SECTION II

HYDROLOGY

Section Editor: Frank K. Ferris

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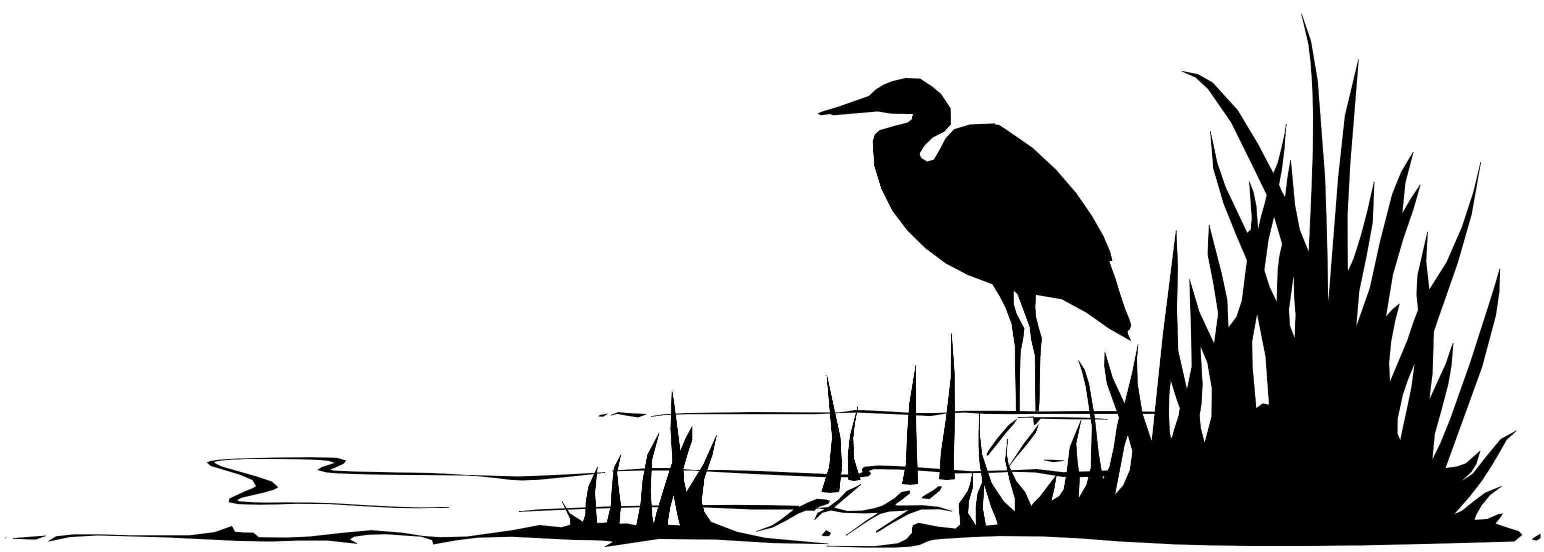

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SECTION II: HYDROLOGY

NOTES

A. Introduction

Section editor: Frank K. Ferris

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Control of water and sediment is important in disturbed areas. One of the most important post-disturbance features is the reconstruction of drainages. These hydrologic features control erosion and restore the surface hydrologic function.

The hydrology techniques in this section cover some common water control structures, sediment control, and reconstructed drainages that have been implemented at various mine locations. Feel free to contact the respective author(s) if you have any questions regarding any of the methods described. The following aspects should be considered when implementing any design:

1. Proper installation is critical to the success of any project. In hydrology, it is extremely critical because once water has bypassed or undermined your structure, structural failure is likely.

2. If the problem or project is too complicated or too large, get experienced help. It is not unusual for an inexperienced person to have several failures prior to solving a hydrology problem.

3. Match the method to the site condition. For example, hay bales may not be effective in a steep draw.

4. Match the method to the climate. For example, a grass filter is less likely to be successful in an arid environment.

There has been an important development regarding a self-functioning sediment reservoir. The reservoir operates without pumping, sampling, or logistical activities in muddy conditions. It will function in all weather at all times of the day and night. This sediment reservoir type discharges the water through a sand filter, which is part of the embankment. The only annual maintenance required is the removal of sediment from the reservoir side of the sand filter. If built according to appropriate designs, the discharge will be cleaner than required. Because the water, which is discharged through the sand filter, is in compliance with suspended solids requirements, sampling is not required.
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The passive sand filter sediment reservoirs have been approved by the Ohio and Pennsylvania Solid Waste agencies, and have been in use for several years. A mine in Kentucky is also constructing one during 1996. This design is a winning situation for industry and regulating agencies alike. Since only clean water is discharged by the sand filter, no out-of-compliance suspended solids discharges can occur.

B. Control Structures
1. Sediment Control Basin Design and Construction

Section editor: Frank K. Ferris Subsection author: Richard C. Warner

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Situation:

Sediment control basins have been used extensively for storm water management and sediment control throughout the mining industry. A variety of dam/impoundment types have been utilized which include excavated basins, embankment dams, and, more recently, infiltration basins. Sediment basins are used to reduce peak flow, trap sediment, and meet effluent limits.

This subsection will address the design and construction components of storm water and sediment control basins. Since construction procedures are readily available (SCS National Engineering Handbook, Section 19 (SCS, 1985); Earth Manual, Department of the Interior (Bureau of Reclamation, 1974); and SCS Engineering Field Manual (SCS, 1984)) emphasis will be placed on design considerations that can enhance basin performance in a cost effective manner.

Special Considerations:

The current effluent limit, which is widely used in the mining industry, is 0.5 milliliters per liter settleable solids at peak discharge. The Imhoff cone test is used to determine the settleable solids concentration at the discharge point from a sediment basin. In addition to meeting the required effluent concentration, basins are used to minimize the hydrologic impact of mining by reducing the peak flow, often to pre-mining conditions. National Pollutant Discharge Elimination System (NPDES) regulations, which may be applicable under certain situations, normally require effluent limits for Total Suspended Solids (TSS), usually specified in milligrams per liter. To meet such regulations additional design measures are frequently needed. Regulations focus on specific criteria, often neglecting the aspects that influence the fluvial system. The sediment discharge frequency/duration/concentration relationship influences aquatic invertebrates and multiple use of the receiving waters. Regional difference, such as the background concentration of sediment in the receiving stream, are also ignored. The implications of a single, nationwide standard, that disregards the flow and sediment regime of the fluvial system, discourages the development of
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procedures and methods that have a holistic approach, thereby reducing the incentive to explore more environmentally sound and cost effective approaches.

Description of Technique:

a. Design Considerations

Sediment basins are used to reduce peak flow, trap sediment, and meet effluent concentrations. The efficiency of basins to accomplish these functions is directly related to basin design and construction procedures. Additionally, the efficiency of a basin is highly influenced by up-gradient mining activities and control measures. Basin efficiency is also directly influenced by the incoming eroded sediment size distribution. If up-gradient controls such as check dams, sediment traps, furrows, terraces, etc. are used, the sand fraction of the transported sediment is reduced. Although the overall trap efficiency of the basin will subsequently be decreased by these measures, the need to provide additional sediment storage and/or expensive sediment removal is also reduced.

Basin design should be performed on a regional basis such that runoff, sediment concentration and amount, and eroded sediment particle size distribution information can be incorporated into the design. Also, if regulations change and provide for consideration of the fluvial system of the receiving stream, regional considerations will be even more important to incorporate in basin design measures.

Basin design considerations include: location, gradient, and stabilization of the inflow channel; length-to-width ratio of the pool measured at the crest of the principal spillway; basin shape and depth; sediment storage capacity; permanent pool storage; location, type, and size of the spillways; passive and active dewatering provisions; use of internal check dams, turbidity curtains, and baffles; and use of flocculation additives. As can be seen from this list of engineering and design considerations, the performance of a basin in reducing the peak flow, capturing sediment, and meeting effluent concentration limits is directly achieved through design and construction rigor.

(1) Inflow Channel

Inlet(s) should be located to provide the hydraulically longest flow path between the inlet and outlet. This will help to reduce short circuiting and provide a higher potential for mixing the inflow with the permanent pool, thereby reducing the sediment concentration through dilution and providing a longer residence time needed for settling sediment. The basin inlet should be a channel versus a pipe to reduce concentrated flow and avoid clogging by debris during large storm events. The inlet should be stabilized by geotextiles, rock riprap, or the other means described in the subsection entitled "Drop Structures" in this section of the handbook. The inlet channel width should be wide to further enhance mixing.

(2) Length to Width Ratio

The length-to-width ratio of the basin should attempt to approach two to one. This ratio was found to reduce dead storage and short circuiting. A ratio of one to one was found to increase dead storage from approximately 20 to 30 percent. Longer length-to-width ratios have not been adequately investigated but should marginally decrease dead storage and marginally increase trap efficiency.

(3) Basin Shape and Depth

The shape and depth of the basin should provide a storage depth that reduces resuspension of previously settled sediment. An alluvial depositional fan is seen at the entrance of many sediment basins. This depositional feature reflects the settling characteristics of incoming sediments. A deeper basin will reduce the potential resuspension of deposited sediment. Thus a tradeoff exists between length and depth with the two to one ratio providing the length needed for settling time and the deeper pond reducing potential sediment resuspension. The difficulty in assessing this trade-off is due to the complicating factor that the deeper pool will allow settling particles to remaining in suspension for a longer period prior to reaching the level of previously settled sediment. Thus, sediment in the deeper pond may be discharged while still in suspension. Field experience indicates that, for a pond with a permanent pool, a length-to-width ratio of two to one is adequate. Two to three feet of permanent pool above the sediment storage area provides a buffer to reduce sediment resuspension and facilitates the tradeoff between sediment settling depth and the potential for resuspension. Further research is needed.

(4) Sediment Storage Capacity

Sediment storage is often sized by a rule-of-thumb such as "X" acre-feet of storage per disturbed contributing watershed acreage. Such simple methods often yield an overdesign of the actual needed sediment storage capacity. Rule-of-thumb methods often have no confirmed data base nor do they reflect the erosional and sedimentary processes occurring within the watershed. There are numerous opportunities to contain sediment within the watershed. A significant portion of water enters the active pit area either as precipitation or runoff directed to the pit. The judicious use of check dams, sediment traps, furrows, terraces, and numerous other onsite control techniques reduces the need for excessive sediment storage. An alternative method to the rule-of-thumb approach is to estimate the sediment load associated with the 10-year 24-hour design storm event and normalize for average annual sediment yield based on the published annual R-factor. Refer to the Sediment, Erosion, Discharge by Computer Aided Design (SEDCAD+) Manual, Version 3 (Warner and Schwab, 1992) for further information regarding this method. Another approach is to simply specify the sediment clean out level based on past experience and basin performance in the region. Other methods include estimation using the Soil Conservation Service's universal soil loss equation or its modifications.

(5) Permanent Pool Storage

The size of a permanent pool affects peak flow reduction, sediment trap efficiency and effluent concentration. The primary consideration is how the permanent pool affects the detention time of incoming flow and sediment. The advantage of a permanent pool is that, assuming the water in the basin is clear at the start of a runoff event, it will provide significant dilution, thus reducing the concentration of the effluent. The negative aspect of a permanent pool is that there is usually less space available for detention of the incoming waters (inflow hydrograph), and runoff will be discharged at a faster rate. Additionally, the depth that a sediment particle must traverse to be deposited is increased; thus increasing peak flow, decreasing detention time, and retaining a greater percentage of sediment particles in suspension. If a permanent pool and a partially dewatered basin system are contrasted, these trade-offs can be readily visualized. The partially dewatered basin has initially less water for dilution of the incoming flow but greater capacity to retain a portion of the inflow hydrograph. Additionally, sediment entering the dewatered system will have an initially smaller settling distance and a greater detention time than one entering the permanent pool basin. Refer to the SEDCAD+ Training Manual (Warner and Schwab, 1992) for a more complete discussion and illustration of the efficiency of a passive dewatering system. It appears that the trade-off among all of these design parameters results in the conclusion that dewatering basins provide a higher detention time, greater sediment trap efficiency, a lower peak discharge, a lower peak stage, a smaller basin, reduced embankment height, and lower effluent concentration with respect to settleable solids than the permanent pool situation.

(6) Spillway

Spillway location, type, and size directly influence the performance of sediment basins. A single spillway provides no significant attenuation of the incoming storm. Thus, peak flow will only be slightly reduced, detention time will be minimal, potential sediment trap efficiency will be reduced, and effluent concentration will be higher than alternative spillway techniques. A spillway sized to rapidly discharge the inflow hydrograph will likewise have similar deficiencies.

(7) Dewatering Provisions

The previous discussion of the tradeoffs between a permanent pool and a partially dewatered basin emphasize the potential increased efficiency of a partially dewatered basin. Methods to achieve dewatering are: (1) perforated risers, (2) perforated risers with tapered holes, (3) perforated risers with rock filters, (4) perforated risers with geotextile filters, (5) trickle tube, (6) slow sand filter, (7) fixed siphon, and (8) floating siphon. Methods 1 through 6 can be passive or made active with the use of a discharge valve. Methods 7 and 8 are normally operated passively but can be operated actively with the use of a pump. A perforated riser has a higher trap efficiency than the standard drop-inlet principal spillway. Use of tapered holes in a perforated riser facilitates various operational dewatering schemes used to provide storm water storage by varying incremental dewatering times. The addition of a rock filter, for all or part of the height of the perforated riser, increases sediment trap efficiency and reduces effluent concentration. The filtering action of the geotextile further reduces effluent concentration but significantly increases dewatering time. This increase in dewatering time can be partially overcome by only using the geotextile for the lower perforations. Locating a small trickle tube near the sediment storage volume functions like a single dewatering orifice in a perforated riser but has the disadvantage of releasing sediment deeper in the pond. A fixed siphon tube has similar disadvantages but should reduce sediment concentration due to the forced upward discharge during the siphoning period. The floating siphon tube has the added advantage of always discharging slightly below the surface where sediment concentration is low. Slow sand filters have been installed in Pennsylvania and Ohio to dewater basins at landfills. The effluent concentration is lower than for any other dewatering method observed to date. Research is currently ongoing to mathematically model the sediment removal effectiveness of slow sand filters and will be incorporated into SEDCAD+ version 5.

Passive systems function automatically, which is an advantage for remote locations and reduces work load. The advantage of placing a valve on the discharge line of these dewatering systems is to utilize contained water for fugitive dust control or other mining uses and to discharge lower sediment concentration after a longer settling time has elapsed.

(8) Check Dams, Turbidity Curtains, and Baffles

Internal check dams are provided to accomplish numerous functions: (1) provide a chamber for sediment storage of the larger size sediments, (2) facilitate sediment clean out, (3) provide detention and slow release through previously deposited sediments for small storms, and (4) distribute runoff more uniformly throughout the width of the basin to reduce potential short circuiting and dead storage. The internal check dam should have a rock trench drain beneath it to facilitate dewatering of the first chamber to the second chamber of the sediment basin. For high flows that completely fill both chambers, the internal check dam may exacerbate trap efficiency by actually creating a short circuiting of the inflow by raising the sediment-laden water over the internal check dam to a higher elevation. Further research is needed. Turbidity curtains function to lengthen the flow path between the inlet and outlet. The turbidity curtain should direct flow beneath and to the sides of the curtain. These curtains should be relatively porous such that some flow can also be transported through the curtain.

(9) Flocculants

Flocculants can further increase the effectiveness of sediment basins and may, when used with dewatering techniques, further reduce basin size. Flocculants are predominantly being used in Texas and western Canada to achieve higher trap efficiencies and lower effluent sediment concentrations.

b. Construction Considerations

Several construction elements are discussed in the subsections entitled "Special Considerations in Planning and Constructing Permanent Postmining Impoundments" and "Hydrologic Control Structure Tolerances" in this section of the handbook. This subsection will focus primarily on construction quality control during the compaction process, but will address other facets of construction such as clearing and grubbing, excavating the cutoff trench, and constructing the emergency spillway. Large dam construction is considered beyond the scope of this section and will not be discussed.

(1) Soils

Borings, or at least test pits, should be made throughout the pond area with particular attention paid to the location of the embankment. Soils suitability depends on the ability of the soils to be compacted, thus developing a relatively impervious basin base and embankment. Silty clay loams and sandy clay loams are excellent potential soils for pond and embankment construction.

The purpose of foundation studies is to assure that a stable support of the embankment will be provided during saturated conditions and that necessary elements exist to prevent excessive seepage through the key way. Clearing and grubbing is necessary to remove vegetation, soils with root growth, and soils that are unsuitable for construction. Cutoff trench excavation is an extension of the clearing and grubbing operation. The cutoff trench functions to reduce seepage beneath the embankment. Its width should be that of a dozer or compactor to facilitate operations.

Prior to compaction, standard soil tests need to be conducted primarily to determine the density-moisture content relationship. Scarifying the foundation soils will help bond the compacted lift to the foundation. Additionally, scarification between lifts will also reduce the overall permeability of the soil layers. Lift thickness should relate to the construction equipment. If only a dozer is used, a lift thickness of four to six inches will be provide minimal compaction effort. The use of a compactor and six inch lifts will increase compactive effectiveness and ensure a better basin and embankment.

(2) Construction Quality Control

The key elements for construction quality control are scarification of the previous lift, lift thickness control, soil lift mixing and blending, and, most importantly, proper control of the compacted moisture content. The Proctor test, in conjunction with a permeability test, will provide information necessary for proper compaction needed to assure a low permeability soil liner and embankment. A range of moisture contents and densities needed to provide an acceptable permeability will emerge from these tests. It has been found that providing air-tight bags containing soils at moisture contents below, at, and above the target moisture content readily assist operators in recognizing the correct soil conditions during the construction phase. Furthermore, equipment operation provides an immediate feedback regarding proper moisture content during construction. A properly trained compactor operator can readily determine by the "feel" of the equipment and observation of the equipment foot print if sufficient moisture content exists and needed compaction has been achieved. The compactor should "walk out" after four to seven passes in a properly compacted soil.

All of this compaction testing may not be necessary for every embankment. An adequately compacted embankment and pond surface may be achieved given proper soils, a relatively close moisture content, and passage of construction equipment over the embankment such that the equipment effectively compacts the entire width of the embankment. The level of needed compaction dictates the degree of construction quality control that is necessary for a given operation.

(3) Emergency Spillway

The emergency spillway should use the original ground if practical, otherwise excavation of the inlet channel and exit channel will be required. The emergency spillway should be constructed such that no flow will be conveyed against the embankment. If this is not practical then rock riprap, with a bedding stone blanket and/or geotextile, should be used for protection of the embankment. Spillway dimensions should be selected to convey the design discharge. As a practical consideration, it is advisable to over-design the emergency to convey the 100 year or larger design storm. The cost of this over design is minor with respect to the safeguards that it provides. A rule-of-thumb used by the Soil Conservation Service (SCS) is that the maximum width of the bottom of the emergency spillway should not exceed 35 times the design depth of flow. This is to preclude potential accumulation of deposited material and debris and to reduce the potential for establishing meandering flow through the spillway.

NOTES

2. Diversion Design and Construction

Section editor: Frank K. Ferris Subsection author: Richard C. Warner

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Situation:

Diversions are used throughout mining to intercept and convey runoff. Some diversions used to convey runoff from non-disturbed areas around active mining sites preclude commingling of runoff waters and reduce the quantity of runoff to subsequently be controlled by sediment basins. Diversions take on many design forms depending upon the quantity of runoff and slope of the channel. Classically, as the quantity of runoff increases, there is a progression from bare earthen to grassed waterways to rock riprap channels.

Numerous commercial products can be used to stabilize diversions. Lower flow velocities can be controlled by excelsior mats and geotextiles. As flow increases, grouts, gabions, and concrete filled fabric forms can be used. If properly designed and constructed, diversions perform the duel functions of conveying runoff and remaining stable, i.e. non-erosive. Poor construction techniques and inadequate time for stabilization prior to a significant discharge event can cause temporary failure of the diversion and create recurring cost.

Special Considerations:

In the design of diversions, the development of a stable channel for a rather large design storm appears to be the primary consideration. Often diversions can accommodate the large storm event, but failure to consider potential sediment deposition from intermediate events, and subsequent loss of conveyance capacity, sometimes leads to failure of the control structure. In the case of terraces, the failure of an up-gradient terrace causes the failure of all down-gradient terraces. Diversion failures can occur due to construction procedures that do not adequately provide the needed measure of construction quality control. An aggressive field inspection of the diversion during construction can reduce the propensity of potential failures by assuring that proper slope, depth, freeboard, and channel transitions have been established. Failure to give adequate attention to a stone blanket and/or a geotextile during the placement of rock riprap creates the potential for undercutting beneath the rock layer, erosion and transport of sediment, and ultimately failure of the control structure to function properly. Inadequate design information exists for steep
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slope rock riprap design, i.e. slope greater than 15 percent. The placement and distribution of rock riprap (D_{max}, D_{50}, and D_{10}) along the rock riprap diversion also creates less than adequate construction conditions.

Description of Technique:

a. Design Considerations

Methods will be outlined in this subsection and reference will be made to standard practices. Discussions will center around how to avoid failures and the expense of diversion reconstruction. Since the design of terraces for surface mining has not been adequately addressed in literature, design considerations will also be outlined for terraces. Additionally, techniques that have no real design methodology in literature, but seem to resolve potential problems in the field, will be discussed. It is hoped that this type of informal technology transfer can provide a vehicle of information exchange to the extent necessary for others to try the techniques, and through gained experience improve upon the ideas.

(1) Temporary Diversions

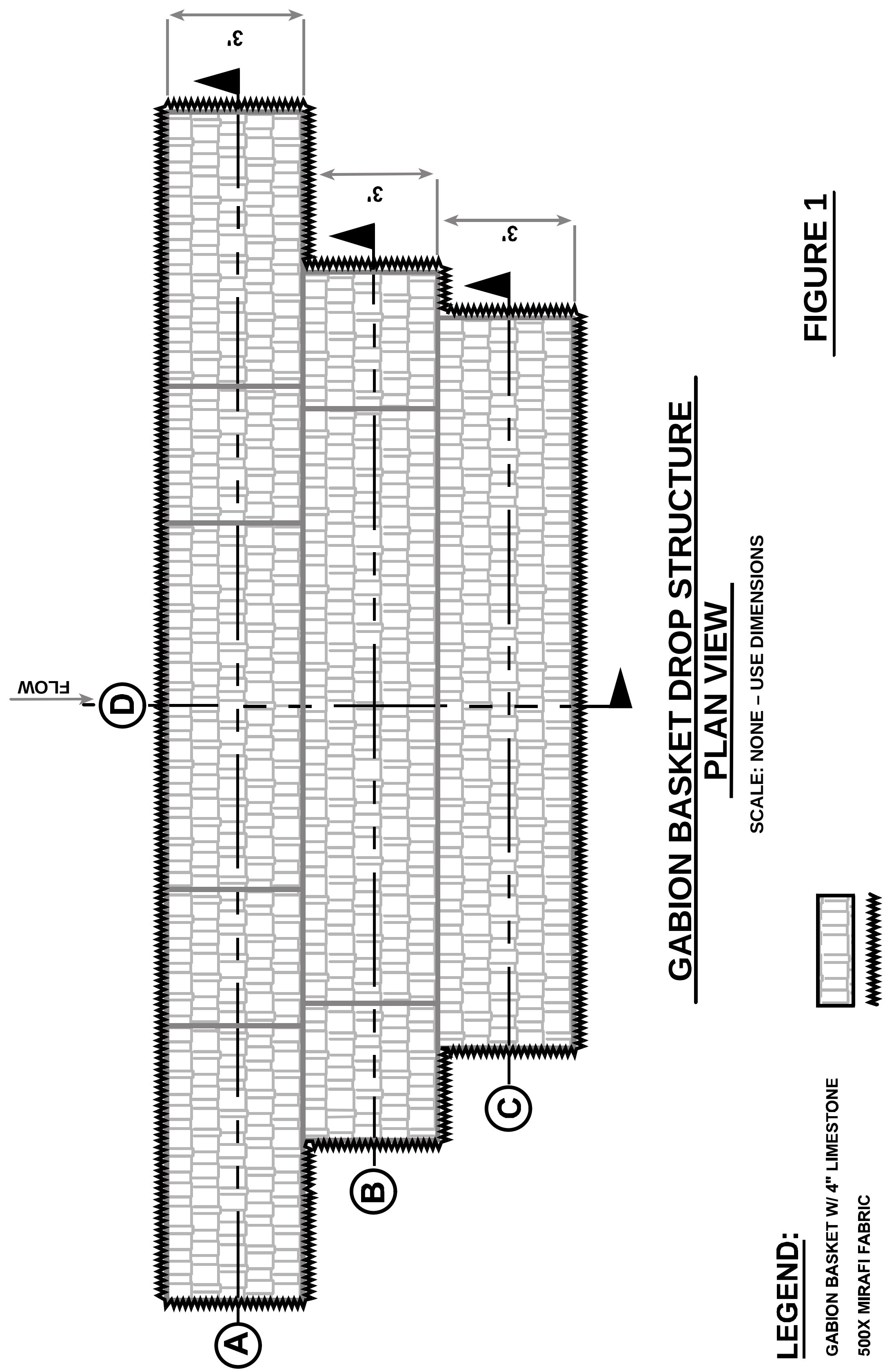
Bare soil or spoil diversions are commonly used as temporary diversions. They are relatively cheap to construct but often require significant maintenance. Thus, the tradeoff between initial capital cost and maintenance cost is readily apparent. The limited permissible velocity approach is normally used. The technique is simple. The soil or spoil is linked with a permissible velocity. If in the actual design the permissible velocity is not exceeded, the diversion is assumed to be stable and will convey the discharge without significant erosion. It is a Mannings' equation solution linked with the continuity equation. Usually many design elements are ignored. The permissible velocities listed in literature are limited and do not readily translate to many spoils. Thus, the initial determination of permissible velocity is not readily apparent. The development of listed permissible velocities is largely based on intuition and experience gained from cut channels used for irrigation that are relatively stable. Often, both cut and fill is necessary in mining operations and the fill soils are not properly compacted to withstand the permissible velocities. The affect of a design near the critical slope is often ignored. Uniform flow at or near the critical depth is unstable. A slight irregularity in the construction or deposition in a reach of the diversion can cause a shift in the Mannings' "n", thereby developing an unstable condition. Uniform flow at or near the critical depth is observed to create a sort of standing wave which can cause an appreciable change in flow depth and in some circumstances, exceed the diversion capacity. Earthen channels often meander, causing erosion and deposition. Where sediment deposit occurs along channel reaches overflow conditions can exist.

(2) Diversion Stability

(a) Rock Check Dams

Besides these design conditions, it should be realized that for many soils and storm conditions for various regions, runoff from a very limited acreage can be controlled by earthen diversions. All of this appears to be bad news. How can earthen diversions be salvaged? Promising techniques use check dams made of durable rock. This is illustrated in Figures 1, 2, and 3.

The check dam creates a back flow condition, thereby reducing transport velocity and creating a depositional opportunity for transported sediment. Thus, the potentially erodible channel is transformed to a stable channel. The design of this channel should take into account the needed additional conveyance capacity, assuming that deposition removes a portion of the channel cross sectional area. The check dams are designed as broad crested weirs, or sharp crested weirs for the geotextile check dam. The dams are the flow constriction within the channel. Since the erodible nature of the problem has been eliminated, these check dam stabilized channels can now accommodate much larger drainage areas and higher peak flows than the standard limited velocity methodology. Check dam spacing is a function of slope. A conservative approach is to have the back water of each dam reach the up-gradient check dam. These designs have been successfully installed in the Piedmont area of South Carolina and in the Mississippi Delta region, both areas which are prone to highly erodible soils.



GABION BASKET DROP STRUCTURE
PLAN VIEW
SCALE: NONE – USE DIMENSIONS

FIGURE 1

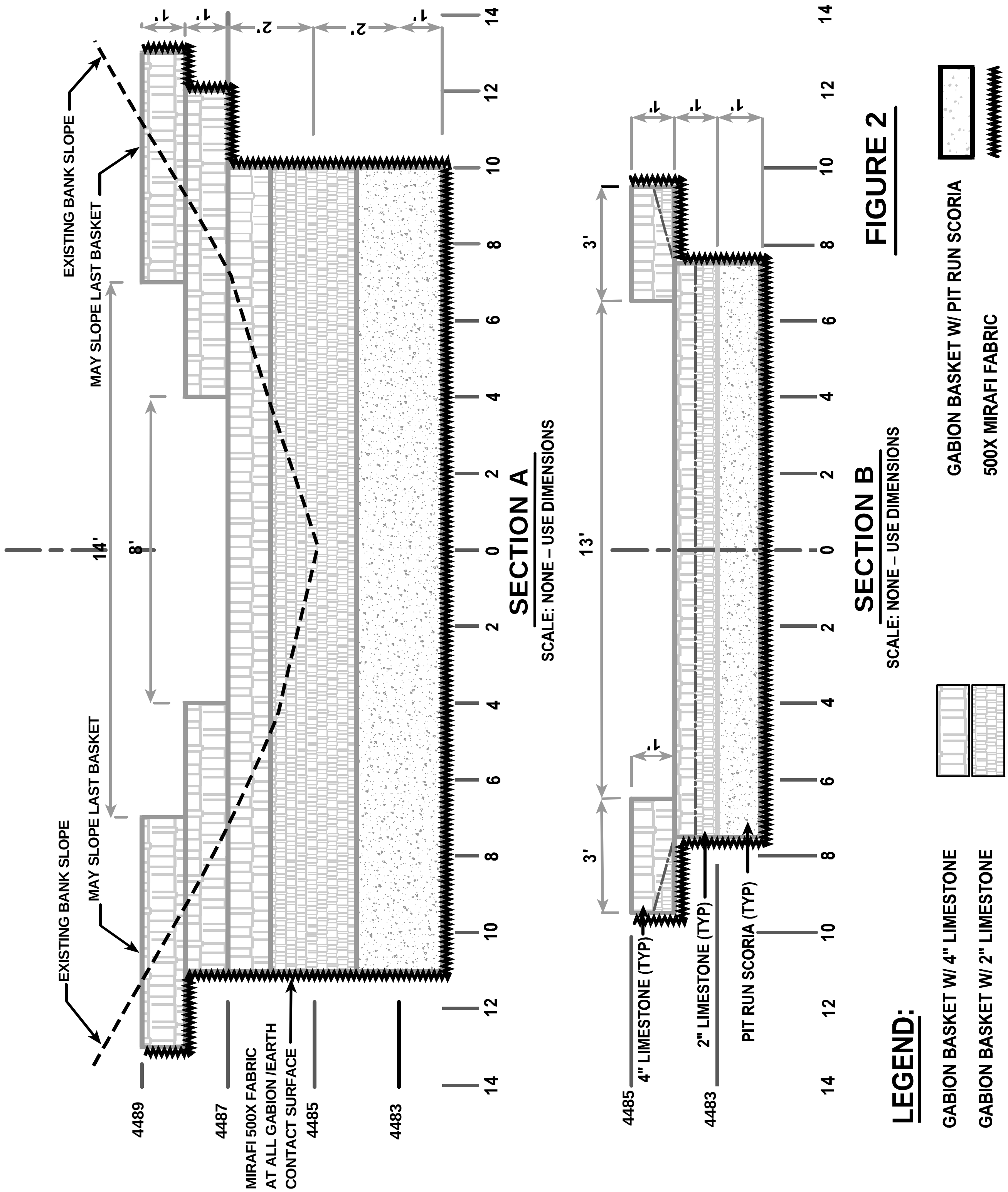

EXISTING BANK SLOPE
MAY SLOPE LAST BASKET
14'
8'
1'
2'
4489
4487
MIRAFI 500X FABRIC
AT ALL GABION /EARTH
CONTACT SURFACE
4485
4483
SECTION A
SCALE: NONE – USE DIMENSIONS
13'
3'
4" LIMESTONE (TYP)
2" LIMESTONE (TYP)
PIT RUN SCORIA (TYP)
SECTION B
SCALE: NONE – USE DIMENSIONS
LEGEND:
GABION BASKET W/ 4" LIMESTONE
GABION BASKET W/ 2" LIMESTONE
GABION BASKET W/ PIT RUN SCORIA
500X MIRAFI FABRIC

FIGURE 2

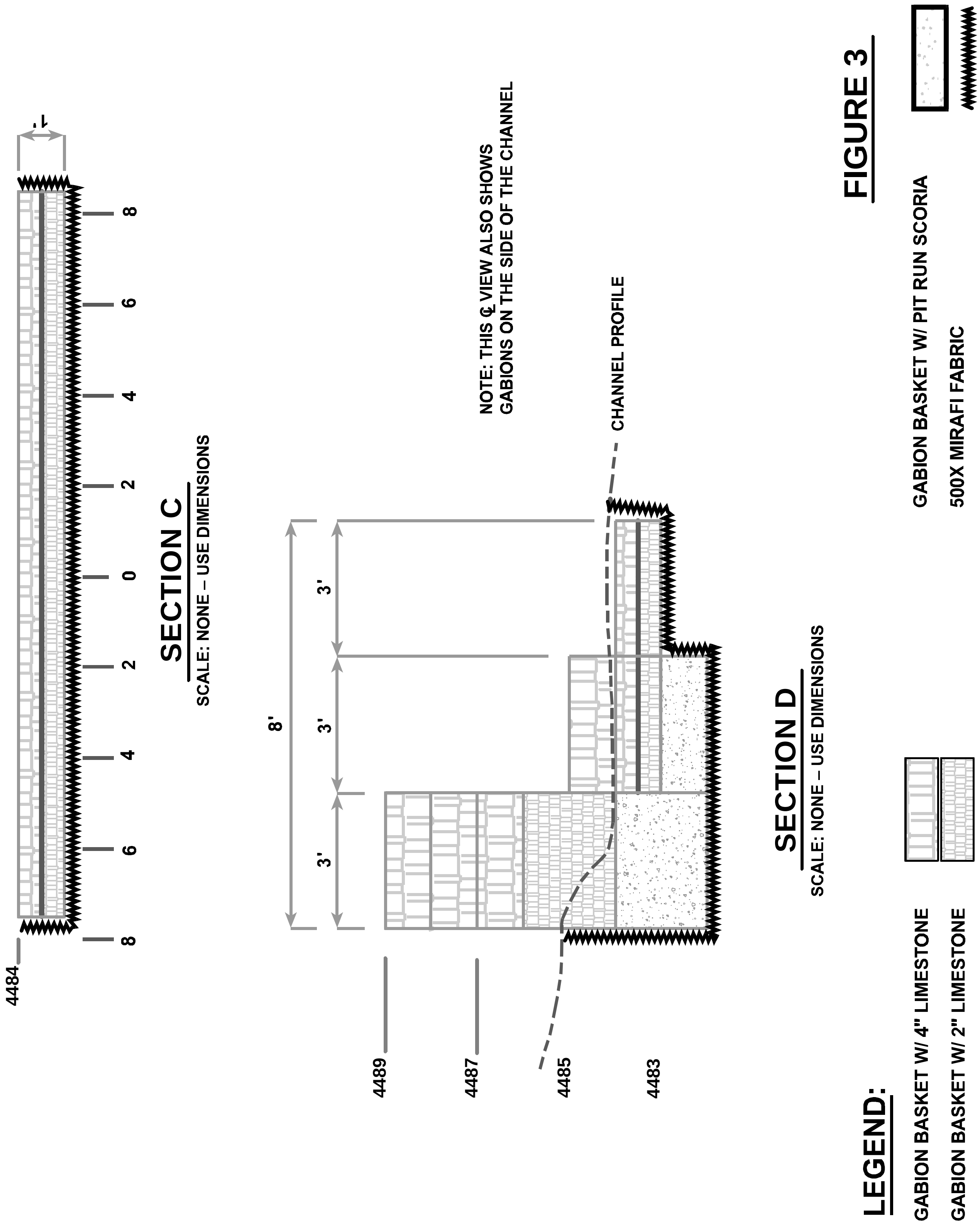

SECTION C
SCALE: NONE – USE DIMENSIONS
1'
8
6
4
2
0
2
4
6
8
4484
NOTE: THIS ℄ VIEW ALSO SHOWS
GABIONS ON THE SIDE OF THE CHANNEL
CHANNEL PROFILE
SECTION D
SCALE: NONE – USE DIMENSIONS
8'
3'
3'
3'
4489
4487
4485
4483
LEGEND:
GABION BASKET W/ 4" LIMESTONE
GABION BASKET W/ 2" LIMESTONE
GABION BASKET W/ PIT RUN SCORIA
500X MIRAFI FABRIC

FIGURE 3

(b) Grassed Waterways

Grassed waterways are often used to increase diversion stability and therefore convey larger runoff quantities. The classic design of grassed waterways is based on retardance classifications which enable the design for conveyance, under long grass conditions, and stability, under short grass conditions. To perform satisfactorily, grassed waterways are dependent upon climatic conditions that are favorable to vegetative establishment and growth.

To successfully establish grassed diversions, many options exist but few are actually employed. The channel can be stabilized by: small check dams as previously described; commercially available products utilized to protect the channel and assist vegetal establishment; construction of the diversion in advance of actual use; use of a rock center section of a low flow channel; or diversion of runoff during establishment. Detailed design procedures are provided in SCS-TP-61, Handbook of Channel Design for Soil and Water Conservation (SCS, 1947).

(c) Rock Riprap

Rock riprap diversions can convey large quantities of runoff on steeper slope than can be considered for earthen or grassed diversions. As previously stated, the data base for designs is based on typical stream gradients and is limited for steeper channels. Thus, extrapolation is the design method for diversions greater than approximately 10 percent.

Numerous methods have been developed to predict the D_{50} rock size. These vary from simply solving Mannings' equation, by estimating Mannings' "n", to methods that compare resisting moments to overturning moments and are linked with a safety factor. Analysis has been completed for a stream approximately 20 feet wide and of trapezoidal shape which compared eight methods. Most of the methods predicted a D_{50} within +/- 3 inches. Thus for channel slopes less than 10 percent, and for relatively small streams, numerous methods may be comparable. It is recommended that alternative methods be used to develop a feel for the probable D_{50} size and, as always, practical experience gained from field applications that actually work is the most valuable design asset available. Unfortunately, the applicable range of various methods is not explicitly documented. Durable rock that is angular in shape should be placed by a backhoe or trackhoe to avoid segregation of rock sizes from dumping and pushing with a dozer.

(3) Terraces

Terrace designs have been predominantly developed for agricultural endeavors. Terraces fail in mining reclamation due to deposition of sediment within the terrace or undercutting by flow at the soil-terrace interface, which sometimes produces a vehicle for piping beneath the terrace. Animal bore holes also sometimes contribute to undercutting terraces. Designs need to address both sediment and storm water. If terraces are to function as lateral sediment traps, either by design or by practice, then sediment deposition must be determined by erosion and transport models. The quantity of sediment expected to be deposited should be predicted and additional capacity provided.

The terrace slope and outlet control are predominant design parameters. The outlet should be designed to rapidly discharge larger runoff events while storing a portion of the runoff from these events. Smaller runoff quantities can be more easily detained through a passively dewatered outlet. The benefit of retaining a portion of the runoff is for establishment of vegetation. Use of small internal check dams located along the length of the terrace can provide runoff storage and also reduce the failure of down-gradient terraces if an up-gradient terrace fails. The SEDCAD+ version 3 program can readily assist in the design of terraces, bare earthen diversions, grass waterways, and rock riprap channels.

3. Drop Structures

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Situation:

Drop structures are typically constructed at locations where the "design" or "as-constructed" channel gradient is too steep, resulting in excessive flow velocities and the need for channel protection. A drop structure can accommodate the required channel fall over a relatively short, protected channel reach, while providing for the construction of a long section of lower gradient unprotected channel upstream and downstream of the structure.

Drop structures can also be located at sediment pond inlets and outlets to enhance the stability of the dam structure during flood overtopping (spillway) events, or the stability of the upstream channel during typical runoff events. Some states and non-coal regulatory agencies allow drop structures in the reclamation plan as a permanent structure.

Special Considerations:

Drop structures should be located in a straight channel section where the fluid forces are steady and uniform. It is recommended that the structure be located at least 100 feet upstream or downstream of any bends in the channel, and a minimum of 100 feet upstream or downstream of channel confluences. Minimizing excavation, earthwork, and rock costs should be considered in the location of the structure.

Many regulatory agencies have guidelines or requirements which dictate the design life, hence hydrologic design event for channel protection structures. Design life may also reflect the level of risk acceptable to the designer or owner of the facility. Peak flow estimates for such design events are generally developed with computer models, which utilize SCS methods to predict the peak discharge. These include the: U.S. Army Corps of Engineers, HEC-1 Flood Hydrograph Package; QTR-55; and Sedimot.
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Description of Technique:

a. Drop Structures

There are three main types of drop structures: concrete drops, rock riprap drops, and wire enclosed rock riprap drops (gabions). Concrete structures can be sloped chute structures or vertical drops. Rock riprap structures are typically constructed as sloped structures, and gabions are usually constructed as stepped structures. Rock riprap structures and gabion structures, which are more cost effective and are utilized more often than concrete drop structures, will be discussed in this section.

(1) Rock Riprap Drop Structures

Figure 1 presents a typical profile of a type of drop structure with which the authors have had success. The basic parts of the structure are the inlet, chute section, and outlet. The rock riprap is sized to be stable during the design flow event. Various procedures are available to estimate the rock diameter or rock weight to ensure stability. This subsection will not present design procedures for sizing the rock riprap, but a listing of references to find design procedures has been included at the end of this section.

The function of the inlet and outlet section of the drop is to ensure a smooth flow transition entering and exiting the structure. The length of the inlet and outlet section should be five times the uniform flow depth of the downstream channel section or 15 feet, whichever is greater (refer to the "Design Manual for Water Diversions on Surface Mine Operations" listed in References). The chute section typically has a drop slope of approximately 4H:1V. In some cases where the design discharge is large, the drop slope may be set at a flatter grade (5H or 6H:1V) to ensure the stability of the rock riprap. The design of the chute and drop height (H) should ensure that a hydraulic jump does not occur at the exit section of the structure. Based on the authors' experience with various structures, it is recommended that the Froude number should not exceed 4.0 in any section of the chute, and that the overall drop height (H) should not exceed 12 to 15 feet. A cross section of a drop structure is presented in Figure 2. The design capacity of the structure must pass the design flow event with a minimum of one foot of freeboard. Freeboard allowance should be increased wherever possible, particularly where turbulent forces are anticipated; e.g. at the bottom of the structure. The side slope Z of the structure should be no steeper than 2.5H:1V and should be flatter under larger design discharges. A cross section of a drop structure is presented in Figure 2. The design capacity of the structure must pass the design flow event with a

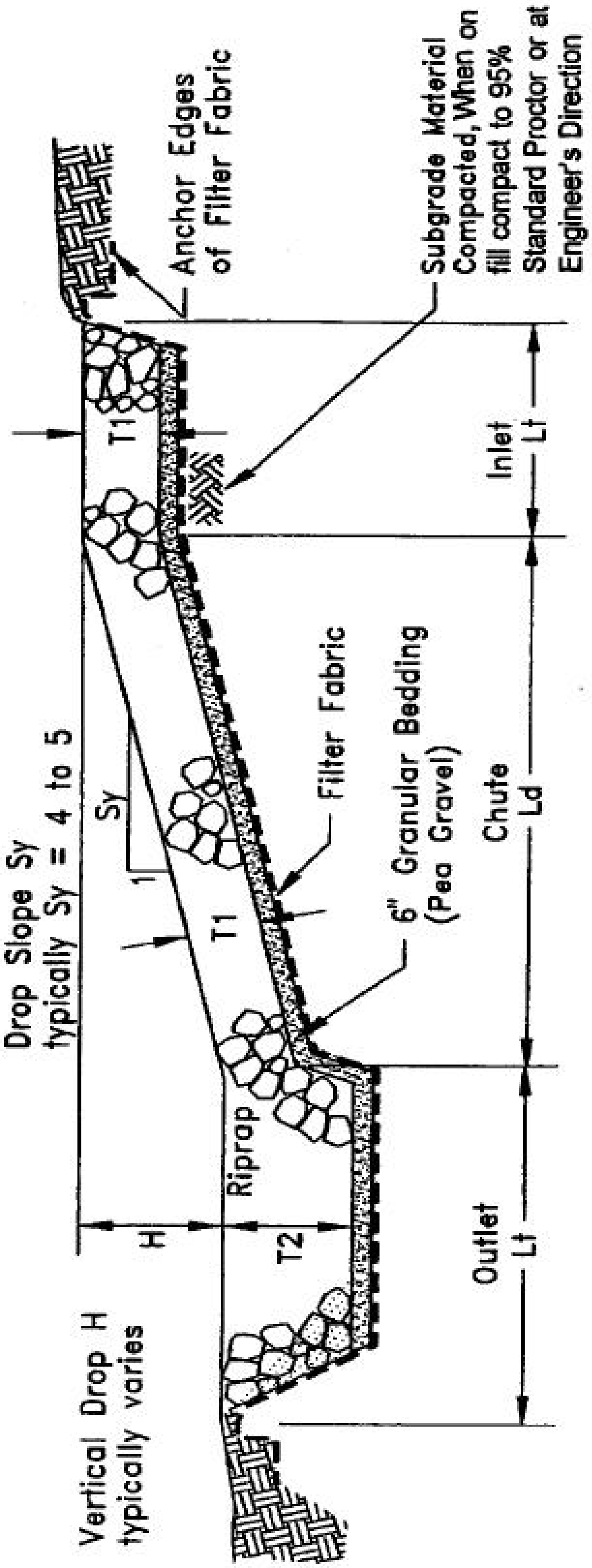


Figure 1. Typical Rock Riprap drop Structure – Profile View

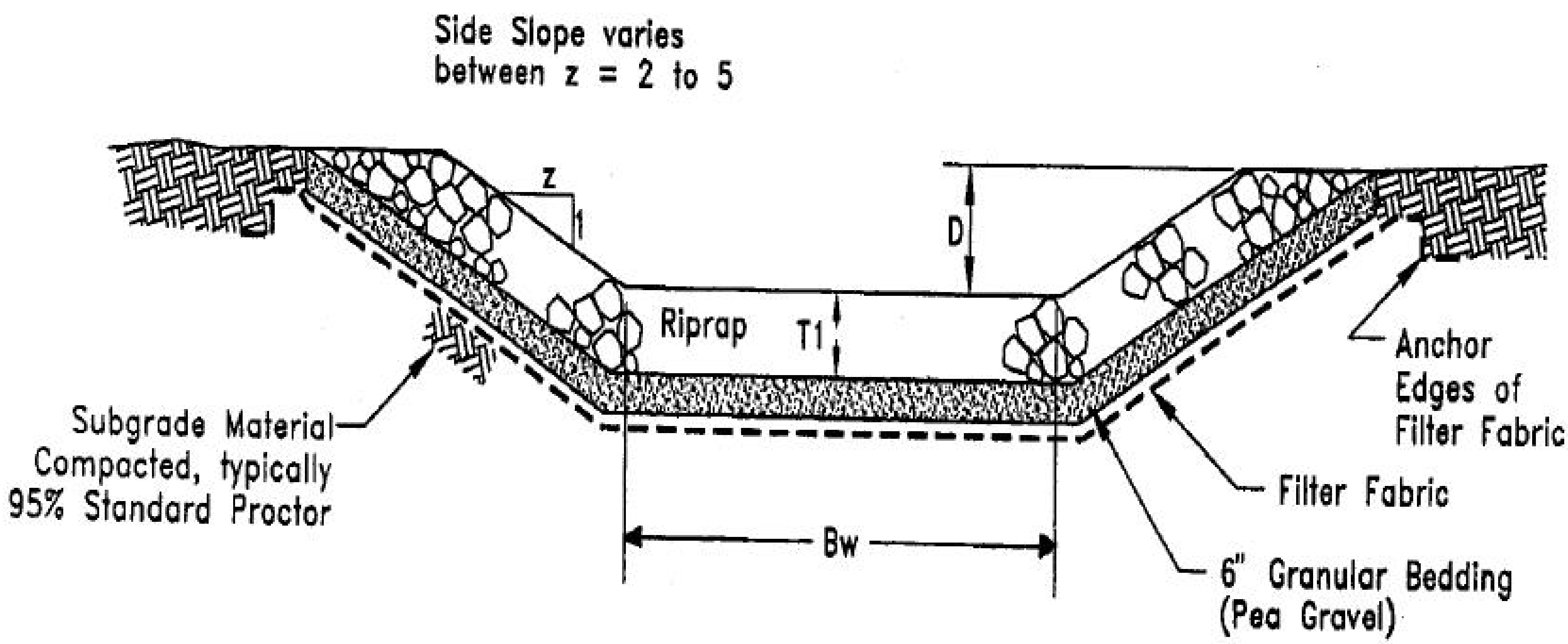


Figure 2. Typical Rock Riprap Drop Structure – Cross Section View

minimum of one foot of freeboard. Freeboard allowance should be increased wherever possible, particularly where turbulent forces are anticipated; e.g. at the bottom of the structure. The side slope Z of the structure should be no steeper than 2.5H:1V and should be flatter under larger design discharges. The bottom width of the structure should be similar to the bottom width of the upstream channel. Similarities in channel geometry will make construction easier and improve the hydraulics through the structure. Bottom widths of the drop structure typically range from eight to sixteen feet. Anything less than eight feet in width is more difficult to construct. Most structures typically have widths varying from 12 to 16 feet.

Two of the most important factors in constructing a sound rock riprap drop structure, include: (1) obtaining rock with a proper gradation and shape, and (2) utilizing a durable and sound rock type. The rock size for the structure is based on median rock diameter, D_{50}. The rock should be angular, blocky and have a uniform gradation to ensure that the individual rocks will interlock with minimum void space. The gradation is based on the D_{50} diameter:

$$D_{100} = 1.5 \text{ to } 2.0 \text{ times } D_{50}$$
$$D_{20} = 1/3 \text{ to } 1/4 \text{ times } D_{50}$$

Rock sizes for the gradation are usually specified by one-quarter foot increments, i.e. D_{50}= 0.5 feet (6 inches), D_{50}=0.75 feet (9 inches), D_{50}=1.0 foot (12 inches). A median rock diameter greater than 2.0 feet (24 inches) with the proper gradation is difficult to obtain from most quarries. Generally, the rock riprap for drop structures will have D_{50} diameters less than 1.5 feet (18 inches). Good quality rock is essential for the long term success of the structure. The following rock properties are recommended:

(a) The rock should be durable;

(b) The rock should have blocky-angular shape;

(c) The rock source should be free of organic material, clay, shale seams, or other structural defects;

(d) The riprap should have a specific gravity of at least 2.50.

Lesser quality rock may by used in site specific situations, where the design flow is relatively small and/or the structure has a small drop. In some instances sub-standard rock can be anchored by vegetation or may be installed in a structure with a relatively short design life or at a site with minimal adverse consequences of failure. Standard construction specifications (ASTM) will provide rock testing requirements. Riprap sources which do not meet these properties may be utilized, but design modifications may be required. The designer will need to ensure that the rock quality will not compromise the stability of the structure.

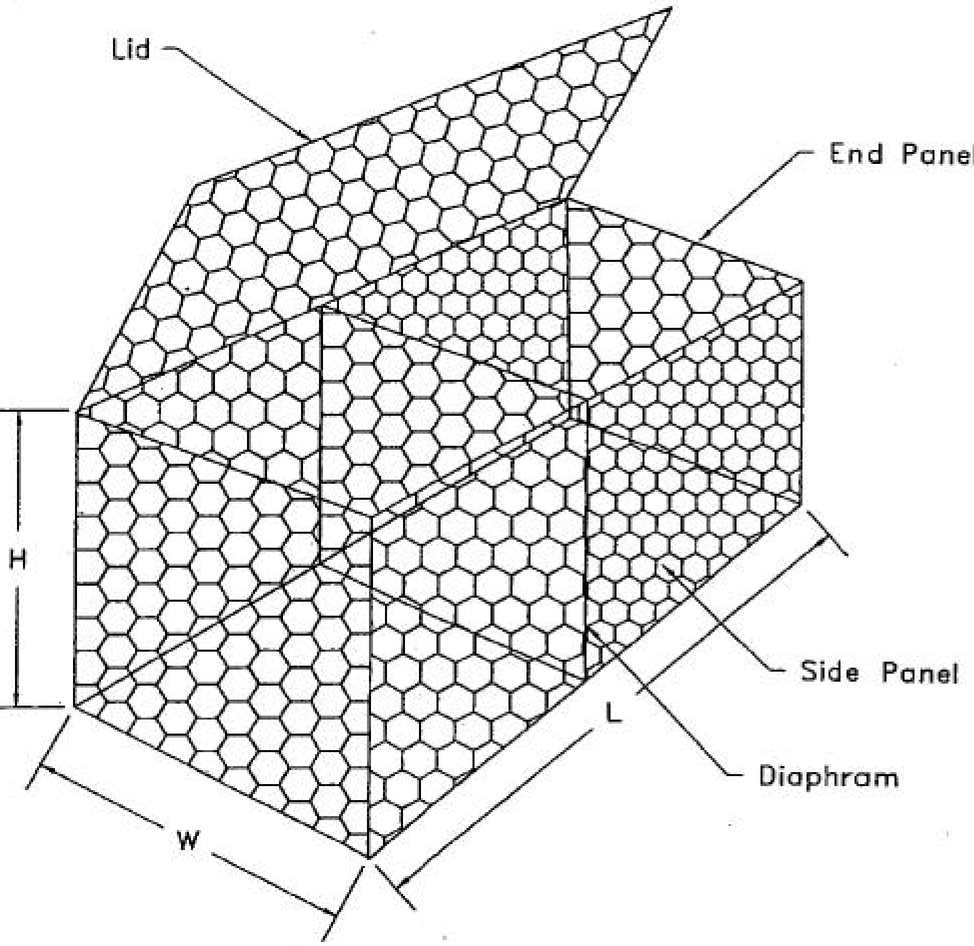
Some measure of protection is required below the drop structure, to prevent failure or winnowing of the underlying soils. This can be accomplished with a graded granular filter or a granular bedding used in conjunction with a geotextile fabric (see Figure 2). Frequently the granular bedding is a pea gravel overlying the geotextile fabric. The fabric will protect the bed material from being "washed out" from below the structure and the granular bedding will protect the geofabric, as angular rock is being placed on the fabric.

There are some guidelines that should be observed during the construction of a rock drop structure. The construction inspector will need to ensure that the rock has a gradation corresponding to the design specification. He will also need to ensure that when the rock is handled (stockpiling and placing), segregation of the rock does not occur. The structures should be constructed from the bottom to the top to minimize the potential of rock segregation.

(2) Gabion Drop Structures

Gabions are wire enclosed baskets filled with rock. The combined weight of the rock in the enclosed structure can withstand higher flow velocities and hydraulic forces when compared to individual stones within a "loose" rock riprap structure. A gabion structure often can utilize on-site rock recovered during mining operations. A range of basket sizes available for construction are listed in Figure 3

A typical layout for a gabion drop structure is presented in Figures 4 and 5. As indicated in the figures, the structures are typically constructed with a stepped profile in both the longitudinal and lateral direction. When the gabions are placed, each basket should overlap no less than one-half the length of the underlying basket (see Figure 5). The baskets will also need to be adequately keyed into the channel bank and bed to prevent failure of the structure by cutting or breaching. An inlet and outlet transition section, similar to that required for rock riprap drops, should be constructed. The individual baskets are also bound to each other with wire fastenings.



Wire Thickness for the
Gabion Baskets ~0.09"

Typical Gabion Basket Dimension

L(ft)	W(ft)	H(ft)
6.5	3.25	3.25
9.75	3.25	3.25
13	3.25	3.25
6.5	3.25	1.67
9.75	3.25	1.67
13	3.25	1.67

Figure 3. Detail of Typical Gabion Basket Sizes

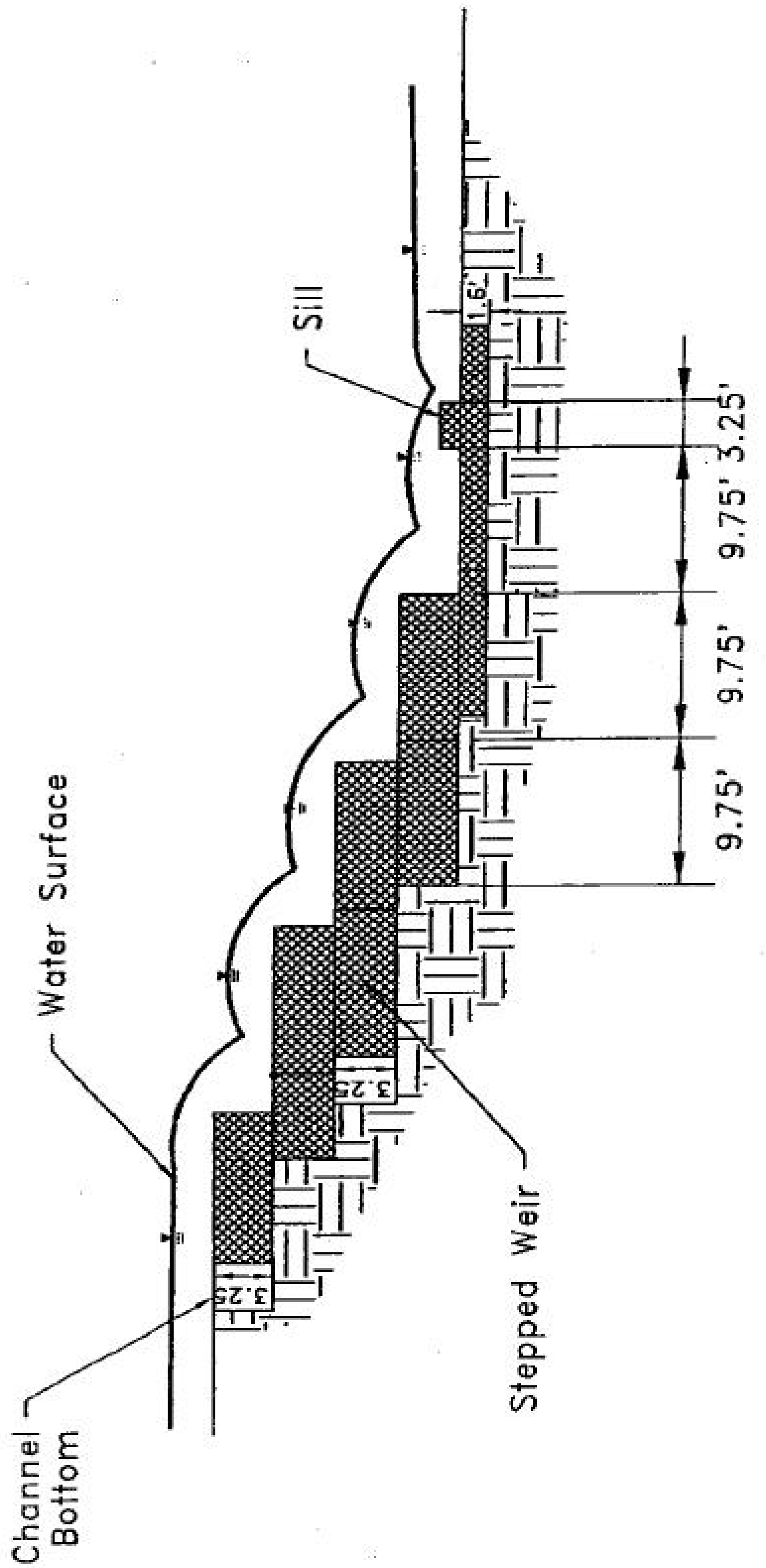


Figure 4. Typical Profile for Rock Gabion Drop Structure

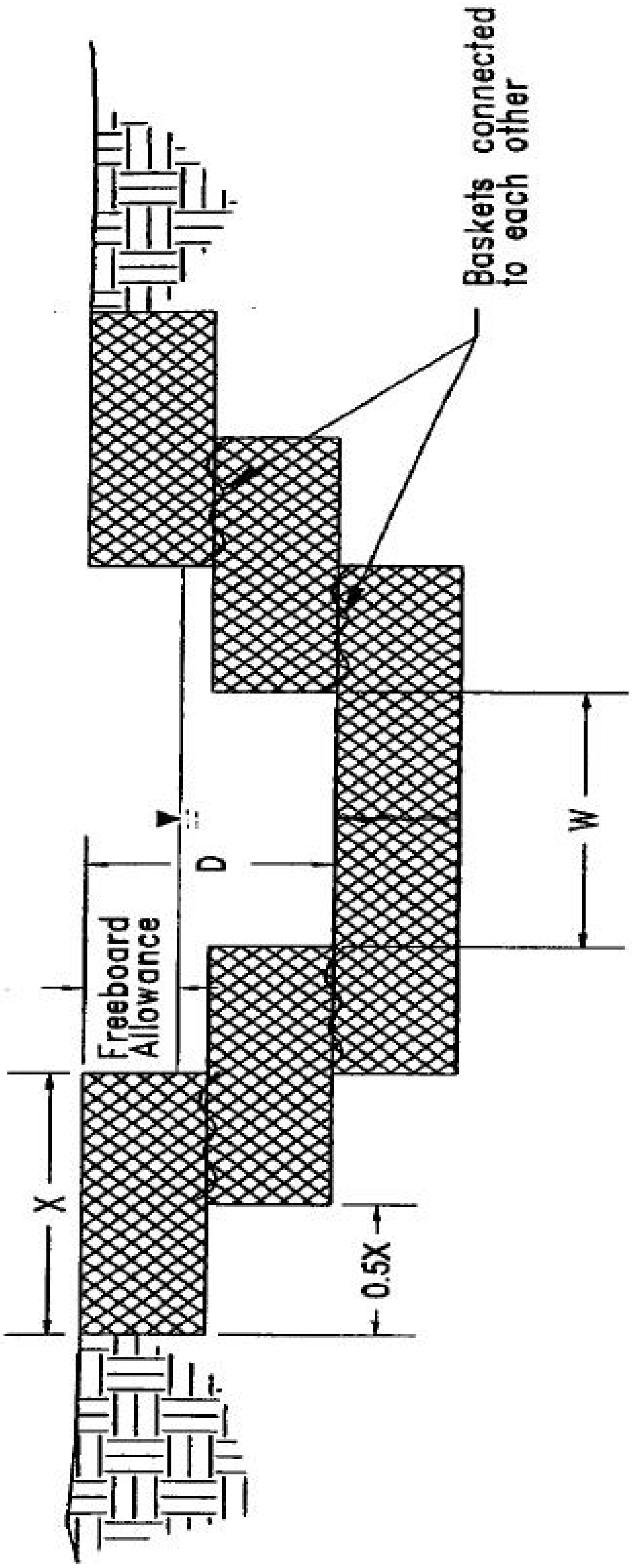


Figure 5. Typical Cross Section for Rock Gabion Drop Structure

Design criteria for the gabion structures is typically based on channel velocity, depth of flow, or the gabion's ability to withstand the force of the flowing water. Specific gabion manufacturers should be contacted regarding design criteria for each basket size. The allowable flow velocity and shear stresses are based on the basket thickness, rock size, and rock specific gravity. For example, and according to manufacturer's recommendations, a basket with a thickness of 1.6 feet, filled with rock with a D_{50}=7.5 inches and specific gravity of 2.5, should remain stable for flow velocities less than or equal to 10 feet per second.

One of the advantages of gabions in drop structure design is the ability to use "on-site" rock for the construction of the structure. However, the rock used to fill the basket should still meet the following criteria: (1) diameter of 5-10 inches; and (2) be durable and free of any structural defects. The designer should be aware that certain rock types, like "clinker" or "scoria", have relatively low specific gravity and poor durability. When utilizing sub-standard rock, structure design (basket size and rock diameter) and placement of the individual baskets should address the limitations of the rock. If low specific gravity rock is utilized, a larger basket thickness and/or larger individual diameter rock will be required to achieve the same level of protection at the individual structure.

For typical applications, the authors have found that galvanized coated gabion baskets meet most design requirements at a lesser cost. If the structure is placed on corrosive soils or exposed to caustic waters or acid drainage, use of polyethylene coated basket wire will extend the design life of the basket at an increased cost. High Density Polyethylene (HDPE) baskets are also available at an even greater cost. HDPE baskets have higher puncture resistance, longer durability, and are easier to transport and assemble. The increased unit cost must be weighed against design intent, transportation costs, and labor factors.

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(3) Rock Riprap Sizing

There are numerous sources and procedures available for determining the rock size requirements for a drop structure. Listed below are three sources that present different procedures for sizing rock riprap:

"Design Manual for Water Diversions on Surface Mine Operations", Prepared for the Office of Surface Mining, Fort Collins, CO. (Simons Li & Associates, Inc., 1982). This publication presents sizing criteria based on a design flowrate and the channel geometry.

"Rock Riprap Design for Protection of Stream Channels near Highway Structures, Volume II Evaluation of Riprap Design Procedures". (Blodget & McConaughy, 1986) This publication presents numerous design procedures for sizing rock riprap developed by the Army Corps of Engineers, Federal Highway Administration, State Department of Transportation and the Bureau of Reclamation (USBR).

"Hydraulic Design of Stilling Basins and Energy Dissipators". (Peterka, 1958) This publication presents an analysis of existing USBR instal-lations and includes a design nomograph, which sizes riprap based on bottom velocity versus weight of rock.

When reviewing a procedure to size rock riprap for a drop structure, the designer will need to ensure that the procedure is valid for the intended application. For example, if the design procedure was developed for rock placed on channel banks, it may not be applicable for sizing the rock riprap placed on the chute section of a drop structure. Some design procedures assume a specific gravity of 2.65 for all rock. Many otherwise suitable rock types, including limestone and leucite, have lower specific gravities. In these cases the rock may be "up-sized" to account for its lower unit weight.

NOTES

4. Backfill Impoundments

Section editor: Frank K. Ferris Subsection author: Frank K. Ferris/Patrick T. Tyrrell

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Situation:

Water structures are needed on a mine site for water treatment and storage. Impoundments created in backfill voids are usually more cost effective than impoundments on unmined areas.

Special Considerations:

Uncompacted backfill slopes may not be stable enough to support equipment if the slopes become saturated.

Description of Technique:

a. Design Considerations

Incised backfill impoundments are created by leaving a void area in the backfill and grading the slopes. Though simple, the following basic design features need to be considered: *size, shape, cells, inlet structures, Mine Safety and Health Administration (MSHA) criteria, stability, location, function,* and *construction*. The function of a reservoir will determine the extent that the design incorporates features for water treatment (shallows, cells, flat slopes, length approximately four times width) or water storage (deeper, steeper sides, length to width ratio variable).

In general, reservoirs should be designed with water treatment in mind, as good water quality is important for any function, and the incremental cost of a treatment reservoir is low compared to reworking or repairing any features of an inexpensive water storage reservoir. Backfill impoundments primarily intended to store water can be deeper, with shape dictated more by available topography, and with a reduced high-water line area to minimize evaporation.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

1) Size

The structure must be large enough to handle the design runoff event plus any pit or process water, and may include additional capacity for dust control or to provide a convenient location to hold excess runoff and minimize offsite discharges. Backfill impoundments with at least 100 acre-feet of water storage are commonplace for large surface mines. This large capacity provides flexibility in pumping and holding large volumes of water in the structure until a discharge is convenient or can be avoided. A larger size reservoir is more conducive to treatment and recycling of water from washing operations. Such a reservoir provides the treatment and storage capacity for dry periods when other sources of water become less reliable.

(2) Shape

If water treatment is the primary purpose of the reservoir, it will be the most effective in a long, shallow (two to three feet deep) reservoir with the inlets as far as possible from the water discharge location. This assures the shortest distances for sediment to drop to the bottom, and limits short circuiting (inflow water travelling directly to the pond outlet). As a guide, a backfill reservoir intended primarily for water treatment should average 5 to 30 feet deep, 200 to 500 feet wide, and 500 to 4000 feet in length, depending on the volume to be treated. Side slopes should be 3H:1V to 4H:1V to accommodate access by people and wildlife (see Figure 1). Angle of repose slopes 1.5H:1V that become saturated will likely fail. **Mobile heavy equipment should be kept off the saturated, uncompacted slopes characteristic of this type of impoundment.**

(3) Cells

Cells should be strongly considered to control any oil spill that might enter the reservoir, limit wave fetch, and eliminate short circuiting caused by temperature inversions (i.e. warm plant water). The connections between cells typically would be culverts installed below the water surface.

All cells should be designed to be at the same elevation regardless of the reservoir volume. Because the base and sides of the reservoir and the dividing embankment are not compacted, cells with differing water levels will likely have piping or seepage from cell to cell. As the soil settles, failure between cells is likely.

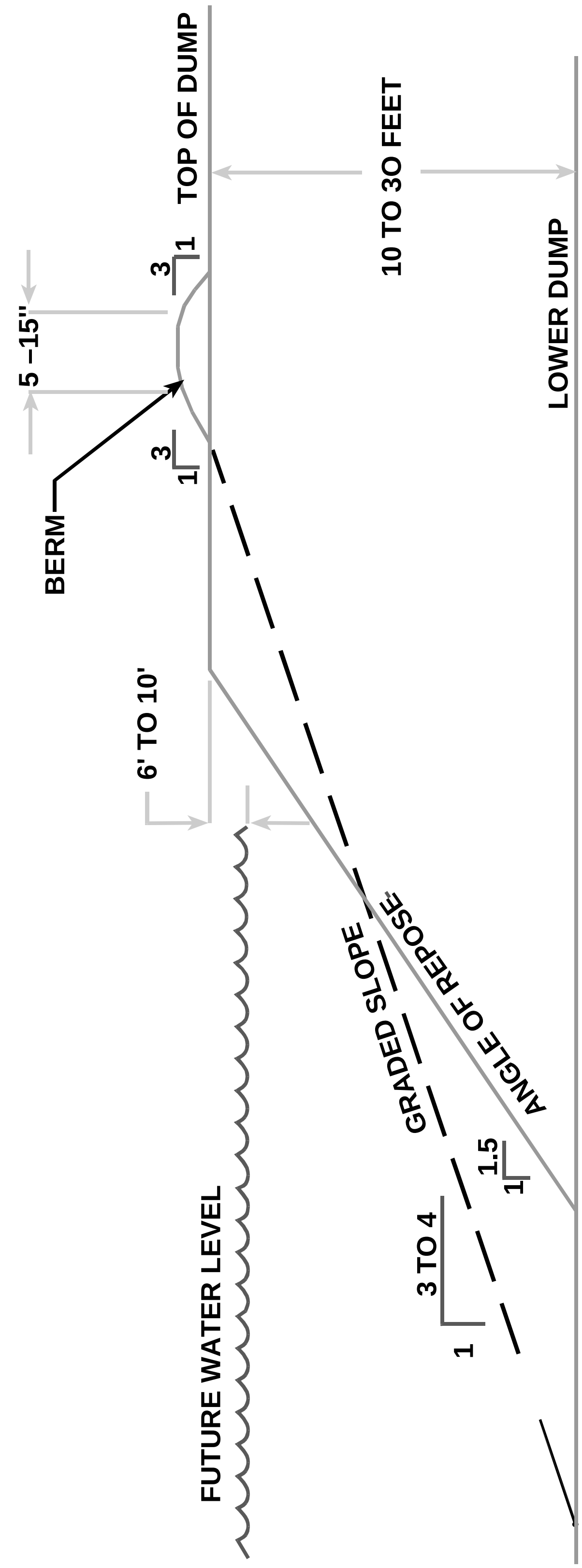

FIGURE 1
NO SCALE

Impoundments constructed primarily for water storage reservoirs do not necessarily need a dividing embankment.

(4) Inlet Structure

Inlet structures must be considered for any reservoir that is expected to function more than one year. Surface or pipeline water that is released above the high-water line and washes down an unprotected slope will cause significant erosion in one season, and much quicker if there is a continuous water flow. The washing of slope soil into the reservoir bottom will quickly fill the lower reservoir volume up to, or possibly clog, a connecting culvert or pump culvert, and will compromise the already marginal stability of the uncompacted slope. One option is a culvert to deliver inflow below the water surface. If the pipeline inlet is on the reservoir floor, it will generally stir up sediment and decrease the reservoir's water treatment effectiveness. Using the same culvert for inflow and outflow can be done, but should only be considered if the quality of the source water is very clean. Pumping sediment laden water into the pump culvert will cause pump problems. See Figures 2, 3, and 4.

(5) MSHA

Generally, MSHA has jurisdiction over any water structure that stores 20 acre-feet or more of water or slurry behind an embankment that is five feet or higher, as measured from the upstream toe to the emergency spillway, or has an embankment that is 20 feet or higher. A 100 acre-feet or larger reservoir normally falls within this criteria.

An incised backfill reservoir does not have a compacted embankment storing water above the surrounding ground level. This generally eliminates such impoundments from MSHA jurisdiction. MSHA and the mines have used the following rule of thumb to qualify the reservoir as incised: backfill 200 to 300 feet wide between the reservoir and the pit, and higher than the reservoir. In 1993, MSHA qualified this by stating that for a structure to be incised and not require design approval, the minimum backfill slope from the high-water line to the pit floor had to be at least 10H:1V.

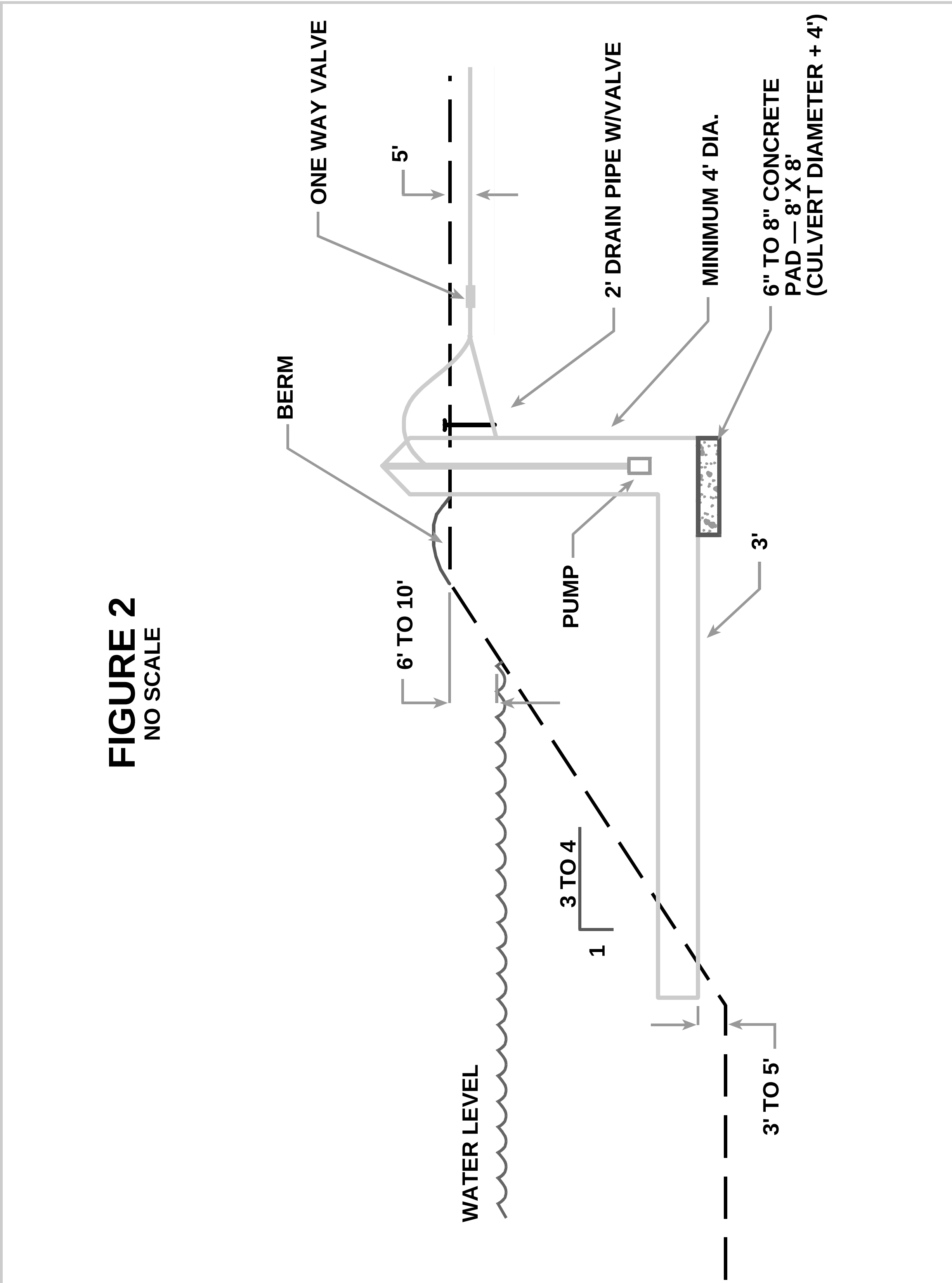

FIGURE 2
NO SCALE

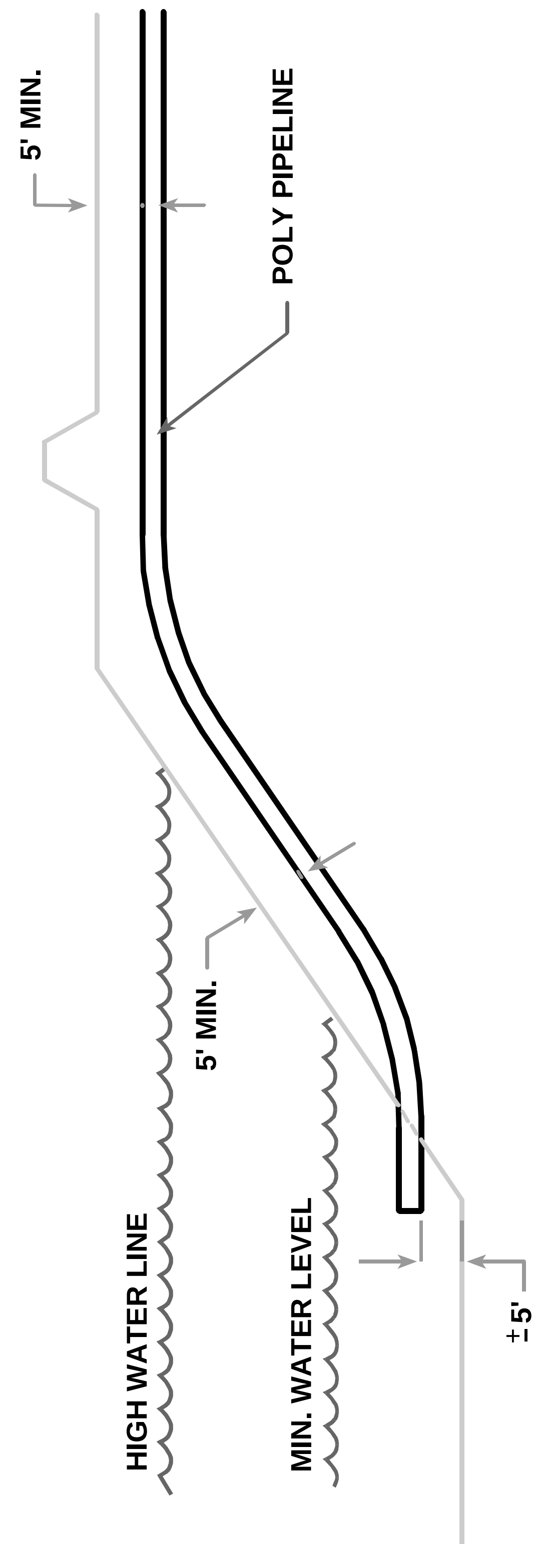

FIGURE 3

NO SCALE

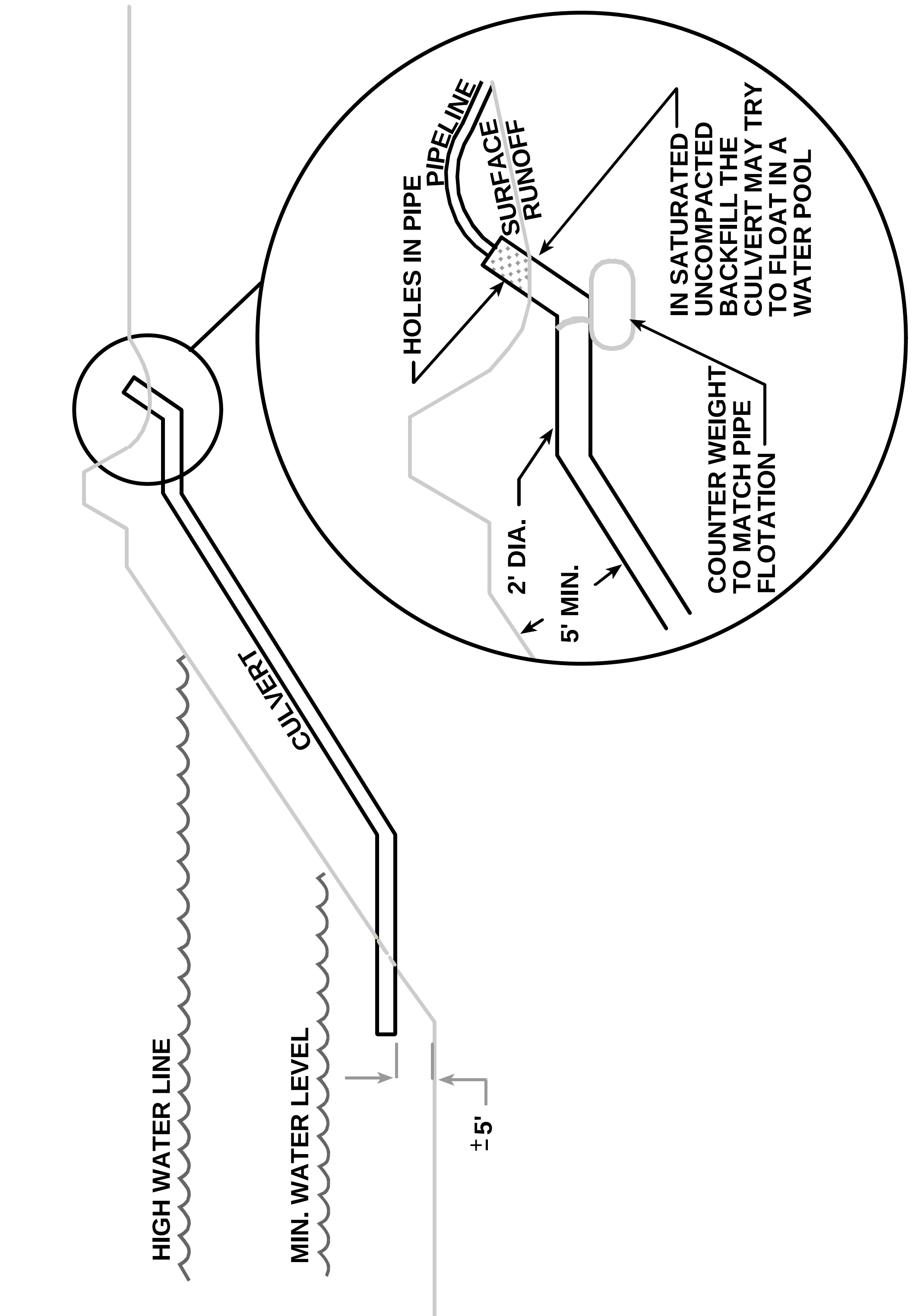

FIGURE 4
NO SCALE

(6) Stability

Uncompacted, saturated backfill is usually unstable when used to contain water or support weight. When used with very flat slopes such as MSHA suggests (10H:1V), stability should not be an issue.

The reservoir site must be conducive to water retention. This means the side slopes and reservoir bottom must be soils that exhibit low permeabilities. Zones of sand or waste coal in or in close proximity to the base or side are likely to cause significant water loss through seepage. A very porous soil backfilled to the reservoir may generate a seep on a backfill bench, if one is nearby.

(7) Location

The location should be chosen to maximize life and assure stability. The longer the reservoir is used, the more cost effective it is. Designing an impoundment to be non-MSHA is a major help in timing and cost. Position the reservoir where MSHA jurisdiction is not required, and the saturated backfill does not become a future obstacle to mining.

(8) Function

Multiple functions of *water treatment, water storage* for dust suppression, *wildlife use,* and *postmining land use* should be considered in the given priority.

(a) Water Treatment

Water Treatment for pit, plant, or disturbed area water sources is usually the primary concern. This reservoir is not likely the final treatment, but the initial step to reduce the Total Suspended Solids (TSS).

(b) Water Storage

A second concern is water storage for use during dust control activities, for storage of water awaiting treatment, or for simply providing a holding area to minimize discharges or provide a water source in extended dry periods.

(c) Wildlife

A reservoir can be made to have some wildlife features at a minimal cost (see the subsection entitled "Wetlands"). These features should be included to show compatibility of the mining operation with wildlife.

(d) Postmining Land Use

It is an added bonus if the structure (or part of it) can be made part of the postmining land use. Keep in mind that water sources may deposit coal fines that should be covered before final reclamation. **You may want to design the reservoir to be partly buried by final reclamation to cover unsuitable sediment.**

(9) Construction

The construction cost-saving in this structure is the use of uncompacted fill for water containment. Sides are dumped in and dozed to final slope (see Figure 1). Berms are required by MSHA to prevent a vehicle from entering the impoundment. A spillway needs to be installed to provide six to ten feet of freeboard. Freeboard is from the high-water line when spilling to the top of the containing backfill bench.

Do not consider a compacted embankment on top of uncompacted backfill. Differential settling of the backfill will negate the purpose of the compaction and possibly cause failure of the embankment. For reservoir access, an old haul road ramp is good (if one is present) for skid mounted pumps or other equipment, because the base will remain firm. Compaction (minimum 90 percent standard proctor is suggested) should be performed around dewatering pipe stands.

b. Dewatering

(1) Gravity Discharge

The simplicity of gravity discharge should be considered because no pump is required. The downside is that it may not always provide surge capacity, there may not be a good way to shut the system off, and a pump may be required to load water trucks or recycle water. Also, gravity discharge is often not possible because the reservoir is usually lower than the surrounding area.

(2) Pumps

Installation of two pumps should be considered to maintain reservoir capacity and discharge system reliability. Pumps with durable, slower speed impellers are better because they will last longer. Existing pump stock may dictate the pump to be used. Pumps that are in continuous use for long periods should be electrically driven, if power is available, because of the lower maintenance and cost compared to diesel engine driven pumps.

Figure 2 illustrates a desirable pump evacuation method for longer duration installations. Figure 5 illustrates the float and pump method, which is usually much cheaper for up to three years duration. Access, safety, winter ice, and maintenance make the land-based design much more desirable when it must be used for many years.

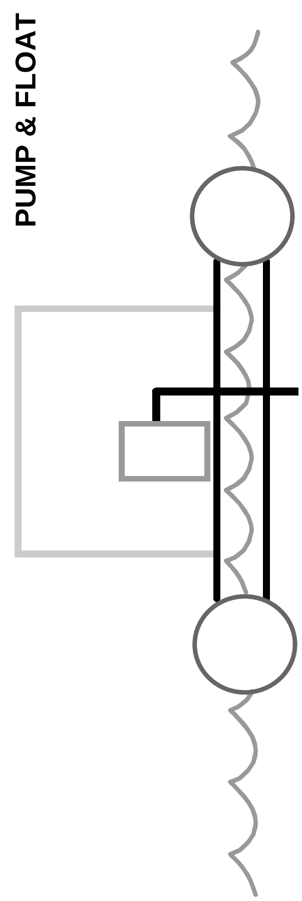

FIGURE 5
NO SCALE

NOTES

C. Alternative Sediment Control
1. Straw or Hay Bale Check Dams

Section editor: Frank K. Ferris Subsection author: Doyl M. Fritz

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Situation:

Use straw or hay bale check dams when temporary sediment or erosion control is needed for one season or less.

Special Considerations:

The channel slope is the most critical aspect, and should be twenty percent or less.

Description of Technique:

a. Definition

Straw or hay bale check dams consist of standard agricultural bales placed end-to-end in rows across a sloping area of land.

b. Function

Straw or hay bale check dams provide a simple, inexpensive method for temporarily controlling sediment by reducing the velocity of runoff and filtering sediment from the runoff.

c. Useful Life

These structures are short-lived and should only be utilized in temporary applications. The useful life of a straw or hay bale check dam is dependent on many factors, but is typically only a few months.
~~~~~~

d. Design Recommendations

(1) Location

Use bale check dams in locations where the bales are not likely to be overtopped by runoff (i.e. small drainage basins with shallow to moderate relief). Do not install bale check dams in areas of highly concentrated flow, such as steep, narrow channels and ditches.

(2) Placement

Place bale check dams along a contour or in shallow swales. Extend both ends of the check dam in an uphill direction so that the elevations of the bottoms of the two end bales are at or above the elevation of the top of the bales that are placed along the contour. Place bale check dams on sloping land in accordance with the following table:

Slope, percent	Maximum slope length above a single bale check dam or between successive bale check dams
2 or less	250
5	100
10	50
15	35
20	25

e. Installation Recommendations

Install straw or hay bale check dams as shown on Figure 1. Do not install straw or hay bale check dams in areas where rock or rocky soil prevents full and uniform depth anchoring of the bale check dam.

(1) Contouring (optional)

If bale check dams are placed in a graded channel, such as a roadside ditch, it is sometimes advisable to place the check dams just downstream from a shallow basin created with the scraper used to build the channel. Such basins provide sediment storage space, reduce maintenance, and also temporarily pond water. This enhances vegetation and provides temporary habitat for certain species of birds and wildlife.

(2) Double Rows (optional)

A second line of bales offset behind the first can also be very effective.

f. Maintenance Recommendations

(1) Inspection

Inspect each bale check dam after every runoff event and at intervals not exceeding one month.

(2) Repair

Reset, stake, and backfill any dislodged bales. Repair all undercutting of the anchor toe with compacted backfill materials.

(3) Sediment Accumulation

Replace bales that have become damaged or clogged with sediment. Remove accumulated sediment as required when uniform accumulations reach one-third the height of the bale check dam.

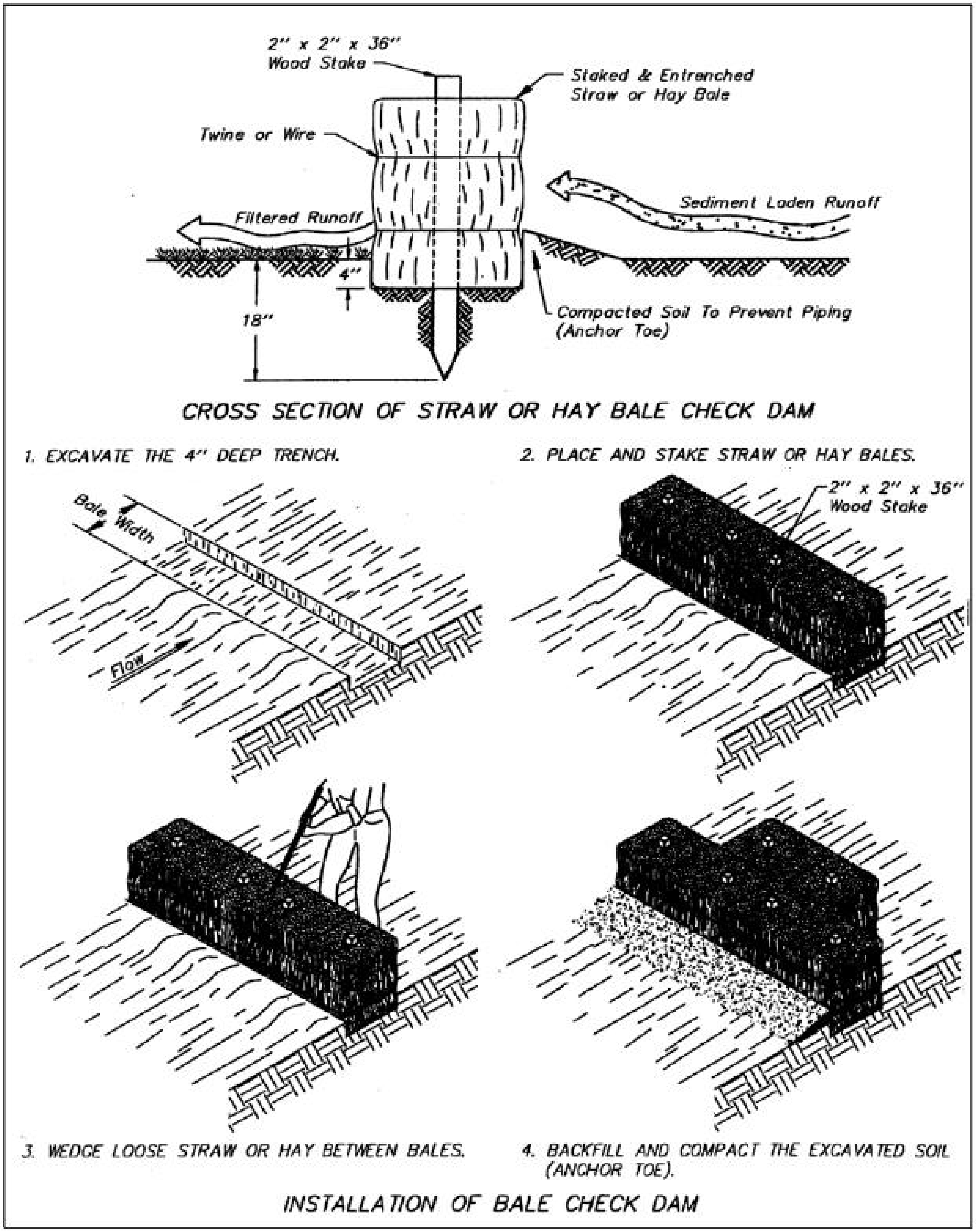

FIGURE 1. STRAW OR HAY BALE CHECK DAM

2. Rock Check Dams

Section editor: Frank K. Ferris | Subsection author: Doyl M. Fritz

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Situation:

Rock check dams should be used in steep, defined drainages when reduction of channelized runoff flow velocity and filtration of sediment from channelized runoff is required for one year or more.

Special Considerations:

Failure to control the flow velocity of channelized runoff on disturbed or newly reclaimed land can result in significant head-cutting in channels. Rock check dams may be used where flow is channelized and flow velocity is too high for the use of other stabilization and sediment control methods, such as straw or hay bale check dams or sediment fence. In addition, they may be used when the duration of stabilization is needed for more than one season/event.

Description of Technique:

a. Definition

A rock check dam is a low, porous, loose-rock embankment that is intended to slow the velocity of channel flow but not to impound water.

b. Function

Rock check dams control the flow velocity of channelized runoff and filter some sediment from the runoff, thereby reducing erosion and transported sediment. They are usually constructed in steep terrain and are most appropriate in narrow channels and ditches.

c. Useful Life

Indefinite.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

d. Design and Construction Recommendations

Design and construct rock check dams as shown on Figure 1.

(1) Placement

Place rock check dams across a swale, ditch, or channel, perpendicular to the direction of flow. Space rock check dams in series along a channel, as required, or in accordance with the following equation:

$$D = \frac{H}{0.5S}$$

D = distance between successive rock check dams, in feet,
H = height of rock check dam, in feet, and
S = slope of channel, in feet-per-feet.

(2) Materials

Install toed-in woven filter fabric before placing rock check dams for those structures intended to remain in place for an appreciable length of time.

Construct rock check dams with check dam rock alone if the sole purpose of the dam is channel stabilization. Construct rock check dams with both check dam rock and filter rock if increased check dam sediment removal capability is desired.

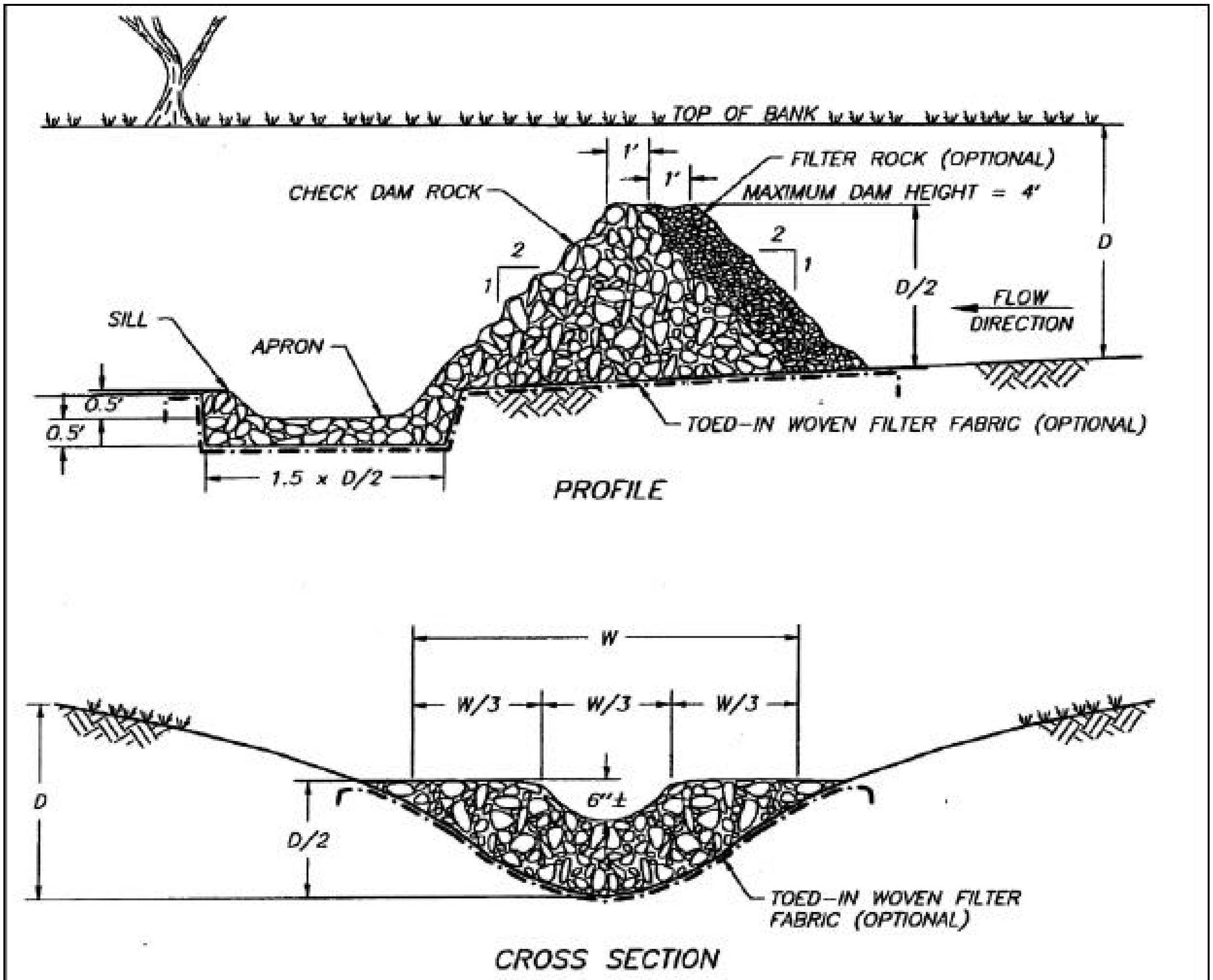
e. Maintenance Recommendations

(1) Sediment Accumulation

Remove accumulated sediment from immediately upstream of a rock check dam at or before the time when the depth of sediment reaches one-half the height of the check dam. Remove and replace rock check dams if they become completely clogged with sediment.

(2) Removal

Rock check dams may be removed or left in place if they have successfully served their purpose. In grass-lined ditches or swales, rock check dams may be left in place when the grass has matured sufficiently to protect the ditch or swale from erosion. If it is desirable to remove the check dams, the areas exposed by removal of rock check dams should be immediately seeded and mulched.



APPROXIMATE ROCK GRADATIONS
FOR CHECK DAMS

CHECK DAM ROCK

D_{max} = 12"
D_{50} = 6"
D_{min} = 3"

FILTER ROCK

SIZE	% PASSING
1"	100
3/4"	90–100
3/8"	20–55
#4	0–15

NOTE: SCORIA IS ACCEPTABLE CHECK DAM OR FILTER ROCK.

FIGURE 1. ROCK CHECK DAM

3. Sediment Fence

Section editor: Frank K. Ferris Subsection authors: Doyl M. Fritz/John D. Berry

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Situation:

Sediment fence should be used when sediment control is needed for one year or more.

Special Considerations:

Sediment fence may be installed as an alternative to straw or hay bale check dams. Sediment fence may have a longer useful life than straw or hay bale check dams.

Description of Technique:

a. Definition

A sediment fence is a low geotextile fabric fence placed across a sloping area of land.

b. Function

Sediment fences control the flow velocity of overland runoff and filter sediment from runoff without impounding water, thereby reducing erosion. The sediment removal efficiency of sediment fence is typically high but varies depending on sediment particle sizes and the quality of sediment fence installation and maintenance. Like straw or hay bale check dams, sediment fences may be placed in series to increase sediment trapping efficiency.

c. Useful Life

The useful life of sediment fence may be indefinite, depending on flow magnitude and the rates of sediment accumulation and fabric degradation due to weathering. Frequent maintenance may be required to maintain the integrity of sediment fence that is left in place during numerous major runoff events.
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d. Types of Sediment Fence

Sediment fence is produced by most major geotextile manufacturers. It may be purchased as prefabricated fence with preassembled posts, as fence fabric with regularly-spaced pockets into which the purchaser places posts, or as fabric with a reinforced top edge and no pockets for posts. Sediment fence fabric is available in varying widths (i.e. fence heights), typically ranging from 2 to 3.5 feet.

e. Design Recommendations

(1) Support Structures

Support structures should be sturdy enough to withstand a considerable amount of hydrostatic and sediment load pressure, particularly before vegetation has become established. The fabric must be backed with support of some kind to keep the water and sediment from pushing the bottom of the fabric out, causing a failure underneath the fabric. Steel posts and wooden snow fence make an excellent support structure. The steel posts can be placed in the bottom of a trench cut with a motor grader and the snow fence is then wired to the posts with the bottom of the snow fence in the trench. Bracing should be added to the back of the support structure to ensure it will not be pushed over by water, sediment accumulation, or wind. Bracing can be accomplished by using steel posts placed at an angle behind every other upright post. It is helpful to use a cutting torch to cut small notches in the uprights to accept the angled braces. The braces should be pounded into the ground a minimal amount to keep them from sliding and should be wired to the upright posts at the top.

(2) Fabric Quality

The sediment fabric should be high quality and UV resistant. The additional cost of quality material will be more than made up for by additional labor required to replace fabric that has deteriorated before sediment control release has been obtained. The bottom of the fabric panel should be extended out from the support structure in the trench at least one foot. The fabric can be wired directly to the snow fence at five foot intervals or lathe can be wired to the side of the fabric opposite the snow fence. The lathe keeps the wire from pulling through the fabric, which can happen in areas prone to wind. The flap of fabric in the trench is covered with soil once the structure is completed, to ensure water and sediment do not run under the fence. This can be accomplished by using the motor grader to gently push the material removed from the trench back over the fabric and refill the trench.

(3) Installation

Place sediment fence along a contour. Extend both ends of the sediment fence in an uphill direction, so that the elevations of the bottoms of both ends of the fence are at or above the elevation of the top of the fence that is along the contour. Sediment fences installed in areas of concentrated flow, including channels, ditches, and swales, should have small drainage areas.

(4) Design Parameters

Place sediment fence on sloping land in accordance with the following table:

Slope, percent	Maximum slope length above 12 to 18 inch high sediment fence	Maximum slope length above 24 to 30 inch high sediment fence
2 or less	250	500
5	100	250
10	50	150
15	35	100
20	25	70
25	20	55
30	15	45
35	15	40
40	15	35
45	10	30
50	10	25

f. Installation Recommendations

Install sediment fences as shown on Figure 1. Do not construct sediment fences in areas where rock or rocky soil prevents the full and uniform anchoring of the fence toe.

Where the ends of sediment fence fabric come together, overlap, fold, and staple the two overlapping ends.

g. Maintenance Recommendations

(1) Inspection

Inspect sediment fence and repair as required after every significant runoff event.

(2) Sediment Accumulation

Remove accumulated sediment at or before the time when the depth of accumulated sediment reaches one-half the height of the sediment fence.

(3) Repair

Immediately repair with compacted backfill all undercutting or erosion of the sediment fence toe anchor. Replace sediment fence that is degraded by weathering in accordance with the manufacturer's recommendations.

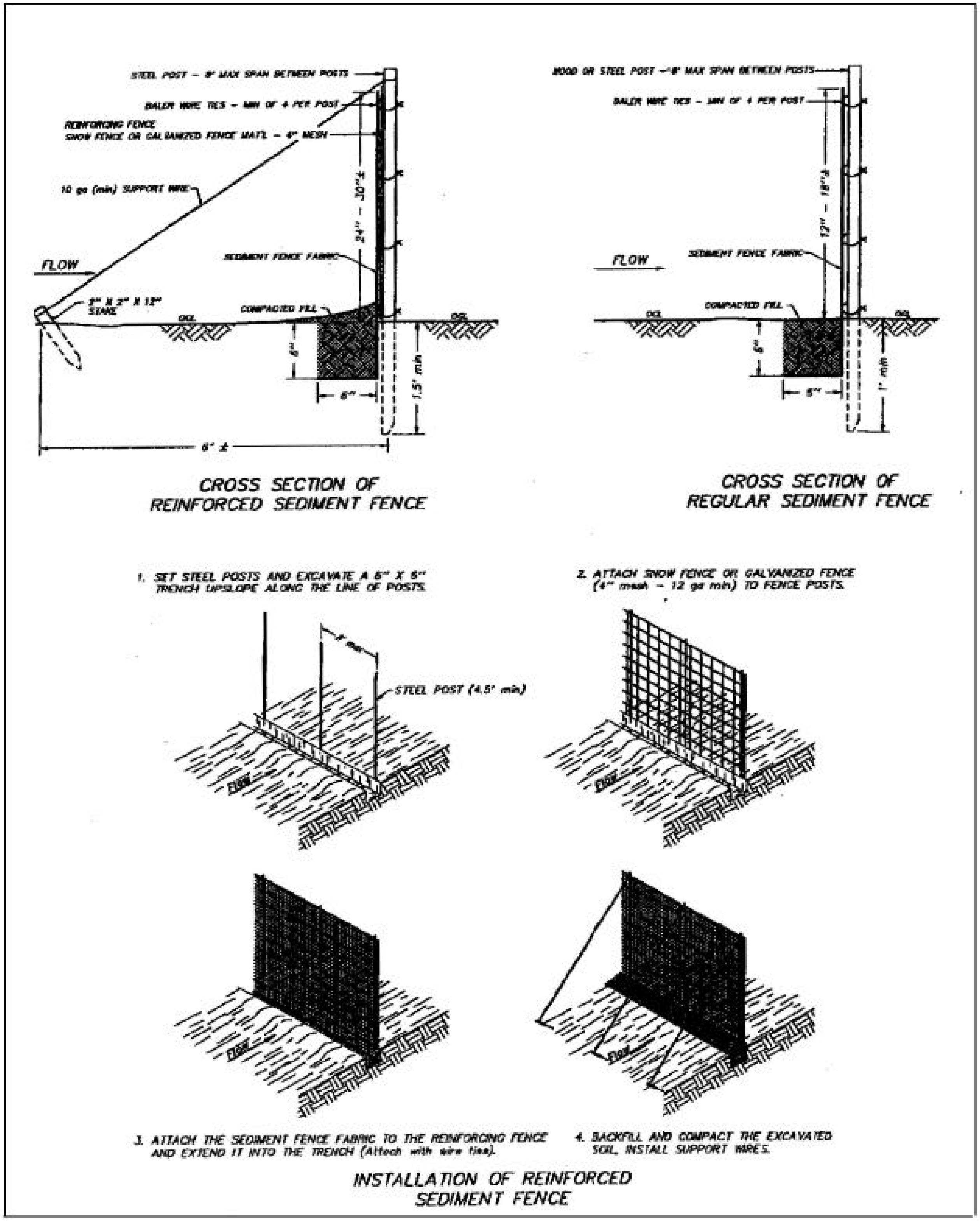

FIGURE 1. SEDIMENT FENCE

NOTES

4. Gabion Baskets

Section editor: Frank K. Ferris Subsection author: Doyl M. Fritz

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Situation:

In high velocity, high volume, or long duration circumstances, gabion baskets should be considered. Reduction of flow velocity or protection from erosion due to high flow velocity in channels is sometimes required during mining and reclamation. Gabion baskets may be used to construct check dams, drop structures, or pipe outlet aprons which are capable of withstanding and/or reducing relatively high-velocity flow.

Gabion basket structures are relatively simple to install and are generally more durable than comparable loose-rock structures. They allow the use of much smaller rock than could be used under similar flow conditions without the wire baskets. They also offer an advantage over rigid concrete structures because they are flexible and can conform to changes in subgrade conditions caused by erosion and settlement.

Special Considerations:

Generally, baskets with a thickness of less than one foot should be avoided. Fabric under the basket and sufficient rock gradation within the basket are necessary to assure minimum flow velocities against the soil under the basket. Otherwise, erosion may undercut the baskets.

Description of Technique:

a. Definition

The term "gabion basket" as used herein applies both to Reno mattresses, which are from 6 to 12 inches thick, and to gabion baskets, which are typically 18 inches or more thick. Both Reno mattresses and gabion baskets are rectangular, rock-filled, wire-mesh boxes that are purchased disassembled and are assembled, filled with rock, and staked in place at the construction site.
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b. Function

Figures 1 through 3 provide examples of gabion structures. Gabion baskets are used to construct check dams, drop structures, and pipe outlet aprons that are intended to withstand and/or reduce relatively high flow velocities. Construction of gabion basket structures is relatively simple and requires no special construction skills. Gabions can also be used to line temporary diversion channels where flow velocities exceed 5 feet-per-second (e.g., see cross section C-C' on Figure 2 and cross section A-A' on Figure 3).

c. Useful Life

Indefinite. The useful life of a gabion basket structure is usually longer than that of a comparable loose-rock structure, and they may outlast rigid concrete structures in some applications. Their durability is dependent on the quality of the rock and wire used in construction. The use of durable rock and heavy gage, corrosion resistant baskets will provide the longest useful life.

d. Design and Construction Recommendations

Design and construct gabion basket structures as shown on Figures 1 through 3.

(1) Design Parameters

Gabion basket structures should be designed in accordance with the parameters recommended in the following table:

Type	Manning's "n"	Thickness (inches)	Rock fill gradation (inches)	Permissible flow velocity (feet/second)
Reno mattress	0.025	6	3 - 6	13.5
Reno mattress	0.025	9	3 - 6	16.0
Reno mattress	0.025	12	4 - 6	18.0
Gabion	0.027	18 +	5 - 9	22.0

(2) Materials

Durable rock such as limestone or granite should be used to fill gabion basket structures that are intended to remain in place for extended periods of time. Scoria rock may be used in temporary gabion basket structures, but longevity and permissible flow velocities may be reduced by use of the less durable scoria rock. One or two layers of woven filter fabric may be used to protect underlying soils. Two layers of fabric will provide additional protection in case the top layer is punctured or torn during installation.

e. Maintenance Recommendations

(1) Sediment Accumulation

Remove accumulated sediment from immediately upstream of a gabion basket check dam, at or before the time when the depth of sediment reaches one-half the height of the check dam.

(2) Repair

Repair broken wire baskets and replace lost or displaced rock as necessary.

(3) Removal

Remove temporary gabion basket structures when their useful lives are completed. In grass-lined ditches or swales, gabion basket check dams may be removed when the grass has matured sufficiently to protect the ditch or swale from erosion. Immediately seed and mulch areas exposed by removal of gabion basket structures.

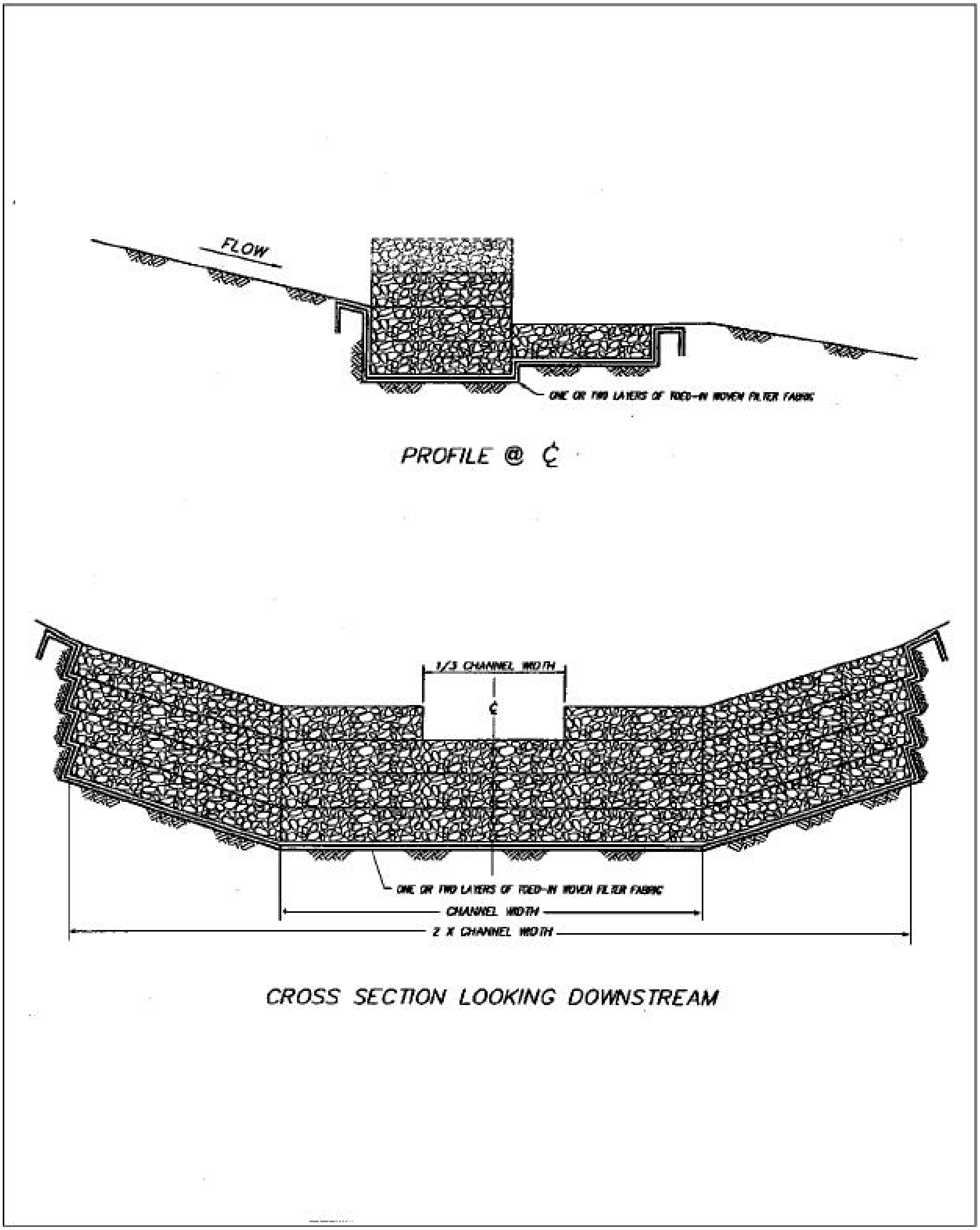

FIGURE 1. GABION BASKET CHECK DAM

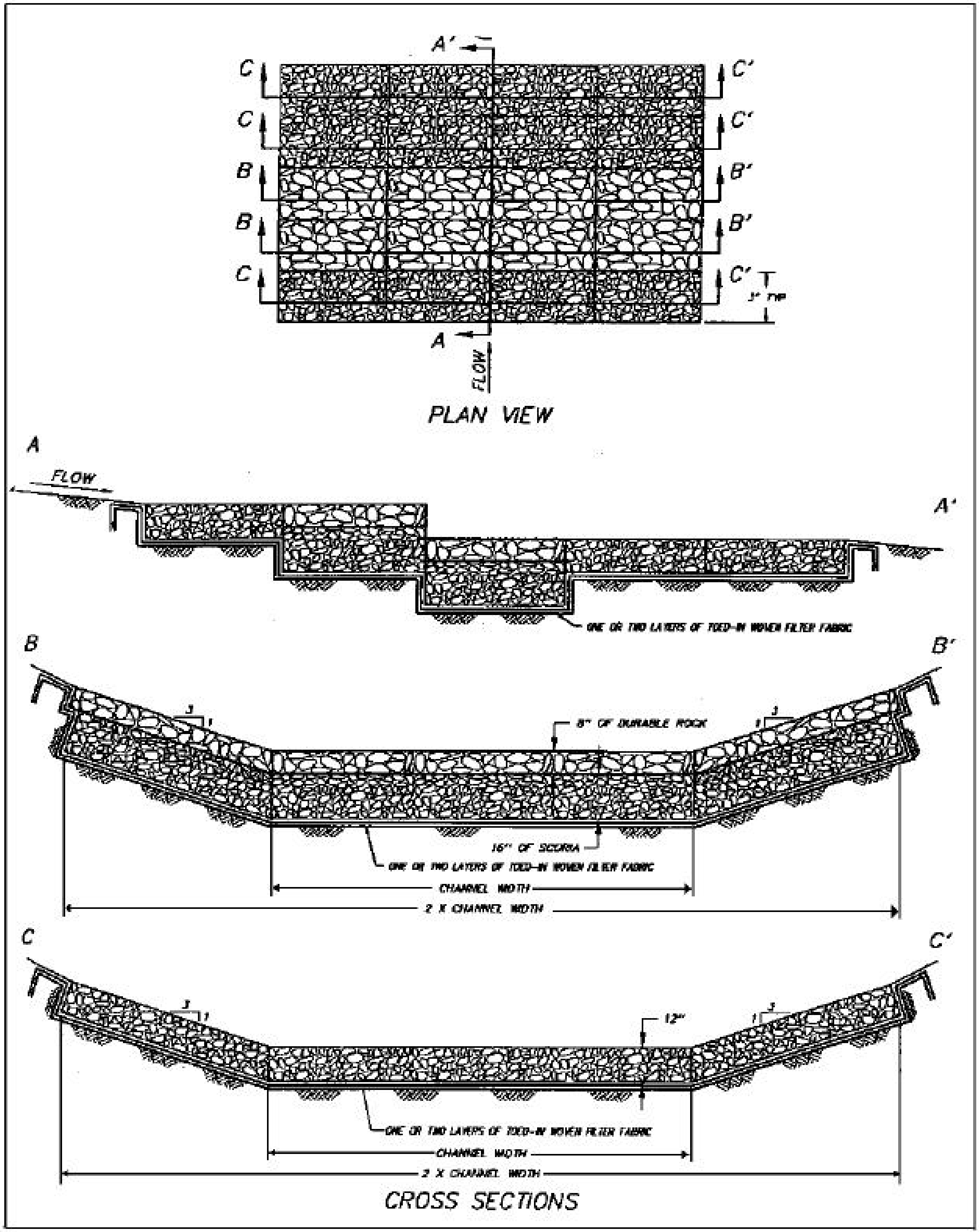

FIGURE 2. GABION BASKET DROP STRUCTURE

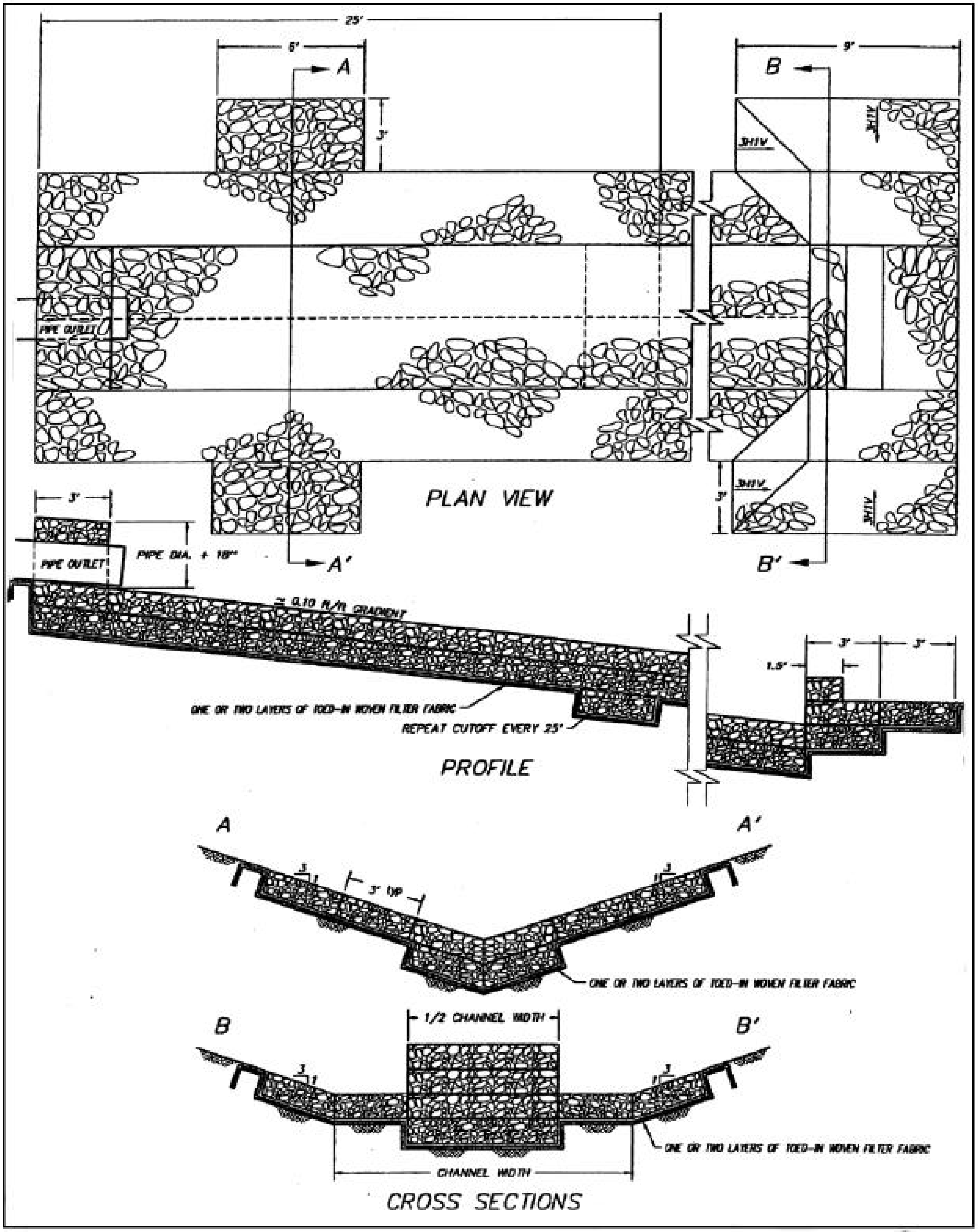

FIGURE 3. GABION BASKET PIPE OUTLET APRON

5. Vegetative Filters

Section editor: Frank K. Ferris Subsection author: Richard C. Warner

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Situation:

Vegetative filters have been investigated as a sediment control mechanism for protection of streams. They have been predominantly used as riparian buffer strips in agriculture (Dillaha et al., 1989, Parsons et al., 1991) and have been analyzed, in experimental settings, for a surface mine (Barfield and Albrecht, 1982), and a construction site (Hayes and Harrison, 1983). Reported sediment trap efficiencies for these experiments range from 70 to greater than 90 percent. Grass filters have been designed to achieve these high efficiencies only when overland flow has been established and directed towards the filter.

Special Considerations:

For grass filters to function at high efficiencies, runoff entering the filter must be maintained as overland flow. Dillaha (1989) concluded that the effectiveness of vegetative filter strips in removing sediment and nutrients from cropland runoff were relatively ineffective due to concentrated flows entering the filters. Sediment-laden waters approaching a vegetative filter are slowed through backwater effects and deposition occurs up-gradient of the filter and in the upper portions of the filter. Dillaha found that after deposition occurred, later runoff events would be transported along the previously deposited sediment barrier until a low spot was reached and then pass as concentrated flow through the filter, thus significantly reducing the effectiveness of the filter. Also, natural depressions in the landscape further exacerbated the problem of developing concentrated flows. For vegetative filters to function properly, overland flow must be established and maintained.

Description of Technique:

Hayes and Dillaha (1991), developed procedures for the design of vegetative filters. Coarser particles are deposited by settling in the reduced velocity created in the up-gradient portion of the filter, whereas finer particles are removed through infiltration at the lower portion of the filter. From this basic knowledge, primary design parameters can be determined. Overland flow must exist.
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Thus grass density should be high and the selected grass must be able to resist flow without bending to the ground. The drainage area generating runoff must be relatively small and situated such that overland flow proceeds to the filter without concentrating. The filter length should accommodate deposited sediment and be sufficiently long to enable time for infiltration of runoff. The selected soils should have a relatively high infiltration rate if the smaller size fraction of sediment is required to be captured.

For mining applications design considerations seem to restrict the use of grass filters to ideal conditions. How can these restrictions be relaxed? If only settleable solid trapping is needed, the length of the filter can be significantly reduced. Dillaha used vegetative filters in the range of 15 to 30 feet. Overland flow must be established and maintained. This is difficult in a natural setting because of the tendency to deposit sediment up-gradient of a filter. It is my recommendation to use vegetative filters in conjunction with a sediment filter fence. The silt fence accomplishes these functions: (1) changing concentrated flow to overland flow as discharge is contained behind the silt fence and subsequently transported through the filter, (2) a large portion of coarser particles are settled behind the sediment fence thereby reducing the need for storage capacity within the vegetative filter, (3) discharge through the silt fence will be low and relatively uniform which enables infiltration, and associated capturing of the finer sediments to be accomplished, and (4) maintenance, i.e. sediment removal, is easily conducted. Thus, the vegetative filter functions as a secondary treatment system which will further reduce effluent concentration entering the fluvial system.

Ideal application areas are along lateral developments such as haul roads, railways, etc., where directing runoff to sediment basins may be economically infeasible. The SEDCAD+ program has a vegetative filter predictive algorithm which will assist in determining the sediment trap efficiency and reduction in flow as a function of filter input parameters for a design storm event.

D. Reconstruction of Hydrologic Features
1. Small Drainage Waterway Construction

Section editor: Frank K. Ferris Subsection authors: Frank K. Ferris/Christopher D. Lidstone/C. Marty Jones

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Situation:

Concentrated flow from small drainage areas usually causes the most erosional problems because a waterway of some type has not been provided.

Special Considerations:

When runoff is generated from a small area as unconcentrated flow and is routed over a steep area, the flow coalesces and becomes concentrated flow. The erosive energy of this concentrated flow increases as additional water is added to the system or as it gains energy traversing the steeper slope. Rills, gullies, and headcuts are formed, where no designed channel existed. Anticipating where the flow will coalesce into concentrated flow and "cutting a waterway" will eliminate or reduce rill and gully erosion.

Contributing drainage basin area is an important consideration in small drainage waterway construction. A rule of thumb may suggest that a small drainage will form for every three to seven acres of contributing basin area. However, there are many variables which affect the development of lower order drainages, including: contributing basin area; basin slope; length of overland flow; slope aspect; and soil or parent material. Many operators collect adequate baseline geomorphic data to assist in prediction of where a small waterway will form. A standard geomorphology text will assist the operator in the selection, measurement, and analysis of relevant morphometric parameters. Specifically, drainage density (total channel length divided by basin area), frequency of first order channels (total number of first order channels divided by the basin area), and the constant of channel maintenance (number of acres of contributing basin area to establish a first order channel) are important parameters.
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Description of Technique:

a. The two aspects of waterway design that need to be considered are the channel water and the inflow from adjacent areas. A flat bottom channel (10 to 12 feet wide) with gentle side slopes reduces flow depth, decreases water concentration, and increases the wetted perimeter. These factors help reduce water velocity which helps control erosion. The channel provides enough water concentration to help sod formation.

Reclamation grading needs to occur with a focus on the water flow from the reclaimed surface. Waterways need to be constructed to the main channel. The waterway grade should continue to get flatter along its route to the design channel. There are three general types of areas that should have waterways:

(1) Flat to Gently Sloped Fields

Large fields usually have an area where water ponds, or during large runoff events, ponds and flows in some direction. On reclaimed land where differential settling will occur, it is best to create a waterway to a designed channel. This prevents head cuts where water exits the field and enters the channel. A waterway should start near the low point of a field and go to the design channel. This is illustrated on Figures 1 and 2.

(2) Long, Moderate Slopes

Long, moderate to steep slopes should be broken by shallow ridges and waterways. Because long slopes of expected sheet flow form concentrated flow and gullies, the length of slope and drainage area should be limited to five acres or less. The drainage area is the most critical factor to determine channel stability. Use waterways and ridges in conjunction with other micro-topography features to break a slope and concentrate the runoff in areas where sod will form and stabilize a waterway. Figure 3 shows this in plan view and cross section.

(3) Backfill Dumps

Large, wide, elevated dumps will require establishing an interior drainage to an access ramp for a shallow gradient waterway off the top of the elevated backfill dump. Otherwise, direct flow over the exterior slopes will cause extensive erosion.

If there is a choice, the channel gradient should be almost flat to promote infiltration. Establishing a small playa may also be an option.

The ramp gradient is usually too steep for non-erosive flow. Extensive grading, or routing the channel onto a bench that is 10 to 20 feet lower, is usually needed to get an acceptable channel gradient. Figure 4 shows the interior drainage route from a large elevated backfill dump. Figure 5 shows how one can transform the top surface of a dump, using loose dumps and grade control, into an interior drainage system.

FIGURE1

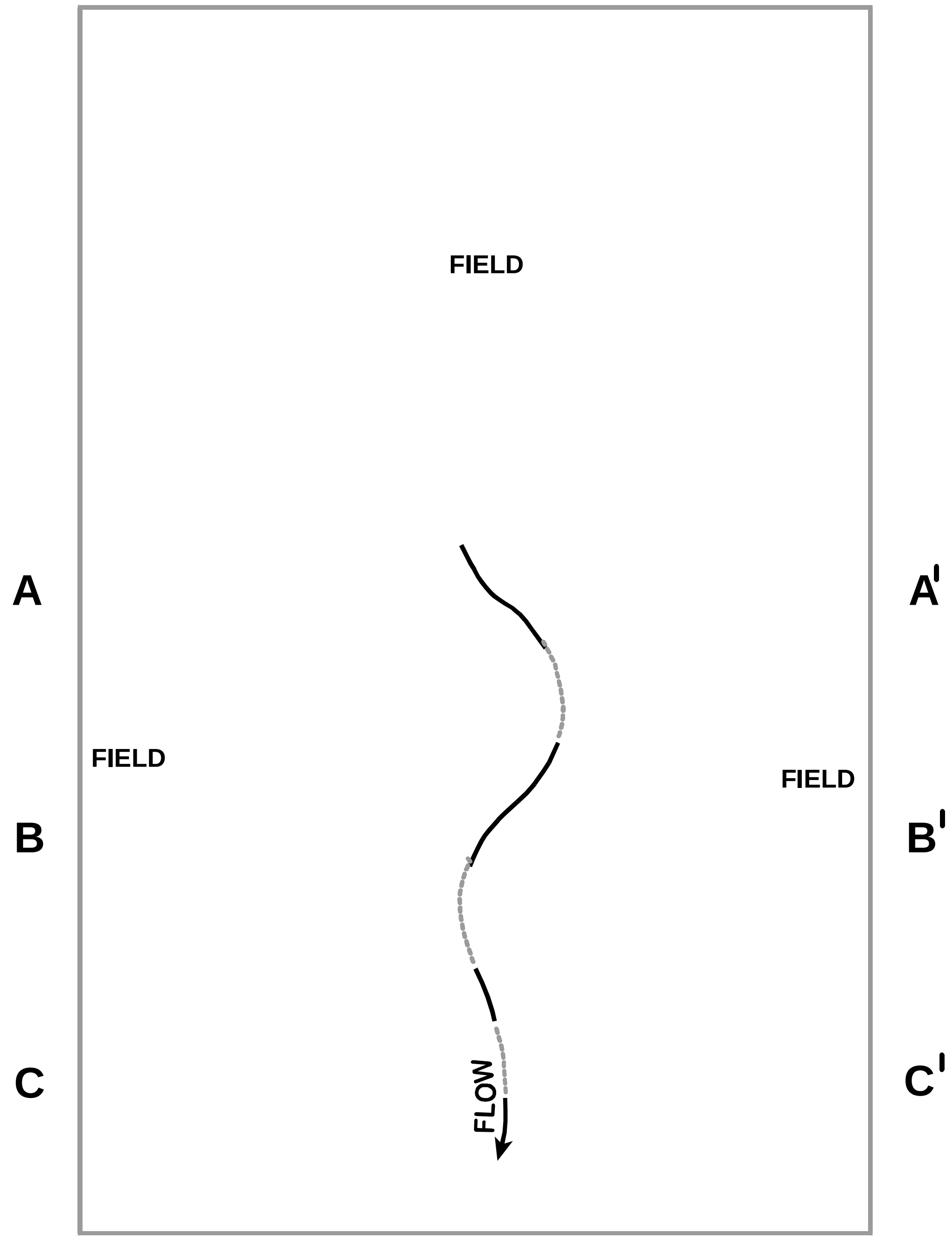
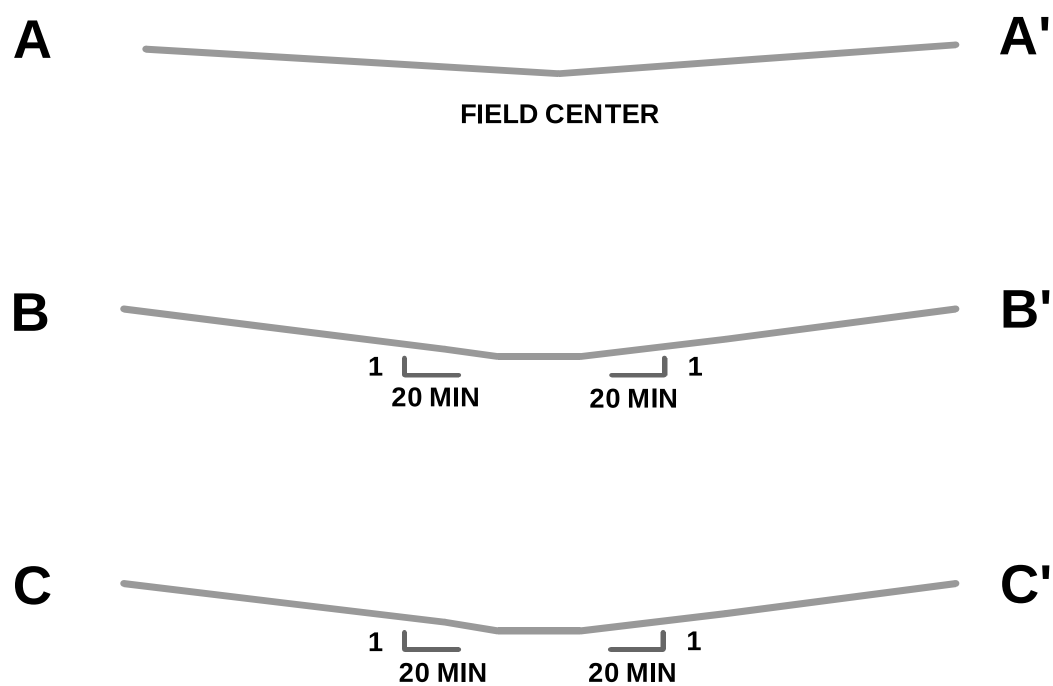


FIGURE 2



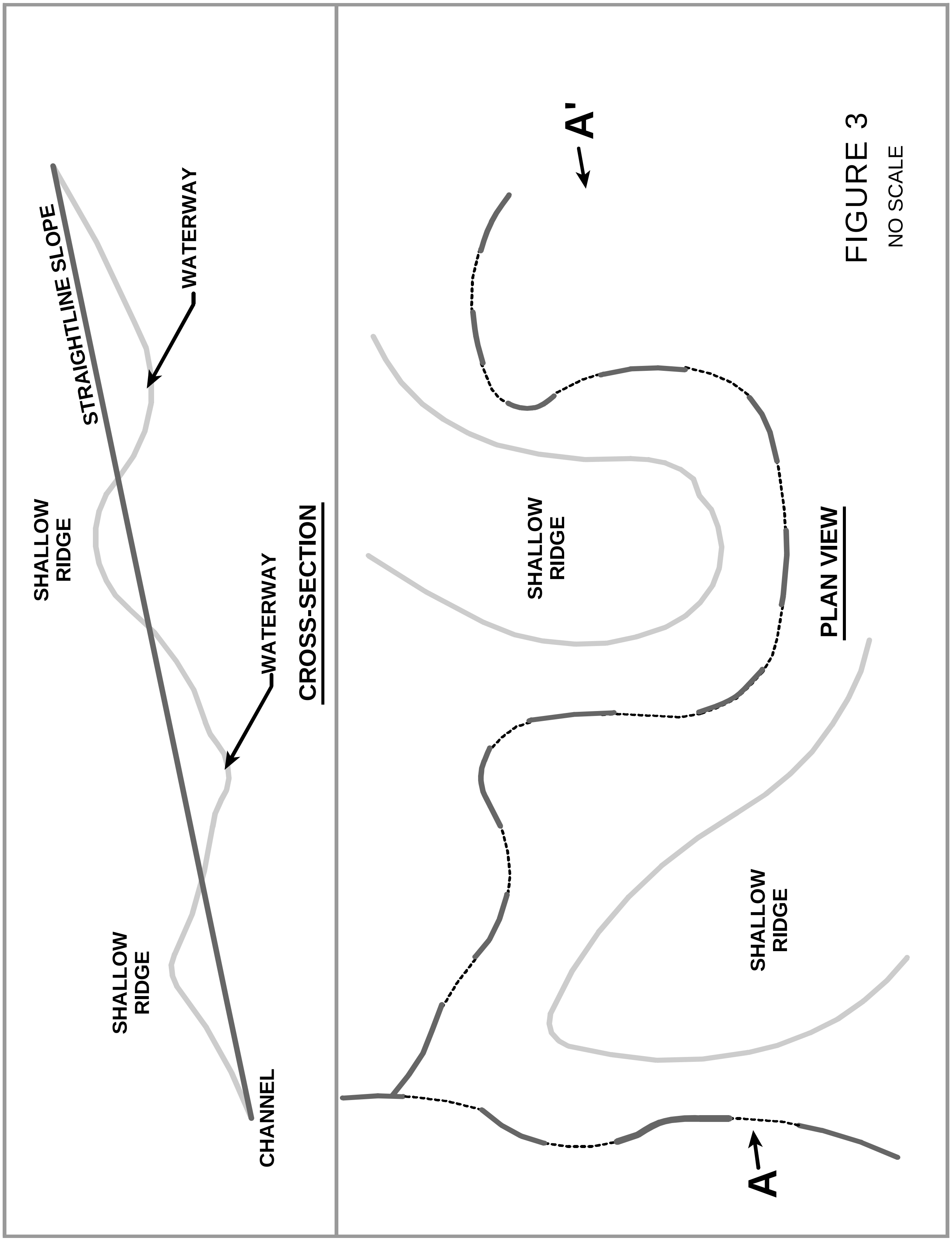
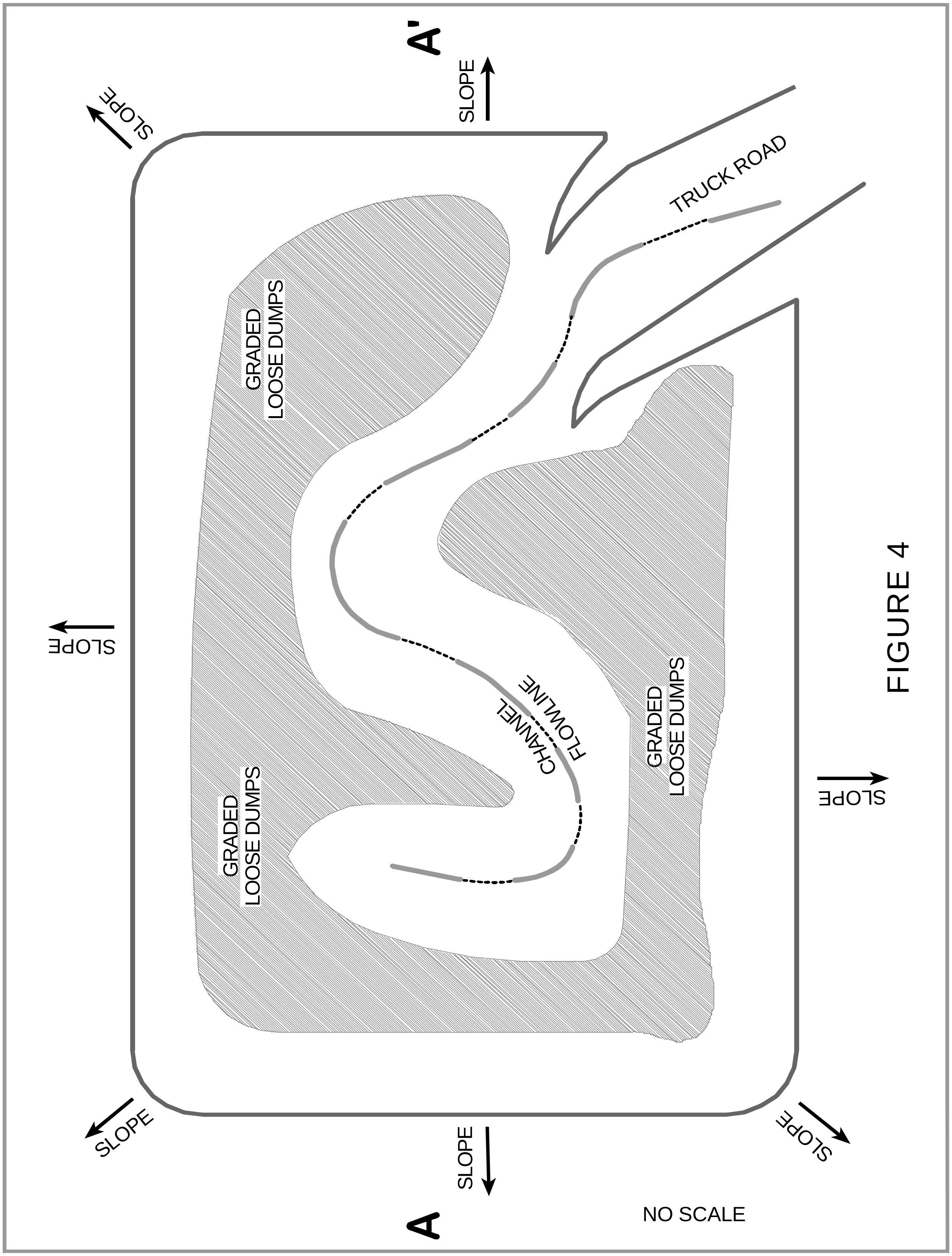


FIGURE 3
NO SCALE


A'
SLOPE
SLOPE
TRUCK ROAD
GRADED
LOOSE DUMPS
SLOPE
CHANNEL
FLOWLINE
GRADED
LOOSE DUMPS
GRADED
LOOSE DUMPS
SLOPE
SLOPE
SLOPE
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SLOPE
A
NO SCALE

FIGURE 4

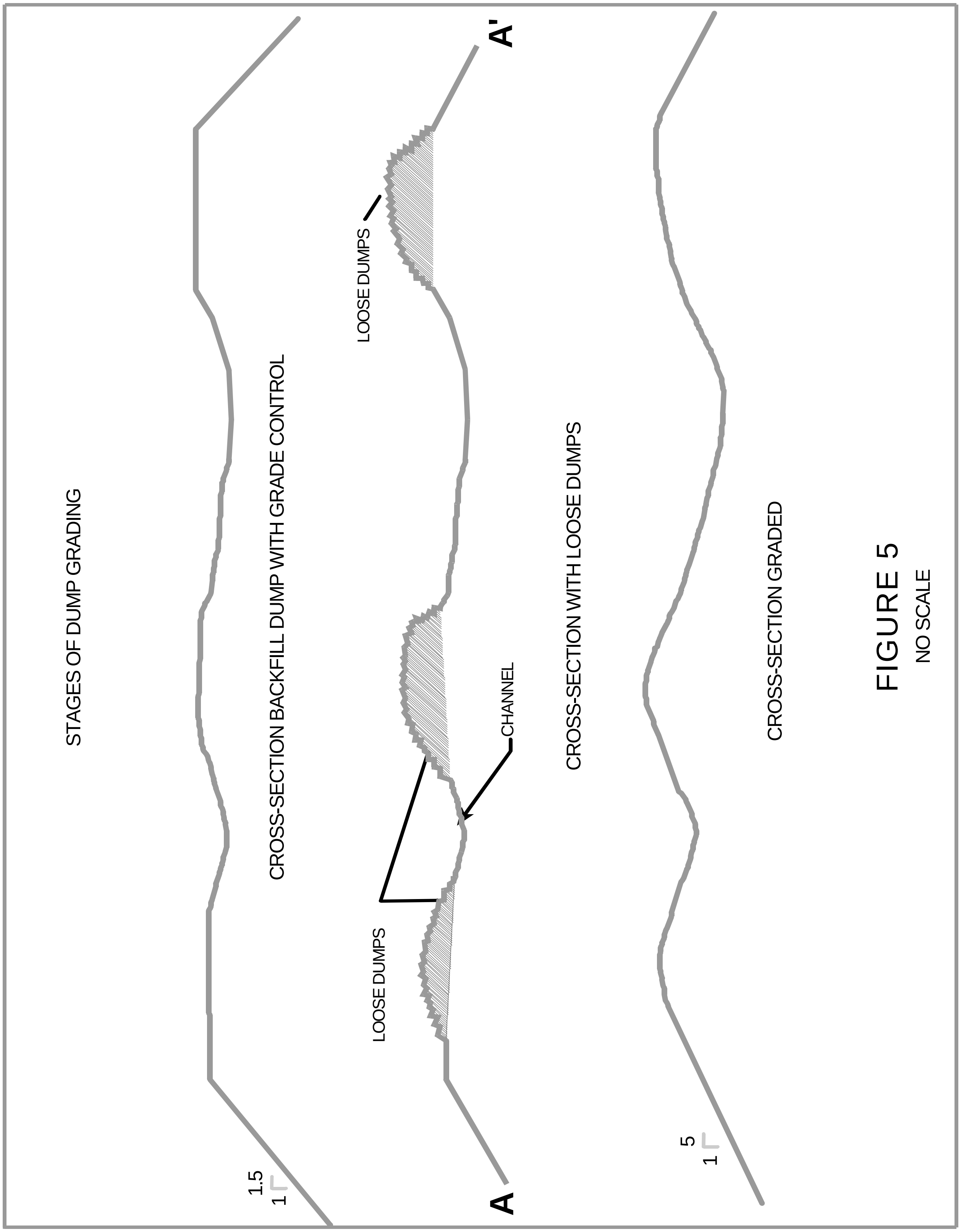

FIGURE 5
NO SCALE

2. Stream Channel Construction

Section editor: Frank K. Ferris Subsection author: Richard C. Warner

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Situation:

Often mining operations require the relocation and reconstruction of streams or stream modifications to increase discharge capacity.

Special Considerations:

An assessment of premining stream parameters and an understanding of flow characteristics necessary for food production, spawning and cover (i.e. habitat) will greatly increase the opportunities for success. Besides stream morphologic parameters, an understanding of stream velocity, depth, and substrate will facilitate construction of a balanced, diverse aquatic ecosystem.

Description of Technique:

a. Planning

The development of a successful reclamation plan that addresses stream considerations is based on the acquisition of premining stream data. A base map normally displays a planview of the channel, flood plains, and generalized vegetation documentation. Such data can be readily obtained through aerial photos or the existing channel can be surveyed. A stream longitudinal profile is extracted. This profile displays distance from a specified downstream location, reach segment number, length and slope of each reach, meander characteristics and cross-section measurements for each reach. The meandering pattern as described by wavelength, sinuosity (ratio of valley slope to stream slope), and radius of curvature. Numerous other meander patterns and characteristics can be helpful in stream reconstruction (Gore, 1985). Meandering has been identified as the primary vehicle of dissipating stream energy and is therefore a principle design tool for stream reconstruction.
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A vertical profile of channel substrate should be detailed for each stream environment, i.e. pool and riffle. Each layer of the vertical profile should contain particle size composition. Note should be made of stream geometric factors such as cross-section shape, stream pattern (meandering patterns and braided), and pool-riffle patterns. Also location and description of point bars and cross currents should be noted.

b. Stream Habitat Components

To enhance stream relocations, it is necessary to gain an understanding of the interplay among aquatic habitat factors and physical factors of stream velocity, depth, and substrate. In a pool-riffle environment, riffles function as food production and spawning areas. Riffles exhibit relatively shallow depths, higher than average velocity, and coarser substrate than pools. Velocity is the primary parameter describing the distribution of aquatic invertebrates. Velocity in riffles governs the rate of oxygen transfer to properly sized substrate (i.e. rubble, boulders, and cobbles) thereby supplying oxygen and removing metabolic waste products from intergravel areas. Water velocity increases the exchange rate, thereby enhancing respiration and food acquisition. Optimal velocity is subject to debate, but the range for riffle segments for good stream productivity is between 0.5 and 3 feet-per-second (fps) or 0.15 and 0.9 meters-per-second (mps) (Delisle and Eliason, 1961). A narrower design range is 1 to 2 fps or 0.3 to 0.6 mps (Giger, 1973).

Velocity controls substrate size to a large extent. The larger size rocks are associated with riffle areas since sands and silt are removed by the higher current velocity. Benthic invertebrates decrease in number and diversity as substrate is changed from rubble to coarse gravel to fine gravel and sand. Rubble appears to play a key role in the riffle environment. It provides a broad surface for invertebrates to cling to and functions to protect insects from high velocities (Gore,1985). Velocity also functions as the vehicle for drift, which is the movement of organisms downstream by current. Drift supplies the mechanism to acquire food which advances increased population densities and diversity.

Depth controls, to a great degree, the intensity of light which controls photosynthetic production of food. Deeper waters are less productive and contain fewer invertebrates than shallower riffle areas. Depth of highest productivity in trout streams range from 0.5 to 3 feet (0.15 to 0.9 meters), provided that current and substrate are suitable (Gore, 1985).

The parameters of velocity, depth and substrate combine in the riffle environment to provide an optimal habitat for aquatic invertebrates (Gore, 1985). The repetitive pool-riffle succession creates an excellent habitat for food production, spawning, cover, and resting.

Stream cover can take many forms. Bank cover is provide by overhanging vegetation and undercut banks whereas in-stream cover is found by aquatic vegetation and the larger substrate. When reconstructing a stream, cover is essential. Elser (1968) found a reduction of 78 percent less trout in a stream having 80 percent less cover.

c. Structures to Enhance Stream Habitat

Structures such as current deflectors, low profile dams, and the selective placement of boulders and substrate during channel reconstruction can enhance habitat. Such devices can locally increase velocity, create pools and scour holes, provide gravel trapping areas, remove silt from spawning areas, protect stream banks, enhance pool-riffle sequencing, aerate the water, reduce or increase water temperature, and generally both create enhanced habitat and simultaneously provide bank stabilization.

d. Current Deflectors

Current deflectors are structures extending outward from the streambank into the channel. Common terms for these devices are jetties, spur dikes, groins, etc. As with many controls, deflectors have been reported to be both successfully and unsuccessfully employed. Wesche (1985) reviewed numerous applications and reported successes summarized by phrases such as "the number of age 1 and older brook trout had doubled in the modified reach"; "the number of good quality pools had increased from nine to twenty nine, average pool depth had increased by 0.5 feet (0.15 meters), and additional spawning gravel had been exposed"; and "...improved the carrying and reproductive capacity of the reach for trout, was cost effective when compared with stocking, and had their greatest effect on the substrate, increasing the exposed gravel in each reach from 14 to 24 percent". Wesche (1985) also summarized failures such as "...deposition which occurred immediately downstream from the structure negated any habitat gains"; "...deflectors were quite susceptible to damage and needed frequent repairs"; and "flood flows reduced the ability of certain structures to concentrate the flow, while the pools provided little trout cover".

To be effective, deflectors require application of design methodology and rigorous construction methods. Unfortunately, few design aids exist for the proper sizing, location and spacing of deflectors. Consideration should be given to: (1) location along the reach, i.e. locate along a straight or concave (the bank at the outside of the bend) stream section; (2) spacing among a sequence of deflectors; (3) location of riffles; (4) stability of the substrate; (5) ability to anchor the deflector in the bank; (6) bank height and stability; (7) point-bar deposition location; (8) bed transport; and (9) specific deflector design parameters. Important deflector design parameters include the deflectors length, width, height, shape and orientation angle. Selection of these parameters will depend upon the channel width, water depth, and velocity, besides those factors previously mentioned.

For habitat enhancement, the development of scour holes at the tip and along the face of the deflector are also design considerations. It should be noted that design for stability of the stream banks and the deflector itself may be based on a design discharge associated with a specified storm recurrence interval, but the predicted size of a scour hole will remain a highly time-dependant aspect due to the time-variability of stream discharge and sediment transport. Scour holes will progressively enlarge and be partially refilled during the rising and falling stages of the hydrograph. Thus, available habitat scour hole size will vary throughout the flow regimes experienced by a stream.

Current deflectors influence the creation of primary and secondary scour holes, gravel and sediment deposition patterns, and the stability of stream banks across and downstream of the deflector. Localized, increased flow velocity occurs near the tip of the deflector, resulting in the creation of the primary scour hole. Intermediate vortices occur both upstream and downstream along the deflector face. The size of the primary scour hole is functionally related to water density and viscosity; flow depth and velocity; deflector length, orientation angle with the downstream bank, and side slope; size, density and gradation of bed sediment; and sediment concentration of transported material (Klingeman et al., 1984). Klingeman et al., (1984) list nine predictive equations for primary scour hole size near current deflectors. Sediment deposition patterns vary depending upon the orientation angle of the deflector. Generally, deposition occurs slowly in the lee of permeable dikes (Lindner, 1969) but due to decreases in flow velocity, upstream deposition can also occur. To enhance habitat in the lee of the current deflector, it may be designed to prevent overtopping during flood events, thereby facilitating scouring by secondary eddy currents during normal flows.

Orientation angle recommendations are normally perpendicular (90 degrees) to the flow or downstream. Klingeman et al. (1984) notes that the upstream-oriented current deflector "is more effective in deflecting the current away from the bank than the downstream-oriented dike". That is, a greater distance occurs before the current returns to the downstream bank, thus bank stabilization is enhanced. Both orientation angle and deflector length influence scour hole development. Effective deflector length is the length perpendicular to the bank. As the effective deflector length and the orientation angle increases, the size of the scour hole increases (Klingeman et al., 1984). The limiting feature is the effective length, since as the length increases the flow section further contracts, thereby creating the potential for an unstable stream bank opposite the deflector. Although no firm design recommendation exists, it is generally recommended that the effective deflector length be less than one half of the stream width.

e. Low Profile Dams

Low profile dams are structures that span the entire width of a stream channel and may be constructed to point upstream, horizontal, or downstream. Low profile dams are also called weirs or check dams, and are usually located along relatively small, headwater streams that have steep gradients and lack adequate pool-riffle environment. As with deflectors, low profile dams provide a broad spectrum of potential habitat enhancements: (1) creation of a pool by raising the water level, thereby inducing upstream deposition of spawning gravel areas, facilitating fish passage, reducing overall channel scour, allowing sedimentation of organic debris, and encouraging the development of riparian vegetation which further enhances bank stabilization and bank cover development; (2) creation of localized scour hole(s) which provides fish rearing areas and temperature regime stability; (3) stream aeration; and (4) formation of gravel bars downstream of the structure. These multifaceted benefits can be enhanced by the proper design, placement and construction of low profile dams.

Design elements encompass weir discharge capability; shape of the downstream face (i.e. vertical, sloped or stepped); structural stability; energy dissipation; seepage control; and creation of the stilling pool by usage of multiple weirs. One relatively overlooked design parameter is the angle of the low profile dam and the influence of the angle on scour hole formation, size, and location. Klingeman et al. (1984) conducted a series of experiments regarding the influence of weir angle on scour hole and depositional area formation. Upstream pointing low profile dams, i.e. with a weir apex angle of less than 180 degrees, created a single scour hole at the center of the channel due to the convergence of flow. The deepest scour hole existed for the 90 degree angle. The 60 and 120 weir apex angles resulted in the formulation of scour holes approximately 15 percent lower in maximum depth than the 90 degree angle. Overall size (i.e. maximum depth times width times length) was greatest for the 90 to 120 degree range of angles. The other advantage of the upstream facing low profile dam is that the scour hole is located at the center of the stream, thereby reducing potential bank instability downstream of the weir. Downstream facing low profile dams create smaller symmetrical scour holes near the channel banks. The advantage to the downstream facing weir is the creation of a gravel bar at the center of the channel. Thus, depending upon the type of habitat enhancements desired, low profile dams can create various sizes of scour holes, placed either adjacent to the banks or centered in the channel, and can facilitate gravel depositional areas, as well as the other potential benefits previously enumerated.

f. Boulder Placement

Only general guidelines exist for the placement of boulders (Wesche, 1985). Either individual boulders or boulder patterns are commonly used. Clusters of boulders are often placed in triangular or diamond patterns. To increase the potential of boulder stability it should be embedded into the stream bed. Boulders ranging from two to five feet (0.6 to 1.5 meters) have been reported to be successfully used (Wesche, 1985). Boulders should consist of durable rock and placement adjacent to stream banks should be avoided.

g. Substrate Development

The use of deflectors, low profile dams and placement of boulders affects the velocity - depth regime and creates spawning gravel areas upstream of structures and downstream gravel bars. The key component to substrate establishment is the control of localized velocity. What is the proper size gradation of substrate to enhance macroinvertebrate production? A vertical profile of the bed material taken from existing established stream segments will yield representative information that if somewhat duplicated should provide background goals for substrate. Highest productivity and diversity of aquatic macroinvertebrates are found in riffle environments composted of gravel substrate intermingled with medium size cobbles (Gore, 1985). It is also important to reestablish the sequence of pools and riffles. Although riffles provide macroinvertebrate habitat, alternating pools provide needed areas for fish habitat and benthic deposition. It may be difficult to establish spawning gravel areas if fine sediments are continuously being generated from watershed areas. Techniques previously detailed for the control of upland sediment should be used in unison with substrate establishment.

The stream bed will normally consist of a series of layers. Ideally these layers include a gravel base, fine sediment-gravel seal, gravel scour protection layer, and an armor layer to facilitate stream bed stabilization. Often in stream reconstruction the bottom three layers are replaced by a single layer consisting of a heterogeneous mixture of silt, sands, and small gravel placed in a series of shallow lifts. The upper armor layer then is required to provide the predominant substrate for habitat and for stream stabilization.

NOTES

3. Wetlands Reconstruction

Section editor: Frank K. Ferris Subsection author: Robert K. Green/Frank K. Ferris

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Situation:

Surface coal mines are required to replace any wetlands to be removed by mining.

Special Considerations:

Wetlands should generally be constructed in reclamation areas low in the topography, such as swales, reclaimed channels, or permanent ponds. Water quality must be adequate to establish and sustain wetland plant species. Wetlands must be designed to function without the support of mine water sources.

Description of Technique:

a. General Requirements

(1) Size

Plans for wetlands must include site determinations that the drainage area is sufficient to support the planned size of those wetlands from the projected runoff event. Particularly for those wetlands which are expected to contain standing water throughout the growing season, the projected volume of wetland segments with seasonal standing water should not exceed the equivalent of the regional one- to two-year runoff event from the applicable drainage area. A two-year event of lesser duration (e.g. two to six hours) can have a high probability of occurrence in any given year. This event is often used to size small impoundments such as stock ponds, and can have equivalent applicability to wetlands development.
~~~~~~

(2) Depth

Depth variation is necessary for diversity. While areas subject to fluctuating periods of inundation and drying will be useful for development of wet meadow communities, there must be some areas in the wetland that will contain seasonal water throughout most of the growing season to establish emergent vegetation stands.

(3) Hydrogeologic Conditions

Functional hydrogeologic conditions which are necessary to facilitate wetlands development include clay soil, high water table, and graduated or intermittent flows.

b. Locations

(1) Ponds

During construction of ponds, topographic diversity of the structure bottom and the periphery of the water line commensurate with the wetland sizing determinations can be implemented to enhance wetland establishment (see Figures 1 and 2). These might include: construction of islands, peninsulas, ridges, and troughs to simulate bars and pools; pitting or furrowing along the contour of the proposed wetland surface to assure extended water retention and soil saturation; or construction of the pond floor at differential elevations. Many of these manipulations can also be applied to existing ponds to enhance wetlands establishment, but generally on a more limited basis due to existing conditions. Guidelines for establishment of these features include the following:

(a) Depth

Deep areas should be four or more feet deeper than the high water line. If a fish population is desired, more depth is required to prevent winter kill. In a pond with no substantial water flow, 25 percent of the total pond area should be at least 12 feet deep. If there is good water flow, 25 percent of the pond need only be 8 feet deep.

(b) Islands

Waterfowl nesting islands should be one to four feet higher than the high water line, and 200 feet from the edge of the water line where possible.

(c) Bars

Shallows and bars need to be within one-half foot of the normal water line.

(d) Pitting and Furrowing

Pitting and furrowing should occur in the periphery of the predicted runoff event high water line. These features should be clustered at runoff concentration points, and should have a minimum depth of one foot.

(e) Volume

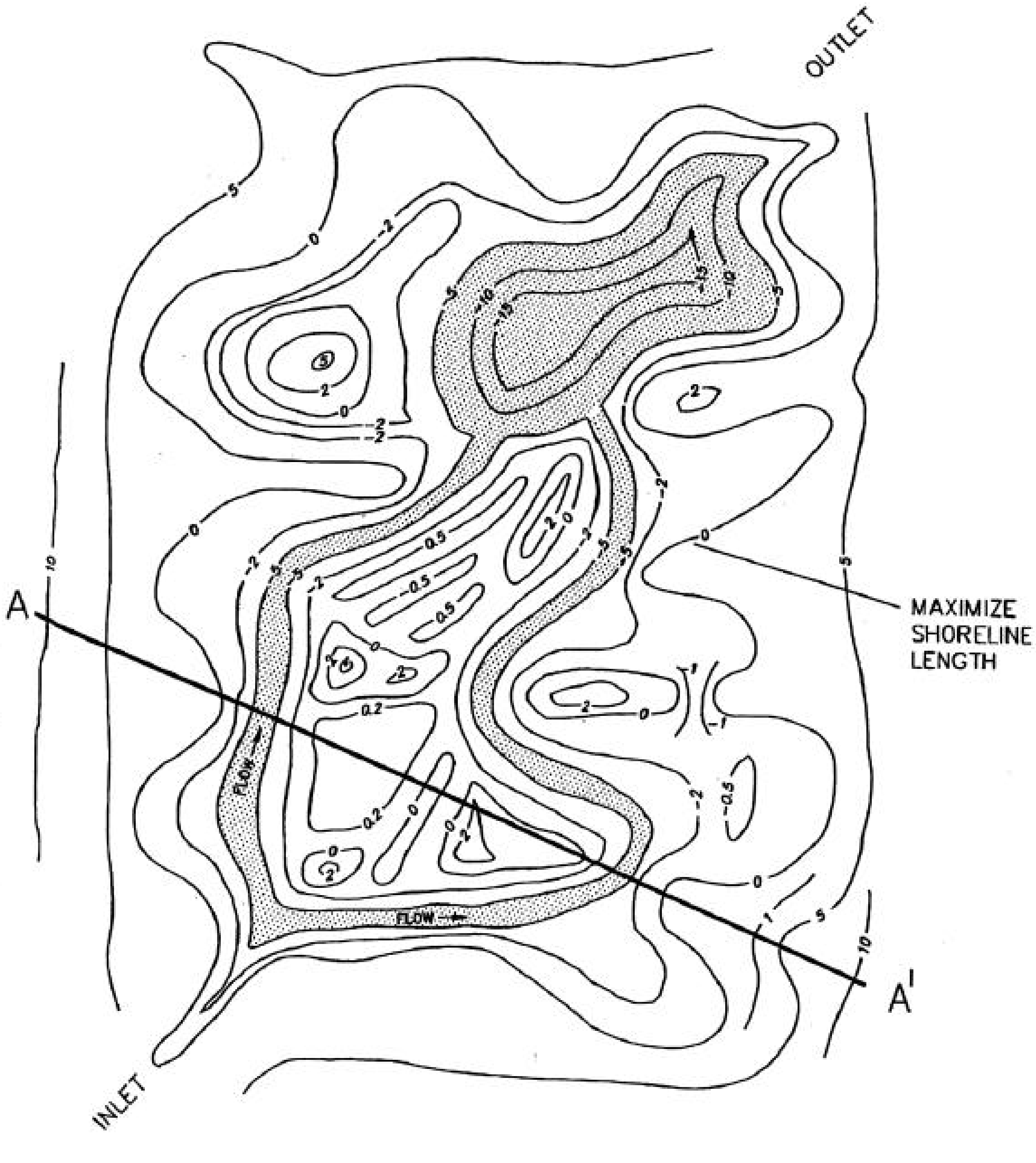
Predicted water volumes for those areas planned to hold seasonal standing water must be sufficient to address the regional evaporation potential.

(2) Minor Draws

One method of establishing wetlands entails construction of a low profile detention dike, or a series of dikes, across the bottom of a reclaimed drainage course (see Figure 3). The structure is intended to detain flows for sufficient time to create a temporary pool behind the dike. This will allow saturation of the soils and development of wet meadow conditions, while allowing ultimate free flow of the majority of the water. Minor retention pools will form along the upstream side of the dike.

A dike height of approximately five feet is recommended for general application. A top dike width of at least ten feet is recommended to allow construction and access by earthmoving and farming equipment. An average base width of 30 to 35 feet is recommended to provide stability and establishment of gentle slopes on both faces of the dike. Exact measurements will depend upon the size of the drainage, slope, base materials, and other site conditions. The length of each dike will vary as necessary to allow keying into the adjacent topography.

FIGURE 1



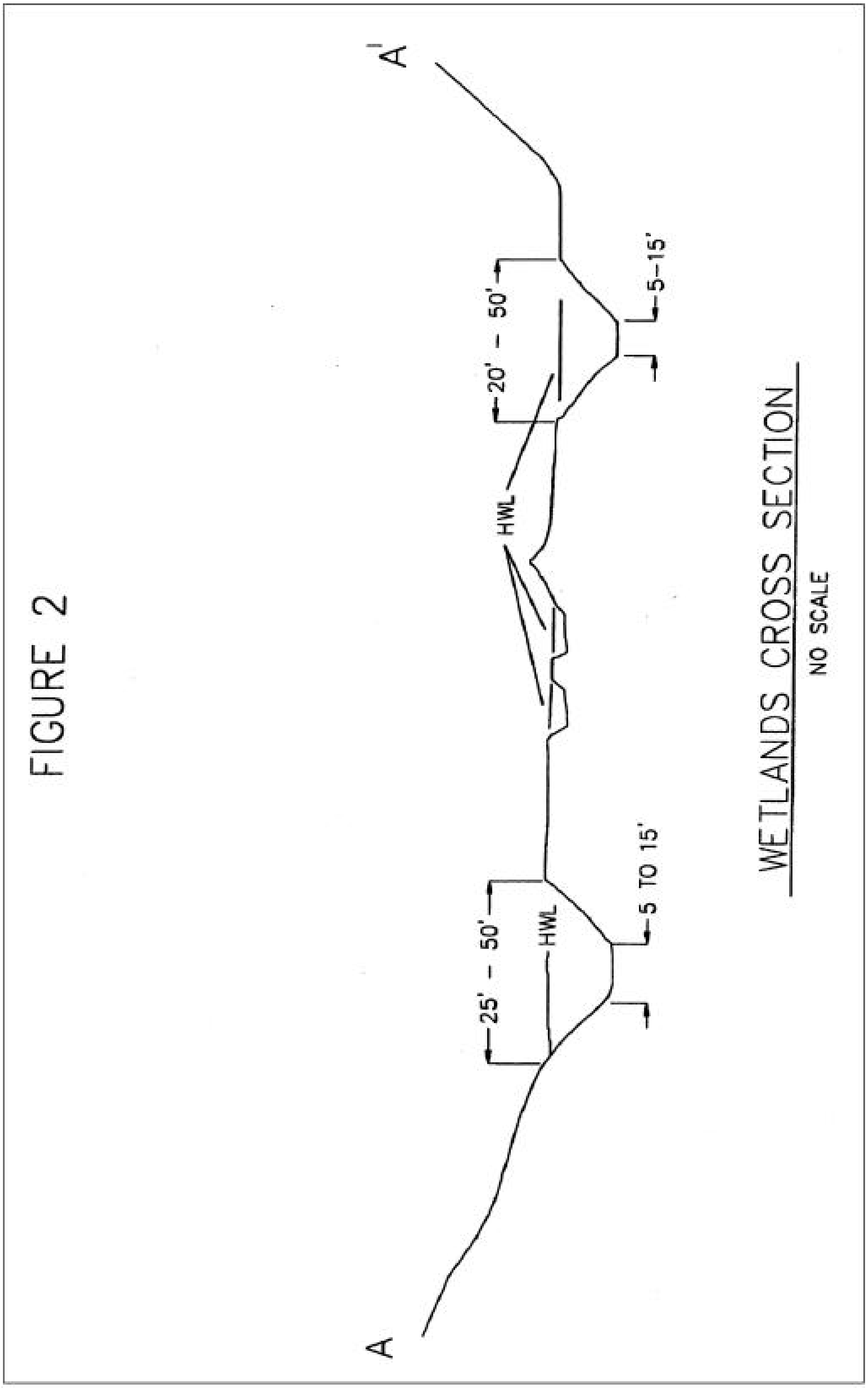
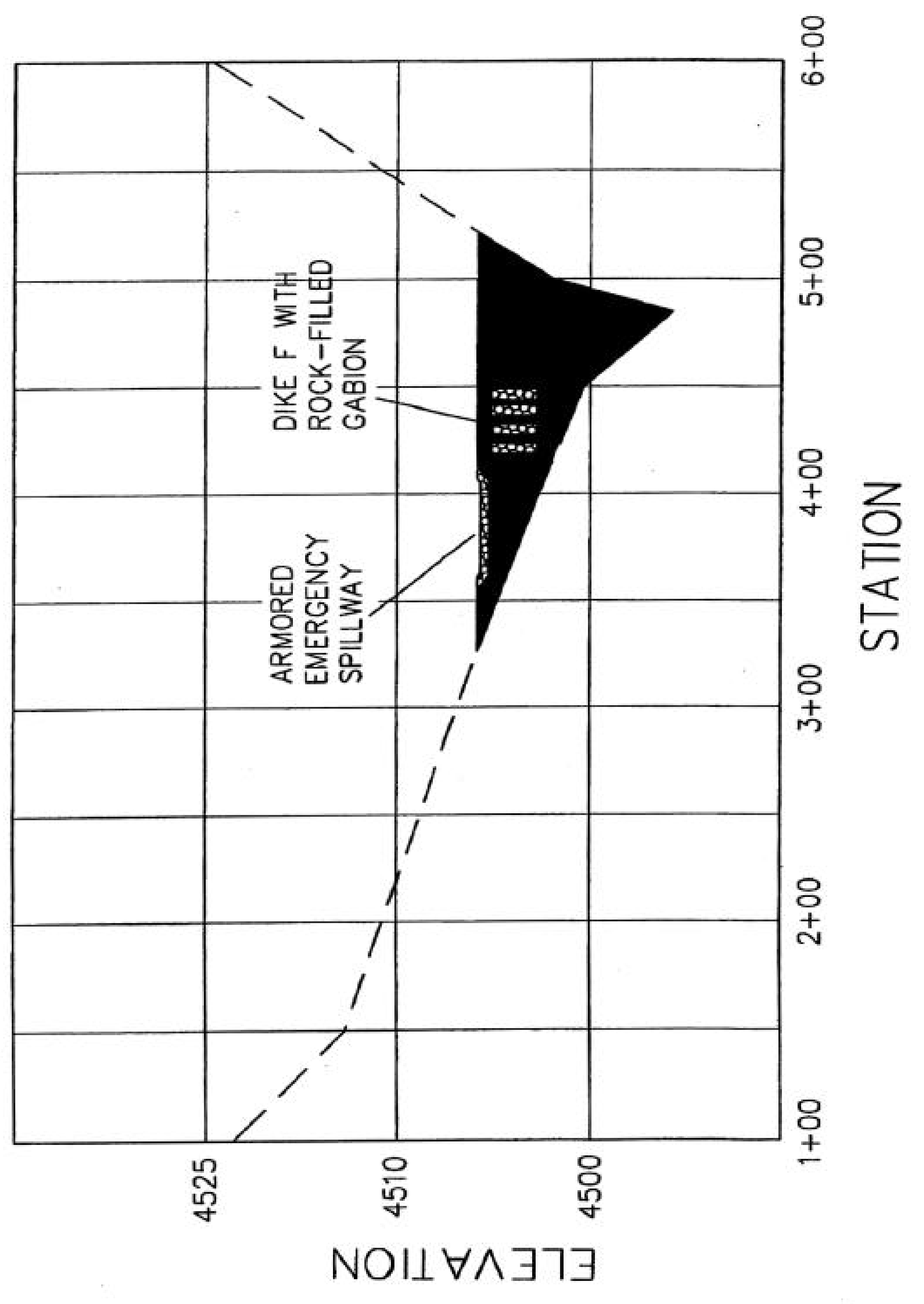


FIGURE 2
A
A'
25' - 50'
HWL
5 TO 15'
20' - 50'
5-15'
HWL
WETLANDS CROSS SECTION
NO SCALE

LONGITUDINAL SECTION

FIGURE 3



Each dike should have an outlet constructed of paired, rock-filled gabions (see Figure 4) to permit the slow escape of water from behind the dike. The rock used to fill the gabions should be competent (e.g. limestone) to assure longevity. Periodic flows of water will reduce silt accumulations in the gabions, producing an overall wetlands longevity approximately equal to that of natural stock ponds and drainage pools

Design planning should ensure minimization of peripheral disturbance to reclaimed lands. Construction timing is generally limited to the driest seasons. Following construction, the dike surfaces are seeded to reduce erosion and ensure stability. Native wheatgrass species are recommended.

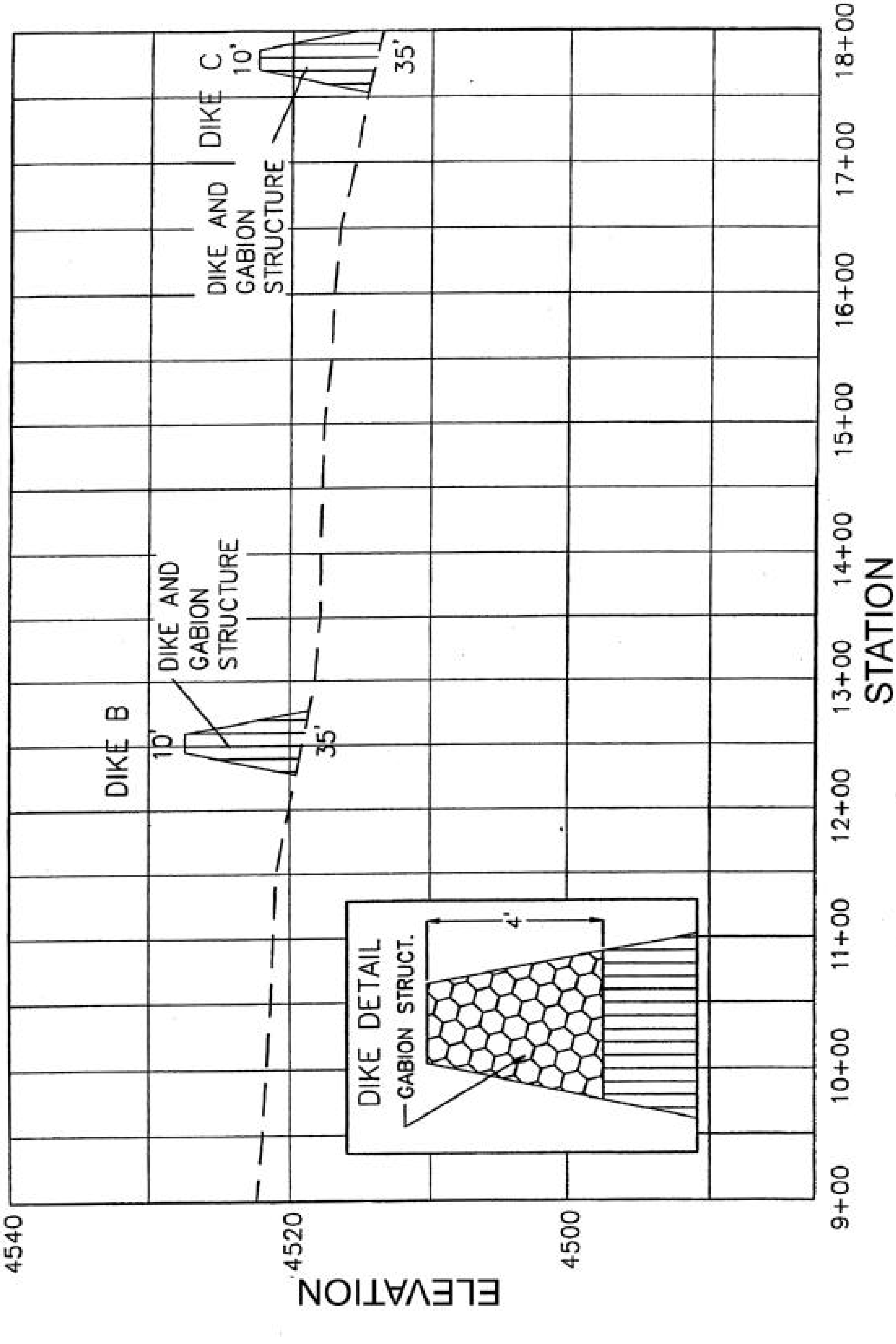
(3) Playas

The areas of water concentration in the playa must be small enough to allow water to collect in sufficient depth (6 to 36 inches). The surface soil must be clayey, or have a high water table, to allow water to stand on the surface.

(4) Major Drainage Channels

Major drainage channels generally provide the greatest topographic diversity for construction/installation of such features as deep pools, waterfowl nesting islands, shallow flats and bars, rock structures, and screened channels. These will assist in establishment of varying zones of wet meadow, emergent vegetation, and open water. The guidelines discussed above for establishment of these features in ponds also apply to their implementation in drainage channels.

LONGITUDINAL SECTION
FIGURE 4



(5) Final Reclamation

The prospective wetland development areas should be broadcast seeded with a seed mix which will facilitate establishment of wet meadow areas. Select areas projected to hold seasonal water can then be augmented with emergent wetland species either through seeding or transplants. The following mix is recommended to enhance and expedite wet meadow establishment:

Species	Rate
Kentucky bluegrass *Poa pratensis*	4.0 PLS pounds per acre
Reed canarygrass *Phalaris arundinacea*	4.0 PLS pounds per acre
Western wheatgrass *Agropyron smithii*	1.0 PLS pounds per acre

A minimum of .5 bulk pounds per acre of at least two of the following species should also be used:

Prairie cordgrass	*Spartina pectinata*
Streambank wheatgrass	*Agropyron riparium*
Sloughgrass	*Beckmannia syzigachne*
American mannagrass	*Glyceria grandis*
Common rush	*Juncus effusus*
Hardstem bulrush	*Scirpus maritimus*
Cattail	*Typha latifolia*
Prairie coneflower	*Ratibida columnifera*
Yarrow	*Achillea millefolium*

The basic mix can also be augmented with transplants such as spikerush, sedge, or other wetland species.

NOTES

4. Special Considerations in Planning and Constructing Permanent Postmining Impoundments

Section editor: Frank K. Ferris Subsection author: Patrick T. Tyrrell

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Situation:

Postmining impoundments are constructed for a variety of reasons. This includes replacement of pre-existing impoundments and construction of new impoundments, where feasible, to take advantage of the resulting reduction in backfill replacement movement. Wetland replacement is another common reason for constructing postmining impoundments. However, wetlands and dam construction techniques are discussed elsewhere in this section. This subsection will deal more with the special considerations faced in planning and constructing permanent postmining impoundments.

Special Considerations:

Function of postmining impoundments will be influenced by water supply and quality, chemical characteristics of backfill underlying the reservoir basin, and sediment inflow. From a permitting standpoint, changes in impoundment function or size from premining conditions may trigger a requirement from the regulatory agency to similarly modify postmining land use descriptions in the Surface Mine Control and Reclamation Act (SMCRA) permit prior to approval. Under SMCRA, reservoir feasibility is scrutinized heavily both in design and in performance (via monitoring). If the impoundment is not a replacement feature, the agency likely will request an alternate reclamation plan to be implemented if the structure does not function as planned.

Description of Technique:

a. Design and Permitting Considerations

Permanent postmining impoundments are as much a permitting project as a construction project. Typically, permitting and construction of smaller features, such as stock ponds, are not as rigorous or costly as similar work for much larger bodies with a capacity of several
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hundred or several thousand acre-feet. These larger impoundments are heavily scrutinized from the design and performance standpoints.

(1) Uses

Design and permit the impoundment for its anticipated uses. Larger impoundments intended for wildlife, fish, and recreation, in addition to stock watering, will have different characteristics than small stock ponds alone. Consult established guidelines for appropriate reservoir characteristics prior to design, so you and your management know where you're headed. For waterfowl or fish, for example, guidelines give recommended percentages for littoral zone (shallows), as well as deeper water, to make the impoundment more conducive to healthy populations.

(2) Topsoil

Make sure a reasonable and protective topsoil handling plan is put forth. Without ample topsoil, compliance problems will arise immediately. Typically, for impoundment drainage areas that are actively disturbed or reclaimed but still bonded, the reservoir basin should contain no topsoil below the high water line. This may cause contamination from overland flow.

(3) Water Supply

Permit the impoundment for an expected water supply. Stock ponds can be permitted to contain the mean annual flood (or some other relatively frequent event, to keep fresh water available) estimated by modeling. Larger impoundments may require operational studies to determine a size that will operate properly given the intended use. Assess such parameters as spilling frequency, range of water level fluctuations, and possibly a salt (TDS) balance to evaluate water quality over time and especially during drought periods. These studies will have to take downstream, senior water rights into account, and may result in construction of a low flow bypass or other mechanism (or administrative arrangement) to accommodate those rights. A water right should be obtained for the anticipated capacity of the impoundment; but remember that, upon construction, the final as-built capacity cannot *exceed* the permitted capacity. This is good to know as construction is commencing so no surprises are encountered. A beautiful pond may never function if insufficient attention is paid to water supply.

(4) Freeform Work

As much as possible, leave flexibility in your permitting language to do freeform work in the field. The freedom to add cost-effective shoreline undulations, small islands, riprap extensions, or simply keep working if unexpected conditions are encountered is invaluable if, as a situation arises, you don't have to convene the legislature to continue. But behave yourself; unlimited flexibility is dangerous when it reduces reliance on planning.

(5) Reservoir Characteristics

Pay special attention to reservoir characteristics. Safety must be considered because of the inherent questions about the long-term stability and settlement characteristics of mine backfill. Impoundments in backfill are more safely operated if they are totally incised than if they include an embankment sitting on many tens of feet of uncompacted truck/shovel or dragline spoils. Plus, in the incised case, a much smaller spillway or overflow channel is needed because there is no embankment to protect. Be aware of the safety concerns associated with operating heavy equipment along the banks and shorelines of backfill impoundments as these will be areas of instability when saturated.

(6) Industrial Uses

Make sure the impoundment is permitted for at least some industrial uses. Impoundments can be a convenient water storage feature your production department will want to use, or need to use, at some point. Plus, pit water or disturbed area runoff can enhance the speed with which the reservoir will fill, if it is not to be hydraulically connected to its ultimate drainage area for a period of time. This is a two-edged sword, however. While the extra water can speed maturation of the impoundment, the mining operation must be careful not to introduce unwanted sediment or poor quality water into a structure you hope to be a clean contributor to the postmining environment. Also, the extra water may bias your evaluation of the water balance for the reservoir, if one is necessary to prove its ultimate functions.

b. Construction Considerations

(1) Strip Topsoil

Much work will be going on in the vicinity of the reservoir basin and dam. Because of this, a first step is to remove all remaining topsoil in the dam, spillway, reservoir basin, borrow, and access areas.

(2) Work *Dry*

Working in wet bottomlands generally can be avoided when creating impoundments in older backfill or small drainages. If you must work in boggy areas, be cognizant of special sediment control measures that may be needed. Also, make sure your equipment operator or contractor can handle the work. In tricky areas, for instance, a floatation dozer may be required. When working in a wet drainage, coffer dams, a temporary diversion, or pumping will be required to keep the active areas workable. In ephemeral channels, most water encountered will be subsurface. A pre-construction borehole grid should awaken you to any potential construction problems.

(3) Survey Control

Maintain good survey control. This is especially important for the as-built drawings, spillway and dam crest elevation confirmation, and high water line delineation. Stake the high water line well in advance of construction to highlight problem areas that may not have been caught when working from maps or photos (i.e. was a power line installed recently, or are there trees that can be salvaged?).

(4) Material Sources and Quantities

Permanent impoundments in backfill environments, particularly the larger ones, will typically require the placement of a layer of "suitable" earth for a specified depth beneath the reservoir bottom. This is material that meets chemical quality criteria agreed to in the permitting process. The suitable zone may be four to eight feet in thickness or more, so a substantial amount must be available. When the time comes that this material is needed, the source quantity and quality must not be in question.

(5) Materials Testing

Do not skimp on materials testing. Since this structure will have to prove its performance during your bond period, and is intended to last many years beyond, thorough testing and documentation thereof is critical. Materials testing will include soil quality (see paragraph D above), compaction, gradation (e.g. for riprap), and classification (for embankment zones).

(6) Monitoring

Especially for the larger impoundments, provisions should be made during construction for the water quantity and quality monitoring that will often be required as a condition of approval. This will include, at a minimum, one or more staff gages, survey monuments (for the embankment, and for the reservoir basin if constructed on backfill), and water quality monitoring station locations. Be sure to stash a johnboat in the brush nearby, if access is unpredictable, to allow for bathymetric surveys and depth-integrated sampling in the future. If the structure serves any industrial uses, it will likely end up as an National Pollutant Discharge Elimination System (NPDES) discharge point. In this case, additional equipment will include a controlled lower-level discharge (in addition to the service discharge and emergency spillway) and a flume or other measuring device at the outfall.

(7) Stabilization

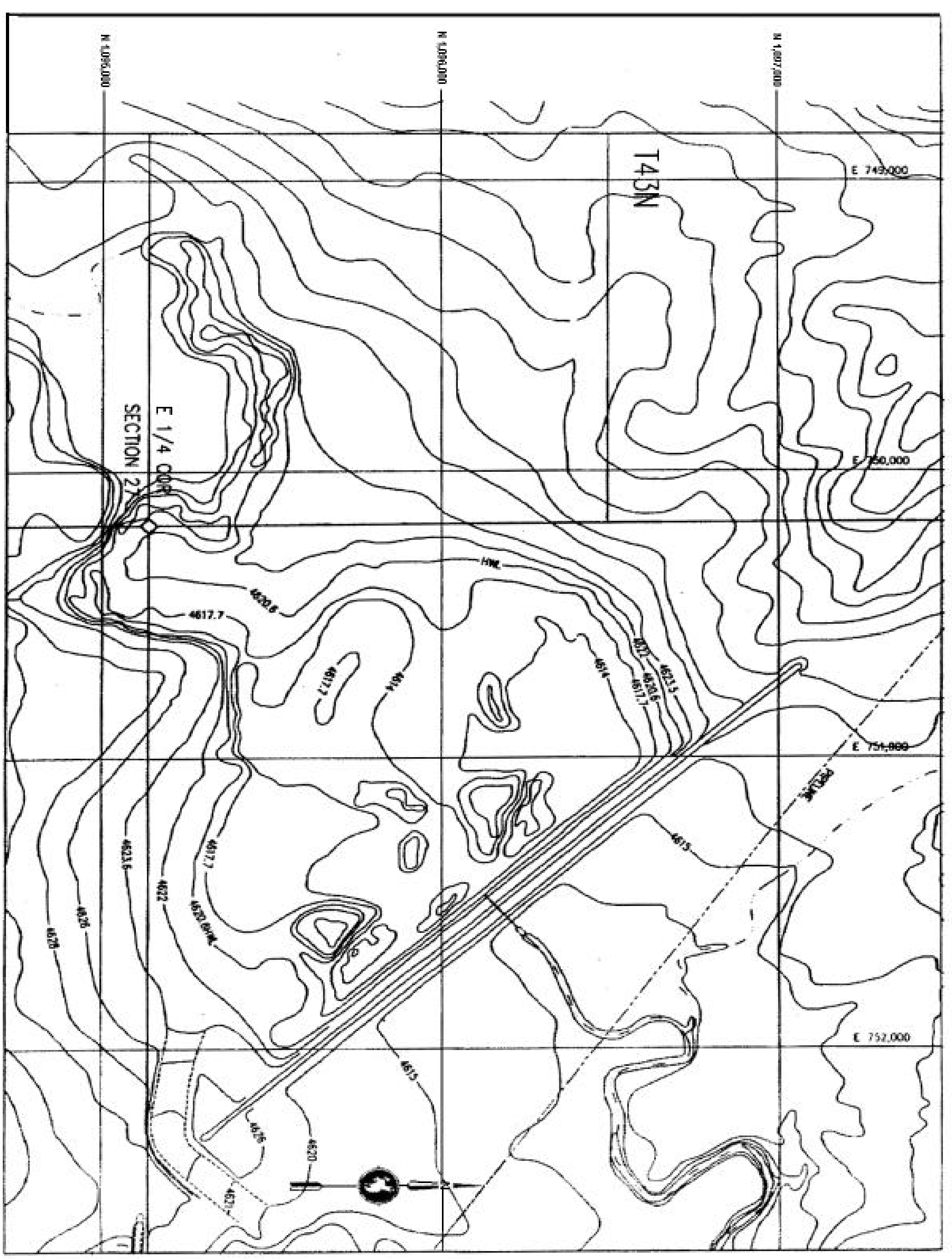
Stabilize areas that will see moving water. Spillways, outlet channels, inlet channels, downwind shorelines, embankments, and mechanical outlet works should all have erosion protection in place and functional before they are needed. Especially steep sections, such as in inlets to incised structures and embankment slopes, will probably require durable riprap. Other areas can adequately be stabilized with vegetation. To enhance the long term aesthetics and habitat characteristics of the structure, consider seeding or transplanting wetland vegetation along shorelines (which should be flatter near the high water line for this purpose, if possible), although many of these will recruit naturally. Do **not** plant trees in embankments, as their root systems may cause destabilization.

(8) Final Touch

Hold back some materials for the *final touch*. As construction of the impoundment nears completion, it is nice to have some extra suitable fill, riprap, and equipment time available to add some meaningful and functional features to the reservoir basin. These need not be costly or extensive. By adding a small peninsula here, a small island or two there, and some additional shoreline sculpting or rock habitat, (all done under dry conditions) the lake will take on a much more natural appearance with more valuable habitat. And, given it will be there much longer than you, it will be much more likely to look like the natural feature it is intended to be.

Figure 1.

This view of the 26-SR-1 Reservoir at the Black Thunder Mine provides a look at islands placed in the reservoir basin following dam construction (view is from the embankment looking west).The dam, its spillway, and the islands received topsoil to aid revegetation establishment. Additional features such as these islands and the littoral zone around them serve as wildlife habitat enhancement features.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4617.7

DRAINAGE BASIN CHARACTERISTICS

DRAINAGE BASIN PARAMETERS

DRAINAGE AREA *	52 mi^2
LONGEST WATERCOURSE	21.6 mi
ELEVATION DIFFERENCE	540 ft.
CURVE NUMBER	66
MIN. INFILT. LOSS	0
10-YR, 24-HR PRECIP.	2.09 in
100-YR, 24-HR PRECIP.	3.23 in

* NOTE: DURING MINING THE DRAINAGE AREA WILL BE REDUCED TO 8.8 mi^2 BY THE CONSTRUCTION OF THE LITTLE THUNDER DIVERSION. AFTER MINING AND RECLAMATION THE DRAINAGE AREA WILL REVERT TO 52 mi^2

AREA CAPACITY TABLE

POSTMINING BENEFICIAL USES

INACTIVE
33.94 ac-ft
STOCK WATERING

INACTIVE
76.81 ac-ft
WILDLIFE
WATERING

ACTIVE
93.50 ac-ft
IRRIGATION
RECREATION

ELEVATION (ft)	ACRE (ac)	AVG-AREA (ac)	CAPACITY (ac-ft)	
			INCR	ACCUM
4606	0.0		0.0	0.0
		0.32		
4608	0.32		0.32	0.32
		1.01		
4610	1.69		2.02	2.34
		7.90		
4614	14.11		31.60	33.94
		20.76		
4617.7	27.41		76.81	110.75
		32.24		
4620.6	37.07		93.50	204.25
		42.07		
4622	47.06		58.89	263.14
		52.67		
4623.5	58.27		79.00	342.14
TOTAL AVAILABLE CAPACITY 204.25 AC-FT				

BENEFICIAL USES DURING MINING

INACTIVE
2.34 ac-ft
INDUSTRIAL
POLLUTION CONTROL
(SEDIMENT STORAGE)

ACTIVE *
108.41 ac-ft
MISC USE
(DUST ABATEMENT)

93.50 ac-ft
MISC USE
(DUST ABATEMENT)

TOTAL AVAILABLE VOLUME AT HWL: 204.25
SURFACE AREA AT HWL: 37.07

* NOTE: ACTIVE CAPACITY BELOW 4617.7 WILL BE DEWATERED BY PUMPING WHEN WATER QUALITY IS ADEQUATE TO MEET EFFLUENT LIMITATIONS OR WHEN REQUIRED FOR DUST ABATEMENT.

CERTIFICATE OF ENGINEER

I,____________________ OF _______________, WY CERTIFY THAT THIS DRAWING WAS PREPARED FROM ACTUAL SURVEY NOTES TAKEN ____,___,19__ FROM ________________ COAL COMPANY, AND FROM A (ANY OTHER INFORMATION APPLICABLE) AND WAS PREPARED BY MYSELF OR UNDER MY DIRECT SUPERVISION, AND THAT ALL INFORMATION HEREON REPRESENTS THE AS-BUILT CONDITION AND IS CORRECT TO THE BEST OF MY KNOWLEDGE.

NOTES

E. Hydrologic Control Structure Tolerances

Section editor: Frank K. Ferris Subsection author: Frank K. Ferris

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Situation:

Implementing a design for a hydrologic control structure often leaves the question of how closely to adhere to that design. Both carelessness and rigid adherence regarding design can lead to structure failure. This subsection was developed as a guide for acceptable tolerances.

Critical Considerations:

Lack of experience in a contractor may lead to deficiencies in structure, although excessive supervision could incur significantly more cost than warranted in the building of the structure. Outlining acceptable and unacceptable tolerances solves this problem.

Description of Technique:

The tolerances outlined on attached Figures 1 through 7 were developed from field experience and research of regulations and professional standards. These tolerances were compiled to prevent repeating past mistakes and to clarify construction standards. They also simplify the certification process required by most regulatory authorities.

Structure size determines how restrictive these tolerances must be. Tolerances are provided for various structures. The following figures illustrate tolerances by showing cross sections and detailing structure component variables:

Figure 1	Spillway Cross Section
Figure 2	Embankment Top Cross Section
Figure 3	Embankment Cross Section
Figure 4	Key Way
Figure 5	Reservoir Dimensions
Figure 6	Diversion Cross Section
Figure 7	Crest Drainage
Figure 8	Reservoir Volume
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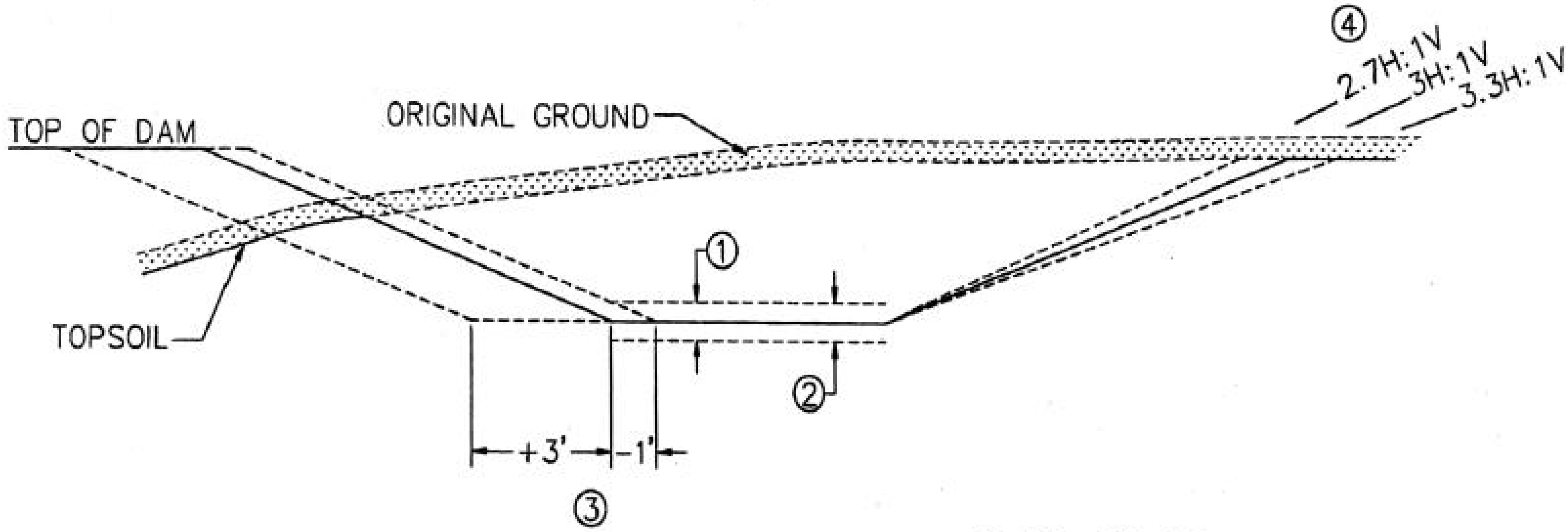
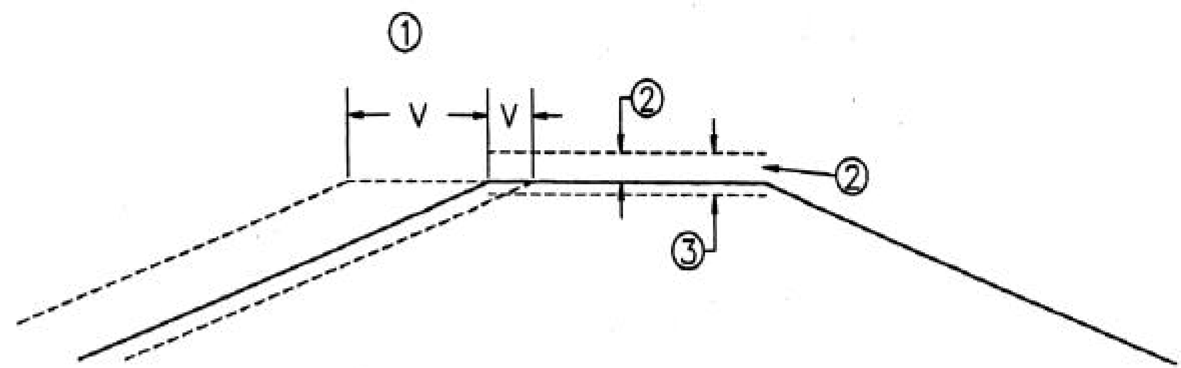
SPILLWAY CROSS SECTION
FIGURE 1



SPILLWAY STRUCTURE COMPONENTS	LESS THAN 2 AC-FT	2 AC-FT OR LARGER, BUT NON-MSHA	MSHA STRUCTURE
① CREST ELEVATION/ CONTROL SECTION	±.3 ft.	±.2 ft.	±.1 ft.
② GRADIENT VARIATION / 100 FEET	±.3 ft.	±.2 ft.	±.2 ft.
③ BOTTOM WIDTH	−1* to +3 ft.	−1* to +3 ft.	−1* to +3 ft.
④ SIDE SLOPES VARIATION	±10%	±10%	±10%

* (−10% max.)

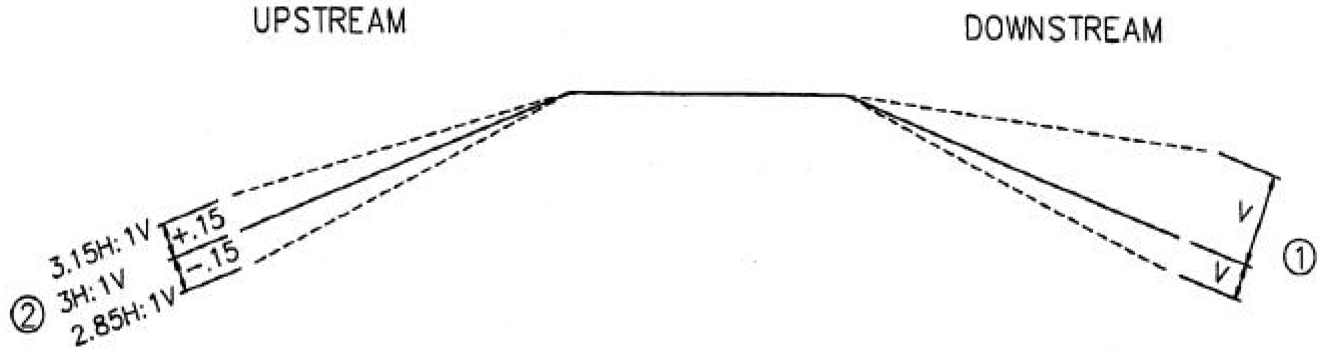
EMBANKMENT TOP CROSS SECTION
FIGURE 2



EMBANKMENT TOP STRUCTURE COMPONENTS	LESS THAN 2 AC-FT	2 AC-FT OR LARGER, BUT NON-MSHA	MSHA STRUCTURE
① WIDTH	-1 to +5 ft.	-1 to +3 ft.	-.5 to +2 ft.
② ELEVATION	-.2 to +2 ft.	-.1 to +1.5 ft.	-.05 to +1 ft.
③ UNIFORMITY OF TOP ELEVATION / 100 FEET (TOTAL VARIATION)	1.0 ft.	.8 ft.	.5 ft.

NOTE: MINIMUM TOP WIDTH DESIGN WOULD BE 10 FEET WIDE.

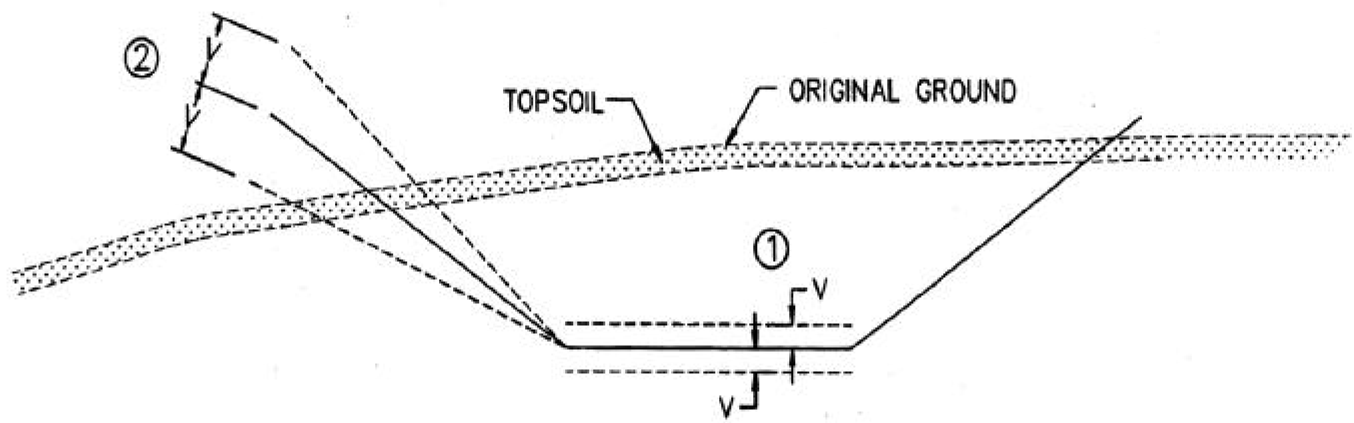
EMBANKMENT CROSS SECTION
FIGURE 3



EMBANKMENT SLOPE STRUCTURE COMPONENTS	LESS THAN 2 AC-FT	2 AC-FT OR LARGER, BUT NON-MSHA	MSHA STRUCTURE
① VARIATION (OUTSIDE, DOWNSTREAM)	-10% to +100%	-5% to +10%	±5%
② VARIATION (INSIDE, UPSTREAM)	±5%	±5%	±5%

NOTE: AS BUILT SLOPES MUST MEET THE SLOPE CRITERIA AS DEFINED. EXAMPLE, IF THE DAM HAS AN OVERFILL OF ONE FOOT HIGH AND TWO FEET WIDE, A 3H:1V TOE WOULD BE 5 HORIZONTAL FEET BEYOND THE TOE STAKES. THE TOE STAKES DO NOT GOVERN ON OVER HEIGHT OR WIDTH FILLS, THE AS BUILT TOP DETERMINES THE MINIMUM TOE OF SLOPE.

KEY WAY
FIGURE 4

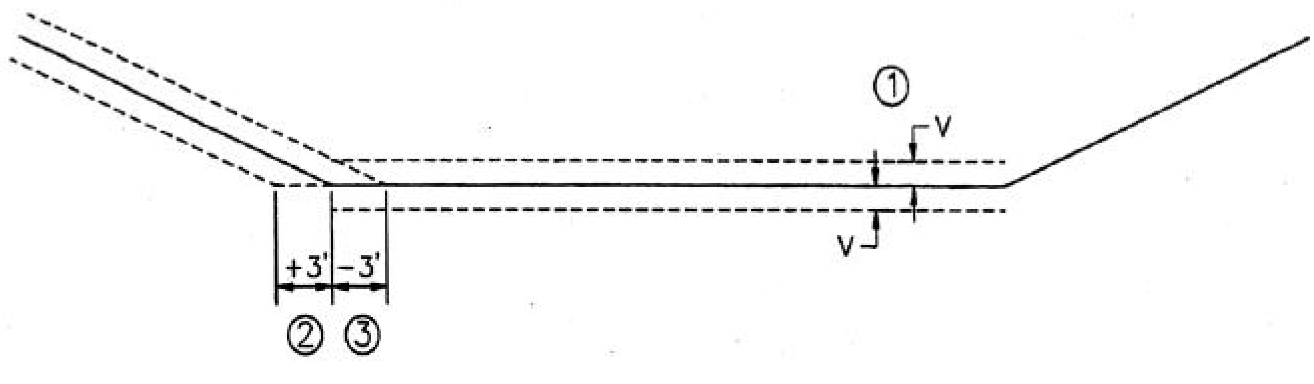


KEY WAY STRUCTURE COMPONENTS	LESS THAN 2 AC–FT	2 AC–FT OR LARGER, BUT NON–MSHA	MSHA STRUCTURE
① DEPTH (FROM DESIGN)	+.5 to –2 ft	+.3 to –2 ft	+.1 to –2 ft
② SLOPES (VERTICAL:HORIZONTAL) (FROM DESIGN)	+50% to –100%	+25% to –100%	+20% to –100%

NOTE: A 15 FEET WIDE KEY IS USUALLY THE MINIMUM NEEDED TO GET COMPACTION WHEN MATERIAL IS REPLACED. 5 FEET WIDE WILL WORK IF APPROPRIATE COMPACTION EQUIPMENT IS USED.

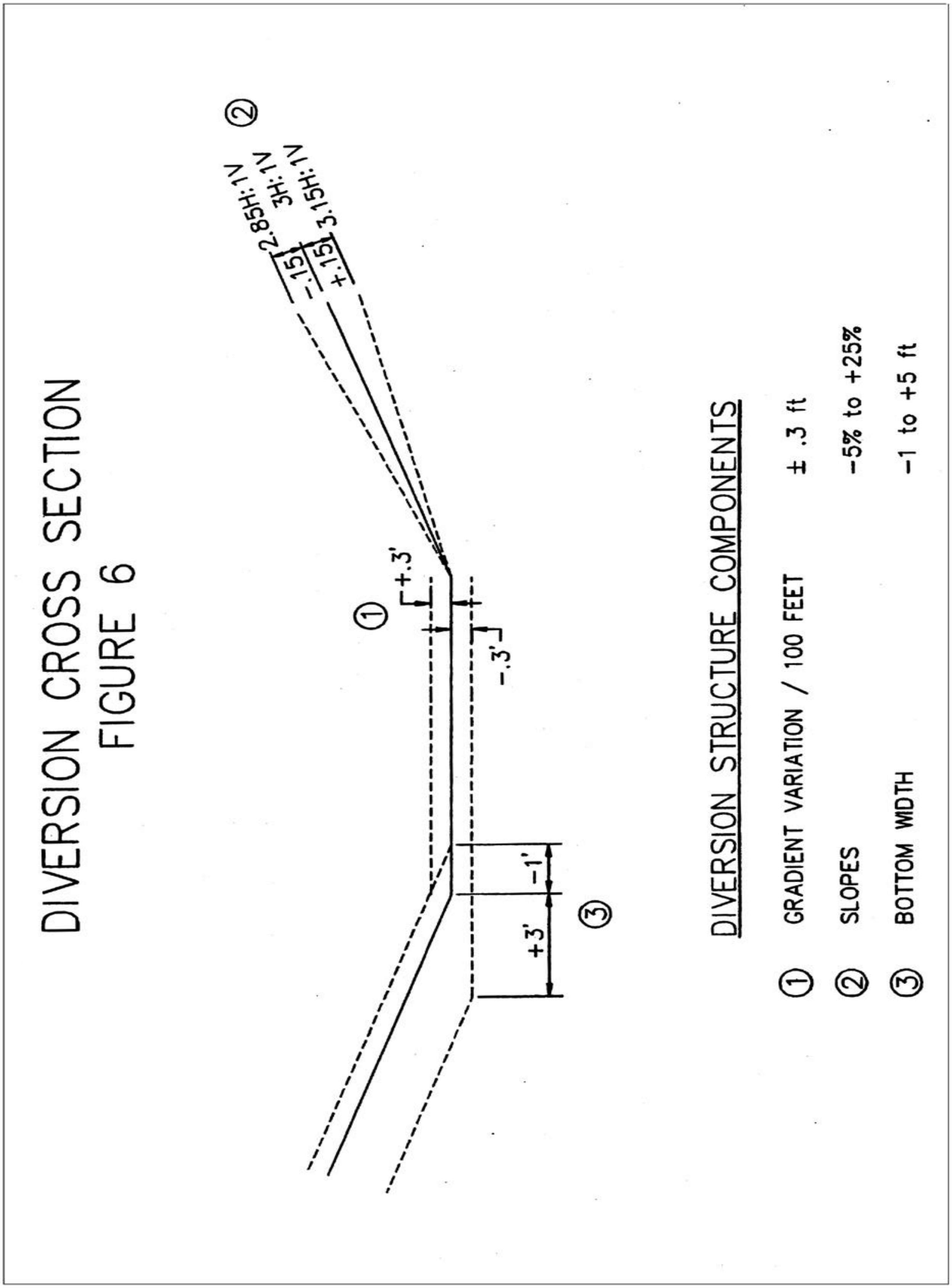
NOTE: SAND LENSES OR OTHER GEOLOGIC FEATURES MAY REQUIRE A DEEPER KEY THAN THE TOLERANCE EXTREME WOULD SEEM TO ALLOW. FIELD CONDITIONS WILL GOVERN WHERE REQUIRED.

RESERVOIR DIMENSIONS
FIGURE 5

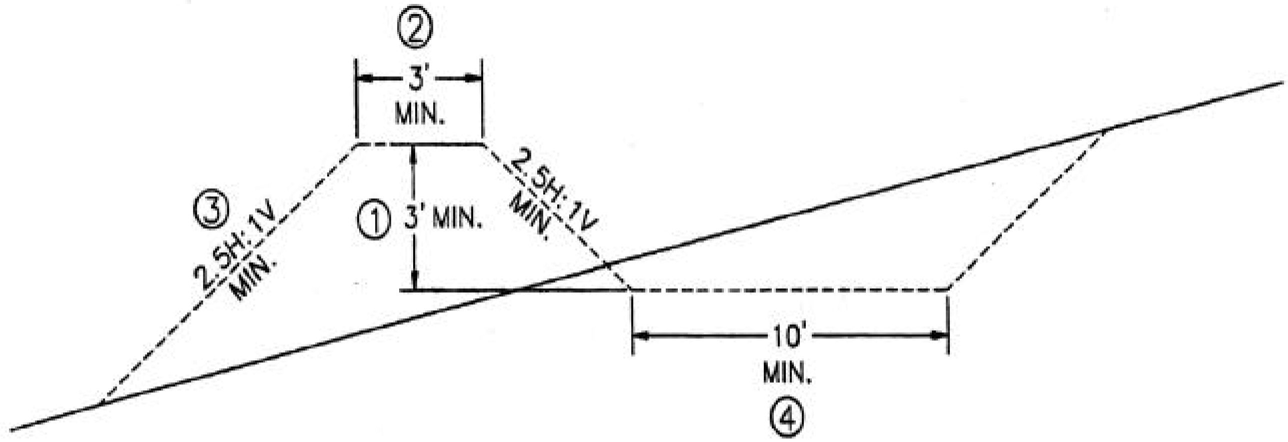


RESERVOIR STRUCTURE COMPONENT	LESS THAN 2 AC-FT	2 AC-FT OR LARGER, BUT NON-MSHA	MSHA STRUCTURE
① DEPTH	± .5 ft	± .3 ft	± .2 ft
② LENGTH	± 3 ft	± 3 ft	± 3 ft
② WIDTH	± 3 ft	± 3 ft	± 3 ft

NOTE: IF THE RESERVOIR DESIGN VOLUME IS NEAR THE TWO ACRE FOOT LIMIT, 20 ACRE FOOT LIMIT, OR SOME OTHER LIMIT FACTOR, USING THE TOLERANCE EXTREMES MAY EXCEED REASONABLE AND CERTIFIABLE CONDITIONS. THUS, THE MOST RESTRICTIVE CRITERIA WILL GOVERN. EXAMPLE: A LONG NARROW RESERVOIR COULD EXCEED THE VOLUME VARIATION EVEN IF THE WIDTH IS WITHIN THE TOLERANCES. THUS, THE VOLUME CRITERIA GOVERNS, THE WIDTH ALLOWANCES MAY HAVE TO BE MORE RESTRICTIVE FOR THE DESCRIBED RESERVOIR.

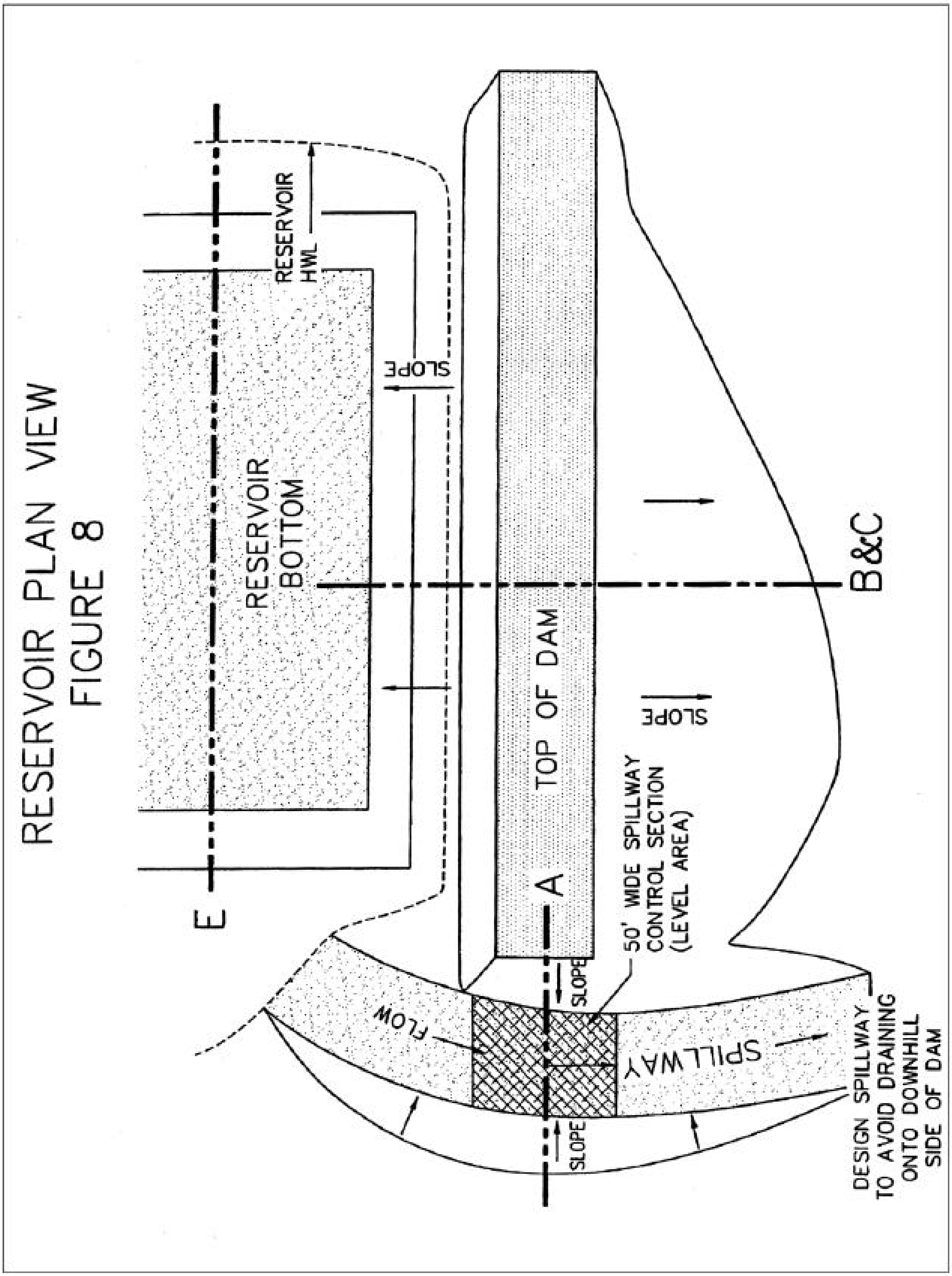

DIVERSION CROSS SECTION
FIGURE 6
2.85H:1V
3H:1V
3.15H:1V
-.15
+.15
+.3'
-.3'
-1'
+3'
DIVERSION STRUCTURE COMPONENTS
1 GRADIENT VARIATION / 100 FEET ± .3 ft
2 SLOPES -5% to +25%
3 BOTTOM WIDTH -1 to +5 ft

CREST DRAINAGE
FIGURE 7



CREST DRAINAGE STRUCTURE COMPONENT

①	BERM HEIGHT	2.5 ft min.
②	BERM TOP WIDTH	2.5 ft min.
③	SLOPES	2.5H:1V min.
④	CHANNEL WIDTH	6 ft min.
	CHANNEL GRADIENT	according to field conditions e.g. large drainage area, shallow slope


RESERVOIR PLAN VIEW
FIGURE 8
RESERVOIR BOTTOM
RESERVOIR HWL
SLOPE
TOP OF DAM
SLOPE
B&C
E
A
50' WIDE SPILLWAY CONTROL SECTION (LEVEL AREA)
SLOPE
SLOPE
FLOW
SPILLWAY
DESIGN SPILLWAY TO AVOID DRAINING ONTO DOWNHILL SIDE OF DAM

NOTES

F. Surface Water Monitoring Using a Weir

Section editor: Frank K. Ferris Subsection author: Frank K. Ferris

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Situation:

Surface water monitoring may be required, and can often be difficult to accomplish. A monitoring site should have long duration and quality construction. The equipment to be used should likewise be of high quality for reliability and durability.

Special Considerations:

A long-term monitoring site can be difficult to locate, but will be well worth the effort. The chosen site should remain undisturbed for ten years, or longer if possible, and be located in a narrow channel area. Short duration data is generally of little value. Construction must be of good quality to eliminate frequent repairs, which are usually costly, time consuming, and invalidate data. During large events, backwater may affect weir hydraulics and require an alternate flow calculation method.

Description of Technique:

Construction of gauge structures generally has been a compound vee-notch weir or Parshall flume. Parshall flumes have limited capacity and generally cannot handle the peak flows from draws. The compound vee-notch weir can have whatever capacity is desired. The length of the compound section determines the capacity. Weirs are usually installed by cutting an open trench perpendicular to the channel, and placing bolted or welded steel plates (4 foot by 8 foot) vertically in the trench. It is often difficult to keep the steel level and straight when installing it in an open ditch. This problem has been solved by using side footings for stabilizing the structure (see design maps). Adjust the footing location and height, and weir size, as channel capacity requires.
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For recording the flows, high quality recording equipment should be used to assure continuous operation during weather extremes. The gauge house equipment records the water level in the gauge house, which corresponds to the water level at the weir.

Backfill around the weir must be compacted, clayey soil to prevent piping. The weir plate should be at least five feet into the soil at all locations to prevent water from going under the weir.

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Hydro\surface water monitoring using a weir

G. References

Barfield, B.J., and S. Albrecht. 1982. Use of a Vegetative Filter Zone to Control Fine Grained Sediment from Surface Mines. In "Proceedings, 1982 Symposium on Surface mine Hydrology, Sedimentology and Reclamation." UKY BU 129, pp. 481-490. College of Engineering, University of Kentucky, Lexington, KY.

Barfield, B. J., and R. C. Warner. 1981. Applied Hydrology and Sedimentology for Disturbed Areas. Department of Agricultural Engineering. Oklahoma State University, Stillwater, Oklahoma.

Blodget, J.C., and C.E. McConaughy. 1986. Rock Riprap Design for Protection of Stream Channels Near Highway Structures, Volume II Evaluation of Riprap Design Procedures. Water-Resources Investigations Report 86-4128, U.S. Geological Survey, Denver, Colorado.

Bureau of Reclamation. 1974. Earth Manual. Water Resources Techniques Publication, 2nd Edition. U.S. Department of Interior, Bureau of Reclamation, Washington, D.C.

Commonwealth of Pennsylvania. 1990. Pennsylvania Erosion and Sediment Pollution Control Manual. Commonwealth of Pennsylvania, Department of Environmental Resources, Bureau of Soil and Water Conservation, One Ararat Blvd. Room 214, Harrisburg, Pennsylvania 17110.

Delisle, G.E., and B.E. Eliason. 1961. Stream Flows Required to Maintain Trout Populations in the Middle Fork Feather River Canyon. Report No. 2. California Dept. of Fish and Game, Sacramento, CA.

Dillaha, T.A., R.B. Reneau, S. Mostaghami, and D. Lee. 1989. Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control. Trans. Am. Soc. Agric. Eng. 32 (2):513-519.

Elser, A.A. 1968. Fish Populations of a Trout Stream in Relation to Major Habitat Zones and Channel Alteration. Transactions, American Fish Society, 97(4):389-97.

Giger, R.D. 1973. Streamflow Requirements of Salmonids. Final Report on Project AFS 62-1, Oregon Wildlife Commission, Portland, OR.

Gore, J.A. 1985. The Restoration of Rivers and Streams. Butterworth Publishers, Stoneham, MA.

Hayes, J.C. and T. Dillaha. 1991. Procedure for the Design of Vegetative Filter Strips. Report prepared for the USDA-Soil Conservation Service, Washington, DC. Available from J.C. Hayes, Department of Agricultural and Biological Engineering, Clemson University, Clemson, SC.

Hayes, J.C., and J. Harrison. 1983. Modeling the Long Term Effectiveness of Vegetative Filters as Onsite Sediment Controls. Paper 83-2081. American Society of Agricultural Engineers, St. Joseph, MI.

Linder, C.P. 1969. Channel Improvement and Stabilization Measures, State of Knowledge of Channel Stabilization in Major Alluvial Rivers. Technical Report No. 7, G.B. Fenwirk, ed., Committee on Channel Stabilization, U.S. Army Corps of Engineers.

Mining and Reclamation Council. 1985. Identification of Alternative Sediment Control Methodologies for Mined Lands. Hess & Fisher, Engineers, Inc., Clearfield, Pennsylvania.

Parsons, J.E., R.D. Daniels, J.W. Gilliam, and T.A. Dillaha. 1990. Water Quality Impacts of Vegetative Filter Strips in Riparian Areas. Paper presented at the Winter Meeting of ASAE, Paper No. 90-2501. St. Joseph, MI.

Peterka, A.J. 1958. Hydaulic Design of Stilling Basins and Energy Dissipators. Engineering Nomograph No. 25, Technical Information Branch, U.S. Bureau of Reclamation

SCS. 1985. National Engineering Handbook, Section 19, Construction Inspection. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

SCS. 1984. Engineering Field Manual. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

SCS. 1947. Handbook of Channel Design for Soil and Water Conservation. SCS-TP-61. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

Simons Li & Associates, Inc. 1982. Design Manual for Water Diversions on Surface Mine Operations. Prepared for the Office of Surface Mining, Contract No. J5101050, U.S. Department of Interior, Fort Collins, Colorado.

Warner, R.C., and P.J. Schwab. 1992. SEDCAD$^+$ (Sediment, Erosion and Discharge by Computer Aided Design) Version 3.0. Design Manual. Civil Software Design, Lexington, Kentucky.

H. Citations

Klingeman, P.C., S.M. Kehe, and Y.A. Owusu. 1984. Streambank Erosion Protection and Channel Scour Manipulation Using Rockfill Dikes and Gabions. Water Resources Research Institute, Oregon State University, Corvallis, OR

Wesche, T.A. 1985. Stream Channel Modifications and Reclamation Structures to Enhance Fish Habitat. Chapter 5 of The Restoration of Rivers and Streams edited by J.A. Gore. Butterworth Publishers, Stoneham, MA.