I. INTRODUCTION

1.1 The Problem

The design and implementation of an adequate drainage system before, during and after surface mining operations is essential to minimize adverse environmental impacts. Surface mining operations are often a source of water pollution. Water pollution from a surface mine generally occurs in two forms: chemical and physical. Chemical pollution is the result of minerals exposed to leaching or oxidation, producing undesirable concentrations of dissolved materials. Physical pollution is the increased sediment loading from excessive erosion. Since sediment is also a major carrier of many chemical pollutants, the two forms of pollution often occur simultaneously.

Compared to industrial pollution, which is usually a result of by-products created while the industrial process is actively pursued, water pollution from surface disturbances can be a continuous source of pollution for years after the mine becomes inactive. Runoff from abandoned mine sites can continue to carry large volumes of sediment and concentrations of chemicals to downstream bodies of water. Sediment in a stream or reservoir, above certain "natural" levels, constitutes pollution and reduces the usefulness of the water. The deposition of sediments reduces storage volumes, complicates flood control and power generation, destroys aquatic life habitat, decreases the value of floodplain areas for recreational and agricultural purposes, and leads to obstructions to navigation in larger rivers. Additionally, the dynamic nature of drainage systems can result in dramatic responses in downstream channel alignment, shape and type to increased sediment loading.

Drainage pollution of any type affects nearly every type of water use. It increases costs to industrial, municipal and navigation water users, for instance, by corroding equipment or by requiring special water treatment. Additionally, relatively small amounts of pollution can prevent the use of surface waters for some recreational uses, as well as for fish and aquatic life production. According to the Appalachian Regional Commission (1969) in House Document 91-160,

> "Over the last 100 years, coal mining in the Appalachian Region has caused increased amounts of acid, sediment, sulfates, iron, manganese, and hardness in the Region's streams, thus substantially altering water quality. This alteration has occurred in approximately 10,500 miles of streams, primarily in the northern half of the Region."

The actual pattern of the streams affected by mining operations in the Appalachian Region generally corresponds to the historical and present patterns of mining. The distribution of streams affected by all types of mine is uneven among the eight states in the Region that are affected. Throughout the Region, the incidence of affected streams decreases from northeast to southwest. This decreasing trend of affected streams toward the southwestern parts of the Region is primarily the result of compositional changes in the coal and adjacent strata, the mining techniques used, and smaller amounts of mining.

1.2 Control of Drainage On a Mine Site

Due to the magnitude and extent of the pollution problems that have arisen as a result of previous mining activities, and the desire to minimize further proliferation of such pollution, drainage abatement and control techniques have been developed. In general, abatement and control techniques can be grouped into the categories of source control to prevent the formation of polluted water, treatment processes to handle water that has become polluted, dispersion and dilution of polluted water by its controlled addition to unpolluted flows, and permanent containment or isolation of contaminated waters by injection into deep disposal wells.

The two major categories which encompass the majority of the preferred abatement and control techniques are treatment and source control. Use of water treatment during mining has no effect on the levels of water pollution after treatment ceases and the mine is abandoned. Thus, preplanning and implementation of source controls to reduce water pollution, both present and future, is considered preferable.

Compared to other categories of pollution control, source control measures such as revegetation and properly engineered drainage structures are relatively inexpensive. Source control measures are further desirable in that they help minimize the formation of polluted water by preventing contact of unpolluted water with areas disturbed by mining operations, thus limiting erosion and sediment loads carried by runoff, contact of runoff with acid- or toxic material-producing materials, and decreasing quantities of water needing treatment.

Diversion practices are particularly suitable in that they provide for a measure of control over the watershed. Using sound engineering design, diversion structures, channel modification and relocations can be constructed in a manner that provides pollution and erosion control through runoff management over a wide range of seasonal and climatic conditions. Such structures can prevent runoff into active mine sites, thus helping to reduce ponding along the bench or in the pit and the resultant downtime. Properly engineered diversions reduce erosion by preventing flow over unstabilized soil in waterways above highwalls, and over disturbed areas where vegetation has not been established.

Diversion is by no means a complete pollution control measure, but simply an integral part of an overall plan. The need for a complete drainage design plan for the permit area based on sound engineering knowledge is necessary to minimize potential environmental damage from surface mining activities. Further, it is essential that the designer realize that the drainage basin in the permit area is only one part of a larger, more complex drainage system. The drainage network in the permit area interacts with other parts of the larger drainage system in a complex fashion. Over time this complicated system has established a state of balance or quasi-equilibrium. The mining operation, or any other large-scale disturbance, will affect this balance or equilibrium and can result in dynamic responses throughout the system. The designer must recognize this phenomenon in order to restore the disturbed topography and drainage to a condition where it will again properly function as part of the larger system.

1.3 OSM Regulations Concerning Water Diversions

General provisions of OSM standards pertaining to surface mine drainage specify the best technology currently available should be used to minimize disturbances of the prevailing hydrologic balance, water quantity, and water quality. This standard is applicable to the mine site as well as outlying areas that would be affected by runoff from the mined region.

Of particular importance in the aforementioned specification is the phrase "best technology currently available," defined by the OSM as (30 CFR 701.5):

> "equipment, services, systems, methods, or techniques which will (a) prevent, to the extent possible, additional contributions of suspended solids to stream flow or runoff outside the permit area, but in no event result in contributions of suspended solids in excess of requirements set by applicable state or federal laws; and

(b) minimize, to the extent possible, disturbances and adverse impacts on fish, wildlife and related environmental values and achieve enhancement of these resources where practicable. The term includes equipment, devices, systems, methods or techniques which are currently available anywhere as determined by the Directors, even if they are not in routine use."

Other federal laws controlling discharges are the Federal Water Pollution Control Act and the Clean Water Act administered by the EPA.

Specifically, OSM regulations require that diversions of overland flow or flow in ephemeral streams are to be undertaken in a manner which prevents erosion, avoids contact with acid-forming and toxic material-forming materials, and reduces the amount of suspended solids entering receiving streams or other off-site bodies of water.

Standard practices and criteria related to the diversion of overland flow, and flow in ephemeral, perennial, or intermittent streams, are summarized in Table 1.1. It is important to note that the diversion channel itself does not necessarily have to be large enough to pass the design flow (Table 1.1, part a). Regulations allow that the combination of channel, bank and floodplain configurations be adequate to pass the required flows. However, the capacity of the channel itself should at least be equal to the capacity of the unmodified stream channel immediately upstream and downstream of the diversion.

1.4 Applications of Water Diversion Structures

Water diversion structures are temporary or permanent water handling structures used to control and manage the drainage above and through the disturbed area of a mine site including the channels diverting and conveying the runoff, grade control structures, erosion control structures, etc. In this manual, diversions are defined as those channels used to intercept and divert surface runoff, and those used to relocate or reestablish ephemeral, intermittent or perennial streams. Perennial streams normally carry water throughout the year because they either drain areas of heavy rainfall or intersect the ground water table at some point. Intermittent streams flow

Table 1.1. Design Requirements by Technologies.

Considerations*	Overland Flows, Shallow Groundwater Flows, Ephemeral Streams	Perennial and Intermittent Streams
<u>Hydrology</u>		
(a) Recurrence Interval-Design Event		
Permanent	10-year, 24-hour	100-year, 24-hour
Temporary	2-year, 24-hour	10-year, 24-hour
<u>Hydraulics</u>		
(b) Channel Capacity	Peak runoff from design event, 0.3 ft freeboard minimum. Protection of critical areas can be more stringent.	Must equal adjacent unmodified stream channel (floodplain capacity can be used for passing design event), but not less than (a).
(c) Channel Lining	Suitable to control and minimize water pollution.	To control erosion, must be stable and only require infrequent maintenance.
(d) Slope or Gradient	Appropriate for sediment control.	Longitudinal profile of the stream to remain stable and to prevent erosion.
(e) Velocities	Regulated to control and minimize water pollution.	Regulated to control and minimize water pollution.
<u>Geotechnical</u>		
(f) Backslopes	Stable	Stable
<u>Ecological</u>		
(g) Restoration		
Permanent	None	Restore or maintain natural riparian vegetation, including aquatic habitats (riffles, pools, drops, etc.) that approximate premining characteristics.
Temporary	Remove regrade topsoil & revegetate.	Same as ephemeral stream
(h) Enhancement	None	"Where practicable" enhance natural riparian vegetation.
(i) Shape	None	Establish or restore natural meandering shape of an environmentally acceptable gradient.
(j) Longitudinal Profile and Cross Section	(see slopes and capacity)	Establish or restore to approximate premining stream channel characteristics (including aquatic considerations below).
(k) Aquatic Habitats	None	"Establish or restore...usually a pattern of pools, riffles and drops...that approximate premining characteristics."

*Where not specifically indicated, temporary and permanent requirements would be the same.

steadily for only a part of the year and are seasonally dry. Ephemeral streams are normally dry and flow only in response to precipitation or snowmelt.

Diversion of surface runoff (overland flow), shallow ground water flow and ephemeral streams helps to control erosion, reduces contact time with acid-and toxic material-forming materials, and reduces the suspended sediments entering downstream bodies of water. Diversion of intermittent and perennial streams into new channels is performed to reduce seepage into or flooding of the work area, and to allow the mining operation in the region of the original stream channel. Diversion of intermittent or perennial streams is allowed only with specific approval from the regulatory authority due to the potential adverse environmental impacts.

Diversion ditches above the highwall or open cut are often portrayed in surface mining publications as a common method of diversion; however, this application is not always practiced. Water diversion channels can also occur within and through the disturbed area to reestablish drainage patterns. Application of diversion channels and relocations to contour, area and mountaintop removal methods are illustrated in Figures 1.1, 1.2 and 1.3, respectively. Diversions are also used below spoil slopes to direct runoff to sediment ponds and as conveyances of natural drainage around excess spoil slopes and on roadways to protect the lower portions of the hillside or roadway from highly erosive flows. Figure 1.4 illustrates the typical surface drainage control techniques used for an excess spoil fill.

Usually the channel is located in the groin area as shown. Due to the steep slope topography typical of the Eastern Coal Province, these channels must be carefully designed and constructed in order to remain stable.

Another diversion technique for excess spoil fills found unique to the Eastern Coal Province is the use of an internal rock core drain. This technique is employed in lieu of a surface diversion to convey runoff from the surface of the fill and from areas above the fill where the fills are not carried to the ridge line. The internal drain is used for handling both the surface and subsurface water. The surface water percolates through the rock core much like a french drain.

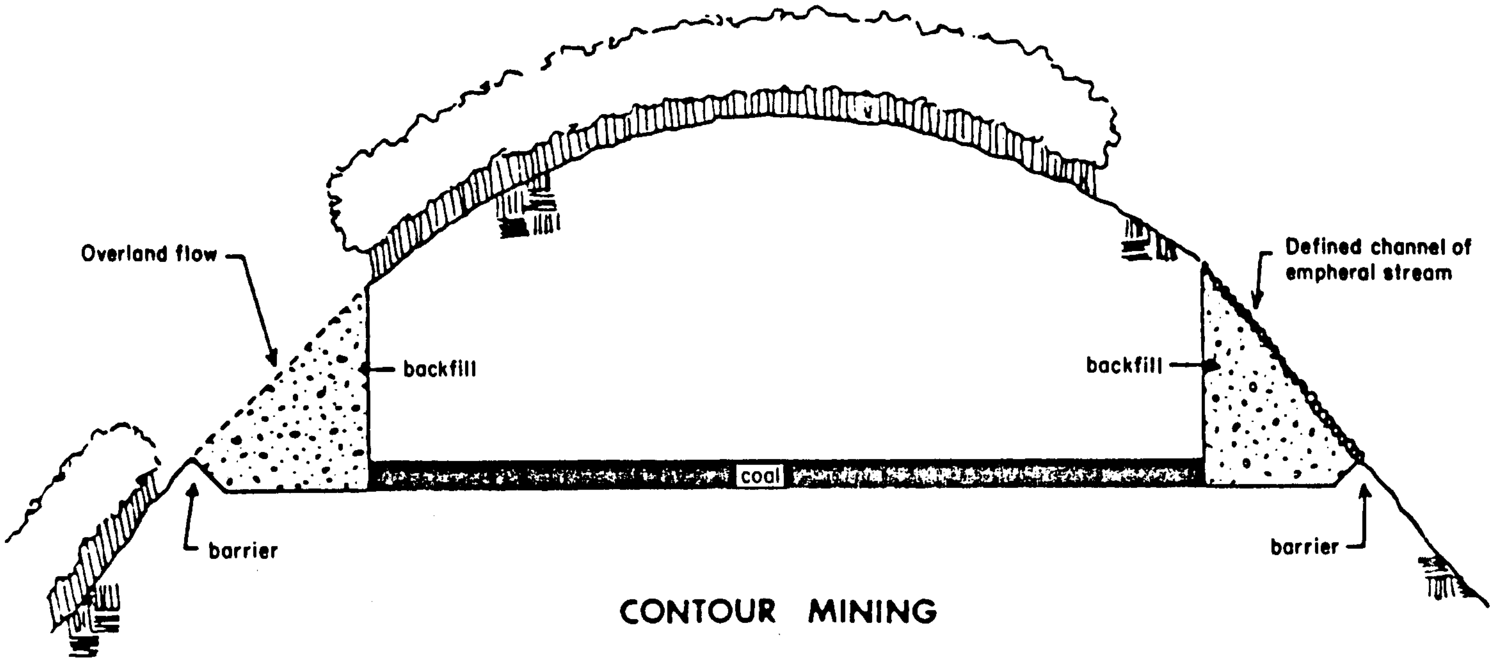

Figure 1.1. Drainage in contour mining.

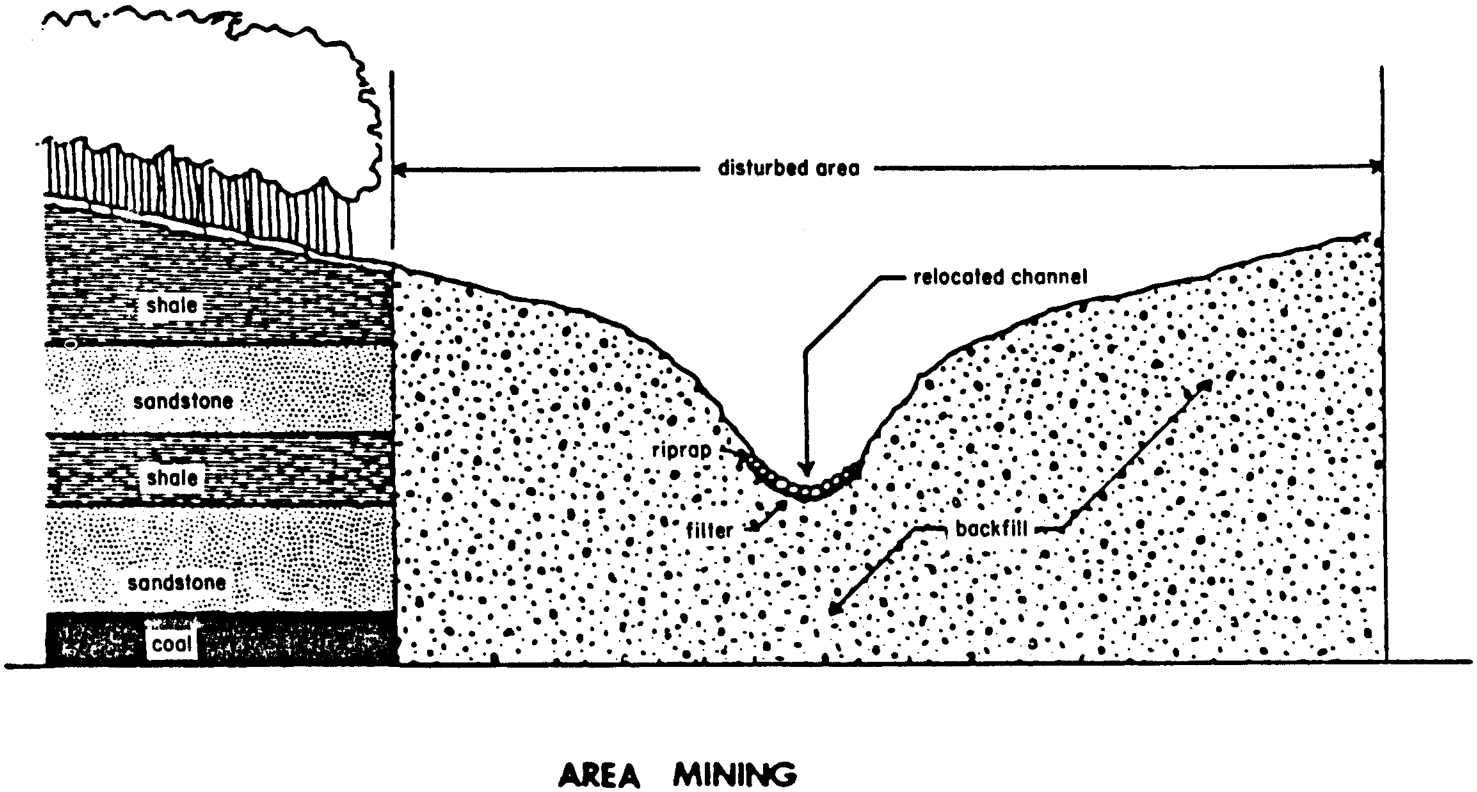

Figure 1.2. Relocated channel in area mining.

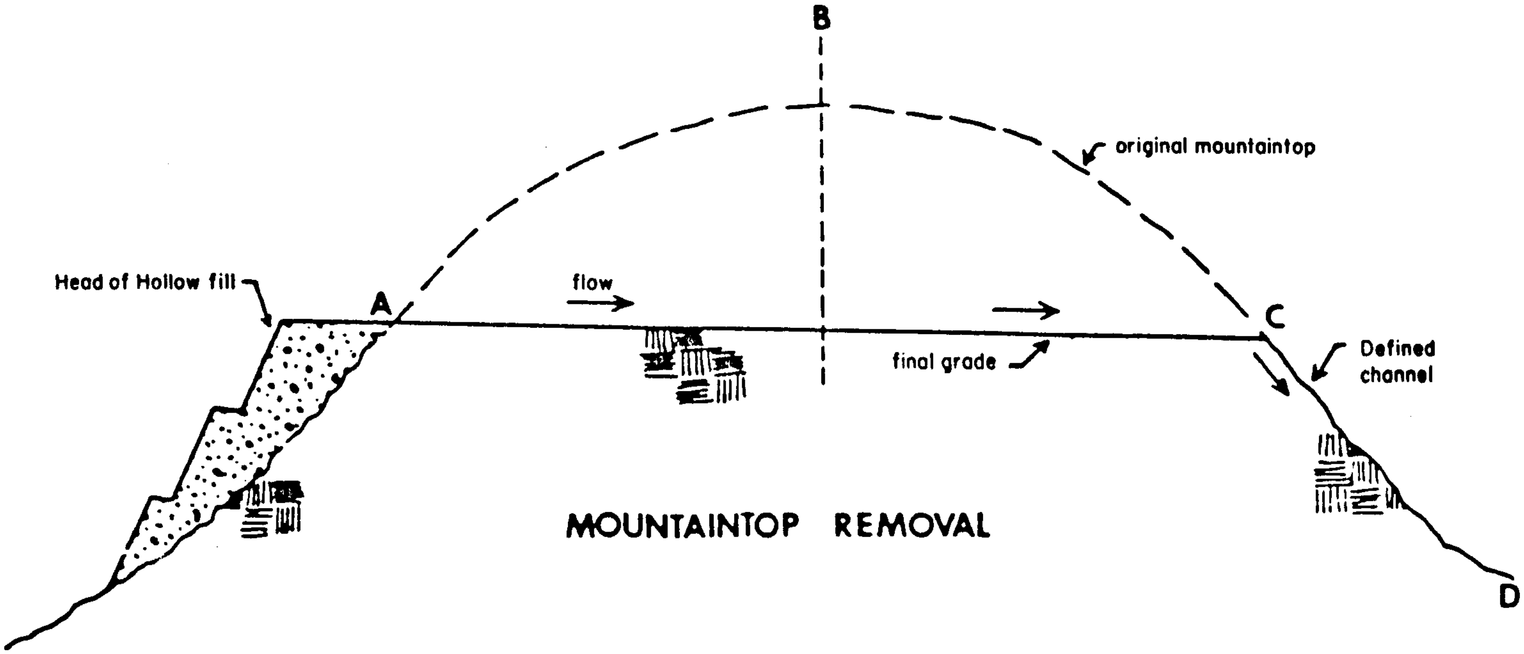

Figure 1.3. Drainage patterns in the mountain removal method.

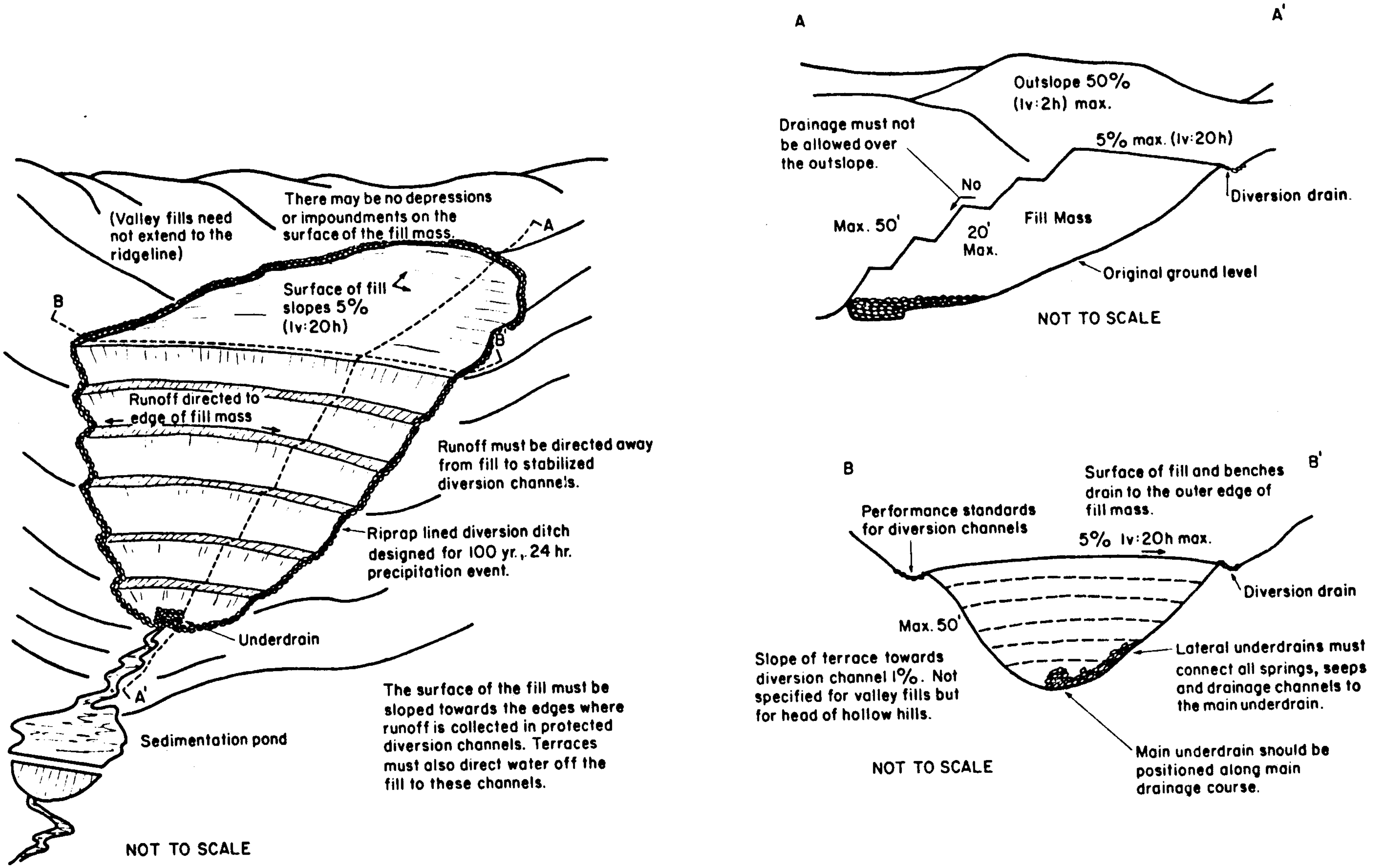

Figure 1.4. Design requirements for valley fills.

Based on current practices of surface conveyance construction observed on surface mine operations, at least for the short term, rock core drains may be a more feasible method for diverting water around spill fills. However, there were no standardized methods of design or analysis found in literature reviews. The construction techniques are also mostly left up to the operator. Additionally, many concerns have been raised as to their long-term functioning. No published research was found to confirm or dispute this concern. Therefore, no design technology for rock core drains in spoil fills is presented in this manual.

In most cases, diversion is an economical form of erosion control. It is not meant as a complete erosion control, but as an integral part of an erosion control plan. The following are some of the factors that can significantly affect the cost of diversion systems:

1. Topography - Unusually steep topography, dense forest cover or rock formations may increase the cost of surface trenching.

2. Equipment - Availability of adequate equipment can significantly affect the cost of diversion ditches.

3. Condition of Soil - Rock fissures and highly permeable soil may necessitate the use of an impermeable material for trench construction.

Small temporary diversion structures may include the use of straw bales, tires, downpipes, brush and other temporary measures in addition to some permanent measures to achieve grade and erosion control. However, after an operation is complete, temporary diversion channels and structures must be converted to permanent standards or removed and the affected land regraded, topsoiled and revegetated in the same way as other disturbed areas of the site.

Permanent diversion structures used for the reestablishment of a drainage system affected by surface mining must perform adequately without the assured benefit of periodic maintenance. Serious environmental problems have resulted in many previously mined areas, particularly in steep slope regions, due to inadequate design of the drainage network and associated diversion structures. Plate 1.1 illustrates the result of improper diversion channel design in fill material. Combined with steep slope conditions and relatively large annual precipitation, channels that are not properly designed or protected become deeply incised in the erodible fill material, thus becoming a con-

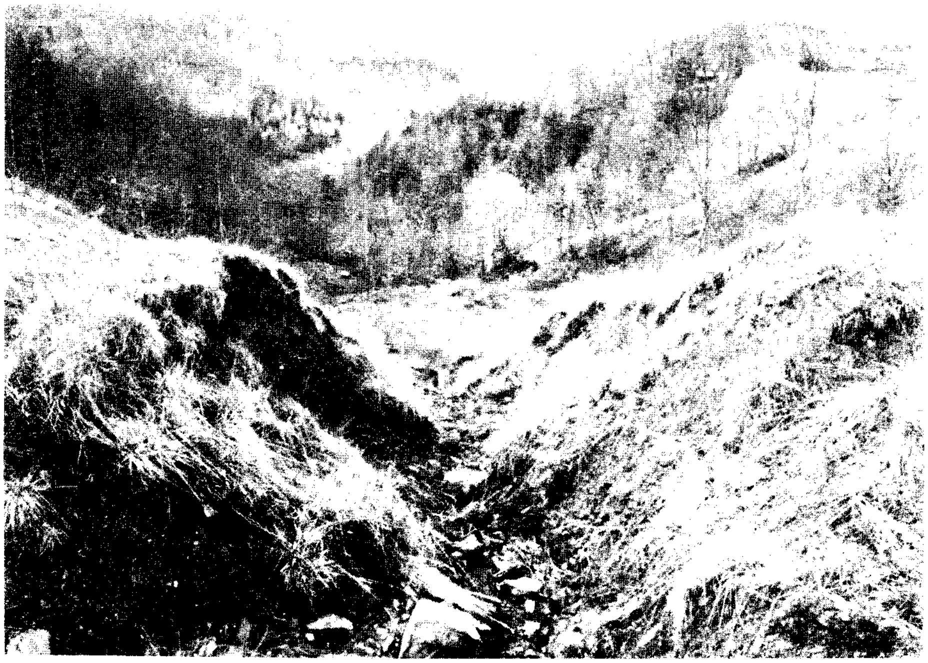

Plate 1.1

Plate 1.2

tinuous source of water pollution. However, even moderately sloped channels (Plate 1.2) can erode and become incised, illustrating the need for proper drainage in all cases. The incision shown in Plate 1.2 is not serious in its current condition; however, it has probably resulted from relatively small flows. If a 100-year event did occur, a much greater incision could be expected.

Typical drainage systems are shown in Figures 1.5 and 1.6 illustrating the relationship of ephemeral, intermittent and perennial streams. Reestablishment of ephemeral streams is the beginning and perhaps the most critical step in restoring the hydrologic balance of steep slope mining areas. If ephemeral streams do not perform adequately, significant erosion can occur in the upslope regions, resulting in large volumes of sediment being delivered to downstream intermittent and perennial streams. The increased sediment loading can cause a dynamic response and readjustment of these streams as the entire drainage network moves to reestablish a balance or quasi-equilibrium.

1.5 Problems Unique to OSM Regions I and II (Eastern Coal Province)

1.5.1 Geographic Considerations

The diversity in terrain, climate, biologic, chemical and physical conditions throughout mining regions of the country was recognized in the Surface Mining Control and Reclamation Act of 1977. The most dramatic differences are apparent between the mining operations of the humid eastern states and those of the arid and semiarid western states. The definitions of humid, arid and semiarid are generally based on precipitation, although a variety of climatological and environmental factors is involved. According to OSM regulations, the 100th Meridian is defined as the legal boundary of the "arid and semi-arid area." This definition is commonly accepted, although it ignores the humid Pacific coast and the snowfall of high mountain regions.

Dryland landscapes are quite different from those of more humid regions. The topography and landforms are more abrupt, the soils are thinner, the bedrock exposures are usually more pronounced and the streams are smaller and are likely to be dry for at least part of the year. Overall, the physical environment reflects the lack of water and the predominance of mechanical weathering and erosion over chemical weathering and solution.

In a humid environment high precipitation produces vegetation and soils that are well developed and stabilized. Under these natural conditions,

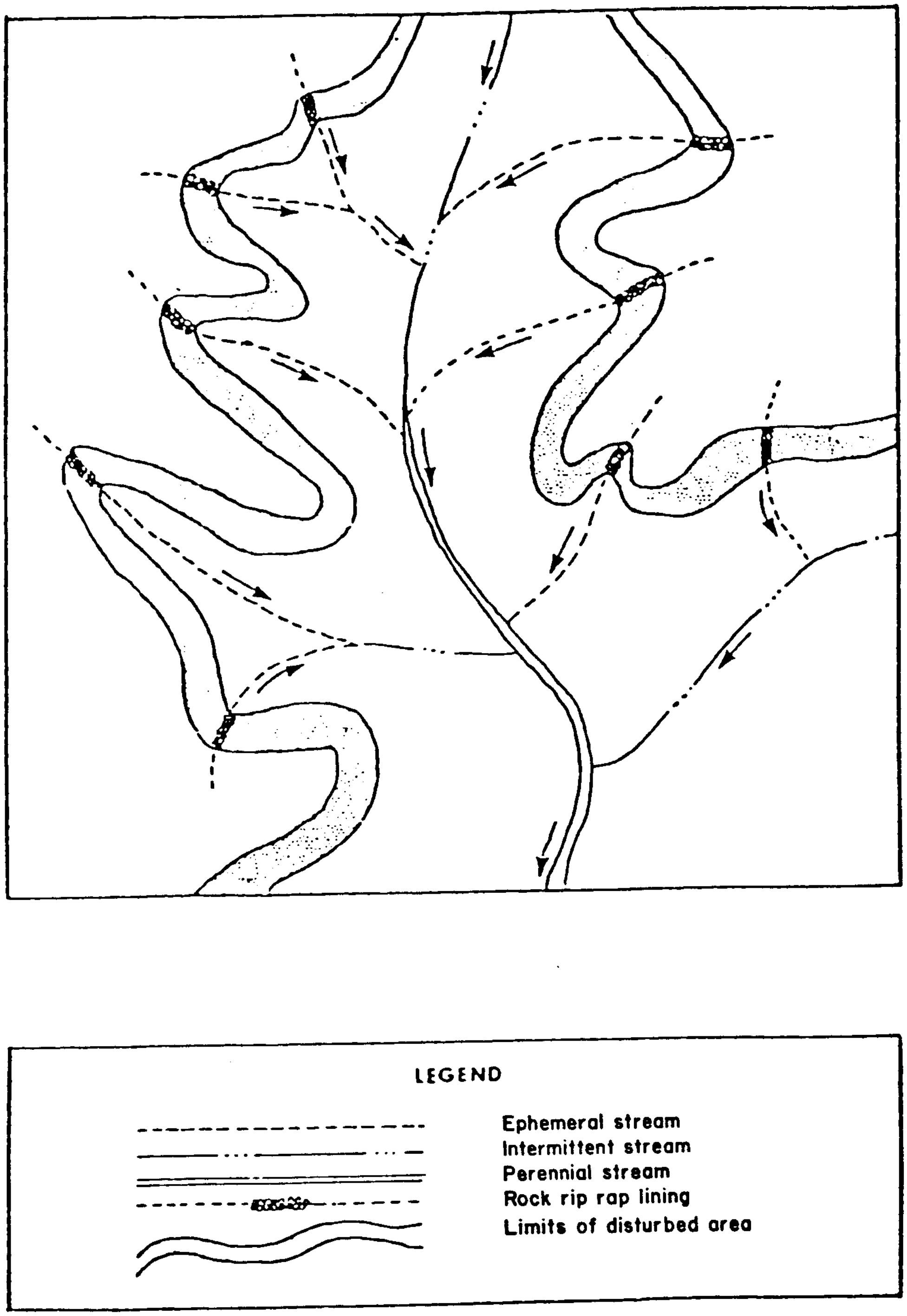

Figure 1.5. Plan view of contour mining drainage plan.

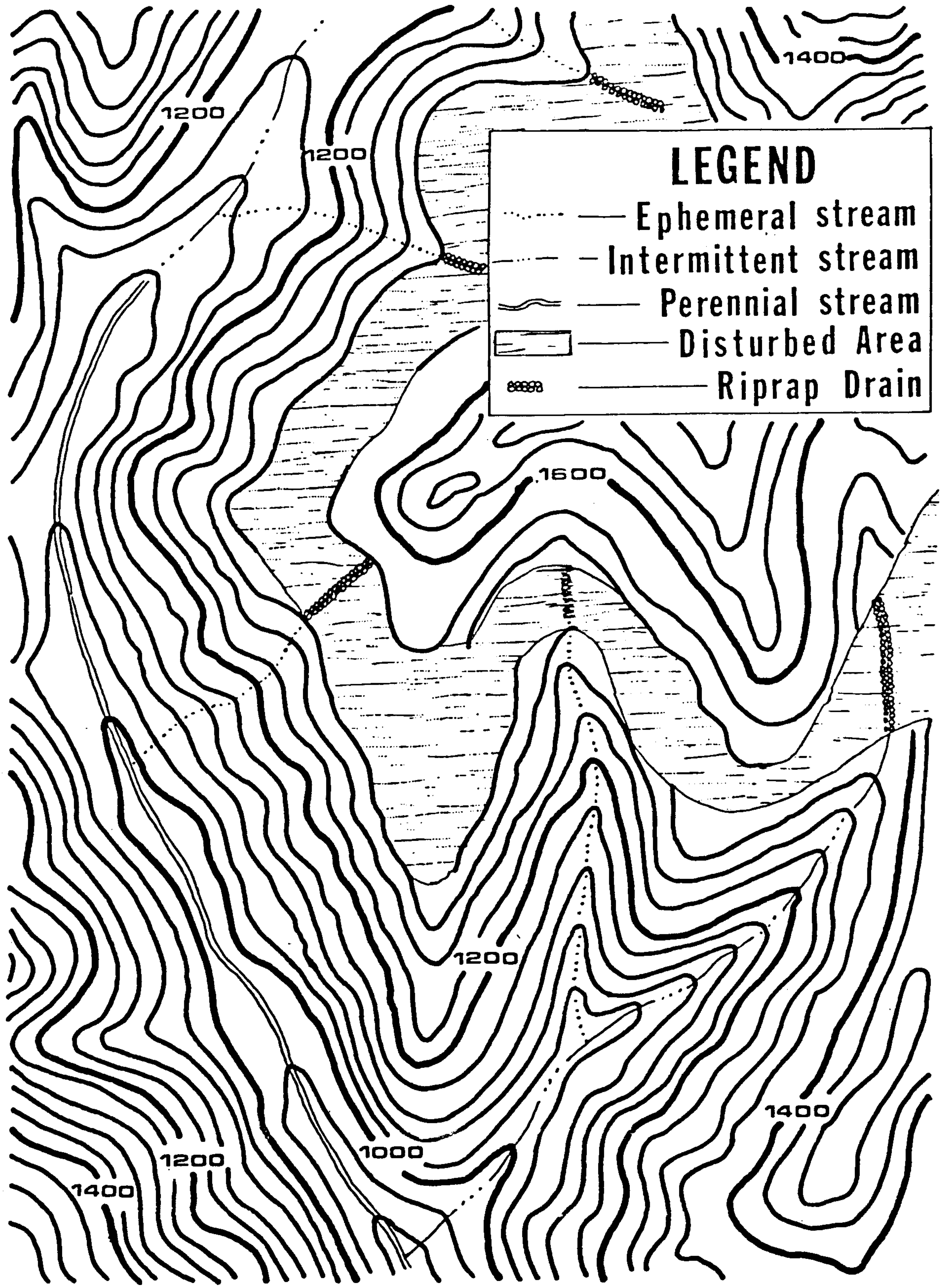

Figure 1.6. Plan view of a contour mine drainage plan.

streams generally carry low suspended sediment loads, reflecting this stability in the upland watersheds. Additionally, high precipitation produces a dilution effect on the sediments that are eroded.

In contrast, dryland streams normally carry quite high sediment loads from erosion by both wind and water. The precipitation generating the erosion in a dryland environment usually results from small storm cells that may be limited in areal extent, but can produce high intensity and rainfall energy. This type of storm produces "flashy" runoff with pronounced capacity for sediment removal and transportation. Only rarely does a single storm produce runoff in all parts of a dryland stream basin, and extended periods may pass with no streamflow at all. Many dryland streams flow only during the spring runoff and immediately after major storms. Therefore in drylands even streams draining large basins are often intermittent or ephemeral, while in a humid region most larger streams would be perennial.

However, in any climate one of the most important factors affecting sediment yield is land use. Wilson (1972) shows that the impact of surface mining on the humid eastern states produces sediment yields from the affected areas that are similar to those of arid regions. Therefore, higher sediment yields from disturbed mining sites in OSM Regions I and II relative to the natural stability of these watersheds must be considered in diversion channel design.

1.5.2 Specific Problems Observed in OSM Regions I and II (Eastern Coal Province)

Based on mine site visits during Phase I of this project, some general observations were made and specific problems identified. In most of the steeper sloped areas, surface mining is relatively high in the watershed, so diversions above the highwall controlling upper watershed drainage are not utilized. However, even in more moderately sloped areas where larger upper watershed drainages exist, such diversions are not utilized for drainage control. Water and sediment control is usually below the strip in the form of diversion structures leading to sediment ponds. The use of diversion channels to route flow through or around fill areas (head-of-hollow or valley fills) is a common application. Culverts and other closed conduit structures were not observed for diversion applications.

In general, a common problem with diversion channels appears to be construction techniques and the lack of proper supervision and inspection of construction work. For example, when riprap was used, it often was not properly designed or placed. Filter blankets beneath the riprap were not observed in any application. Additionally, the riprap layer was typically mounded in channels rather than being placed in a manner that maintained a basic channel shape (Plate 1.3). Consequently, the channel design capacity was greatly reduced, forcing larger flows outside the channel boundary (Plate 1.4). The lack of gradational particle sizes in the riprap layer was also a common problem. Typically, only rock of large diameter was used for riprap.

Part of the problem appears to be the difficulty in placing riprap on steep slopes. Catepillar D-9 bulldozers with 14-foot blades are used for earthmoving work, including diversion channel construction. In many instances, this piece of machinery is too large for effective or efficient channel construction based on permit design. For example, the typical technique for steep-slope riprap placement is end-dumping at the upslope end of the channel and then working a D-9 downslope to position the riprap. However, the result is usually a channel that is level or mounded and full of rock. More effective construction techniques will have to be implemented to insure adequate drainage in these situations. For example, the diversion channels could be built concurrently with the fill instead of after completion of the fill. As each lift is completed, the channel and riprap lining could be constructed, thus simplifying construction.

Plates 1.5 and 1.6 show the use of large boulders placed parallel to the channel to prevent meandering. Under the low flow conditions existing when the pictures were taken, the design may appear reasonable. However, under higher flow conditions, these boulders would probably not contain the flow. Although the boulders themselves would not move, the stream would move out of the riprapped channel by cutting a new course between any given pair of boulders.

Plate 1.7 illustrates another case where excessively large rocks have been used. The picture shows the entrance to a fill slope diversion. Under high flows most of the water would probably be forced around these boulders, thereby missing the riprapped channel entirely.

Given the difficulties in designing and placing riprapped diversions, some attempts have been made to avoid the problem entirely. Plate 1.8 illustrates a case where the natural drainages were completely blocked. The reasoning behind this design is that water caught behind the blockage will

Plate 1.3

Plate 1.4

Plate 1.5

Plate 1.6

Plate 1.7

Plate 1.8

slowly infiltrate and move through the fill as groundwater. Forcing overland flow from the upper watershed to groundwater flow can result in slope stability problems on the fill. This design could also create serious problems in the future. If, through time, the ground surface is sealed by deposition of fine silts and clays, ponded water could overtop the barrier, causing excessive erosion on the fill slopes.

Some examples of properly designed and constructed channels were observed. Plate 1.9 shows a small channel leading to a sediment pond. The riprap appears to have been hand-placed; however, the important concept is that the basic shape of the channel has been maintained. This basic concept is critical to a successful, long-lasting channel. Plate 1.10 shows another example of a larger channel on a steeper slope. Again, the riprap was probably hand-placed, which is not economically feasible on a larger scale. Regardless of the placement technique, the basic channel shape must be maintained in order for the channel to operate as designed.

Some examples of larger-scale channels that have been properly designed and constructed were observed in the mountains of Colorado. Plate 1.11 is a steep drainage channel along Interstate 70 on Vail Pass. Note how the rocks are placed, probably by machinery (i.e., not hand-placed), in a manner that maintained the basic channel shape. Plate 1.12 shows another approach using wire gabions to stabilize a steep slope drainage.

1.6 Design Manual Organization and Use

1.6.1 Design Manual Organization

The Design Manual is organized in two parts. Both parts are contained in this volume and the chapters are consecutively numbered for easy reference. Part II begins with Chapter XI. Part I considers design methodologies that are primarily applicable to the Eastern Coal Province. Additionally, it presents the other general information and background knowledge required to complete a good design. Part II contains supplemental design information required to design channels in sandy soil regions.

Due to the predominantly steep slope conditions that exist in the Eastern Coal Province, Part I gives special consideration to design procedures for steep slope channels (Chapter V). However, mild slope channels are also considered (Chapter VI). Rock riprap channels are emphasized due to their current widespread use.

Plate 1.9

Plate 1.10

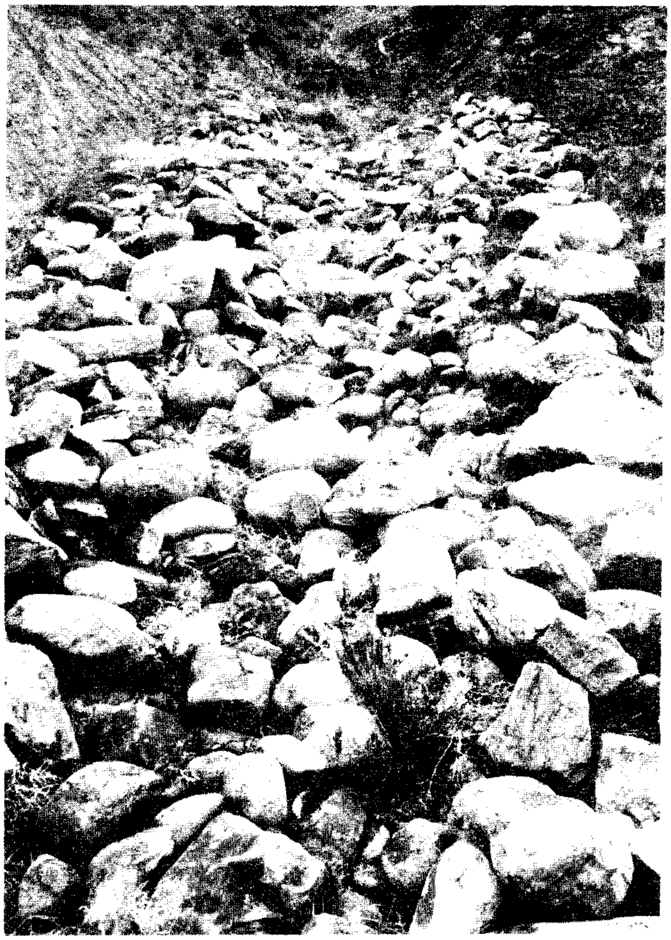

Plate 1.11

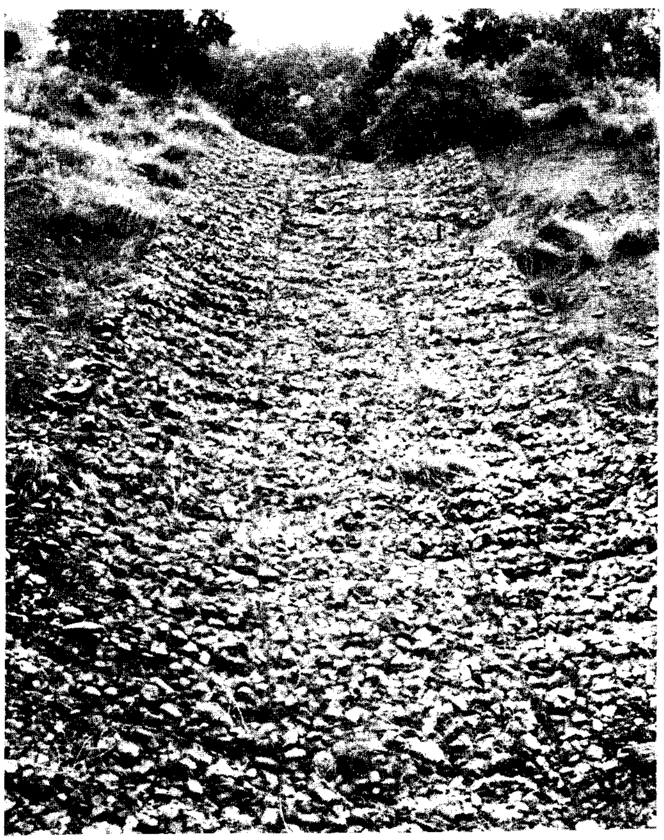

Plate 1.12

Due to the significant differences in stream morphology between the humid eastern states and the dryland environment of the western states, Part II presents the additional information required to design channels in sandy soils. Bed form conditions common in sand-bed channels and their effect on resistance to flow are discussed in Chapter XII. Chapter XIII discusses alluvial channel concepts, particularly movable boundary hydraulics. The design of large rock riprap drop structures is discussed in Chapter XVI and the design of dikes in Chapter XVII.

Assessment of the best technology currently available for application to surface mine operations as presented in this Design Manual was based on a comprehensive literature review. For those methodologies applicable to the Eastern Coal Povince a written literature review was prepared as the Phase I report for this project. Selection criteria for inclusion in the Design Manual from the broad range of design methodologies available included consideration of the physical environment at surface mine operations, current design procedures employed, the problems with existing diversion structures, and the level of effort required to produce an adequate diversion design. Many of the state-of-the-art procedures that provide the best possible design are too complicated and laborious to be used and are not included in the manual. In contrast, many of the simplified procedures, including some methods in common use, produce inadequate designs that probably would not survive the high flows required for permanent structures by OSM regulations. Therefore, the objective was to produce a usable document that provides reliable, accurate design procedures for conditions that exist on a surface mine operation.

Information in both the Phase I report and the Phase II Design Manual, Part 1 and Part 2, concentrates on permanent water diversion structures due to their greater long-term importance. Many publications are available providing design guidelines for temporary diversion design. Culverts and other closed conduit conveyance structures were also not considered. These structures may represent viable alternatives as a short-term, temporary water conveyance method; however, their permanent, long-term use cannot be considered reliable due to maintenance requirements. Additionally, due to concrete requirements, their construction can be very labor intensive, making them relatively infeasible for use on surface mine sites.

1.6.2 Design Manual Use

At first glance the Design Manual may appear difficult to use with complex and elaborate design procedures; however, upon closer examination the user should realize that throughout the manual an effort has been made to simplify the design procedures as much as reasonably possible. It may be that the Design Manual appears complex only relative to the procedures currently used. To overcome this potential problem, a flow chart has been prepared and numerous examples are given. The flow chart (Figure 1.7) illustrates the overall organization and decision-making process involved in the design of diversion channels and relocations. Familiarity with this flow chart will greatly aid the designer in utilizing the manual. For example, the flow chart indicates the first and perhaps most important decision in the design process is whether or not the slope condition is hydraulically steep or mild. Note that this definition of slope is in the hydraulic and not the topographic sense. This slope definition is assumed throughout the Design Manual. The hydraulic slope is based on the Froude number (Section 4.2.5) which depends on velocity and depth of flow. However, both velocity and depth of flow depend on the channel size and roughness. Therefore, the designer must first assume a slope condition based on topographic considerations and proceed with the design. At a later point in the design process this initial assumption is checked to insure the correct procedures have been followed. A good assumption to make is if the slope is greater than 10 percent the steep slope procedures should be followed; however, the designer must realize that in some cases slopes as low as four to five percent may be hydraulically steep.

The comprehensive examples given in Chapters X and IXX illustrate the application of the design procedures to conditions typical of eastern and western state mining operations, respectively. Users of the Design Manual are encouraged to carefully review these examples and the other examples within each chapter to better understand the design methodologies. With a little practice the complete design process will become familiar and straightforward.

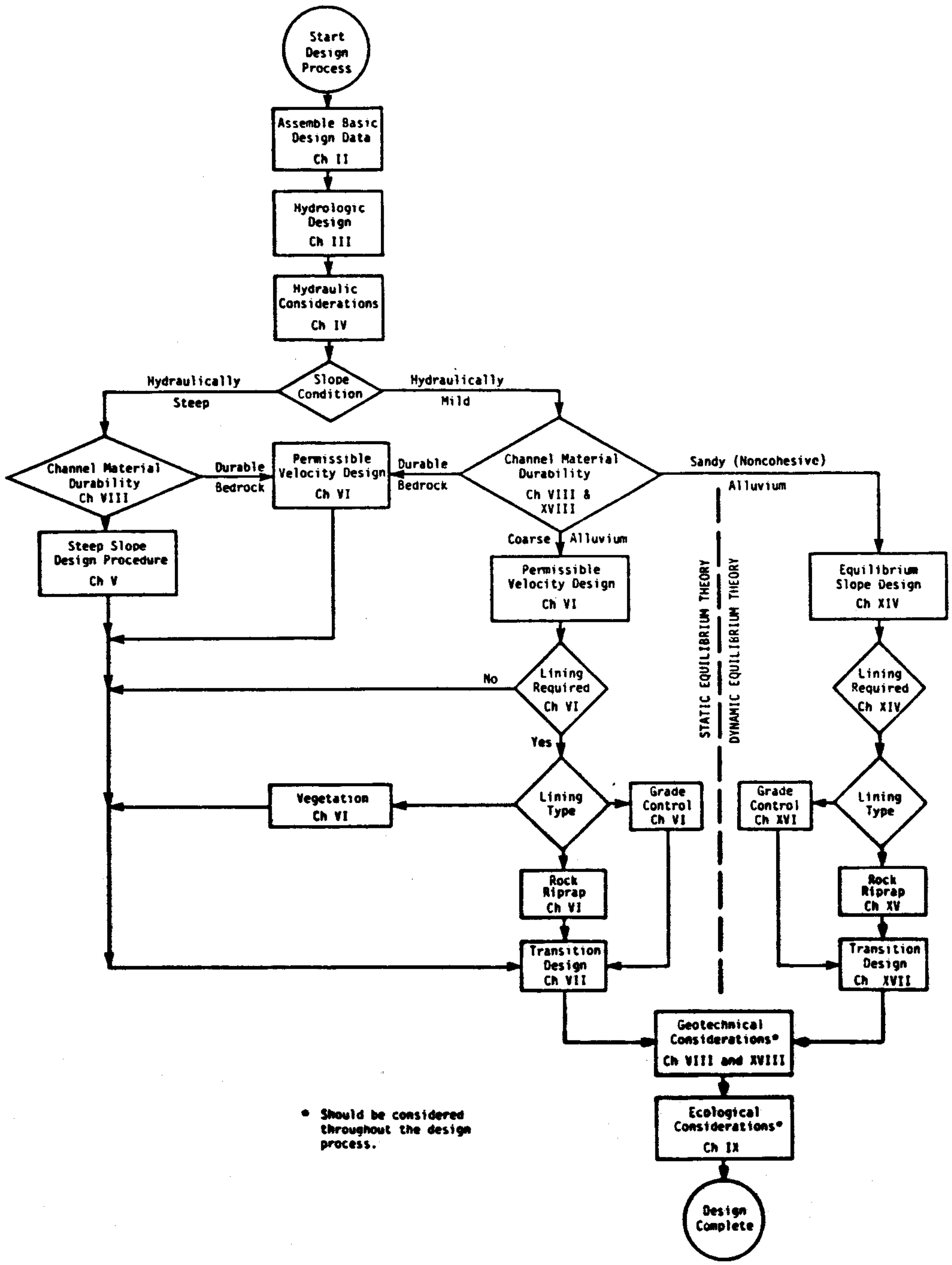

Figure 1.7. Flow chart illustrating design manual organization.

1.7 References

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