

ATTACHMENT A

Methodology for Analysis of
Existing Diversions

REPORT

Methodology for Analysis of
Existing Diversions

Kayenta and Black Mesa Mines

for

PEABODY COAL COMPANY



Dames & Moore
10139-011-22

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1.0 INTRODUCTION

The purpose of this report is to explain the analytical methodologies employed in the investigation of five existing diversion channels (J16, N7/8, N14, N14-S and Coal Mine Wash) at the Kayenta and Black Mesa Mines. These investigations were conducted by Dames & Moore in October 1985.

2.0 CHOICE OF DESIGN STORM

The storm events used for designing diversion channel capacity and stability are specified in the Department of the Interior, Office of Surface Mining (OSM) regulation 30 CFR 816.43. These regulations specify varying design storms depending upon whether the diversion channel is permanent or temporary, and depending upon whether the replaced natural channel contains a perennial, intermittent or ephemeral stream.

The five diversion channels covered by this report all occupy reaches of channel which are dry, except for periods immediately following rainfall events. This aspect of each channel was determined by an October 1985 field inspection conducted at the end of the usual annual wet season, following a week without appreciable rainfall. These field inspections determined the investigated channels contain ephemeral streams.

Since the investigated diversion channels are permanent diversions, the channels were analyzed using the 10-year, 6-hour storm, in accordance with the regulations cited above.

The determinations of the rainfall and runoff associated with the storm are explained in Section 3.0, Hydrology. The peak flowrate thus determined is used to check the capacity and stability of the diversion channels. This analytical procedure is explained in Section 4.0, Hydraulics.

3.0 HYDROLOGY

3.1 PRECIPITATION

Precipitation depths for the 10-year storm were developed using procedures and data published in the National Oceanic and Atmospheric Administration Atlas 2 (NOAA, 1973). Table 1 shows the precipitation frequency-depth-duration data developed for the Kayenta and Black Mesa Mines.

3.2 RUNOFF

The inflow hydrograph for each watershed tributary to a diversion channel was calculated using the computer program HEC-1 Flood Hydrograph Package developed by the U.S. Army Corps of Engineers (1981). HEC-1 provides several unit hydrograph methods for modeling the hydrologic response of a watershed. It includes procedures to account for rainfall-depth-duration, precipitation losses, and unit hydrograph shape.

Table 1

PRECIPITATION FREQUENCY - DEPTH - DURATION
KAYENTA AND BLACK MESA MINES, ARIZONA

| Precipitation (inches) | |
|------------------------|------------------|
| Duration | 10-Year Storm |
| 5 min | 0.35 |
| 10 min | 0.54 |
| 15 min | 0.68 |
| 30 min | 0.95 |
| 1 h | 1.20 |
| 2 h | 1.34 |
| 3 h | 1.43 |
| 6 h | 1.60 |
| 12 h | 1.80 |
| 24 h | 2.10 |

Synthetic storms for each storm frequency were developed by HEC-1 using the depth-duration data. A triangular precipitation distribution was constructed such that the depth specified for the duration occurred during the central part of the storm. This result is referred to as a balanced storm.

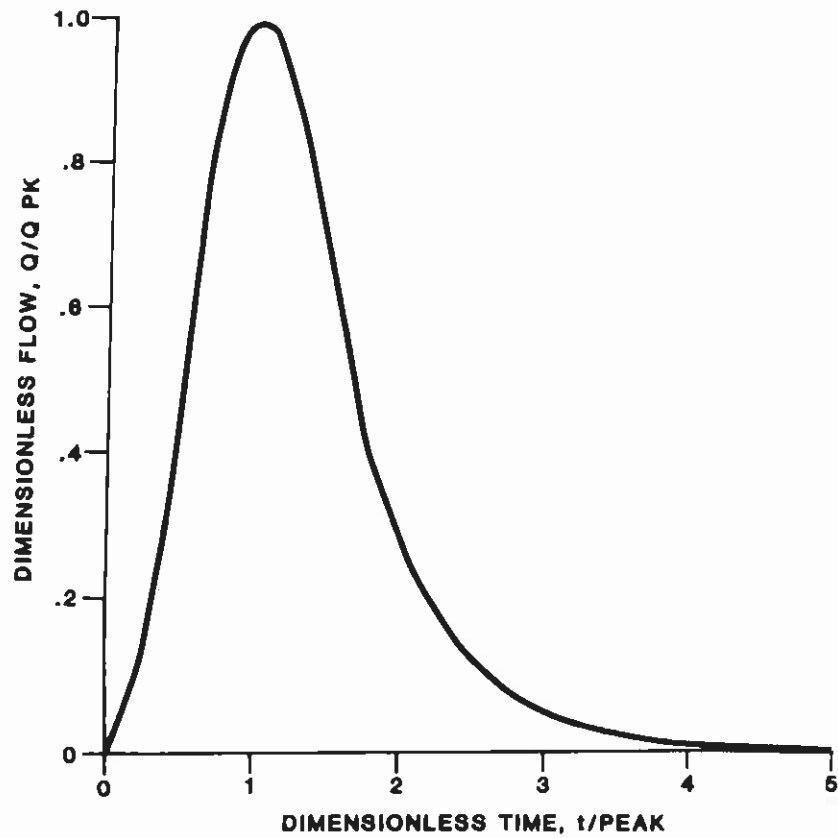
Interception and infiltration losses were calculated using the U.S. Soil Conservation Service (SCS) curve number method (SCS, 1972). A curve number was assigned to each tributary watershed to describe the drainage characteristics of the watershed. Since the SCS method gives total precipitation excess for a storm, HEC-1 calculates the incremental excess for each time period in the hydrograph analysis as the difference between the accumulated excess at the end of the current time period and the accumulated excess at the end of the previous period. The initial abstraction was calculated by HEC-1 using the formula:

$$IA = 0.2 \frac{(1000 - 10(CN))}{(CN)}$$

Where CN = the SCS curve number

IA = the initial abstraction in inches.

A synthetic unit hydrograph for each tributary watershed was developed by HEC-1 using the SCS dimensionless unit hydrograph method. Figure 1-1 shows the SCS dimensionless unit hydrograph. The time to peak and peak flow for the unit hydrograph were calculated based on a single parameter, lag time. Lag time is defined as the time between the center of mass of rainfall excess and the peak of the unit hydrograph. The time to peak is calculated using:



SCS DIMENSIONLESS UNIT HYDROGRAPH

BY **Dames & Moore**

Figure 1-1

$$T_p = 0.5 (t) + LAG$$

Where T_p = time to peak,
 t = the storm duration
LAG = the lag time.

The peak flow of this unit hydrograph is calculated using

$$Q_p = 484 (AREA)/T_p$$

Where Q_p = peak flow
AREA = the drainage area in square miles (USCS, 1972).

The synthetic storm, infiltration and interception losses, and synthetic unit hydrograph were used by HEC-1 to calculate the inflow hydrograph from each watershed tributary to a diversion channel. From the above discussion, it is apparent that to use the HEC-1 model, one must provide the SCS curve number, lag time, and drainage areas for each watershed draining into a diversion channel. These parameters were developed using the following procedures.

3.2.1 Curve Numbers

SCS curve numbers were estimated for each tributary drainage area based on the cover type, percent vegetation cover, hydrologic conditions and hydrologic soil type. Several sources were used to obtain this data:

1. Cover type -- Aerial photographs of the mine site and maps delineating the proposed active mine areas were used to identify the cover type. Three general categories of cover type were used: reclaimed, undisturbed and disturbed. Further sub-classifications were made in each category as shown in Table 2.

The cover type (and the tributary drainage area) for some structures will vary throughout the life of the structure as mining and subsequent reclamation occurs. For these cases, the worst condition was assumed for the hydrologic analysis. Usually the worst condition is the maximum disturbed area at the end of the mining activity and just prior to the start of land reclamation.

2. Percent Vegetation Cover -- The percent of the ground surface covered by vegetation in undisturbed areas was estimated from field inspections.
3. Hydrologic Conditions -- The hydrologic condition was directly related to the percent vegetation cover as shown in Table 2.
4. Hydrologic Soil Type -- Soil survey maps (Espey, Huston and Associates, 1980) provided the basis for determining hydrologic soil type. Tables 3 and 4 show the soil type for each soil series name.

Cover types and hydrologic soil types were delineated for each drainage area contributing flow to a diversion channel. A curve number was assigned to each distinct hydrologic region of the watershed, based on comparison with the conditions in Table 2. An overall curve number for the watershed was derived by calculating a watershed weighted average, based on relative acreage of each distinct hydrologic region.

Table 2
SCS CURVE NUMBERS
KAYENTA AND BLACK MESA MINES, ARIZONA

| Cover Type | Vegetation Cover | Hydrologic Conditions | Hydrologic Soil Type | | |
|--|---------------------|--------------------------|-------------------------|----|----|
| | | | B | C | D |
| <u>Reclaimed Areas (Herbaceous)</u> | | | | | |
| Pre-Law (1977) | | poor | -- | 87 | -- |
| Post-Law (1977) Contoured | | fair | -- | 81 | -- |
| <u>Undisturbed Areas</u> | | | | | |
| <u>Pinion-Juniper</u> | | | | | |
| Poor Conditions | 0-30% | poor | 75 | 85 | 89 |
| Average Mine Conditions | 35% | -- | 65 | 78 | 83 |
| Fair Conditions | 30-70% | fair | 58 | 73 | 80 |
| <u>Sagebrush-Grass</u> | | | | | |
| Poor Conditions | 0-30% | poor | 67 | 80 | 85 |
| Average Mine Conditions | 30% | -- | 60 | 73 | 79 |
| Fair Conditions | 30-70% | fair | 51 | 63 | 70 |
| <u>Disturbed Areas</u> | | | | | |
| Paved w/open ditches (including right-of-way) | | -- | 89 | 92 | 93 |
| Gravel roads (including right-of-way) | | -- | 85 | 89 | 91 |
| Dirt roads (including right-of-way) | | -- | 82 | 87 | 89 |
| Newly graded areas or bare ground | | -- | 86 | 91 | 94 |

Sources: Revised SCS Technical Release No. 55.
Communication with Colorado and Arizona SCS
State Hydrologist (8-5-85).

Table 3

HYDROLOGIC SOIL TYPES
BLACK MESA AND KAYENTA MINES, ARIZONA

| Hydrologic Soil Type | Map Symbol* | Map Unit Name |
|----------------------------|----------------|---|
| D | 1 | Zyme very channery loam, 0 to 8 percent slopes |
| D | 2 | Zyme very channery loam, 8 to 30 percent slopes |
| D | 3 | Zyme-Travessilla complex, 15 to 30 percent slopes |
| D | 4 | Zyme-Travessilla complex, 8 to 15 percent slopes |
| B | 5 | Cahonavery fine sandy loam, 0 to 3 percent slopes |
| B | 6 | Begay loam, 0 to 3 percent slopes |
| B | 7 | Las Lucas sandy clay loam, 0 to 8 percent slopes |
| B | 8 | Las Lucas sandy clay loam, severely eroded, 0 to 8 percent slopes |
| D | 9 | Travessilla gravelly fine sandy loam, 0 to 8 percent slopes |
| D | 10 | Travessilla gravelly fine sandy loam, 8 to 15 percent slopes |
| D | 11 | Travessilla gravelly fine sandy loam, 15 to 30 percent slopes |
| C | 20 | Zyme-Cahona-Dulce association, 0 to 30 percent slopes |
| C | 21 | Zyme-Las Lucas complex, 0 to 15 percent slopes |

Table 3 (Continued)

| Hydrologic Soil Type | Map Symbol* | Map Unit Name |
|----------------------------|----------------|---|
| C | 22 | Zyme-Las Lucas-Dulce association, 0 to 30 percent slopes |
| D | 23 | Zyme-Dulce complex, severely eroded, 0 to 30 percent slopes |
| D | 24 | Zyme-Dulce association, 8 to 30 percent slopes |
| D | 25 | Zyme-Dulce-Las Lucas association, 0 to 30 percent slopes |
| C | 26 | Cahona-Zyme association, 0 to 30 percent |
| B | 27 | Begay-Las Lucas association, 0 to 8 percent slopes |
| C | 28 | Las Lucas-Zyme-Dulce complex, 0 to 8 percent slopes |
| D | 29 | Dulce gravelly fine sandy loam, 0 to 30 percent slopes |
| D | 30 | Dulce-Zyme association, 15 to 30 percent slopes |
| C | 31 | Dulce-Cahona association, 0 to 30 percent slopes |
| C | 32 | Dulce-Las Lucas association, 0 to 15 percent slopes |
| D | 33 | Dulce-Las Lucas-Zyme association, 8 to 30 percent slopes |
| D | 34 | Pits and dumps |

Table 3 (Continued)

| Hydrologic Soil Type | Map Symbol* | Map Unit Name |
|----------------------------|----------------|---|
| D | 35 | Torriorthents, reclaimed |
| B | 36 | San Mateo silt loam, 0 to 8 percent slopes |

*Map symbol refers to symbols in Espey, Huston and Associates, 1980.

Sources: Espey, Huston & Assoc., Soil Survey, 1980
Intermountain Soils Inc., Soil Survey, 1985

Table 4

HYDROLOGIC SOIL GROUP
BLACK MESA AND KAYENTA MINES

| Soil Series | Hydrologic Group |
|-------------|---------------------|
| Begay | B |
| Bond | D |
| Cahona | B |
| Chilton | B |
| Dulce | D |
| Las Lucas | B |
| Oelop | B |
| Pulpit | B |
| San Mateo | B |
| Sharps | B |
| Travessilla | D |
| Zyme | D |
| Soil A | B |
| Soil B | B |

(Intermountain Soils, Inc., 1985)

3.2.2 Drainage Area

Each tributary drainage area was measured on 1 inch equals 400 feet topographic maps supplied by Peabody Coal Company (Drawing #85400, Sheets 1 to 26 of 26).

3.2.3 Time of Concentration and Lag Time

The runoff time of concentration was calculated using the following standard SCS equation (U.S. Department of the Interior, 1977):

$$T_c = \left[\frac{11.9 (L)^3}{H} \right]^{0.385}$$

Where: L = length of longest water course in miles
H = watershed elevation difference in feet
T_c = time of concentration in hours

The lag time was calculated as 60 percent of the time of concentration (Linsley and Franzini, 1972).

3.3 ROUTING

Once HEC-1 calculated the inflow hydrograph from a watershed tributary to the diversion channel, the program added this hydrograph to the existing hydrograph of upstream flows already in the channel. This combined hydrograph was then routed through the diversion channel to the next junction with a tributary watershed.

Modified Puls routing (Linsley and Franzini, 1972), a storage routing method, was used for analyses. Cross sections along each reach of channel were measured and their coordinates input into HEC-1. The initial flow in each reach, prior to the design storm, was set equal to zero.

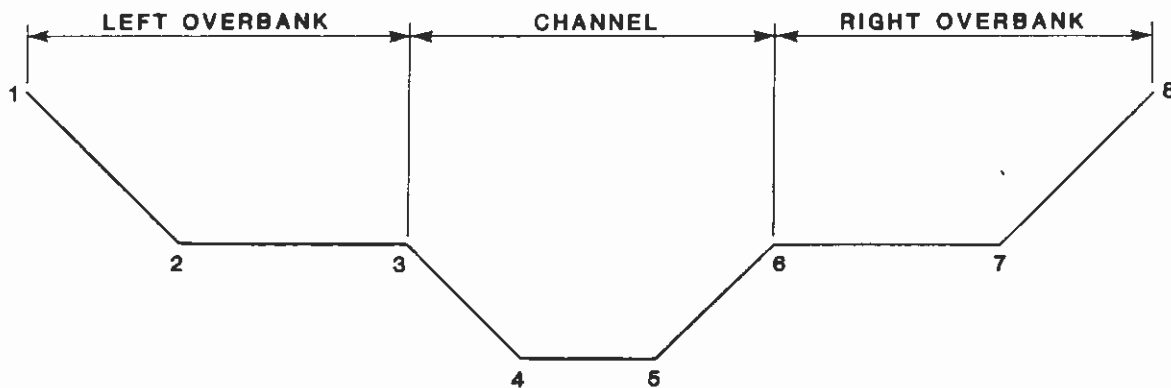
4.0 HYDRAULICS

The purpose of investigating the existing diversion channels was to determine the capacity and stability of these man-made channels relative to the capacity and stability of the replaced natural channels. The hydraulic analysis portion of this investigation: 1) points out the regions where channel capacity for the design flood may be inadequate, and 2) complements the field inspection by explaining the causes of the areas of observed channel instability. Of these two, the primary consideration is channel stability. This requires the matching of natural and man-made channel velocities (OSM, 1982, Section 13). For this evaluation of relative velocities, an analysis using Manning's equation suffices, as long as uniform flow is approximated in the channel. Except for short stretches of each diversion channel, cross sections and parameters are relatively constant and the uniform flow assumption is valid. The exceptions and their implications are discussed in each diversion channel report in the field inspection appendix and in the Summary of Results and Recommendations section.

The hydraulic analysis involved inserting predetermined channel hydraulic characteristics (roughness, cross-sectional shape, bed slope) and design flowrates (generated by HEC-1) into the Manning equation. Flow

depth, channel and overbank velocities, tractive stress and tractive power were computed. Each input and output from the equation is discussed below.

Cross sections were surveyed at points in each diversion channel roughly in the middle of uniform reaches, at the mid-points between points of major channel lateral inflows or at changes in slope. Cross sections were also measured in natural channels 500 feet upstream and downstream of the diversion channel. These cross sections were idealized into an eight-point profile, shown below.



When Manning's equation calculations were performed, depths were chosen (relative to the minimum elevation at Point 4 or 5) and velocities calculated in both overbank regions and the channel region. The sum of these velocities times their respective areas then computed the channel flowrate. This procedure was repeated until a depth corresponding to the design flowrate was found. Overbank and channel velocities in the channel diversion reports refer to velocities bounded within the numbered channel coordinates shown above.

Roughness characteristics for the overbank regions were estimated from the field inspection descriptions. Almost without exception, the overbank regions were covered with Sagebrush/grass (about 1.5 feet tall) of varying density. Values of roughness were chosen based on density of growth. For low density (0 to 40 percent), a roughness of .03 was chosen; for 40 to 60 percent density a roughness of .05 was chosen. These values correspond to those as shown under "pasture, no brush, high grass" in Table 5-6 of Chow (1980).

Roughness characteristics for the channel region were also estimated from field inspection descriptions. Almost without exception, the channel bed consisted of a fine grained, non-cohesive sand. Samples of this sediment of the same soil type as that found in the natural washes showed a D_{50} less than .1 mm (Intermountain Soils, Inc., 1985). Roughness values were taken from Table 12.2 using a bed form found in Figure 12.2; both Table 12.2 and Figure 12.2 are reproduced from Surface Mining Water Diversion Design Manual (OSM, 1982). Figure 12.2 is included with this report as Appendix A and Table 12.2 is reproduced below.

Table 12.2

VALUES OF MANNING'S COEFFICIENT "n" FOR DESIGN OF
CHANNELS WITH FINE TO MEDIUM SAND BEDS

| Bed Roughness | <u>Manning's Coefficient "n"</u> |
|----------------|---|
| | For Sediment Transport and Bank Stability |
| Ripples | 0.018 - 0.022 |
| Dunes | 0.025 - 0.030 |
| Transition | 0.020 - 0.025 |
| Plane Bed | 0.015 - 0.020 |
| Standing Waves | 0.015 - 0.020 |
| Antidunes | 0.020 - 0.025 |

In all the natural and man-made channels analyzed, calculated tractive power in the channel sections did not drop below .4 pound per square foot, yielding a bed form based on Figure 12.2 of antidunes. For this reason, all channels analyzed were assigned roughness values of .022 based on Table 12.2.

Bed slopes for the natural and man-made channels were scaled from 1 inch equals 100 feet and 1 inch equals 400 feet maps. These maps were derived from aerial photographs taken for Peabody Coal Company in September 1985 and November 1984. Bed slopes for the natural channel cross sections were taken from the 1000 feet of natural channel preceding or following, as applicable, the surveyed natural cross section.

Design flowrates were derived using HEC-1 and the 10-year, 6-hour storm.

Calculations of tractive stress were averaged over the entire cross section, rather than determined for individual channel regions (i.e., channel and overbank). The hydraulic radius of the entire cross section was multiplied times the bed slope and the unit weight of water to find the tractive stress (OSM, 1982, Section 13).

Calculations of tractive power were also averaged for the entire cross section. Average velocity (flowrate divided by channel and overbank flow areas) was multiplied by tractive stress to obtain tractive power. This parameter was useful in determining roughness and as a gage of relative stream suspended sediment capacity.

5.0 REFERENCES

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* * *

Appendix A is attached and completes this report.

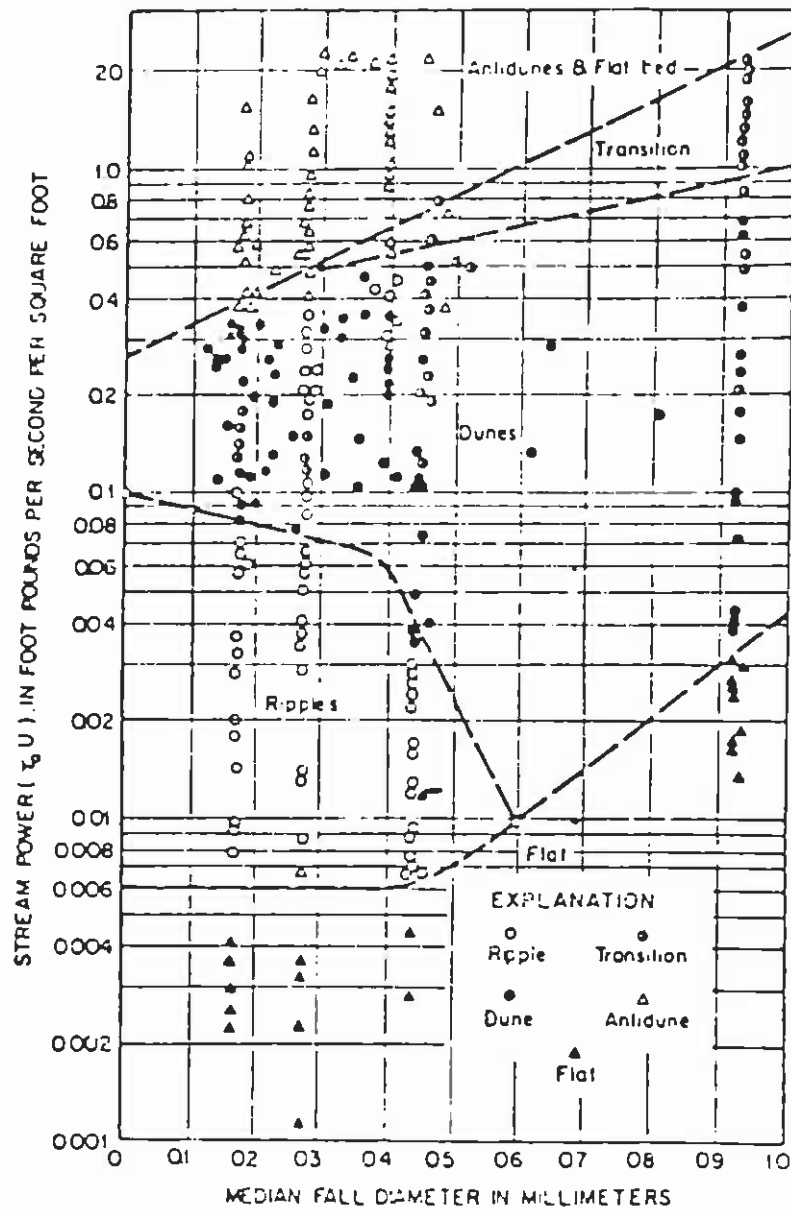


Figure 12.2. Relation of bed forms to stream power and median fall diameter of bed sediment (after Simons and Richardson, 1966).