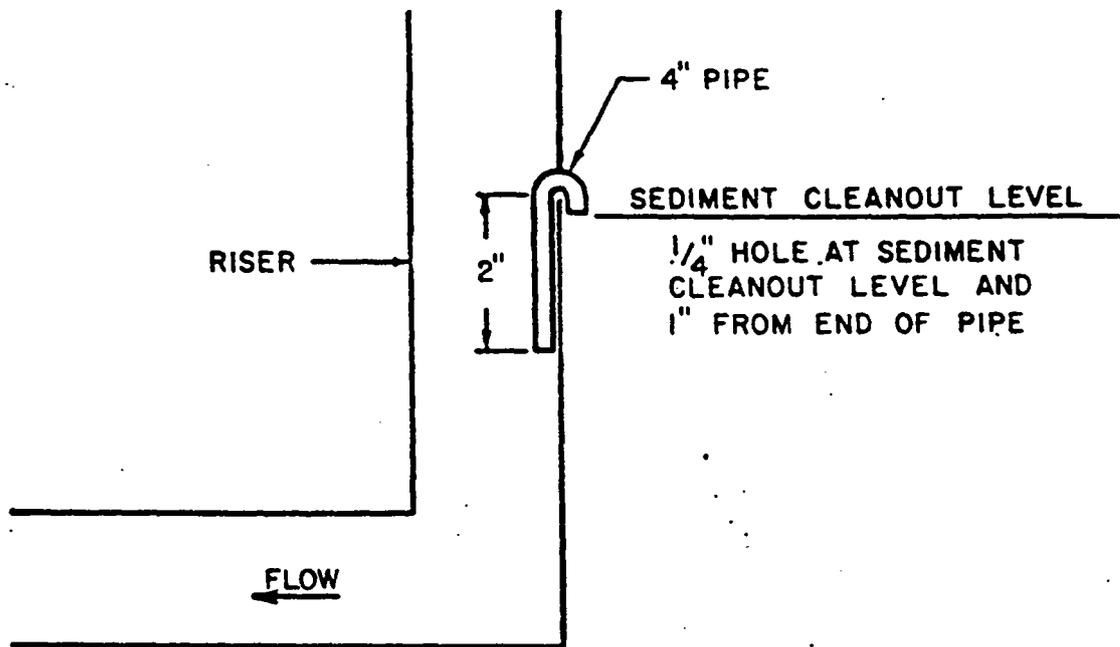
With the siphon methods of dewatering, a (four-inch) pipe siphon can be substituted for the single perforation as described previously (Figure 3.17). The length of siphon depends on the dewatering time desired. In each case, the inlet to the siphon is placed at the elevation of the sediment clean-out level to facilitate drainage without removing sediment. The siphon is also an efficient skimmer of surface debris, will always drain the pond to the sediment clean-out level, and has a higher discharge capacity than the single perforation method with the same size of opening.

For excavated ponds without a permanent pool, risers may not be practical. Therefore, a self-priming or portable pump can be used to dewater the pond.

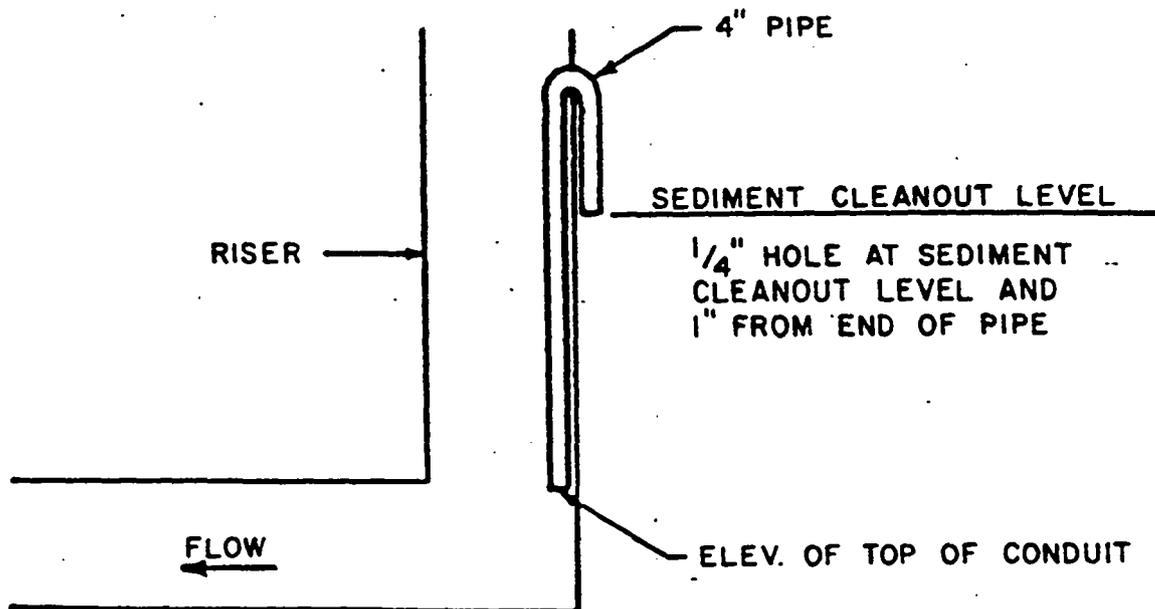
The effect of dewatering devices on the discharge quality depends greatly on the level of sediment in the pond. When sediment is allowed to accumulate up to the dewatering outlet, the amount of scour and resuspension of settled sediment increases, decreasing the discharge quality. Therefore proper maintenance and sediment removal can decrease the effects of dewatering. It is recommended that the sediment be cleaned out when it reaches 60 percent of the design sediment storage. For properly designed and constructed dewatering devices, the ability to maintain the discharge quality can be related to the level of control at the dewatering device. Perforated risers and single perforations provide less control than a single perforation with a baffle skimmer or a siphon type arrangement. A gate on the dewatering opening provides the most control by enabling the operator to vary the detention time and physically verify that the sediment has settled before dewatering the pond.

3.9.3 Principal Spillway Modifications

The purpose of modifications to drop inlet or pipe culvert spillways is to reduce short circuiting, eliminate turbulence, and thus increase trapping efficiency of the pond. After proper sizing, the effectiveness of a principal spillway is related to location within the pond, discharge point from within the pond, and turbulent flow conditions at the outlet. As discussed in



A. SHORT SIPHON CROSS-SECTION



B. LONG SIPHON CROSS-SECTION

FIGURE 3.17 SIPHON DEWATERING METHODS (EPA, 1980)

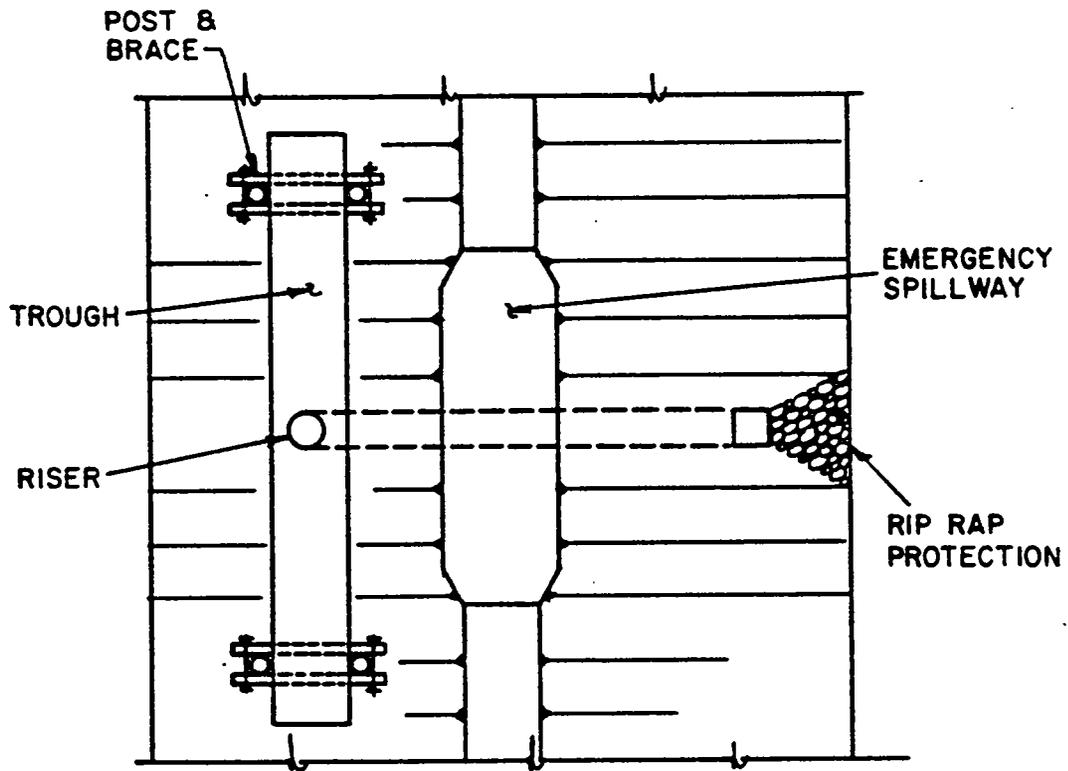
Section 3.8.2.3, short circuiting and turbulence can reduce the trapping efficiency of the sedimentation pond. Studies of existing ponds have shown poor pond performance as a result of short circuiting and turbulence at the outlet of the pond (reference EPA, 1980; EPA, 1979; EPA, 1976). Several studies have made recommendations as to what spillway modifications can help improve the sediment removal efficiency of a particular pond. The following discussion presents some of the more commonly used modifications and their effects on discharge quality.

3.9.3.1 Weir Troughs

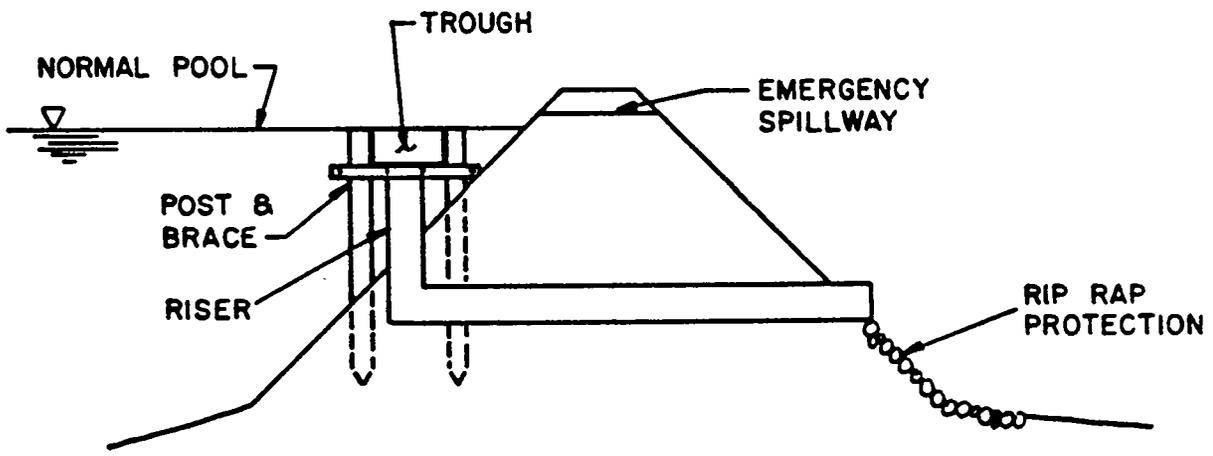
Drop inlets and culvert spillways are single point outlets that usually create short circuiting and resuspension. One modification that eliminates the point discharge is a weir trough connected to the outlet. A weir trough discharges along the length of the weir and creates less turbulence than a single discharge point. By discharging from more than a single point the flow-through area and effective surface area are also increased. Thus, by reducing turbulence and increasing the effective surface area, a weir trough outlet can provide improved discharge quality over that of a single point discharge outlet. Figure 3.18 shows a typical weir trough arrangement. In application of a weir trough, structural integrity and maintenance are required for effective operation and performance. Weir troughs are susceptible to the same structural problems as baffles (see Section 4.2.2.2).

3.9.3.2 Floating Discharge

Typical principal spillways are generally fixed and discharge from the same point elevation. As the water surface elevation in the pond rises above the spillway elevation, the concentration of sediment increases due to the settling of particles from the surface down. From this it is easy to see that the minimum concentration within the pond will be near or at the water surface elevation. Therefore, the discharge quality can be improved by discharging from the surface of the pond. A variable elevation discharge orifice has been field tested by OSM. Three tests were conducted using different outlet sizes. The results of the test showed settleable solids concentration in the discharge to be consistently less for the pivotal elbow type outlet as compared to a typical perforated riser outlet. This device was adapted from



PLAN



ELEVATION

FIGURE 3.18 WEIR TROUGH

floating weir spillways originally suggested for management of fish ponds. Figure 3.19 shows the device tested by OSM. The floating weir (or inclined arm) allows removal of surface water regardless of surface elevation. The floating weir consists of a riser pipe connected to the drain via a pivotal 90° elbow designed and constructed to enable quarter rotation about the axis of the drain. Buoyancy and submerged depth of the orifice are adjusted by weights and flotation jugs to maintain the orifice to two to four inches below the water surface (OSM, draft report). Discharge is controlled by varying the orifice size. Another advantage to this device is that it can also provide dewatering of the pond.

3.9.3.3 Filtering

As in municipal water treatment, filtering of the discharge can greatly improve the quality by removing finer sediments that do not settle out in the pond. Riser pipe filters have been used to improve trapping efficiency. Riser pipe filters include cloth or fiberglass wraps and gravel cones placed around the filters. The filter wraps have been found to be fairly effective in trapping fine particles. However, the filter wraps become clogged very rapidly (Oscaryan, 1975). This clogging may cause the water level in the pond to rise above the riser crest, thus negating the filter effect.

Another inexpensive filtering mechanism is the use of straw bales around an outlet. This method is most applicable to pipe culverts. Straw bales, like filter wraps, are effective in trapping fine particles; however, they require frequent maintenance.

3.9.3.4 Gated Spillways

A gated spillway gives the operator complete control of the discharge from the pond. With the gate closed the pond is allowed to fill and completely store the runoff from a rainfall event. After an adequate time period for settling of the sediment, the gate valve is opened and the pond allowed to drain.

Gated spillways are applicable only to ponds that do not have a constant base flow or ponds on ephemeral drainages. The pond should be designed to store the entire runoff volume from the design rainfall event. Often times ponds with gated spillways are designed to store twice the design runoff

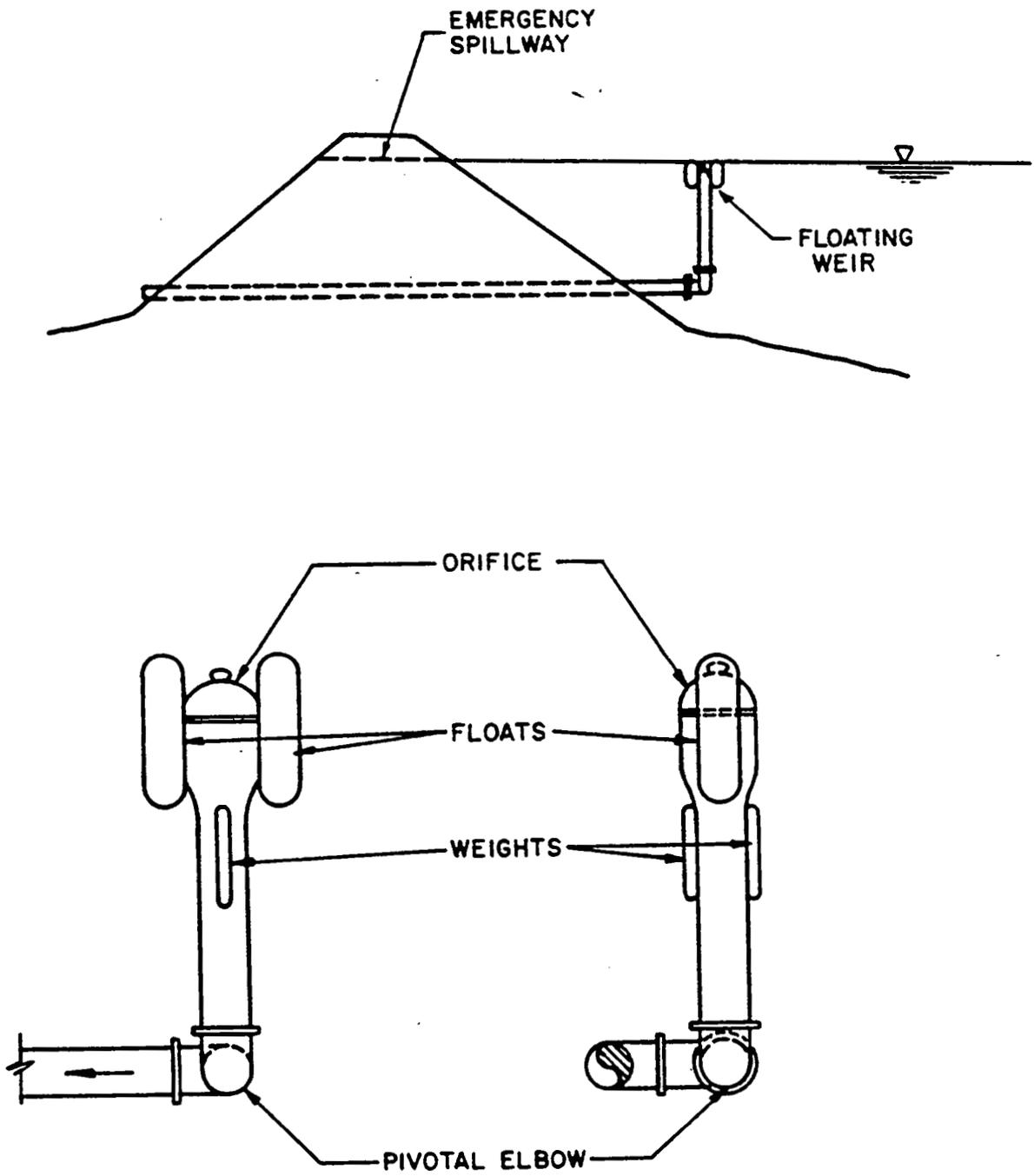


FIGURE 3.19 FLOATING WEIR

volume due to the nature of one or more rainfall events to occur within a short time period.

Slide gates or butterfly valves are usually used for control at the downstream end of the outlet conduit. Gates can also be used at the upstream end (within the pond) of the spillway, however, access must be provided when the pond is full. Again, proper maintenance is necessary to keep the valves in good working condition.

Gated spillways have an indirect effect on discharge water quality. As stated previously, a gated spillway enables the operator to increase the detention time within the pond. Thus, the longer the operator is able to store the runoff in the pond, the more settling can take place, and thus improve the discharge water quality.

3.9.3.5 Anti-Vortex Devices

An anti-vortex device is used to reduce turbulence at the outlet and to reduce the range of headwater depth where slug-flow action prevails and to allow full pipe flow to occur at a lower headwater depth. Slug-flow action results from the induction of air into the conduit by entrance drawdown and vortices immediately upstream of the inlet. If no anti-vortex device is used, discharge efficiency values may be reduced by up to 50 percent (SCS, 1975).

Anti-vortex devices include grills, racks, vertical plates, or fixed solid hoods placed to break up the vortices or to prevent their formation where they could feed air into the conduit (Figure 3.20). In order to be effective, the hood or grill must be placed immediately above the entrance and the area between the inside of the anti-vortex device and the outside of the riser must be equal to or greater than the area inside the riser.

Another anti-vortex device is a thin, vertical plate normal to the centerline of the dam and firmly attached to the top of the riser. Length of the plate must equal the diameter of the riser plus 12 inches and height must equal the diameter of the barrel.

3.9.4 Emergency Spillways

Emergency spillways are used to convey large flood events safely out of the pond without overtopping or breaching the dam. For dams less than 20 feet in height or 20 acre-feet in active storage, OSM requirements call for design-

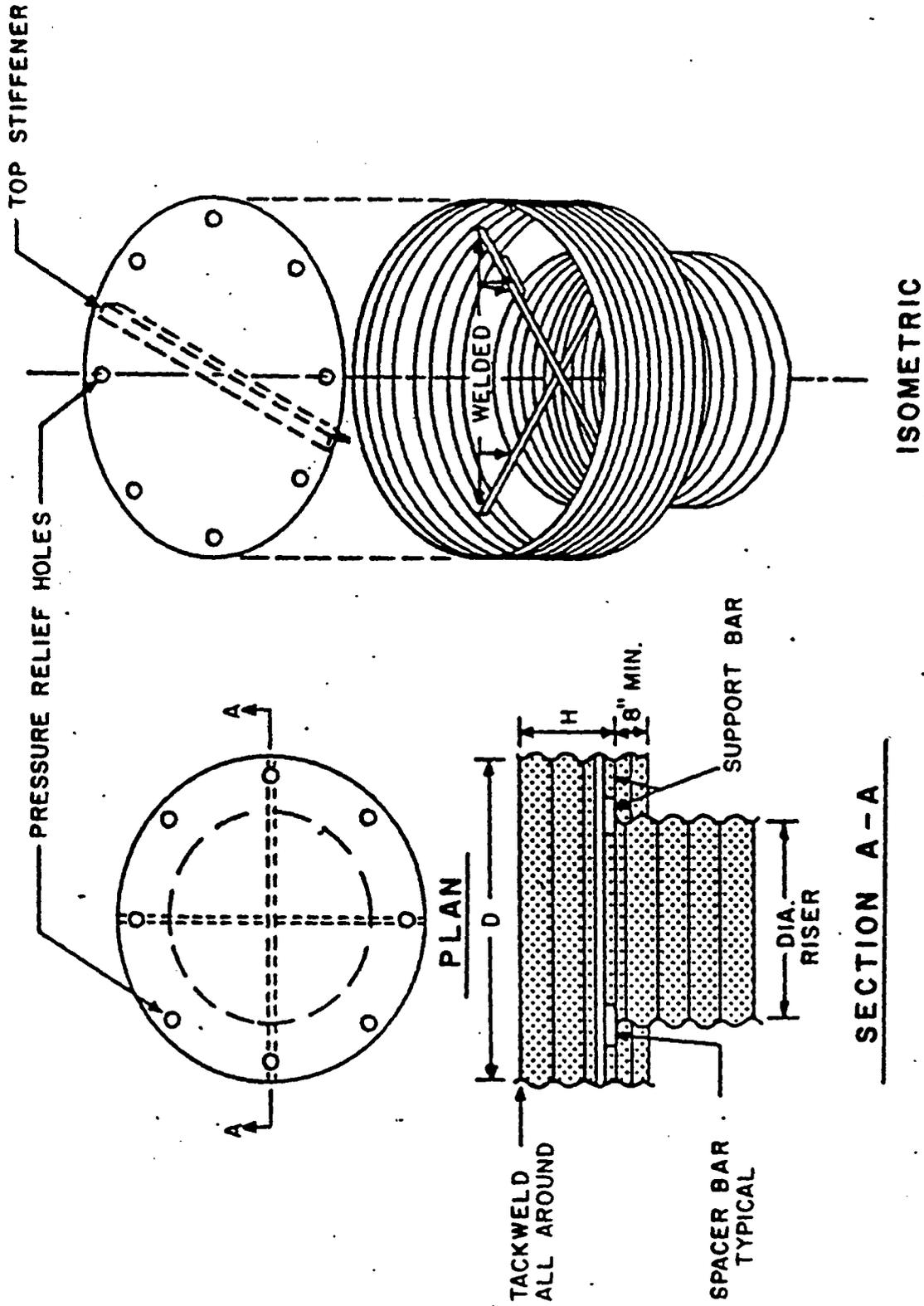


FIGURE 3.20 ANTI-VORTEX DEVICE (SCS, 1975)

ing the combination of the principal and the emergency spillway to safely convey the runoff resulting from the 25-year, 24-hour precipitation event. For larger dams, the spillways must safely discharge the runoff resulting from the 100-year, 24-hour precipitation event or a larger event as required by the regulatory agency. The design of the emergency spillway should take into account the design discharge of the principal spillways. In general, emergency spillways consist of a crest section, a conveyance section, and a discharge section. There are two types of emergency spillways, overflow spillway and channel spillway.

Selection of the type of emergency spillway is dependent on the soils and climate of the site. Vegetated emergency spillways have higher protection from damaging erosion than earth spillways. They are applicable to sites where a vigorous grass growth can be sustained by normal maintenance without irrigation.

Earth spillways are used in those areas where vegetative growth cannot be maintained. They are similar to vegetated spillways but are designed for lower permissible velocities and less frequent use. Normally, they will require more maintenance after a flow event.

Rock emergency spillways are applicable on undisturbed land where parent bedrock material is present. Allowable frequency of use and permissible velocities must be ascertained for the specific site based on a knowledge of hardness, condition, durability, weathering characteristics, and structure of the rock formation.

Excavated open channel spillways are to have cut-and-fill slopes in earth and rock which are stable against sliding. If the dam is to be permanent, cut slope stability is to be evaluated for the long-term natural moisture conditions. Side slopes shall be stable for the material in which the spillway is constructed and shall not be steeper than 3 horizontal to 1 vertical in earth and 1 horizontal to 1 vertical in rock.

The exit channel should be straight whenever possible. Slope of the constructed exit channel should fall within the range established by discharge requirements and permissible velocities based on spillway material (Tables 3.5 and 3.6). Riprap may be used to stabilize the spillway for higher design velocities. Spillway discharge should be at a point downstream from any part

Table 3.5. Permissible Velocities for Vegetated Spillways¹
(Soil Conservation Service, 1981).

Vegetation	Permissible Velocity in fps			
	Erosion Resistant Soils ²		Easily Erodible Soils ²	
	Slope of Exit Channel in percent		Slope of Exit Channel in percent	
	0 to 5	5 to 10	0 to 5	5 to 10
Bermudagrass	8	7	6	5
Bahiagrass				
Buffalograss				
Kentucky bluegrass				
Smooth bromegrass	7	6	5	4
Tall fescue				
Reed Canarygrass				
Sod-forming grass legume mixtures	5	4	4	3
Lespedeza sericea				
Weeping lovegrass				
Yellow bluestem	3.5	N/A ³	2.5	N/A ³
Native grass mixtures				
Annuals				

¹ SCS-TP-61

² As defined in TR-52

³ Use on slopes steeper than 5 percent is not recommended.

Table 3.6. Permissible Spillway Velocities after Aging¹.

Original Material Excavated	Feet per second
Fine sand, non-colloidal	2.50
Sandy loam, non-colloidal	2.50
Silt loam, non-colloidal	3.00
Alluvial silts, non-colloidal	3.50
Ordinary firm loam	3.50
Volcanic ash	3.50
Fine gravel	5.00
Stiff clay, very colloidal	5.00
Graded, loam to cobbles, non-colloidal	5.00
Alluvial silts, colloidal	5.00
Graded, silt to cobbles, colloidal	5.50
Cobbles and shingles	5.50
Coarse gravel, non-colloidal	6.00
Shales and hardpans	6.00

¹ Recommended in 1926 by Special Committee on Irrigation Research, American Society of Civil Engineers.

² Values shown apply to water transporting colloidal silts.

of the earth embankment. If this is not practical, a wing dike should be constructed to prevent flows from encroaching on the downstream toe of the dam.

Elevation of the crest of the emergency spillway is dependent upon the type of spillway to be used. In all cases, the design depth of water over the spillway must be a minimum of one foot below the elevation of the settled height of the dam. The current OSM regulations allow discharge through the emergency spillway for events less than the 10-year, 24-hour precipitation event as long as effluent limitations are achieved. Therefore, the elevation difference between the principal spillway and the emergency spillway is site dependent. Local state requirements may specify full containment of the design storm.

3.9.5 Erosion Control Below Spillways

3.9.5.1 General

During operation, the outlet discharge from the principal spillway of a sedimentation pond is a highly concentrated, fast-moving jet (with its associated turbulence) that has considerable potential for causing damage downstream. If protective measures are not taken, pond discharge can cause erosion downstream of the structure; undermine the outlet; form a wide, deep scour hole in the outlet area; and possibly endanger the safety of the dam embankment. Protection is necessary to prevent the jet and its associated turbulence from causing erosion until the jet flow has dissipated to a milder, non-scouring flow. The most common method of protecting the channel from erosive forces caused by high velocities and turbulent flow is to line the channel with riprap. In this manner, the channel is protected from erosion until the outflow jet has dissipated to a milder flow condition of decreased velocity and turbulence.

Where the pond will discharge onto an area which had not previously been exposed to flow, there is the likelihood of severe erosion from the flow over loose soils. On the other hand, if the pond discharges into a well-armored natural channel, the downstream erosion affects will be minimal. Alignment of the outlet and the channel at the outlet should be straight so discharge does not impinge on any of the channel banks a short distance downstream. By properly choosing an outlet location and geometry, the amount of downstream ero-

sion is minimized. The application and design of riprap for erosion control below principal spillways are discussed in the following sections.

3.9.5.2 Riprap

Riprap consists of a layer of discrete fragments of durable rock possessing sufficient size to withstand the dynamic, erosive forces generated by the flow of water. Riprap should be hard, dense, and durable to withstand long exposure to weathering. In surface mining operations, riprap is the most common and economical means of preventing erosion of channel bed and banks upstream and particularly downstream of sedimentation ponds where there is a high erosive potential due to contraction of flow, flow alignment, changes in slope, and etc. When the material is of sufficient size, shape, gradation, and hardness, riprap is excellent erosion protection.

The important factors to be considered in designing rock riprap protection are: rock durability, density, size, weight, shape, and angularity; direction and magnitude of the velocity of flow near the rock; bed or bank slope; and angle of repose of the rock. In addition, the desired level of protection may not be provided by the riprap if design criteria concerning rock gradation, placement, riprap thickness, and filter design are not considered.

There are many means and methods by which riprap protection can be constructed and placed. Following is a categorization of riprap materials and methods of placement:

- Dumped riprap
- Hand-placed riprap
- Wire-enclosed riprap (gabion)
- Grouted riprap

When available in sufficient size, dumped rock riprap is usually the most economical material for bank protection. Dumped rock riprap has many advantages over other types of protection, including its flexibility and the ease of local damage repair. Construction must be accomplished in a prescribed manner but is not complicated. If riprap is placed during construction of the embankment, rocks can be dumped directly from trucks from the top of the embankment. To prevent segregation of sizes, rock should never be placed by dropping down the slope in a chute or pushed downhill with a bulldozer.

Dumped riprap can be placed with a minimum of expensive hand work. The appearance of dumped riprap is natural, and after a time, vegetation will grow between the rocks. Finally, in temporary channels when usefulness of the protection is finished, the rock is salvageable.

Dumped riprap is extensively used on surface mine sites due to the availability of rock and the ease of placement. Sizing of riprap is important for the proper stability and erosion control. Several references for sizing riprap are available (Simons, Li & Associates, Inc., 1982; Barfield, 1981, Bureau of Reclamation, 1977).

3.10 Summary

Sedimentation pond design is based upon meeting effluent limitations for the design storm runoff event. A particle size that must be removed in the pond is determined such that effluent limitations are satisfied. The pond configuration is then determined to provide the required settling conditions. This requires an iterative process. Once the pond configuration is established, the principal spillway is sized to produce the required detention time and the emergency spillway is then sized so that the combination of principal and emergency spillways are adequate. The final step in the design process is to check the effluent for base flow conditions after the pond is operational. The design example in Chapter VI presents how the previous sections are interrelated in the design process.

TABLE OF CONTENTS
CHAPTER IV

	<u>Page</u>
IV. SEDIMENTATION POND MODIFICATIONS	
4.1 <u>Sedimentation Pond Configuration</u>	4.1
4.2 <u>Sedimentation Pond Inlet Control Measures</u>	4.3
4.2.1 Channel Modification	4.3
4.2.1.1 <u>Channel Realignment</u>	4.4
4.2.1.2 <u>Check Dams</u>	4.4
4.2.1.3 <u>Riprap</u>	4.9
4.2.1.4 <u>Multiple Inlets</u>	4.9
4.2.2 Spreaders	4.11
4.2.2.1 <u>Aprons</u>	4.11
4.2.2.2 <u>Baffles</u>	4.13
4.2.2.3 <u>Level Spreaders</u>	4.16
4.2.3 Filtration Measures	4.16
4.2.3.1 <u>Straw Bale and Sandbag Barriers</u>	4.16
4.2.3.2 <u>Vegetation Filters</u>	4.23
4.2.4 Summary	4.24
4.3 <u>Multiple Pond Treatment Measures for Sediment Control</u>	4.26
4.3.1 General	4.26
4.3.2 Field Application	4.27
4.3.3 Multiple Pond Design Considerations	4.28
4.3.3.1 <u>Multiple Pond in Series</u>	4.28
4.3.3.2 <u>Compartmentalization</u>	4.30
4.3.4 Water Quality Resulting from Multiple Ponds	4.30
4.4 <u>Physical/Chemical Treatment</u>	4.31
4.4.1 General	4.31
4.4.2 Use of Coagulants and Flocculants	4.32
4.4.3 Field Application in the Use of Physical/Chemical Treatment	4.34

TABLE OF CONTENTS (continued)
CHAPTER IV

	<u>Page</u>
4.4.4 Types of Coagulants	4.37
4.4.5 Water Quality Resulting from Physical/Chemical Treatment	4.38
4.5 <u>Areas in Which Future Research May Provide Improved Technology</u>	4.39

LIST OF FIGURES
CHAPTER IV

	<u>Page</u>
Figure 4.1 Idealized triangular shaped pond	4.2
Figure 4.2 Definition sketch of small-scale drop structures used in series	4.5
Figure 4.3 Loose rock check dam	4.7
Figure 4.4 Log check dam	4.8
Figure 4.5 Multiple inlets by inlet channel branching	4.10
Figure 4.6 Apron	4.12
Figure 4.7 Sedimentation pond inlet baffles	4.14
Figure 4.8 Sedimentation pond basin baffles	4.15
Figure 4.9 Level spreader	4.18
Figure 4.10 Proper placement of straw bale barrier in drainageway	4.20
Figure 4.11 Construction of straw bale barrier	4.21
Figure 4.12 Illustration of multiple ponds	4.29
Figure 4.13 Effective concentration range of coagulants and flocculants	4.33
Figure 4.14 Chemical treatment application at Centralia mine site, Centralia, Washington	4.35

LIST OF TABLES
CHAPTER IV

	<u>Page</u>
Table 4.1 Flow (Q) versus Spreader Length	4.17
Table 4.2 Flow Rates and Filtering Efficiencies of Various Sediment Filter Materials	4.22
Table 4.3 Effect of Decreasing Particle Size on Settling	4.32

IV. SEDIMENTATION POND MODIFICATIONS

Modifications to a sedimentation pond are done primarily to improve settling conditions, thus improving sediment removal efficiencies. The modifications are designed to control nonideal settling conditions as discussed in Section 3.8.2. Field studies have verified the conditions and causes of nonideal settling in sedimentation ponds and several studies have made recommendations as to modifications for controlling these conditions. Some efforts have been made to field test the effectiveness of various modifications; however, due to unforeseen problems, no significant data were collected (EPA, 1981). Various modifications to sedimentation ponds have been recommended. These modifications apply to various aspects of the pond, including pond configuration, inlet controls, outlet controls, multiple ponds, and physical/chemical treatment. Outlet controls related to the principal spillway were discussed in Section 3.9.3. The following sections describe various modifications and their application. When available, information pertaining to removal efficiencies is reported.

4.1 Sedimentation Pond Configuration

Sedimentation pond shape and depth affect the performance of a pond in sediment removal. In most cases, the configuration of the pond is controlled by the topography, and therefore modifications to pond configuration are very limited. It has become recognized that the length-to-width ratio greatly influences the short-circuiting potential of the pond. Dye studies have shown that a length-to-width ratio of 5:1 produced the best sediment removal efficiencies. However, length-to-width ratios of 5:1 are generally hard to achieve due to the topography.

Specifying a length-to-width ratio does not account for or regulate the depth of the sedimentation pond. A sedimentation pond design developed by Bondurant et al (1975) has a varying depth through the length of the sedimentation pond. This pond design is triangular shaped with a narrow inlet and a wide exit with a skimming weir outlet. The depth is the greatest near the inlet and continually decreases towards the outlet of the pond. Figure 4.1 presents the top view and side view of this type of pond. Ideally, this type of pond would be efficient in sediment removal. This pond design provides a sediment storage volume near the inlet, a decreasing settling depth through

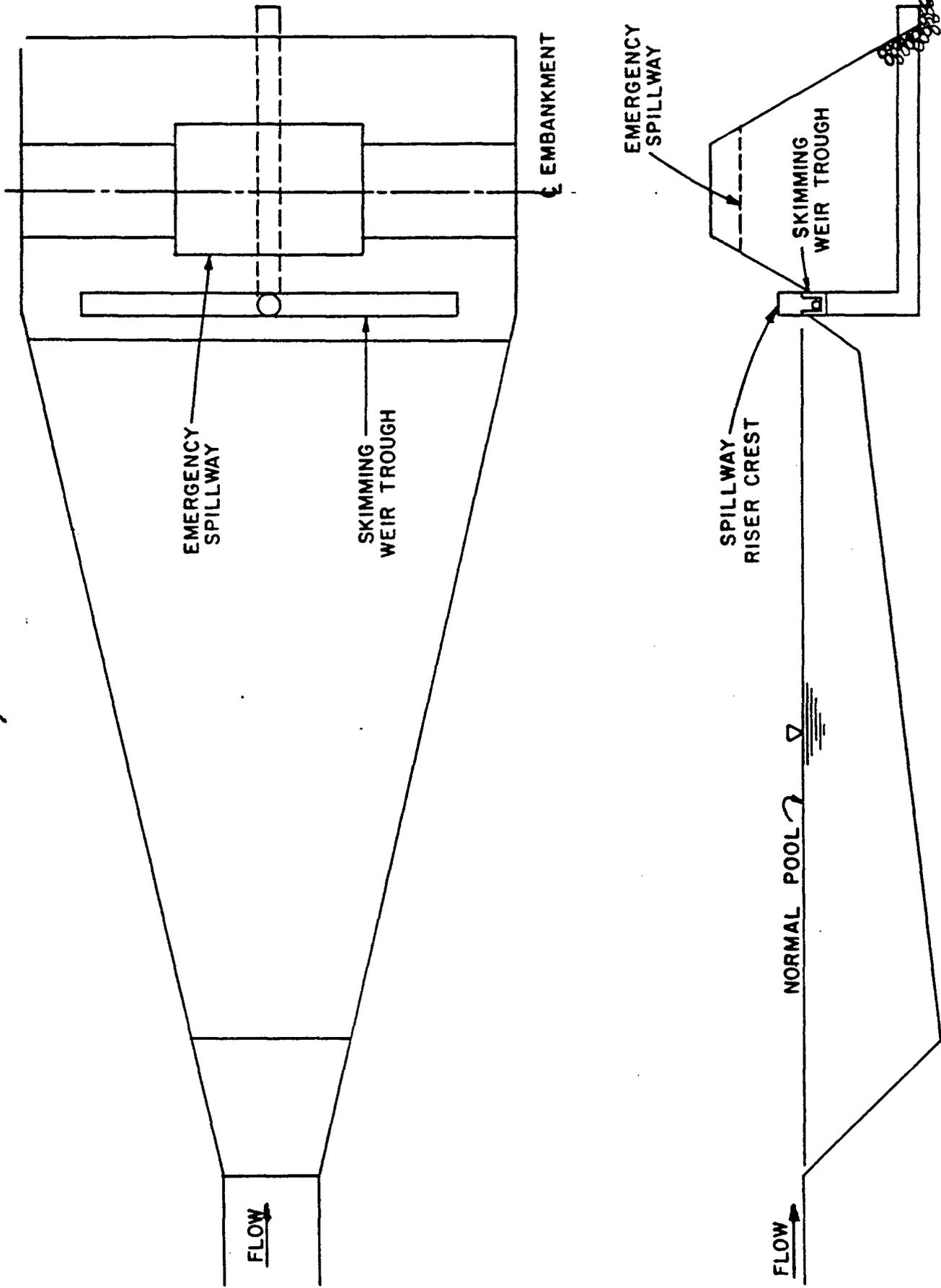


FIGURE 4.1 IDEALIZED TRIANGULAR SHAPED POND

the length of the pond, and a continually decreasing horizontal velocity through the pond. In addition, this type of pond would fit well into the natural drainageways, however, excavation and protection of the inlet against erosion and headcutting would be required. Field studies on the performance of this type of pond are needed to improve its effectiveness.

4.2 Sedimentation Pond Inlet Control Measures

The inlet to a sedimentation pond is a section of channel where the runoff enters the pond. The main concern at an inlet to a pond is to dissipate the energy of the flow and thus reduce the velocity of the inflow. There are several ways to do this with the use of riprap, logs, and other debris. The operator can use any type of inlet control as long as it remains stable near the inlet and dissipates the energy of the inflow. In this respect, the operator can develop his own modifications for the control at the inlet.

Three major types of inlet control measures have been identified: channel modifications, spreaders, and filtration measures. Channel modifications work to dissipate the energy of the water flowing into the pond by increasing the length of the channel, roughness of the channel, or by allowing discrete drops in elevation at protected sections. Spreaders make use of the entire area of the pond, thus reducing the average forward velocity of the runoff. Filtration measures work to increase the roughness of the inlet section and directly settle out some of the incoming sediment.

Inlet control measures should be located where they will be most effective and where there is access for maintenance. Installation and design should take into account the entire range of design flows. The sedimentation pond should be designed with sufficient sediment storage volume near the inlet to take into account stage settling that often times results from inlet control measures.

4.2.1 Channel Modification

An effective measure for controlling the flow of water into a pond is through modification of the channel length, shape, or roughness. All channel modification measures require a high degree of maintenance. Sediment accumulated in the channel may be removed and disposed. Any aggradation or degradation of the inlet section should be evaluated in terms of the effect on the

hydraulic capacity of the channel. The most common types of channel modifications include check dams, riprap, and multiple inlets.

4.2.1.1 Channel Realignment

Channel realignment is usually used to increase the channel length, thus reducing the channel gradient and flow velocity. The resultant lower velocities allow some suspended sediment to deposit in the inlet section. Channel realignment usually creates channel bends which need bank protection. Channel realignment is relatively low in cost; however, the application is usually limited by topography.

4.2.1.2 Check Dams

A check dam is a low-head structure, usually used in series (Figure 4.2), that reduces the gradient of the water profile by providing for discrete drops in elevation at protected sections of the channel. The resultant lower velocities allow some suspended sediment to deposit. Check dams are used in steep channels that would otherwise have excessively high velocities. Since check dams can be costly and require maintenance, they should only be used when channel realignment is not possible.

The check dams should be located in a straight channel section in order to minimize bank cutting (U.S. Forest Service, 1976). Maintenance access should be provided to allow for clean out of accumulated sediment upstream of the dam and repairs required for check dams.

The height of the check dam depends upon the design flow and the type of structure. A drop height of two to three feet is common. Drop height should not exceed four feet due to high velocity below the dam which will increase erosion potential downstream of the dam.

Riprap or a concrete stilling basin is needed to control erosion below the check dam. Channel bank upstream and downstream of the check dam should be protected from erosion. Channel bank protection should extend to the designed flow depth.

Several states require a spillway on a check dam. Usually, the spillway is formed by lowering a section of the center of the dam by a minimum of six inches.

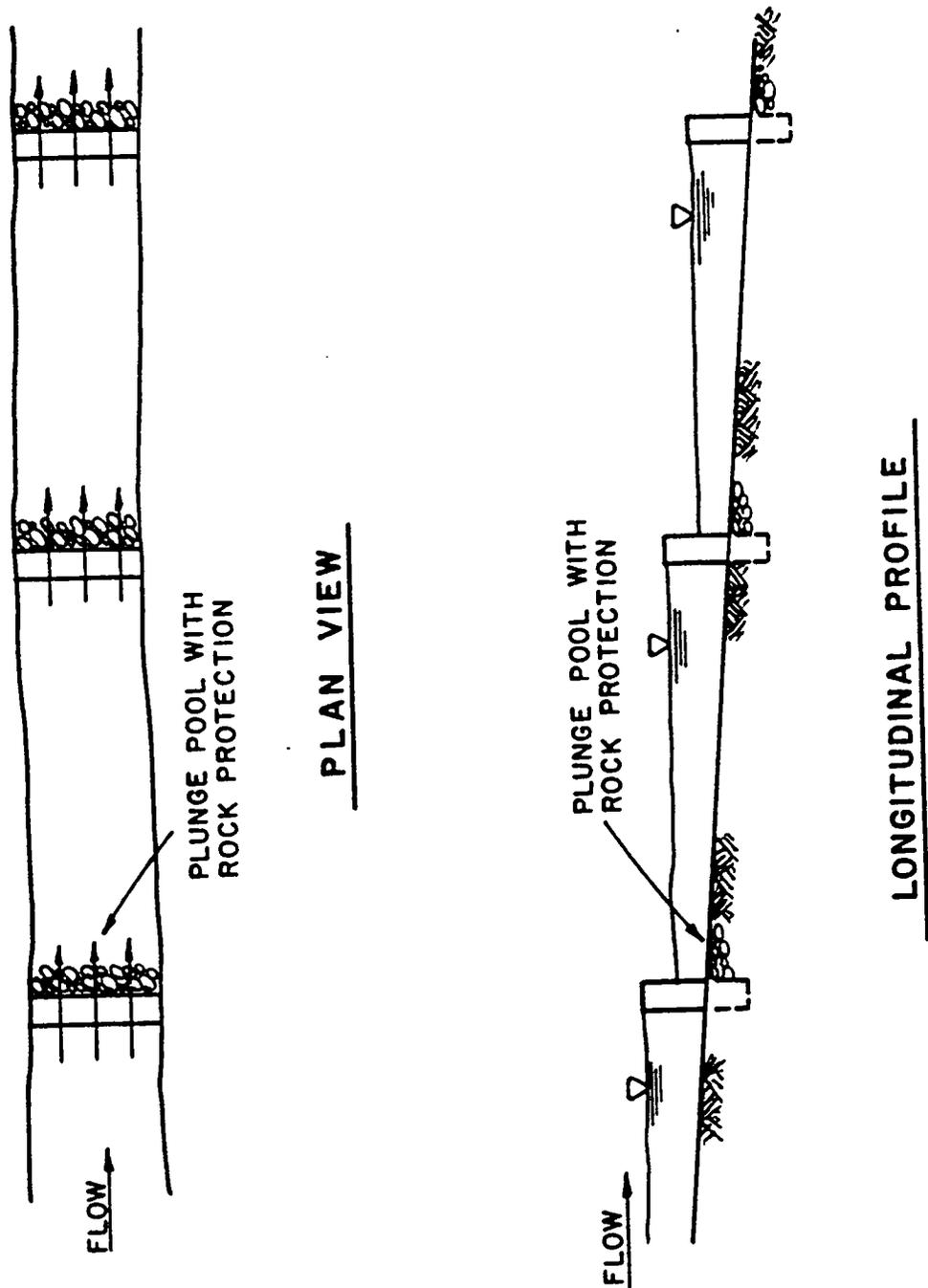


FIGURE 4.2 DEFINITION SKETCH OF SMALL-SCALE DROP STRUCTURES USED IN SERIES (OSM, 1981)

Sediment buildup behind check dams should be removed when the sediment level is at one-half the height of the dam. Disposal should be in a manner that will prevent sediment from being carried back into the waterways of the mine. If displacement of riprap has occurred or if scour is present, repairs should be made immediately.

Check dams can be constructed of porous or nonporous material. Porous check dams can be built of loose rock, wire-enclosed rock, logs, and logs and brush combination.

Since loose rock dams are not reinforced, the angle of repose of the rock should determine the slopes of the dam sides. For the design of check dams, a maximum side slope of 1.25 horizontal to 1 vertical for angular rock and 1.5 horizontal to 1 vertical for round rock is recommended. Hand or mechanical placement may be necessary to achieve complete coverage of the ditch or swale. Riprap protection or a concrete apron should be placed at the downstream toe of the check dam in order to prevent undercutting of the structure. A typical loose rock check dam is given in Figure 4.3.

Wire-enclosed rock refers to rocks that are bound together in a wire basket so that they act as a single unit. Check dams with wire-enclosed rock can be built with steeper side slopes, but not steeper than 1 horizontal to 1 vertical.

Log check dams are more economical from the standpoint of material costs since logs can usually be salvaged from clearing operations. However, log dams require more time and hand labor to install and remove. Log check dams should be constructed of four- to six-inch diameter logs, either upright or slanted. The logs should be driven into the streambed a minimum of 24 inches on a line perpendicular to the stream flow. A filter cloth may be attached to the upstream side of the dam to retard the flow and to trap additional sediment. If a filter cloth is used, it should be securely stapled to the top of the dam and adequately anchored in the streambed. A typical log check dam is given in Figure 4.4.

Nonporous check dams can be built of concrete, metal sheet pilings filled with rock, or metal sheet pilings alone. Since check dams are low in height, vertical drops are usually satisfactory. The check dam should extend its depth beyond the anticipated scour depth downstream of the dam.

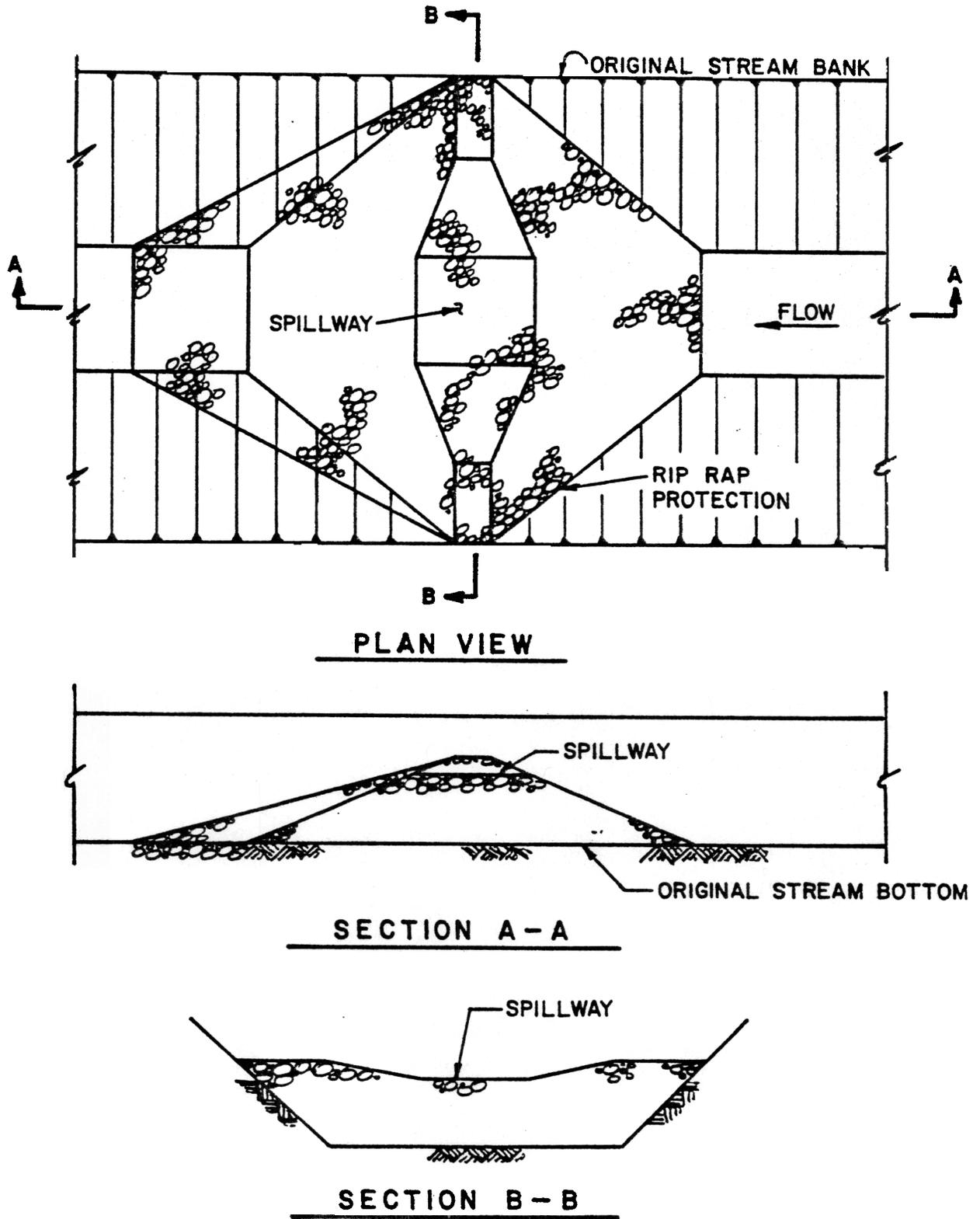
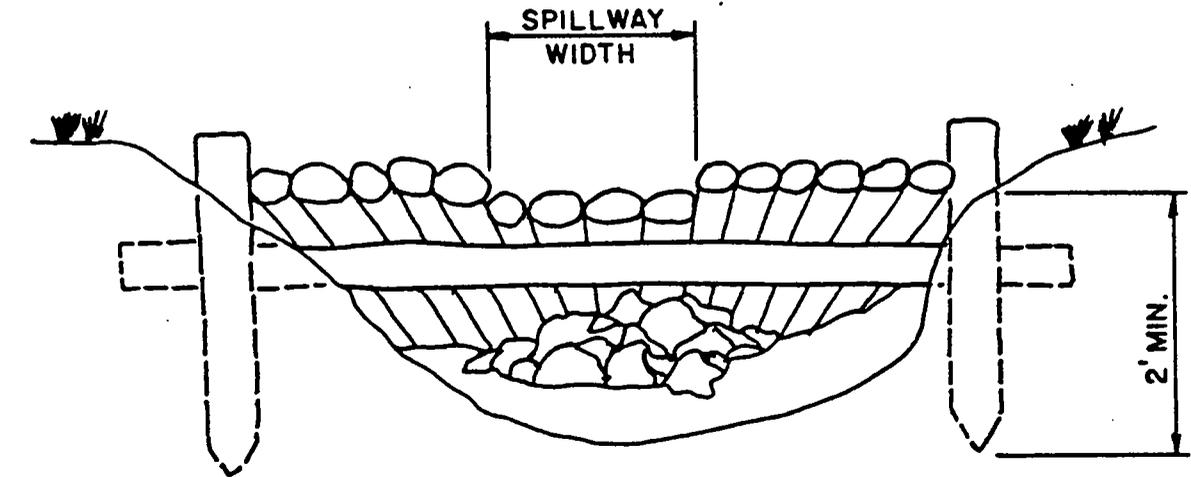
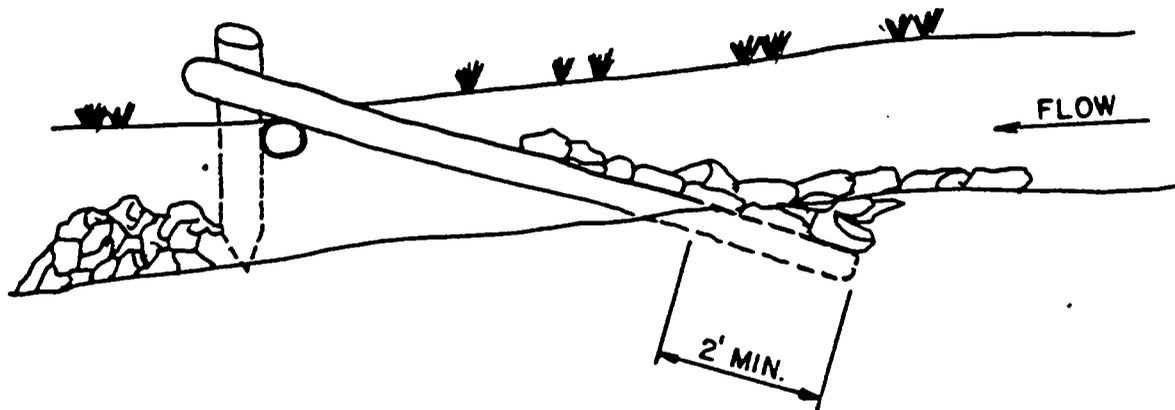


FIGURE 4.3 LOOSE ROCK CHECK DAM
(U.S. FOREST SERVICE 1976)



LOOKING UPSTREAM



CROSS SECTION

FIGURE 4.4 LOG CHECK DAM

Application of check dams in the field has shown that they can remove approximately five percent of the incoming sediment load (Reed, 1978). The portion of sediment removed is large particles and the pond must still be designed to remove the smaller particles. However, the storage volume required for sediment can be reduced.

4.2.1.3 Riprap

One of the simplest control measures is the placement of loose rock at the inlet section. This technique increases the channel roughness and effectively reduces the flow velocity at the inlet.

Experience has shown that the usual causes of riprap failure are generally undersized individual rocks, improper riprap gradation, thickness of riprap, and bedding material. Among them, 80 percent of all riprap failures are directly attributed to bedding failure. Factors that affect performance of riprap are:

- Durability of rock
- Density of the rock
- Velocity (both magnitude and direction of the flow in the vicinity of the rock)
- Slope of the bank or bank line being protected
- Angle of repose for the rock
- Size of the rock
- Shape and angularity of the rock
- Placement and use of filters on fine bank materials

In addition, the winnowing of fine materials from between and beneath the riprap often causes failure. Proper installation of riprap on fine bank material requires that a gravel or fabric filter be placed on the bank before riprap is installed.

4.2.1.4 Multiple Inlets

Another modification for achieving decreased influent flow velocity is use of multiple inlets. Construction of multiple inlets is more feasible in relatively flat areas because there are no limitations of excavation capability due to topographic constraints. If branching is used (Figure 4.5), care must be taken to provide adequate channel erosion control in order to direct

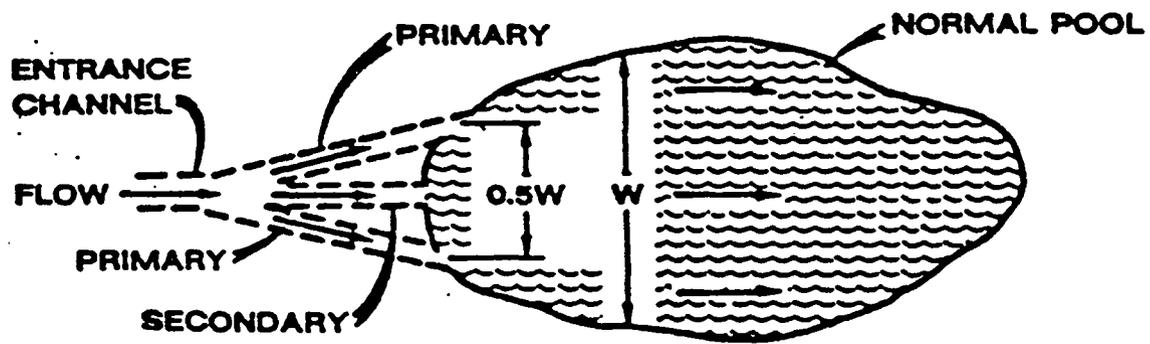


FIGURE 4.5 MULTIPLE INLETS BY INLET CHANNEL BRANCHING (EPA, 1980)

the flow in controlled areas. As an example, the two primary branches will handle normal inflow to the pond. The control channel will be used only during high flow conditions. A control device, such as a v-notch weir or a check dam, should be used on the control channel to prevent straight-through flow or by passing of the primary branches during low flow.

4.2.2 Spreaders

An effective means of inlet control deals with discharging the influent over the total width of the sedimentation pond. Aprons and baffles located in both the inlet and the pond are two most commonly used control measures. Spreaders can significantly reduce the velocity of concentrated storm-water flow and spread it uniformly across the pond reducing, short circuiting through the pond.

4.2.2.1 Aprons

An apron is an expanded section located at the downstream end of the inlet channel to reduce inflow velocity and spread inflow uniformly across the pond. Location of the apron is dependent upon the elevation of the maximum water surface because submergence of the apron by high water will reduce the effectiveness of the apron as a spreader. The apron should be located at least one foot above the designed pool level. Aprons should be located downstream of a straight inlet channel to avoid nonuniform distribution of the inflow to the aprons. Riprap or concrete paving is required to reduce erosion potential of the apron. No stilling basin is needed if the inlet channel is designed to keep the Froude number in the inlet channel below a value of 2.5. If a Froude number is greater than 2.5, a stilling basin is needed for energy dissipation. Designs for stilling basins can be found in several publications (Bureau of Reclamation, 1974; Chow, 1959). The bottom of the apron should be flat with the rate of lateral expansion not to exceed 2 horizontal to 1 vertical for inflow Froude number less than 2.5 and 5 horizontal to 1 vertical for inflow Froude number greater than or equal to 2.5. A typical apron is shown in Figure 4.6.

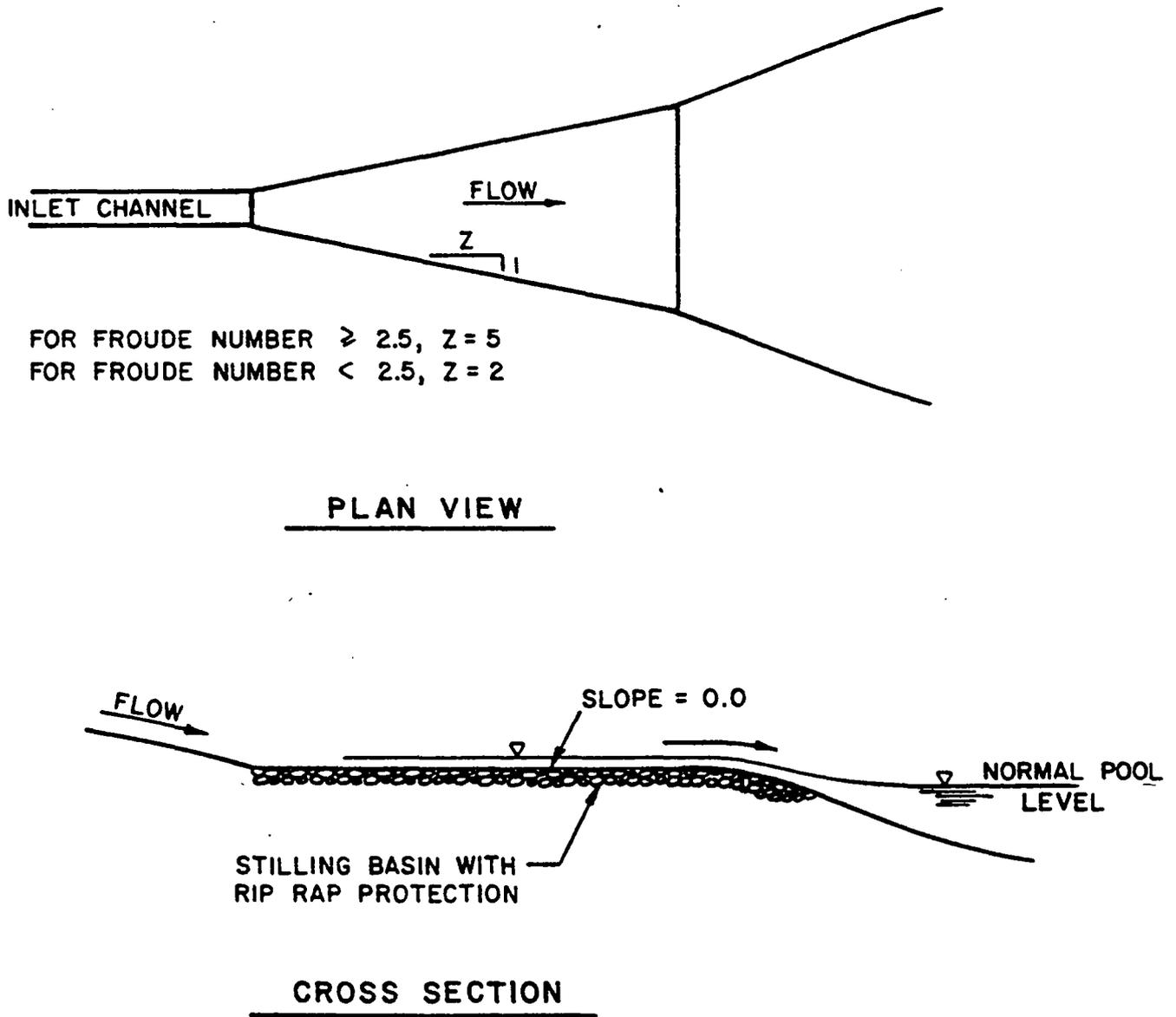


FIGURE 4.6 APRON (EPA, 1976)

4.2.2.2 Baffles

Baffles can be used near the inlet of the pond to ensure uniform flow distribution. Inlet baffles should be located approximately one-third the distance from the inlet to the outlet to allow for velocity reduction. Several types of baffles can be used (Figure 4.7). Some are constructed along the entire inlet width of the pond (overflow baffles). Other types, directional baffles, are used to direct the inflow to the sides of the pond.

Baffles can also be used for increasing the effective length of the basin. The length of the flow path L is the shortest distance from where the water flow enters the normal pool to the outflow point. Baffles should be placed midway between the inflow point and the riser. Examples of sediment basin baffles and a baffle detail are shown in Figure 4.8. Example C is a special case where the water is allowed to go around both ends of the baffle, and the effective length is $L_e = L_1 + L_2$. This special procedure for computing L_e is allowable only when the two flow lengths L_1 and L_2 are equal.

Baffles are presently being used at several coal mines, using both wooden and cloth baffles. Studies to prove the effectiveness of plywood baffles are very limited. One of the most common problems has been the installation and maintenance of the support post. Installation of baffles may be difficult where pond bottom conditions are either too soft or too hard. Another problem is due to frost-heaving action on the support post. Frost-heaving may lift the posts and cause the baffle to collapse. Therefore, proper anchoring of the support posts must not be overlooked. Baffles have also failed due to the weight of sediment on the upstream side of the baffle and due to damage from trees toppling onto the baffles. Filter fabric baffles are currently in use, however, they too have problems. The fabric tends to deteriorate due to sun exposure. Additional research in the use of baffles is required since they are a viable means of improving sedimentation pond efficiency. Again, the effectiveness of these measures needs to be documented by detailed monitoring results.

For all baffles, the side slopes of the pond must be protected from scour, usually through the use of riprap. Riprap should be placed from the

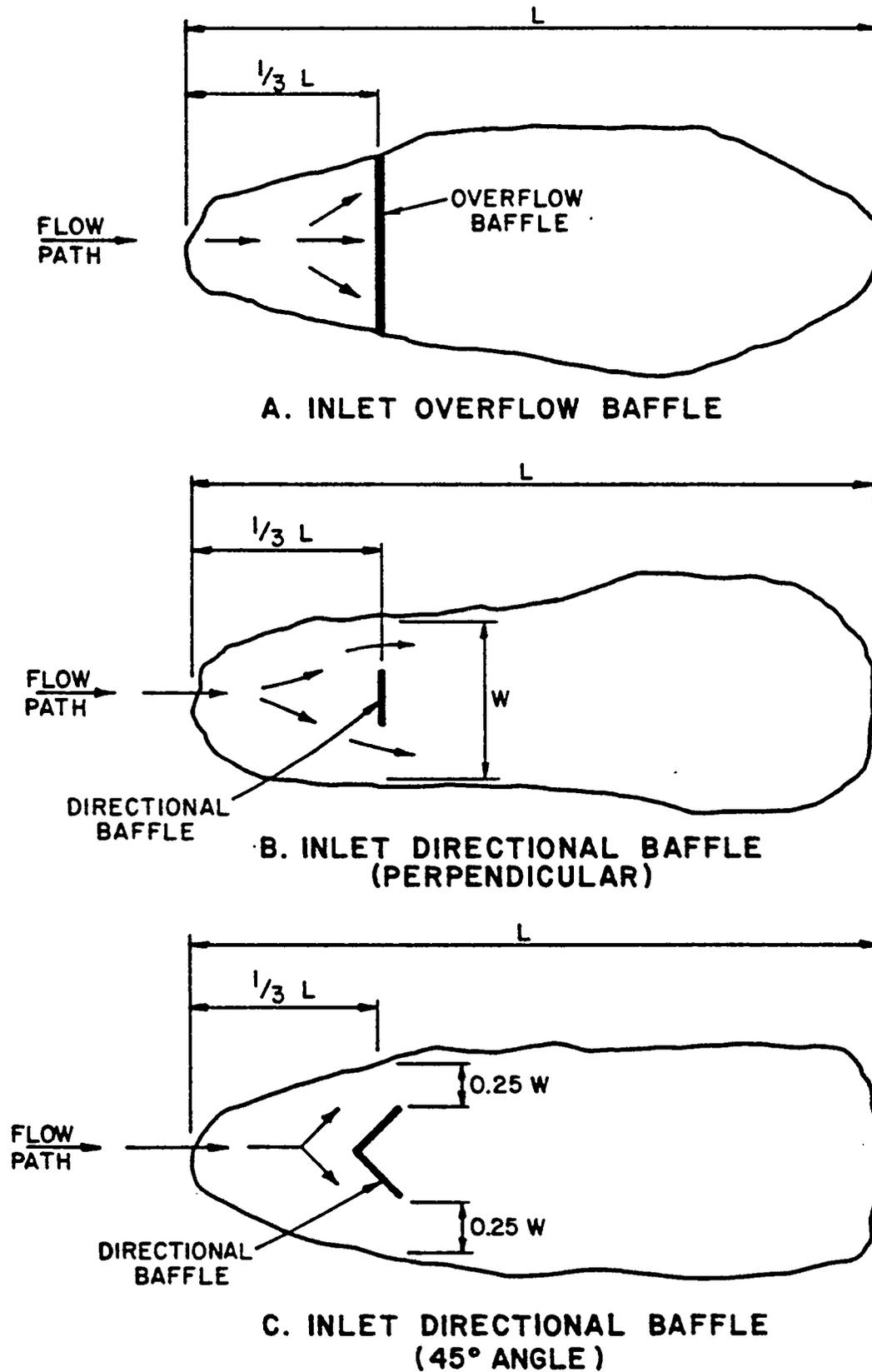


FIGURE 4.7 SEDIMENTATION POND INLET BAFFLES (EPA, 1980)

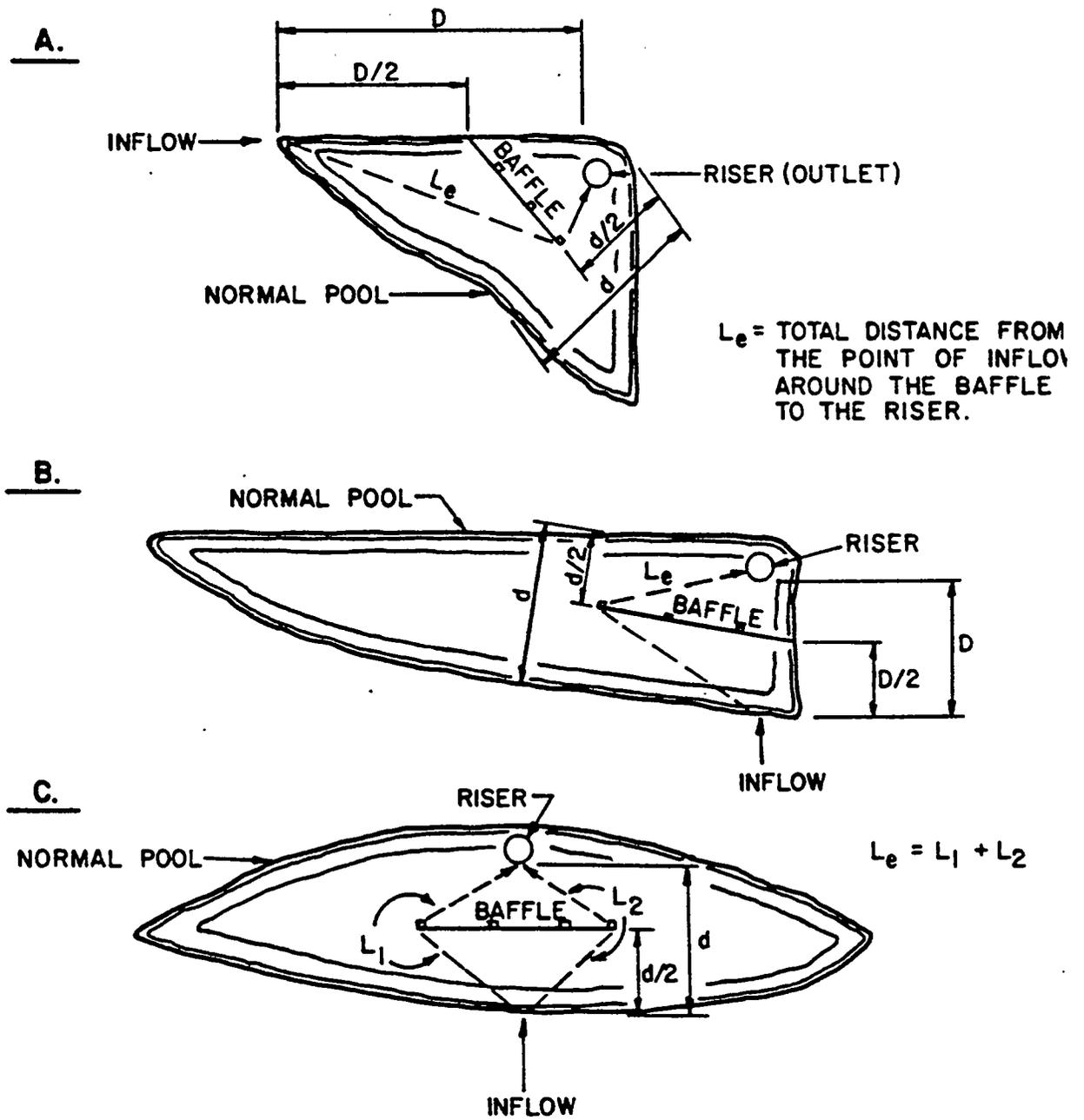


FIGURE 4.8 SEDIMENTATION POND BASIN BAFFLES (EPA, 1976)

base of the pond to above the elevation of the emergency spillway. Baffles should be designed to be lower than the elevation of the emergency spillway.

4.2.2.3 Level Spreaders

Level spreaders are used at diversion ditch outlets to convert channel flow into sheet flow. An advantage of level spreaders is that they can turn the diversion ditch flow and spread the flow over a large inlet section of a sedimentation pond (Figure 4.9). By uniformly spreading the flow over the entire length of the inlet, the velocity of the water flowing into the pond will be reduced.

Some type of erosion control should be used over the entire level lip. Usually fiberglass or jute matting is effective in stabilizing the lip area. The slope of the entrance channel must be less than 0.5 to 1.0 percent for the last 20 feet before entering the spreader. The spreader itself is flat for its entire length. Length of the spreader can be determined from Table 4.1.

4.2.3 Filtration Measures

Filtration measures are designed to decrease the flow velocity. Filtration measures are inexpensive to construct but require high maintenance. Filtration is useful for sheet or overland flow and low-level channel flows (less than 20 cfs). Straw bales, sandbag barriers, and vegetative filters are the most commonly used filtration measures. Silt fences are not applicable as inlet control measures because they cannot filter the volumes of water generated by channel flows and many of the fabrics do not have sufficient structural strength to support the weight of water ponded behind the fence line. Usable life of these measures is usually three to six months. Vegetative filters can provide long-term control for conditions with proper slope, soils, climate, and flow volumes.

4.2.3.1 Straw Bale and Sandbag Barriers

Straw bales and sandbag barriers have been demonstrated to be fairly effective for decreasing the flow velocity and trapping sandy sediments. Design procedures for both straw bale and sandbag barriers are similar. The primary objective of the design is to prevent erosion around and under the barrier. A trench is excavated to the width of a single bale or sandbag and

Table 4.1. Flow (Q) versus Spreader Length
(EPA, 1972).

Q in cfs	L in feet
Up to 10	15
10 - 20	20
21 - 30	26
31 - 40	36
41 - 50	44

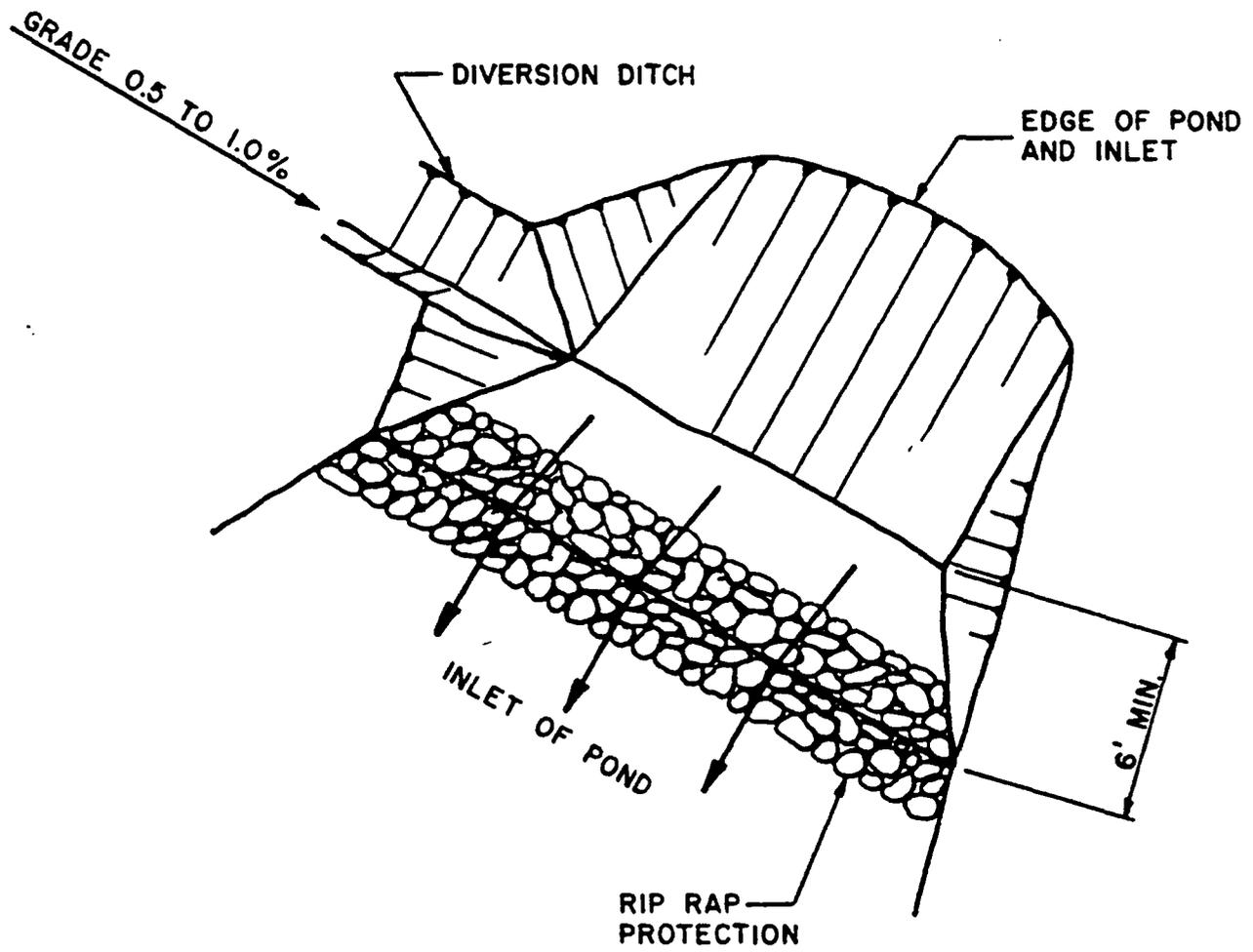
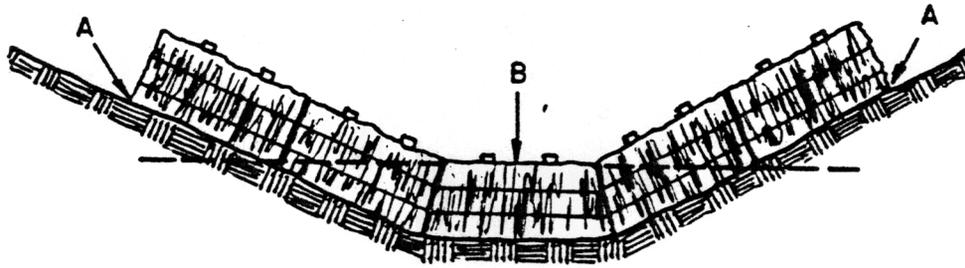


FIGURE 4.9 LEVEL SPREADER (OSM, 1981)

the length of the proposed barrier to a minimum depth of four inches. The bales or sandbags are placed in a single row, lengthwise and perpendicular to the flow of the channel. In order to minimize flow around the barrier, the bottoms of the end bales should be higher in elevation than the top of the lowest middle bale (Figure 4.10). When placing the barriers, the ends of adjacent bales or sandbags are tightly butted to one another (Figure 4.11). After the bales are stacked, each bale is securely anchored by at least two stakes or rebar driven through each bale. The length of the stake should be twice the height of the bale. The first stake in each bale is driven toward the previously laid bale to force the bales together. All gaps between bales are to be filled with straw to prevent water from escaping between the bales. Anchoring is required for sandbags if the structure height exceeds two bags. Sandbags tend to mold to one another, thereby minimizing gaps.

Straw bales and sandbags are subject to extensive damage during high water flows. Therefore, the barriers are to be inspected after each runoff event. Repairs to damaged barriers or backfilling of eroded areas should be made immediately. Trapped sediment should be removed after each runoff event. The barriers must be replaced when the level of deposition reaches approximately one-half the height of the barrier.

Theoretically, straw has a fairly high filtering efficiency (Table 4.2). However, observations made in Virginia, Pennsylvania, Maryland, and other parts of the nation (OSM, draft report), noted that field application of straw bale barriers have not been as effective as hoped. There are three major reasons for the lack of effectiveness. Improper use of straw bale barriers has been a major problem. These barriers have been used in streams and drainageways where high water velocities and volumes have destroyed or impaired their effectiveness. Improper placement and installation of the barriers, such as not entrenching the barrier, has allowed undercutting and end flow. This has resulted in additions of, rather than removal of, sediment from runoff waters. Finally, inadequate maintenance lowers the effectiveness of these barriers. No information is available on the effectiveness of sandbag barriers; however, optimum installation for both measures must be emphasized. If such procedures are carefully followed, straw bale and sandbag barriers can be quite effective.

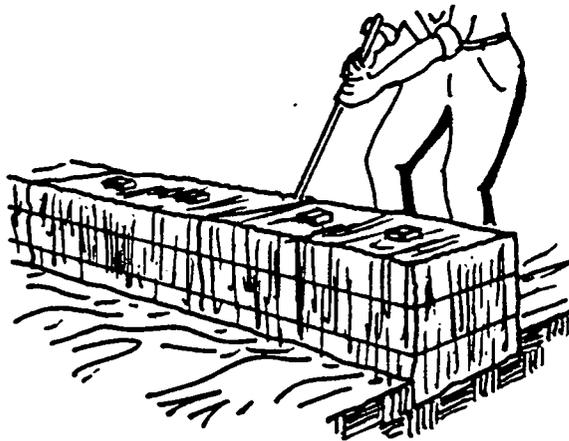
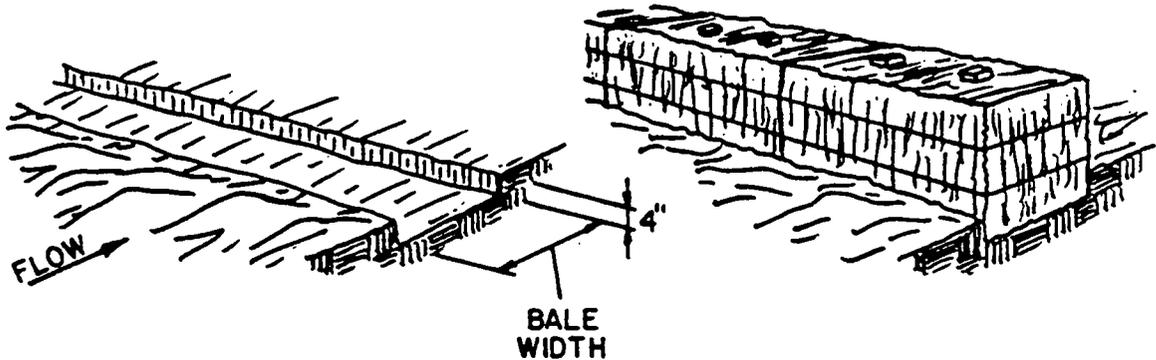


POINTS A SHOULD BE HIGHER THAN POINT B

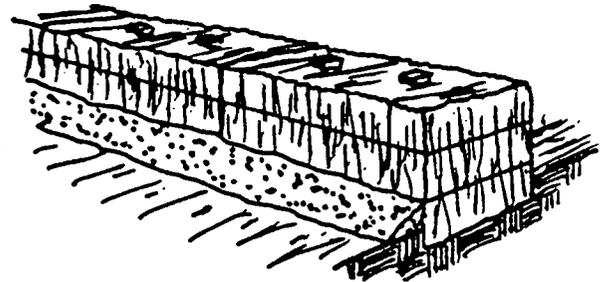
FIGURE 4.10 PROPER PLACEMENT OF STRAW BALE BARRIER
IN DRAINAGEWAY (OSM, 1981)

1. EXCAVATE THE TRENCH

2. PLACE AND STAKE STRAW BALES



3. WEDGE LOOSE STRAW
BETWEEN BALES



4. BACKFILL AND COMPACT
THE EXCAVATED SOIL

FIGURE 4.11 CONSTRUCTION OF STRAW BALE BARRIER (OSM, 1981)

Table 4.2. Flow Rates and Filtering Efficiencies of Various Sediment Filter Materials (OSM, draft).

Material	Flow Rate (gal/ft ² /min)	Filter Efficiency (percent)
Straw	5.6	67
Burlap (10-ounce fabric)	2.4	84
Synthetic fabric	0.3*	97*

* Average

4.2.3.2 Vegetative Filters

Vegetation can be used to form natural screens which reduce inflow velocities and increase the roughness coefficient, encouraging deposition upstream of the pond. The effectiveness of vegetative filters in reducing sediment inflow to active storage space depends upon the size characteristics of the pond. The effectiveness of vegetative filters in reducing sediment inflow to active storage space depends upon the size characteristics of the sediment, the gradient of the channel and the sediment storage space available at the inlet of the pond. To be effective, vegetative filter strips require flat slopes and concentrated flow must be avoided. Channel modification measures may be needed to flatten and widen the approach channel. The maximum steepness of slope is dependent on the soil type, climate, and vegetative cover. For sandy soils, a slope of not greater than three percent is needed for the filters to be effective (Robinson, et al, 1980). In some eastern states, vegetative filters have been effective on ten percent slopes (OSM, draft report).

Usually, if the slope is less than five percent and the flow velocity is less than five feet per second, a vegetative filter is effective. Sodding can increase the range of effectiveness for a vegetative filter.

Grasses are the most common type of vegetative filter used. Typically, bermuda grass, grass-legume mixtures, or annual cereals are used to provide dense, even cover. The choice of grass will influence the effectiveness of the filter. Some grasses (such as bermuda grasses) exhibit higher resistance to flow, which in turn results in a higher sediment removal (Wilson, 1967). Growth is usually not inhibited by deposited sediment if grasses propagated by rhizomes are used.

To maintain a good stand of vegetation, a good seedbed must be prepared. Vegetation should not be established on slopes that are unsuitable due to inappropriate soil texture, volume of overland flow or excessive steepness. The area should be flat enough to ensure uniform distribution of flow. The soil surface should be clear of trash, debris, roots, branches, and stones. Any irregularities in the soil surface should be filled or leveled in order to prevent the formation of depressions.

Requirements for fertilizing, liming, or topsoiling need to be addressed on a site-specific basis. Soil tests should be made to determine the exact

requirements. Any amendments to the soil should be spread evenly over the area to be used and incorporated into the top three to six inches of soil by disking, harrowing, or other acceptable means.

Vegetative filters, either as continuous areas or in strips, can be established through a number of methods. The most common and least expensive method is to seed the area. Seed should be evenly applied with a cyclone seeder, drill, cultipacker seeder, or hydroseeder. Seeding will usually require a mulch application. Depending upon location, seeding will establish an effective vegetative filter in one or two seasons.

Where speed is essential, sprigging or sodding may be preferred. Sprigging is a mixture of sprigs and stolons. Sprigs are small sections of rhizome (underground stems) and stolons are above-ground stems. Both rhizomes and stolons spread by creeping and rooting at the nodes.

Sodding can be applied to disturbed areas which require immediate vegetative covers or where sodding is preferred to other means of grass establishment. Sod strips should be laid perpendicular to the direction of flow. Care should be taken to butt ends of strips tightly. Pegs or staples should be used to fasten sod firmly. In critical areas, chicken wire, jute netting, or other netting should be stapled over the sod for extra protection.

Vegetative filter trap efficiencies are variable and dependent on site conditions. Soil Conservation Service plot studies have achieved sediment removal rates of 80 percent and higher (Robinson, et al, 1980), while removal rates on farmer-managed filters ranged from nearly zero to consistent removal efficiencies of 26 to 54 percent (Robinson, et al, 1980). Other studies range from 95 percent with Bermuda grasses to 60 percent with alfalfa (Wilson, 1967). Many of the problems associated with vegetation filters are caused by water channeling through the filter area and inconsistent cover density. Also if the flow rates are sufficient in intensity and duration, the filters will be submerged. Under submerged conditions, filtration efficiencies are markedly reduced (Wilson, 1967) and grass survival is threatened.

4.2.4 Summary

Inlet control measures can substantially increase the sediment trapping efficiencies of sedimentation ponds by reducing the forward flow velocity and by minimizing short circuiting. Common inlet control measures include channel

alignment, check dams, riprap, multiple inlets, aprons, baffles, level spreaders, straw bale dikes and sandbag dikes, and vegetative filters. Proper placement, installation, and maintenance is the key to the effectiveness of these measures.

Channel alignment is a permanent adjustment to the length of the inlet channel in order to reduce the channel slope, which in turn reduces the average flow velocity. Since channel alignment is permanent, it will be effective for a range of flows. Topographic constraints may preclude the use of channel alignment where there is not enough space to lengthen the inlet channel.

Check dams are simple structures used to dissipate, in controlled areas, the energy of the water flowing into the sedimentation pond. Check dams can be used for a range of flows; however, they are most effective for low and moderate flows (less than 50 cfs). Check dams may be expensive to construct and they require inspection and perhaps maintenance after each storm.

Riprap is perhaps the most common control used at areas where high water velocities are expected. Riprap should be used whenever the water flow velocity exceeds the maximum permissible velocity (usually three to six feet per second). Almost all of the structures discussed in this section require some use of riprap. Proper use and sizing of riprap is discussed in Section 3.9.5. Riprap should be inspected after each major flow to check for displacement of the riprap or damage to the filter cloth. Costs for riprap are usually low.

Multiple inlets are both channel modification measures as well as a spreader. They work well for a range of flows if sediment accumulation in the channels is kept to a minimum. If sediment starts to accumulate in one channel, the sediment will act as a dam, precluding the use of that channel during low flows where the water flow velocity is less than approximately two feet per second. Multiple inlets work best on shallow slopes because the flow is easier to divert into the side channels.

Aprons work to increase the surface area of the inlet section. The rate of divergence of the side slopes is dependent on the flow conditions in the inlet channel. The higher the Froude number, the narrower the apron flare. Aprons work well to reduce the forward flow velocity of the water flowing into the pond.

Baffles act either to divert the water or slow the water. They can be used either near the inlet of the pond or in the body of the pond; they can be made of plywood or filter cloth. Problems associated with the use of baffles are numerous. Anchoring of the posts is difficult for hard or soft bottoms. Frost heaving is also a problem with anchoring. Filter cloths tend to clog rapidly in waters with fine suspended solids. Despite these disadvantages, barriers are effective in slowing the forward flow velocity and increasing the effective length of the ponds. Baffles function best under flows with Froude numbers under 2.5.

Level spreaders are specifically used to turn the direction of the inlet channel and to reduce the flow velocity of the water flowing into the pond. Proper installation and clean out of accumulated sediment of level spreaders is necessary for them to function properly. Level spreaders work best for low to moderate flows (less than 50 cfs).

Straw bale and sandbag dikes function essentially the same as check dams. However, straw bale and sandbag dikes are applicable only for low-flow velocities. Typically, these controls need to be replaced every three to six months.

Vegetative filters work for low-flow velocities and where the channel is not continuously submerged. They usually require considerable effort to establish and require at least annual inspections to ensure complete ground coverage. After the area is established, operating costs are usually minimal.

All of these measures will aid in increasing the sediment trapping efficiency of the sedimentation pond. Choice as to which measure to use should be based on topographic constraints, flow velocities, and costs. The actual increase in trapping efficiency is not known. The effectiveness of these measures needs to be documented by detailed monitoring results.

4.3 Multiple Pond Treatment Measures for Sediment Control

4.3.1 General

Multiple pond treatment measures include both individual sedimentation ponds in series and compartmentalization of a single larger pond. The concept behind multiple ponds is to provide stage settling. In the first pond or compartment the larger particles are settled out. Then, finer particles are

settled out in the second pond or compartment, with the smallest particles being settled out in the last pond or compartment.

Multiple ponds can improve sediment removal during base flow and storm runoff conditions. However, the advantages are more significant during storm runoff events because a larger quantity of larger particles will be carried by storm runoff. The advantage of multiple ponds during base flow or steady-state pumping is simply that the size of the individual multiple ponds are smaller than one larger pond with an equivalent surface area. Because the size of the individual ponds is smaller, it is easier to control and promote ideal settling conditions than it would be in the single larger pond. Smaller ponds are subject to less wind action and generally less embankment erosion.

Along with the advantages of smaller ponds, multiple ponds during storm runoff events have an added advantage over a single larger pond in that the peak discharge or flow rate is reduced by each pond due to storage. This effectively reduces the flow rate, and the surface area required for settling in one individual pond can generally be reduced by using more than one sedimentation pond.

Maintenance is also often an advantage with multiple ponds. Most of the maintenance is required in the first pond where larger sediment particles are removed. The frequency of maintenance decreases for each additional pond where the third and fourth ponds will only require sediment removal every few years depending on the specific site conditions. In effect, this limits the maintenance to a smaller area which can be advantageous over maintenance requirements on a single larger pond.

There are disadvantages to multiple ponds that should be realized. As the word implies, more than one embankment is constructed for ponds in series. Each pond requires principal and emergency spillways with adequate erosion protection. Each site also requires reclamation and removal of the embankment and channel stabilization when the ponds are on a drainageway. Therefore, a major consideration in the use of multiple ponds is economics.

4.3.2 Field Application

The use of multiple ponds in actual field application has been designed generally for one of two purposes. Most applications of multiple ponds are used to provide for adequate storage volume. In steep sloped areas, the size

of one embankment to provide adequate storage is often very large. The design and structural requirements of a large embankment are quite significant and multiple ponds reduce the size of embankments required but still provide the required storage.

Multiple ponds have also been used in conjunction with physical/chemical treatment. By removing the larger particles in the first pond or compartment, the sediment concentration in the discharge to the second pond is less. Since the dosage of chemical coagulant generally increases with the concentration of the suspension, the use of multiple ponds can reduce the dosage or quantity of chemical coagulant required. This can result in a significant cost savings.

4.3.3 Multiple Pond Design Considerations

4.3.3.1 Multiple Ponds in Series

For design of multiple ponds in series, each pond is considered as a single pond and is designed as such. All the considerations of pond location, configuration, and inlet and outlet design apply to multiple ponds. However, certain considerations for sediment storage and the design inflow rate for sizing inlet and outlet structures are required.

The design inflow rate to the first pond is based on the estimated runoff hydrograph from the contributing drainage area. The inflow rate to the second pond and subsequent ponds in a series should be based on runoff from the incremental increase in drainage area and the outflow hydrograph from the upstream pond. The runoff hydrograph produced by the additional drainage area is additive to the outlet hydrograph from the upstream pond. This concept is illustrated in Figure 4.12. For the situation presented in Figure 4.12, Pond 1 would be designed for the runoff from drainage area A_1 and Pond 2 would be designed for the runoff from drainage area A_2 plus the runoff from area A_1 routed through Pond 1.

Another consideration for design and maintenance of multiple ponds in series is sediment storage volume. The first pond in a series will remove most of the larger sediment particles depending on the pond design. The second pond and subsequent ponds in a series will receive finer and finer sediment particles. Thus, the sediment volume accumulation in the first pond will occur faster than downstream ponds due to the larger size particles being removed. From the illustration in Figure 4.12, the sediment storage volume

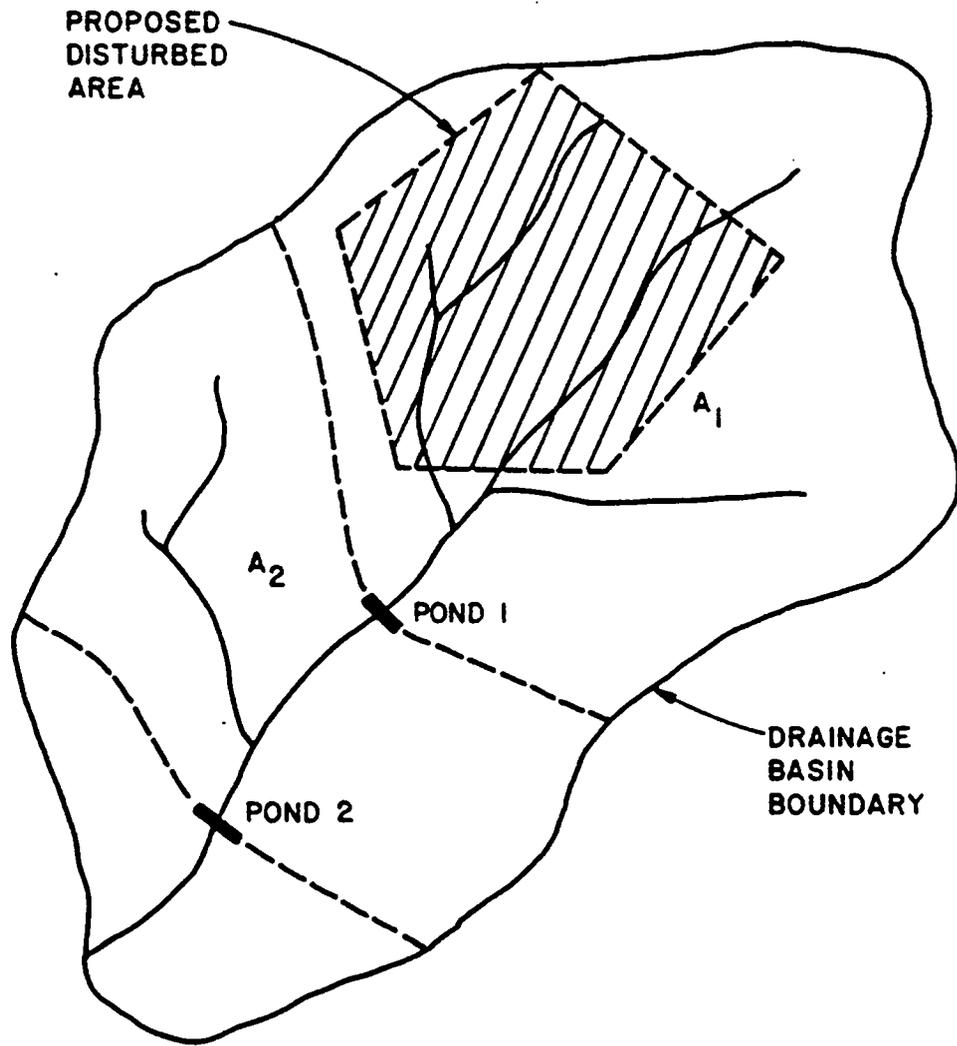


FIGURE 4.12 ILLUSTRATION OF MULTIPLE PONDS

for Pond 1 would be based on the yield from area A_1 . The sediment storage for Pond 2 should be based on the yield from area A_2 and a certain percentage of the yield from area A_1 based on the trap efficiency of Pond 1.

4.3.3.2 Compartmentalization

A single pond compartmentalized by baffle walls constructed of wood or other suitable material provides the same staged settling as multiple ponds in series. However, the design flow to each compartment is different from that for multiple ponds in a series. The removal and storage of sediment in a compartmentalized pond is similar to multiple ponds in series.

For design of compartmentalized ponds, the flow rate to the first compartment is based on the upstream drainage basin. The flow rate to the second compartment and subsequent compartments is based specifically on the discharge from the upstream compartment. The flow from one compartment will be based on the outlet device which is typically some type of weir overflow. The discharge from each compartment can be developed the same as for any spillway based on the characteristics of the outflow device (Section 3.9).

Most of the sediment storage for compartmentalized ponds should be provided in the first compartment. The sediment storage provided in the first compartment can be based on the trap efficiency, however, a conservative storage volume should be provided to reduce the frequency of maintenance.

4.3.4 Water Quality Resulting from Multiple Ponds

Multiple ponds or compartmentalization of a single pond has been used to provide the required storage volume in place of one larger pond and to increase the detention time for small particles. Data have shown that multiple ponds, with an equivalent surface area of one pond, will remove finer particles than the single pond and thus are more efficient (EPA, 1976). However, even the use of multiple ponds will not provide adequate settling for colloidal particles. Multiple ponds can provide a viable means of sediment removal, especially in steep sloped terrain. For multiple pond systems to perform well requires the same considerations for geometry, location, and inlets and outlets as for a single sedimentation pond.

4.4 Physical/Chemical Treatment

4.4.1 General

As sediment particles become very small the time required under gravitational settling conditions becomes very large. Sediment sizes greater than 10 microns are considered to be settleable in a sedimentation pond while sizes between 1 micron and 10 microns are settleable but usually not in the time available in a typical sedimentation pond. Sediment sizes between 10^{-3} microns and 1 micron are described as colloidal dispersions and are held in suspension by electrical forces. Colloidal particles yielded from disturbed lands are primarily clays. The time required to settle one foot for each class particle is illustrated in Table 4.3.

4.4.2 Use of Coagulants and Flocculants

The use of coagulants and flocculants to increase the settling of colloidal sediments can be effective provided reasonable influent conditions can be obtained. Coagulants and flocculants are effective over a relatively narrow range of concentration in water (Figure 4.13). A change in the coagulant concentration of five times in either direction from the optimal concentration will completely eliminate any effect on colloidal settling. Even a change of twice the optimal concentration of the coagulant will reduce colloidal settling by 50 percent.

The inflow to a sedimentation pond will vary by an order of magnitude for a single storm and will vary by several orders of magnitude for different storm events. An application of a coagulant at a constant rate to this type of inflow condition would be unacceptable since the coagulant concentration would vary greatly.

Two approaches can be taken to controlling the coagulant concentration to maintain effective colloid settlement. One method is to control the inflow rate of water to be treated so that a constant application rate of coagulant can be used. This requires that two sedimentation ponds be used. The first pond is designed to settle coarse sediments and contain the storm volume. Coagulants are then added to the outflow of the first pond where the outflow structure has been designed to control the outflow rate within an acceptable

Table 4.3. Effect of Decreasing Particle Size on Settling.

Diameter of Particle (microns)	Class of Particle	Time Required to Settle One Foot
100	Very fine sand	38 seconds
10	Fine silt	33 minutes
1	Medium clay	55 hours
<u>< 1</u>	Very fine clay and colloidal particles	<u>> 230 days</u>

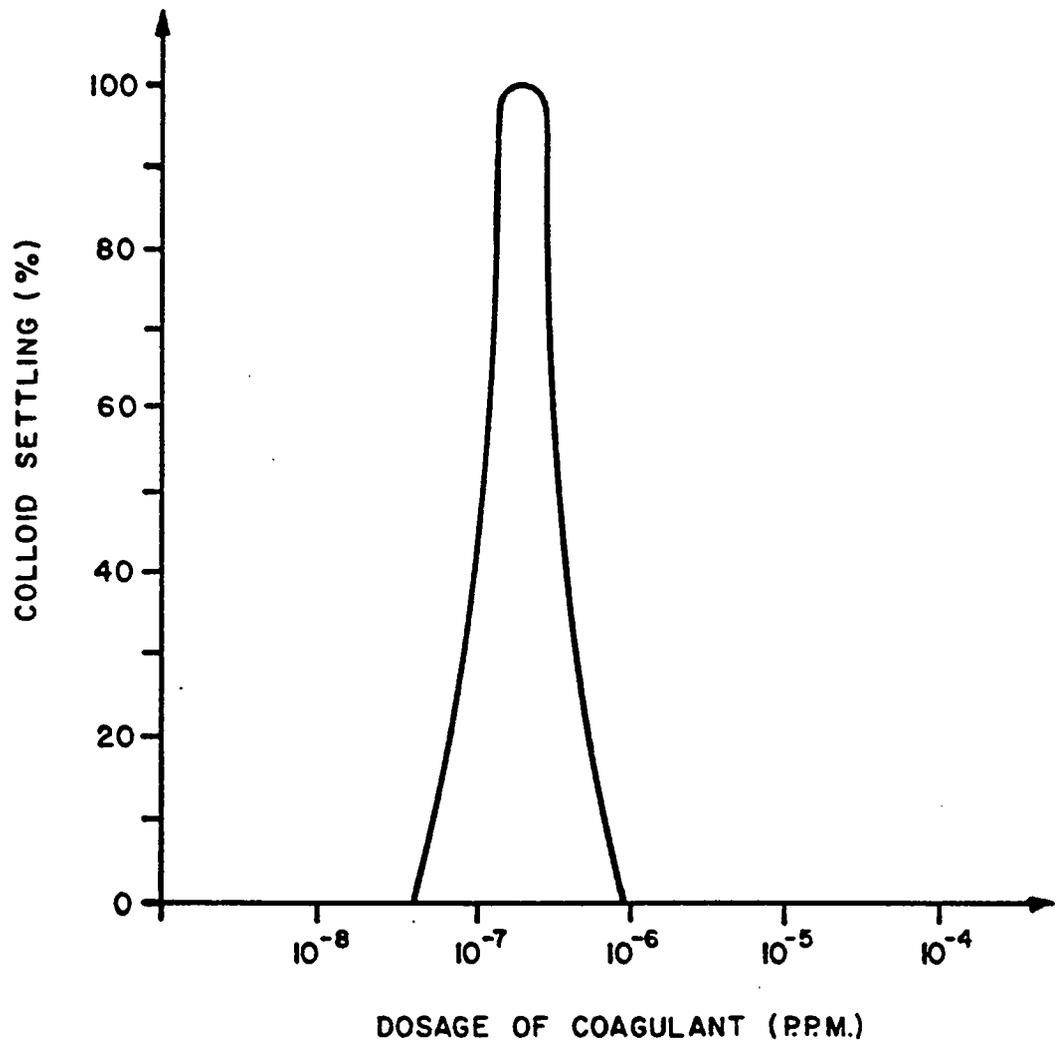


FIGURE 4.13 EFFECTIVE CONCENTRATION RANGE OF COAGULANTS AND FLOCCULANTS

range. In this way, coagulant would be used only for fine and colloidal sediments in the most effective and economical manner. The second pond is designed to settle fine and colloidal sediments.

An alternative method is to allow an uncontrolled outflow from the first pond and to vary the amount of coagulant based on the rate of discharge to the second pond. In this type of system, a monitoring device is required to indicate the liquid level which controls a pump delivering coagulant to the outflow. This type of system is beneficial when large discharges are being treated to meet stringent water quality requirements.

4.4.2 Field Application in the Use of Physical/Chemical Treatment

The use of chemical coagulants and flocculants in sedimentation ponds varies from sophisticated rate controlled application to simplified constant point applications. Most field hardware is fairly simple and consists of a storage or mixing tank for dilution of the chemical, chemical feed pump, and plastic hose to the point of application.

Sophisticated systems such as that used by Washington Irrigation and Development Company at a mine site near Centralia, Washington, include flow measurement and rate feed control of the chemical. The final set up used at the Centralia mine was the result of significant field testing prior to application. The final system is shown in Figure 4.14 and consisted of four major components:

1. Liquid level capacitive probe.
2. Liquid level monitoring and control instrument with flow proportional output circuit.
3. Automatic pump control.
4. Chemical metering pump.

This system was developed to prevent contamination of a salmon fisheries stream that received the runoff from the mine site. The effluent quality was reported in JTU turbidity units. The system reduced the turbidity from 1000 + JTU to less than 15 JTU (McCarthy, 1973). It should be pointed out that the application point was at the effluent of the first pond of a two pond system.

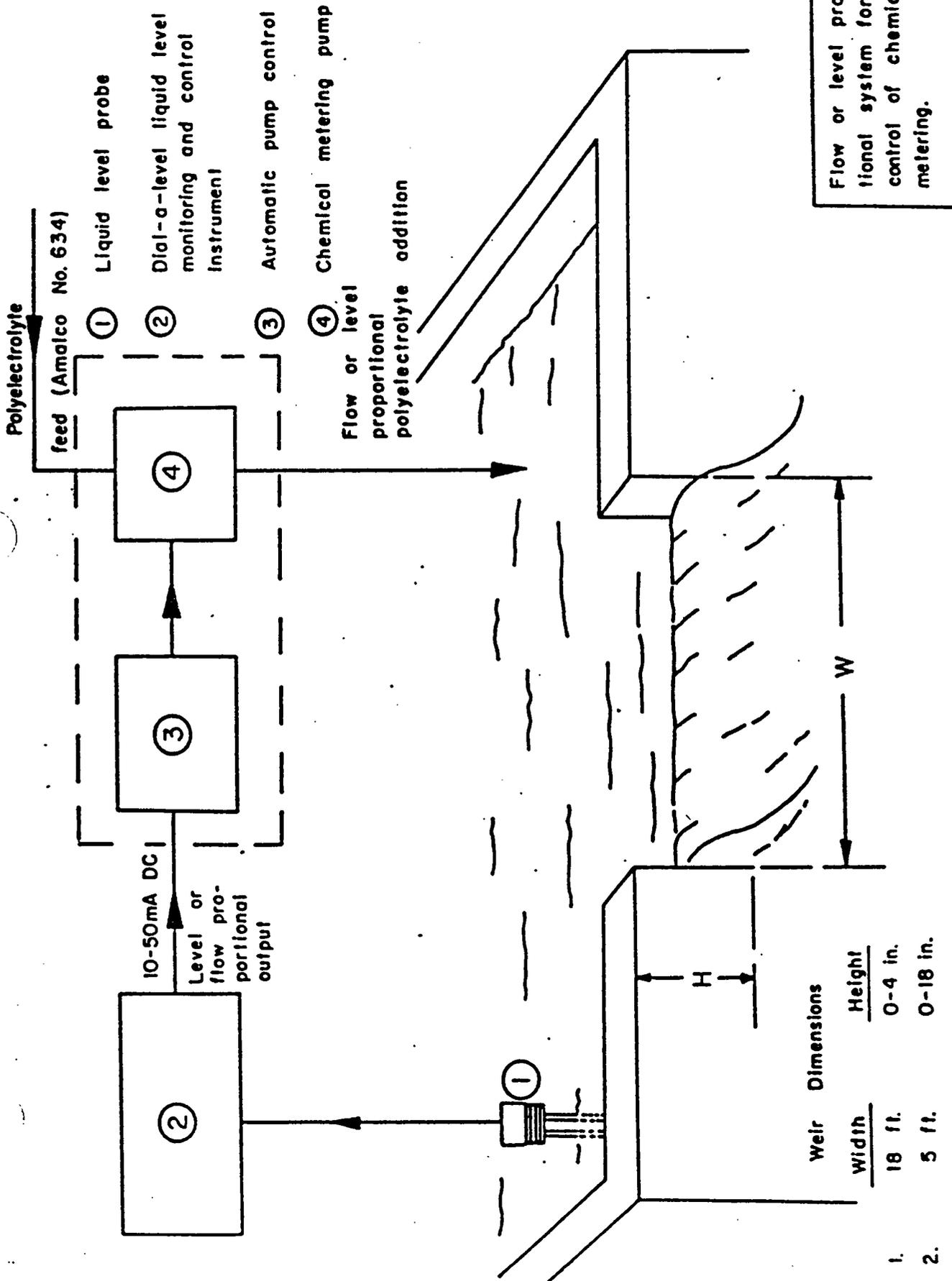


FIGURE 4.14 CHEMICAL TREATMENT APPLICATION AT CENTRALIA MINE SITE, CENTRALIA, WASHINGTON (Mc CARTHY, 1973)

This system is more typical of hardware used in industry and water treatment. These types of systems required significant field investigation, design, adequate power source, and clean water source.

Most mine sites are remote, and power sources and the ability to install and maintain a sophisticated system are quite difficult. Thus, many of the existing applications have been simplified to enable easier application. Very simple applications are represented by spreading of solid coagulants in roadside channels carrying disturbed area runoff where the flow in the channels scour up the coagulants; or by diverting the disturbed area runoff through barrels with solid or brickete forms of coagulants in the barrel where the flow turbulence through the barrel dissolves and mixes the coagulant. Sophistication of simple systems increases with addition of a tank for chemical storage, a feed pump, and a plastic feed line to the application point. These systems are constant rate feed that can be adjusted manually to change the dosage.

Constant coagulant feed systems work well when the flow being treated is constant. Examples of constant flow are base flow conditions and pumping from a collection sump at a constant rate to a sedimentation pond. A unique application at a mine site in North Dakota has a mobile system consisting of a storage tank, feed pump, feed line, recirculation pump, and recirculation pipe. The system is set up on a covered flat bed truck that can move to various sedimentation ponds with gated outlets. One major requirement of this system is that the outlets to the ponds remain closed to store an entire runoff event. At the pond, the recirculation pump draws water from the pond through a recirculation line (PVC pipe). The water is routed back to the truck where the chemical coagulant is fed into the recirculation pipe and then pumped back to the opposite end of the pond. The coagulated sediments are allowed to settle and the water is released from the pond when the water in the pond has reached acceptable conditions (determined from visual observation).

Another innovative application is being tested in the field at a mine site in Alabama. Here, the application is a solid "gel log" of synthetic, high molecular weight polyacrylamide copolymers. Initial bench tests are still required to select the most suitable flocculant. The logs are placed directly in the flow so that maximum contact between the flow and the log

occurs. The logs should be placed so that sufficient mixing occurs. This is done by placing the logs in or upstream of a highly turbulent flow area. The log requires a secure position in the flow so it is not washed downstream. The exact dosage requirement requires trial and error adjustments in the field by varying the number of logs and observing the results. They work well under low-flow conditions, but dissolve during high runoff events. Maintenance is required to keep leaves, twigs, and sediment from covering the log and reducing the contact surface and thus the dosage. The logs are effective in cold temperatures, however, the dosage is reduced due to a decrease in dissociation of the polymer and more logs are required.

In comparison, sophisticated control of feed rate enables treatment during high- and low-flow conditions. Documentation of the application at the Centralia Mine in Centralia, Washington, shows that this type of treatment system is very efficient and can perform well during high- and low-flow conditions. The less sophisticated and simplified applications lose a significant amount of control during dynamic conditions where both flow rate and sediment concentration vary during a storm runoff event. The simplified methods can provide effective treatment under certain conditions, but as the conditions change and no adjustment is made, the effectiveness of the method is reduced and often nullified. Also, no documentation on the results of these methods exist. Performance information on "gel logs" is expected to be published in the near future.

4.4.4 Types of Coagulants

Commonly used coagulants include:

1. Metal salts

- Aluminium sulfate
- Ferrous sulfate
- Ferric chloride

2. Metal hydroxides

- Aluminum hydroxides
- Calcium hydroxides

3. Synthetic polymers or polyelectrolytes

- Anionic
- Cationic
- Nonionic

Metal salts and hydroxides are available in a dry granular form and are dissolved in clean water before mixing. Synthetic polymers or polyelectrolytes are usually available in liquid form which need not be diluted prior to use if good mixing is available. Metal salts and hydroxides are cationic and are useful in removing colloidal solids. Synthetic polymers and polyelectrolytes are either cationic, anionic, or nonionic. Settleable solids which require a coagulant will use one which is normally anionic.

Advantages and disadvantages of liquid and solid coagulant will depend on a number of factors. The volume of solid coagulant needed is much greater than for liquid coagulants. Dilution of solid coagulants can be difficult under field conditions when a clean water source is unavailable or because mixing is slow. Both liquid and solid coagulants are extremely caustic and may cause severe corrosion of the containers in which they are stored. Leaking of liquid polymers during storage can be a problem, also polymers can be damaged if stored in freezing temperatures. Gelled polymers are presently available which combine several of the advantages of solid and liquid polymers. They are easy to handle and transport and do not require dilution. Disadvantages of gelled polymers are the inability to control the dosage level of the coagulant, where it will not work well during high flow events.

4.4.5. Water Quality Resulting from Physical/Chemical Treatment

The effects of coagulants on settling of colloidal particles has been demonstrated to be effective in municipal and industrial applications. Well monitored and controlled sedimentation ponds have also shown significant improvement in water quality from treatment with coagulants. The treatment of colloidal suspensions in water with coagulants is still more of an art than a science and any application will require a significant amount of testing and experimentation to produce good results. Overdosing and underdosing are significant problems to be overcome in any system, as well as the problem of adequate mixing and floc formations. Settling efficiency must be determined

from test data and actual pond performance will vary from one mine site to another.

Tests on pilot scale sedimentation ponds showed that the effluent suspended solids concentration for flocculation tests were at least one order of magnitude lower than those from identical tests without flocculants (Barfield, 1981). It was concluded from these tests that the use of chemical coagulants and/or flocculants will improve the performance of sedimentation ponds. However, the procedures to predict effluent concentrations using flocculants are not highly accurate (Barfield 1981).

The sediment removed from a sedimentation pond treated with coagulant will contain flocculated sediment and the coagulant. Metallic salts and hydroxides are stable and will remain so after they have been disposed of, sediment containing polymers will undergo more complex interactions, possibly with micro-organisms both in the pond and in the disposed area. No definite information is known on the rate of biodegradation of various polymers by micro-organisms. Information on the toxicity of potential degradation products is also unknown. Caution should be exercised in the use of polymers because of the limited knowledge concerning the biodegradation products and their potential effects on plants, animals, and man. The proper disposal methods of treated sediments should be obtained from local, state, and federal regulatory agencies.

4.5 Areas In Which Future Research May Provide Improved Technology

Monitoring programs of the sedimentation pond influent and effluent need to be implemented so it can be determined which pond configurations, inlets, outlets, and coagulant types are the most effective in sediment removal. From the monitoring program it can be determined which types of inlets and outlets work the best for a certain pond configuration. Since the pond configuration is generally controlled by the topography, innovative techniques in the use of inlets, outlets, and physical/chemical techniques will have to be implemented to make the sedimentation pond more efficient in sediment removal.

Factors which produce poor sediment removal efficiencies in sedimentation ponds have been identified and documented. These factors include untimely removal of the settled sediment, poor construction techniques, and pond geometries which are susceptible to short circuiting.

TABLE OF CONTENTS
CHAPTER V

	<u>Page</u>
V. MAINTENANCE FOR WATER QUALITY CONTROL	
5.1 <u>Pond Maintenance</u>	5.1
5.1.1 Accessibility	5.2
5.1.2 Monitoring/Maintaining Sediment Storage Volume	5.2
5.1.3 Bank Stability and Maintenance	5.3
5.1.3.1 <u>Vegetation Stabilization</u>	5.3
5.1.3.2 <u>Riprap Stabilization</u>	5.4
5.1.3.3 <u>Rill and Gully Control</u>	5.4
5.1.4 Maintenance of Inlet and Outlet Structures	5.4

V. MAINTENANCE FOR WATER QUALITY CONTROL

5.1 Pond Maintenance

The useful life of a pond is partially a function of the maintenance of the pond and the embankment. The primary purposes of maintenance are to preserve the structural integrity of the dam to ensure that essential design features of the outlets are maintained, and to ensure adequate storage and capacity for the pond. Minor problems should be repaired before they become major problems. It is usually less costly to implement a regular maintenance program than it is to make repairs after an extended period of negligence.

Written instructions for maintenance and operation of the structure (and any required monitoring equipment) should be prepared as part of the design. These instructions should establish the frequency, and describe the nature of, inspections. Instructions should also be provided for routine maintenance of inlet and outlet structures. If a spillway is controlled by manually operated gates, specific instructions should be given regarding the operation of the gates.

A record of all inspections and any maintenance performed on the pond should be kept. The date, last major rainfall, sediment storage level, and any problems should be noted. If maintenance has been performed, the date and type of repair should be noted. These two records will aid the operator in determining if chronic problem areas exist in the pond design.

After an area has been stabilized and successfully revegetated, sedimentation ponds may be removed. The decision for removal or retention of a sedimentation pond is usually addressed in the mining and reclamation plan submittal. The options available to the operator will be discussed later in this chapter.

Repairs of embankments and emergency spillways are extremely important for the proper functioning of the sedimentation pond system. In humid regions, embankments are usually stabilized by mulching and then by establishing a good vegetation cover. Where conditions do not allow the establishment of a vegetative cover, riprap or mulching may be used. The use of either a vegetative cover or riprap is not specifically required by OSM. However, both of these measures will aid in stabilizing the embankment or spillway and will usually reduce the required maintenance. The design

engineer should check with the regulatory authority to determine regionally accepted methods to stabilize the embankment and spillway.

Studies investigating the performance of existing sediment ponds for the control of erosion from surface mining operations have shown that once the pond has been constructed and operated maintenance of sediment level, inlets and outlets is one of the main causes of poor pond performance (EPA 1980, EPA 1979).

5.1.1 Accessibility

Location of the pond is of prime importance. The pond should be accessible for construction, monitoring, and maintenance. Accessibility for maintenance should be considered during the planning of the pond. The design engineer should consider the type of equipment used for construction and maintenance and the room required for this equipment to function efficiently. In a well designed pond, the heavier sediment will deposit near the inlet of the pond. Therefore, access to the inlet end of the pond is essential. A well constructed and regularly maintained road is very helpful for providing proper maintenance, including sediment removal, riprap repair, or embankment repair. Adequate accessibility is vital if chemical flocculation is being used.

5.1.2 Monitoring/Maintaining Sediment Storage Volume

Most sedimentation ponds are designed with sufficient annual sediment storage volume for a number of years. However, designing for excess storage volume does not guarantee that this storage volume will not be exceeded by a large storm event.

In order to ensure adequate storage volume, the available sediment storage volume in a pond must be monitored. Pre-defining the clean-out level is helpful for monitoring. One of the simplest means of pre-defining the clean-out level is to install a staff gage in the pond and to determine the sediment accumulation level that requires clean out. Most design manuals (Virginia Soil and Water Conservation Commission, 1980) recommend clean out when the accumulated sediment reaches 60 percent of the design sediment storage volume. An acceptable schedule should be established by the design engineer, operator, and regulatory agency. It is the responsibility of the operator to ensure that the schedule is followed.

Clean out of sediment is usually handled by a small dragline, clamshell bucket, or a backhoe for wet ponds and by a front-end loader for dry ponds. If a front-end loader is used, the ponds should be sufficiently dried in order to support the weight of equipment. For large ponds which cannot be cleaned by draglines operating from the banks, cleaning is more difficult. In such cases dredging may be necessary. Dredging will often require the service of professionals experienced in this procedure.

Sediment removed from a pond is usually incorporated into the spoil material. If the removed sediment is found to contain acid- or toxic-forming materials, the sediment will have to be disposed of in a more controlled manner. Sediment removed from a pond may be used as a substitute for topsoil. Use of this material as a topsoil substitute may be very useful for underground coal mining activities where the amount of available topsoil is limited. If chemical flocculation is used to improve the efficiency of the pond, use of the accumulated sediment will probably not be suitable as a topsoil substitute because of the possible toxic effects of the chemicals. Chemical and physical analyses are needed before any material can be used as a substitute for topsoil.

5.1.3 Bank Stability and Maintenance

Depending on the pond surface area, location, and local climate, maintenance of side slopes is important. Wave action, excavation, and removal of vegetation will promote the erosion of side slopes and subsequent increase in solids concentration of the pond. Several methods and maintenance procedures are discussed.

5.1.3.1 Vegetation Stabilization

Maintenance of vegetative measures should occur on a regular basis, consistent with favorable plant growth, soil, and climatic conditions. This involves regular seasonal work for fertilizing, liming (if applicable), pruning, fire controls, reseeding, and weed and pest control. Open channel spillways are subject to rapid infestation of weeds and woody plants. These should be eradicated or cut back since they often reduce drainageway efficiency. Well-maintained vegetation will provide a comfortable margin of erosion control .

5.1.3.2 Riprap Stabilization

Large storms may displace the riprap and allow erosion of the underlying material. Displacement and damage to the riprap will usually occur where flow velocities are highest. Typically, discharge structures and spillway areas experience the most damage. If displacement of the riprap has occurred, the riprap filter blanket should be checked for damages. Repairs should be made as soon as practical. These areas should be checked for erosion or silting of the channel in order to assess the impact of the carrying capacity of the channel.

Riprap is commonly used to control the upstream embankment of the dam from damages due to wave action. If riprap is damaged, the size of the riprap may have to be increased. The riprap filter blanket should be checked for damages wherever the riprap is displaced.

5.1.3.3 Rill and Gully Control

Concentrated water flow will cause rills and gullies on the embankment slope. Vegetation and riprap will often stop their development; however, a certain amount of erosion is expected on any earth embankment. The size and density at which rills and gullies become uncontrollable is difficult to define and is dependent on the soils, climate, and land use of the local area. OSM requires rills or gullies deeper than nine inches in reclaimed areas to be filled, graded, or otherwise stabilized (i.e., straw mulch) (30 CFR 816.106). Use of this rule as a guideline for embankment stabilization is suggested and will preclude the formation of large gullies. State agencies may require a more stringent maintenance program.

5.1.4 Maintenance of Inlet and Outlet Structures

Maintenance of inlet and outlet structures is an extremely important requirement in achieving effective sediment control. All water-handling structures should be inspected after every major storm. Erosion damages require prompt repair to prevent further damage and to help prevent similar damage in the future.

Sediment buildup in the inlet section and behind check dams and filter barriers should be checked. Sediment and other debris removed from these

areas should be disposed of in a manner that will prevent sediment from being carried back into the waterways at the mine. Possible use of this material as a substitute soil medium should be considered. Straw bales and sandbag barriers should be replaced before they become clogged or overtopped.

When vegetation is used to stabilize the area or as a vegetative filter, top dressing with fertilizer is usually required. Fertilizer will help keep a dense stand and provide growth of desirable plants. Areas where failures have been experienced in the establishment of vegetative protection must be promptly treated. Timely maintenance will reduce costs in the long run. If the area continues to exhibit vegetation failure due to either high or prolonged water flow, more extensive stabilizing measures such as riprap may be needed.

Pipe culvert spillways should be examined for structural stability both at the inlet and at the discharge point. Trash racks should be cleaned of debris. If gates or valves are used, they should be tested to see that they work freely.

TABLE OF CONTENTS
CHAPTER VI

	<u>Page</u>
VI. DESIGN PROCEDURES AND EXAMPLE	
6.1 <u>Design Procedure</u>	6.1
6.2 <u>Design Example</u>	6.4

LIST OF TABLES
CHAPTER VI

	<u>Page</u>
Table 6.1 Development of Influent Size Distribution	6.6
Table 6.2 Summary of Sedimentation Pond Design	6.20

LIST OF FIGURES
CHAPTER VI

	<u>Page</u>
Figure 6.1 Sedimentation pond site	6.5
Figure 6.2 Sediment size distribution	6.7
Figure 6.3 Stage-storage area and stage-storage curves of Pond Site No. 1	6.11
Figure 6.4 Sedimentation Pond Site No. 2	6.15
Figure 6.5 Stage-storage area and stage-storage curves of Pond Site No. 2	6.17

VI. DESIGN PROCEDURES AND EXAMPLE

6.1 Design Procedure

Step 1. Site selection (Section 3.1)

The sedimentation pond location is selected considering the factors presented in Section 3.1.

Step 2. Hydrology (Section 3.2.1)

The peak inflow rate and runoff volume for the design storm event are determined.

Step 3. Influent sediment size distribution (Section 3.2.2.1)

The size distribution of the inflowing sediment is required. Where existing information from the mine site or nearby mine sites is available, it should be used. When there is no existing data, a size distribution can be developed using information from soil surveys.

Step 4. Sediment yield (Section 3.2.2.2)

Determine the annual sediment yield and the storm sediment yield.

Step 5. Inflow suspended solids concentration (Section 3.2.3)

Using the storm sediment yield and the storm runoff volume, determine the average influent suspended solids concentration.

Step 6. Settleable solids concentration (Section 3.5)

Develop the settleable sediment size distribution (particles > 0.001 mm) from the influent sediment size distribution. Select a particle size to be removed in the pond. Determine the trapping efficiency from the settleable sediment size distribution. Determine the average effluent suspended solids concentration using the trapping efficiency, sediment yield, and runoff volume (Equation 3.6). Calculate the settleable solids concentration (SS) from Equation 3.5. If $SS > 0.5$ ml/l, select a smaller size particle and repeat procedure. If $SS \approx 0.5$ ml/l, go to Step 7 and design pond to remove selected particle size. If $SS < 0.5$ ml/l, select a larger size particle and repeat procedure.

Step 7. Available storage volume (Section 3.7)

Develop stage-storage curve for sedimentation pond location. Determine the required sediment storage volume and the corresponding depth. Determine the available detention storage depth by

$$D = \text{embankment height} - (\text{embankment settlement} + \text{required freeboard} + \text{emergency spillway depth} + \text{sediment storage depth})$$

Determine the available detention storage volume above the sediment storage depth from the stage-storage curve.

Step 8. Required storage volume (Section 3.6)

Assume a detention storage depth and determine the required detention time for the design particle size from Figure 3.10. Calculate the time base of the inflow hydrograph. Determine the required storage volume from Figure 3.7. Determine the required outflow rate from Figure 3.8. Compare the required storage volume to the available storage volume. If the available storage volume is less than the required storage volume, either

- (a) Increase the embankment height and determine the new available storage volume. Repeat Step 8.
- (b) Excavate the pond side slopes and develop new stage-storage curve. Repeat Step 8.
- (c) Construct a pond downstream and return to Step 1.

If the available storage volume is larger than the required storage volume, check the required surface area (Section 3.8.3.1). If the measured surface area is less than the required surface area, (1) excavate pond side slopes or (2) raise principal spillway crest. If the measured surface area is greater than the required surface area, check length-width ratio (Section 3.8.2.2) and calculate required length to settle design particle size (Section 3.8.1). If the length is not large enough, increase the flow length (Section 4.2). If the length criteria is met, check scouring (Section 3.8.3.4). If the scouring velocity is smaller than the horizontal velocity, increase the depth and return to Step 7. If the scouring velocity is greater than the horizontal velocity, go to Step 9.

Step 9. Principal spillways (Section 3.9.1)

Select principal spillway type and design for the peak outflow rate and the corresponding head.

Step 10. Emergency spillway (Section 3.9.4)

Select emergency spillway type and design the spillway system to pass the peak discharge from the 25-year, 24-hour runoff event.

Step 11. Erosion control below the spillways (Section 3.9.5)

Size the riprap below the principal spillway.

Step 12. Check base flow conditions after pond is operational.

6.2 Design Example

The design example is to illustrate the procedures of sizing a detention pond to meet the effluent standard. Design of principal spillway (Step 9), emergency spillway (Step 10), erosion control below the spillway (Step 11), and base flow condition (Step 12) are not included because methodologies can be found in various texts and references.

Step 1. Considerations for sedimentation pond selection have been presented in Section 3.1. In this design example, a site is preselected and presented in Figure 6.1.

Step 2. Hydrology

<u>Design Event</u>	<u>Q_I (cfs)</u>	<u>V (acre-feet)</u>
10-year, 24-hour	77	2.31
25-year, 24-hour	91.5	3.35

Step 3. Sediment size distribution

For the purpose of illustrating the methodology, develop influent size distribution from Soil Surveys (Table 6.1).

55 percent of area is sand
 40 percent of area is sandy clay
 5 percent of area is silty clay

Figure 6.2 presents the influent size distribution. The distribution is extended with a straight line to a particle size of 0.001 mm.

Step 4. Sediment yield (use USLE for annual sediment yield and MUSLE for storm sediment yield)

Annual sediment yield = 115 tons
 Storm sediment yield = 50 tons (10-year, 24-hour storm)

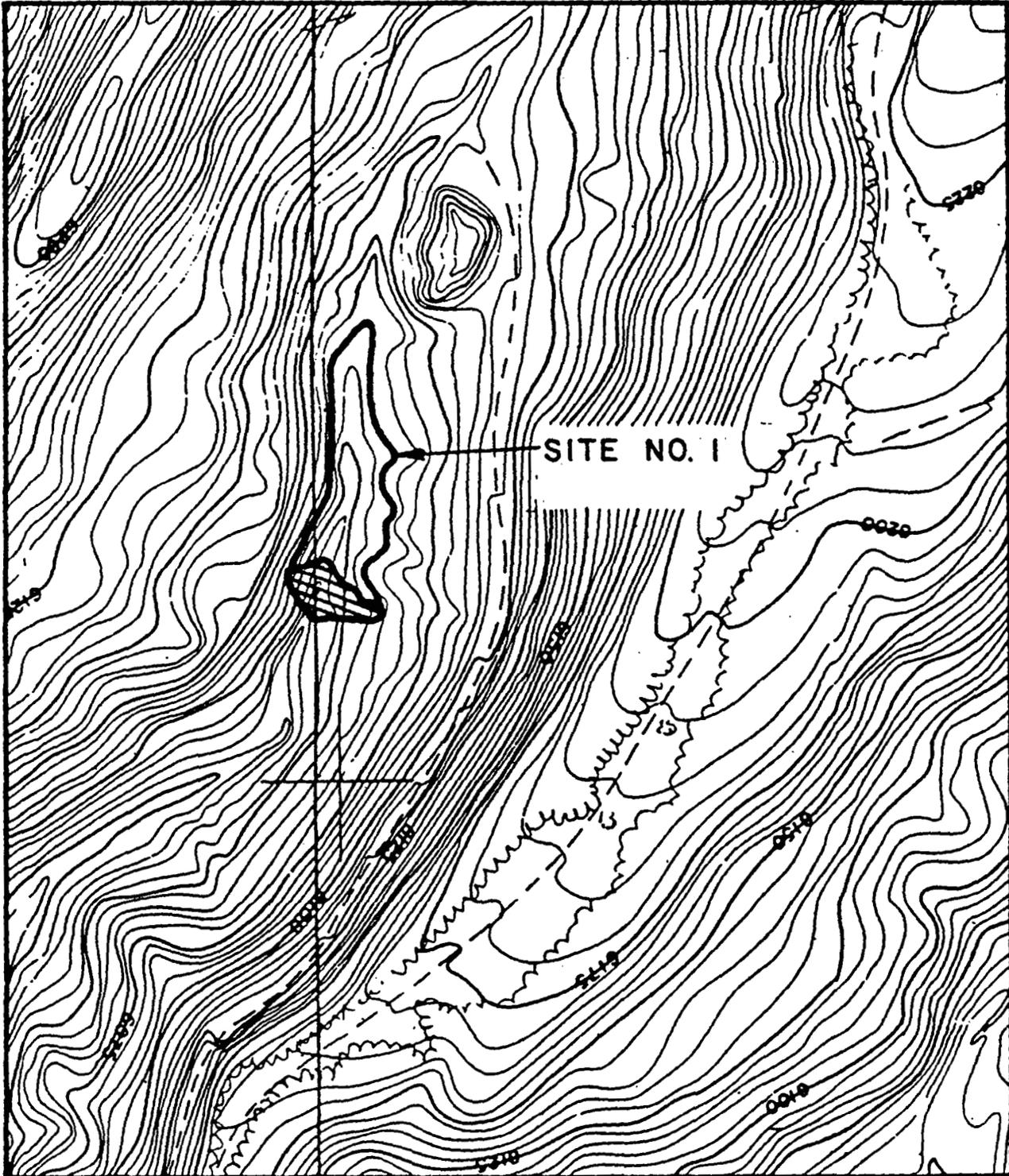


FIGURE 6.1 SEDIMENTATION POND SITE

Table 6.1. Development of Influent Size Distribution.

Particle Size Range (mm) (1)	Mean Particle Size (mm) (2)	Sand			Silty Clay			Influent Size Distribution Σ Col. 9 (\$ finer) (10)	
		From Table 3.1 (\$ finer) (3)	Col. 3 x 0.55 (\$ finer) (4)	From Table 3.1 (\$ finer) (5)	Col. 5 x 0.40 (\$ finer) (6)	From Table 3.1 (\$ finer) (7)	Col. 7 x 0.05 (\$ finer) (8)		
< 0.002	0.002	2	1.1	55	22.0	45	2.2	25.3	25.3
0.002-0.05	0.010	10	5.5	5	2.0	45	2.2	9.7	35.0
0.05-0.10	0.070	15	8.3	5	2.0	5	0.3	10.6	45.6
0.10-1.0	0.316	35	19.2	10	4.0	5	0.3	23.5	69.1
1.0-2.0	1.414	38	20.9	25	10.0	--	---	30.9	100.0

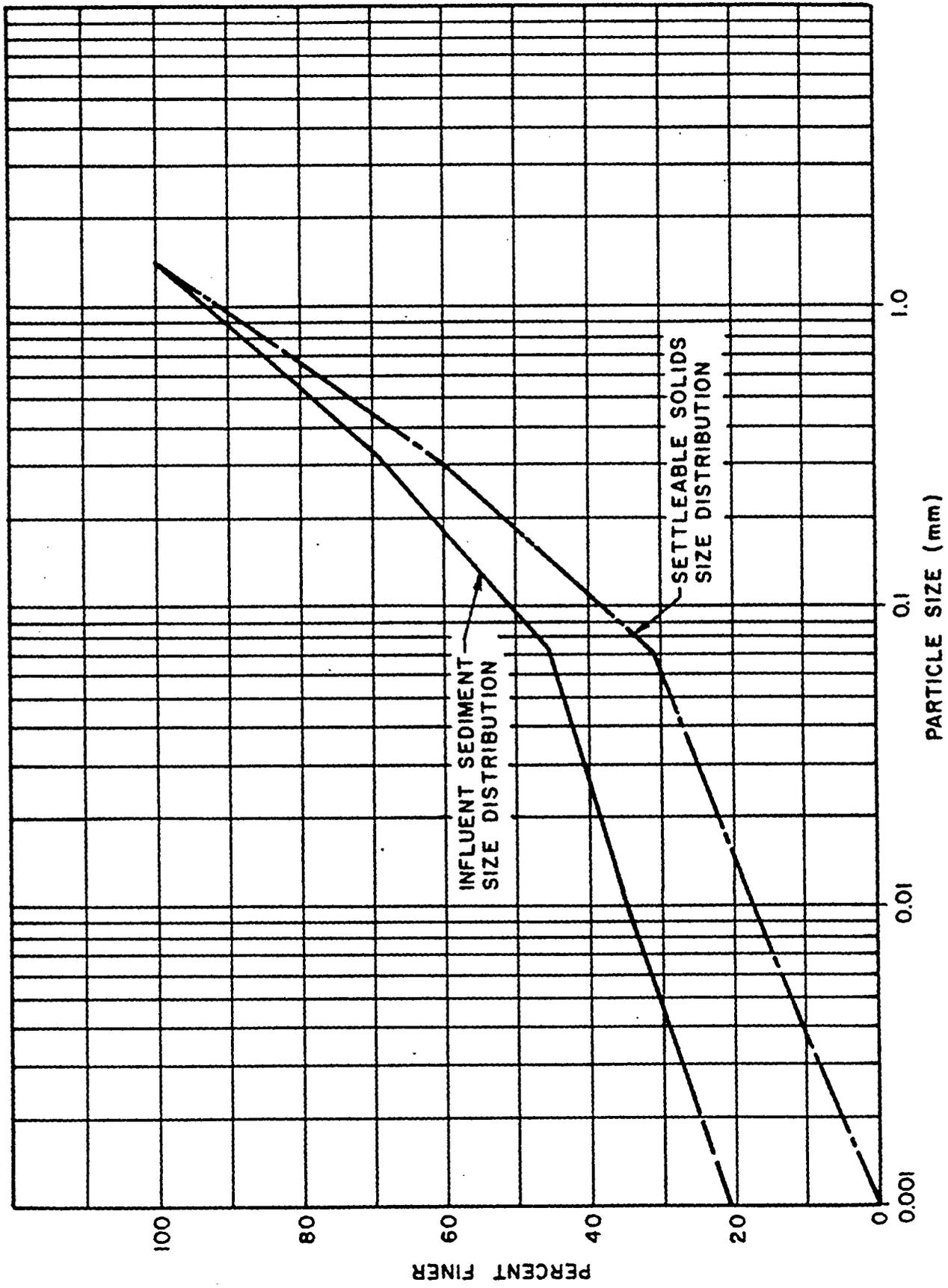


FIGURE 6.2 SEDIMENT SIZE DISTRIBUTION

Step 5. Average inflow suspended solids concentration

$$C_I = \frac{50 \text{ tons} \times 2000 \text{ lb/ton} \times 10^6}{2.31 \text{ ac-ft} \times 43,560 \text{ ft}^2/\text{ac} \times 62.4 \text{ lb/ft}^3} = 15,926 \text{ mg/l}$$

Step 6. Settleable solids concentration

From Figure 6.2, 21 percent of the influent size distribution is non-settleable (< 0.001 mm). The redistributed settleable size distribution is also presented in Figure 6.2.

Start with $d = 0.011 \text{ mm}$.

From Figure 6.2, trapping efficiency $E = 0.82$ and fraction of settleable solids $K = 0.79$, using Equation 3.6.

$$C_o^* = \frac{(1.0 - 0.82) \times 0.79 \times 50 \text{ tons} \times 2000 \text{ lb/ton}}{2.31 \text{ ac-ft} \times 43,560 \text{ ft}^2/\text{ac} \times 62.4 \text{ lb/ft}^3} \times 10^6 = 2265 \text{ mg/l}$$

The settleable solids concentration is determined as follows:

Particle Size Range	Mean Size (di)	Influent ΔX_i	Effluent ΔX_i	$(d_i/0.011)^6 \times \Delta X_i$
0.001 -0.002	0.0014	0.05	0.28	1.19×10^{-6}
0.002 -0.0038	0.0028	0.05	0.28	7.62×10^{-5}
0.0038-0.0072	0.0052	0.05	0.28	3.12×10^{-3}
0.0072-0.011	0.0089	<u>0.03</u>	<u>0.16</u>	<u>4.49×10^{-2}</u>
		0.18	1.0	0.048

From Equation 3.5, settleable solids concentration can be calculated as

$$SS = \frac{2265 \text{ mg/l}}{1120 \text{ mg/ml}} [(1.0 - 1.0) + 0.048] = 0.10 \text{ ml/l} < 0.5 \text{ ml/l}$$

Try with a larger size of settleable solids, $d = 0.020$ mm.

$$X_o = \frac{\% \text{ of settleable size distribution smaller than } 0.011 \text{ mm}}{\% \text{ of settleable size distribution smaller than } 0.020 \text{ mm}}$$

$$= \frac{0.18}{0.22} = 0.818$$

From Figure 6.2, $E = 0.78$ and $K = 0.79$

$$C_o = \frac{(1.0 - 0.78) \times 0.79 \times 50 \text{ tons} \times 2000 \text{ lb/ton}}{2.31 \text{ ac-ft} \times 43,560 \text{ ft}^2/\text{ac} \times 62.4 \text{ lb/ft}^3}$$

$$\times 10^6 = 2768 \text{ mg/l}$$

$$SS = \frac{2768 \text{ mg/l}}{1120 \text{ mg/ml}} [(1.0 - 0.818) + (0.818 \times 0.048)]$$

$$= 0.55 \text{ ml/l} > 0.5 \text{ ml/l}$$

Try with a smaller size of settleable solids, $d = 0.018$ mm.

$$X_o = \frac{\% \text{ of settleable size distribution smaller than } 0.011 \text{ mm}}{\% \text{ of settleable size distribution smaller than } 0.018 \text{ mm}}$$

$$= \frac{0.18}{0.215} = 0.837$$

From Figure 6.2, $E = 0.785$ and $K = 0.79$

$$C_o = \frac{(1.0 - 0.785) \times 0.79 \times 50 \text{ tons} \times 2000 \text{ lb/ton}}{2.31 \text{ ac-ft} \times 43,560 \text{ ft}^2/\text{ac} \times 62.4 \text{ lb/ft}^3}$$

$$\times 10^6 = 2705 \text{ mg/l}$$

$$SS = \frac{2705 \text{ mg/l}}{1120 \text{ mg/ml}} [(1.0 - 0.837) + (0.837 \times 0.048)]$$

$$= 0.49 \text{ ml/l} \approx 0.5 \text{ ml/l}$$

In order to meet the 0.5 ml/l standard, the pond is designed to remove all particles equal to and larger than 0.018 mm.

Step 7. Available storage volume

Based on the selected site (Figure 6.1), the stage-storage curve is obtained using the methodology described in Section 3.7 and is presented in Figure 6.3. The sediment storage volume should provide for three times the annual sediment yield

$$V_s = \frac{3 \text{ yr} \times 115 \text{ ton/yr} \times 2000 \text{ lb/ton}}{70 \text{ lb/ft}^3 \times 43,560 \text{ ft}^2/\text{ac}} = 0.23 \text{ ac-ft}$$

From Figure 6.3, depth of sediment = 4.2 ft

Total maximum embankment height (assumed) = 16 ft
 Allow 5 percent settlement (0.5 x 16) = 0.80 ft

Required freeboard = 1.0 ft
 Allow 2.5 ft for emergency spillway = 2.5 ft

Maximum depth of sediment storage = 4.2 ft

Available detention storage depth (D_1)
 $16 - (0.80 + 1.0 + 2.5 + 4.2) = 7.5 \text{ ft}$

Stage at maximum detention storage depth
 $7.5 + 4.2 = 11.7 \text{ ft}$

The available storage volume is described by taking the difference between the storage volume at the stage of the maximum detention storage depth and the storage volume at the elevation of the principal spillway.

From Figure 6.3,
 available detention storage volume
 $1.71 - 0.23 = 1.48 \text{ ac-ft}$

Step 8. Required storage volume

The total depth (D_T) of the pond is used in the following computations and is equal to the sum of the sediment storage depth, detention storage depth, and the permanent pool depth (if used).

Time base of inflow hydrograph

$$T_b = \frac{2V}{Q_I} = \frac{2 \times 2.31 \text{ ac-ft} \times 43,560 \text{ ft}^2/\text{ac}}{77 \text{ ft}^3/\text{sec} \times 3600 \text{ sec/hr}} = 0.73 \text{ hours}$$

For $d = 0.018 \text{ mm}$ and $D_T = 11.70 \text{ ft}$,

$$T_D = 4.50 \text{ hours (From Figure 3.10)}$$

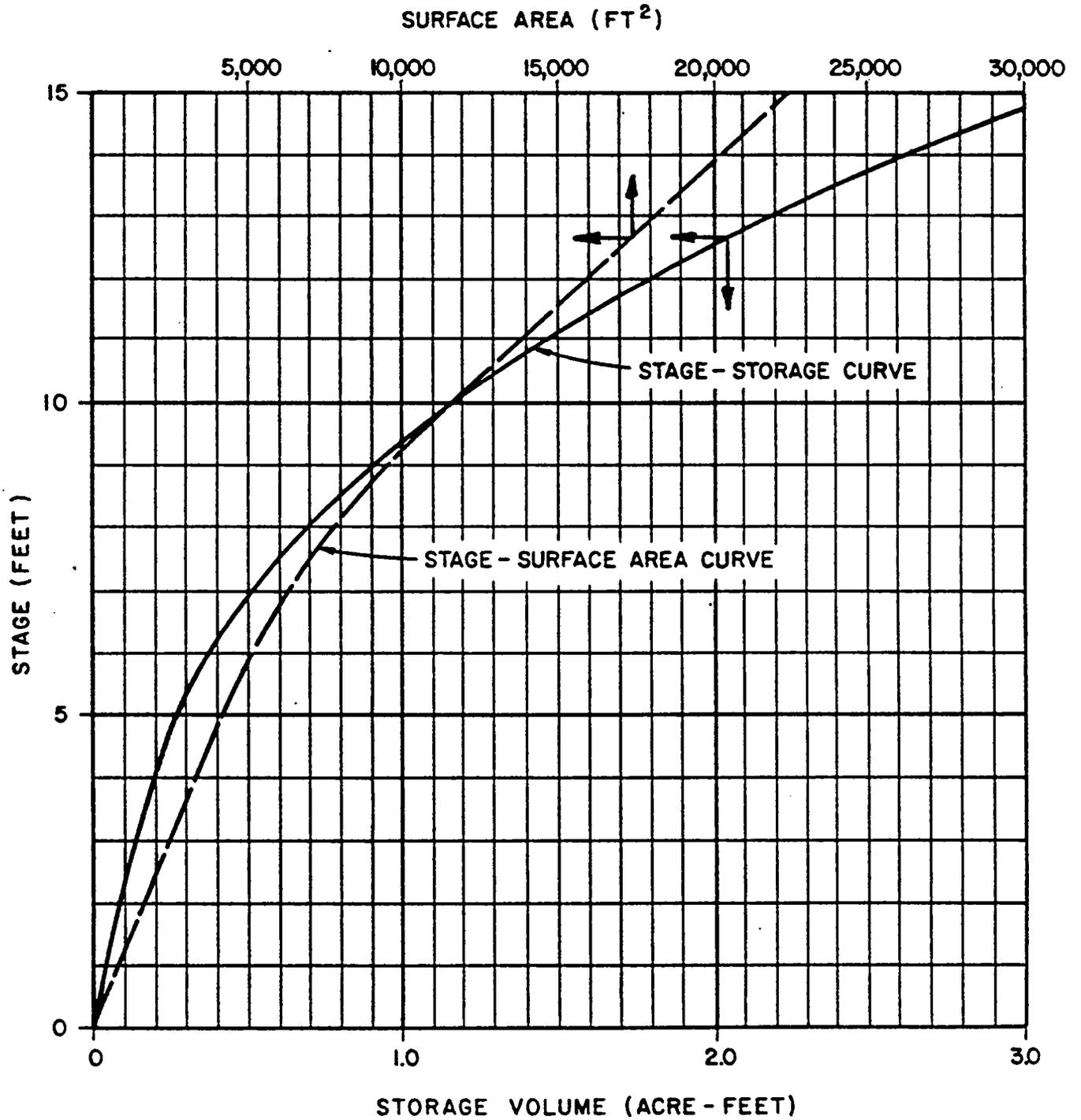


FIGURE 6.3 STAGE - SURFACE AREA AND STAGE - STORAGE CURVES OF POND SITE NO. 1

For $T_b = 0.73$ hours and $T_D = 4.50$ hours,

$$\frac{S}{V} = 0.950 \quad (\text{From Figure 3.7})$$

$$\frac{Q_o}{Q_I} = 0.05 \quad (\text{From Figure 3.8})$$

$$S = 0.950 \times 2.31 \text{ ac-ft} = 2.19 \text{ ac-ft} > 1.48 \text{ ac-ft}$$

Since the pond location with an assumed 16 ft embankment height cannot provide the required storage volume, the designer has three alternatives.

- (a) Increase the detention storage depth and return to Step 7 and determine the new available storage.
- (b) Excavate the pond side slopes no steeper than 2 horizontal to 1 vertical and return to Step 7 and develop new stage-storage curve.
- (c) Construct another pond downstream.

For purposes of illustrating multiple pond design, alternative (c) is chosen.

Step 8c. Determine the sediment removal in the upstream pond

$$\frac{S}{V} = \frac{1.48 \text{ ac-ft}}{2.31 \text{ ac-ft}} = 0.64$$

For $\frac{S}{V} = 0.64$ and $T_b = 0.73$ hours,

$$T_D = 0.4 \text{ hours} \quad (\text{Figure 3.7})$$

$$\frac{Q_o}{Q_I} = 0.360 \quad (\text{Figure 3.8})$$

For $T_D = 0.4$ hours and $D_T = 11.70$ ft,

$$2.254 d^2 = \frac{D_T}{3600 T_D} \quad (\text{Equation 3.10})$$

$$d = \sqrt{\frac{D_T}{2.254 \times 3600 T_D}} = \sqrt{\frac{11.7 \text{ ft}}{2.254 \times 0.4 \text{ hrs} \times 3600 \text{ sec/hr}}} \\ = 0.060 \text{ mm}$$

Therefore, only particles larger than 0.060 mm can be removed in the first pond based upon ideal settling.

Check surface area

$$A \text{ (measured at depth = 4.2 ft)} = 3490 \text{ ft}^2$$

$$Q_0 = 0.360 \times 77 \text{ cfs} = 27.7 \text{ cfs}$$

From Equation 3.14, required surface area

$$A_{\text{req}} = 1.2 \times \frac{27.7 \text{ ft}^3/\text{sec}}{2.254 \times (0.060)^2} = 4096 \text{ ft}^2 > 3490 \text{ ft}^2$$

Due to nonideal settling conditions, the smallest particle which will be removed using the available surface area is

$$d = \sqrt{\frac{1.2 \times Q_0}{2.254 \times A}} = \sqrt{\frac{1.2 \times 27.7}{2.254 \times 3490}} = 0.065 \text{ mm}$$

Check length-to-width ratio

$$L \text{ (measured at depth = 4.2 ft)} = 130 \text{ ft}$$

$$W = \frac{A}{L} = \frac{3490 \text{ ft}^2}{130 \text{ ft}} = 26.8 \text{ ft}$$

$$\frac{L}{W} = \frac{130}{26.8 \text{ ft}} = 4.9 > 2.0$$

Check Scouring

$$V_H = \frac{Q_0}{WD} = \frac{27.7 \text{ ft}^3/\text{sec}}{26.8 \text{ ft} \times 7.5 \text{ ft}} = 0.14 \text{ fps (Equation 3.18)}$$

$$V_{sc} = 1.67 d^{1/2} = 1.67 \times (0.065)^{1/2} = 0.43 \text{ fps (Equation 3.17)}$$

$$V_H < V_{sc}$$

The smallest particle which will be removed in the first pond is 0.065 mm which corresponds to a removal efficiency of 69.5 percent (Figure 6.2).

Design of Downstream Pond (repeat Steps 1 through 8)

Step 1. Site selection (Figure 6.4). Select a second pond just downstream of the first pond.

Step 2. Hydrology (10-year, 24-hour design event)

<u>10-year, 24-hour design event</u>	<u>Q (cfs)</u>	<u>V (acre-feet)</u>
First pond (Q_0)	27.7	2.31
Additional contributing area (Q_I)	22.0	0.39
Design parameter (Q_I second pond)	49.7	2.70
<u>25-year, 24-hour design event</u>	<u>Q (cfs)</u>	<u>V (acre-feet)</u>
First pond (Q_0)	91.5	3.35
Additional contributing area (Q_S)	26.1	0.56
Design parameter	117.6	3.91

Notes: 1. The design inflow peak flow for second pond should be determined by reservoir routing and added to the hydrograph of the additional contributing area. For illustration of sedimentation pond design, the peak outflow from the first pond is added directly to the peak flow of the additional contributing area.

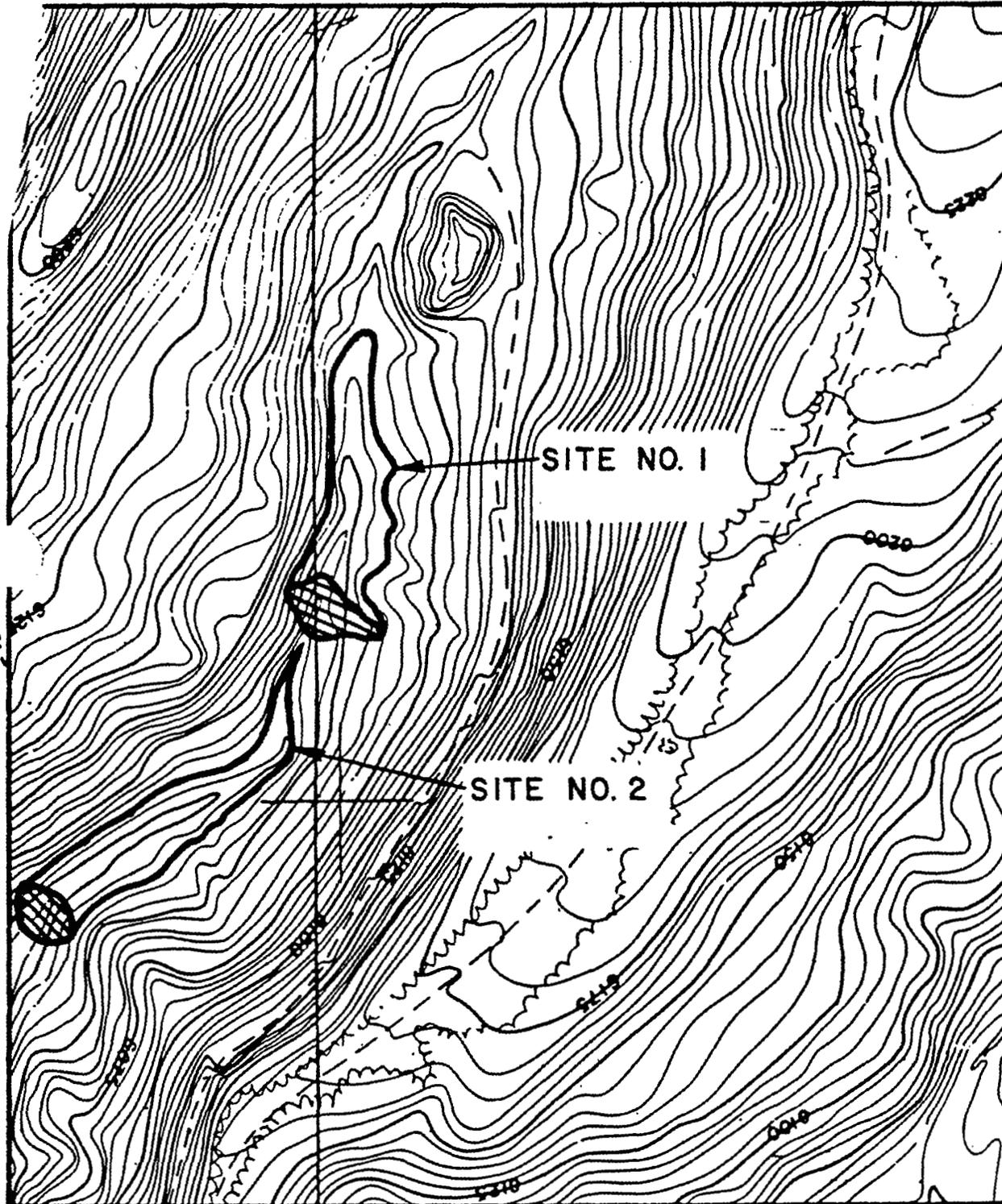


FIGURE 6.4 SEDIMENTATION POND SITE NO. 2

2. If there is any permanent pool storage in the first pond, the stored volume should be subtracted from the total volume for designing the second pond.

Step 3. Sediment size distribution

Use the same sediment size distribution as the first pond.

Step 4. Sediment yield (use USLE for annual sediment yield and MUSLE for storm sediment yield)

From additional contributing drainage area (10 acres)

$$\begin{aligned}\text{Annual sediment yield} &= 19 \text{ tons} \\ \text{Storm sediment yield} &= 8.3 \text{ tons}\end{aligned}$$

Step 5. Inflow suspended solids concentration

Since the design is to remove all particles larger than 0.018 mm, calculation of the inflow suspended solids concentration is not required.

Step 6. Settleable solids concentration

Must remove all particles larger than 0.018 mm.

Step 7. Available storage volume

The stage-storage curve is presented in Figure 6.5. Since the first pond has a trapping efficiency of 69.5 percent, the sediment storage volume required in the second pond is equal to 30.5 percent of the upstream sediment yield plus the sediment yield from the additional contributing drainage area.

$$\begin{aligned}v_s &= \frac{[(115 \text{ ton/yr} \times 0.305) + 19 \text{ ton/yr}] \times 3 \text{ yr} \times 2000 \text{ lb/ton}}{70 \text{ lb/ft}^3 \times 43,560 \text{ ft}^2/\text{ac}} \\ &= 0.11 \text{ ac-ft}\end{aligned}$$

From Figure 6.5, depth of sediment = 1.3 ft

Using the same embankment settlement, required freeboard, and emergency spillway depth as the first pond, the available detention storage depth is

$$D_1 = 16 - (0.80 + 1.0 + 2.5 + 1.3) = 10.4 \text{ ft}$$

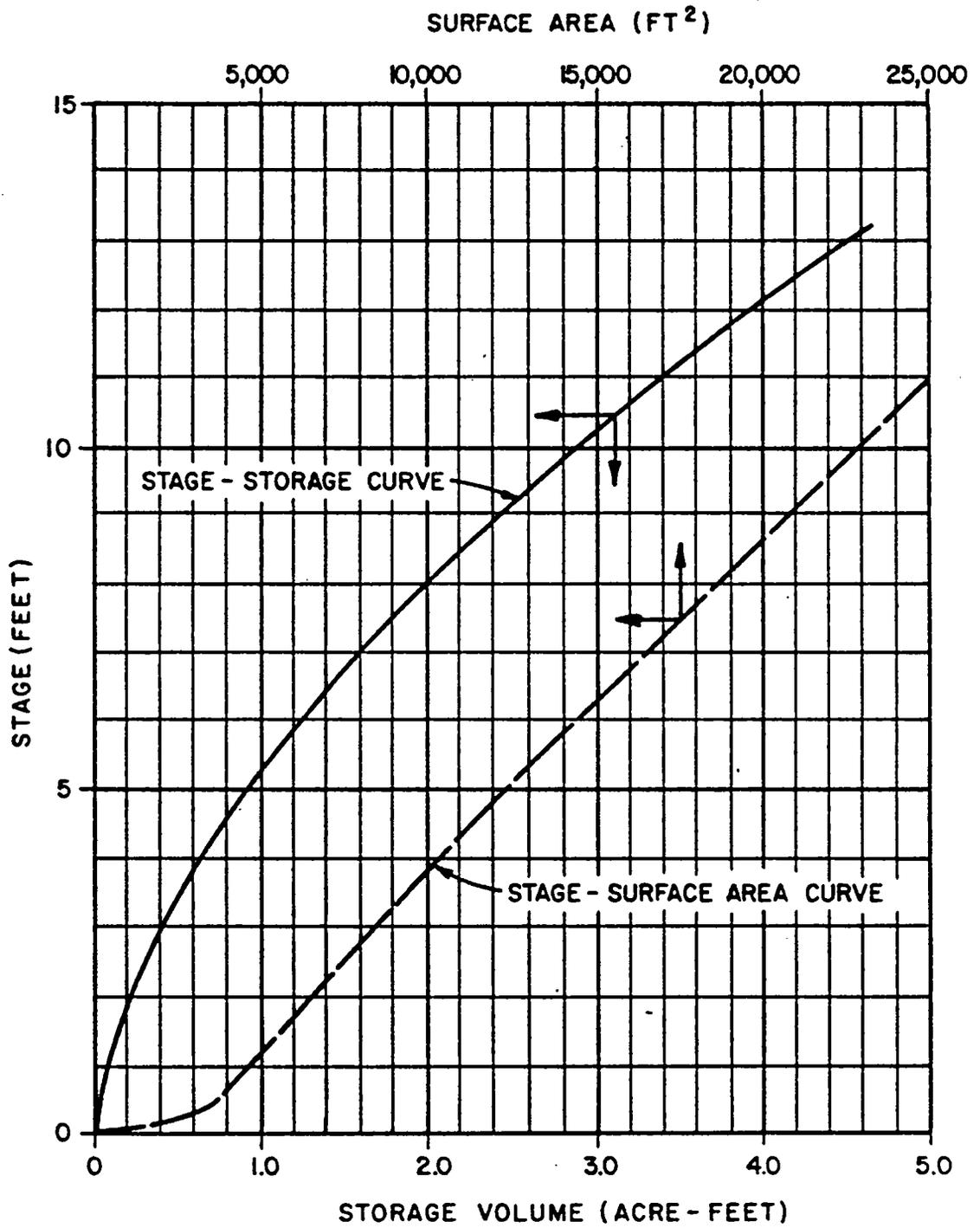


FIGURE 6.5 STAGE - SURFACE AREA AND STAGE - STORAGE CURVES OF SITE NO. 2

Stage at maximum detention stage depth

$$10.4 + 1.3 = 11.7$$

From Figure 6.5, available storage volume is

$$3.75 - 0.11 = 3.64 \text{ ac-ft}$$

Step 8. Required storage volume

Time base of inflow hydrograph

$$T_b = \frac{2V}{Q_I} = \frac{2 \times 2.70 \text{ ac-ft} \times 43,560 \text{ ft}^2/\text{ac}}{49.7 \text{ ft}^3/\text{sec} \times 3600 \text{ sec/hr}} = 1.31 \text{ hours}$$

For $d = 0.018 \text{ mm}$ and $D_T = 11.7 \text{ ft}$,

$$T_D = 4.5 \text{ hours}$$

For $T_b = 1.31 \text{ hours}$ and $T_D = 4.5 \text{ hours}$,

$$\frac{S}{V} = 0.930, \quad S = 0.930 \times 2.70 \text{ ac-ft} = 2.51 \text{ ac-ft} < 3.64 \text{ ac-ft}$$

$$\frac{Q_o}{Q_I} = 0.070, \quad Q_o = 0.070 \times 49.7 = 3.48 \text{ cfs}$$

Since the required storage volume is less than the available storage volume, decrease the depth and repeat Step 8.

Assume $D_1 = 8.5 \text{ ft}$

From Figure 6.5, stage at maximum detention depth

$$8.5 + 1.3 = 9.8 \text{ ft}$$

$$\text{Available storage} = 2.80 - 0.11 = 2.69 \text{ ac-ft}$$

For $d = 0.018 \text{ mm}$ and $D_T = 9.8 \text{ ft}$

$$T_D = 3.9 \text{ hours}$$

For $T_b = 1.31 \text{ hours}$ and $T_D = 3.9 \text{ hours}$

$$\frac{S}{V} = 0.910, \quad S = 0.910 \times 2.70 = 2.46 \text{ ac-ft} < 2.69 \text{ ac-ft}$$

$$\frac{Q_o}{Q_I} = 0.09, \quad Q_o = 0.09 \times 49.7 = 4.47 \text{ cfs}$$

Check surface area

$$A \text{ (measured at depth = 1.3 ft)} = 5300 \text{ ft}^2$$

$$A_{\text{req}} = 1.2 \times \frac{4.47}{2.254 \times (0.018)^2} = 6120 \text{ ft}^2 > 5300 \text{ ft}^2$$

The pond must be excavated to meet the surface area requirement or raise the principal spillway crest to elevation 2.0 ft. This will provide more sediment storage than is required. A permanent pool will exist if a dewatering device is not provided.

$$A \text{ (measured at depth = 2.0 ft)} = 6500 \text{ ft}^2$$

Check available storage volume

$$\text{Available storage} = 3.20 - 0.25 = 2.95 \text{ ac-ft} > 2.46 \text{ ac-ft}$$

Check length-to-width ratio

$$L \text{ (measured at depth = 2.0)} = 250 \text{ ft}$$

$$W = \frac{A}{L} = \frac{6500}{250} = 26 \text{ ft}$$

$$\frac{L}{W} = \frac{250}{26} = 9.6 > 2.0$$

Check scouring

$$V_H = \frac{Q_o}{WD_1} = \frac{4.47 \text{ ft}^3/\text{sec}}{26 \text{ ft} \times 8.5 \text{ ft}} = 0.02 \text{ fps}$$

$$V_s = 1.67 d^{1/2} = 1.67 \times (0.018)^{1/2} = 0.22 \text{ fps}$$

$$V_H < V_s$$

A summary of the design is presented in Table 6.2.

Table 6.2. Summary of Sedimentation Pond Design.

Description	Pond No. 1	Pond No. 2
1. Design inflow (Q_I), cfs	77	49.7
2. Design runoff volume (V), ac-ft	2.31	2.7
3. Annual sediment yield, tons	115	54
4. Storm sediment yield, tons (10-year, 24-hour storm)	50	---
5. Inflow suspended solids concentration, mg/l	15,926	---
6. Minimum size of particle settled, mm	0.065	0.018
7. Detention time, hours	0.4	4.5
8. Principal spillay elevation, ft	4.2	2.0
9. Sediment storage required, ac-ft	0.23	0.11
10. Sediment storage provided, ac-ft	0.23	0.25
11. Runoff detention depth provided, ft	7.5	8.5
12. Runoff detention volume provided, ac-ft	1.48	2.95
13. Surface area required, ft ²	3490	6120
14. Surface area provided, ft ²	3490	6500
15. Length-to-width ratio	4.9	9.6
16. Scour velocity (V_{sc}), fps	0.43	0.22
17. Flow-through velocity (V_H), fps	0.14	0.02
18. 10-year, 24-hour design outflow, cfs	27.7	4.47
19. 25-year, 24-hour design outflow, cfs	63.8	113.13

VII. REFERENCES

American Public Health Association, American Water Works Association, Water Pollution Control Federation, 1981, "Standard Methods for the Examination of Water and Wastewater," 15th Edition, American Public Health Association, Washington, D.C.

Anderson, C. E. and J. M. Briggs, 1979, "Planning Erosion Control for Coal Mining and Restoration," Iowa State University, Dept. Agricultural Engineering, Jour. Soil Water Conservation 34: 234-236.

Barfield, B. J., R. C. Warner and C. T. Haan, 1981, Applied Hydrology and Sedimentology for Disturbed Areas, Oklahoma Technical Press; Stillwater, Oklahoma.

Bondurant, J. A., C. E. Brockway and M. J. Brown, 1975, "Some Aspects of Sediment Control, University of Kentucky; Lexington, KY, pp. 117-121.

Bureau of Reclamation, 1974, Design of Small Dams, A Water Resources Technical Publication.

Camp, T. R., 1946, "Sedimentation and the Design of Settling Tanks," Transactions of the ASCE, Vol. III, pp. 895-958.

Chen, Charng-Ning, 1975, "Design of Sediment Retention Basins," National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, KY, pp. 285-293.

Chow, V. T., 1959, Open-Channel Hydraulics, McGraw-Hill, New York.

Curtis, D. C. and R. H. McCuen, 1977, "Design Efficiency of Stormwater Detention Basins," Jour. Water Resources Planning and Management Division, ASCE; Vol. 103, pp. 125-139.

Environmental Protection Agency, 1981, "Development of Methods to Improve Performance of Surface Mine Sediment Basins, Phase II and III," EPA Contract No. 68-03-2677.

Environmental Protection Agency, 1980, "Development of Methods to Improve Performance of Surface Mine Sediment Basins, Phase I," EPA 660/7-80-072.

Environmental Protection Agency, 1980, "Demonstration of Debris Basin Effectiveness in Sediment Control," EPA 600/7-80-154.

Environmental Protection Agency, 1979, "Evaluation of the Performance Capability of Surface Mine Sedimentation Basins," EPA 440/1-79-200.

Environmental Protection Agency, 1979, "Removal of Trace Elements from Acid Mine Drainage," EPA 660/7-79-101.

Environmental Protection Agency, 1978, "Erosion and Sediment Control Handbook," EPA 440/3-78-003.

Environmental Protection Agency, 1976, "Erosion and Sediment Control: Surface Mining in the Eastern United States, Vol. 1 Planning and Vol. 2 Design," EPA 625/3-76-006.

Environmental Protection Agency, 1976, "Effectiveness of Surface Mine Sedimentation Basins," EPA 660/2-76-117.

Environmental Protection Agency, 1976, "Debris Basins for Control of Surface Mine Sedimentation," EPA 600/2-76-108.

Environmental Protection Agency, 1976, "Methods for Control of Fine Grained Sediments Resulting from Construction Activity," EPA 440/9-76-026.

Environmental Protection Agency, 1972, "Guidelines for Erosion and Sediment Control Planning and Implementation," EPA R2-72-72-015.

Gilbreath, J. L., 1979, "The State of the Art of Erosion and Sediment Control for Surface Mined Areas," U.S. Army Military Personnel Center, Virginia, NTIA Report AD-A077 709.

Guy, H. F., 1979, "Performance and Environmental Effects of Sedimentation Ponds Required for Surface Coal Mining Operations," IES 25th Annual Technical Meeting, Seattle, Washington.

Haan, C. T. and B. J. Barfield, 1978, Hydrology and Sedimentology of Surface Mined Lands, Institute for Mining and Minerals Research, Kentucky Center for Energy Research Laboratory, University of Kentucky, Lexington, Kentucky.

Hazen, A., 1904, "On Sedimentation" Transactions ASCE Vol. 53:45-71.

Hill, R. D., 1975, "Sediment Control and Surface Mining," Polish-United States Symposium Environmental Protection in Open Pit Coal Mining, University of Denver Research Institute, Denver, Colorado (Sept; 89-95).

Lara, J. M. and E. L. Pemberton, 1963, "Initial Unit Weight of Deposited Sediments," USDA Miscellaneous Publication.

Mallory, C. W. and M.A. Nawrocki, 1974, "Containment Area Facility Concepts for Dredged Material Separation, Drying and Rehauling," U.S. Army Engineering Waterways Experiment Station, DACW 39-73-C-0136.

McCarthy, R. E., 1973, "Preventing the Sedimentation of Streams in a Pacific Northwest Coal Surface Mine," Research and Applied Technology Symposium on Mined Land Reclamation, Pittsburgh, Pennsylvania (133-143).

Office of Surface Mining, 1982, "Design of Sediment Control Measures for Small Areas in Surface Coal Mining," prepared by Simons, Li & Associates, Inc., OSM Contract No. J5110061.

Office of Surface Mining, 1982, "Surface Water Hydrology and Sedimentology Manual," prepared by J. F. Sato and Associates and Simons, Li & Associates, Inc., OSM Contract No. J7000584.

Office of Surface Mining, 1981, "Design Manual for Water Diversions in Surface Mine Operations," prepared by Simons, Li & Associates, Inc., OSM Contract No. J5101050.

Office of Surface Mining, (draft), "Erosion and Sediment Control Measures for Coal Mines, Contract No. H-C1022/001-81-100-8D.

Office of Surface Mining, (draft), "Proof of Principal Demonstration of an Improved Effluent Discharge System for Sediment Ponds."

Oscaryan, P. C., 1975, "Design of Sediment Basins for Construction Sites," National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, Kentucky.

Reed, L. A., 1978, "Effectiveness of Sediment Control Techniques Used During Highway Construction in Central Pennsylvania," U. S. Geological Survey, Water Supply Paper 2054.

Reed, L. A., 1975, "Controlling Sediment from Construction Areas," Third Symposium on Surface Mining and Reclamation, Louisville, Kentucky (Oct.; 48-51).

Robinson, C. W. and C. E. Brockway, 1980, "Sediment Removal with Vegetal Filters," Proceedings of the 1980 Specialty Conference, Irrigation and Drainage: Today's Challenges, Boise, Idaho (July).

Shames, I. H., 1962, Mechanics of Fluids, McGraw-Hill Book Company.

Simons, D. B. and F. Senturk, 1976, Sediment Transport Technology, Water Resources Publications, Fort Collins, Colorado.

Simons, Li & Associates, Inc., 1982, Engineering Analysis of Fluvial Systems, BookCrafters, Inc.

U.S. Department of Transportation, 1965, "Hydraulic Engineering Circular No. 5."

U.S. Forest Service, 1976, "Gully Development and Control: The Status of Our Knowledge," Research Paper RM-169, Fort Collins, Colorado.

U.S. Soil Conservation Service, 1981, "Earth Dams and Reservoirs," Technical Release No. 60.

U.S. Soil Conservation Service, 1981, "Erosion and Sediment Control in Urbanizing Areas of Colorado," An Interim Guide.

U.S. Soil Conservation Service, 1977, "Sediment Pond Design," SMA 2117-POND D.

U.S. Soil Conservation Service, 1975, "Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas."

U.S. Soil Conservation Service, 1969, "Turn-Down Drain Pipes for Fish Ponds," A K-BIOL-44-2.

U.S. Soil Conservation Service, 1961, "Engineering Geology," National Engineering Handbook, Section 8.

Virginia Soil and Water Conservation Commission, 1980, "Virginia Erosion and Sediment Control Handbook," Richmond, Virginia.

Ward, A. D., C. T. Haan and B. J. Barfield, 1980, "The Design of Sediment Basins," Transactions ASAE, Vol. 23:351-356.

Ward, A. D. and C. T. Haan, 1980, "Evaluation of Stripmine Sediment Detention Basins in Kentucky," Transactions ASCE, Vol. 23:854-865.

Ward, A. D., 1979, "Model Studies Aid Pond Design," Water and Wastes Engineering (May; 36-38).

Ward A. D., C. T. Haan and J. S. Tapp, 1979a, "The Deposits Sedimentation Pond Design Manual," OISTL, Institute for Mining and Minerals Research, University of Kentucky, Lexington, Kentucky.