HYDROLOGIC AND ENGINEERING STUDIES
at the
PEABODY COAL COMPANY MINES
near
KAYENTA, ARIZONA

VOLUME I

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HYDROLOGIC AND ENGINEERING STUDIES AT THE PEABODY COAL COMPANY MINES NEAR KAYENTA, ARIZONA

SUMMARY AND CONCLUSIONS

This report details the results of studies conducted at the Peabody Coal Company mines near Kayenta, Arizona. A computer simulation was conducted to estimate the probability that water would exist in impoundments that may exist in topsoiled graded spoils at the mine. As a result of site visits and ring infiltrometer tests, the most reasonable value for the SCS Curve Number appears to be in the range of 75 to 80. For these curve numbers the probability of the ponds containing water is less than 60% on an annual basis. June appears to be the critical month with probabilities of 40% or less. Based on results of the simulation, the quality of the water impounded should be good enough for use as livestock drinking water. For the Curve Numbers specified above, the model estimated sediment yield to range from 1-2 tons per acre per year. This estimate compares favorably with estimates made by other research conducted in similar climates.

Spoil slope stability was also analyzed. Using conservative data, Factors of Safety of 1.9 for static loading conditions and 1.35 for earthquake loading conditions were computed. These are well in excess of those required by OSM regulations.

1.00 INTRODUCTION

On April 15, 1981, Water, Waste & Land, Inc. (WWL) was contracted by the Arizona Division of Peabody Coal Company (PCC) to provide hydrological and geotechnical engineering services. The purposes of the study were to assess the quantity, quality, and persistence of water that may be impounded within graded and topsoiled spoil banks and to assess the stability of the graded spoil piles and ponds. A meeting was held with Office of Surface Mining (OSM), WWL, and PCC personnel to assess the approach and goals of the study. The results of the studies are presented in this report. For convenience the report has been broken into two chapters - Chapter Two deals with the hydrologic study and Chapter Three deals with the geotechnical engineering portion of the study. In the following paragraph, general site conditions are reviewed.

The Black Mesa mine site lies within the boundary of the Navajo Reservation and is approximately 20 miles southwest of Kayenta, Arizona. The coal mines are situated on a plateau-like feature ranging in elevation from about 6500 feet to over 7000 feet. The climate is semi-arid with a mean annual rainfall of slightly less than 12 inches. The Many Farms weather station, the closest location for evaporation data of any duration, reports an average pan evaporation of approximately 86 inches per year.

The Appendices contain a documentation of data collected in the field and pertinent supporting information.

2.00 HYDROLOGY WORK

2.10 OBJECTIVES AND GENERAL APPROACH

The overall objectives of the hydrologic study at the Black Mesa Mine were as follows:

1. Assess the quantity, quality, and persistence of water that may be impounded within graded and topsoiled spoil banks.
2. Provide information necessary to aid PCC personnel in the design of such impoundments.

The approach used in the study is based upon a computer model used to generate a sequence of rainfall events based on the statistics of a historic rainfall record. After the rainfall record was generated, runoff was calculated using the Soil Conservation Service (SCS) method for estimating runoff. An additional method for estimating runoff was utilized for comparison. Water quality in the impoundments was also evaluated using the rainfall/runoff record and the quality of surface runoff. The calculations included the effects of evaporation and seepage from the impoundment. The concentration of TDS in the impoundment water was estimated as a function of time based on climatic conditions and analyses of soils in the mine area. The probability of exceeding a certain concentration was calculated. Sediment loading of the ponds was also estimated.

2.20 BACKGROUND AND THEORY

2.21 STOCHASTIC PRECIPITATION MODELS - Several daily precipitation recording stations are located near the Black Mesa Mine and such stations have been established within the mine boundaries. The weather stations within the permit boundary have not been in existence for sufficient time to permit their use as a data base for a precipitation model, however. As a result, precipitation records from nearby NOAA stations were used as the input historic rainfall record for the precipitation model. Thirty-one years of daily rainfall records are available at both Kayenta and Betatakin, Arizona. Since Betatakin is near to the mine and more nearly conforms to the topography and elevation of the mine, the Betatakin records were selected as most representative of conditions at the mine. A complete record of daily rainfall at Betatakin is included in Appendix A.

The historic rainfall record at any location is but one of an infinite number of records that could occur in the future. Most engineers, designers, and planners have concluded that design of water resource systems based on a repetition of the historical record does not fully reflect the statistical nature of the data. Therefore a method generally accepted for design and planning is to use the historical record as input to a Monte Carlo simulation model with the objective of generating a seqùence of events that preserves the statistical properties of the historical record. This method is used to analyze many types of hydrologic sequences. As opposed to the case of streamflow, for instance, daily precipitation is an intermittent series. That is there are many days when rainfall does not occur, interspersed with days which are "wet" or on which rainfall does occur. It is therefore necessary that the model properly account for two processes:

1. The model must be able to determine if rainfall occurs on any given day, and,

2. If rainfall does occur on a given day, the model must determine the quantity of that rainfall.

As the above indicate, the classical auto-regressive Markov process models for streamflow data (in general, streamflow is regarded as continuous) are not appropriate for intermittent series such as daily rainfall without some modifications.

Gabriel and Neumann (1962) developed one of the first methods to handle the process of intermittent series. In general, their method consisted of a simple two-state Markov chain with the statistical properties that only two events can occur. Although this method has been used and evaluated by many reserachers (Caskey, 1963; Nicks, 1974; Pattison, 1965), it was not selected for use in this study since it works well only for regions where there is no seasonality of rainfall occurrences. It is a generally accepted fact that storms in arid or semiarid regions are seasonal in nature and the statistics of the Betatakin historical record reinforce this fact. It should be noted that the Gabriel and Neumann method can be modified to account for this seasonality, but the resulting algorithm is computationally costly.

Although substantial research has been conducted for multivariate hydrologic processes, most of this work has been directed at streamflow. Work by Fiering (1964) introduced the multivariate concept of generating streamflow data. This method provided for correlation of temporal and spatial events by using serial and cross correlation coefficients, respectively, instead of conditional probabilities such as those used in the simple Markov chain model discussed in the previous section. One of the more important advantages of this method is the ability to account for the areal distribution of rainfall if the method is adapted for precipitation generation. This would be important for very large areas; however, for the areas under consideration uniform rainfall events can be assumed since the drainage basins are not very large. Multivariate daily precipitation models have been developed but in general they are very complex and were developed primarily for large watersheds. In addition, these methods incorporate correlations that can be spurious for short periods.

A lag-one auto-correlation model for streamflow developed by Fiering (1967) does not include the cross-correlation, i.e. the areal distribution. This model has been used often in stochastic hydrology. Scott (1979) modified this method for use as a rainfall generating model by assuming that 1) the monthly statistics are stationary, 2) there is no persistence or correlation from one day to the next, and, 3) the historical data is normally distributed. Since Scott's work was directed at small watersheds in the arid and semiarid western United States, it was selected as the precipitation generating model for this study. The model is fairly simple and allows the user to develop long term precipitation sequences at a relatively small computation cost. The stochastic precipitation generator presented by Scott is of the form,

$$y = m_j + s_j r \qquad (2\text{-}1)$$

where

- y is the amount of precipitation in inches per day
- m_j is the mean daily precipitation in month j
- s_j is the standard deviation of daily precipitation in month j
- r is the random normal variate in the range 0 to 1.

The simplicity of Equation 2-1 is a result of the first two assumptions listed above. However, to use this equation, condition 3 above must be met and the day must be determined to be a wet day. To meet the normality condition, the historic precipitation data is assumed to have a log-normal distribution (this assumption will be tested in a later section). The transformation to log-normal is accomplished by adding a bias correction factor (Matalas, 1967) to the daily precipitation for wet days in the historic record and taking the natural logarithm of the result. The statistics of the transformed data are then calculated using the method of moments and these values are used in Equation 2-1 to generate a sequence of rainfall events. To ascertain if a day is "wet" or "dry" a random uniform variate between 0 and 1 is generated. If the value of the generated variate is greater than the probability of precipitation for month j no precipitation is generated, otherwise a rainfall event occurs and Equation 2-1 is used to calculate the quantity. Since parameters of the log-normal distribution are used in the generating scheme, it is necessary to transform the data and subtract the bias correction factor. If the result is less than zero, the rainfall amount is set at 0.00001 inch, so as not to "lose" a data value. The following assumptions are inherent in the model development:

1. the introduction of a bias addressed by Matalas (1967) is corrected by subtraction of a constant value without the solution of simultaneous equations.
2. the areal distribution of the rainfall is uniform.
3. the effect of the discontinuity of statistical parameters that occurs between the last day of one month and the first day of the next month is negligible.

In a subsequent section the data generated using the above model are compared with the historical precipitation record at Betatakin.

2.22 RAINFALL-RUNOFF PARTITIONING Models - The process of runoff as a result of a precipitation event can be partially characterized by the following list of variables:

a. interception - rainfall that falls on vegetal cover and is evaporated before reaching the ground.

b. depression storage - component of rainfall that is stored in puddles, ditches and other depressions in the soil surface.

c. evaporation - part of precipitation that is returned to the atmosphere as water vapor.

d. surface retention - combination of interception, depression storage and evaporation.

e. infiltration - fraction of rainfall that moves down into the soil

f. overland flow - part of rainfall that flows over the land surface toward streams, channels, or impoundments.

g. runoff - that part of precipitation that eventually reaches a surface stream, channel or pond.

h. interflow - movement of water through the soil to a surface stream, channel or pond.

i. ground water flow - movement of water from a saturated ground water zone to a surface stream, channel or pond.

j. transpiration - part of soil water that is extracted from the soil by vegetation.

Neither interflow nor ground water flow were considered in this study. It was assumed that all water infiltrated during a rainfall event is lost from the system either by transpiration or deep percolation, i.e. the pond did not gain water as a result of these types of flow. In fact, the final model accounts for seepage from the impoundment. It is evident, therefore, that the only variables of interest for this study are surface retention, overland flow, and infiltration. For the system under consideration, runoff as defined above can be ignored and any references to runoff in this report will actually be references to overland flow.

Although the literature contains many different types of rainfall-runoff partitioning models, only two will be discussed in this report. The first, developed by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture (1972), estimates runoff depth using the relationship:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad (2\text{-}2)$$

where

Q is the depth of runoff,

P is the depth of precipitation, and,

S is a parameter that accounts for both surface retention and infiltration.

It is apparent that Equation 2-2 is valid only for values of P greater than $0.2S$. Equation 2-2 is for normal Antecedent Moisture Conditions (AMC-2). Other Antecedent Moisture Conditions are AMC-1 for dry conditons and AMC-3 for wet conditions. For the system under consideration, it was assumed that only AMC-2 conditions apply. The SCS has defined runoff curve numbers (CN) for many types of soils. The CN can be related to the parameter S by the following equation

$$S = (1000/CN) - 10 \qquad (2\text{-}3)$$

so that if precipitation is known and the curve number can be identified the depth of runoff can be calculated using Equation 2-2. From Equation 2-3 it is evident that values of the SCS curve number are greater than zero and less than or equal to 100. Small values of the curve number result in less runoff due to a larger initial abstraction as well as increased infiltration. A curve number of 100 is indicative of an impervious surface.

The second runoff model utilized in this study is a triangular model developed by Scott (1979). This work was based on earlier work by Lewis (1969), Schreiber and Kincaid (1967), and Osborn and Lane (1969). These researchers studied the rainfall-runoff relationship for small watersheds using multiple linear regression analysis. Lewis' work was conducted in the arid Mexico highlands while that of Schreiber and Kincaid and Osborn and Lane was conducted in Arizona. The model developed by these researchers is of the form:

$$Q = aP - b \tag{2-4}$$

where

- Q is average runoff,
- P is daily precipitation,
- a is the slope of the rainfall-runoff line, and,
- b is the runoff intercept, functionally equivalent to surface retention.

Scott (1979) modified the method to reflect a statistical analysis of the slope to make it a multi-regional rainfall-runoff model. The major hypothesis presented in this research is that the mechanism of rainfall-surface retention-runoff-infiltration has two distributions, one about the value of initial abstraction (IA) and one about the value of infiltration-runoff percentage (a). The value of IA is dependent on antecedent moisture conditions, time of year, amount and distribution of vegetation, and rainfall intensity, among other factors. The distribution about a is influenced by the same variables and, in addition, by the duration of the storm. Although Scott hypothesized that it was possible to apply a probability distribution to the value of IA, no research has been conducted concerning Equation 2-4. Therefore, for the purposes of this research the value of IA was assumed to be a constant. Scott did apply a triangular probability distribution to the slope of the runoff line, a. Two possible representations of this runoff model are presented graphically in Figure 2.1. Figure 2.1a represents the limiting conditions of the triangular

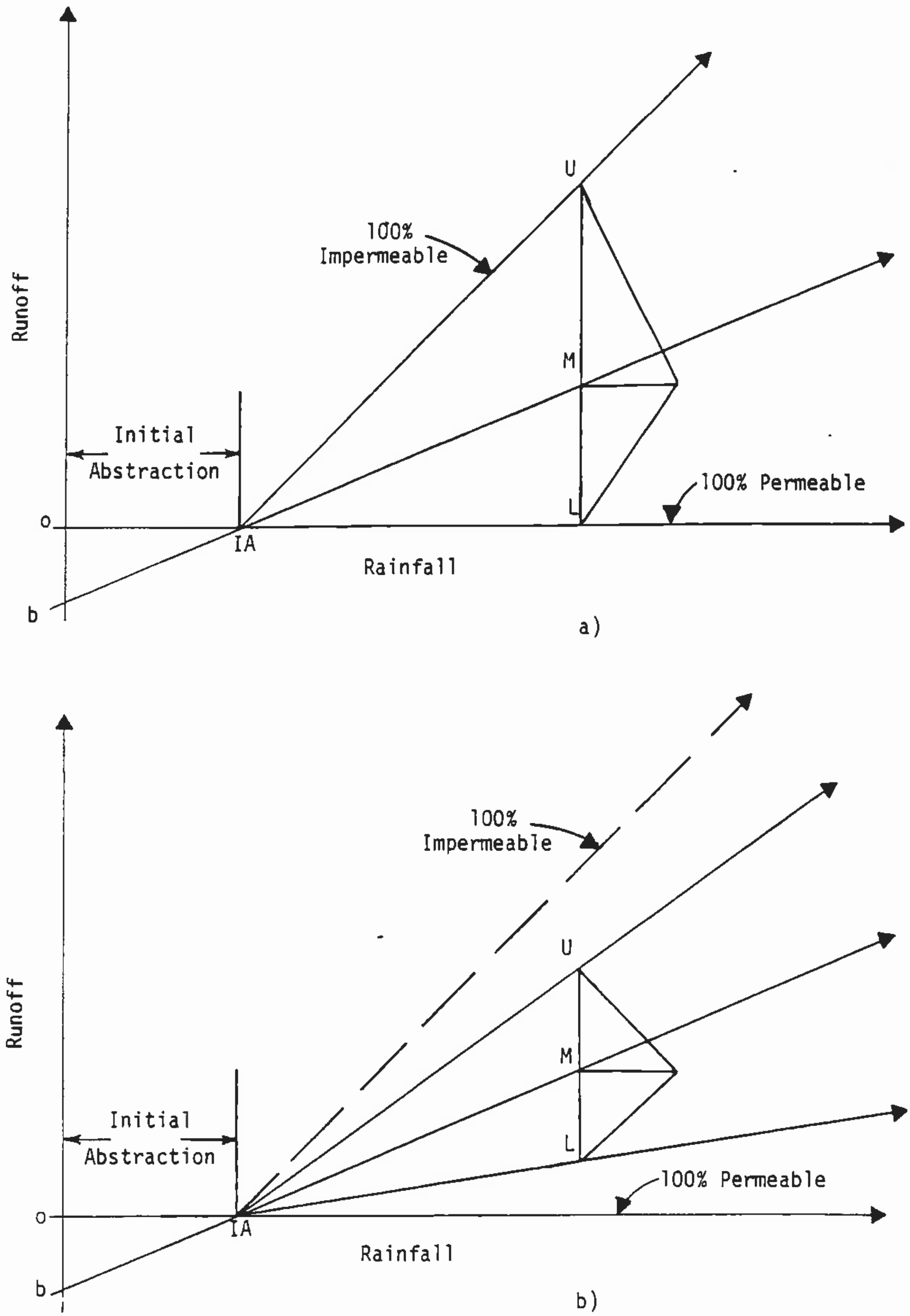


FIGURE 2.1 TWO POSSIBLE REPRESENTATIONS OF THE TRIANGULARLY DISTRIBUTED RUNOFF MODEL

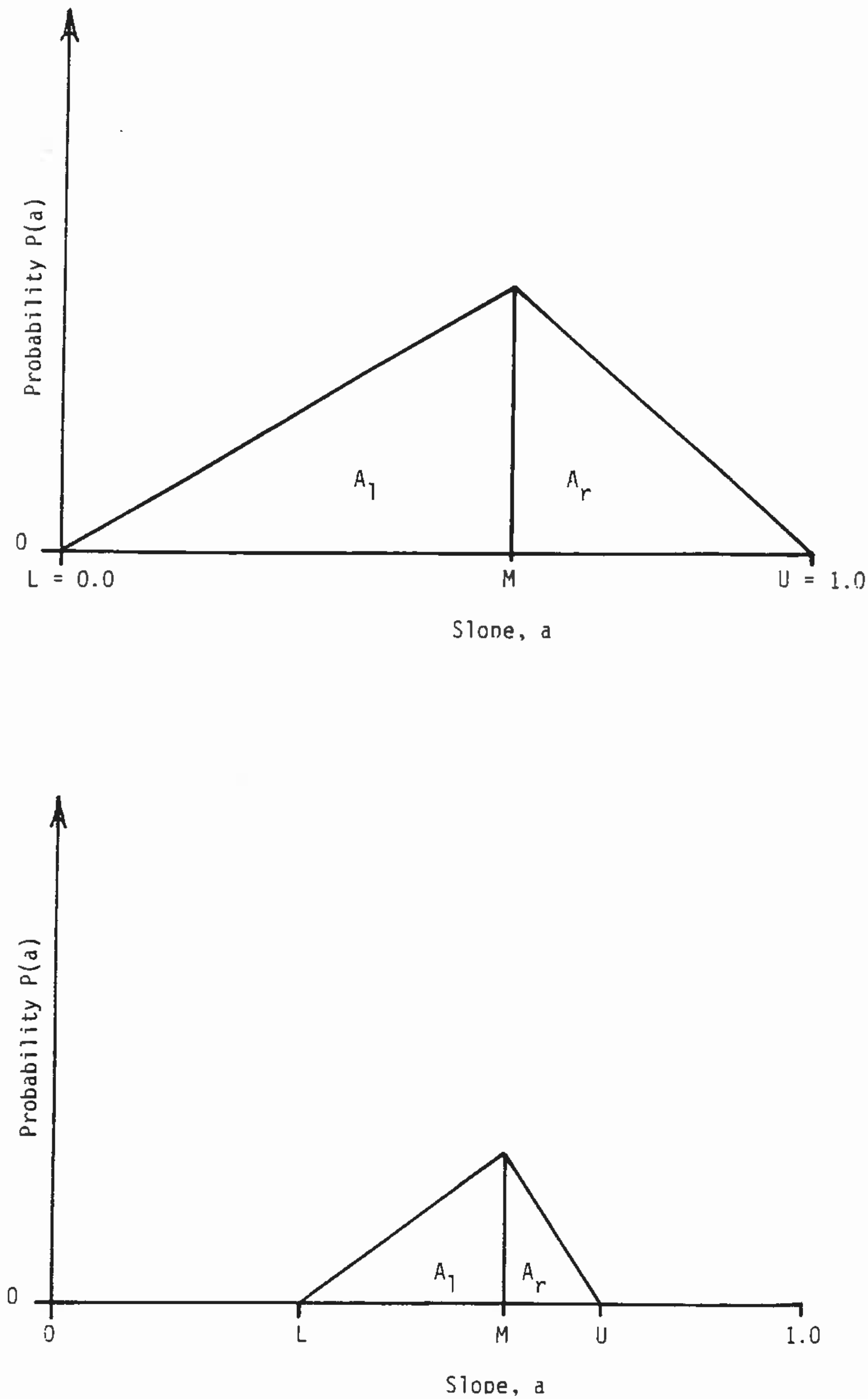


FIGURE 2.2 Definition Sketch for the Triangular Distribution

distribution applied to the slope. For this example, the upper limit of the distribution, U, is 1 and the lower limit of the distribution, L, is zero. That is, the slope of the runoff line will vary about the mode of the distribution, M, from zero, i.e. no runoff, to 1, i.e. 100% of precipitation in excess of IA will become runoff. Figure 2.1b represents an example in which the slope of the runoff line varies in a more restricted manner. In this example U is less than 1 and L is greater than zero. The values of U and L should be selected based on knowledge of the runoff characteristics of the watershed being investigated.

To use Equation 2-4, it is necessary to rewrite it in terms of the initial abstraction, IA. Obviously, the runoff is zero when the precipitation is less than or equal to IA. Substituting IA for P and zero for Q in Equation 2-4 and solving b leads to

$$b = a(IA) \tag{2-5}$$

and substituting the results back into Equation 2-4 results in the runoff equation in terms of precipitation and initial abstraction:

$$Q = a(P - IA) \tag{2-6}$$

Equation 2-6 is the functional form of Equation 2-4 that is used to estimate the runoff for the triangular model. The method of calculating a will be discussed subsequently. It should be noted that the value of IA is held constant even though the slope is allowed to statistically vary.

The triangular distribution is determined by areas of triangles. The two triangular distributions presented in Figure 2.1 are presented in Figure 2.2 to facilitate discussion of the method used to determine the value of a. From Figure 2.2, it is apparent that the areas of the triangles are:

$$A_t = \frac{1}{2} P(M) \quad (U - L) \tag{2-7}$$

$$A_l = \frac{1}{2} P(M) \quad (M - L) \tag{2-8}$$

$$A_r = \frac{1}{2} P(M) \quad (U - M) \tag{2-9}$$

where

A_t = area of triangle,
A_l = area of left triangle,
A_r = area of right triangle,

P(M) = probability,
M = mode of distribution,
L = lower value of distribution, and,
U = upper value of distribution.

The probability that the slope is less that the mode, M, is given by

$$P(1) = \frac{A_1}{A_t} = \frac{(M - L)}{(U - L)} \qquad (2\text{-}10)$$

while the probability that the slope will exceed the mode is given by

$$P(r) = \frac{A_r}{A_t} = \frac{(U - M)}{(U - L)} \qquad (2\text{-}11)$$

The general procedure, then, is to obtain a uniform random variate, U1, and compare it with P(1):

if: U1 < P(1) then obtain X(L,M) : case 1
U1 > P(1) then obtain X(M,U) : case 2

and generate two more uniform random variates, U2 and U3. For case 1

R = max (U2,U3), which yields a distribution about 0 and 1.
X = (M - L)R + L, which yields a distribution about L and M.

For case 2

R = min (U2,U3), which yields a distribution about 0 and 1.
X = (U - M)R + M, which yields a distribution about M and U.

The value of X that is calculated using the above procedure is then substituted for a in Equation 2-6 and the runoff is calculated.

2.23 WATER QUALITY MODEL - To calculate water quality as a function of time and depth of water in the pond, a simple mass balance model was developed to account for the concentration of Total Dissolved Solids (TDS) in the impoundment water. Based on the mass balance, the concentration at any time is given by:

$$C^t = \frac{C^{t-1}d^{t-1} + C_r^t d_r^t + C_p^t d_p^t - C_e^t d_e^t - C_w^t d_w^t}{d^{t-1} + d_r^t + d_p^t - d_e^t - d_w^t} \qquad (2\text{-}12)$$

where C is the concentration in parts per million (ppm) and d is the depth of water. The subscripts r, p, e, and w represent runoff, precipitation, evaporation, and seepage, respectively, while the superscript t indicates current time period and $t-1$ indicates the previous time period. Using the symbol convention presented above, the depth of water in the pond at time t is given by

$$d^t = d^{t-1} + d_r^t + d_p^t - d_e^t - d_w^t \qquad (2\text{-}13)$$

Assuming the rain water and evaporated water are pure (i.e. concentration of zero) and in view of Equation 2-13, Equation 2-12 can be simplified to the following form:

$$C^t = \frac{C^{t-1} d^{t-1} - C_w^t d_w^t + C_r^t d_r^t}{d^t} \qquad (2\text{-}14)$$

Since the water that is seeping out of the pond during a time period has the same concentration as the water in the pond Equation 2-14 has only one unknown, namely the pond water concentration for time period t. The solution to Equation 2-14 is not explicit, however, and to obtain a solution it was assumed that the concentration of the water within the pond at the end of the previous time step, i.e. $t-1$. Therefore Equation 2-14 can be rewritten as:

$$C^t = \frac{C^{t-1}(d^{t-1} - d^t) + C_r^t d_r^t}{d^t} \qquad (2\text{-}15)$$

Equation 2-15 was used to calculate the concentration of the pond water in conjunction with the pond volume calculations. At each time step the new concentration was calculated using Equation 2-15 if there was water in the pond; if the pond was dry, the concentration was set to zero. It should be noted that this procedure does not properly account for the fact that the surface of the pond will contain some salts that will become redissolved upon the introdcution of water to the pond. This effect is believed to be negligible, however.

A rather extensive search of the literature did not turn up any direct measurements of salt concentration in small ponds that are intermittently wet and dry. Therefore, the effect of residual salts left in the pond during a dry period could not be estimated from direct data. The assumption that residual salts left on a dry pond bottom will not contribute significantly to the salinity level in the pond water during the next wet period is based on the following reasoning.

Residual salts left on a dry pond bottom result from crystallization from the concentrated solution that exists as the volume of water in the pond approaches zero. These salt crystals are highly soluble and are quickly dissolved when contacted by precipitation and/or runoff (White, 1977). The infiltration capacity of the materials covering the pond bottom is greatest when the pond is dry. The first increments of precipitation and/or runoff contacting the dry pond bottom infiltrate and carry the highly soluble salts below the surface. Thus, the large fraction of the residual salts are not solubilized by the water standing in the pond. Both capillary and gravitational gradients are oriented downward as long as water stands in the pond. Therefore, the only mechanism by which the salts carried below the surface can re-enter the pond is by diffusion. Once ponded water is again depleted by evaporation and percolation, the capillary gradient reverses and water will move upward in response to the evaporative potential. Salts dissolved in this upward moving water are precipitated at or near the ground surface and are in addition to those precipitated from the pond water.

2.24 SEDIMENT MODELS - Probably the best known and most widely used sediment model is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965);

$$Y = R\ K\ LS\ C\ P \qquad (2\text{-}16)$$

where

Y = sediment yield in tons/acre/year,

R = rainfall factor usually expressed as the product of rainfall energy times the maximum 30-minute intensity for a given rainstorm,

K = soil erodibility factor,

LS = length slope factor,

C = cropping or cover factor, and

P = conservation practice factor.

Determination of a reliable estimate for R makes Equation 2-16 difficult to use and, since R is different for each storm, using a single value for R can result in erroneous results.

For these reasons, Williams (1976) modified Equation 2-16 resulting in the modified USLE (MUSLE):

$$Z = 95\,(Qq_p)^{0.56}\ K\ LS\ C\ P \qquad (2\text{-}17)$$

where

Z = sediment yield in tons from a storm,

q_p = the peak discharge for the storm (cfs),

Q = the volume of runoff for the storm (acre-ft)

and all other variables are as previously defined. Williams selected the coefficient 95 and the exponent 0.56 by optimization. For small watersheds in Texas and Nebraska, Equation 2-17 explained about 92% of measured variation in sediment yield. Even though some climatic and watershed differences existed between the two locations from which data was collected, Equation 2-17 predicted sediment yields that were very close to those actually measured. Since there was not enough data available in the mine area to develop new constants using Williams' procedures, it was assumed that the original constants as specified by Williams could be used to develop sediment yield estimates at the Black Mesa mine. The obvious advantage of Equation 2-17 is that it is based on individual events and can be used in a stochastic modeling process. In order to use Equation 2-17 the peak discharge for each storm must be calculated. The SCS (1972) peak flow equation provides the method to accomplish this:

$$q_p = \frac{484\ A\ Q}{t_p} \qquad (2\text{-}18)$$

where

A = watershed area in sq. mi.

t_p = time to peak discharge in hrs.,

and other variables are as defined previously.

2.25 MODEL DESCRIPTION - The model utilized in this study is actually three computer models that use the equations presented in the previous sections to estimate pond depth, pond water quality, and sediment yield as a function of time. In a subsequent section the data collected for input into the model will be discussed. The first computer program is the precipitation generation model developed by Scott (1979). This model develops the precipitation sequence based on the input historical record and writes the results to tape for subsequent use by the other models. Runoff partitioning and water quality calculations are performed by another computer program that uses the generated precipitation record as input. Two versions of this model were used - the SCS model and the triangular distribution model presented by Scott (1979). The third program is the sediment yield model and uses Equation 2-17 to calculate sediment yield from a single storm. Again the precipitation sequence generated using the first model is used as input.

For the runoff partitioning models and sediment yield models, it is necessary to calculate a volume of runoff in order to perform a mass balance of water in the pond and to estimate the total yield of sediment from the watershed. Since both Equations 2-2 and 2-6 calculate only a depth of runoff it is necessary to know the area of the watershed to estimate the total volume of water that an impoundment will receive as a result of a precipitation event. Because it is highly unlikely that all of the watersheds within the mine area will be of the same size a dimensionless parameter called the Area Index was introduced. It is apparent that the most important geometric parameter of an impoundment from the standpoint of water losses is area. With this in mind the Area Index is defined as the watershed area divided by the pond area. A schematic representation of a drainage basin with an impoundment is presented in Figure 2.3.

It is apparent that

$$A_D = A_B - A_P \tag{2-19}$$

where

A_D = drainage area of the watershed,

A_B = total watershed area, and

A_P = area of the impoundment.

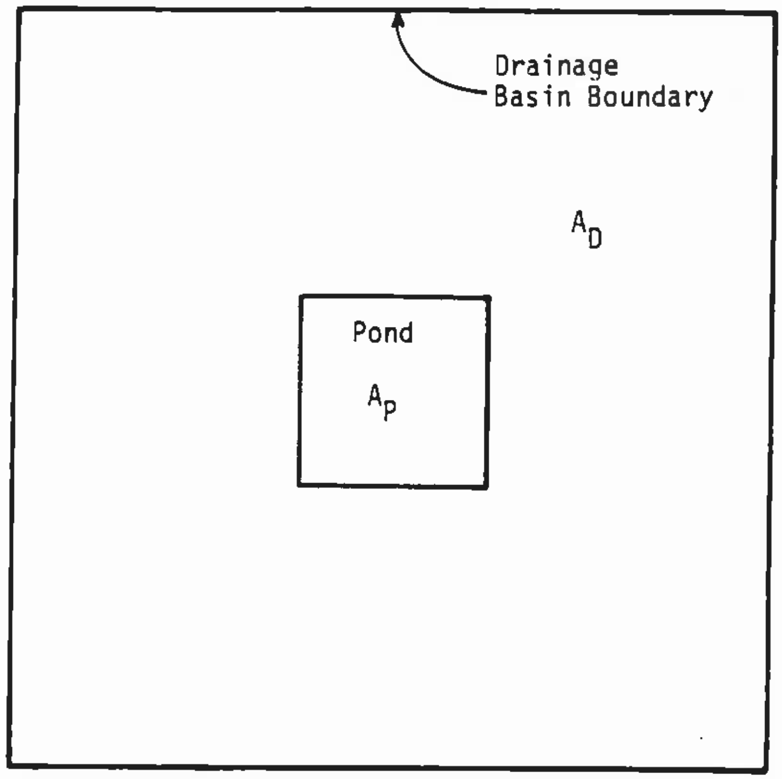


FIGURE 2.3 Schematic of Watershed

Dividing both sides of Equation 2-19 by the pond area results in

$$\frac{A_D}{A_P} = \frac{A_B}{A_P} - 1.0 = AI - 1.0 \qquad (2\text{-}20)$$

where AI is the Area Index. Using Equation 2-20 it is evident that the depth of water supplied to the pond as a result of a precipitation event is given by

$$D = P + Q(AI - 1.0) \qquad (2\text{-}21)$$

where D is the depth of water in the pond and other symbols are as previously defined on page 2-5. The use of the Area Index as a rainfall concentrator allows analysis of depth, water quality, and sediment yield for a large number of potential pond/watershed configurations without requiring that the actual basin geometry be specified. The pond depth/water quality computer program works in the following manner:

1. Read the generated precipitation sequence.
2. Calculate the sequence of runoff depths using the appropriate runoff model.
3. Initialize the Area Index.
4. Loop through the runoff depth record generated in step 2. If runoff occurs on any day, calculate the depth of water added to the pond using Equation 2-21. Calculate the current depth of water in the pond by adding runoff depth calculated to the previous day's depth and subtracting the depth of water that evaporates and the depth that seeps from the pond. The result is a sequence of daily pond depths for the given Area Index.
5. Calculate mean daily depth, standard deviation, and probability of the pond having water in it using the depth record generated in step 4.
6. Generate the sequence of daily TDS concentrations using Equation 2-15 with the depth record generated in step 4 and the rainfall sequence as inputs.
7. Calculate mean daily concentration, standard deviation, and probability of the TDS exceeding a certain minimum amount using the water quality record generated in step 6.
8. Increment the Area Index.
9. If the Area Index is greater than the maximum desired then stop. Otherwise perform the calculations for the new Area Index starting at step 4.

As stated earlier Equation 2-18 is used to calculate the peak discharge for any storm so that Equation 2-17 can be used to calculate sediment yield from the storm. In order to use Equation 2-18, an estimate of the time to peak discharge must be made. The SCS has presented a series of equations that can be used to estimate this parameter based on watershed characteristics. Lag time can be estimated from

$$t_l = \frac{L^{0.8} (S + 1)^{0.7}}{1900\ Y^{0.5}} \qquad (2\text{-}22)$$

where

t = lag time in hours

L = hydraulic length of watershed in feet,

Y = average land slope in percent, and

S = curve number parameter as calculated using Equation 2-3.

The SCS (1972) presents the following equations which can be used to relate lag time to peak:

$$t_p = \frac{\Delta d}{2} + t_l \qquad (2\text{-}23)$$

and

$$\Delta d = 0.133\ t_c \qquad (2\text{-}24)$$

and

$$t_l = (t_c/0.6) \qquad (2\text{-}25)$$

where

Δd = duration of unit excess rainfall,

t_c = the time of concentration,

and other variables are as defined previously. Algebraic manipulation allows time to peak to be defined in terms of log time:

$$t_p = 1.111 t_l \qquad (2\text{-}27)$$

The length and slope parameters in Equation 2-22 were related to the Area Index based on maps supplied by PCC so that a peak time could be calculated as a function of Area Index. The procedure used and the results are presented in the following section. The sediment yield model can be summarized as follows:

1. Read the generated precipitation sequence.
2. Calculate the runoff record using Equation 2-2.
3. Initialize the Area Index.

4. Calculate time to peak for the Area Index in question using Equations 2-22 and 2-26.
5. Loop through the runoff record. On days that runoff occurs, calculate the volume of runoff using Equation 2-21 and peak discharge using Equation 2-18 with the Area Index substituted for the area variable. Use Equation 2-17 to calculate the sediment yield for the storm. A running total of sediment yield is kept.
6. Calculate the mean quantity of sediment yield per unit area per year.
7. Increment the Area Index.
8. If the Area Index is greater than the maximum desired then stop. Otherwise perform the calculations for the Area Index starting at step 4.

2.26 MODEL LIMITATIONS - All computer models have some limitations. In this section the limitations of the models utilized in this study are discussed. The model does not properly account for the fact that seepage rates from the ponds decrease with time. For a dry pond surface the infiltration rate is initially high and decreases as more water is infiltrated. The time required for infiltration rates to reach the basic intake rate is relatively short, on the order of a few hours to a few days. Since the time for the basic intake rate to be reached is very short compared to the time being considered it is felt that neglecting the time variation of infiltration rate will not significantly affect the results obtained. Another reason for the time variation of infiltration is that, as the pond receives more fines as sediment that settle to the bottom of the pond, the infiltration rate will decrease. After some period of time additional sediment will not materially effect the infiltration rate. It is difficult to estimate the length of time required to reach this condition. This limitation can be ignored if the ponds are properly compacted during construction.

Another limitation of the model is that runoff during the winter months is not properly computed. The model calculates runoff for all events in the same manner regardless of the season in which the precipitation event occurs. The effect of this is to allow winter precipitation which may be in the form of snow to be immediately routed to the pond when in fact, the runoff event may not occur until a warm period occurs. This limitation is at least partially offset by the fact that the Betatakin station does not have a heated rain gauge so that measured winter precipitation in the form of snow is probably less than what is actually recieved. The net result is that the model probably underestimates pond depth in the winter months and in the early spring months.

It is felt that the above limitation will not materially effect the pond depth for the critical months when evaporation is high.

Perhaps the most severe limitation of the model is the method used to calculate the peak flow rate for use in the sediment yield calculations. The method utilized assumes that the storm duration is approximately equal to the time of concentration which is very small for the small watersheds under consideration. Because the storm duration is underestimated, the peak discharge is overestimated resulting in an estimate of sediment yield that is somewhat higher than would probably be observed.

2.30 DATA COLLECTION AND ANALYSES

2.31 SITE INVESTIGATIONS - WWL personnel visited the mine site on three separate occasions. The first visit was for reconnaisance purposes. During the second visit, several soil samples were obtained for laboratory analyses. The samples were analyzed for TDS and pH as determined in both saturated extracts and five to one dilution extracts. The latter was obtained as it was felt that it would provide a reasonable maximum estimate of the TDS concentration of runoff water. A more detailed discussion of this assumption is presented in Section 2.36. Five of the surface samples from the J1, N6 area were also subjected to particle size analyses and the results are presented in Table 2.1. Laboratory results of the chemical analyses are presented in Table 2.2. Complete laboratory reports for the chemical analyses as well as particle size distribution curves are contained in Appendix B to this report.

Table 2.1. Results of Particle Size Analyses.

No.	% Sand	% Silt	% Clay
3-S	55	23	22
5-S	65	13	22
8-S	43	17	40
10-S	67	15	18
16-S	49	20	31

An additional site visit was made by a WWL engineer to conduct ring infiltrometer tests. The data from these tests were analyzed using a method presented by the SCS. The infiltration curves as well as the original data are presented in Figure 2.4.

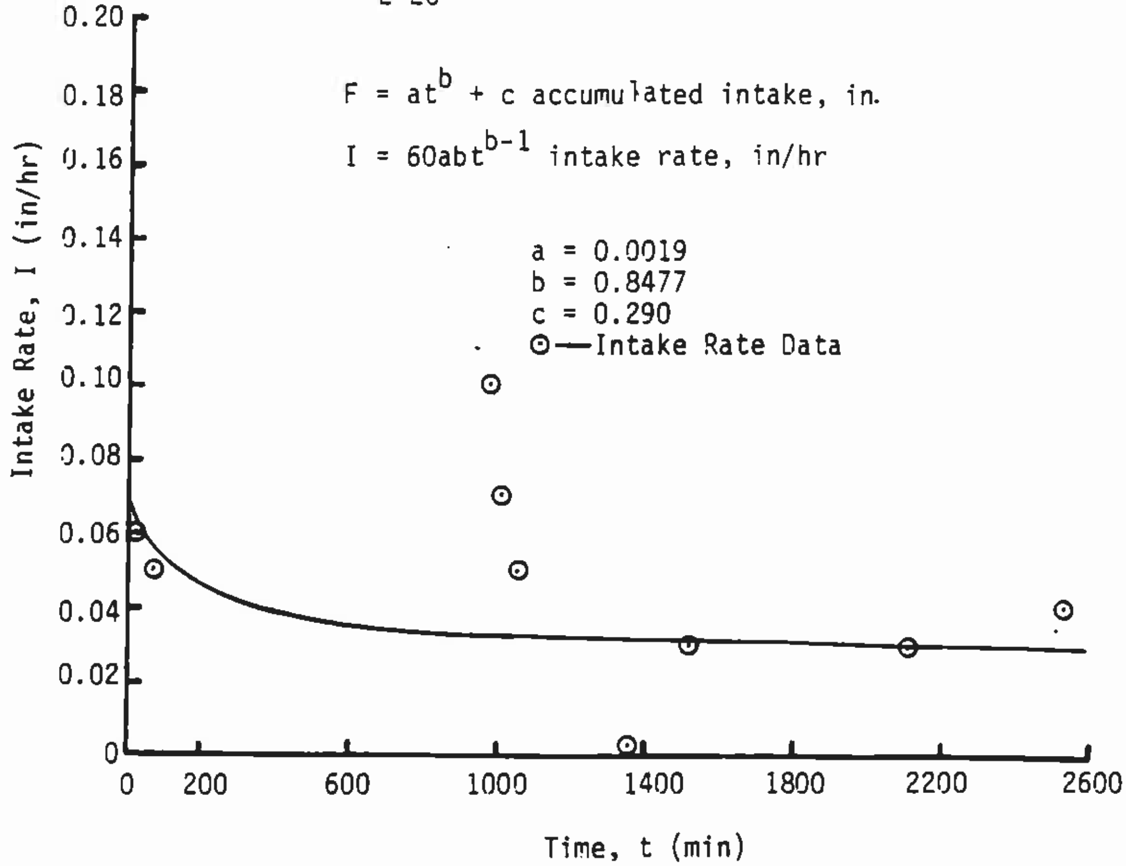


FIGURE 2.4a Infiltration Ring Test on J1,N6 Topsoiled Area

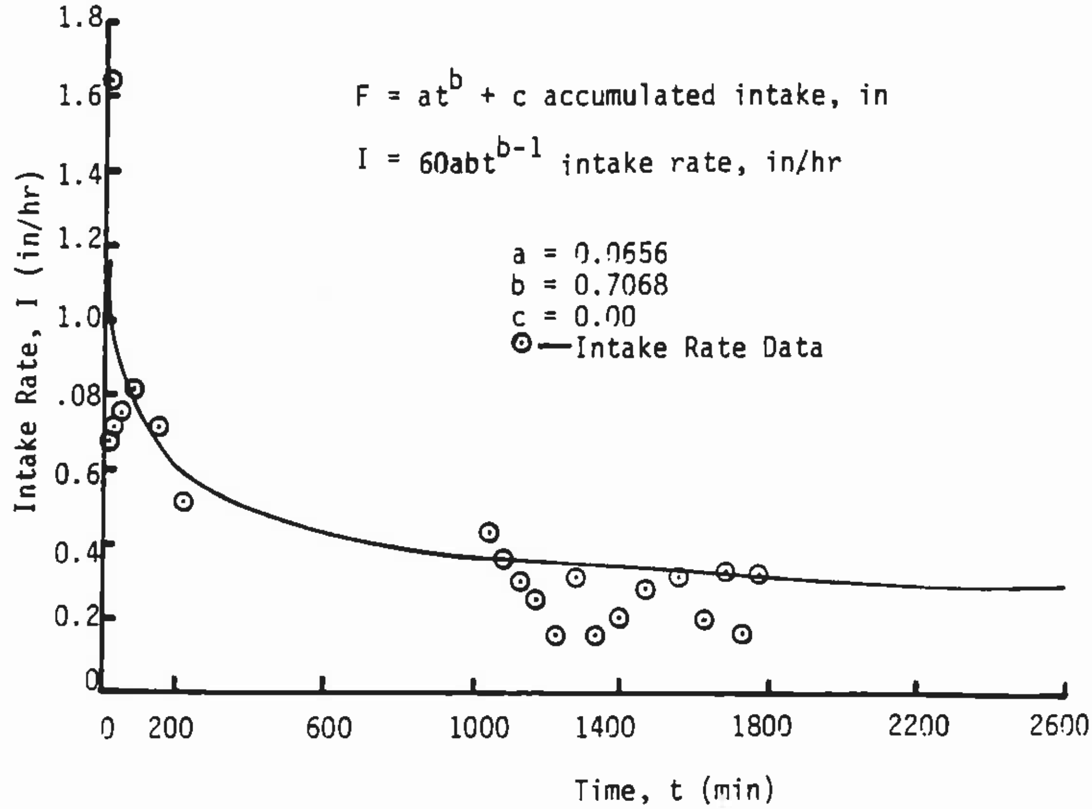


FIGURE 2.4b Infiltration Ring Test on J1,N6 Pond Edge

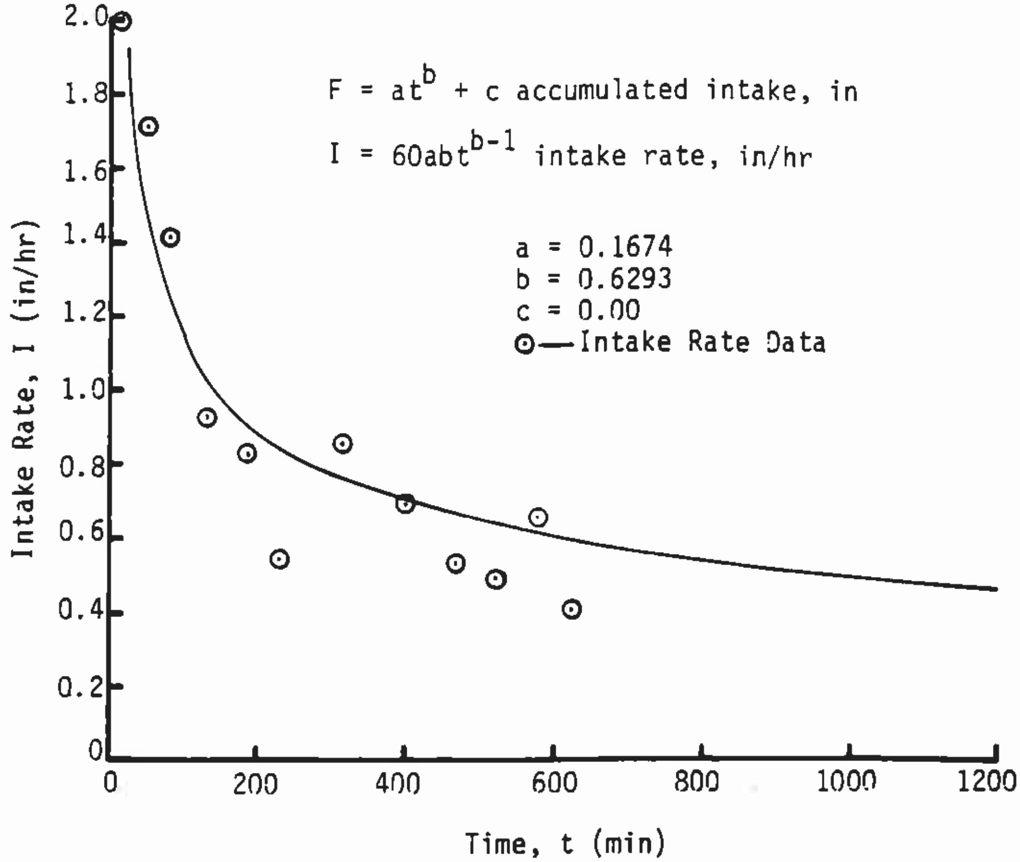


FIGURE 2.4c Infiltration Ring Test on J1,N6 Topsoiled Area

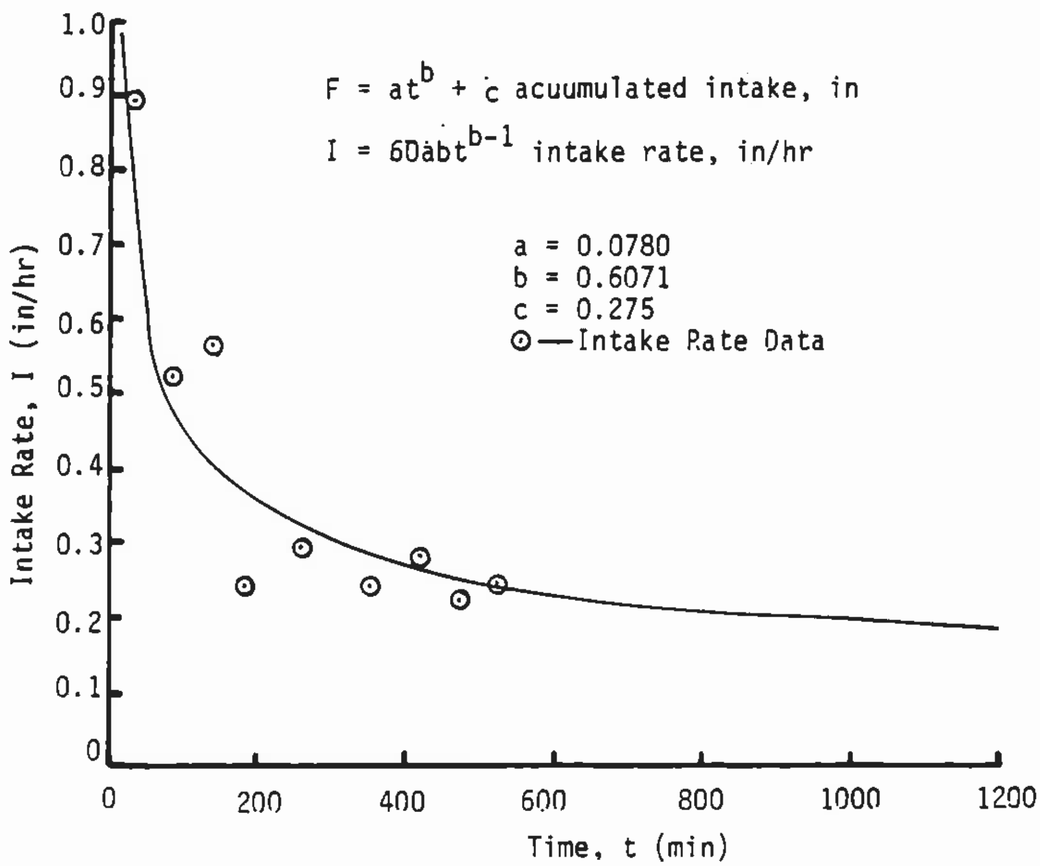


FIGURE 2.4d Infiltration Ring Test on J1,N6 Topsoiled Area

2.32 ADDITIONAL DATA - In addition to the data obtained as a result of field investigations and the rainfall data obtained from NOAA records, PCC personnel provided maps delineating several watersheds containing impoundments. PCC personnel also conducted an additional ring infiltrometer test on an existing pond to aid in the determination of a seepage rate for the computer model. PCC personnel also provided weather data collected at the mine site and partial reports of studies conducted at the mine by the University of Arizona.

Table 2.2a Laboratory Results for J1,N6 Surface Samples.

	Saturation Extract		5:1 Dilution Extract	
No.	TDS	pH	TDS	pH
1-S	1050.6	8.15	224.0	7.81
2-S	1457.3	8.18	160.6	7.75
3-S	540.2	8.36	164.2	8.38
4-S	1605.1	8.09	775.5	7.58
5-S	1845.2	7.62	656.6	7.93
6-S	3270.4	7.36	447.1	7.90
7-S	1185.1	8.23	248.6	8.04
8-S	2070.0	7.70	323.3	8.03
9-S	780.0	8.11	171.2	8.04
10-S	1230.0	7.95	200.9	7.38
11-S	1845.4	8.26	299.5	8.17
12-S	525.1	8.19	76.6	7.73
19-S	510.0	8.04	120.5	8.07
20-S	943.1	7.83	247.7	7.42
21-S	510.5	8.02	172.3	7.56
22-S	835.5	8.03	184.4	7.71

Table 2.2b Laboratory Results for J1, N6 Subsurface Samples.

	Saturation Extract		5:1 Dilution Extract	
	TDS	pH	TDS	pH
1-6"	752.4	7.52	200.0	8.19
2-6"	915.9	8.23	203.1	8.46
3-6"	750.2	8.19	236.5	8.28
4-6"	1485.1	7.63	520.3	7.77
5-6"	1065.1	8.13	323.4	8.59
6-6"	510.1	7.79	380.6	8.69
7-6"	780.1	8.00	204.0	8.03
8-6"	1050.3	7.64	264.0	8.03
9-6"	1245.1	8.04	451.1	7.91
10-6"	1185.2	8.54	248.7	7.48
11-4"	746.5	6.97	108.8	8.81
12-6"	795.1	8.32	92.2	7.44
20-6"	720.4	7.72	144.0	8.57
21-6"	661.5	7.80	192.4	8.91
22-6"	315.4	7.91	176.0	8.11

Table 2.2c Laboratory Results for N1,N2 Surface Samples

No.	Saturation Extract TDS	Saturation Extract pH	5:1 Dilution Extract TDS	5:1 Dilution Extract pH
15-S	1365.2	6.92	284.9	7.87
16-S	6045.0	7.23	1079.1	6.99
17-S	4219.3	8.20	2245.4	7.35
18-S	1395.1	7.38	212.0	8.38

Table 2.2d Laboratory Results for N1,N2 Subsurface Samples

	Saturation Extract TDS	Saturation Extract pH	5:1 Dilution Extract TDS	5:1 Dilution Extract pH
16-6"	2463.4	8.40	517.5	7.26
18-6"	900.2	7.52	160.2	7.64

Table 2.2e Laboratory Results for Topsoil Samples

	Saturation Extract TDS	Saturation Extract pH	5:1 Dilution Extract TDS	5:1 Dilution Extract pH
13-TS	1830.4	6.45	156.3	7.30
14-TS	1470.2	7.10	148.1	7.41

NOTE: TDS units are mg/l.

2.33 ANALYSIS OF RAINFALL DATA - As discussed previously, the input rainfall record for the stochastic precipitation generator was obtained from NOAA data for Betatakin, Arizona. Since the precipitation generation model requires that the data have a log-normal distribution, this assumption was tested using a Chi-Square goodness of fit test. The general procedure is to obtain parameters of the distribution to be tested and, using these parameters, calculate the cumulative density function (CDF) of the distribution. The data are then sorted into ascending order and the number of occurrences for each class interval are counted. A test statistic is then obtained by summing the squares of the deviations of the observed values from the theoretical values in each class interval for the parameters calculated. This test statistic is then compared to a table value of the Chi-Square distribution with k-n-1 degrees of freedom and at the confidence level desired. The value of k is the number of equal class intervals into which the distribution is divided and n is the number of parameters estimated. If the value of the test statistic is less than that of the table value, the hypothesis that the data has the assumed distribution is accepted.

The Betatakin daily rainfall data were subjected to the above test on a month by month basis. The CDF was divided into 11 equal class intervals and two parameters, the mean and standard deviation, were estimated ($k = 11$, $n = 2$). At the 99.99 significance level with 8 degrees of freedom the table value is 26.1. The calculated test statistics are presented in Table 2.3. All values, with the exception of May's value, are less than the table value. The test statistic for May is very close and it is concluded that the data are indeed log-normally distributed.

Table 2.3 Results of Chi-Square Test

Month	Chi-Square Statistic	
	Computed value	Table Value
January	12.9325	26.1
February	22.5000	26.1
March	12.9825	26.1
April	12.5455	26.1
May	26.9485	26.1
June	5.1325	26.1
July	26.0538	26.1
August	25.2957	26.1
September	19.4752	26.1
October	12.8960	26.1
November	12.7200	26.1
December	9.0604	26.1

Another test of the reliability of the generated data can be accomplished by comparing the historic data with the generated data. The statistics of both data sets are presented in Table 2.4. A visual inspection of all parameters indicates that the data sets are very similar. A more quantitative way of testing the assumption that there is no statistical difference in the means can be accomplished by applying the Student-t test of significance. In order to perform this test, it is necessary to calculate the pooled variance:

$$s_w^2 = \frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{(n_1 + n_2 - 2)} \qquad (2\text{-}27)$$

where

s_w = pooled standard deviation,

s_1 = standard deviation of historic data,

s_2 = standard deviation of generated data,

n_1 = number of observations in historic data, and

n_2 = number of observations in generated data.

Table 2.4a. Natural Rainfall Statistics

Period	Number Observations	Number Events	Mean	Standard Deviation	Precipitation Probability
January	961	163	0.1801	0.1928	0.1696
February	876	148	0.1808	0.2113	0.1689
March	961	173	0.1591	0.1440	0.1800
April	930	121	0.1484	0.1553	0.1301
May	961	97	0.1451	0.1332	0.1009
June	930	83	0.1716	0.2663	0.0892
July	961	223	0.2075	0.2542	0.2320
August	961	230	0.2010	0.2569	0.2393
September	930	141	0.2091	0.2700	0.1516
October	961	125	0.2703	0.3327	0.1301
November	930	125	0.2428	0.2836	0.1344
December	961	149	0.2252	0.3174	0.1550
Annual	11323	1778	0.1966	0.3174	0.1570

Table 2.4b. Generated Rainfall Statistics

Period	Number Observations	Number Events	Mean	Standard Deviation	Precipitation Probability
January	1550	241	0.1659	0.1647	0.1555
February	1413	223	0.1787	0.2259	0.1578
March	1550	268	0.1683	0.1390	0.1729
April	1500	222	0.1337	0.1369	0.1480
May	1550	165	0.1365	0.1231	0.1065
June	1500	122	0.1743	0.2475	0.0813
July	1550	356	0.1931	0.2140	0.2297
August	1550	358	0.1848	0.2099	0.2310
September	1500	234	0.2223	0.2935	0.1560
October	1550	202	0.2593	0.2883	0.1303
November	1500	200	0.2495	0.3542	0.1333
December	1550	249	0.2173	0.2439	0.1606
Annual	18263	2840	0.1907	0.3192	0.1555

Table 2.4c. Log Natural Rainfall Statistics.

Period	Number Observations	Number Events	Mean	Standard Deviation	Precipitation Probability
January	961	163	-1.7298	0.7031	0.1696
February	876	148	-1.7775	0.7569	0.1689
March	961	173	-1.7704	0.6366	0.1800
April	930	121	-1.8677	0.6936	0.1301
May	961	97	-1.8489	0.6531	0.1009
June	930	83	-1.8871	0.7932	0.0892
July	961	223	-1.7173	0.8141	0.2320
August	961	230	-1.7377	0.8019	0.2393
September	930	141	-1.6944	0.7858	0.1516
October	961	125	-1.5344	0.8650	0.1301
November	930	125	-1.5820	0.8205	0.1344
December	961	149	-1.6148	0.7774	0.1550
Annual	11323	1778	-1.7238	2.2994	0.1570

Table 2.4d. Log Generated Rainfall Statistics.

Period	Number Observations	Number Events	Mean	Standard Deviation	Precipitation Probability
January	1550	241	-1.7669	0.6860	0.1555
February	1413	223	-1.7471	0.7245	0.1578
March	1550	268	-1.7105	0.6239	0.1729
April	1500	222	-1.9311	0.6882	0.1480
May	1550	165	-1.8714	0.6182	0.1065
June	1500	122	-1.8539	0.8067	0.0813
July	1550	356	-1.7372	0.8112	0.2297
August	1550	358	-1.7735	0.8121	0.2310
September	1500	234	-1.6363	0.7934	0.1560
October	1550	202	-1.5302	0.8531	0.1303
November	1500	200	-1.5547	0.8031	0.1333
December	1550	249	-1.6391	0.7930	0.1606
Annual	18263	2840	-1.7260	2.3003	0.1555

The computed test statistic, t, is then calculated using:

$$t = \frac{m_1 - m_2}{s_w \, (1/n_1 + 1/n_2)^{1/2}} \qquad (2\text{-}28)$$

where

m_1 = mean of historic data and

m_2 = mean of generated data.

The value of t calculated using Equation 2-28 is compared to the Student's t value from a table using v degrees of freedom (v is equal to the denominator in Equation 2-27) at the confidence level desired. If the calculated value is less than the table value, the hypothesis that the means are not significantly different is accepted. Again this test was performed on a month by month basis at the 97.5% confidence level. The results are presented in Table 2.5. As can be seen the assumption that the generated means and the historic means are from the same population is valid.

The mean monthly depths of precipitation at the Betatakin station were calculated. The results are presented in Table 2.6. The limited data available from the mine site indicate that precipitation at the mine should be very similar to that observed at the Betatakin station. For the above reasons it is concluded that the historic rainfall record utilized in this study is appropriate for the model and adequately reflects the precipitation of the site in question.

Table 2.5. Student's t-Test Results.

Period	Degrees of Freedom	Pooled Standard Deviation	t - Statistic Computed	t - Statistic Table Value	PASS/ FAIL
January	402	0.1766	0.7931	1.97	PASS
February	369	0.2202	0.0899	1.97	PASS
March	439	0.1410	0.6691	1.97	PASS
April	341	0.1436	0.9056	1.97	PASS
May	260	0.1269	0.5296	1.97	PASS
June	203	0.2553	0.0743	1.97	PASS
July	577	0.2303	0.7322	1.97	PASS
August	586	0.2294	0.8356	1.97	PASS
September	373	0.2849	0.4346	1.97	PASS
October	325	0.3060	0.3159	1.97	PASS
November	323	0.3289	0.1787	1.97	PASS
December	396	0.2497	0.3055	1.97	PASS
Annual	4616	0.3185	0.6125	1.97	PASS

Table 2.6. Mean Monthly Precipitation at Betatakin.

Month	Depth (in.)
January	0.95
February	0.86
March	0.89
April	0.58
May	0.45
June	0.46
July	1.49
August	1.49
September	0.95
October	1.09
November	0.98
December	1.08
Total	11.27

2.34 ANALYSIS OF EVAPORATION DATA - Since long-term records of evaporation are not available the historic record of pan evaporation at Many Farms, Arizona, was used to estimate the daily evaporation from a free water surface at the mine site. The Many Farms data as well as that used in the computer model are presented in Table 2.7. The Many Farms data were reduced to approximately 80 percent to account for the fact that pan evaporation tends to overestimate the amount of evaporation that will occur from a larger body of water (Sellers and Hill, 1974).

Table 2.7 Evaporation Data.

Month	Many Farms Pan Evaporation (inches/month)	Estimated Mine Site Pond Evaporation (inches/month)	(inch/day)
January	1.0	0.87	0.028
February	3.4	2.63	0.094
March	5.7	4.68	0.151
April	9.2	7.38	0.246
May	12.5	10.54	0.340
June	12.9	10.77	0.359
July	11.9	9.95	0.321
August	10.0	8.49	0.274
September	8.7	7.08	0.236
October	5.6	4.68	0.151
November	3.3	2.82	0.094
December	1.7	1.46	0.047
Annual	85.9	71.35	0.195

2.35 ANALYSIS OF INFILTRATION DATA - The infiltration data collected indicates that the soils in question have a moderate to low intake rate. The SCS method for analyzing the infiltrometer test was developed primarily for irrigation design and the analysis allows for the selection of a soil intake family. The results indicate that, at least for irrigation purposes, the soils in the mine area are on the low end of infiltration rates listed in the literature. Based on the results of the infiltration tests it is estimated that the soils in the mine area are probably of hydrologic type C as defined by the SCS. The results of the above tests were used only as an aid in selection of the SCS Curve Numbers for the runoff partitioning model. In order to estimate the amount of seepage through an impoundment bottom an additional ring infiltrometer test was conducted on an existing pond bottom by PCC personnel. The data from this test is presented in Table 2.8. Although not enough data was collected to perform the SCS analysis, the measured average intake rate varies from 0 to 0.100 inch/day with a mean of about 0.031 inch/day. The soils in the pond bottoms have a textural classification of silty clays. Morris and Johnson (1967) list the hydraulic conductivity of such soils as about 0.034 inch/day. Based on the above discussion, a value of 0.034 inch/day was used in the model as the rate of seepage from the pond bottom. It is felt, based on site inspection of existing ponds, that this value is conservatively high.

Table 2.8. Pond Bottom Ring Infiltrometer Test Data.

Elapsed Time (days)	Cumulative Infiltration (inch)	Time Increment (days)	Infiltration Increment (inch)	Avg. Intake Rate (inch/day)
0.00	0.00			
0.21	0.00	0.21	0.00	0.000
1.98	0.04	1.77	0.04	0.023
3.08	0.15	1.10	0.11	0.100
3.13	0.15	0.04	0.00	0.000

2.36 ANALYSIS OF LABORATORY DATA - The mean and standard deviation of each group of samples was obtained for each parameter. These results are presented in Table 2.9. The mean concentration of the 5:1 dilution extract of the surface samples from the J1,N6 area was used to estimate the mean concentration of runoff water for the water quality model. The mean value of about 280 mg/l was rounded to 300 for input to the model. Since the subsurface samples from this same area had TDS concentrations less than those observed at the surface it can be concluded that some erosion of the surface soils will not cause an increase in the salinity of the runoff water.

Table 2.9. Statistical Summary of Laboratory Results.

		Saturation Extract		5:1 Dilution Extract	
		mean	std. dev.	mean	std. dev.
J1,N6 Surface	TDS	1262.73	743.17	279.56	192.53
	pH	8.01	0.26	7.84	0.28
J1,N6 Subsurface	TDS	865.23	289.91	249.67	121.89
	pH	7.90	0.38	8.22	0.46
N1,N2 Surface	TDS	3256.15	2290.89	955.35	945.45
	pH	7.43	0.55	7.65	0.61
N1,N2 Subsurface	TDS	1681.80	1105.35	338.70	252.44
	pH	7.96	0.62	7.45	0.27
Topsoil	TDS	1650.30	254.70	152.20	5.80
	pH	6.78	0.46	7.36	0.08

The use of the average dissolved solids concentration in 5:1 water-to-soil extracts as representing the reasonable maximum value of salt concentration in overland runoff is based upon observations in mine spoil studies and elsewhere. McWhorter, et.al., (1979) measured the average dissolved solids concentration in overland flow on mine spoil in Colorado. These investigators also determined the salt concentration in the spoils contacted by the overland flow. It was observed that the average salt concentration in runoff from plots subjected to simulated precipitation was 246 mg/l from spoil with an average TDS concentration of 2690 mg/l in saturation extracts. It is estimated that the corresponding TDS concentration in 5:1 extracts was 595 mg/l. Thus, the average salt concentration in runoff was about 41 percent of that in 5:1 extracts.

Ponce (1975) made extensive investigations of the relationship between the electrical conductivity of direct runoff from Mancos shale and the electrical conductivity of 1:1 soil-to-water extracts prepared from the surface materials. His regression equation is

$$EC_w = -193 + 0.502\ EC\ (1:1),\ r^2 = 0.912 \qquad (2\text{-}29)$$

where

EC_w is the electrical conductivity of the overland runoff, and,
EC(1:1) is the electrical conductivity of 1:1 soil-to-water extracts prepared from soil at 0 - 0.1 inch depth.

Electrical conductivity values must be expressed in micromhos/cm at 25 degrees Centrigrade. Richards (1954) reports the ratio of EC of 1:1 extracts to the EC of saturation extracts for sulfate salts to be about 0.6. McWhorter, et.al., (1979) found the ratio to be 0.68. Using a ratio of 0.68, the measured average TDS in saturation extracts of 1263 mg/l for the Black Mesa soils converts to a TDS (1:1) of 864 mg/l. This value is in turn converted to EC(1:1) of 1110 micromhos/cm using a correlation between TDS and EC developed from extensive data on waters with a chemical composition similar to that measured in extracts from the Black Mesa soils (McWhorter, et.al., 1979).

Using EC(1:1) of 1110 micromhos/cm in Ponce's equation (Equation 2-29) yields an electrical conductivity in the overland runoff of 365 micromhos/cm or a TDS of 252 mg/l. This estimate is nearly equal, but somewhat less, than the average TDS concentration of 280 mg/l measured in 5:1 extracts prepared from soils collected at the immediate surface on top soiled areas at the Black Mesa mine.

Based upon the above, it is believed the use of a TDS concentration equal to 300 mg/l in surface runoff is a reasonable maximum for the average value at the Black Mesa mine. It is worth noting that both the spoil material studied by McWhorter, et.al. (1979) and the Mancos shale derived soils studied by Ponce (1975) are much higher in soluble salt content than the Black Mesa soils.

The results of the textural analyses were used to estimate the value of K used in Equation 2-17. Using the nomograph presented by Wischmeier et.al. (1971) the average value of K for the soils in the J1,N6 area is estimated to be 0.15.

2.40 RESULTS AND DISCUSSION

2.41 POND DEPTH - Pond depth as a function of time was calculated using the model presented earlier for 50 years of simulated rainfall data. Area Index was allowed to vary from 10 to 130 for these calculations. Calculations were performed for SCS Curve Numbers of 70, 75, 80, 85, and 90 using Equation 2-2. As a check the calculations were performed using the triangular method presented by Scott (1979) for values of a and IA that correspond to Curve Numbers of 75, 80, and 85. The mode of the distribution about a was set at 0.26 (Osborn and Lane, 1969). The upper limit of the distribution was set at one and the lower limit was set at zero, as insufficient data was available to obtain more restrictive values. The value of IA was set to the same value as the value of initial abstraction calculated by the SCS method, i.e. 0.2S, for each corresponding Curve Number. Complete sets of computer output for the SCS model are presented in Appendix C and similar output for the Triangular model are presented in Appendix D. The annual probabilities and mean depths are compared in Table 2.10. A graphical comparison of all probabilities is presented in Figure 2.5.

It is apparent that although the probabilities are similar there is quite a variance in mean depth. The SCS model for a Curve Number of 80 with the Triangular model superimposed on it is presented in Figure 2.6. From this plot it is apparent that the triangular model will underestimate the volume of runoff, relative to the SCS model, for large events, while for smaller events the reverse is true. Since large events are relatively rare, it is not surprising that the probabilities are generally smaller for the SCS model than for the Triangular model. On the other hand, the SCS model will cause a much larger amount of runoff for large storms and this causes

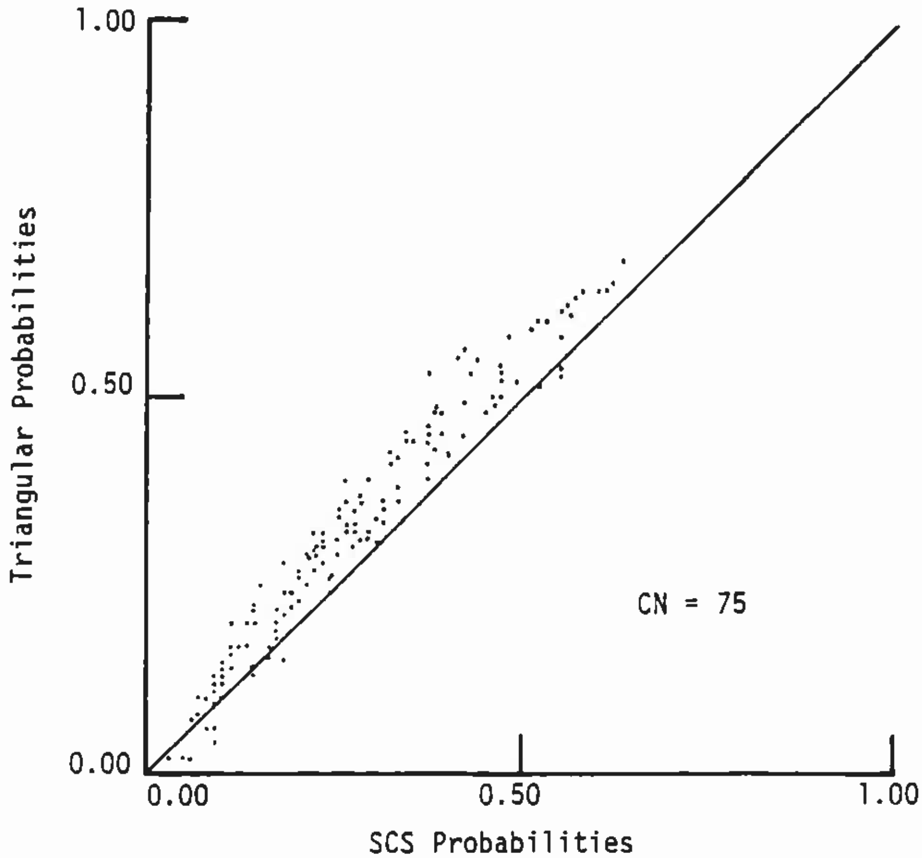


FIGURE 2.5a. Comparison of Model Probabilities

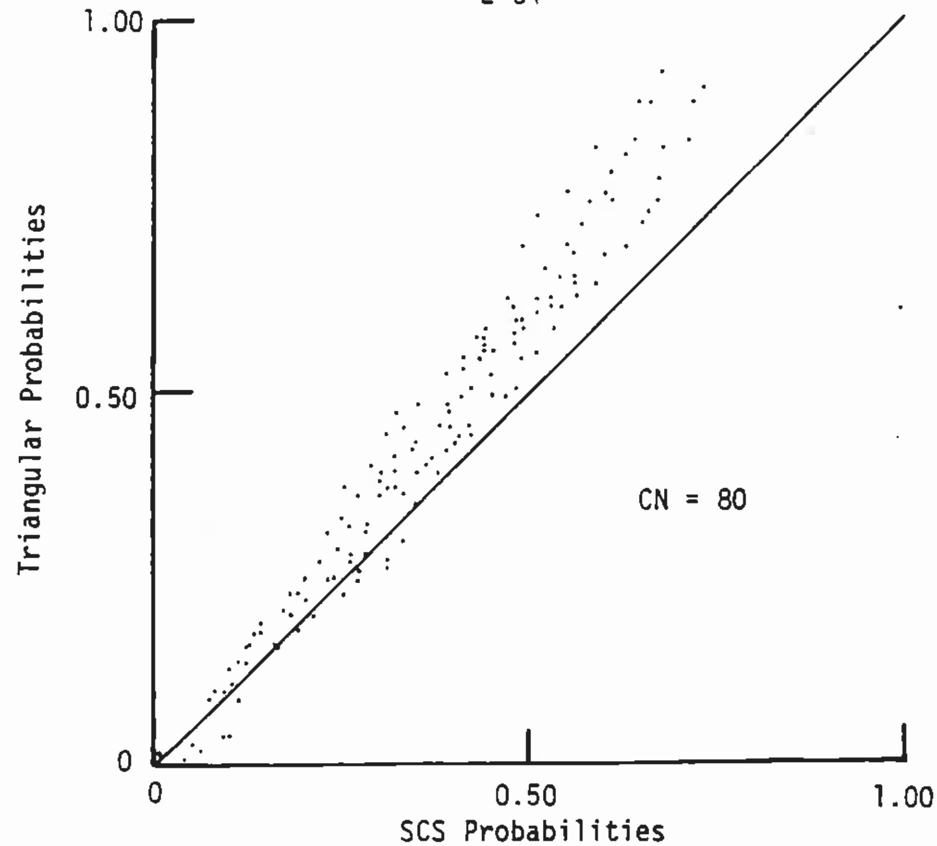


FIGURE 2.5b. Comparison of Model Probabilities

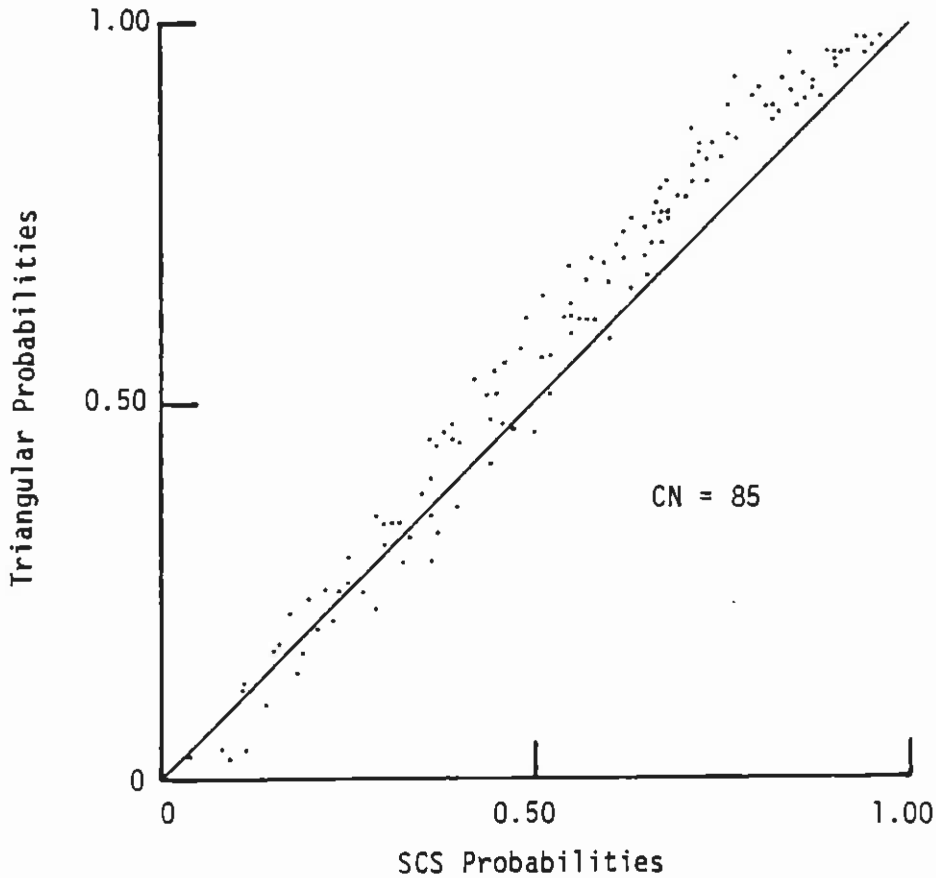


FIGURE 2.5c. Comparison of Model Probabilities

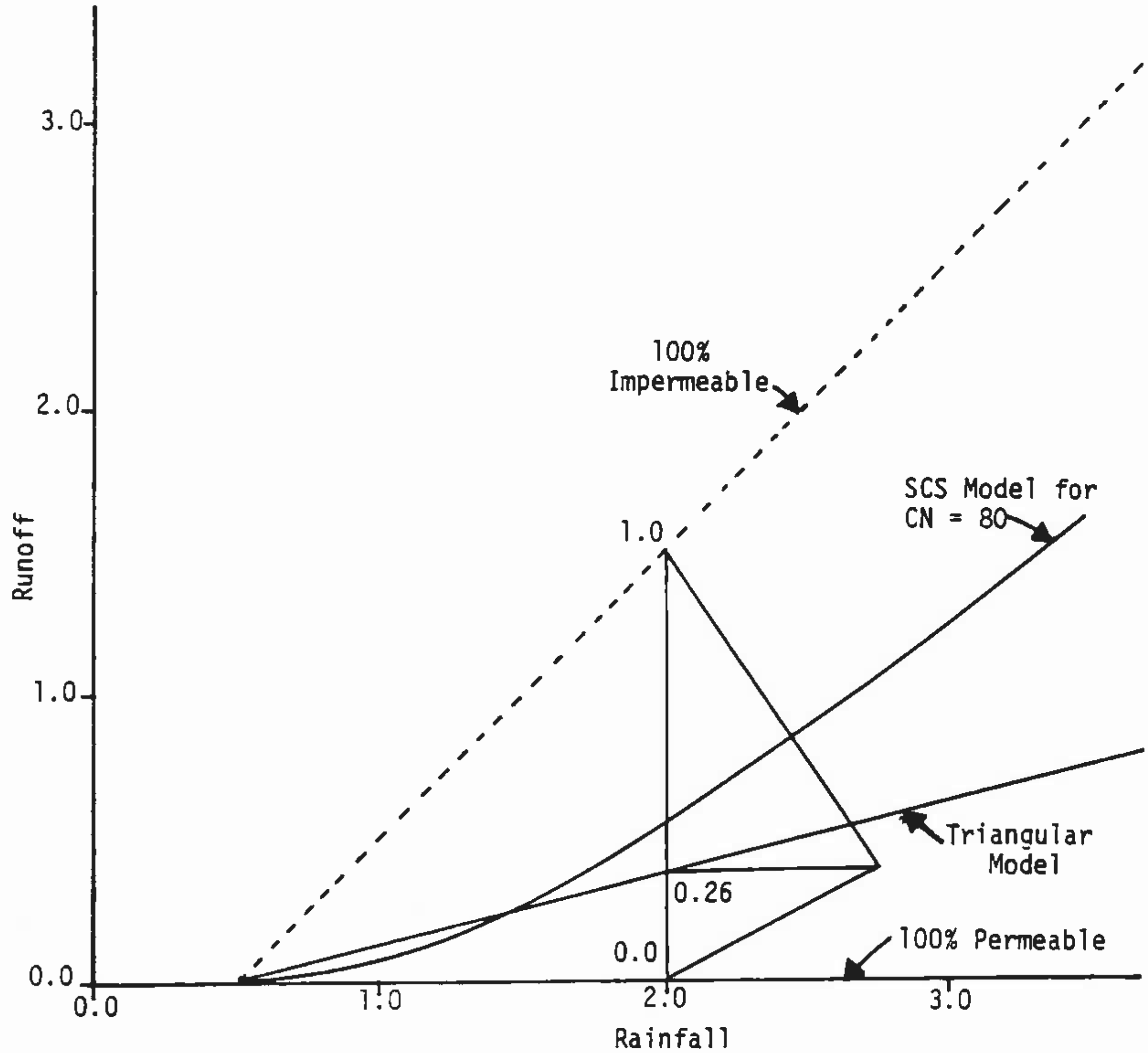


FIGURE 2.6 Comparison of SCS and Triangular Models

more water to be added to the pond. The result is a larger mean depth of water in the pond. This difference is amplified with an increase in Area Index. In addition, the Triangular model estimates runoff in a probabilistic manner, which will have some effect on the depth of runoff produced from any storm and, thus, the mean depths. It is felt that, although two distinctly different models were used, the similar probabilities increase the confidence in the results of the SCS model. Because of the widespread use of and familiarity with the SCS model, it was selected as the primary model to be used in this study. In addition, methods for estimating parameters for the triangular model are not readily available whereas much work has been published on Curve Number selection for the SCS method, thereby making it a better design tool.

Table 2.10a. Comparison of Annual Probabilities for Runoff Models

Area	CN = 75		CN = 80		CN = 85	
Index	TRI	SCS	TRI	SCS	TRI	SCS
10	.1629	.1542	.1833	.1741	.2186	.2100
20	.1967	.1775	.2375	.2131	.3037	.2791
30	.2259	.1961	.2824	.2455	.3773	.3400
40	.2503	.2140	.3229	.2765	.4464	.4026
50	.2734	.2318	.3624	.3079	.5142	.4703
60	.2954	.2484	.4021	.3449	.5788	.5220
70	.3164	.2672	.4383	.3787	.6434	.5826
80	.3372	.2898	.4780	.4080	.7110	.6525
90	.3578	.3106	.5225	.4315	.7654	.7034
100	.3802	.3255	.5621	.4566	.8133	.7611
110	.4096	.3404	.6001	.4912	.8656	.8084
120	.4360	.3602	.6423	.5237	.9163	.8600
130	.4573	.3747	.6781	.5526	.9652	.9058

Table 2.10b. Comparison of Annual Mean Depths for Runoff Models

Area	CN = 75		CN = 80		CN = 85	
Index	TRI	SCS	TRI	SCS	TRI	SCS
10	0.19	0.22	0.25	0.34	0.34	0.56
20	0.47	0.57	0.68	0.95	1.04	1.70
30	0.88	1.02	1.31	1.76	2.06	3.26
40	1.38	1.56	2.09	2.74	3.36	5.44
50	1.96	2.18	3.00	3.93	5.02	8.88
60	2.61	2.89	4.07	5.49	7.28	13.17
70	3.35	3.70	5.38	7.61	10.51	18.57
80	4.19	4.67	7.03	10.12	14.71	25.57
90	5.17	5.89	9.11	13.10	20.54	34.12
100	6.34	7.27	11.60	16.32	27.98	44.37
110	7.71	8.78	14.40	19.89	39.36	59.31
120	9.32	10.56	17.65	24.11	56.24	80.61
130	11.07	12.52	21.33	28.72	91.32	115.43

The output from the computer model for the impoundment water quantity calculations included mean daily depth, standard deviation and probability of depth exceeding zero inches by month and on an annual basis for each Area Index and Curve Number used in the simulation. For each Curve Number the probability of depth exceeding zero inches was plotted as a function of Area Index for each month and on an annual basis. The result is 65 curves (13 per Curve Number, 5 different Curve Numbers) which allow the user to estimate the probability that water will exist in the pond for a given Area Index and Curve Number. The curves are presented in Appendix E. An example of the use of these curves follows.

> EXAMPLE: After regrading, a watershed is determined to have an area of 25 acres. With no additional earthwork the impoundment size is estimated to have an area of .5 acres. It has been determined that the Curve Number for the watershed is 85. Estimate the probability that the impoundment will contain water in June.

The Area Index for the watershed with the given impoundment size is 50. June was specified since it represents the critical month with regard to depth. Using the curve for June with a Curve Number of 85, it is seen that the probability of the pond containing water is about 0.19, i.e. the pond will contain water about 19% of the time in June. Of course, the probabilities are higher in other months. If it is felt that this value is too low, then an acceptable probability can be specified and the required Area Index determined so that the specified probability is equaled or exceeded. For the same example, assume an acceptable probability of the pond containing water has been established at the 50% level. Again going to the June curve for a Curve Number of 85, it can be seen that an Area Index of about 90 is required. To achieve such an Index it would be necessary to regrade the impoundment so that its area is about 0.28 acres.

Additional computer runs were made using the SCS model for Curve Numbers of 75, 80, and 85 and allowing the Area Index to vary from 50 to 750. The output from these runs as well as the corresponding graphs is presented in Appendix F. Interestingly for the critical months, the probabilities approach a maximum of one only for very large Area Indices. For example, the probabilities for June are very near their maximum for Area Indices of 450, 250, and 150 with Curve Numbers of 75, 80, and 85, respectively. It should be pointed out that an Area Index greater than about 150 is probably not practical from a physical point of view as the very large mean depths in Appendix F. show.

A large Area Index indicates a very large drainage basin relative to pond size. For large events, the result is a very large volume of runoff delivered to the pond. Obviously to successfully catch this runoff the pond depth would have to be very large due to the necessity of a small surface area.

2.42 WATER QUALITY - To evaluate water quality in a statistical manner it was necessary to establish some acceptable upper limit of TDS concentration for the water in the pond and then estimate the probability of that limit being exceeded. An upper limit of 3000 ppm was selected based on review of EPA's Water Quality Criteria (1972). According to this manual, 3000 ppm represents an acceptable upper level deemed "satisfactory for livestock under almost any circumstances." It should be noted that this publication also states that concentrations of up to 7000 ppm can be used with reasonable safety for cattle, sheep, swine, and horses. In addition, the Water Quality Bureau, Montana Department of Health and Environmental Sciences, recommends that the concentration of TDS not exceed 2860 ppm when used for livestock. The method used to evaluate water quantity was also utilized to statistically evaluate water quality. The computer output shows that the probabilities of exceeding 3000 ppm of TDS is quite small for all cases considered, the maximum being about .09. It is, therefore, concluded that the TDS concentration will exceed 3000 ppm less than 10% of the time in any month.

2.43 SEDIMENT YIELD - As stated earlier, Equation 2-17 was used to estimate the sediment yield for the watersheds in the mine area. The parameter K was estimated in Section 2.35 from textural analysis of soils to be 0.15; the other parameters LS, C, and P were estimated as follows. The length-slope factor (LS) is a geometric parameter and determination of the value of this parameter will be discussed in the following paragraph. Based on site visits and tables in the literature (Table 5.5 and 5.6, Haan and Barfield, 1978), the cover factor, C, was estimated to be 0.30 and the conservation practice factor, P, was estimated to be 0.40. The former was selected for a Rangeland or Idle Land type with no appreciable canopy and about 10% ground cover. The latter was estimated based on observation of the contour farming practices for the existing watersheds, i.e. furrows on the contour. According to Haan and Barfield (1978), very rough surface depressions have a major effect on runoff and sediment storage and they recommend multiplying the cover factor by 0.40 to account for this type of practice. This then was taken as the value of the conservation practice factor.

Sediment yield, like runoff, is a function of watershed geometry. In order to estimate sediment yield for the drainage basins in the mine area, it was necessary to devise a method of estimating the necessary geometric parameters based on Area Index. PCC provided maps which delineated existing drainage basins and impoundments. For each drainage basin, the pond area and the watershed area were measured by planimeter and the Area Indices were calculated. In addition, other watershed geometry parameters were estimated from these maps. For each watershed the length-slope factor, LS, was estimated using the slope length versus topographic factor nomograph presented by the SCS (1977). The average value of these measurements, 3.1, was taken as the value of LS to be used in Equation 2-17. Equations 2-22 and 2-26 presented earlier were used to estimate the time to peak discharge for each individual event in the computer simulation. Obviously estimates of hydraulic slope length, L, and average watershed land slope, Y, are necessary in order to use Equation 2-22. Once again each of these parameters was estimated for each watershed from the maps supplied by PCC. Since there was substantial variation of these parameters as a function of Area Index, regression equations were used to estimate the value of each of these parameters within the computer model. The equations are

$$L = 3.79\ AI + 303.84,\ ft. \qquad (2\text{-}30)$$

$$Y = -0.03\ AI + 11.82,\ \% \qquad (2\text{-}31)$$

The geometric data developed from the supplied maps is presented in Table 2.11 and the fitted equations and the measured data are presented in Figure 2.7.

Table 2.11. Geometric Data for Existing Ponds

Location	Watershed Area (ac)	Hydraulic Length (ft)	Average Land Slope (%)	Length-Slope Factor	Area Index
J1,N6	20.46	503	10.3	3.2	45
J1,N6	40.43	755	7.9	2.7	126
N1	16.20	558	10.5	3.5	57
N1	11.49	298	11.4	2.9	10

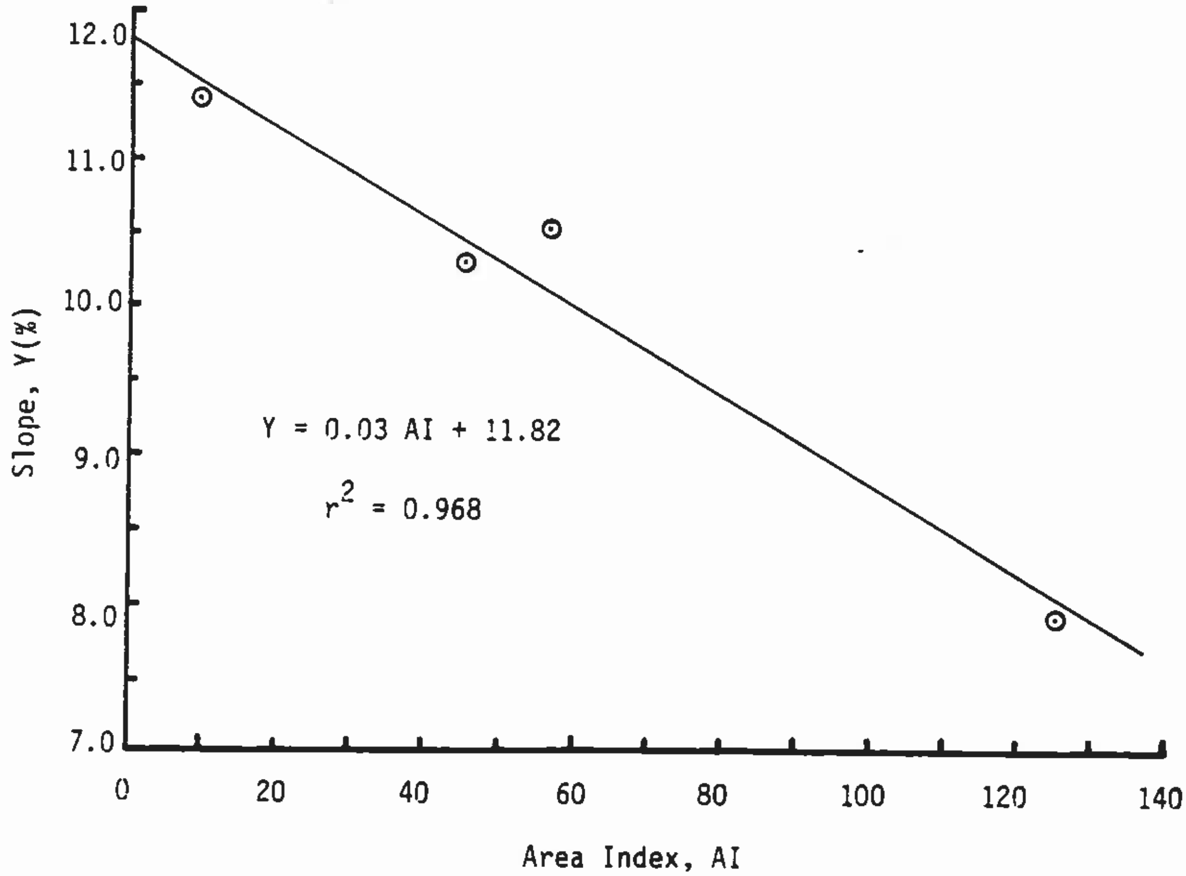


FIGURE 2.7a Slope vs. Area Index

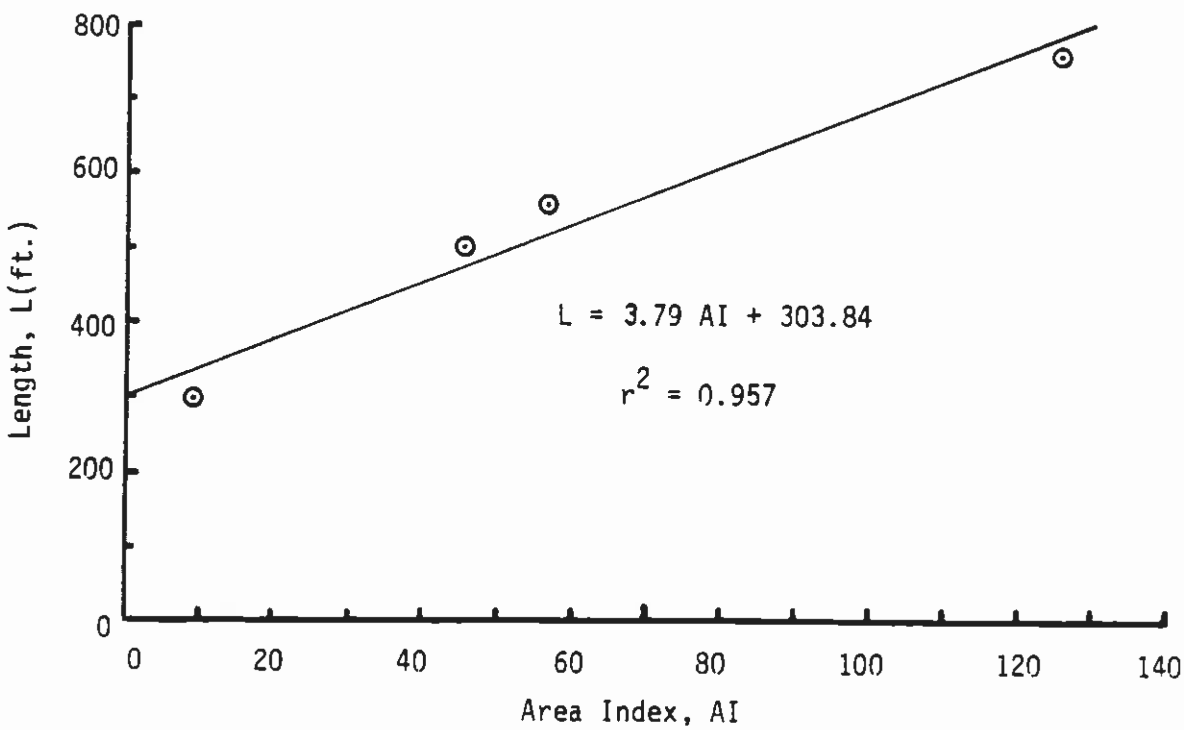


FIGURE 2.7b Length vs. Area Index

The computer model used Equations 2-30 and 2-31 in the following manner. For each area index in the simulation, Equation 2-30 is used to calculate the hydraulic length, L, of the watershed and Equation 2-31 is used to estimate the average land slope of the watershed, Y. These values are in turn substituted into Equation 2-22 to calculate a lag time and Equation 2-26 is in turn used to calculate a time to peak. This information is then used to calculate the peak flow rate for each runoff event observed in the simulation using Equation 2-18 with Area Index substituted for area. The volume of runoff is estimated using Equation 2-21. Equation 2-17 is then used to estimate the volume of sediment yield for the runoff event.

Output from the sediment yield model is presented in Table 2.12. It should be noted again that these values are probably somewhat high due to the failure of the model to properly account for storm duration. An estimate of observed sediment yield was made for two impoundments, one in the J3 area and one in the J1,N6 area. The J3 area has not been topsoiled while the J1,N6 area has been topsoiled. A pit excavated in the center of the pond in the J3 area revealed a sediment depth of approximately 18 inches. Since this was in the very center of the pond the average sediment depth in the pond was estimated at 7.2 inches. The pond has an area of 0.414 acres and it was estimated that it had been in existence for about 8 years. The density of the sediment was estimated at 80 lbs/cu. ft. Using these estimates the total volume of sediment delivered to the pond is 432 tons. The area of the watershed is about 20.3 acres and the average sediment yield is about 2.7 tons/acre-year. For the impoundment in the J1,N6 area, the estimated average depth of sediment is 3 inches; the pond area is 0.453 acres; the watershed area is 20.46 acres. It was estimated that the pond had been in existence about 3 years. The resultant sediment yield is about 3.2 tons/acre-year. It is important to point out that these figures are higher than what could be expected over a long period of time since sediment yield tends to decrease with time. In fact Curtis (1974) studied sediment yield as a function of time for strip-mined watersheds in Eastern Kentucky and concluded that erosion and sediment yield have a half-life of six months, i.e. about one-half of the total sediment yield observed occurs during the first six months of operation. The half-life at the Black Mesa mine is probably longer due to the much lower amounts of precipitation received. Curtis (1976) estimated average sediment yield in the state of New Mexico to be 0.54 acre-ft./sq.mi./year or approximately

1.5 tons/acre/year. This number is only an estimate and includes all types of land uses. Measured sediment yields for small watersheds in Arizona were obtained from Renard (1980). These data are presented in Table 2.13. As can be seen there is a substantial amount of variation in the sediment yield and the data cannot be correlated by area or cover complex. Comparison of this data with the values predicted by the model reveal some similarity for Curve Numbers of 75 to 80. The above indicate that the sediment yields predicted herein are reasonable.

Table 2.12. Sediment Yield Estimates.

Area Index	Mean Sediment Yield in tons/acre-year CN = 70	CN = 75	CN = 80	CN = 85	CN = 90
10	0.52	0.99	1.93	4.00	9.20
20	0.54	1.02	1.99	4.15	9.52
30	0.54	1.02	2.00	4.15	9.53
40	0.54	1.01	1.97	4.10	9.42
50	0.53	1.00	1.94	4.04	9.27
60	0.52	0.98	1.90	3.96	9.09
70	0.51	0.96	1.87	3.88	8.91
80	0.50	0.94	1.83	3.80	8.72
90	0.49	0.92	1.79	3.72	8.53
100	0.48	0.90	1.75	3.63	8.34
110	0.47	0.88	1.71	3.55	8.16
120	0.45	0.86	1.67	3.47	7.98
130	0.44	0.84	1.63	3.40	7.80

Table 2.13. Measured Sediment Yields In Arizona.

Watershed Area (acres)	Record Length (years)	Cover Type	Annual Sediment Yield (tons/acre)
87.0	11	Brush	2.14
108.2	15	Brush	0.92
108.8	10	Brush	1.50
108.8	9	Grass	0.40
208.0	15	Grass	1.56
227.8	4	Grass	0.40
273.9	15	Brush	0.34
371.8	20	Grass	1.13
394.2	17	Brush/grass	0.28
842.2	13	Brush	0.34

2.50 CONCLUSIONS

Based on the results of the infiltration tests and in view of the conservation practices utilized at the mine site, i.e. contour farming practices, the best estimate of SCS Curve Number seems to be in the range of 75 to 80. For a Curve Number of 80, the model indicates that the probability that water will exist in the ponds is 0.56, on an annual basis, with an Area Index of 130. For a Curve Number of 75 the corresponding probability is 0.37. For smaller Area Indices the probabilities are less. The critical month, i.e. the month with the lowest probabilities, for both Curve Numbers is June. The probabilities for June for these Curve Numbers are presented in Table 2.14. As the results of this study show, it is important to maximize the Area Index. Since it is less practical to vary watershed area, the best way to vary Area Index is by sizing the impoundment. Water impounded should not have a large concentration of TDS except, possibly, for short periods of time just prior to the time at which the impoundment becomes dry.

A method has been presented to allow PCC personnel to estimate required pond size based on watershed size. In many cases it may not be possible to obtain high values of Area Index. For example, a very small pond is required for a small watershed and it may not be physically possible to construct such a small pond. In order to maximize the amount of time that a pond will contain water certain construction techniques should be followed:

1. The pond should be constructed so that the resultant surface area is as small as possible.
2. The pond should have side slopes as steep as permissible so that surface area does not vary greatly with depth.
3. The bottom of the pond should be compacted during construction to minimize seepage through the bottom of the pond during the early years of operation.

Even these construction practices will not insure a high probability that the pond will retain water for long periods of time. Unfortunately, the objective of minimizing erosion (sediment) also results in a low Curve Number and tends to reduce the amount of water that is delivered to the pond.

Table 2.14. Critical Month Probabilities.

Area Index	CN = 75 Probability	CN = 75 Probability
10	0.0107	0.0120
20	0.0113	0.0140
30	0.0167	0.0607
40	0.0547	0.0973
50	0.0887	0.1060
60	0.0920	0.1207
70	0.0927	0.1247
80	0.1000	0.1673
90	0.1140	0.2540
100	0.1200	0.3080
110	0.1373	0.3313
120	0.1720	0.3527
130	0.1753	0.4113

3.00 GEOTECHNICAL WORK

3.10 SITE INVESTIGATION

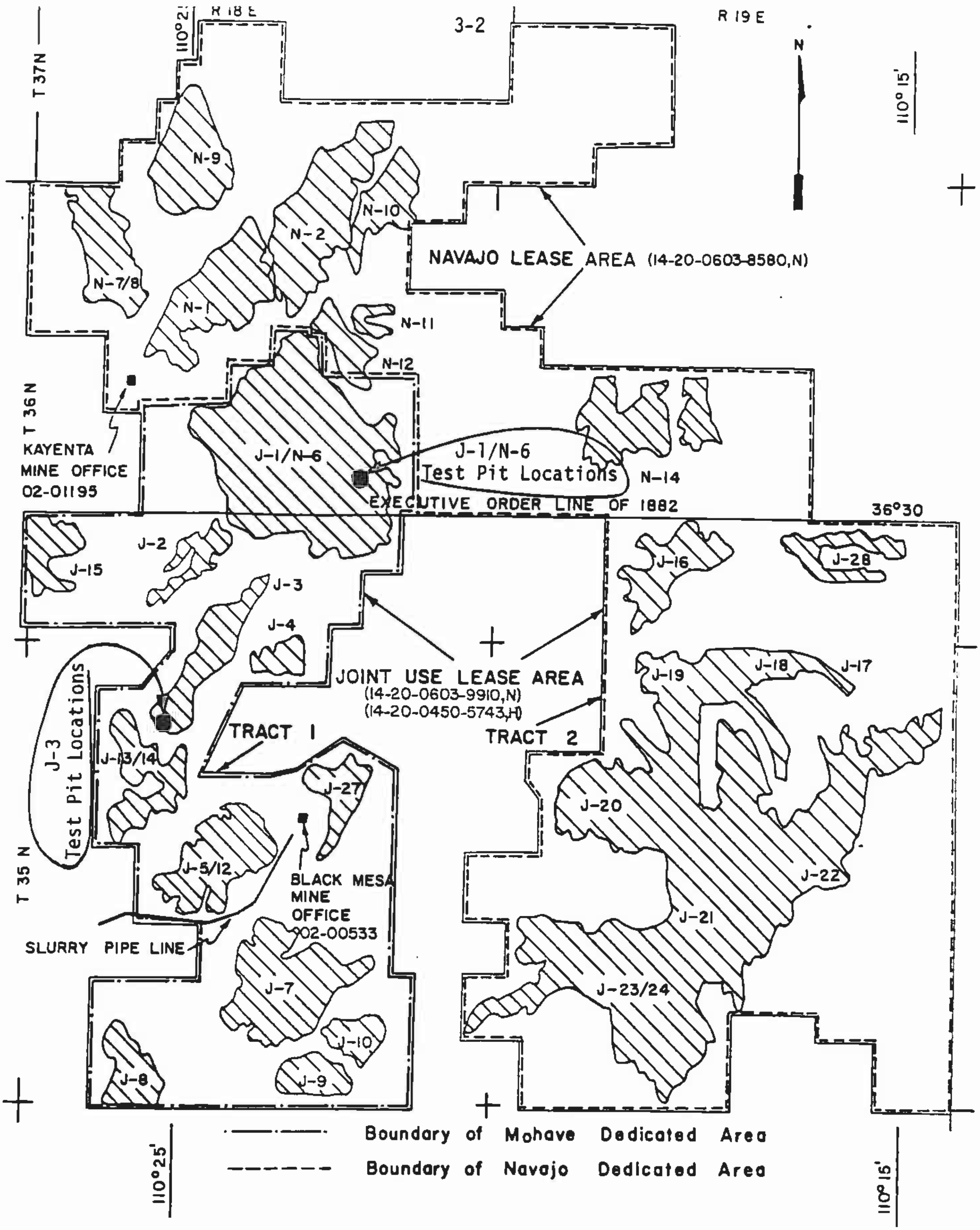
A site visit was made on March 16 and May 15 and 16, 1981. During these site visits, present grading practices were reviewed. Test pits were dug to evaluate subsurface spoil and ground water conditions in the existing pond areas. Seven backhoe test pits were dug and logged. Two test pits (TP-1 and TP-2) were dug in the J3 area and 5 test pits (TP-3 through TP-7) were dug in the J1,N6 area. Locations of these test pits are shown in Figures 3.1a and 3.1b. The profiles from these test pits and descriptions of the soils encountered are presented in Appendix G. All test pits were photographed. The photographs are included in Appendix H.

Bag samples, volumetric samples (S-series), and shelby tube samples (ST-series) were taken from the test pits and brought back to the laboratory for classification and shear strength testing. The composition and consistency of the coal mine spoils varies from area to area.

In the J3 area, a layer of gray to black topsoil approximately 6 inches thick overlaid the spoils. A root zone was evident. The spoil material ranged from a sandy silt and clayey silty sand to a coarse sand with some cobbles and boulders up to 18 inches in size. On the east side of the pond, this soil was observed to be light tan in color with low plasticity fines. One test pit at this site (TP-2) was dug to a depth of 10 feet and showed no evidence of weathering or percolation zones. In contrast, test pit TP-1, excavated at the toe of the spoil slope, contained slightly moist plastic fines with more carbonaceous material. Directly under the pond area the soil was wet. The interface between the wet zone and the dryer area up the slope indicates the infiltration of water that had collected in the pond.

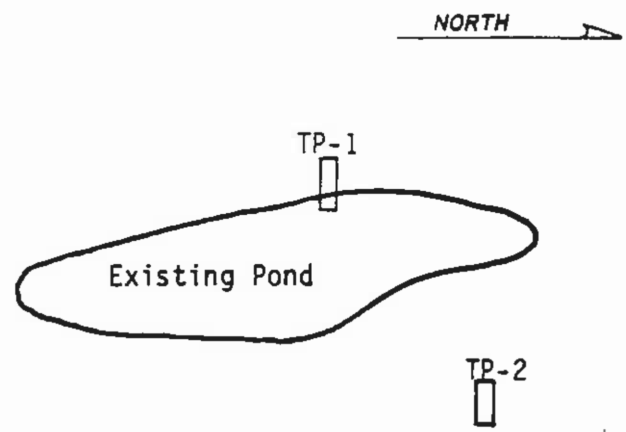
The test pits excavated in the post law area, J1,N6, were all located in one drainage area. In this entire area the spoil consisted of black to dark gray mixtures of siltstone and shale with numerous coal fragments. The fines were generally clayey in nature. A large portion contained large rocks and boulders up to 3 to 4 feet in size. Considerably more oversize material was present in this area than in the J3 area.

It appears that the material in the J1,N6 area has not undergone the degree of weathering that the spoils at Site J3 apparently have. The pond

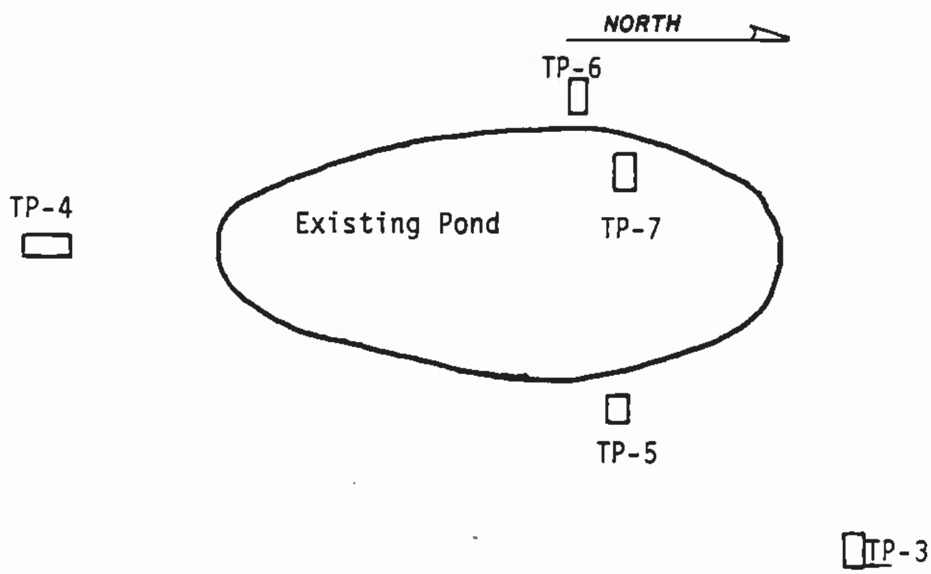


APPROXIMATE LOCATION OF TEST PONDS
RELATIVE TO **PEABODY COAL COMPANY LEASES**

FIGURE 3.1a



a. J3 AREA



b. J1,N6 AREA

FIGURE 3.1b Test Pit Locations

area itself, in J1,N6 (as evident in TP-7) is underlain by about 2.5 feet of soft moist, very clayey silt overlying a wet gray and black silty clay with coal pieces and cobbles up to 1.5 feet in diameter. It is estimated that the high percentage of fine material in this zone was carried in by runoff from the slopes.

3.20 LABORATORY TESTING

Laboratory tests were performed on the bag samples taken from each test pit to determine Atterberg limits and grain size distributions. The spoils were classified according to the Unified Classification System.

These classification tests were performed on bag samples taken from the test pits and contained only material finer than 2 inches. In the field, larger size material was observed up to three to four feet in diameter. However, the fine fraction is present in sufficient amounts such that it will govern the overall properties of the materials such as shear strength and compressibility. Consequently the classification of the finer grained material is of primary importance particulary with regard to consistency limits.

Laboratory test results are summarized in Table 3.1. The grain size distribution curves are shown in Figure 3.2. Additional grain size distribution test results are presented in Appendix B. Most grain size distribution curves indicate that greater than 50% of the material falls within the sand and gravel size range. For samples taken from test pit 4 and test pit 5, only about 14% passed the 200 mesh sieve. For all remaining samples, between 42% and 54% passed the number 200 mesh sieve. Of the soil passing the 200 mesh sieve, most samples had a relatively high clay fraction. Consequently, with the exception of the sample from TP-4, all samples are classified as an SC or a subgroup thereof, according to the Unified Classification System.

Direct shear tests were performed on samples taken from test pits 1, 2 and 5 to determine the shear strength. These shear tests were performed on material passing the #4 sieve. It is believed that these shear strength values are appropriate for use in stability analyses because, as noted above, the fine fraction will govern the engineering properties of the spoils.

Shear strength results are shown in Figure 3.3 and Table 3.2. Only the sample from test pit #1 was conducted on a saturated sample. The tests on samples from test pits #2 and #5 were performed on unsaturated samples having water contents approximately equal to those observed in the field. The sample

TABLE 3.1 - Classification of Bag Samples from Test Pits

Test Pit	Natural Water Content (%)	Description	Percent Passing #200 Mesh	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Classification
TP-1	18.1 (Shelby) 13.9 (bag)	Gray Silt-Clay, some Sand, some Gravel (Sandstone & Coal pieces to 1") very moist	51	35	19	16	SC-CL
TP-2	8.5	Tan SAND, some Silt Clay, little Gravel to 1", moist	45	24	17	7	SC
TP-3	10.7	GRAVEL and SAND, some silt, little clay, pieces to 2" max., moist	37	34	24	10	SC
TP-4	7.9	GRAVEL, some Sand, trace Silt-Clay 2" max., moist, Coal pieces	14	27	21	6	GM
TP-5	11.6 (Shelby) 11.4 (bag)	Gray-brown SAND and GRAVEL, some silt trace Clay, 1" max., very moist	42	32	20	12	SC-GC
TP-6	13.6	GRAVEL and SAND, trace Silt-Clay 1" max., very moist	14	32	20	12	SC-GC
TP-7	15.4	Silty SAND and SILT, some Clay, trace Gravel, Coal pieces, 3/4" max., very moist	54	30	17	13	SC-CL

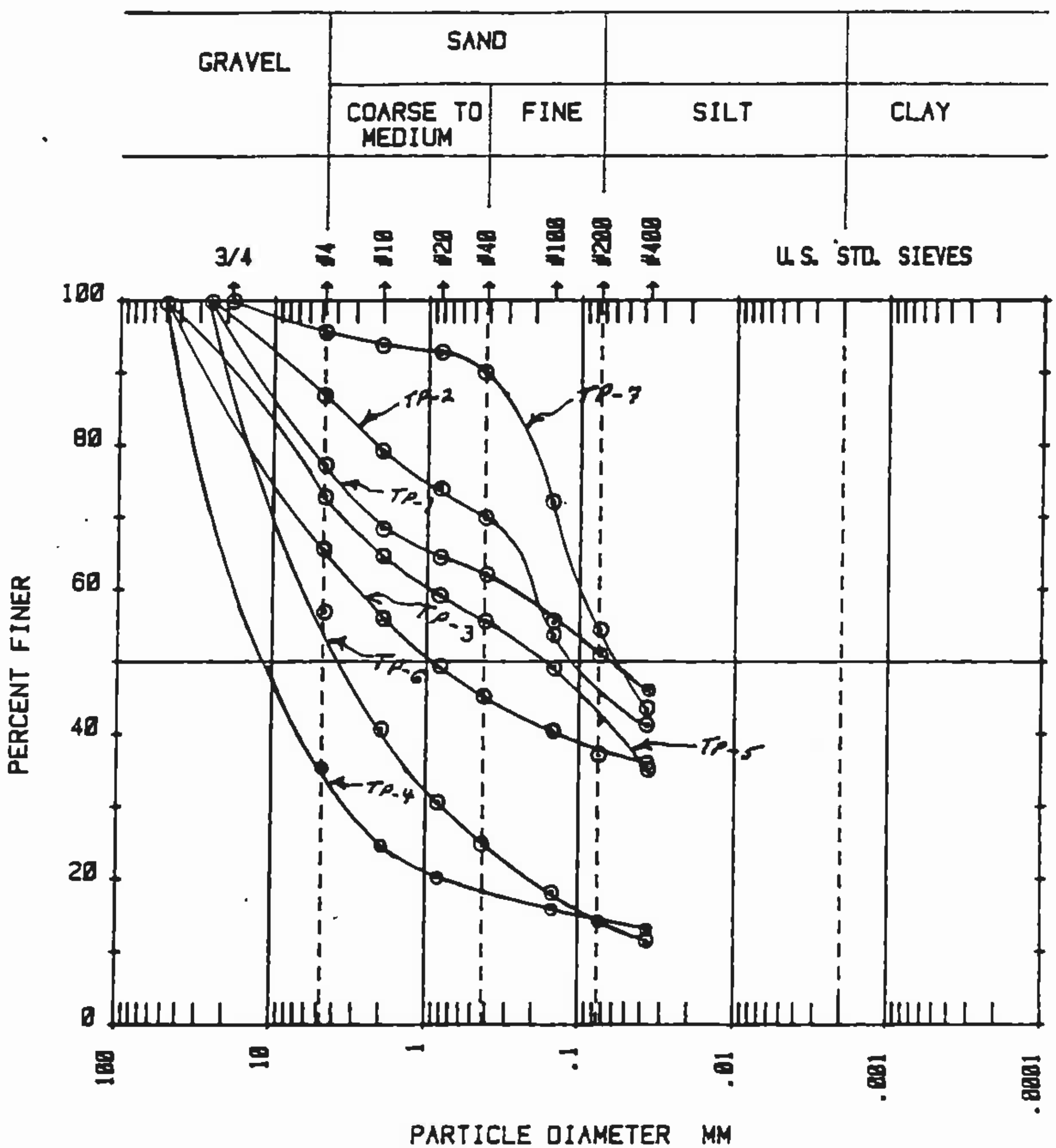


FIGURE 3.2 - Grain Size Distribution Curves

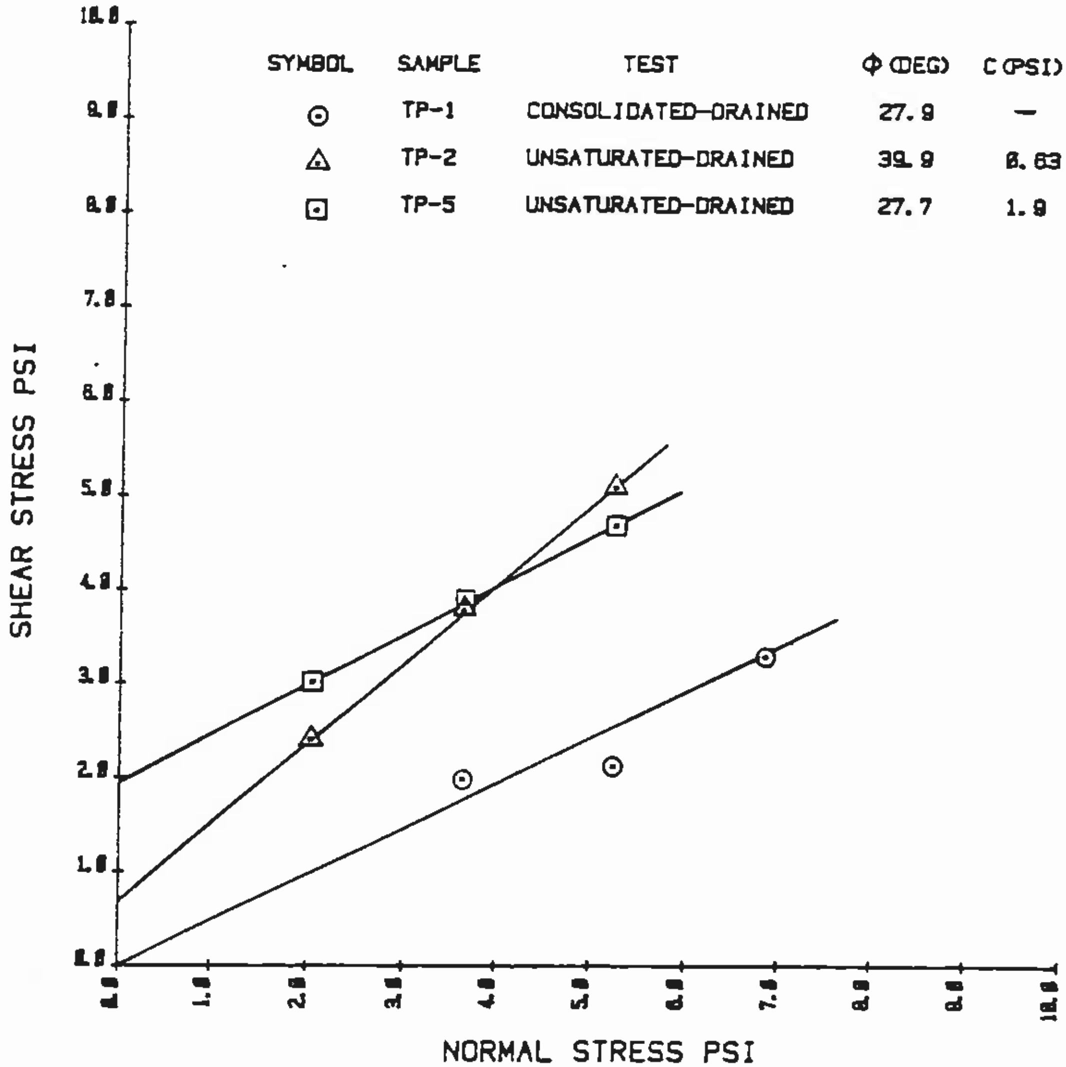


FIGURE 3.3 - Direct Shear Test Results

TABLE 3.2 Direct Shear Test Results

Test Pit	Test	Packing Water Content (%)	Test Dry Density (pcf)	Degree of Saturation (%)	Angle of Internal Friction (degrees)	Cohesion (psi)
TP-1	Consolidated-Drained (Saturated)	19.7	92.3	100	27.90	0.00
TP-2	Unsaturated-Drained	8.9	87.8	≈25	39.90	0.63
TP-5	Unsaturated-Drained	14.2	77.6	≈33	27.70	1.90

from test pit #2 exhibited an angle of internal friction close to 40 degrees and a cohesion of 90 lbs. per square foot. The material taken from this test pit was more sandy in nature and exhibited some degree of gap grading. Samples from test pits 1 and 5 indicated greater plasticity (i.e., Liquid Limit of 32-35% and Plasticity Index of 12-16%). These samples, therefore, contain a greater percentage of clay in the fine fraction. As can be seen they exhibited similar angles of internal friction.

The shear strength values that were obtained are reasonable for materials of that type.

3.30 CLIMATIC CHARACTERIZATION

Investigations into the change in soil moisture content in semi arid regions have been conducted by Abrahams, et al. (1961), Galbraith (1971), and Van Havern (1974). These investigations measured soil moisture content at various depths within the soil profile and at different times of the year so that changes in soil moisture content could be evaluated with respect to seasonal variation in precipitation and evapotranspiration. The investigation by Abrahams, et al. (1961) took place in north-central New Mexico while the Galbraith (1971) and Van Haveren (1974) investigations were conducted in a grasslands region of northeastern Colorado. All investigations were conducted on undisturbed, well drained sites with native vegetation in semi-arid climates. These sites are similar to the Peabody site once revegetation has been accomplished although rooting depths at the Peabody site will probably be shallower.

The results of these investigations showed no change in soil moisture contents below a maximum depth of approximately 6 feet for the New Mexico site and approximately 4 feet for the Colorado site. Seasonal variations did effect soil moisture contents above these depths with the maximum soil moisture content occurring in spring or early summer. Galbraith (1971) and Van Haveren (1974) concluded that this maximum recharge was due to snowmelt infiltration. Evapotranspiration which occurred throughout the summer growing season reduced soil moisture in the upper zone to minimum values by early to late fall.

All investigators concluded that there was no percolation of moisture below the root zone (at a maximum, the upper 6 feet of the soil profile) and therefore, there was no recharge of underlying water tables due to surface infiltration. Winograd (1974) and Striffler (1972) support this conclusion.

From these conclusions and from infiltration tests conducted on graded and topsoiled spoils, it may be concluded that similar conditions will prevail at this site. Thus, it is expected that little or no deep percolation will occur.

3.40 STABILITY ANALYSES

3.41 CRITICAL SECTION FOR ANALYSIS - The maximum slope to which the spoils will likely be graded according to governmental regulations is 3h:1v. The height of slopes in area J3 were measured using a hand level and rule. The maximum height of the 3h:1v portion of the slope was observed to be approximately 55 feet. For purposes of analysis, and to provide some conservatism in the results, a maximum vertical height of 100 feet with a slope of 3h:1v was selected for analysis. The analyzed cross-section is shown in Figure 3.4.

In test pit #1 it was observed that a relatively wet zone existed from the edge of the pond area and extended downward at an angle of approximately 45 degrees or less from the vertical. Consequently, the soil in the slope was considered to consist of two zones as indicated by the dashed lines shown in Figure 3.4. This wet zone is believed to represent the infiltration of water downward from the pond area. As noted in Section 3.3, Climatic Characterization, and from the hydrologic investigation, it is not expected that a phreatic surface will develop within the slope. Maximum penetration of water will be on the order of 4 feet or less. Directly under the pond area high water contents can occur but it is not believed that a ground water mound would develop in sufficient height to affect stability of the slope. However, to take into account the higher water content in this zone, lower shear strength values were used directly under the pond area (i.e. beneath the dashed line in Figure 3.4). Furthermore, if an embankment were to be placed across any of the drainage area, it is expected that vertical seepage through the foundation soils would result in a condition for the upstream slope similar to that analyzed herein. In that case any phreatic surface in the embankment would be expected to be sufficiently low that stability of the downstream face would not be adversely affected.

Figure 3.3 shows that cohesion is the primary cause of shear strength differences between the saturated and unsaturated spoils. Samples from both test pits TP-1 and TP-5 contained relatively large clay fractions and exhibited

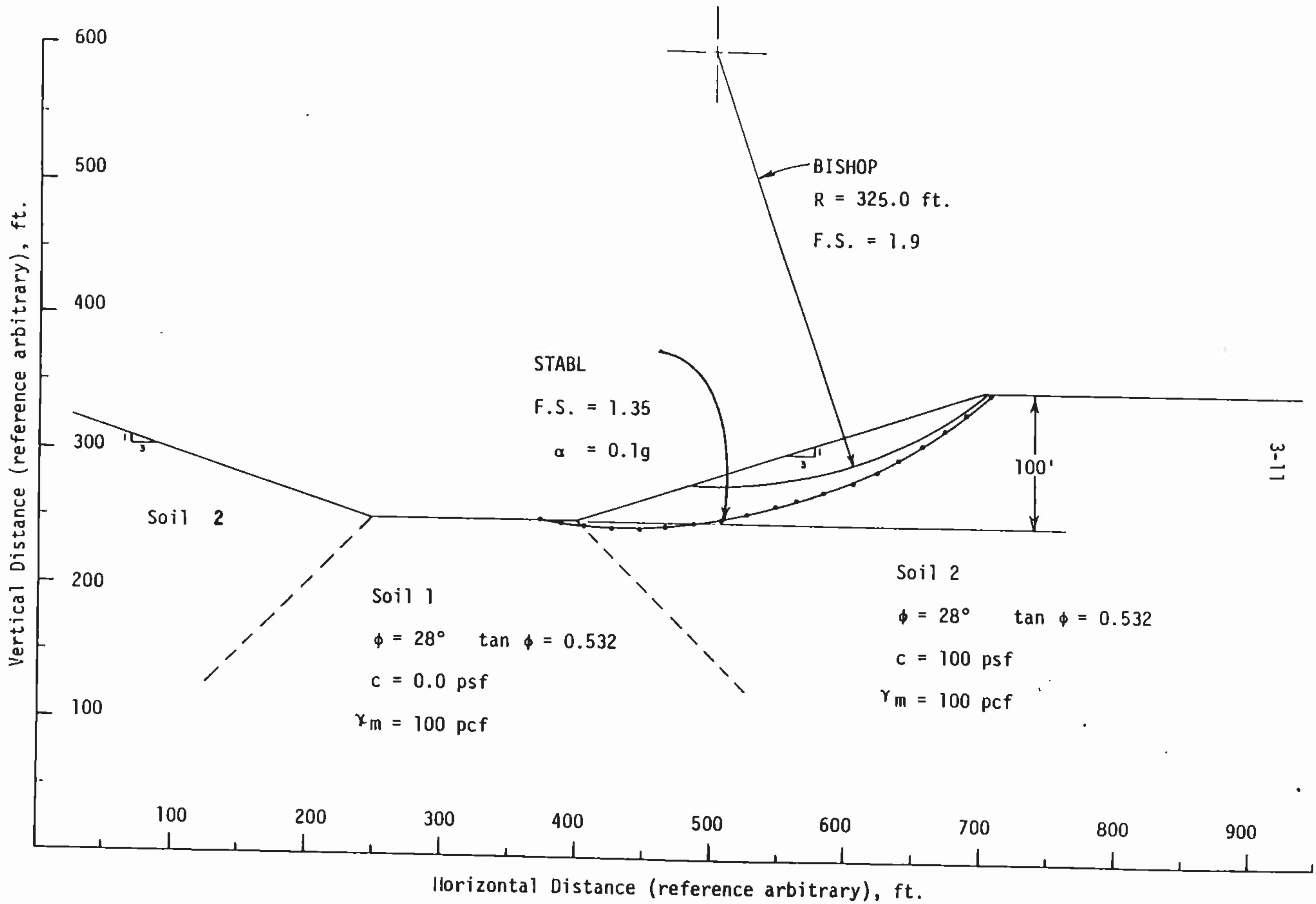


FIGURE 3.4 - Critical Section Analyzed Showing Critical Shear Surfaces

angles of internal friction of approximately 28 degrees. As noted previously in this report, the material in the field contained rocks up to 4 feet in size and therefore, the shear strength of the overall spoil material will be somewhat greater than that of the finer fraction. Nevertheless, because the fine fraction governs the shear strength of the material, the values listed in Table 3.2 for samples from test pits TP-1 and TP-5 were used in the analysis.

The difference in the cohesion intercept between test pits TP-1 and TP-5 is believed to represent the contribution due to capillary water existing in the soil. Consequently, for stability analyses both soils shown in Figure 3.4 were assigned angles of internal friction of 28 degrees. The material above the dashed line is expected to exist in a unsaturated state at all times and was assigned the cohesion value of 100 pounds per square foot. This value is somewhat lower than shown in Table 3.2, but it represents a conservative value which would exist if water contents did increase somewhat over that at the time of sampling.

Below the dashed line the cohesion was taken as zero. Test pit #1 was located near the toe of the slope in area J3. This slope has been in existence for a considerable period of time and the material sampled therefrom will have experienced some degree of weathering over that time period. The shear strength was measured on a sample taken by Shelby tube in the wet zone directly beneath the pond area. This sample therefore is believed to represent the mimimum shear strength values that one may expect to exist after some degree of weathering has occurred and under high water content conditions.

It is important to note that in each decision regarding the critical section or shear strength, conservative selection of parameters was exercised. Thus, the situation that was analyzed represent a worst condition. In general, stability in the area will be higher than that indicated herein.

3.42 COMPUTER ANALYSIS - Analysis of the slope for static loading conditions utilized the computer program BISHOP. This program was developed by the U.S. Bureau of Mines and is based on the Modified Bishop method of analysis. The mimimum factor of safety was determined by performing analyses for trail circular failure surfaces having centers at nodal points on a grid system. At each point on the grid system, circles with different radii were used until a mimimum value was found. The minimum factors of safety were plotted and contour lines were drawn. In this way the critical circle was located and the minimum value of factor of safety was computed for the overall slope.

The critical circle determined by that method is drawn on Figure 3.4. As indicated thereon a minimum factor of safety of 1.9 for static loading conditions was computed.

The slope was analyzed for potential earthquake loading conditions using computer program STABL. This method of analysis utilizes the Carter method of analysis. That method is a form of the Modified Bishop method that has been revised to allow consideration of noncircular failure surfaces. The basic assumptions in the analysis are the same as for the Bishop method. In this, program, potential failure circles are represented by a series of straight lines. The search for the minimum factor of safety is accomplished by a selection of a series of circles beginning at various points along the toe of the slope and extending upward to the top of slope. This program allows for pseudostatic loading conditions to be accomodated to represent earthquake loading. For purposes of these analyses a pseudostatic seismic coefficient of 0.1g was used. This seismic coefficient is considerably in excess of that which may be expected to occur in the Black Mesa area. The factor of safety computed therefrom is shown in Figure 3.4 to be 1.35. The seismic coefficient was applied in the upward and horizontal directions simultaneously. Consequently, this condition represents a condition considerably worse than that which is expected to actually occur. However, because stability can be demonstrated for these conditions, greater refinement of the input parameter is not warranted.

A phenomenon corresponding to earthquake loading which is not addressed in slope stability programs is that of liquefaction. If liquefaction should occur, the shear strength could be reduced, resulting in factors of safety lower than those determined using pseudostatic loading conditions. However, for the material existing in the spoil piles, it is unlikely that the spoils would be saturated. That, along with the clayey nature of the fine soil, would preclude the occurrence of liquefaction at this site.

3.43 DISCUSSION OF RESULTS - The spoil material was observed to consist of very broadly graded soil consisting of rocks up to three to four feet in size grading down to clay size material. In all but one test pit, the fine grained material was observed to be clayey in nature. Consequently, shear strength values determined using only the fine fraction were used to represent the shear strength of the spoil piles. While these values are somewhat conservative because of the presence of large size material, they are considered to be reasonable for this type of soil.

The critical cross-section that was analyzed consists of a slope having a steepness of 3h:1v and a height of 100 feet. The slope value of 3h:1v represents the maximum value allowed according to OSM regulations. The maximum height of 100 feet represents the generally highest slope expected to exist under normal grading conditions.

According to investigations of climatic conditions and the hydrologic investigation, it is not believed that a phreatic surface will develop within the spoil piles sufficiently high to adversely effect stability of the slope. Consequently, for purposes of analysis a phreatic surface within the slope was not considered. The potential for high water contents to develop in the soil directly beneath the pond area was taken into account by assigning a cohesion intercept equal to 0.0 for the material in the lower parts of the slope. In the upper parts of the slope a cohesion intercept of 100 pounds per square foot was assumed. This cohesion intercept is conservative and represents low values for saturated conditions. If an embankment were to be placed across the drainage area, it is expected that vertical seepage through the foundation soils would result in conditions for the upstream slope which are similar to that present with the existing cut slopes. As such, any phreatic surface in the embankment would be expected to be sufficiently low that stability of the downstream face would not be adversely affected.

Mimimum factors of safety of 1.9 for static loading conditions and 1.35 for earthquake loading conditions were computed. These factors of safety were computed for loading conditions in excess of the most critical that could be expected to occur and for conservative estimates of shear strength. It is believed therefore, that actual factors of safety are well in excess of those computed.

The computed factors of safety are well in excess of those required according to OSM regulations and are well in excess of those which are generally considered prudent to be required for normal engineering work. It may be concluded, therefore, that slopes, in the configuration that exists and for existing hydrologic conditions, will continue to remain stable over indefinite periods of time.

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HYDROLOGIC AND ENGINEERING STUDIES
at the
PEABODY COAL COMPANY MINES
near
KAYENTA, ARIZONA

VOLUME II

APPENDICES

Submitted to:

THE PEABODY COAL COMPANY

October, 1981

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VOLUME II

Appendix

APPENDIX A

BETATAKIN PRECIPITATION DATA

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1950

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1							.25						1
2			.26			.09							2
3						.48							3
4					.48			.08					4
5							.03		.05				5
6							.11	.05	.02				6
7		.22					.16						7
8				.02			.57						8
9				.06									9
10									.21				10
11		.66						.07					11
12			.20					.06					12
13													13
14											.12		14
15				.10									15
16													16
17									.10				17
18							.18		.05				18
19							.01				.06		19
20													20
21													21
22													22
23													23
24	.08						.25						24
25	.02												25
26			.30				.27	.46					26
27		.43						.11					27
28													28
29	.29												29
30													30
31													31
TOTALS	.39	1.31	.76	.18	.48	.57	1.83	.84	.43	0.00	.18	0.00	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1951

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1				.09	.01			.36		.48			1
2			.08					.45				.60	2
3								.90					3
4								.03					4
5												.78	5
6												.09	6
7													7
8													8
9													9
10													10
11													11
12	.42												12
13												.08	13
14												.01	14
15					.49		.14						15
16					.13								16
17							.27						17
18					.02		.04						18
19				.22								.23	19
20									.03				20
21													21
22							.05						22
23		.02									.83		23
24		.07									.36		24
25													25
26		.07								.16			26
27		.36					.03			.12			27
28								.03					28
29				.51				.54	.15				29
30	.42		.02	.33					.05			1.25	30
31			.38				.39			.22			31
TOTALS	.84	.52	.48	1.15	.65	0.00	.92	2.31	.23	.98	1.19	3.13	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ   YEAR: 1952

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1			.25										1
2			.25			.05							2
3	.59		.05			.33							3
4			.05			[illegible]							4
5							[illegible]						5
6							.23						6
7	1.02							.11					7
8													8
9							.09	.44	.03				9
10		.08										.08	10
11			.47										11
12		.16		.12									12
13			.12										13
14	.04												14
15									.06				15
16									.17		.41		16
17			.06		.13							.10	17
18	.65	.08										.12	18
19													19
20			.02	.36					.60				20
21	.07	.08							1.82			.08	21
22					.07			.06	.32				22
23								.13			.63		23
24								.06					24
25	.05												25
26							.09						26
27				.47				.55					27
28							.12						28
29							.65	.09					29
30				.10							.24		30
31												.18	31
TOTALS	2.42	.40	1.27	1.05	.20	1.09	1.50	1.44	3.00	0.00	1.28	.56	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ   YEAR: 1953

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1	.06		.09					.22					1
2								.02					2
3			.07										3
4													4
5											.19	.51	5
6				.03									6
7	.09			.69		.08							7
8							.10						8
9		.05					.15		.37				9
10								.50					10
11										.02			11
12		.06											12
13		.12						.10	.37				13
14													14
15													15
16							.52						16
17					.03		.78				.02		17
18							.02				.86		18
19		.02									.03		19
20			.13								.01		20
21													21
22								1.33					22
23													23
24		.05											24
25													25
26							.11	.20					26
27							.04	.71				.07	27
28		.01		.15				[illegible]					28
29							.24	.14					29
30			.11				1.40						30
31							.08						31
TOTALS	.15	.31	.40	.87	.03	.08	3.44	3.27	.74	.02	1.11	.58	TOTALS

DAILY PRECIPITATION-BETATAKIN. AZ YEAR: 1954

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1					.44								1
2									.55				2
3							.23		.48	.12		.02	3
4							.12	.06				.03	4
5							.13						5
6										.06			6
7										.02			7
8							.07						8
9							.02			.09			9
10												.54	10
11								.08				.07	11
12	.01		.15				.02		.54		.05		12
13	.26						.64		.17		.08		13
14		.59											14
15													15
16													16
17			.11				.18						17
18							.02						18
19													19
20	.25												20
21	.09												21
22			.34		.29		.86						22
23			.37		.14				.30				23
24			.17				.48		.04	.22			24
25	.09		.05				.03		.02				25
26	.27					1.89			.10				26
27						.18							27
28													28
29													29
30			.17	.11							.31		30
31													31
TOTALS	.97	.59	1.36	.11	.87	2.07	2.85	.14	2.20	.51	.44	.66	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1955

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1													1
2		.24			.08							.30	2
3		.03											3
4	.37							.13					4
5	.03												5
6								.37					6
7	.02												7
8													8
9								.02					9
10													10
11													11
12													12
13						.50		.40			.05		13
14						.09					.14		14
15								.22			.22		15
16	.36						.08	.27					16
17	.07	.08									.45		17
18		.32					.05						18
19		.16					.03						19
20			.04										20
21													21
22													22
23				.18				.92					23
24								.03	.01				24
25		.07					.52	.03					25
26		.17			.08		.12						26
27													27
28													28
29													29
30							.01						30
31	.12						.38						31
TOTALS	.97	1.07	.04	.18	.16	.59	1.59	2.39	.01	0.00	.87	.30	TOTALS

DAILY PRECIPITATION–BETATAKIN, AZ YEAR: 1956

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1											.04		1
2				.03									2
3													3
4													4
5													5
6			.04							.01			6
7				.01								.34	7
8													8
9													9
10													10
11													11
12			.27					.18					12
13								.01					13
14			.02	.36				.25					14
15				.01				.68					15
16		.21											16
17													17
18				.21									18
19				.05	.23						.03		19
20	.22				.15								20
21	.15								.04				21
22								.01					22
23	.09				.01		.52						23
24					.03					.03			24
25	.12				.03								25
26							.38						26
27	.09												27
28	.53						.02	.13					28
29	.14						.48			.37			29
30						.10							30
31	.20						.02						31
TOTALS	1.54	.21	.33	.67	.45	.10	1.42	1.26	.04	.41	.07	.34	TOTALS

DAILY PRECIPITATION–BETATAKIN, AZ YEAR: 1957

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1			.37										1
2			.03	.37				.01			.21		2
3			.10	.07							.33		3
4								.10			.96		4
5								.74			.27	.12	5
6	1.18					.02	.01				.18		6
7							.01				.01		7
8					.40								8
9							.27						9
10			.01			.60	.08						10
11					.26	.65				.68			11
12										.18			12
13							.02	.04					13
14													14
15					.46						.04	.12	15
16										.01		.10	16
17			.18				.51				.75	.02	17
18		.07	.01	.02			.15					.10	18
19		.02			.15		.04	.06		.04			19
20		.02						.05		.23			20
21		.04		.06	.12			.08			.01		21
22		.16	.24		.01		.03			.29			22
23		.33		.76	.26		.10						23
24		.02			.17			.11					24
25													25
26	.51						.05	.23					26
27	1.04						.01						27
28	.08	.01		.18						.04			28
29	.18			.22		.10		.09		.02			29
30	[illegible]					.01	.03	.01					30
31	.02									.25			31
TOTALS	3.30	.67	.94	1.68	1.83	1.38	1.31	1.52	0.00	1.74	2.76	.46	TOTALS

DAILY PRECIPITATION—BETATAKIN, AZ   YEAR: 1958

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1													1
2				.15					.22				2
3				.01									3
4		.10		.29				.03	.06				4
5						.09		.01					5
6			.07			.06							6
7			.33	.16									7
8								.07	.20				8
9			.10					.02					9
10													10
11	.02	.03	.11		.11						.31		11
12			.02						.45	.09			12
13	.03	.06	.01										13
14								.87					14
15													15
16			.06										16
17			.20					.12					17
18								.64					18
19	.04							.20			.17		19
20													20
21					.02			.03					21
22			.21					.37					22
23			.01				.20						23
24			.16				.09		.26				24
25		.14					.11			.18			25
26		.01								.02	.14		26
27	.16								.82				27
28			.08						.21			.11	28
29			.05	.13						.03			29
30	.15				.05					.19			30
31													31
TOTALS	.40	.34	1.41	.74	.18	.15	.40	2.36	2.22	.51	.62	.11	TOTALS

DAILY PRECIPITATION—BETATAKIN, AZ   YEAR: 1959

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1								.35		.74			1
2		.07					.29	.22		.01	.39		2
3								.01			.19		3
4								.08					4
5													5
6	.20												6
7				.40									7
8		.02											8
9		.78						.25					9
10												.10	10
11													11
12		.33						.01					12
13							.01						13
14													14
15								.28				.35	15
16							.03		.04				16
17									.03				17
18				.05				.04					18
19						.53		.02					19
20	.15					.63							20
21					.05	.01							21
22		.15										.67	22
23						.15		.01					23
24		.03						.02					24
25			.03		.03								25
26				.16									26
27										.02			27
28													28
29										.30			29
30							.20			.18			30
31			.03				.20			.36		1.55	31
TOTALS	.35	1.38	.06	.61	.08	1.32	.73	1.29	.07	1.61	.58	2.67	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1960

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1			.18						.43				1
2		.69							.23			.05	2
3													3
4											.17		4
5					.21				.16			.47	5
6						.07	.10		.06			.03	6
7						.02					.22	.59	7
8										.27			8
9		.07								.71		.35	9
10												.09	10
11													11
12	.02			.04									12
13	.29		.14						.04				13
14	.15		.06						.40				14
15									.24	1.12	.03		15
16	.10												16
17										.30			17
18									.04				18
19		.30											19
20		.30											20
21													21
22		.06						.02					22
23								.01					23
24				.01									24
25													25
26							.02						26
27		.03		.01							.24		27
28			.02	.55			.03						28
29		.17		.07									29
30							.69						30
31								.46					31
TOTALS	.56	1.62	.40	.68	.21	.09	.84	.49	1.60	2.40	.66	1.58	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1961

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1								.25			.37		1
2							.03	.03					2
3			.33		.03		.47		.19			.05	3
4			.40		.02		.08						4
5			.04	.02	.02								5
6			.09		.02								6
7			.01	.21	.07		.02		.01				7
8				.13			.09		.66	.36	.19		8
9										.17			9
10				.14								.61	10
11				.01				.05					11
12													12
13											.15		13
14												.18	14
15								.02				.40	15
16			.14					.17				.10	16
17									.07		.09		17
18			.09					.19	.15				18
19			.12					.02	.08				19
20													20
21											.15		21
22								.03					22
23													23
24				.10				.12					24
25			.06								.11		25
26	.30	.21				.04	.83				.03		26
27	.53												27
28			.35										28
29			.80				.05	.54		.15			29
30							.57	.02		.47			30
31							.14	.04		.08			31
TOTALS	.83	.21	2.43	.61	.16	.04	2.28	1.48	1.16	1.22	1.09	1.34	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1962

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1												.02	1
2													2
3													3
4													4
5								.06		.02			5
6									.59				6
7			.05										7
8		.50											8
9													9
10			.28										10
11													11
12			.03										12
13	.09	.28											13
14		.02									.10		14
15					.02								15
16					.03					.12	.28		16
17		.13				.13		.33		.26	.24		17
18								.06		.53	.42	.05	18
19								.01	.09	.03		.05	19
20		.10							.51	.13			20
21	.54												21
22	.06						.05	.13					22
23			.30										23
24												.21	24
25	.20	.47		.03							.02		25
26		.20											26
27									.19				27
28									.05				28
29						.12							29
30						.20							30
31													31
TOTALS	.89	1.70	.66	.03	.05	.45	.05	.59	1.43	1.09	1.06	.33	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1963

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1													1
2				.13			.04	.08					2
3	.17		.18					.12					3
4								.36	.02				4
5								.82	.01				5
6								.34					6
7								.10				.19	7
8								.05	.07		.10		8
9							.06	.05					9
10		.57						.26					10
11	.21	.26											11
12													12
13							.08		.12				13
14													14
15		.09					.03						15
16								.06					16
17			.20	.18					.10				17
18			.09	.06		.08			.17	.10			18
19	.12							.02	.05	.38			19
20										.09			20
21							.10				.21		21
22													22
23					.05		.14						23
24											.14		24
25								.12					25
26				.41									26
27				.02				.05					27
28													28
29								[illegible]					29
30								.25					30
31													31
TOTALS	.50	.92	.47	.80	.05	.08	.45	3.62	.54	.56	.45	.19	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1964

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1				.02				.03					1
2			.19	.27				.12			.02	.42	2
3			.20	.09				.54				.08	3
4				.12									4
5													5
6			.14	.07				.02	.47				6
7			.16		.17			.35					7
8			.18										8
9													9
10													10
11								.07			.36		11
12								.25					12
13			.17				.16	.02					13
14									.16				14
15							.05		.10		.14		15
16							.05				.37		16
17													17
18												.31	18
19	.10											.60	19
20		.19											20
21	.09						.03		.10				21
22	.20		.21				.20						22
23	.14	.01	.39										23
24			.55	.13			.28						24
25			.14	.05									25
26					.20		.04	.30					26
27					.03	.15							27
28													28
29				.06			.08						29
30							.63						30
31							.10						31
TOTALS	.53	.20	2.32	.81	.40	.15	1.64	1.70	.83	0.00	.89	1.41	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1965

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1				.02								.01	1
2								.07	.18				2
3				.30					.13				3
4				.24									4
5				.12					.04				5
6	.52	.49		.11									6
7	.07	.51		.39			.06						7
8	.39			.03	.06								8
9		.24		.21				.02				.19	9
10		.25		.06		.16		.28				.61	10
11		.08	.08	.02			.16	.02	.10				11
12				.13									12
13			.08									.12	13
14							.05				.02	.06	14
15							.53				.25	.10	15
16			.70					.58		.86	.01		16
17							.07	.21	.16	.32			17
18							.28		1.67				18
19							.10		.21				19
20	.17												20
21	.01							.03					21
22	.01						.04				.04	.70	22
23						.28	.31				.97	.38	23
24	.03		.45		.29	.24							24
25	.05		.10	.20	.34						.49		25
26							.04				.13		26
27													27
28			.11										28
29							.31						29
30												.29	30
31								.06					31
TOTALS	1.25	1.57	1.52	1.83	.68	.68	1.95	1.27	2.49	1.18	1.91	2.46	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1966

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1	.02	.07							.60				1
2			.03					.13					2
3							.24					.03	3
4										.04		.18	4
5										.30		.08	5
6									.15	.07		.06	6
7										.15		[illegible]	7
8		.82									.62		8
9		.15			.01						.04		9
10		.07					.26						10
11					.16					.17			11
12					.30								12
13		.01		.02									13
14													14
15		.03											15
16								.02					16
17						.04	.02	.03					17
18	.42			.03									18
19				.52					.62				19
20	.04			.23		.02	.01						20
21							.24						21
22							.12		.01				22
23							.33	.10	.14				23
24							.37						24
25		.01					.01						25
26			.02					.01				.22	26
27						.01			.18			.15	27
28						.04							28
29						.03	.36						29
30								.45				.08	30
31	.63							.36				.02	31
TOTALS	1.11	1.16	.05	.80	.47	.14	1.96	1.10	1.70	.73	.66	1.41	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1967

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1								.02				.12	1
2										.01			2
3													3
4				.01		.20		.01					4
5			.18	.05	.06	.11			.04				5
6	.07							.06					6
7							.30	.08	.02				7
8								.12	.24			.02	8
9								.45					9
10							.08						10
11									.01				11
12				.13			1.01						12
13				.03		.30						.05	13
14												.32	14
15												.16	15
16							.24					.25	16
17							.22					.10	17
18									.01			.01	18
19						.45	.01		.09			.82	19
20						.06		.01				.20	20
21								.08					21
22											.06		22
23	.29						.16						23
24									.53				24
25	.15			.10	.10				.25				25
26					.05		.01						26
27					.17		.12						27
28					.10								28
29			.16				.02	.02			.10		29
30			.07		.28		.40						30
31					.14		.10	1.88					31
TOTALS	.51	0.00	.41	.32	.90	1.12	2.67	2.73	1.19	.01	.16	2.05	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1968

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1				.01				.27			.30	.18	1
2				.07								[illegible]	2
3							.03			.20			3
4					.05		.02			.50			4
5								.01					5
6			.01	.12			.06						6
7			.10					.95					7
8			.08			.04							8
9			.01			.12							9
10			.12						.05				10
11	.01				.14			.34				.04	11
12								.04	.06				12
13		.03			.20			.08	.05		.12		13
14		.07	.13								.08		14
15										.02	.31		15
16										.07			16
17												.21	17
18				.01									18
19			.01	.05									19
20			.06									.21	20
21		.21		.04								.15	21
22				.01									22
23													23
24							.07						24
25							1.01						25
26							.65					.08	26
27							.04	.04					27
28	.05												28
29	.05								.03				29
30										.04			30
31	.03						.17			.14			31
TOTALS	.14	.31	.52	.31	.39	.16	2.05	1.73	.19	1.07	.81	1.09	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1969

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1			.31					.03					1
2													2
3				.10				.12	.04	.92			3
4			.04		.17		.03		.11				4
5			.01		.32		.05					.03	5
6			.06		.12	.03							6
7		.23	.01		.43	.04					.09		7
8													8
9								.09			.13	.23	9
10			.12					.02					10
11			.09			.01		.15	.04	.13			11
12		.04				.09		.09					12
13		.22				.06	.11						13
14	.32												14
15	.17	.06											15
16		.21				.04					.29		16
17	.02								.05		.31		17
18	.08			.01		.02	.21	.04					18
19	.06	.26					.43	.06					19
20	.03	.16					.01						20
21	.04	.04								.13			21
22		.02					.03		.03	.69			22
23	.01	.02											23
24	.17					.02	.07	.01					24
25	.27												25
26	.13	.05				.02		.02					26
27												.07	27
28								.06					28
29	.15						.07						29
30								.12	.05				30
31								.04					31
TOTALS	1.45	1.31	.64	.11	1.04	.33	1.01	.85	.32	1.87	.82	.33	TOTALS

DAILY PRECIPITATION–BETATAKIN, AZ YEAR: 1970

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1	.05		.70						.02				1
2			.40										2
3			.15				.47						3
4						.01	.04	.25	.12				4
5			.18				.07	.31	.34				5
6													6
7						.13					.03		7
8							.06			.25			8
9												.07	9
10			.06				.03						10
11			.05										11
12													12
13												.11	13
14		.04										.10	14
15	.32												15
16	.01												16
17	.13		.02	.23			.05						17
18				.40			.05	.15				.17	18
19								.03				.01	19
20								1.22				.16	20
21		.05										.18	21
22		.02				.02				.20		.19	22
23		.09				.28	.01						23
24													24
25								.10					25
26											.05		26
27			.10							.03	.15		27
28	.03			.02									28
29			.03			.03		.04					29
30			.03								.06		30
31			.14										31
TOTALS	.54	.20	1.86	.65	0.00	.47	.78	2.10	.48	.48	.29	.99	TOTALS

DAILY PRECIPITATION–BETATAKIN, AZ YEAR: 1971

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1			.04							.50			1
2	.16		.06										2
3	.02	.03										.03	3
4													4
5													5
6					.06								6
7								.02				.40	7
8					.10		.20					.21	8
9					.02								9
10													10
11												.02	11
12						.08							12
13			.06						.03			.61	13
14												.03	14
15											.55	.02	15
16								.01		.12	.19		16
17		.01					.55			.65	.01		17
18		.10		.20						.03			18
19		.01					.30	.25					19
20		.33		.07				.06					20
21		.06		.04			.15				.04		21
22								.20				.02	22
23												.04	23
24								.15					24
25		.01						.59		.29		.12	25
26		.05						.50		.35		.16	26
27							.02	.19					27
28		.02						.17					28
29									.25	.59	.02	.02	29
30										.34	.11		30
31													31
TOTALS	.18	.62	.16	.31	.18	.08	1.22	2.13	.28	2.57	.91	1.69	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1972

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1													1
2													2
3													3
4						.08				1.16		.02	4
5						.04		.30				1.01	5
6						.15				.31			6
7						.01			.22	1.30		.06	7
8						.66		.36			.01	.03	8
9												.26	9
10												.07	10
11											.10	.03	11
12				.10				.05			.48		12
13				.01									13
14				.01				.04					14
15				.03				.03		.36	.01		15
16										.37			16
17										1.22			17
18							.08	.06	.02	1.43			18
19								.35	.47	1.74			19
20								.06	.07	.43	.06		20
21													21
22						.27							22
23						.21							23
24										.01			24
25								.19		.43			25
26								.18					26
27								.23		.10			27
28			.01									.52	28
29										.14		.43	29
30													30
31										.01			31
TOTALS	0.00	0.00	.01	.15	0.00	1.42	.08	1.85	.78	9.01	.66	2.43	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1973

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1					.04	.01							1
2				.28									2
3	.03			.14		.04						.82	3
4	.05		.10			.30							4
5			.14		.26								5
6		.06			.09				.06				6
7		.02	.25										7
8			.05										8
9	.06		.03				.20			.17			9
10	.08	.03							.31				10
11													11
12		.06	.21				.30						12
13		.02	.06			.20							13
14		.02				.03							14
15													15
16							.19						16
17	.14												17
18			.13	.02			.10	.12					18
19	.02						.10				.80		19
20	.07							.30					20
21		.03	.14										21
22		.10	.27								.15		22
23		.23	.47										23
24													24
25									.06		.12		25
26											.20		26
27			.36										27
28		.04	.15				.36						28
29			.34										29
30				.05				.14					30
31								.01					31
TOTALS	.45	.61	2.70	.49	.39	.58	1.25	.57	.43	.17	1.27	.82	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ   YEAR: 1974

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1	.45							.13			.02		1
2				.17									2
3											.37		3
4			.12										4
5												.10	5
6								.05					6
7	.01												7
8	.17							.04			.25	.10	8
9	.38		.25										9
10													10
11								.05					11
12										.15			12
13		.24								.27			13
14							.15						14
15							.10						15
16							.22		.15				16
17	.19	.46											17
18									.27				18
19							.57						19
20													20
21							.19		.13	.15			21
22							.03			.28			22
23										.17		.12	23
24													24
25													25
26	.15									.10			26
27										.68			27
28	.09									.11			28
29										.48		.14	29
30										.02			30
31													31
TOTALS	1.44	.70	.37	.17	0.00	0.00	1.26	.27	.55	2.41	.64	.46	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ   YEAR: 1975

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1				.19							.06		1
2	.11						.61						2
3							.07		.02				3
4		.08											4
5					.06								5
6													6
7	.05			.02					.22				7
8							.15		.14				8
9	.02		.15				.03						9
10			.26				.76						10
11		.07	.31	.26			.37	.09	.13				11
12			.27	.06			1.32		.03				12
13									.55			.03	13
14		.22										.30	14
15		.90	.44										15
16		.19					.10						16
17		1.06	.14	.40	.07		.09						17
18				.08		.17					.06		18
19											.02		19
20						.03		.10					20
21					.17							.10	21
22													22
23										.06			23
24													24
25													25
26			.04										26
27							.35				.09		27
28	.20				.15						1.25		28
29					.02		.42				1.50		29
30													30
31	.10									.03		.23	31
TOTALS	.48	2.52	1.61	1.01	.47	.20	4.27	.19	1.09	.09	2.98	.66	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ — YEAR: 1976

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1													1
2								.30		.05			2
3			.16										3
4			.17							.01			4
5		.96											5
6	.05	.14							.42				6
7			.04		.41		.25	.16					7
8					.40			.11					8
9		.48					.05		.10				9
10									.08				10
11													11
12													12
13											.05		13
14		.38					.12				.02		14
15											.22		15
16							.96						16
17							.02	.13					17
18							.02						18
19								.40					19
20					.27			.43					20
21					.27				.38				21
22									.01				22
23													23
24									.01				24
25							.47	.08	.95				25
26							.17		.59				26
27							1.21		.04				27
28													28
29						.06							29
30						.02							30
31							1.08					.09	31
TOTALS	.05	1.96	.37	0.00	1.35	.08	4.35	1.61	2.58	.06	.29	.09	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ — YEAR: 1977

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1													1
2				.10					.48				2
3	.21					.01			.10				3
4							.02						4
5	.20						.05	.17					5
6										.04	.05		6
7											.02		7
8	.14					.01		.30					8
9	.01												9
10													10
11		.05											11
12							.02	.77	.05				12
13					.05								13
14					.15								14
15													15
16								.48					16
17							.12	.25					17
18								.22				.05	18
19							.35				.04	.24	19
20							.55				.06		20
21										.05			21
22	.23	.08					.01						22
23													23
24							.35						24
25			.12										25
26													26
27													27
28							.05					.25	28
29												.19	29
30												.03	30
31													31
TOTALS	.79	.13	.12	.10	.20	.02	1.52	2.19	.63	.09	.17	.76	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1978

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1			.63	.55					.04			.01	1
2			.03		.06						.06	.70	2
3			.16								1.32	.04	3
4	.08												4
5	.01				.19							.07	5
6	.04		.20		.03	.07						.51	6
7		.09			.03							.08	7
8													8
9		.13		.10				.01					9
10	.25		.02				.02						10
11	.16										.91		11
12			.15								.59		12
13		.10											13
14									.13				14
15	.32						.01				.21		15
16		.74					.02						16
17	.25								.05			.28	17
18							.05					.95	18
19	.22											.17	19
20	.22									.13			20
21										.10			21
22			.05							.17			22
23	.23												23
24	.21						.05		.24	.06	.12		24
25										.03	.14		25
26											.23		26
27													27
28						.05							28
29													29
30													30
31	.34												31
TOTALS	2.33	1.06	1.24	.75	.31	.12	.15	.01	.46	.49	3.58	2.81	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1979

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1		.15				.03							1
2		.11	.08										2
3					.05								3
4													4
5	.11												5
6	.15												6
7	.15										.09		7
8					.07	.61		.17			.66		8
9	.02				.22								9
10				.11									10
11								.85					11
12	.28			.01									12
13	.05							.13					13
14			.08										14
15	.06							.13					15
16	.20				.07			.10					16
17	.56							.02					17
18	.05							.02					18
19	.11	.09	.12				.05				.66		19
20		.22	.05		.02				.04	.12	.31		20
21		.01	.02							1.46		.21	21
22	.03	.01	.11									.10	22
23		.08											23
24					.39								24
25	.26				.32								25
26	.16				.01							.41	26
27		.09										.22	27
28	.02												28
29	.03		.30							.06			29
30						.03				.04			30
31			.20										31
TOTALS	2.24	.76	.96	.12	1.15	.67	.05	1.42	.04	1.68	1.72	.94	TOTALS

DAILY PRECIPITATION-BETATAKIN, AZ YEAR: 1980

DAY	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	DAY
1							.02	.10					1
2				.30			.08	.05					2
3					.03								3
4			.13										4
5									.11			.45	5
6									.06			.03	6
7		.10	.34		.03				.20			.04	7
8					.13		.05		.15			.39	8
9	.08								.35				9
10	.19								.89				10
11	.36		.35		.49								11
12							.23						12
13										.24			13
14		.29						.24					14
15	.13	.21			.06					.37			15
16		.23								.06			16
17		.45											17
18	.21												18
19	.58												19
20	.02	.75											20
21		.25											21
22		.12	.17				.08						22
23								.20					23
24				.31				.33			.23		24
25			.50										25
26										.11			26
27										.04			27
28			.10						.02				28
29	.19												29
30				.08									30
31			.06										31
TOTALS	1.76	2.40	1.65	.69	.74	0.00	.46	.92	1.78	.82	.23	.91	TOTALS