TABLE OF CONTENTS
CHAPTER IV

TABLE OF CONTENTS (continued)
CHAPTER IV

LIST OF FIGURES
CHAPTER IV

LIST OF TABLES
CHAPTER IV

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 non-ideal 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

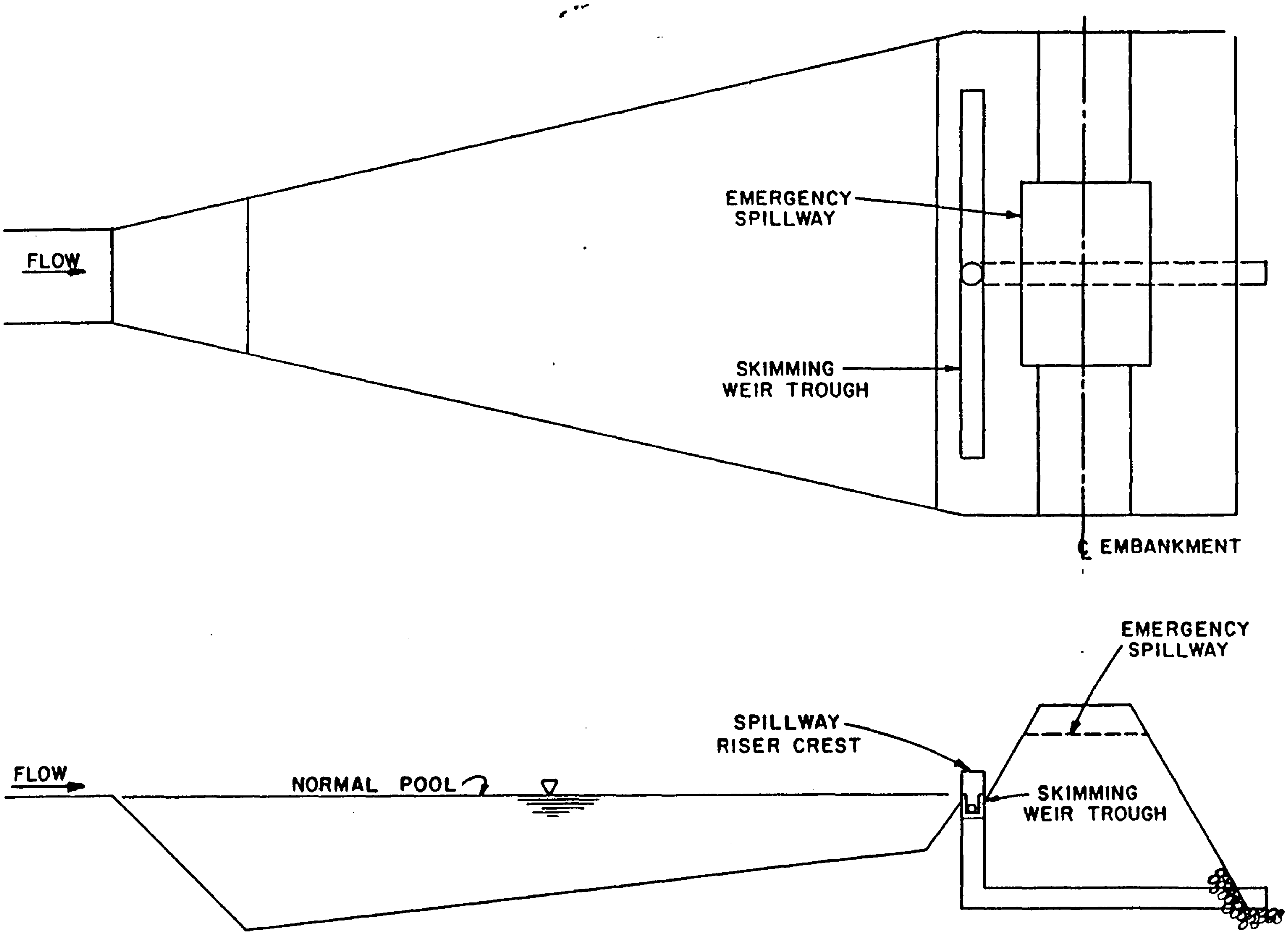


FIGURE 4.1 IDEALIZED TRIANGULAR SHAPED POND

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.

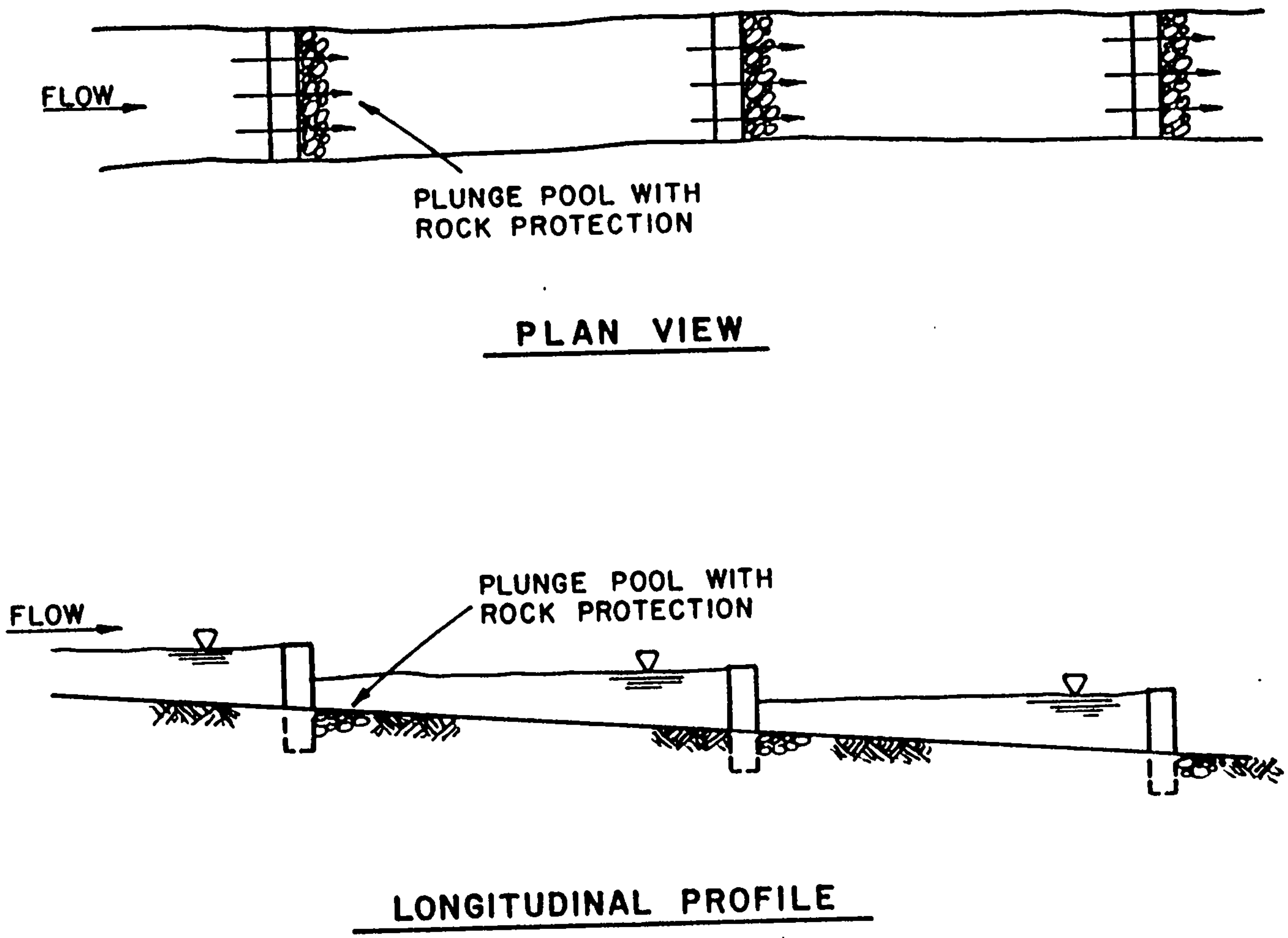


FIGURE 4.2 DEFINITION SKETCH OF SMALL-SCALE DROP STRUCTURES USED IN SERIES (OSM, 1981)

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.

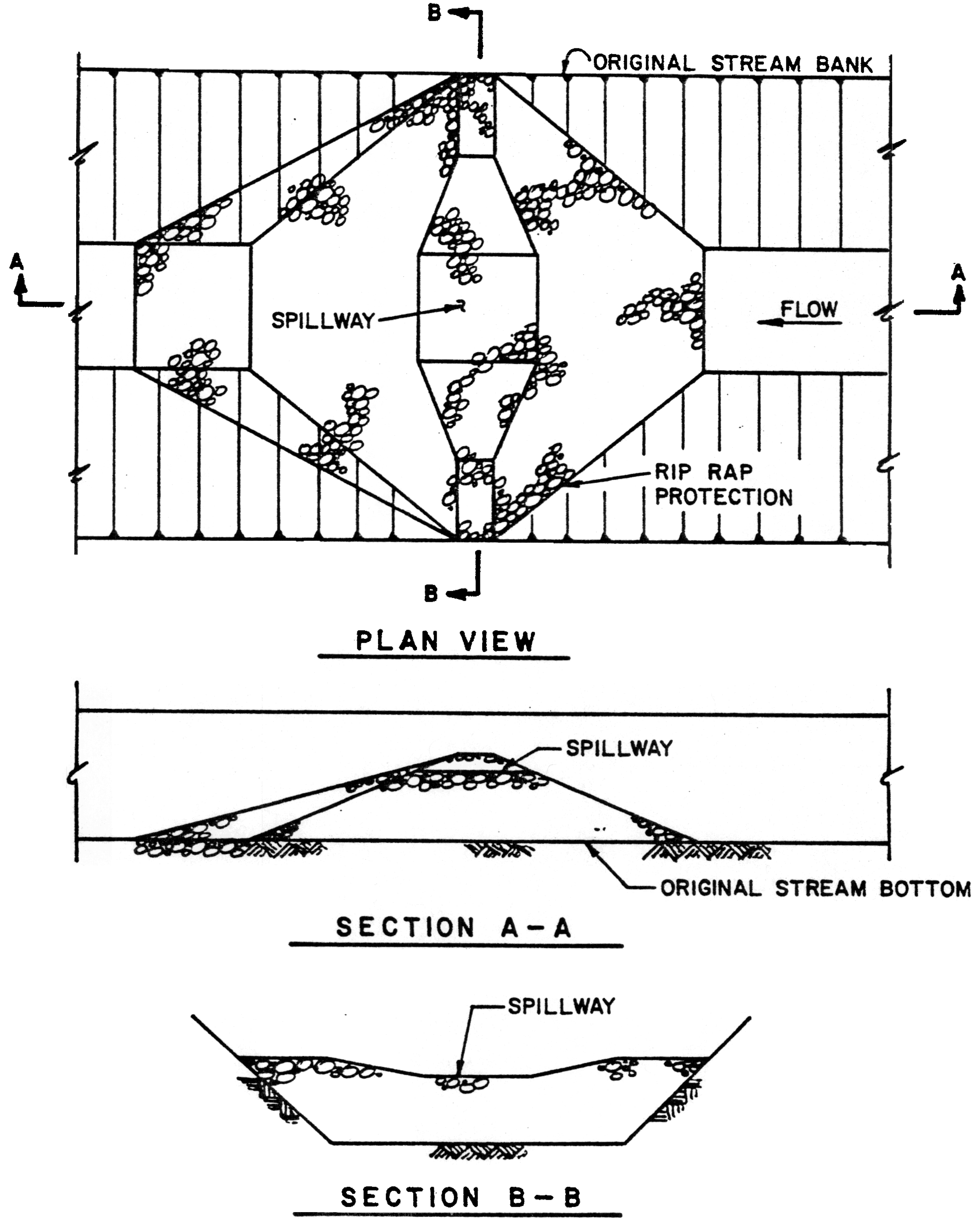
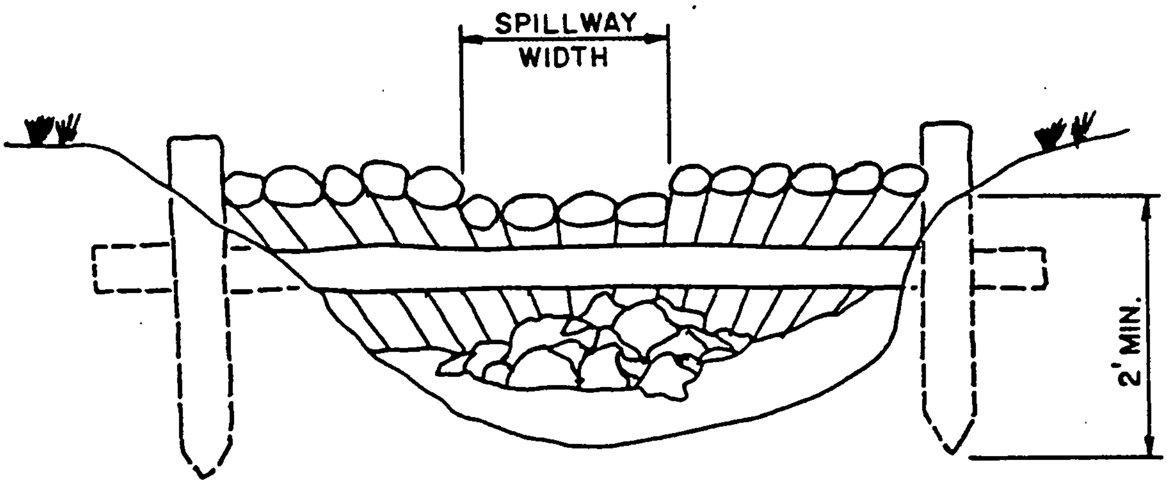
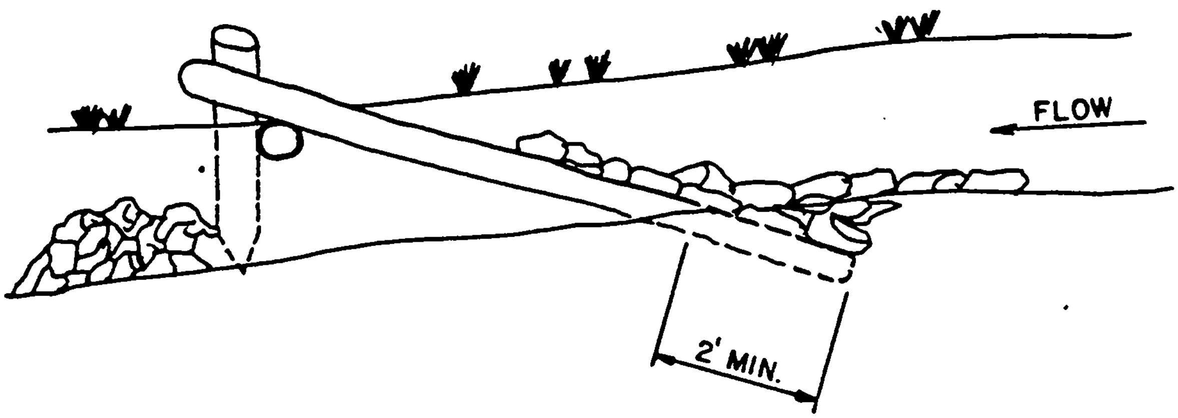


FIGURE 4.3 LOOSE ROCK CHECK DAM
(U.S. FOREST SERVICE, 1976)



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

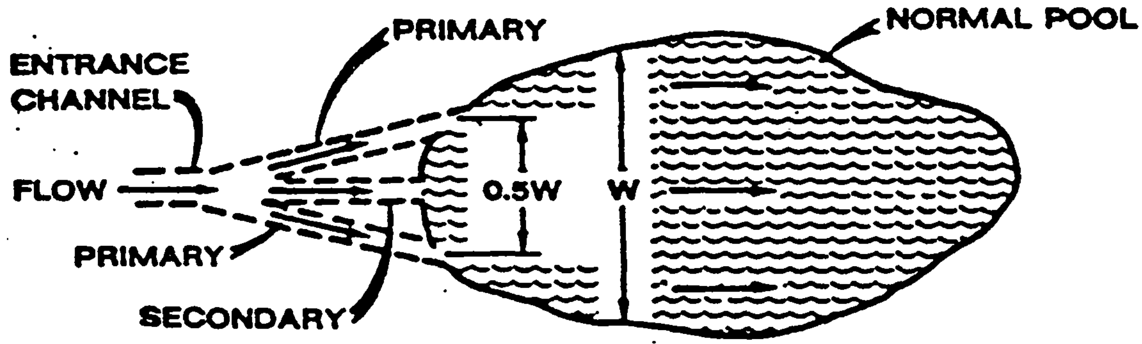


FIGURE 4.5 MULTIPLE INLETS BY INLET CHANNEL BRANCHING (EPA, 1980)

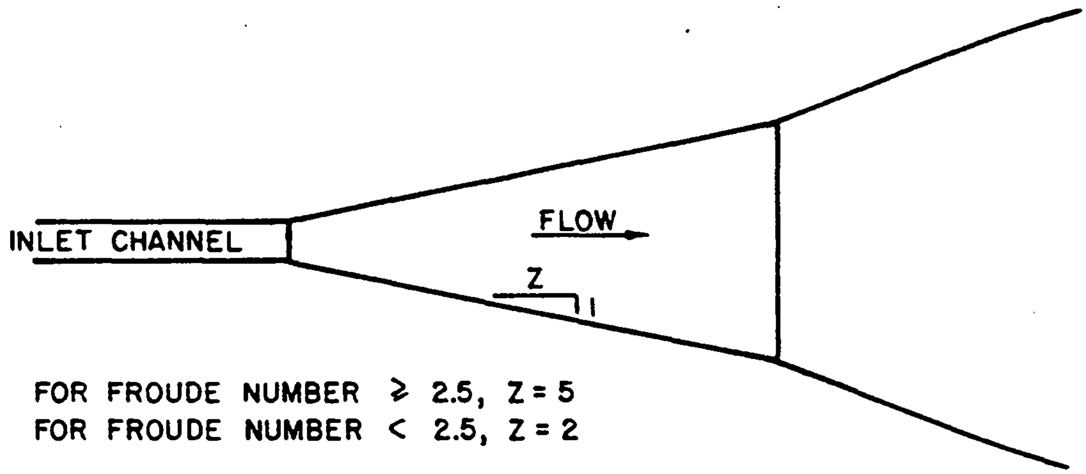
the flow in controlled areas. As an example, the two primary branches will handle normal inflow to the pond. The control channel will be used only during high flow conditions. A control device, such as a v-notch weir or a check dam, should be used on the control channel to prevent straight-through flow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

4.2.2 Spreaders

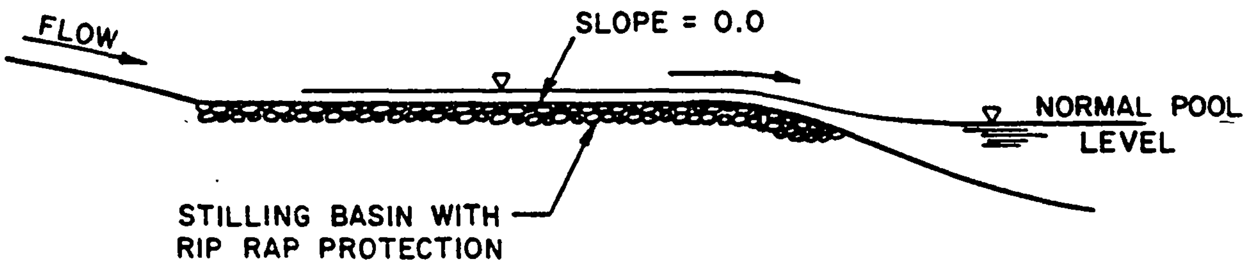
An effective means of inlet control deals with discharging the influent over the total width of the sedimentation pond. Aprons and baffles located in both the inlet and the pond are two most commonly used control measures. Spreaders can significantly reduce the velocity of concentrated storm-water flow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



PLAN VIEW



CROSS SECTION

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

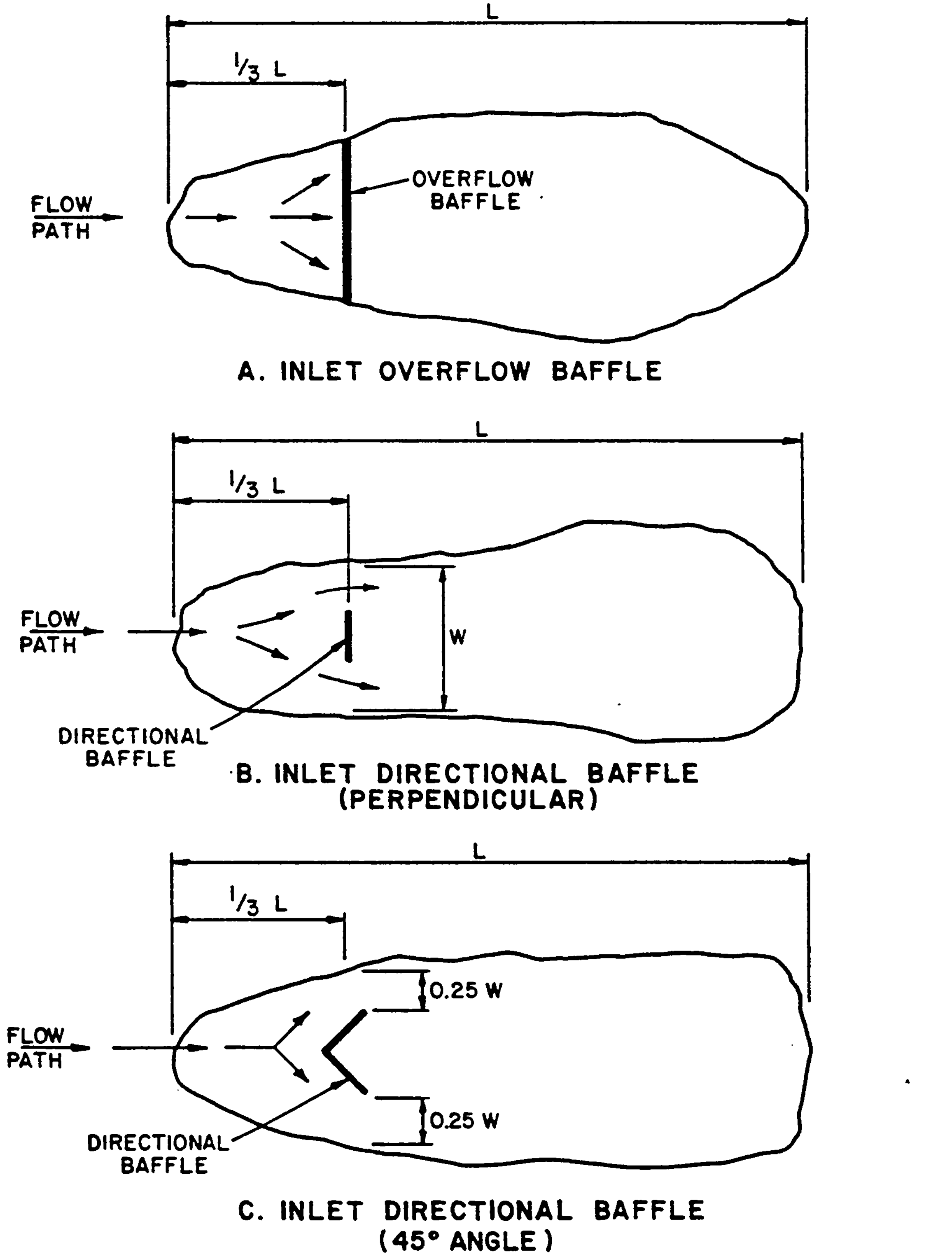


FIGURE 4.7 SEDIMENTATION POND INLET BAFFLES (EPA, 1980)

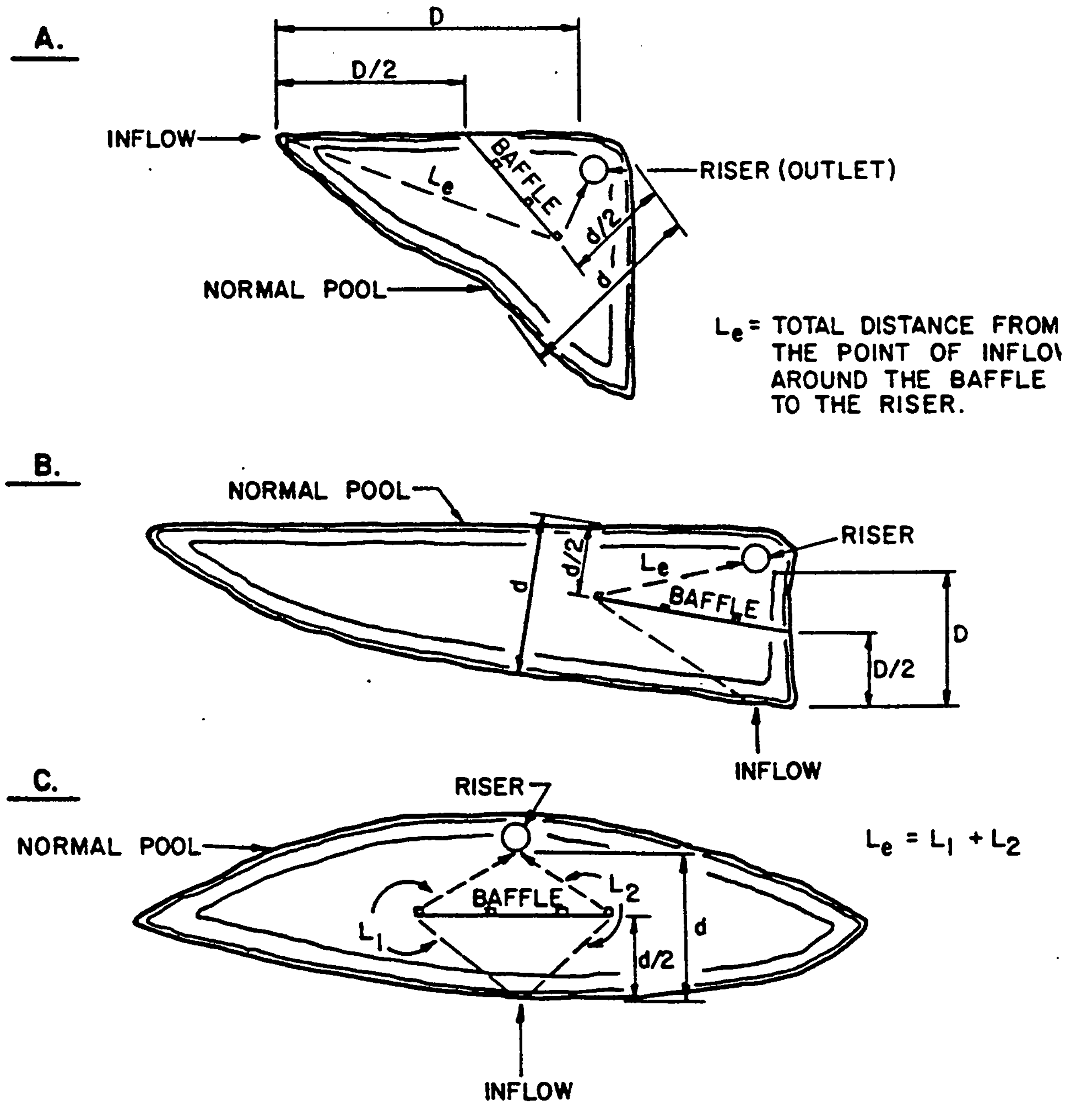


FIGURE 4.8 SEDIMENTATION POND BASIN BAFFLES (EPA, 1976)

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 fiberglasss 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

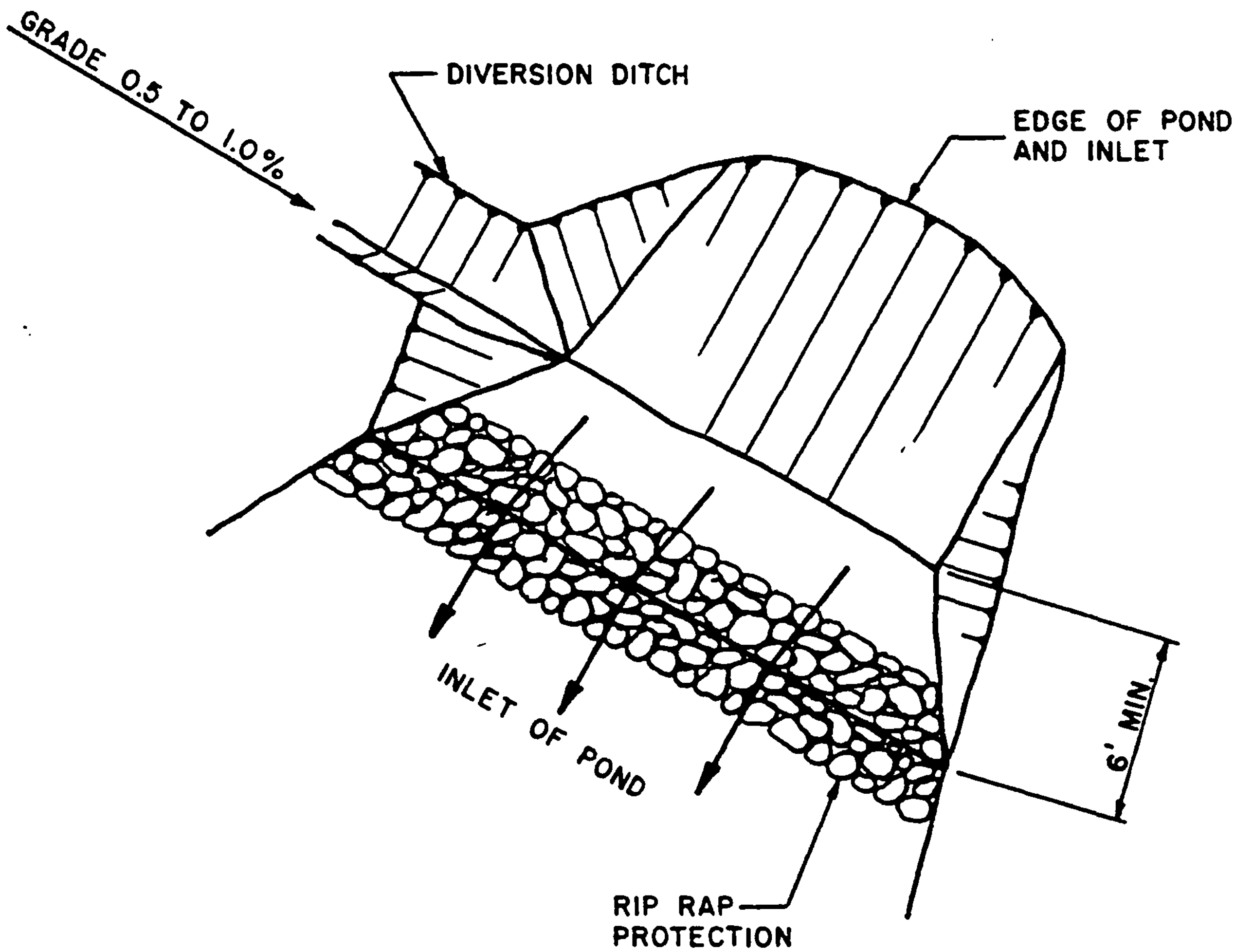
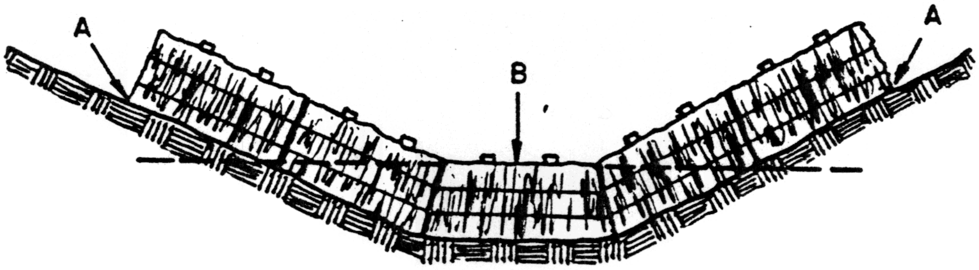


FIGURE 4.9 LEVEL SPREADER (OSM, 1981)

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-halfthe 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)

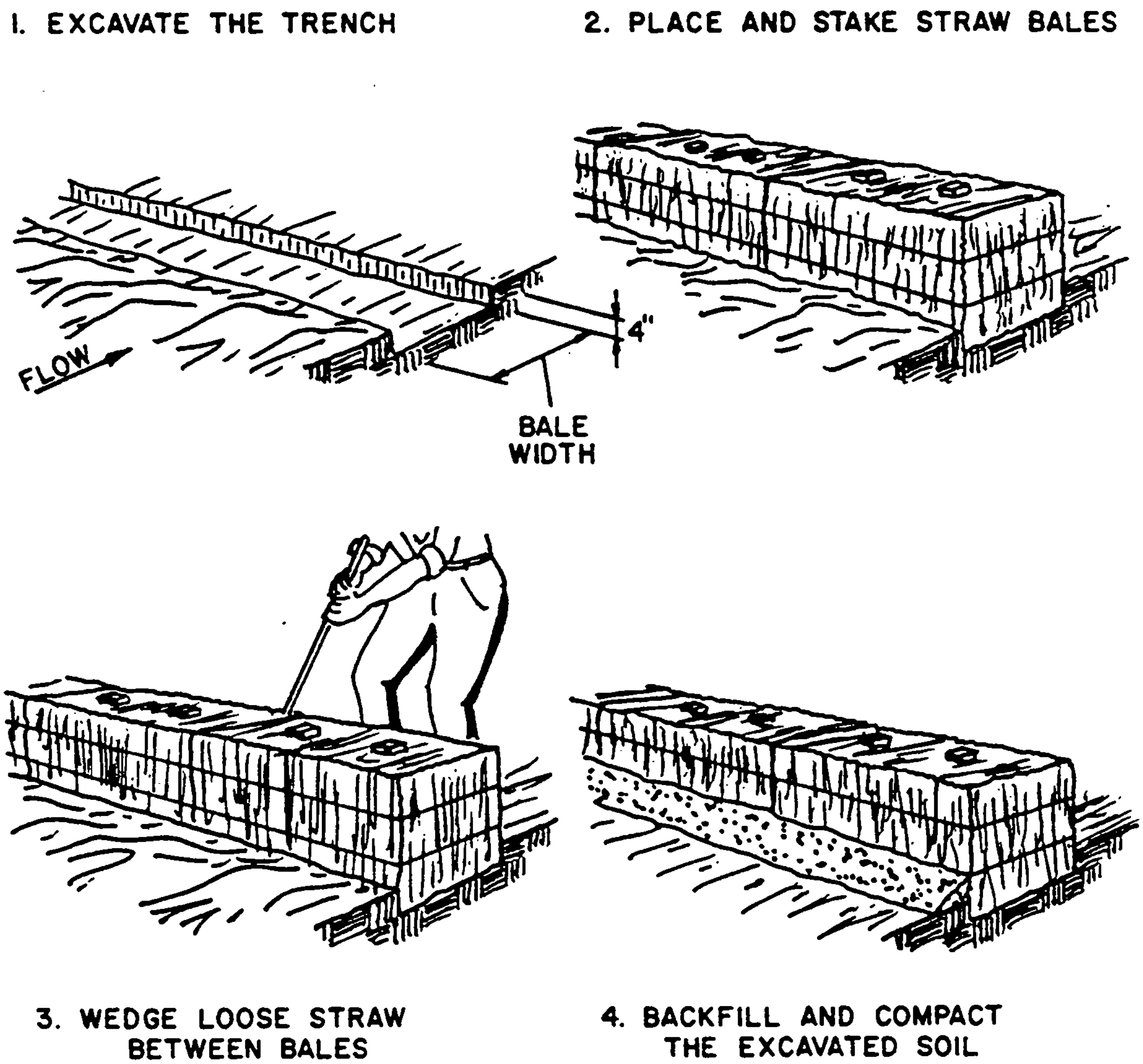


FIGURE 4.11 CONSTRUCTION OF STRAW BALE BARRIER (OSM, 1981)

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 vegetataive 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 stolens 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 layed 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 precent 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 vegetataive 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 muliple 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

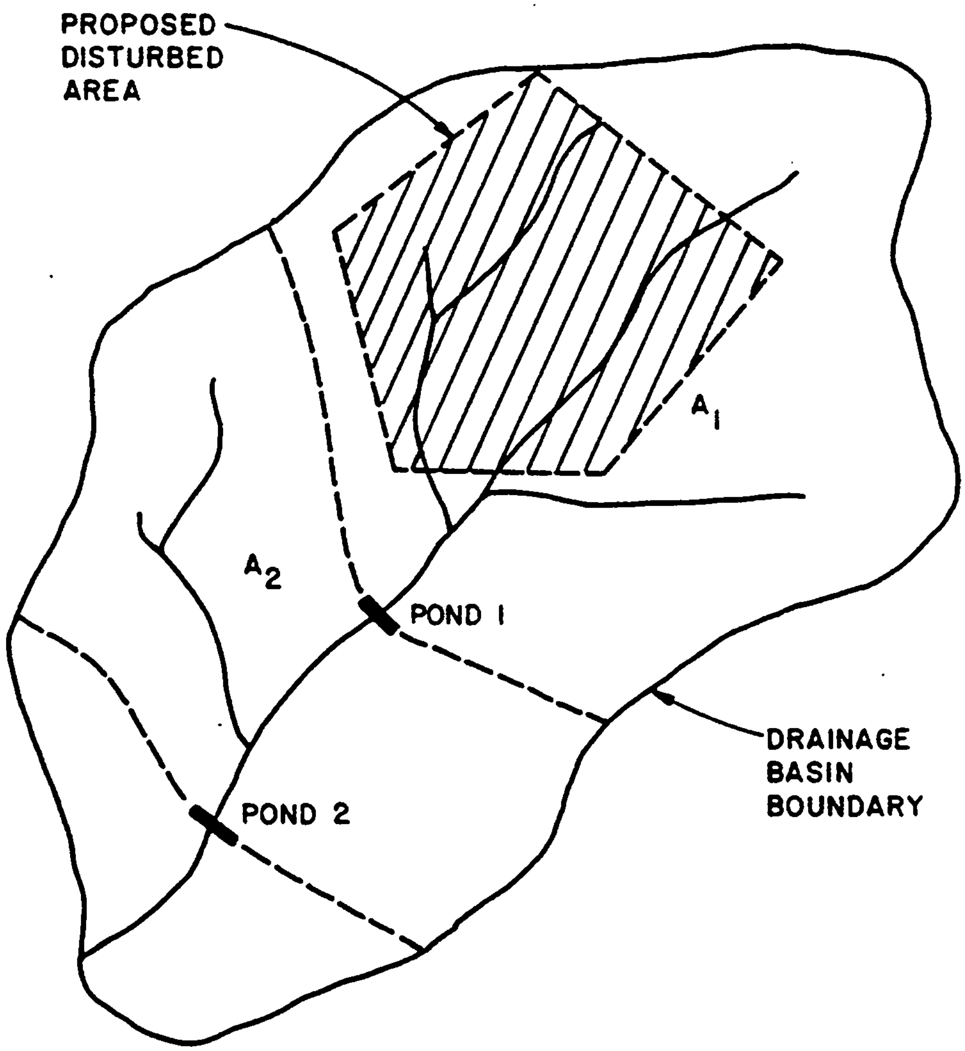


FIGURE 4.12 ILLUSTRATION OF MULTIPLE PONDS

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 acceptaable

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
$\leq$ 1	Very fine clay and colloidal particles	$\geq$ 230 days

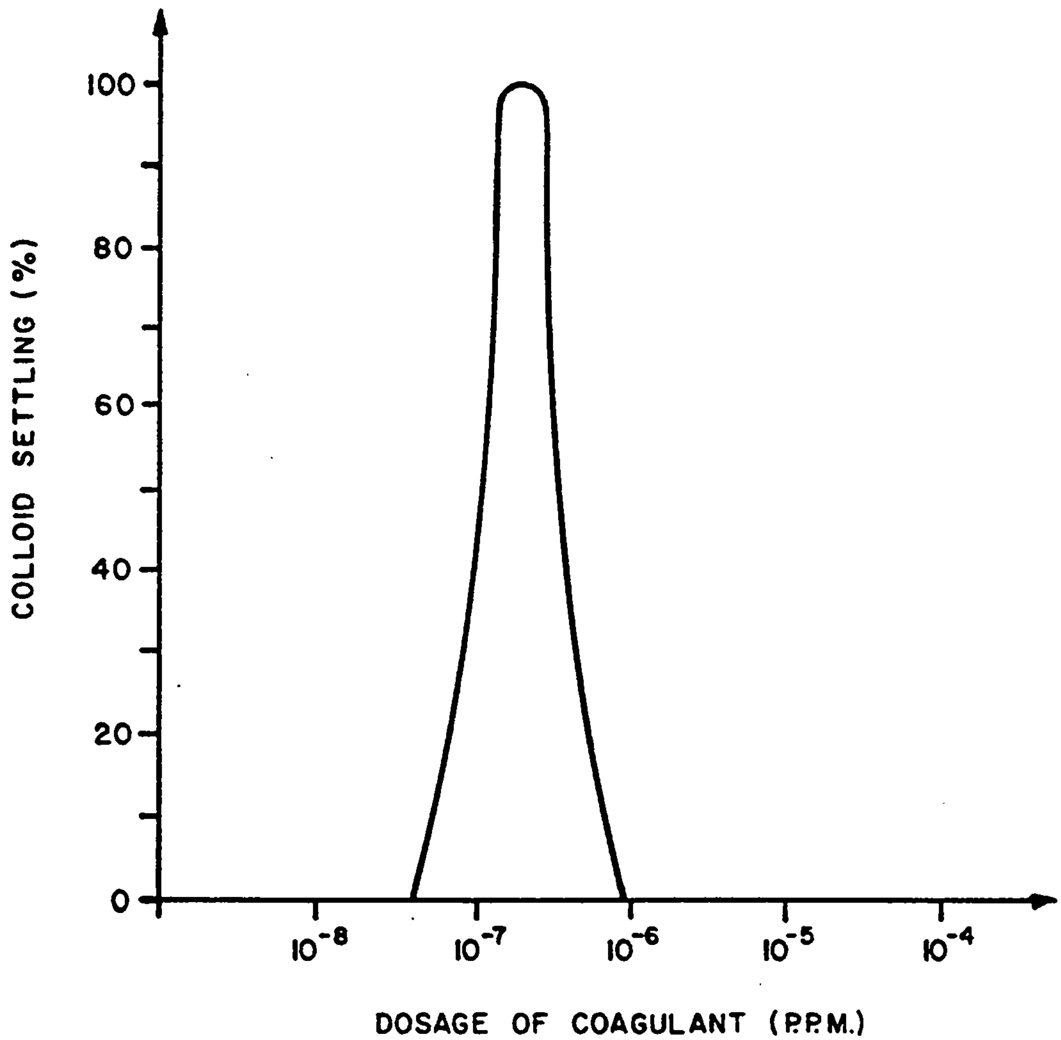


FIGURE 4.13 EFFECTIVE CONCENTRATION RANGE OF COAGULANTS AND FLOCCULANTS

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.

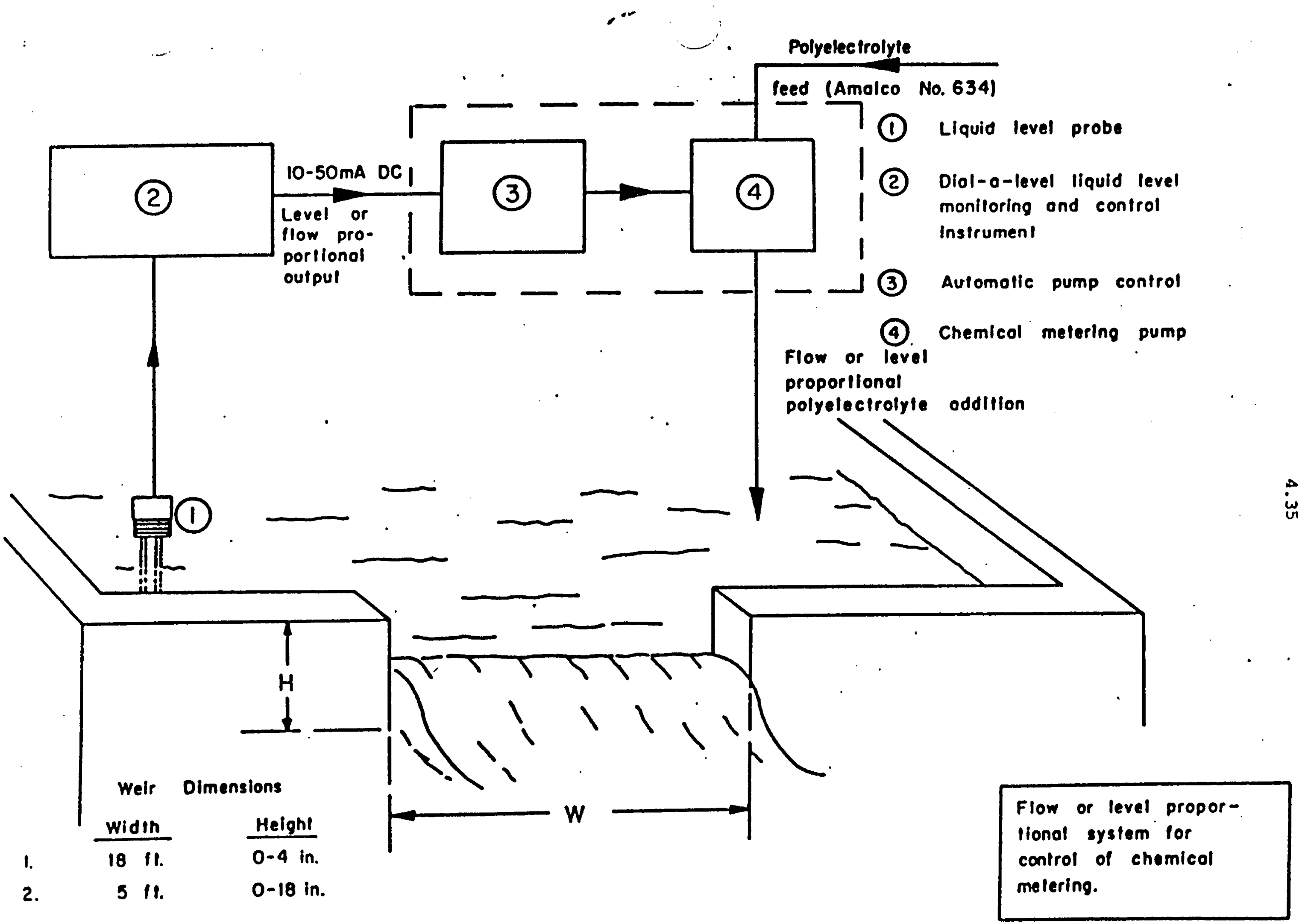


FIGURE 4.14 CHEMICAL TREATMENT APPLICATION AT CENTRALIA MINE SITE, CENTRALIA, WASHINGTON (Mc CARTHY, 1973)

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 disavantages 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 concentation 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.