EXAMPLE CALCULATIONS OF POSSIBLE GROUND-WATER INFLOW TO MINE PITS AT THE WEST DECKER, EAST DECKER, AND PROPOSED NORTH DECKER MINES, SOUTHEASTERN MONTANA

by Robert E. Davis

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CONVERSION FACTORS

The inch-pound units used in this report can be converted to the International System of Units (SI) by the following conversion factors:

Multiply inch-pound unit	By	To obtain SI unit
foot	0.3048	meter
foot per day	0.3048	meter per day
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
mile	1.609	kilometer
square foot	0.09290	square meter

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ABSTRACT

Proposed plans to raise the spillway of the Tongue River Dam 14 feet would result in an increase in the reservoir stage, which will affect the amount of ground-water inflow from the reservoir to existing and proposed surface coal mine pits in the vicinity of the Tongue River Reservoir. This study was conducted to provide an example of how the ground-water inflow could be estimated.

The example calculations are based on flow from the reservoir to the mine pits approximately perpendicular to the long axis of the reservoir. As shown, the calculations indicate that the planned increase in the stage of the reservoir will result in an increase of inflow to the mine pits in most areas. The increases will be greatest where the mine pits are near the reservoir and separated from the reservoir solely by aquifer zones of relatively large hydraulic conductivity. However, the inflow determined from the calculations is subject to a large degree of error, owing to the simplified method of calculation and the assumptions used.

INTRODUCTION

The U.S. Bureau of Reclamation and the Montana Department of Natural Resources and Conservation are presently evaluating the possibility of raising the existing spillway structure of the Tongue River Dam by 14 feet, from 3,424 feet to 3,438 feet above sea level, which would also raise the reservoir pool altitude. If the spillway and reservoir pool altitude were raised, existing surface coal mining operations at the West Decker and East Decker Mines and proposed operations at the North Decker Mine probably would be affected, owing to their proximity to the reservoir (fig. 1). One of the potential effects would be an increase in the amount of ground-water inflow from the reservoir to the mine pits.

The purpose of this study, conducted in cooperation with the U.S. Bureau of Reclamation, was to provide example calculations of how ground-water inflow could be estimated. Darcy's law was used to calculate one-dimensional inflow from the reservoir to the mine pits. Existing hydrogeologic data from mine-permit applications and previously published reports were used. For areas where data were not available, values were estimated.

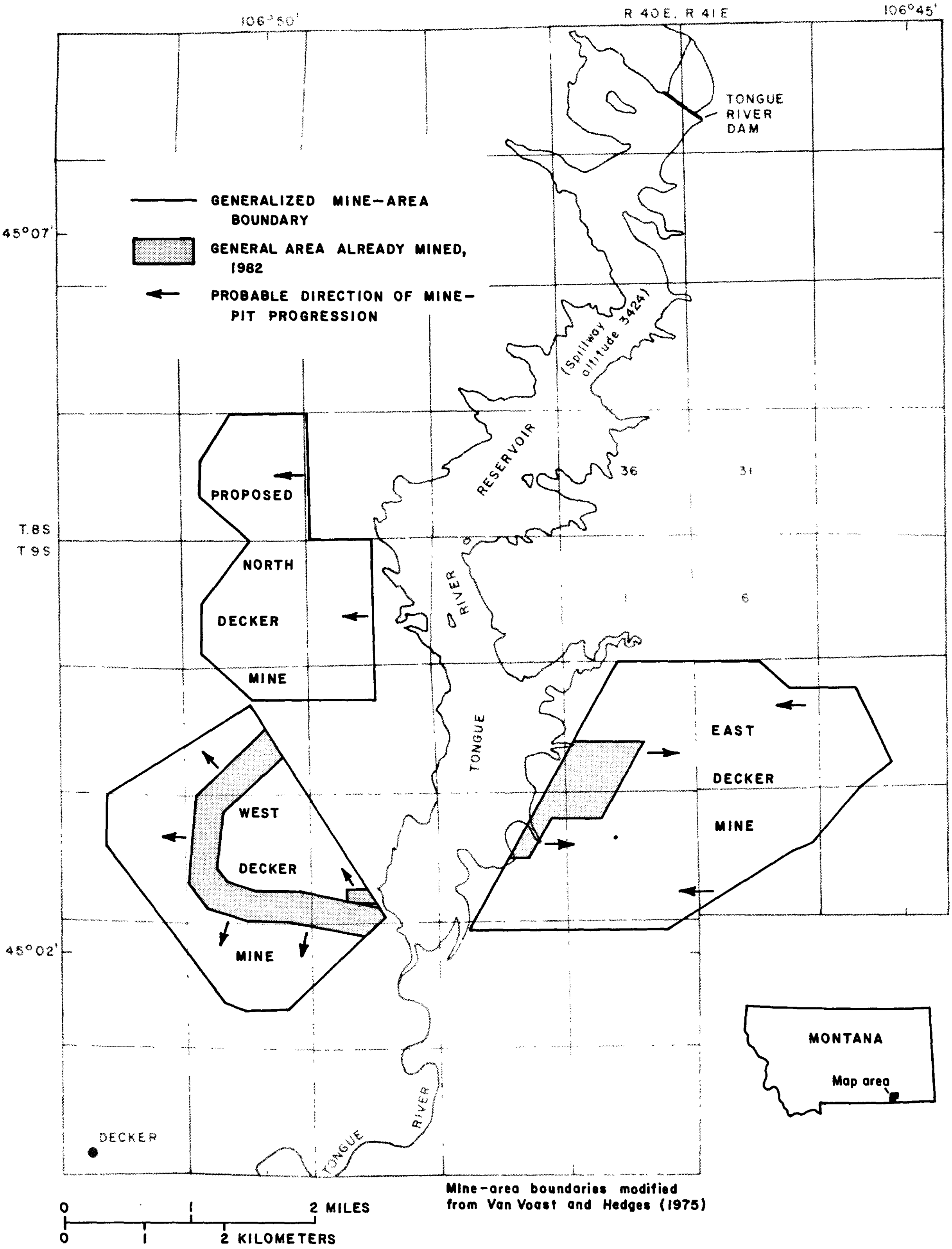


Figure 1.--Location of mine areas.

GEOHYDROLOGIC SETTING

The study area is underlain by the Tongue River Member of the Paleocene Fort Union Formation and Quaternary alluvial deposits. The Tongue River Member consists of tan to gray shale, siltstone, very fine to fine-grained sand and sandstone, and coal beds. The main near-surface coal beds are, in descending stratigraphic order, the Anderson bed, the Dietz 1 bed, the Dietz 2 bed, and the Canyon bed. The Tongue River Member dips gently in various directions depending on specific location. Also present is clinker, which consists of fractured shale, siltstone, and sandstone that has been baked by the burning of underlying coal beds.

In the study area, the primary aquifers are the clinker, coal beds, and alluvium. The clinker is very permeable as a result of fracturing. Undisturbed shale and sandstone within the Tongue River Member in the study area are relatively impermeable and, for the purposes of this study, are not considered to be aquifers.

Recharge to the undisturbed hydrologic system is mainly from infiltration of precipitation in areas of outcropping clinker. Discharge from the undisturbed system is to the Tongue River Reservoir. However, mining excavations in most areas are below the reservoir stage and locally serve as areas of discharge. Ground-water inflow to the mine pits occurs primarily through the clinker, coal beds, and alluvium and also through the mine spoils created by replacement of overburden material moved during mining.

METHOD OF CALCULATION

Raising the altitude of the reservoir spillway would result in a rise in the average stage of the reservoir and also increase the areal extent of the reservoir. These changes would affect ground-water inflow to the mines by changing the difference in hydraulic head between the reservoir and the mines and, in some areas, by decreasing the distance between the reservoir and the mines. Several methods are available to estimate the ground-water inflow. Digital-modeling techniques could be used to produce relatively accurate estimates if based on accurate and complete geohydrologic data. Analytical line-sink channel methods, such as those described in Ferris and others (1962), also could be used if warranted by the completeness of the hydrologic data. However, because of constraints on time, money, and existing data, a simplified one-dimensional solution based on Darcy's law was used in this report to estimate ground-water inflow.

Using Darcy's law, one-dimensional inflow may be expressed as:

$$Q = KA \frac{\Delta h}{\Delta x} \tag{1}$$

where

- Q is inflow rate, expressed as cubic feet per day or cubic feet per second, as indicated;
- K is hydraulic conductivity, expressed as feet per day;
- A is the cross-sectional area through which flow occurs, determined as the product of the saturated thickness multiplied by the width of the area, expressed as square feet;
- Δh is change in hydraulic head, expressed as feet; and
- Δx is distance over which the change in hydraulic head is determined, expressed as feet.

Darcy's law is valid for steady-state and laminar-flow conditions. It also assumes horizontal-flow conditions for unconfined aquifers. These conditions probably do not exist near the mine-pit face and might not exist in areas of fractured clinker. Thus, the cross-sectional area A was determined for a location at a sufficient distance from the mine-pit face such that dewatering near the mine-pit face did not affect the size of the area.

The example calculations represent only the part of total ground-water inflow to the mine pits that is derived from the reservoir. The reservoir inflow to the pits is assumed to occur approximately perpendicular to the long axis of the reservoir through designated subareas (fig. 2). This assumption neglects any inflow from other directions. For some subareas used in the calculations, inflow along the sides may be negligible, non-existent, or included in the inflow calculation of a neighboring subarea. For other subareas, particularly the northern parts of the East Decker and North Decker Mines, the inflow along the sides may be as significant as the inflow through the cross-sectional area used for the calculations. Calculations of inflow from the reservoir to the mine pits are shown only for aquifers intercepted by the mine cut. Inflow resulting from vertical leakage from underlying aquifers within the Tongue River Member was not considered.

Calculations of inflow are based on the known or assumed hydrologic conditions of an east-west section through the middle of each subarea (fig. 2). The stratigraphic relationships are illustrated by generalized cross sections included with the calculations for each subarea. The information on which the illustrations are based was obtained from mine-permit applications and monitoring data on file with the Montana Department of State Lands in Helena, Mont., and reports of Van Voast and Hedges (1975), Law and Grazis (1972), and Galyardt and Murray (1981).

The method of calculation is simplified and is based on a number of assumptions that do not necessarily reflect actual hydrologic conditions. Therefore, the amount of inflow determined from the calculations may be subject to a large degree of error.

ASSUMPTIONS OF CONDITIONS

The major conditions assumed to exist and used for the example calculations are:

1. The average annual stage of the reservoir in the future, with the existing dam, will be the same as the 1972-82 average annual stage of 3,411 feet (data from U.S. Geological Survey).

2. The average annual stage of the reservoir behind a raised spillway during a year of maximum precipitation will be 3,438 feet (or 14 feet above the present maximum stage), based on calculations provided by the Montana Department of Natural Resources and Conservation.

3. The average annual stage of the reservoir behind a raised spillway during a year of normal precipitation will be 3,433 feet, based on calculations provided by the Montana Department of Natural Resources and Conservation.

4. Flow from the reservoir to the mine pit is limited by the least transmissive segment of each aquifer zone, which may consist of spoils, coal, clinker, or alluvium.

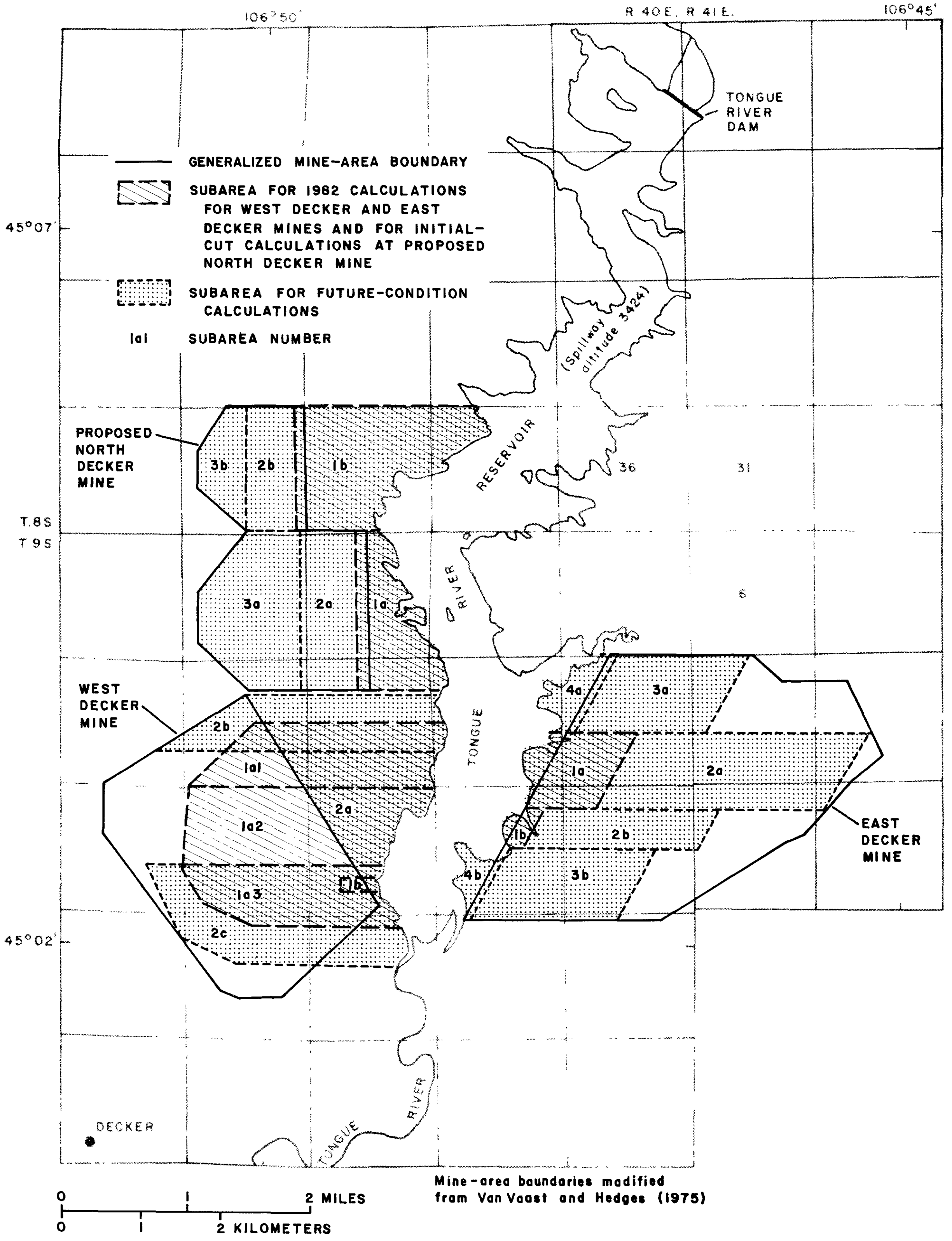


Figure 2.--Location of mine areas and subareas used for the calculations. Generalized cross sections of figures 3-7 are based on conditions existing along an east-west line located near the middle of each subarea.

5. Hydraulic head at the mine-pit face is arbitrarily set equal to the altitude at one-third the thickness of the aquifer above the base of the aquifer. If the altitude at one-third of the aquifer thickness is above the altitude of the reservoir stage, the hydraulic head is set equal to the altitude of the base of the aquifer. Determination of the actual hydraulic head at the mine-pit face or the average hydraulic gradient for the area due to drainage at the mine-pit face is a complex problem. Solution of the problem requires accurate knowledge of the aquifer properties and head distribution at the time of concern, which are not known. If the assumed hydraulic head is in error, the magnitude of the error is probably less than two-thirds of the aquifer thickness or saturated thickness and is averaged over the distance used to determine the hydraulic gradient. The effect of the error probably would be to overestimate the hydraulic gradient.

6. Hydraulic-conductivity values used for the aquifers are:

Aquifer	Assumed maximum, in feet per day	Assumed average, in feet per day
Coal beds	30	5
Clinker and alluvium	1,000	240
Spoils at West Decker Mine	8.4	3
Spoils at East Decker Mine	17	3
Spoils at North Decker Mine	1,000	200

The hydraulic-conductivity values for the coal beds and the spoils at the West Decker Mine are based on values presented by Van Voast and others (1978). All other hydraulic-conductivity values are estimates, based on the author's experience in the area, and may not be representative of actual conditions.

7. Saturated thickness of the permeable spoil zone is 20 feet unless otherwise specified. The value 20 is an estimate of the thickness of the permeable "rubble zone" at the base of the spoils.

8. Saturated thicknesses of the clinker and alluvium are estimated to be 10 feet unless otherwise specified.

9. Thicknesses for the coal beds are:

Coal bed	Average thickness, in feet
Anderson	25
Dietz 1	18
Anderson-Dietz 1 combined	50
Dietz 2	15

10. For generally confined conditions, the saturated thicknesses of the coal-bed aquifers will be equal to the thickness. If unconfined conditions prevail, saturated thickness will be specified.

EXAMPLE CALCULATIONS OF POSSIBLE GROUND-WATER INFLOW

The example calculations of ground-water inflow from the reservoir to the mine pits illustrate one method by which such inflow could be estimated. The calculations are shown in expanded form to enable the user to substitute values other than those pertaining to the conditions assumed in the examples. Inflow rates are calculated for each section and then summed for each mining area, using both assumed average and assumed maximum values for hydraulic conductivity. Specific assumptions and conditions are included at the beginning of each section. The inflow rate (Q) has two subscripts. The upper subscript refers to the approximate date at which the stated conditions might exist according to the general mine plan, or to "worst-case" conditions where mine plans were not available. The lower subscript refers to the reservoir stage, in feet above sea level. Some calculations are included for present mining conditions but with the increased stage of the proposed reservoir. These calculations are included for comparison only.

West Decker Mine

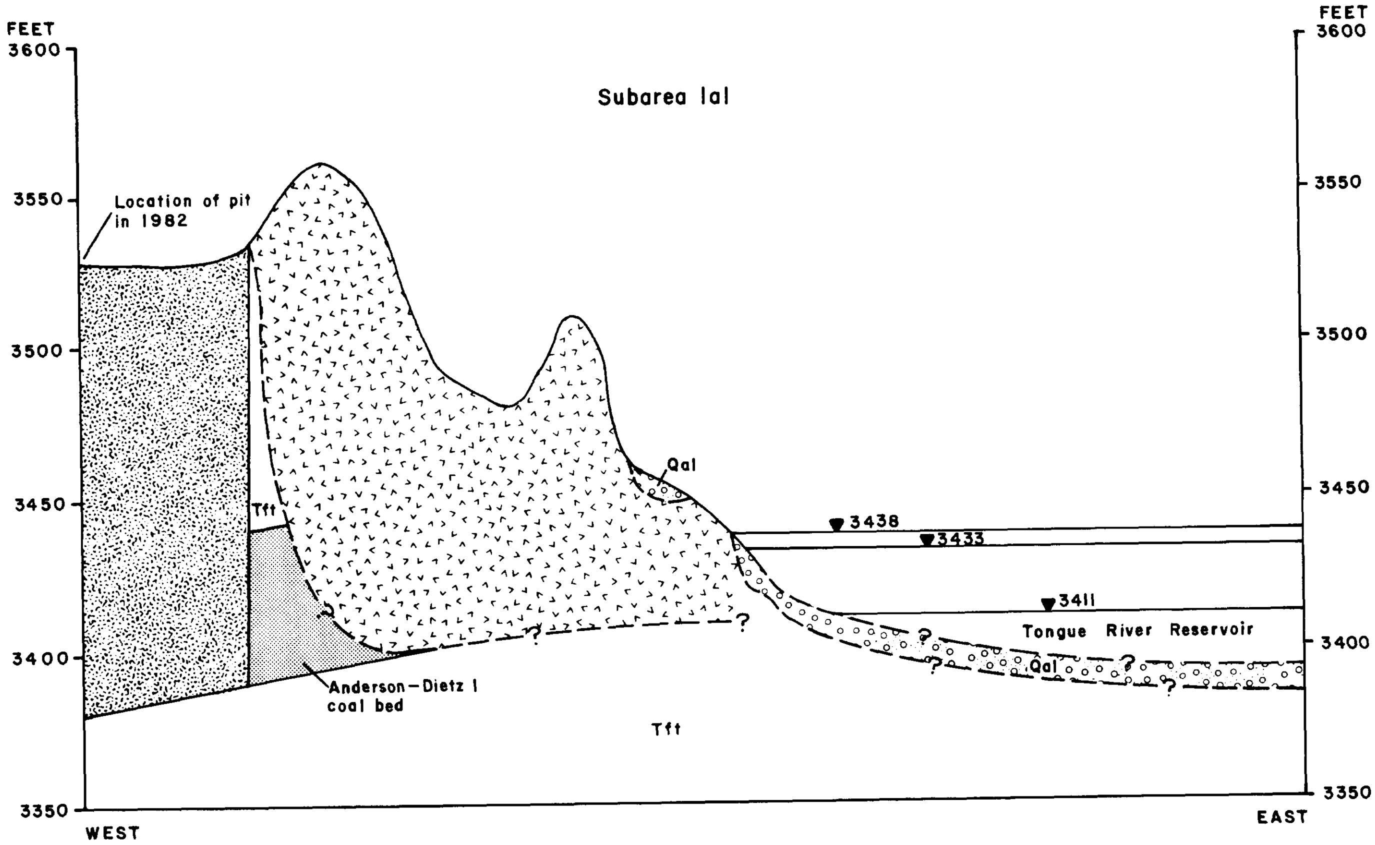
At the West Decker Mine, the mine plans include a horseshoe-shaped pit, with mining progressing generally westward, and smaller cuts in the interior of the horseshoe-shaped pits with mining progressing generally northward or westward, or both (fig. 1). The first set of calculations approximates present (1982) mining conditions. The horseshoe-shaped pit is subdivided into subareas 1a1, 1a2, and 1a3 (fig. 2). Subarea 1b pertains to the interior pit. Stratigraphic relationships are illustrated in figure 3.

Assumed conditions for subarea 1a1 are that the spoils are the least transmissive aquifer zone, the hydraulic head in the coal at the coal-spoils contact is equal to the reservoir stage, the distance from the contact to the pit is 2,400 feet, and the width of the cross-sectional area through which flow occurs is 2,900 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated using equation 1 as:

$$Q\,\frac{1982}{3411} = (3)[(20)(2,900)]\,\frac{(3,411-3,387)}{(\quad 2,400\quad)} = 1,700\ ft^3/d = 0.02\ ft^3/s \qquad (2)$$

$$Q\,\frac{1982}{3438} = (3)[(20)(2,900)]\,\frac{(3,438-3,387)}{(\quad 2,400\quad)} = 3,700\ ft^3/d = 0.04\ ft^3/s \qquad (3)$$

$$Q\,\frac{1982}{3433} = (3)[(20)(2,900)]\,\frac{(3,433-3,387)}{(\quad 2,400\quad)} = 3,300\ ft^3/d = 0.04\ ft^3/s \qquad (4)$$



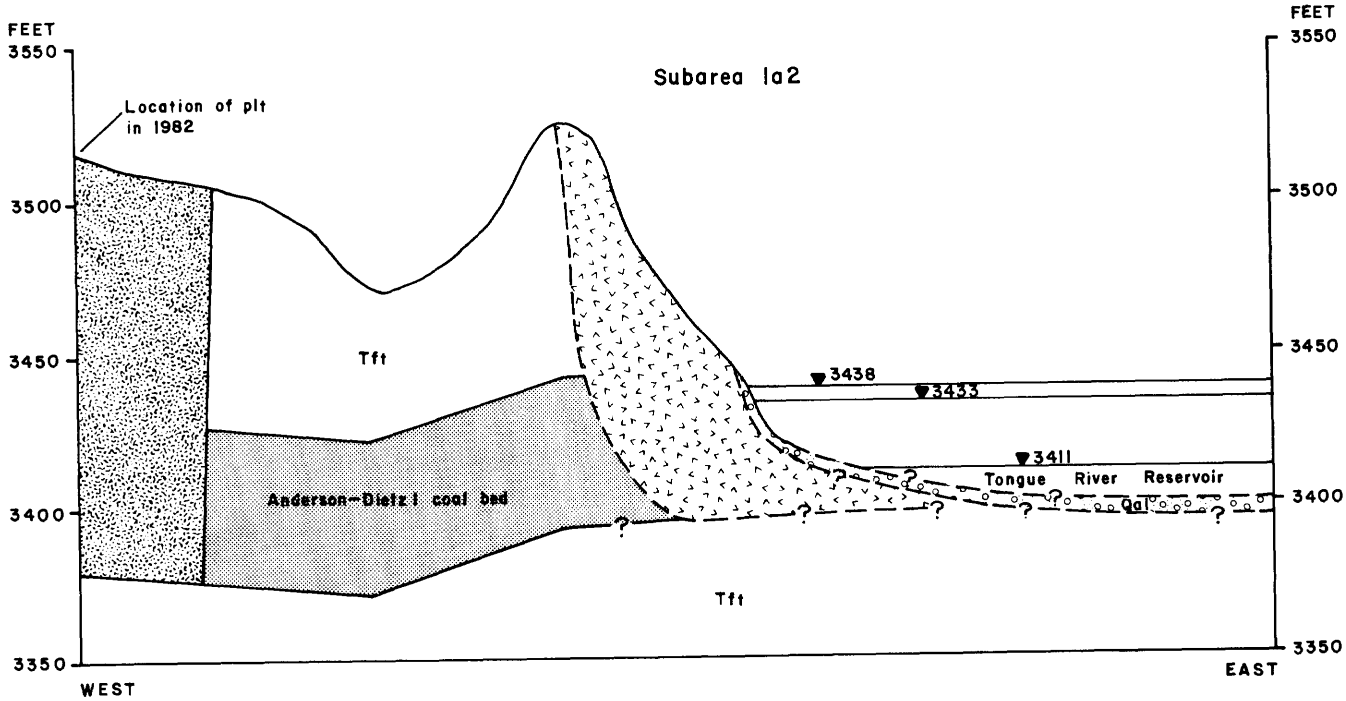
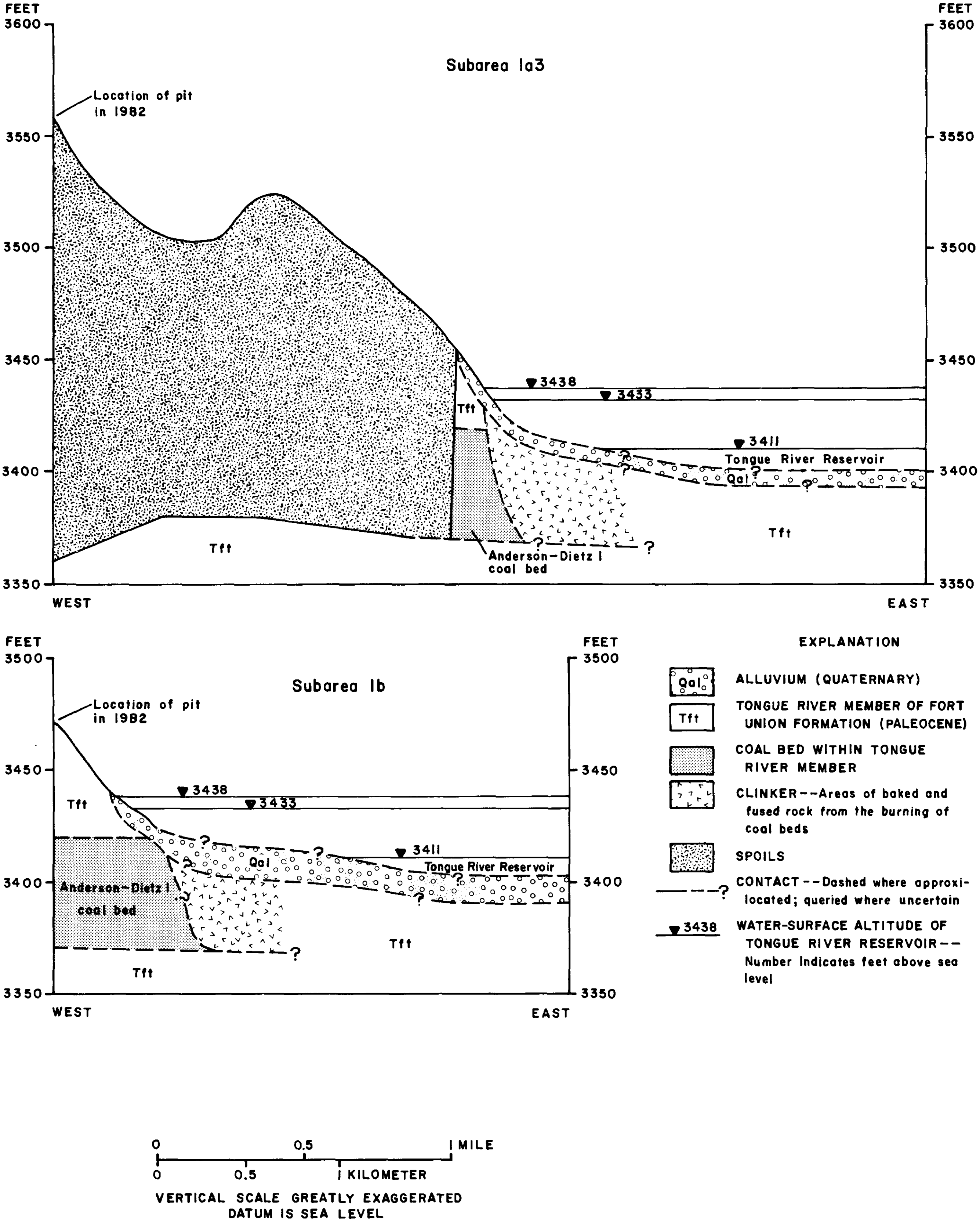


Figure 3.--Generalized cross sections for subareas 1a1,



la2, la3, and lb of the West Decker Mine.

Assumed conditions for subarea 1a2 are that the spoils are the least transmissive aquifer zone, the hydraulic head at the coal-spoils contact is equal to the reservoir stage, the distance from the contact to the pit is 1,700 feet, and the width of the cross-sectional area through which flow occurs is 3,500 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q\,\frac{1982}{3411} = (3)[(20)(3,500)]\left(\frac{3,411-3,387}{1,700}\right) = 3,000\ ft^3/d = 0.03\ ft^3/s \qquad (5)$$

$$Q\,\frac{1982}{3438} = (3)[(20)(3,500)]\left(\frac{3,438-3,387}{1,700}\right) = 6,300\ ft^3/d = 0.07\ ft^3/s \qquad (6)$$

$$Q\,\frac{1982}{3433} = (3)[(20)(3,500)]\left(\frac{3,433-3,387}{1,700}\right) = 5,700\ ft^3/d = 0.07\ ft^3/s \qquad (7)$$

Assumed conditions for subarea 1a3 are that the spoils are the least transmissive aquifer zone, the hydraulic head at the coal-spoils contact is equal to the reservoir stage, the distance from the contact to the pit is 7,200 feet, and the width of the cross-sectional area through which flow occurs is 2,200 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q\,\frac{1982}{3411} = (3)[(20)(2,200)]\left(\frac{3,411-3,367}{7,200}\right) = 810\ ft^3/d = 0.01\ ft^3/s \qquad (8)$$

$$Q\,\frac{1982}{3438} = (3)[(20)(2,200)]\left(\frac{3,438-3,367}{7,200}\right) = 1,300\ ft^3/d = 0.02\ ft^3/s \qquad (9)$$

$$Q\,\frac{1982}{3433} = (3)[(20)(2,200)]\left(\frac{3,433-3,367}{7,200}\right) = 1,200\ ft^3/d = 0.01\ ft^3/s \qquad (10)$$

Assumed conditions for subarea 1b are that the coal bed is the least transmissive aquifer zone, at reservoir stage of 3,411 feet the saturated thickness of the coal bed is 41 feet, the hydraulic head at the clinker and alluvium-coal contact is equal to the reservoir stage, the distance from the contact to the pit is 2,000 feet, and the width of the cross-sectional area through which flow occurs is 300 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q\,\frac{1982}{3411} = (5)[(41)(300)]\left(\frac{3,411-3,384}{2,000}\right) = 830\ ft^3/d = 0.01\ ft^3/s \qquad (11)$$

$$Q\,\frac{1982}{3438} = (5)[(50)(300)]\left(\frac{3,438-3,387}{2,000}\right) = 1,900\ ft^3/d = 0.02\ ft^3/s \qquad (12)$$

$$Q_{\frac{1982}{3433}} = (5)[(50)(300)]\left(\frac{3{,}433-3{,}387}{2{,}000}\right)$$
$$= 1{,}700\ ft^3/d = 0.02\ ft^3/s \qquad (13)$$

The total reservoir inflow to the pits, using assumed average hydraulic conductivity, is:

$$Q_{\frac{1982}{3411}} = 0.07\ ft^3/s \qquad (14)$$

$$Q_{\frac{1982}{3438}} = 0.15\ ft^3/s \qquad (15)$$

$$Q_{\frac{1982}{3433}} = 0.14\ ft^3/s \qquad (16)$$

Similarly, the total reservoir inflow to the pits, using assumed maximum hydraulic conductivity is:

$$Q_{\frac{1982}{3411}} = 0.25\ ft^3/s \qquad (17)$$

$$Q_{\frac{1982}{3438}} = 0.49\ ft^3/s \qquad (18)$$

$$Q_{\frac{1982}{3433}} = 0.45\ ft^3/s \qquad (19)$$

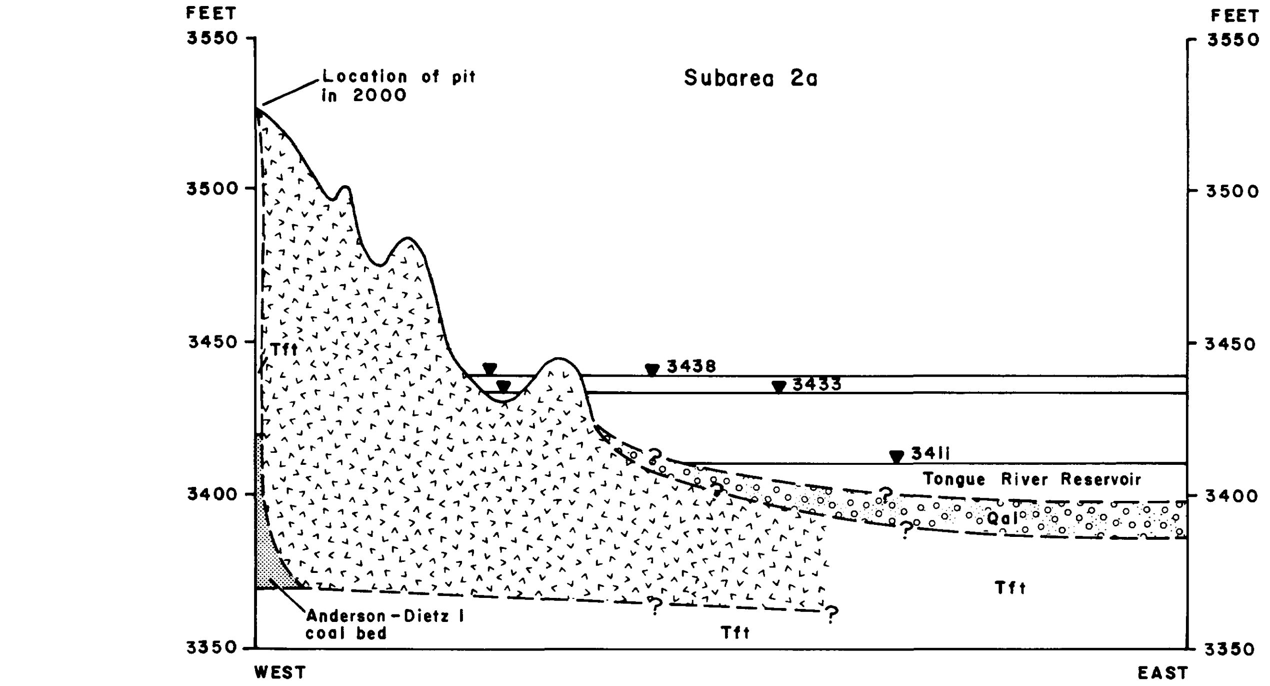
The following set of calculations approximates hypothetical future mining conditions. Subarea 2a pertains to an interior pit along the entire eastern edge of the interior of the mine area. Subareas 2b and 2c pertain to the northern and southern parts of the horseshoe-shaped pit. Stratigraphic relationships are illustrated in figure 4.

Assumed conditions for subarea 2a are that clinker and alluvium constitute the only aquifer between the reservoir and the pit, the distance from the pit to the reservoir varies with the reservoir stage, the saturated thickness of the aquifer varies with reservoir stage, and the width of the cross-sectional area through which flow occurs is 4,900 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q_{\frac{2000}{3411}} = (240)[(41)(4{,}900)]\left(\frac{3{,}411-3{,}384}{5{,}600}\right)$$
$$= 230{,}000\ ft^3/d = 2.7\ ft^3/s \qquad (20)$$

$$Q_{\frac{2000}{3438}} = (240)[(68)(4{,}900)]\left(\frac{3{,}438-3{,}393}{2{,}700}\right)$$
$$= 1{,}300{,}000\ ft^3/d = 15\ ft^3/s \qquad (21)$$

$$Q_{\frac{2000}{3433}} = (240)[(63)(4{,}900)]\left(\frac{3{,}433-3{,}391}{3{,}000}\right)$$
$$= 1{,}000{,}000\ ft^3/d = 12\ ft^3/s \qquad (22)$$



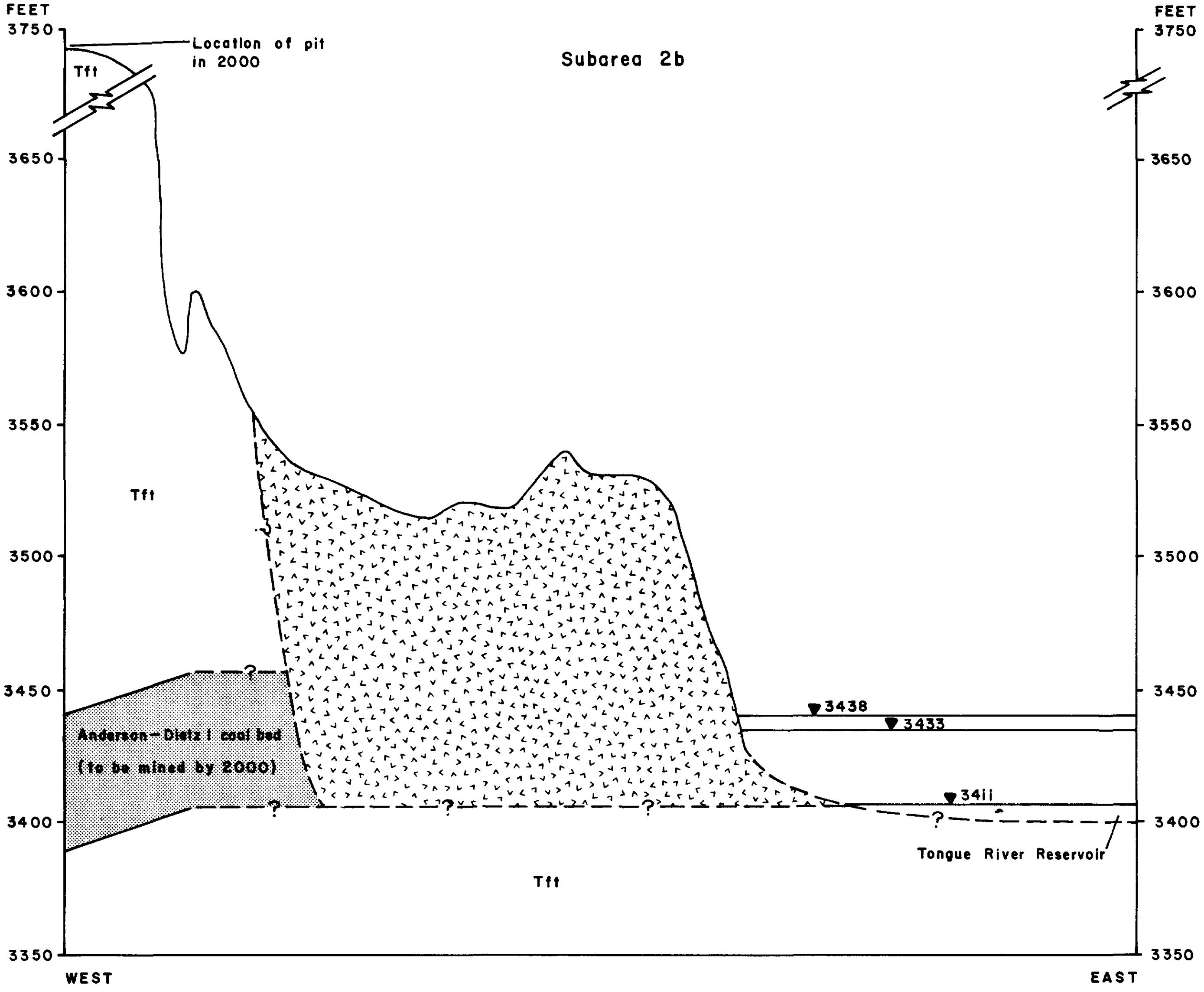
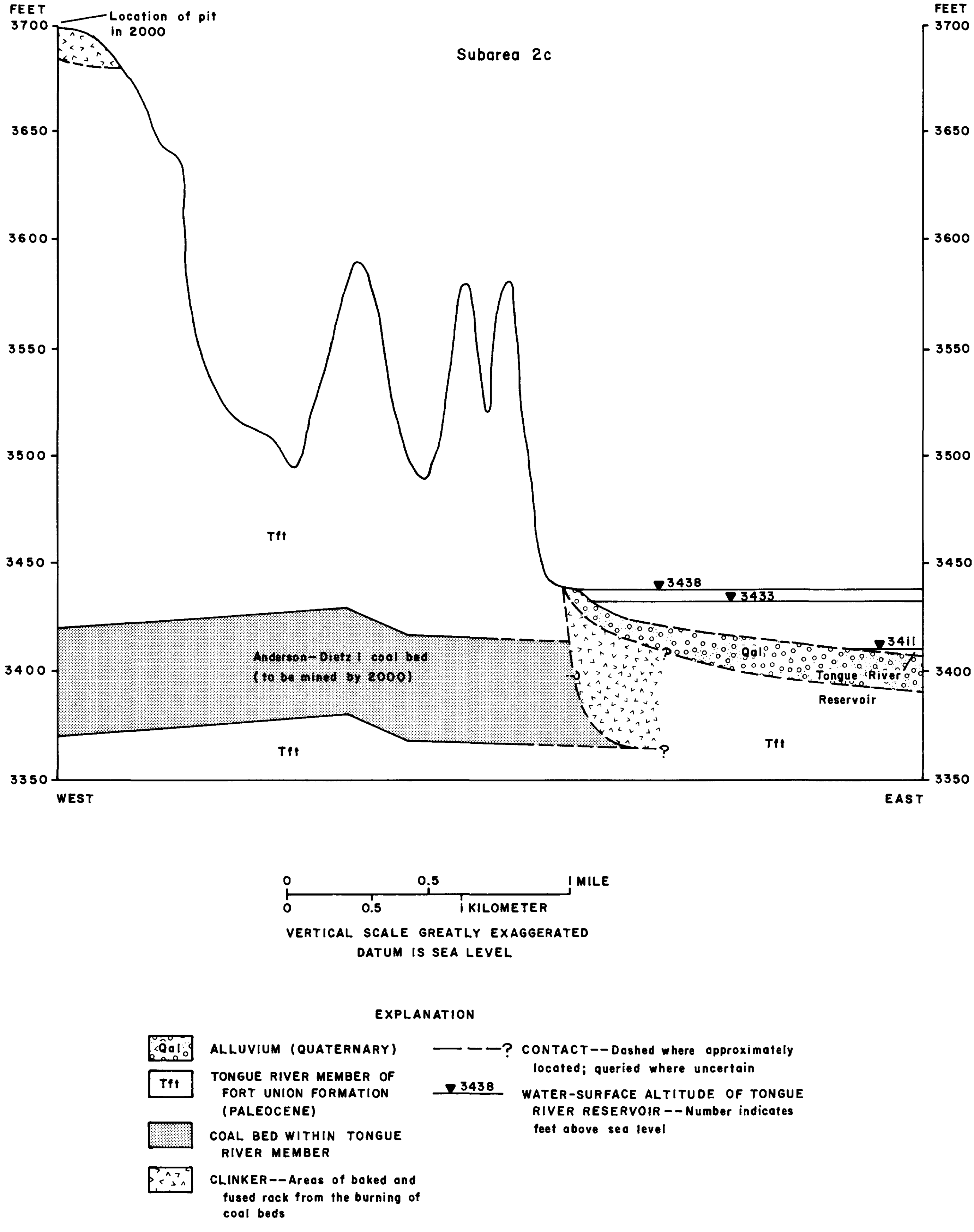


Figure 4.--Generalized cross sections for subareas 2a,



2b, and 2c of the West Decker Mine.

Assumed conditions for subarea 2b are that spoils are the least transmissive aquifer zone, the hydraulic head at the spoils-clinker contact is equal to the reservoir stage, the distance from the pit to the contact is 3,200 feet, and the width of the cross-sectional area through which flow occurs is 2,900 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q\,\frac{2000}{3411} = (3)[(20)(2{,}900)]\left(\frac{3{,}411-3{,}397}{3{,}200}\right) = 760\ \text{ft}^3/\text{d} = 0.01\ \text{ft}^3/\text{s} \tag{23}$$

$$Q\,\frac{2000}{3438} = (3)[(20)(2{,}900)]\left(\frac{3{,}438-3{,}397}{3{,}200}\right) = 2{,}200\ \text{ft}^3/\text{d} = 0.03\ \text{ft}^3/\text{s} \tag{24}$$

$$Q\,\frac{2000}{3433} = (3)[(20)(2{,}900)]\left(\frac{3{,}433-3{,}397}{3{,}200}\right) = 2{,}000\ \text{ft}^3/\text{d} = 0.02\ \text{ft}^3/\text{s} \tag{25}$$

Assumed conditions for subarea 2c are that the spoils are the least transmissive aquifer zone, the hydraulic head at the spoils-clinker contact is equal to the reservoir stage, the distance from the pit to the contact is 9,100 feet, and the width of the cross-sectional area through which flow occurs is 4,600 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q\,\frac{2000}{3411} = (3)[(20)(4{,}600)]\left(\frac{3{,}411-3{,}377}{9{,}100}\right) = 1{,}000\ \text{ft}^3/\text{d} = 0.01\ \text{ft}^3/\text{s} \tag{26}$$

$$Q\,\frac{2000}{3438} = (3)[(20)(4{,}600)]\left(\frac{3{,}438-3{,}377}{9{,}100}\right) = 1{,}900\ \text{ft}^3/\text{d} = 0.02\ \text{ft}^3/\text{s} \tag{27}$$

$$Q\,\frac{2000}{3433} = (3)[(20)(4{,}600)]\left(\frac{3{,}433-3{,}377}{9{,}100}\right) = 1{,}700\ \text{ft}^3/\text{d} = 0.02\ \text{ft}^3/\text{s} \tag{28}$$

The total reservoir inflow to the pits, using assumed average hydraulic conductivity, is:

$$Q\,\frac{2000}{3411} = 2.7\ \text{ft}^3/\text{s} \tag{29}$$

$$Q\,\frac{2000}{3438} = 15\ \text{ft}^3/\text{s} \tag{30}$$

$$Q\,\frac{2000}{3433} = 12\ \text{ft}^3/\text{s} \tag{31}$$

Similarly, the total reservoir inflow to the pits, using assumed maximum hydraulic conductivity, is:

$$Q\,\frac{2000}{3411} = 11\ \text{ft}^3/\text{s} \tag{32}$$

$$Q_{\frac{2000}{3438}} = 64 \text{ ft}^3/\text{s} \tag{33}$$

$$Q_{\frac{2000}{3433}} = 50 \text{ ft}^3/\text{s} \tag{34}$$

East Decker Mine

In the East Decker Mine area, two rhomboidal-shaped pits will be progressively mined eastward through the center of the mine area to the eastern boundary. Mining will then progress westward along the northern and southern parts of the area (fig. 1). The first set of calculations approximates ground-water inflow under present (1982) mining conditions. Subarea 1a pertains to the northernmost of the eastward-progressing pits in the center of the mine area (fig. 2). Subarea 1b pertains to the southernmost of the pits in the center of the mine area. Stratigraphic relationships are illustrated in figure 5.

Assumed conditions for subarea 1a are that the spoils are the least transmissive aquifer zone, the hydraulic head in the coal beds at the coal-spoils contact is equal to the reservoir stage, the distance from the contact to the pit is 1,500 feet, and the width of the cross-sectional area through which flow occurs is 3,200 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q_{\frac{1982}{3411}} = (3)[(20)(3{,}200)]\left(\frac{3{,}411-3{,}311}{1{,}500}\right) = 13{,}000 \text{ ft}^3/\text{d} = 0.15 \text{ ft}^3/\text{s} \tag{35}$$

$$Q_{\frac{1982}{3438}} = (3)[(20)(3{,}200)]\left(\frac{3{,}438-3{,}311}{1{,}500}\right) = 16{,}000 \text{ ft}^3/\text{d} = 0.19 \text{ ft}^3/\text{s} \tag{36}$$

$$Q_{\frac{1982}{3433}} = (3)[(20)(3{,}200)]\left(\frac{3{,}433-3{,}311}{1{,}500}\right) = 16{,}000 \text{ ft}^3/\text{d} = 0.19 \text{ ft}^3/\text{s} \tag{37}$$

Assumed conditions for subarea 1b are that no spoils have been replaced and the coal beds are the least transmissive aquifer zones, the distance from the reservoir to the pit depends on the reservoir stage, the width of the cross-sectional area through which flow occurs is 1,800 feet, and the Anderson coal bed might not be confined at low reservoir stage. Therefore, inflow to the pit is a sum of three coal aquifers and, using assumed average hydraulic conductivity, is calculated as:

$$Q_{\frac{1982}{3411}} = (5)[(16)(1{,}800)]\left(\frac{3{,}411-3{,}400}{1{,}600}\right) + (5)[(18)(1{,}800)]\left(\frac{3{,}411-3{,}366}{1{,}600}\right) + (5)[(15)(1{,}800)]\left(\frac{3{,}411-3{,}305}{1{,}600}\right) = 14{,}000 \text{ ft}^3/\text{d} = 0.16 \text{ ft}^3/\text{s} \tag{38}$$

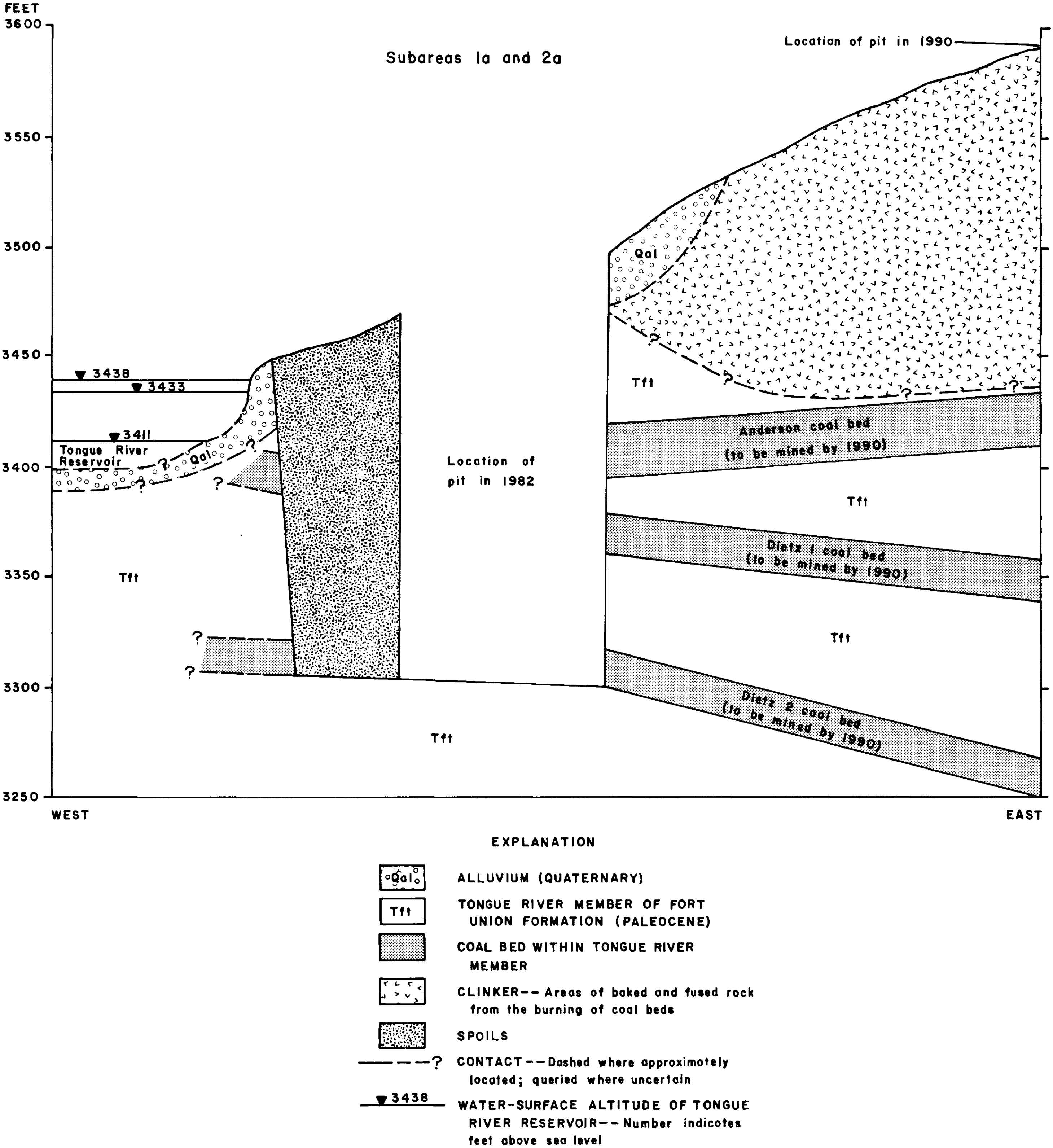
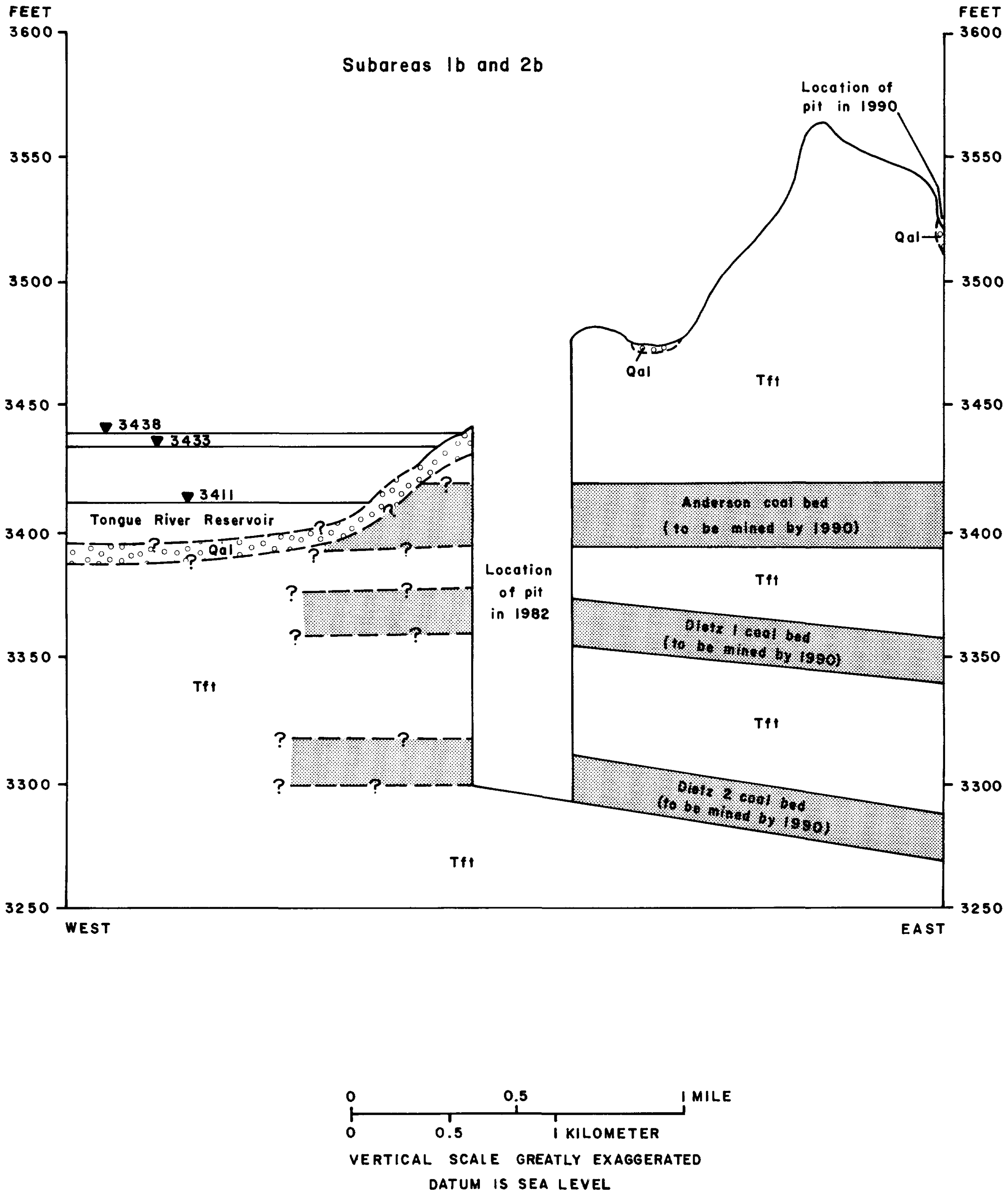


Figure 5.--Generalized cross sections for subareas la, 2a,



1b, and 2b of the East Decker Mine.

$$Q\,\frac{1982}{3438} = (5)[(25)(1{,}800)]\left(\frac{3{,}438-3{,}403}{400}\right) + (5)[(18)(1{,}800)]\left(\frac{3{,}438-3{,}366}{400}\right)$$
$$+ (5)[(15)(1{,}800)]\left(\frac{3{,}438-3{,}305}{400}\right)$$
$$= 94{,}000\ ft^3/d = 1.1\ ft^3/s \qquad (39)$$

$$Q\,\frac{1982}{3433} = (5)[(25)(1{,}800)]\left(\frac{3{,}433-3{,}403}{600}\right) + (5)[(18)(1{,}800)]\left(\frac{3{,}433-3{,}366}{600}\right)$$
$$+ (5)[(15)(1{,}800)]\left(\frac{3{,}433-3{,}305}{600}\right)$$
$$= 58{,}000\ ft^3/d = 0.67\ ft^3/s \qquad (40)$$

The total reservoir inflow to the pits, using assumed average hydraulic conductivity, is:

$$Q\,\frac{1982}{3411} = 0.31\ ft^3/s \qquad (41)$$

$$Q\,\frac{1982}{3438} = 1.3\ ft^3/s \qquad (42)$$

$$Q\,\frac{1982}{3433} = 0.86\ ft^3/s \qquad (43)$$

Similarly, the total reservoir inflow to the pits, using assumed maximum hydraulic conductivity, is:

$$Q\,\frac{1982}{3411} = 1.8\ ft^3/s \qquad (44)$$

$$Q\,\frac{1982}{3438} = 7.6\ ft^3/s \qquad (45)$$

$$Q\,\frac{1982}{3433} = 5.0\ ft^3/s \qquad (46)$$

If alluvium is found to be a hydraulic connection between subarea 1b and the reservoir, the additional inflow would need to be calculated and added to the totals above.

The following set of calculations approximates possible future mining conditions. Subareas 2a and 2b are similar to subareas 1a and 1b except they are near the eastern edge of the mine area. Stratigraphic relationships are illustrated in figure 5.

Assumed conditions for subarea 2a are that the spoils are the least transmissive aquifer zone, the hydraulic head at the coal-spoils contact is equal to the reservoir stage, the distance from the pit to the contact is 13,700 feet, and the width of the cross-sectional area through which flow occurs is 3,200 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q\,\frac{1990}{3411} = (3)[(20)(3{,}200)]\left(\frac{3{,}411-3{,}257}{13{,}700}\right)$$
$$= 2{,}200\ ft^3/d = 0.03\ ft^3/s \qquad (47)$$

$$Q_{\frac{1990}{3438}} = (3)[(20)(3,200)]\frac{(3,438-3,257)}{(13,700)}$$
$$= 2,500\ ft^3/d = 0.03\ ft^3/s \tag{48}$$

$$Q_{\frac{1990}{3433}} = (3)[(20)(3,200)]\frac{(3,433-3,257)}{(13,700)}$$
$$= 2,500\ ft^3/d = 0.03\ ft^3/s \tag{49}$$

Assumed conditions for subarea 2b are that the spoils are the least transmissive aquifer zone, the hydraulic head at the coal-spoils contact is equal to the reservoir stage, the distance from the pit to the contact is 7,500 feet, and the width of the cross-sectional area through which flow occurs is 1,800 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q_{\frac{1990}{3411}} = (3)[(20)(1,800)]\frac{(3,411-3,277)}{(7,500)}$$
$$= 1,900\ ft^3/d = 0.02\ ft^3/s \tag{50}$$

$$Q_{\frac{1990}{3438}} = (3)[(20)(1,800)]\frac{(3,438-3,277)}{(7,500)}$$
$$= 2,300\ ft^3/d = 0.03\ ft^3/s \tag{51}$$

$$Q_{\frac{1990}{3433}} = (3)[(20)(1,800)]\frac{(3,433-3,277)}{(7,500)}$$
$$= 2,200\ ft^3/d = 0.03\ ft^3/s \tag{52}$$

The total reservoir inflow to the pits, using assumed average hydraulic conductivity, is:

$$Q_{\frac{1990}{3411}} = 0.05\ ft^3/s \tag{53}$$

$$Q_{\frac{1990}{3438}} = 0.06\ ft^3/s \tag{54}$$

$$Q_{\frac{1990}{3433}} = 0.06\ ft^3/s \tag{55}$$

Similarly, reservoir inflow to the pits, using assumed maximum hydraulic conductivity, is:

$$Q_{\frac{1990}{3411}} = 0.27\ ft^3/s \tag{56}$$

$$Q_{\frac{1990}{3438}} = 0.32\ ft^3/s \tag{57}$$

$$Q_{\frac{1990}{3433}} = 0.31\ ft^3/s \tag{58}$$

The following set of calculations approximates additional possible future mining conditions. Subarea 3a pertains to westward-progressing cuts in the northern part of the mine area. Subarea 3b pertains to westward-progressing cuts in the southern part of the mine area. Stratigraphic relationships are illustrated in figure 6.

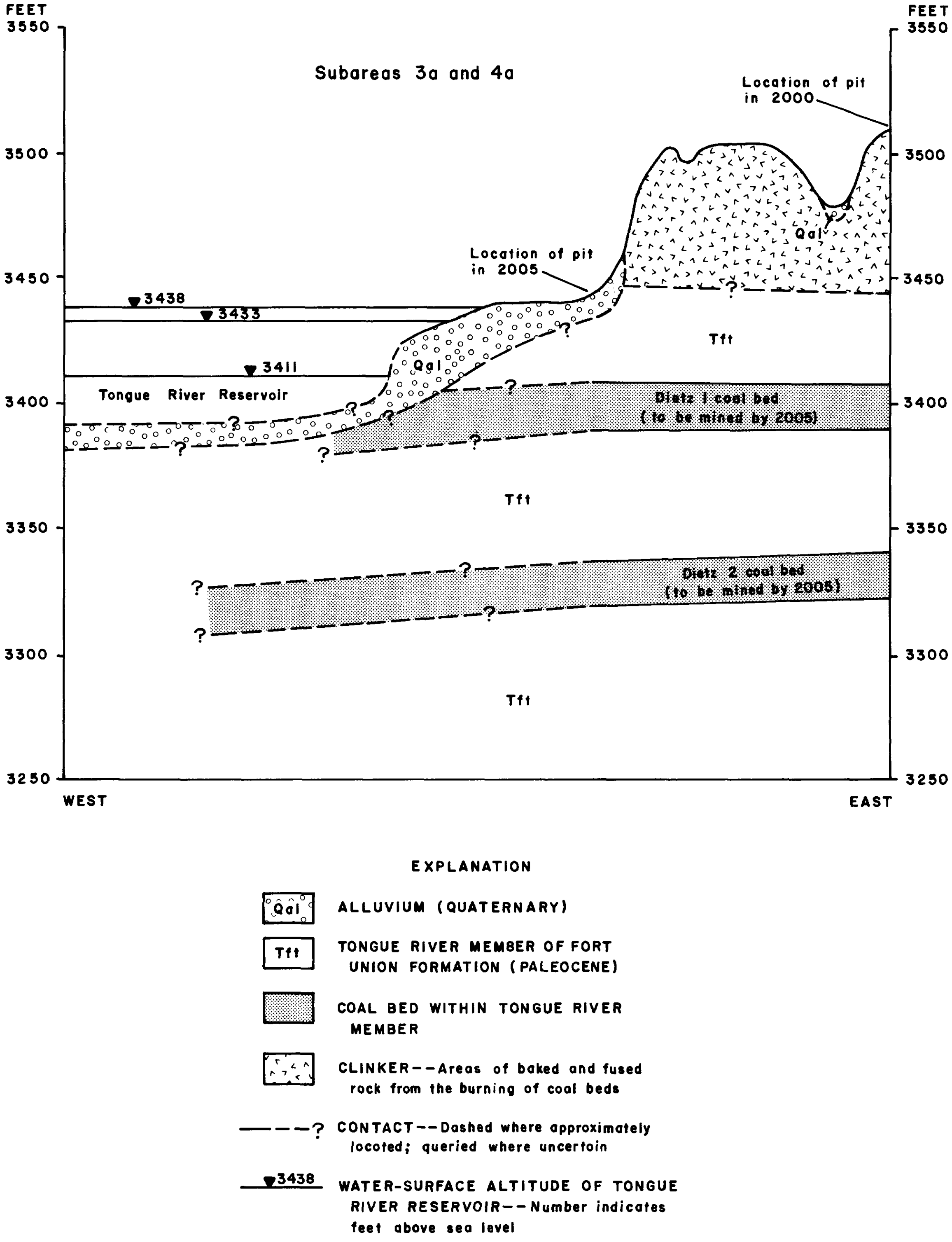
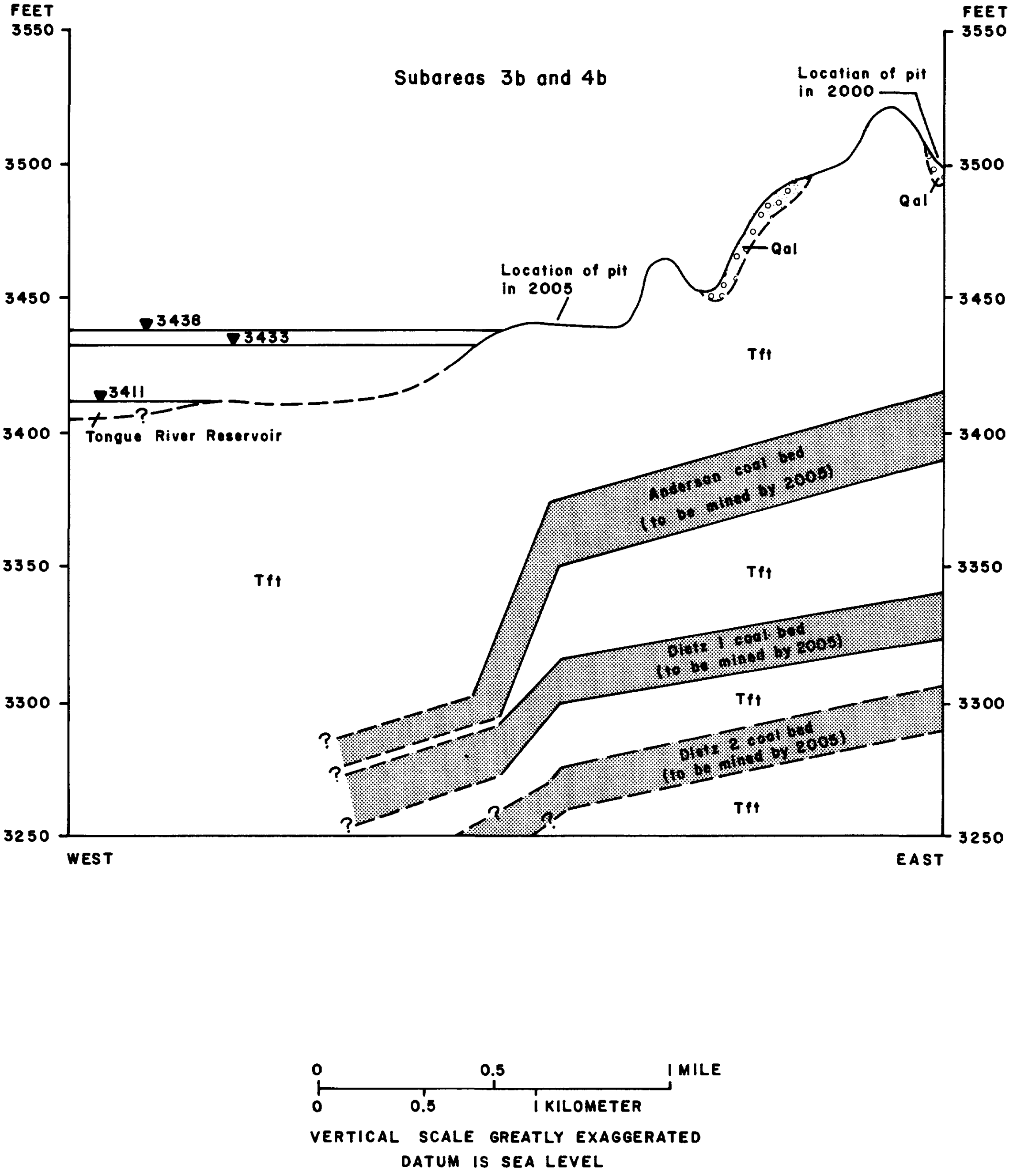


Figure 6.--Generalized cross sections for subareas 3a, 4a,



3b, and 4b of the East Decker Mine.

Assumed conditions for subarea 3a are that the Dietz 1 and Dietz 2 coal beds are the only transmissive aquifer zones, the distance from the pit to the reservoir depends on the reservoir stage, and the width of the cross-sectional area through which flow occurs is 3,200 feet. Therefore, inflow is a sum of the two aquifers and, using assumed average hydraulic conductivity, is calculated as:

$$Q\frac{2000}{3411} = (5)[(18)(3{,}200)]\frac{(3{,}411-3{,}396)}{(7{,}900)} + (5)[(15)(3{,}200)]\frac{(3{,}411-3{,}333)}{(7{,}900)}$$
$$= 2{,}900\ ft^3/d = 0.03\ ft^3/s \qquad (59)$$

$$Q\frac{2000}{3438} = (5)[(18)(3{,}200)]\frac{(3{,}438-3{,}396)}{(6{,}500)} + (5)[(15)(3{,}200)]\frac{(3{,}438-3{,}333)}{(6{,}500)}$$
$$= 5{,}700\ ft^3/d = 0.07\ ft^3/s \qquad (60)$$

$$Q\frac{2000}{3433} = (5)[(18)(3{,}200)]\frac{(3{,}433-3{,}396)}{(7{,}100)} + (5)[(15)(3{,}200)]\frac{(3{,}433-3{,}333)}{(7{,}100)}$$
$$= 4{,}900\ ft^3/d = 0.06\ ft^3/s \qquad (61)$$

Assumed conditions for subarea 3b are that the Anderson, Dietz 1, and Dietz 2 coal beds are the only transmissive aquifer zones, the distance from the pit to the reservoir varies with the reservoir stage, and the width of the cross-sectional area through which flow occurs is 2,600 feet. Therefore, inflow is a sum of the three aquifers and, using assumed average hydraulic conductivity, is calculated as:

$$Q\frac{2000}{3411} = (5)[(25)(2{,}600)]\frac{(3{,}411-3{,}398)}{(10{,}300)} + (5)[(18)(2{,}600)]\frac{(3{,}411-3{,}331)}{(10{,}300)}$$
$$+ (5)[(15)(2{,}600)]\frac{(3{,}411-3{,}295)}{(10{,}300)}$$
$$= 4{,}400\ ft^3/d = 0.05\ ft^3/s \qquad (62)$$

$$Q\frac{2000}{3438} = (5)[(25)(2{,}600)]\frac{(3{,}438-3{,}398)}{(6{,}600)} + (5)[(18)(2{,}600)]\frac{(3{,}438-3{,}331)}{(6{,}600)}$$
$$+ (5)[(15)(2{,}600)]\frac{(3{,}438-3{,}295)}{(6{,}600)}$$
$$= 10{,}000\ ft^3/d = 0.12\ ft^3/s \qquad (63)$$

$$Q\frac{2000}{3433} = (5)[(25)(2{,}600)]\frac{(3{,}433-3{,}398)}{(6{,}900)} + (5)[(18)(2{,}600)]\frac{(3{,}433-3{,}331)}{(6{,}900)}$$
$$+ (5)[(15)(2{,}600)]\frac{(3{,}433-3{,}295)}{(6{,}900)}$$
$$= 9{,}000\ ft^3/d = 0.10\ ft^3/s \qquad (64)$$

The total reservoir inflow to the pits, using assumed average hydraulic conductivity, is:

$$Q\frac{2000}{3411} = 0.08\ ft^3/s \qquad (65)$$

$$Q\frac{2000}{3438} = 0.19\ ft^3/s \qquad (66)$$

$$Q\frac{2000}{3433} = 0.16\ ft^3/s \qquad (67)$$

Similarly, reservoir inflow to the pits, using assumed maximum hydraulic conductivity, is:

$$Q\,\frac{2000}{3411} = 0.51 \text{ ft}^3/\text{s} \qquad (68)$$

$$Q\,\frac{2000}{3438} = 1.1 \text{ ft}^3/\text{s} \qquad (69)$$

$$Q\,\frac{2000}{3433} = 0.97 \text{ ft}^3/\text{s} \qquad (70)$$

The following set of calculations approximates another set of possible future mining conditions. Subarea 4a pertains to the westernmost of the westward-progressing cuts in the northern part of the mine area. Subarea 4b pertains to the westernmost of the westward-progressing cuts in the southern part of the mine area. Stratigraphic relationships are illustrated in figure 6.

Assumed conditions for subarea 4a are that the Dietz 1 and Dietz 2 coal beds are the only transmissive aquifer zones, the distance from the pit to the reservoir depends on the reservoir stage, and the width of the cross-sectional area through which flow occurs is 3,200 feet. Therefore, inflow is a sum of the two aquifers and, using assumed average hydraulic conductivity, is calculated as:

$$\begin{aligned} Q\,\frac{2005}{3411} &= (5)[(18)(3{,}200)]\left(\frac{3{,}411-3{,}396}{3{,}200}\right) + (5)[(15)(3{,}200]\left(\frac{3{,}411-3{,}325}{3{,}200}\right) \\ &= 7{,}800 \text{ ft}^3/\text{d} = 0.09 \text{ ft}^3/\text{s} \end{aligned} \qquad (71)$$

$$\begin{aligned} Q\,\frac{2005}{3438} &= (5)[(18)(3{,}200)]\left(\frac{3{,}438-3{,}396}{1{,}600}\right) + (5)[(15)(3{,}200)]\left(\frac{3{,}438-3{,}325}{1{,}600}\right) \\ &= 25{,}000 \text{ ft}^3/\text{d} = 0.29 \text{ ft}^3/\text{s} \end{aligned} \qquad (72)$$

$$\begin{aligned} Q\,\frac{2005}{3433} &= (5)[(18)(3{,}200)]\left(\frac{3{,}433-3{,}396}{2{,}300}\right) + (5)[(15)(3{,}200)]\left(\frac{3{,}433-3{,}325}{2{,}300}\right) \\ &= 16{,}000 \text{ ft}^3/\text{d} = 0.19 \text{ ft}^3/\text{s} \end{aligned} \qquad (73)$$

Assumed conditions for subarea 4b are that the Anderson, Dietz 1, and Dietz 2 coal beds are the only transmissive aquifer zones, the distance from the pit to the reservoir depends on the reservoir stage, and the width of the cross-sectional area through which flow occurs is 2,600 feet. Therefore, inflow is a sum of the three aquifers and, using assumed average hydraulic conductivity, is calculated as:

$$\begin{aligned} Q\,\frac{2005}{3411} &= (5)[(25)(2{,}600)]\left(\frac{3{,}411-3{,}360}{5{,}100}\right) + (5)[(18)(2{,}600)]\left(\frac{3{,}411-3{,}306}{5{,}100}\right) \\ &\quad + (5)[(15)(2{,}600)]\left(\frac{3{,}411-3{,}265}{5{,}100}\right) \\ &= 14{,}000 \text{ ft}^3/\text{d} = 0.16 \text{ ft}^3/\text{s} \end{aligned} \qquad (74)$$

$$\begin{aligned} Q\,\frac{2005}{3438} &= (5)[(25)(2{,}600)]\left(\frac{3{,}438-3{,}360}{900}\right) + (5)[(18)(2{,}600)]\left(\frac{3{,}438-3{,}306}{900}\right) \\ &\quad + (5)[(15)(2{,}600)]\left(\frac{3{,}438-3{,}265}{900}\right) \\ &= 100{,}000 \text{ ft}^3/\text{d} = 1.2 \text{ ft}^3/\text{s} \end{aligned} \qquad (75)$$

$$Q\,\frac{2005}{3433} = (5)[(25)(2{,}600)]\left(\frac{3{,}433-3{,}360}{1{,}200}\right) + (5)[(18)(2{,}600)]\left(\frac{3{,}433-3{,}306}{1{,}200}\right)$$
$$+ (5)[(15)(2{,}600)]\left(\frac{3{,}433-3{,}265}{1{,}200}\right)$$
$$= 72{,}000\ ft^3/d = 0.83\ ft^3/s \qquad (76)$$

The total reservoir inflow to the pits, using assumed average hydraulic conductivity, is:

$$Q\,\frac{2005}{3411} = 0.25\ ft^3/s \qquad (77)$$

$$Q\,\frac{2005}{3438} = 1.5\ ft^3/s \qquad (78)$$

$$Q\,\frac{2005}{3433} = 1.0\ ft^3/s \qquad (79)$$

Similarly, the total reservoir inflow to the pits, using assumed maximum hydraulic conductivity, is:

$$Q\,\frac{2005}{3411} = 1.5\ ft^3/s \qquad (80)$$

$$Q\,\frac{2005}{3438} = 8.6\ ft^3/s \qquad (81)$$

$$Q\,\frac{2005}{3433} = 6.1\ ft^3/s \qquad (82)$$

If alluvium is found to be a hydraulic connection between either subarea 4a or 4b and the reservoir, the additional inflow would need to be calculated and added to the totals above.

Proposed North Decker Mine

Mine plans for the North Decker Mine include two areas of north-south oriented rectangular pits that progress westward (fig. 1). Mining has not yet begun, and any changes in the mine plans would call for appropriate changes in the calculations. The first set of calculations, dated 1982, approximates conditions at the first, or easternmost, pits. Subarea 1a pertains to the southern area and subarea 1b pertains to the northern area (fig. 2). Stratigraphic relationships are illustrated in figure 7.

Assumed conditions for subarea 1a are that clinker and the Dietz 2 coal bed are the only transmissive aquifer zones, the saturated thickness of the clinker varies with the reservoir stage, the distance from the reservoir to the pit depends on the reservoir stage, and the width of the cross-sectional area through which flow occurs is 6,100 feet. Therefore, inflow is a sum of flow through the two aquifers and, using assumed average hydraulic conductivity, is calculated as:

$$Q\,\frac{1982}{3411} = (240)[(10)(6{,}100)]\left(\frac{3{,}411-3{,}403}{2{,}600}\right) + (5)[(15)(6{,}100)]\left(\frac{3{,}411-3{,}365}{2{,}600}\right)$$
$$= 53{,}000\ ft^3/d = 0.61\ ft^3/s \qquad (83)$$

$$Q\frac{1982}{3438} = (240)[(30)(6{,}100)]\left(\frac{3{,}438-3{,}410}{1{,}500}\right) + (5)[(15)(6{,}100)]\left(\frac{3{,}438-3{,}365}{1{,}500}\right)$$
$$= 840{,}000\ ft^3/d = 9.7\ ft^3/s \qquad (84)$$

$$Q\frac{1982}{3433} = (240)[(25)(6{,}100)]\left(\frac{3{,}433-3{,}408}{1{,}500}\right) + (5)[(15)(6{,}100)]\left(\frac{3{,}433-3{,}365}{1{,}500}\right)$$
$$= 630{,}000\ ft^3/d = 7.3\ ft^3/s \qquad (85)$$

Assumed conditions for subarea 1b are that clinker and the Dietz 2 coal bed are the only transmissive aquifer zones, the distance from the pit to the reservoir depends on the reservoir stage, and the width of the cross-sectional area through which flow occurs is 5,300 feet. For calculation 86, the base of clinker is above the reservoir and flow through that aquifer zone is not included. Therefore, inflow, generally as a sum of flow through the two aquifers and using assumed average hydraulic conductivity, is calculated as:

$$Q\frac{1982}{3411} = (5)[(15)(5{,}300)]\left(\frac{3{,}411-3{,}385}{6{,}400}\right)$$
$$= 1{,}600\ ft^3/d = 0.02\ ft^3/s \qquad (86)$$

$$Q\frac{1982}{3438} = (240)[(10)(5{,}300)]\left(\frac{3{,}438-3{,}423}{2{,}400}\right) + (5)[(15)(5{,}300)]\left(\frac{3{,}438-3{,}385}{2{,}400}\right)$$
$$= 88{,}000\ ft^3/d = 1.0\ ft^3/s \qquad (87)$$

$$Q\frac{1982}{3433} = (240)[(10)(5{,}300)]\left(\frac{3{,}433-3{,}423}{2{,}900}\right) + (5)[(15)(5{,}300)]\left(\frac{3{,}433-3{,}385}{2{,}900}\right)$$
$$= 50{,}000\ ft^3/d = 0.58\ ft^3/s \qquad (88)$$

The total reservoir inflow to the pits, using assumed average hydraulic conductivity, is:

$$Q\frac{1982}{3411} = 0.63\ ft^3/s \qquad (89)$$

$$Q\frac{1982}{3438} = 11\ ft^3/s \qquad (90)$$

$$Q\frac{1982}{3433} = 7.9\ ft^3/s \qquad (91)$$

Similarly, the total inflow to the pits, using assumed maximum hydraulic conductivity, is:

$$Q\frac{1982}{3411} = 2.8\ ft^3/s \qquad (92)$$

$$Q\frac{1982}{3438} = 45\ ft^3/s \qquad (93)$$

$$Q\frac{1982}{3433} = 34\ ft^3/s \qquad (94)$$

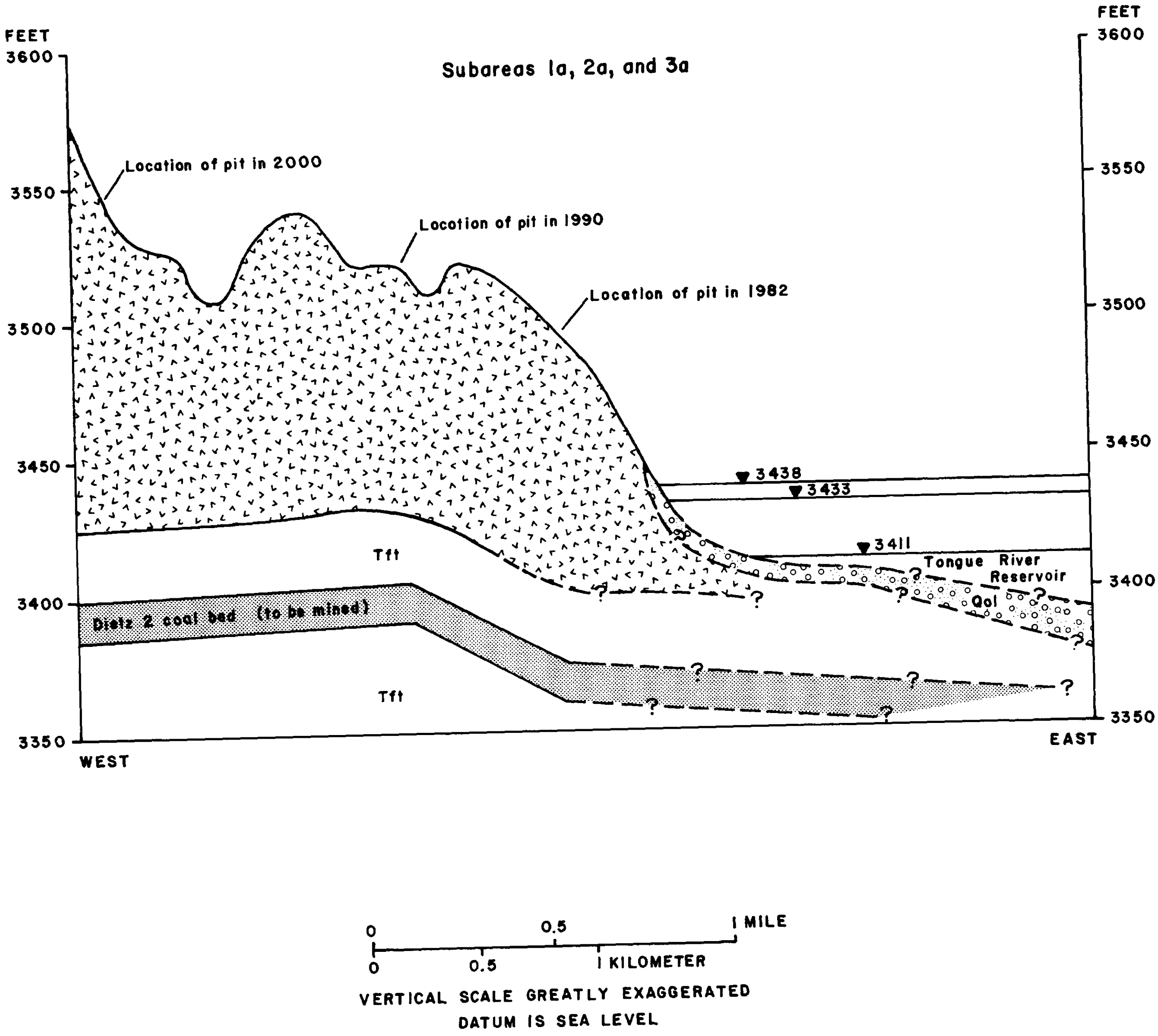
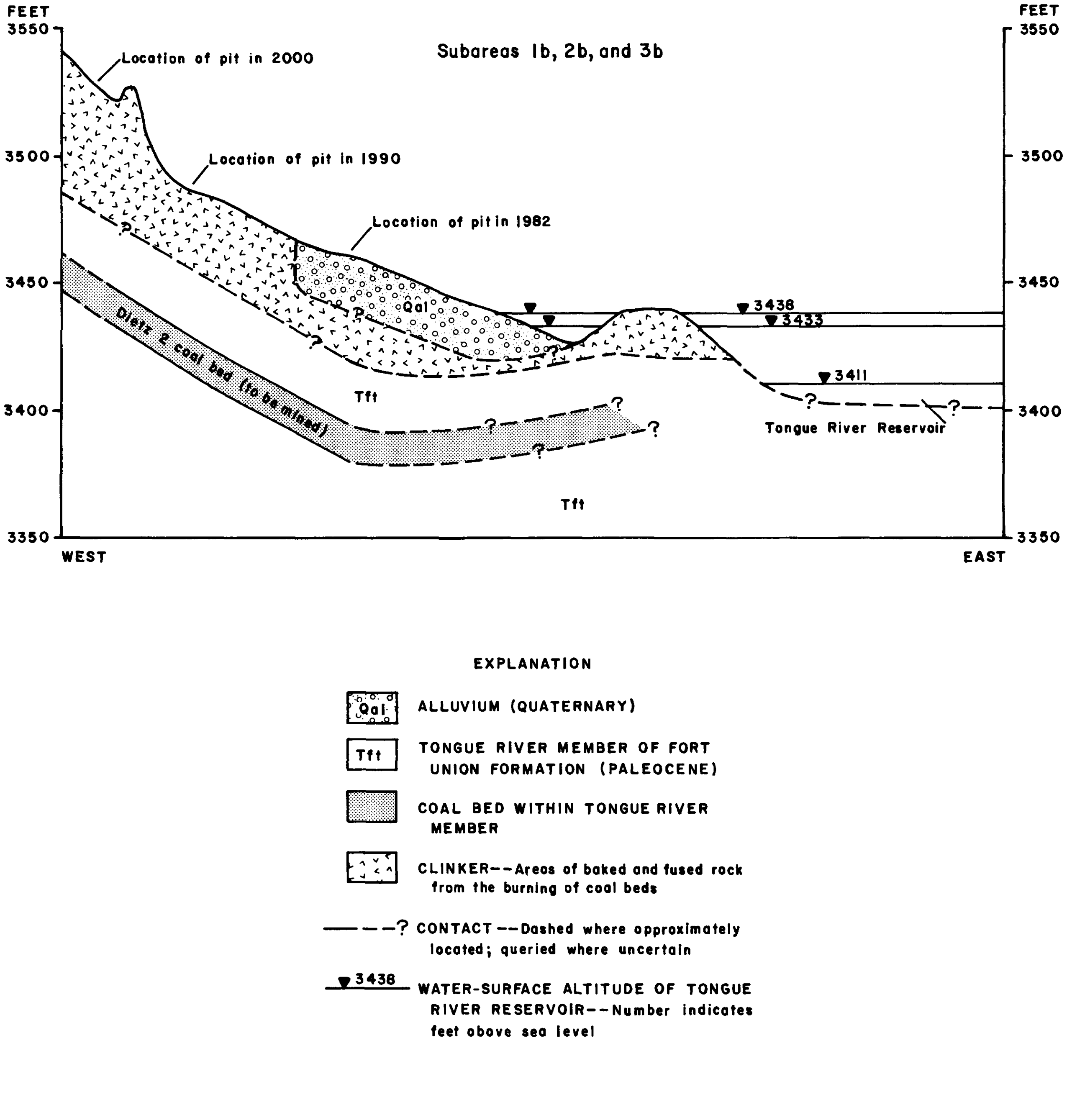


Figure 7.--Generalized cross sections for subareas 1a, 2a, 3a, 1b,



2b, and 3b of the proposed North Decker Mine.

The following set of calculations approximates possible future mining conditions about halfway through the life of the mine. Subarea 2a pertains to the southern area and subarea 2b pertains to the northern area. Stratigraphic relationships are illustrated in figure 7.

Assumed conditions for subarea 2a are that the spoils will be the least transmissive aquifer zone, the hydraulic head at the clinker-spoils contact is equal to the reservoir stage, the distance from the pit to the contact is 2,200 feet, and the width of the cross-sectional area through which flow occurs is 6,100 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q\,\frac{1990}{3411} = (200)[(20)(6{,}100)]\left(\frac{3{,}411-3{,}397}{2{,}200}\right)$$
$$= 160{,}000\ \mathrm{ft^3/d} = 1.9\ \mathrm{ft^3/s} \qquad (95)$$

$$Q\,\frac{1990}{3438} = (200)[(20)(6{,}100)]\left(\frac{3{,}438-3{,}397}{2{,}200}\right)$$
$$= 450{,}000\ \mathrm{ft^3/d} = 5.2\ \mathrm{ft^3/s} \qquad (96)$$

$$Q\,\frac{1990}{3433} = (200)[(20)(6{,}100)]\left(\frac{3{,}433-3{,}397}{2{,}200}\right)$$
$$= 400{,}000\ \mathrm{ft^3/d} = 4.6\ \mathrm{ft^3/s} \qquad (97)$$

Assumed conditions for subarea 2b are that the spoils will be the least transmissive aquifer zone, the saturated thickness of the spoils may be less than 20 feet at low reservoir stage, the hydraulic head at the clinker-spoils contact is equal to the reservoir stage, the distance from the pit to the contact is 2,200 feet, and the width of the cross-sectional area through which flow occurs is 5,300 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q\,\frac{1990}{3411} = (200)[(1)(5{,}300)]\left(\frac{3{,}411-3{,}410}{2{,}200}\right)$$
$$= 480\ \mathrm{ft^3/d} = 0.01\ \mathrm{ft^3/s} \qquad (98)$$

$$Q\,\frac{1990}{3438} = (200)[(20)(5{,}300)]\left(\frac{3{,}438-3{,}417}{2{,}200}\right)$$
$$= 200{,}000\ \mathrm{ft^3/d} = 2.3\ \mathrm{ft^3/s} \qquad (99)$$

$$Q\,\frac{1990}{3433} = (200)[(20)(5{,}300)]\left(\frac{3{,}433-3{,}417}{2{,}200}\right)$$
$$= 150{,}000\ \mathrm{ft^3/d} = 1.7\ \mathrm{ft^3/s} \qquad (100)$$

The total reservoir inflow to the pits, using assumed average hydraulic conductivity, is:

$$Q\,\frac{1990}{3411} = 1.9\ \mathrm{ft^3/s} \qquad (101)$$

$$Q\,\frac{1990}{3438} = 7.5\ \mathrm{ft^3/s} \qquad (102)$$

$$Q\,\frac{1990}{3433} = 6.3\ \mathrm{ft^3/s} \qquad (103)$$

Similarly, the total inflow to the pits, using assumed maximum hydraulic conductivity, is:

$$Q\,\frac{1990}{3411} = 9.0\ \mathrm{ft^3/s} \tag{104}$$

$$Q\,\frac{1990}{3438} = 38\ \mathrm{ft^3/s} \tag{105}$$

$$Q\,\frac{1990}{3433} = 32\ \mathrm{ft^3/s} \tag{106}$$

The following set of calculations approximates possible future mining conditions near the end of the life of the mine. Subarea 3a pertains to the southern area and subarea 3b pertains to the northern area. Stratigraphic relationships are illustrated in figure 7.

Assumed conditions for subarea 3a are that the spoils will be the least transmissive aquifer zone, the hydraulic head at the clinker-spoils contact is equal to the reservoir stage, the distance from the pit to the contact is 6,500 feet, and the width of the cross-sectional area through which flow occurs is 6,100 feet. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$\begin{aligned} Q\,\frac{2000}{3411} &= (200)[(20)(6{,}100)]\left(\frac{3{,}411-3{,}392}{6{,}500}\right) \\ &= 71{,}000\ \mathrm{ft^3/d} = 0.82\ \mathrm{ft^3/s} \end{aligned} \tag{107}$$

$$\begin{aligned} Q\,\frac{2000}{3438} &= (200)[(20)(6{,}100)]\left(\frac{3{,}438-3{,}392}{6{,}500}\right) \\ &= 170{,}000\ \mathrm{ft^3/d} = 2.0\ \mathrm{ft^3/s} \end{aligned} \tag{108}$$

$$\begin{aligned} Q\,\frac{2000}{3433} &= (200)[(20)(6{,}100)]\left(\frac{3{,}433-3{,}392}{6{,}500}\right) \\ &= 150{,}000\ \mathrm{ft^3/d} = 1.7\ \mathrm{ft^3/s} \end{aligned} \tag{109}$$

Assumed conditions for subarea 3b are that the spoils will be the least transmissive aquifer zone, the saturated thickness of the spoils may be less than 20 feet, the hydraulic head at the clinker-spoils contact is equal to the reservoir stage, the distance from the pit to the contact is 3,800 feet, and the width of the cross-sectional area through which flow occurs is 5,300 feet. For calculations 110 and 112, the base of the pit is above the reservoir stage, which precludes flow from the reservoir to the pit. Therefore, inflow to the pit, using assumed average hydraulic conductivity, is calculated as:

$$Q\,\frac{2000}{3411} = 0.00\ \mathrm{ft^3/d} = 0.00\ \mathrm{ft^3/s} \tag{110}$$

$$\begin{aligned} Q\,\frac{2000}{3438} &= (200)[(20)(5{,}300)]\left(\frac{3{,}438-3{,}435}{3{,}800}\right) \\ &= 17{,}000\ \mathrm{ft^3/d} = 0.20\ \mathrm{ft^3/s} \end{aligned} \tag{111}$$

$$Q\,\frac{2000}{3433} = 0.00\ \mathrm{ft^3/d} = 0.00\ \mathrm{ft^3/s} \tag{112}$$

The total reservoir inflow to the pits, using assumed average hydraulic conductivity, is:

$$Q_{\frac{2000}{3411}} = 0.82 \text{ ft}^3/\text{s} \tag{113}$$

$$Q_{\frac{2000}{3438}} = 2.2 \text{ ft}^3/\text{s} \tag{114}$$

$$Q_{\frac{2000}{3433}} = 1.7 \text{ ft}^3/\text{s} \tag{115}$$

Similarly, the total inflow to the pits using assumed maximum hydraulic conductivity, is:

$$Q_{\frac{2000}{3411}} = 4.1 \text{ ft}^3/\text{s} \tag{116}$$

$$Q_{\frac{2000}{3438}} = 11 \text{ ft}^3/\text{s} \tag{117}$$

$$Q_{\frac{2000}{3433}} = 8.9 \text{ ft}^3/\text{s} \tag{118}$$

CONCLUSIONS

The example calculations of ground-water inflow from the Tongue River Reservoir to nearby mine pits illustrate a method by which such inflow could be estimated. The calculations are based on assumed conditions. Actual conditions will probably be different from the assumed conditions, and actual inflow-rate estimates would need to be recalculated using values based on the actual conditions. The method of calculation is simplified and is subject to a large degree of error. However, the calculations given indicate that the planned increase in the stage of the reservoir will result in an increase of inflow to the mine pits in most areas. The increases will be the greatest where the pits are near the reservoir and separated from the reservoir solely by aquifer zones of relatively large hydraulic conductivity, such as the area of clinker near the interior of the West Decker Mine and areas of clinker or mine spoils at the North Decker Mine. Inflow along the sides of some subareas, such as the northern parts of the North Decker and East Decker Mines, could be significant but was not included in the calculations presented.

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