GROUND-WATER STUDY 6

by

Devin L. Galloway

and

James B. Foster

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1.0 ABSTRACT

Geology and the Occurrence of Coal

Glacial deposits as much as 200 feet thick overlie bedrock of Pennsylvanian age. The composition of glacial deposits ranges from sand and gravel to clay. Sand and gravel occur in buried bedrock valleys and in alluvial deposits along stream channels.

The bedrock geology consists of flat-lying Pennsylvanian sedimentary rocks composed of shale and clay, some sandstone, and a little limestone and coal. Minable coal beds include the Herrin (No. 6) and Harrisburg-Springfield (No. 5).

Hydrology and Hydrologic Monitoring

The water-bearing capability of the glacial deposits is variable, depending upon the grain and pore sizes within the materials. The sand aquifer overlying the proposed mine site has measured hydraulic conductivity values of 60 to 125 ft/yr. Specific yield values range from 0.15 to 0.32. Wells in the sand and gravel yield as much as 500 gal/min.

Hydrologic boundaries of the sand aquifer at the mine site include the overlying clayey-silt alluvium, the underlying fireclay and shale bedrock, the unreclaimed mine spoils to the east, and the Possum River to the west. Hydraulic conductivity of the mine spoil ranges from 2 to 300 ft/yr.

The sandstone and limestone bedrock units, above and below the coal units, are water-bearing. The productivity of these aquifers is variable, depending on the development of secondary permeability from fracturing, parting along bedding planes, or solution cavities in limestone. The yield of bedrock aquifers to wells ranges from 20 to 100 gal/min.

Mining Method and Potential Stresses on Aquifer

The surface mine will start near the stream and advance toward the abandoned mine spoils. The first cut will require drains, sump drains, and pumps to remove inflow from the aquifer. Inflow to subsequent cuts will be decreased by covering the river side of the first cut with fireclay (underclay) and covering the clay with spoils material.

The alluvial sand and gravel aquifer is used for domestic, municipal, industrial, and small commercial water supplies. The bedrock aquifers are used in areas where the alluvial aquifers are absent or of limited productivity. By mining part of these aquifers, the surface mine will create a potential water-supply problem for users of these resources.

Probable Hydrologic Impact and Proposed Hydrologic Monitoring Network

During the post-mining period, the concentrations of dissolved solids in the ground water may increase, owing to the presence of iron sulfides in the spoils. The ground water may have a lower pH, depending on the buffering capacity of the mine spoils. Because ground water may flow from the mine spoils toward the river, acidic mineralized water may flow to the municipal well field and contaminate the supply. Dilution by upstream river water will minimize the effect of spoils water on river quality.

During mining, dewatering of the open pit will decrease ground-water flow to nearby wells to some extent. The flow of river water infiltrating through the alluvial aquifer material into the pit will reach a steady rate of 155 gal/d per linear foot of excavation in about 60 days. The ground-water inflow to the pit from the abandoned mine to the east will be 35 gal/d per foot of excavation in 400 days. Use of the underclay to seal the wall on the river side of the cut becomes more significant in reducing ground-water inflow with increasing time.

The post-mining ground-water monitoring program will include wells in the mine spoils and a river-sampling point downstream. Water levels will be measured to determine the rate of recovery and the direction of flow. Ground-water quality will be monitored, in the spoils area, to determine the concentrations of selected chemical constituents moving toward the river and toward the municipal well field.

2.0 GEOLOGIC SETTING

2.1 QUATERNARY SYSTEM

UNCONSOLIDATED DEPOSITS OVERLIE THE COAL-BEARING BEDROCK

Unconsolidated deposits of the Pleistocene Series overlie the Pennsylvanian sedimentary bedrock which contains the coal seams.

Unconsolidated deposits, which overlie the coal-bearing Pennsylvanian bedrock, occur throughout the general area. These deposits consist of glacial till (also called ground moraine and glacial drift), lake (or lacustrine) deposits, and alluvium. The till is variably in composition and thickness, and is poorly sorted. The till deposits are commonly sandy, with lenses of silt, sand, and gravel. Lake deposits are well-bedded and include layers of silt, clay, and sand. Alluvial deposits consist of sand and gravel, which have been transported and deposited by streams. These Unconsolidated deposits can vary in thickness from 0 to 200 feet. In the proposed mine-permit area, the thickness is about 30 feet.

Figure 2.1-1 shows the general area containing the proposed mine permit site, which is overlain by alluvium. These deposits are bounded on the west by the silty clay terrace deposits, and on the east by the unreclaimed mine spoils from a previous mining operation. Figure 2.1-2 is a generalized cross section of these deposits overlying the coal-bearing bedrock.

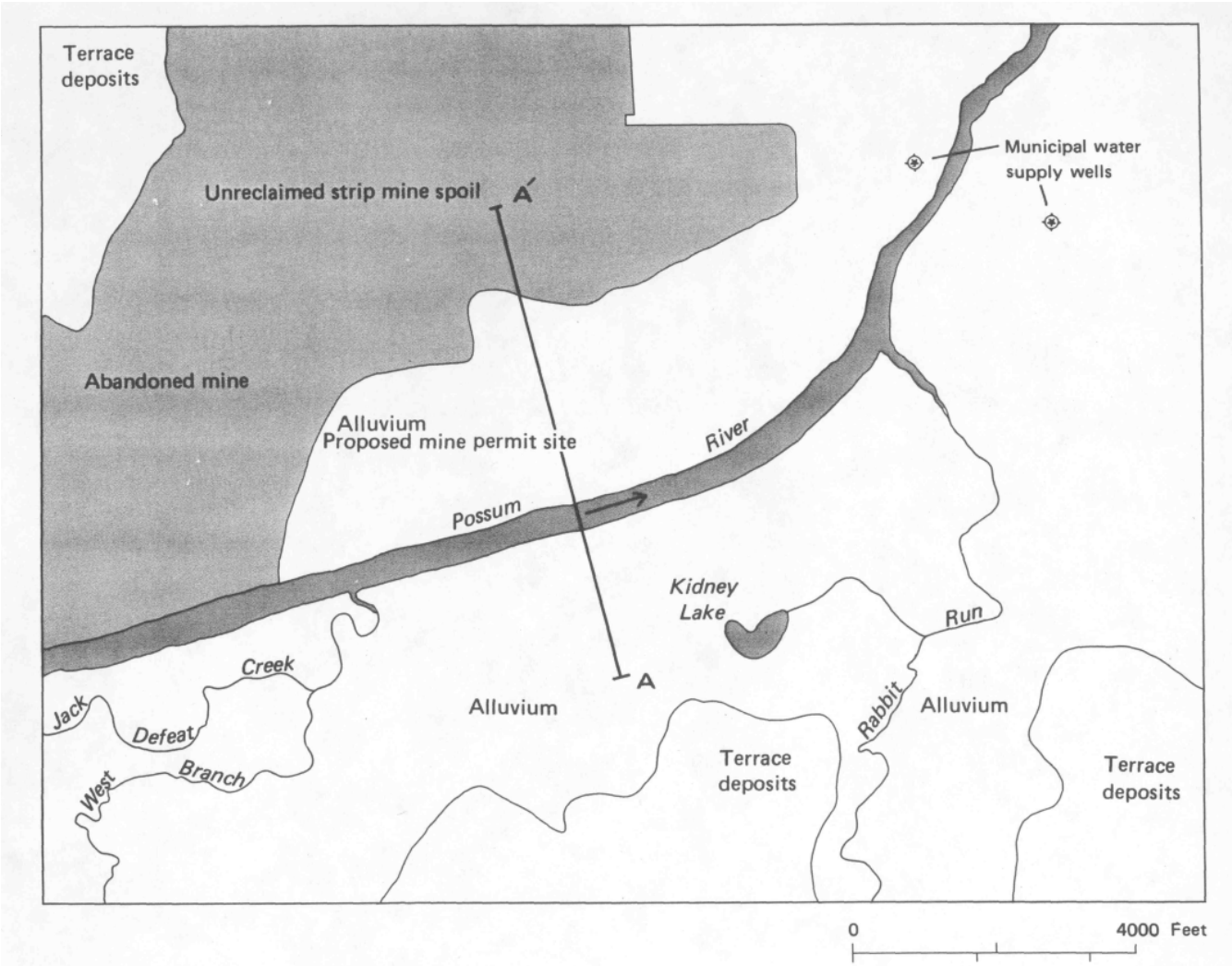

Figure 2.1-1.— Mine setting in Possum River flood plain northwest of Iona, Illinois.

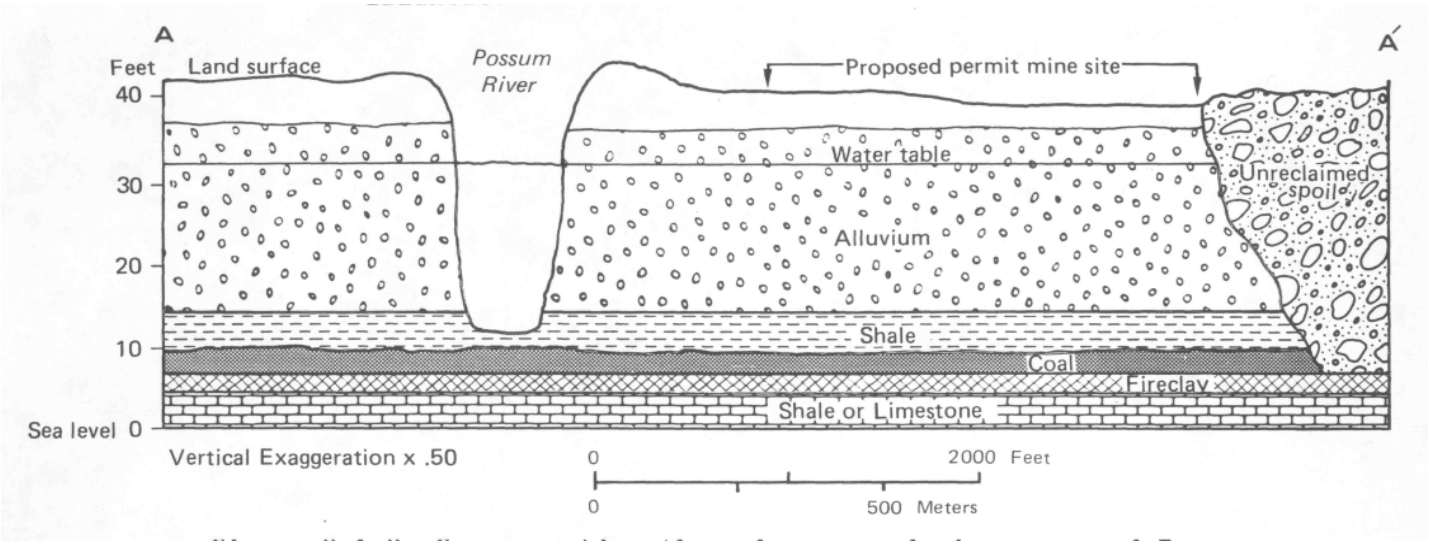

Figure 2.1-2.— Cross-section through proposed mine area and Possum River showing hydrogeologic setting.

2.0 GEOLOGIC SETTING

2.2 PENNSYLVANIA SYSTEM

CARBONDALE FORMATION CONTAINS MOST OF THE COAL MINED

In the Carbondale Formation, the Herrin and Harrisburg-springfield coal members are the coal seams mined most in the area.

The general mine area is underlain by the sedimentary bedrock of the Pennsylvanian System (fig. 2.2-1). This bedrock consists of sandstone, siltstone, limestone, shale, clay, and coal. The proposed mine-permit area is on the southern edge of a basin, where the sedimentary layers dip gently to the north at a low angle. The bedrock is underlain by Mississippian rocks, which are primarily limestone (20). The Kewanee Group consists of two formations–the Carbondale Formation overlying the Spoon Formation (figs. 2.2-1 and 2.2-2)–and contains most of the coal seams (17). In the mine area, most of the coal mined is Herrin (No. 6) coal and Harrisburg-springfield (No. 5) coal of the Carbondale Formation. The average thickness of the Herrin coal is 5.5 feet; 56 percent of the mapped reserves have a thickness of 6 feet or more (15). The average thickness of the Harrisburg-Springfield coal is 4.5 feet; 47 percent of the mapped reserves have a thickness of 5 feet or more (15).

Figure 2.2-1— Bedrock geology of the general area.
(From Willman and others, 1967.)

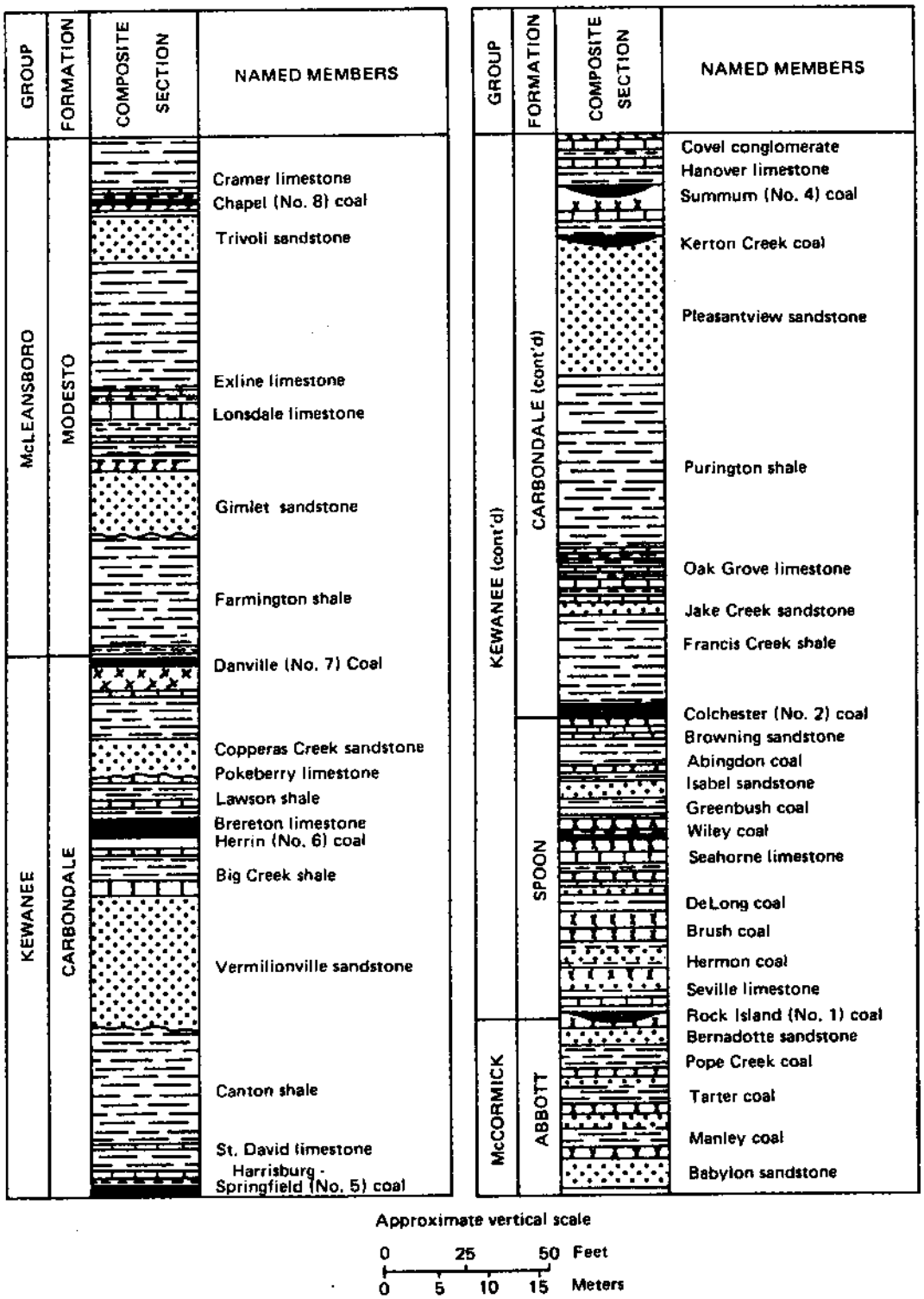

Figure 2.2-2.— Composite section of the Pennsylvanian-age strata in the general area. (After Smith and Berggren, 1963.)

3.0 HYDROLOGIC SETTING

3.1 PHYSIOGRAPHY AND CLIMATE

MINE AREA IS IN A HUMID CLIMATE AND THE TOPOGRAPHY IS FLAT

Average annual precipitation is 44 inches, most of which is from rainstorms during the warm season.

The general mine area lies within the glaciated Central Lowland physiographic province. The area is a prairie plain with generally level to gently undulating topography. The average altitude of the land surface is 600 feet and the local relief is generally less than 200 feet.

The climate is of the humid continental type. The average annual temperature is 57˚F. The average annual precipitation is 44 inches (11). Rainstorms account for more than 70 percent of the warm-season precipitation (20). The mean annual snowfall varies from 10 to 15 inches (20).

3.0 HYDROLOGIC SETTING

3.2 GROUND-WATER SYSTEM

GROUND-WATER AVAILABILITY IS GREATEST IN THE ALLUVIAL AQUIFERS

Sand and gravel aquifers occur as alluvium in stream valleys and as outwash deposited in pre-glacial bedrock valleys. Bedrock aquifers may occur above or below minable coal seams.

Saturated alluvial deposits of sand and gravel occur in stream valleys and as buried pre-glacial outwash channels overlying the bedrock. Ground water in the alluvial deposits flows toward and into the river, and is hydraulically connected with the river. Water-table contours based on measurements in observation wells indicate the direction of ground-water flow (fig. 3.2-1).

Recharge to the sand and gravel aquifers is largely from the infiltration of precipitation and from leakage of streamflow during floods. These aquifers are used for domestic and small commercial water supplies, and are capable of producing as much as 500 gal/min to wells for municipal and industrial supplies. The hydraulic conductivities of alluvial aquifers range from 100 to 1,000 times the conductivity values of the bedrock aquifers.

Bedrock aquifers are composed of sandstones and limestones and are present both above and below the coal seams in the mine-permit area. Ground-water availability in the aquifers is variable and depends on the development of secondary permeability from fracturing or from solution cavities in the limestone.

Water in the shallow bedrock aquifers is generally derived from circulation of shallow ground-water flow systems. Precipitation infiltrates the ground in the upland areas, percolates downward, and enters the bedrock formations through joints and fractures (5).

Shallow bedrock aquifers discharge primarily to major streams. These aquifers are used for water supplies in areas where sand and gravel aquifers are either absent or of limited productivity. The yield of bedrock aquifers to wells ranges from 20 to 100 gal/min.

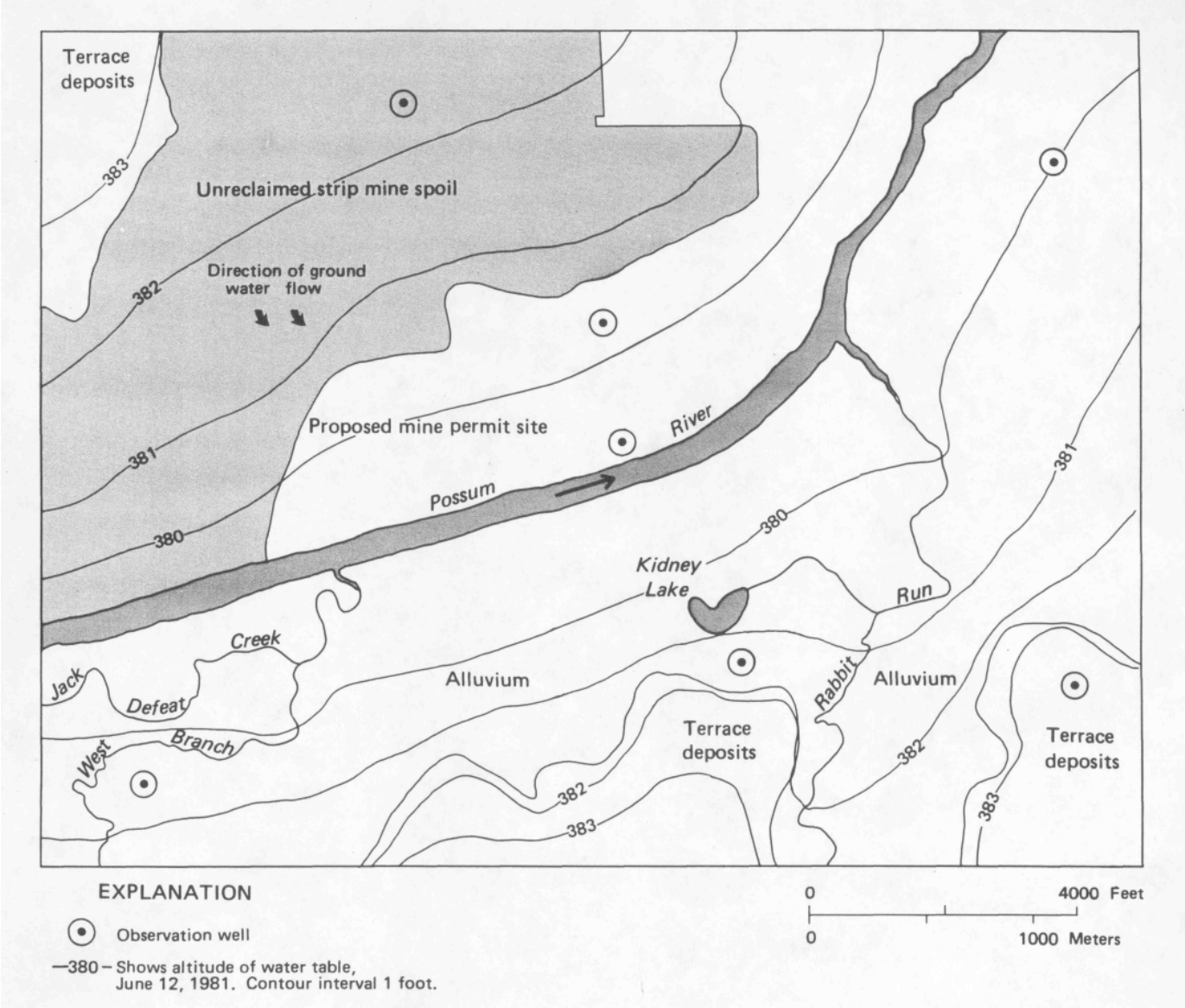

Figure 3.2-1.— Proposed mine area and adjacent area showing water-table contours.

3.0 HYDROLOGIC SETTING

3.3 HYDRAULIC PROPERTIES OF THE ALLUVIAL AQUIFER

HYDRAULIC-CONDUCTIVITY AND SPECIFIC-YIELD VALUES ARE TYPICAL FOR ALLUVIAL AQUIFERS

The alluvial aquifer has an average hydraulic conductivity of about 90 feet per year and an average specific yield of about 0.20.

Average hydraulic-conductivity (K) values for the aquifer ranged from 60 to 254 ft/yr, and averaged 90 ft/yr. Average specific yield values ranged from 0.15 to 0.32, and averaged about 0.20. Data obtained from slug tests on 10 wells distributed across the proposed min£ site were used to compute hydraulic conductivities. The areal distribution of aquifer properties is shown in figure 3.3-1.

The 'Bouwer and Rice' slug-test method (4), a single-well recovery test, was chosen because the method can be applied to completely or partially penetrating wells for a wide range of well geometries in unconfined aquifers. The method can also be applied, in some instances, to confined aquifers. The equation for calculating K by this method is

$$K = r_c^2 \frac{\ln (R_e/r_w)}{2L} \frac{1}{t} \ln(y_o/y_t)$$

where L = length of screen open to aquifer,
r_c = radius of the casing,
r_w = radial distance between the undisturbed aquifer and the well center (includes sand or gravel envelopes),
R_e = effective well radius,
R_e/r_w = determined as a fraction by equation 3.3-2,
t = time after the start of the aquifer test,
y_o = drawdown at t = 0 (and y_t is taken as drawdown at some time greater than zero).

$$\mathrm{Ln}(R_e/r_w) = \left[\frac{1.1}{\ln(h/r_w)} + \frac{A + B \ln((D-h)/r_w)^{-1}}{(l/r_w)} \right]$$

with an upper limit of ln((D-H)/rw) = 6, and if D = H then

$$\mathrm{Ln}(R_e/r_w) = \left[\frac{1.1}{\ln(h/r_w)} + \frac{A + B \ln((D-h)/r_w)^{-1}}{(l/r_w)} \right]$$

where values for A, B, and C are obtained from figure 3.3-2.

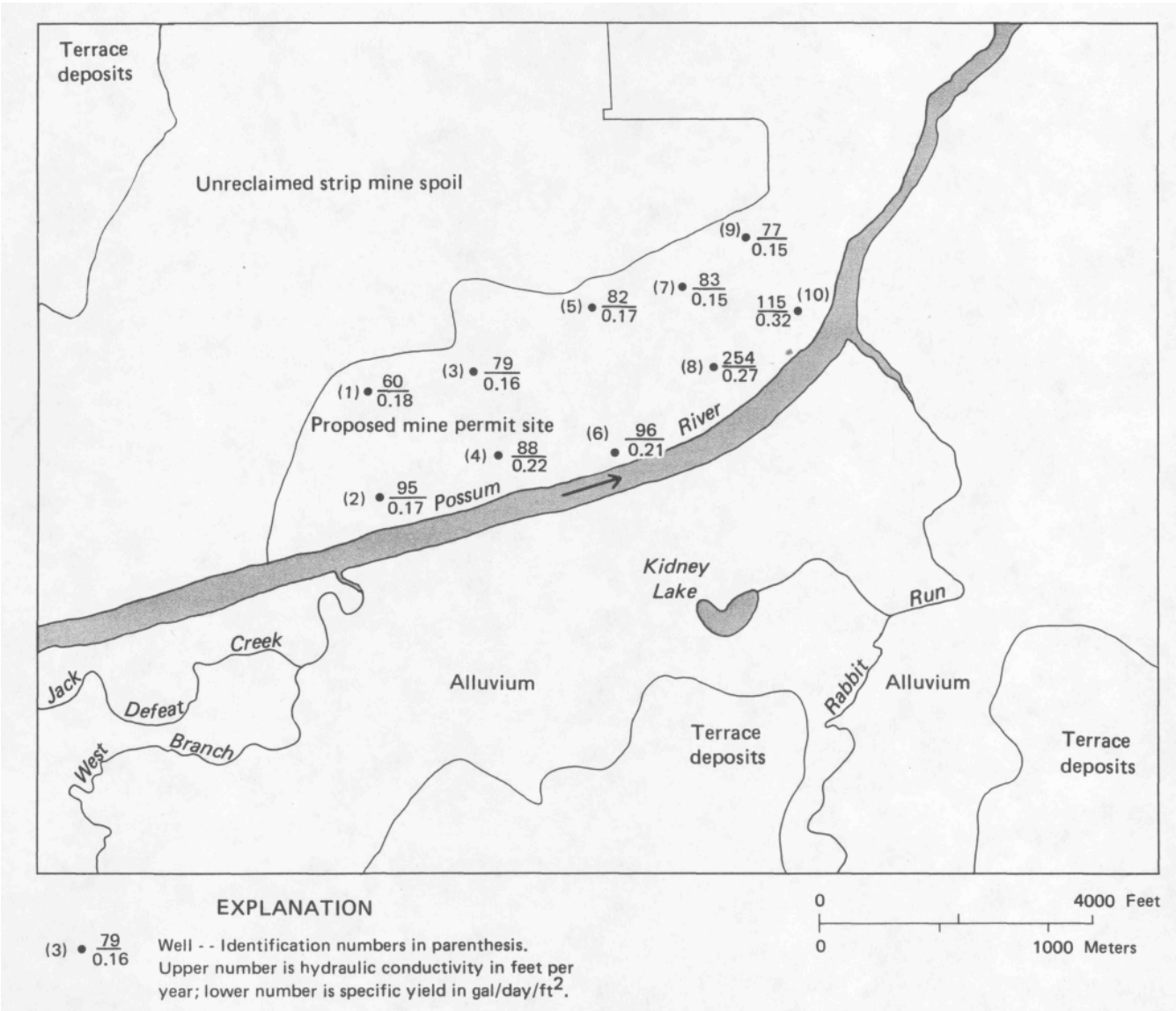

Figure 3.3-1.— Proposed mine area showing areal distribution of hydraulic conductivity and specific yield of alluvial aquifer overlying coal seam.

Figure 3.3-3 shows a vertical cross section of well 8 at some time after a slug of water has been removed. Values for the parameters necessary to calculate K are given. In addition, R_e is equivalent to the radial distance over which the head loss y is dissipated, and depends on the geometry of the flow system.

The drawdown curve for a slug test on well 8 is shown in figure 3.3-4. A bailer, with a volume capacity equivalent to a 3.0-foot change in water level in the well, was used to remove a slug of water. Subsequent water-level measurements yielded the drawdown curve. The straight-line section of the curve is used to compute hydraulic conductivity and transmissivity, as shown in figure 3.3-5.

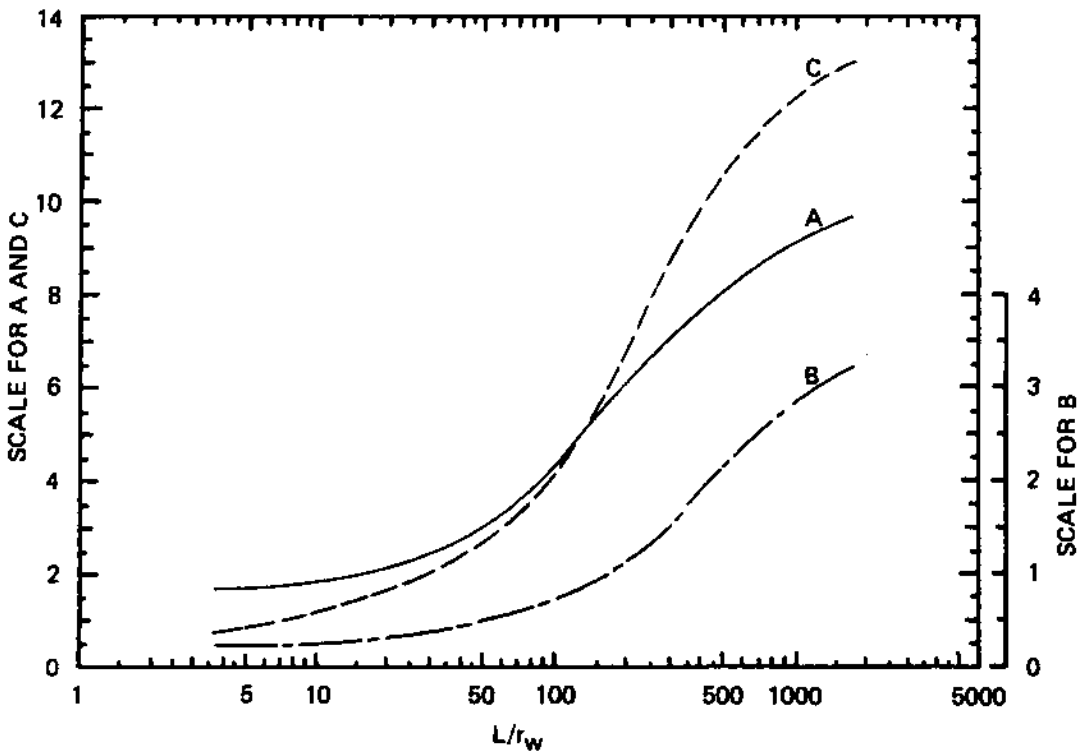

Figure 3.3-2.— Curves relating coefficients A, B, and C to L/r_w .
(From Bouwer and Rice, 1976, fig. 3.)

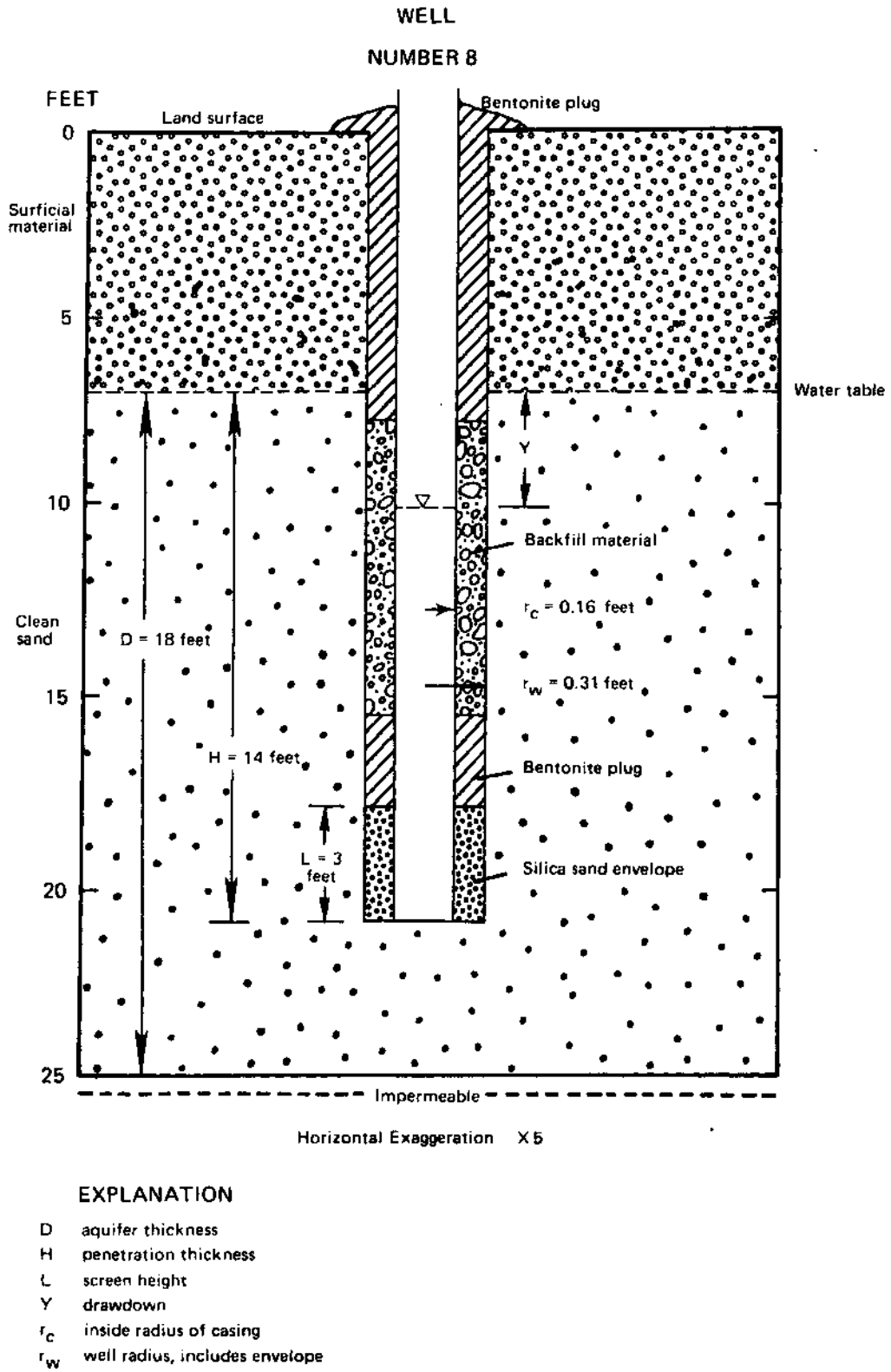

Figure 3.3-3.— Geometry of well number 8 and symbols used in slug test. (From Bouwer and Rice, 1976.)

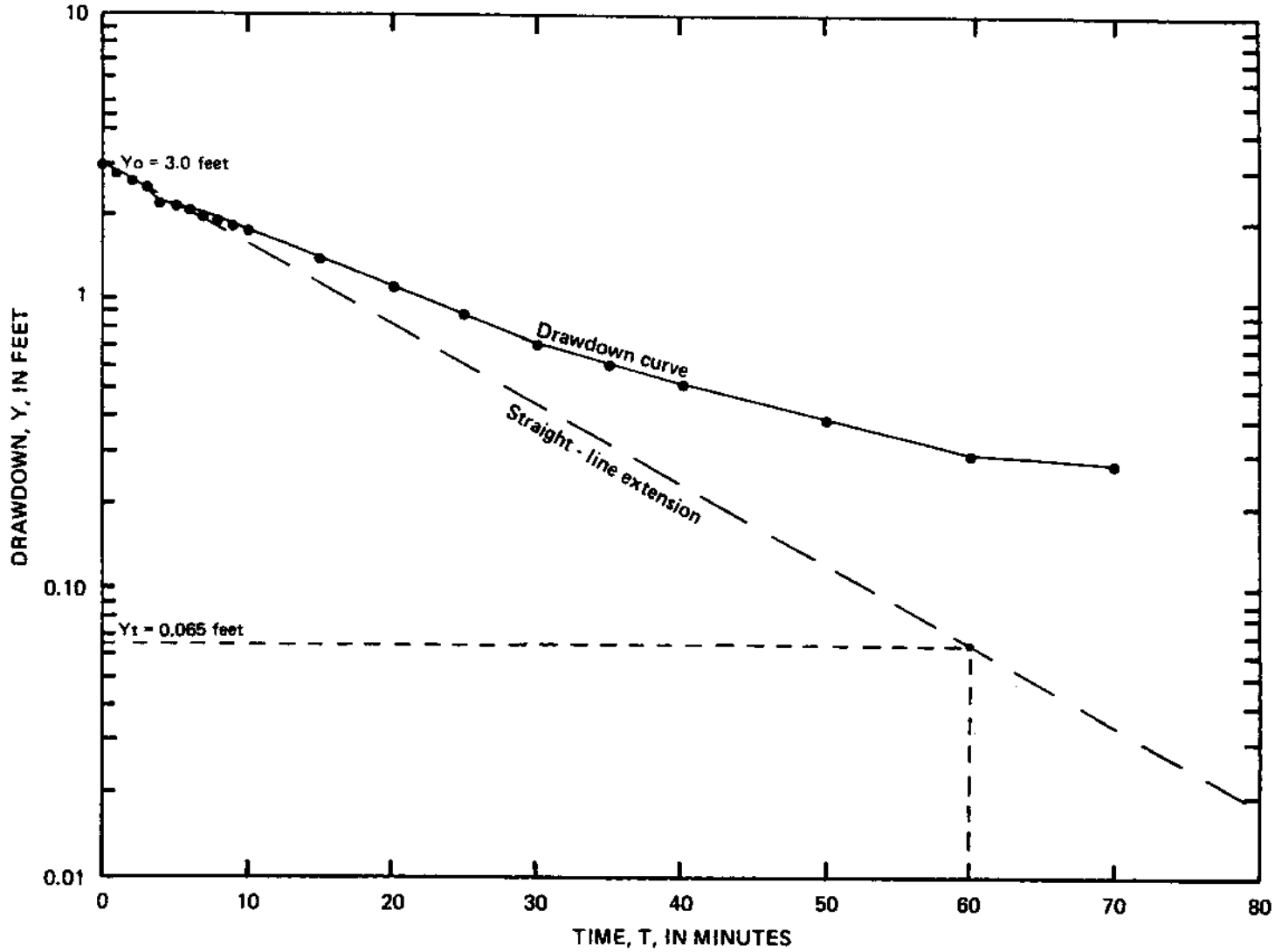

Figure 3.3-4. —Drawdown curve for slug test on well number 8.

Given: from figure 3.3-3

$r_c = 0.16$ foot
$r_w = 0.31$ foot
$L = 3$ feet
$H = 14$ feet
$D = 18$ feet

from figure 3.3-4

$y_o = 3.0$ feet
$y_t = 0.065$ foot

Find: hydraulic conductivity (K) and transmissivity (T) for well no. 8

$$K = \frac{(r_c)^2}{2L} \frac{\ln(R_e/r_w)}{} \frac{1}{t} \ln(y_o/y_t) \quad \text{and} \quad T = KD$$

$$\ln(R_e/r_w) = \left| \frac{1.1}{\ln(H/r_w)} + \frac{A + B \ln((D - H)/r_w)}{(L/r_w)} \right|^{-1}$$

with $L/r_w = 3/0.31 = 9.68$, then $A = 1.9$ and $B = 0.3$, from figure 3.3-2.

$$\ln(R_e/r_w) = \left| \frac{1.1}{\ln(14/0.31)} + \frac{1.9 + 0.3 \ln((18-14)/0.31)}{9.68} \right|^{-1} = \frac{1}{0.2887 + 0.2755}$$

$$= 1.77$$

$$K = \frac{(0.16)^2 \times 1.77}{2 \times 3} \frac{1}{60} \ln(3.0/0.065) = 0.000483 \text{ foot per minute}$$

$$= 254 \text{ feet per year}$$

$$T = K\,D = 254 \times 18 = 4570 \text{ feet squared per year}$$

Figure 3.3-5.— Calculation of transmissivity for well no. 8 using Bouwer and Rice method.
(From Bouwer and Rice 1976.)

3.0 HYDROLOGIC SETTING

3.4 SURFACE-WATER GROUND-WATER INTERRELATIONSHIP

GROUND-WATER LEVELS AT THE PROPOSED MINE PERMIT SITE FLUCTUATE WITH CHANGING RIVER STAGE

Hydraulic conductivity of the alluvial aquifer permits ground-water levels adjacent to the streambank to fluctuate in response to changes in river stage.

The Possum River is hydraulically connected with the alluvial sand aquifer, which is continuous over the proposed mine site. Water moves into or out of the aquifer depending on the river stage (figs. 3.4-1 and 3.4-2). When the river stage is lower than the water level in the aquifer, which is normally the situation, a hydraulic gradient is established that allows water to flow from the aquifer to the river. Similarly, when the river stage rises above the water level in the aquifer, such as during a flood, water flows from the river into the aquifer. The extent of infiltration depends on the length of time of the flood stage and the hydraulic conductivity of the stream-aquifer interface and the alluvial material.

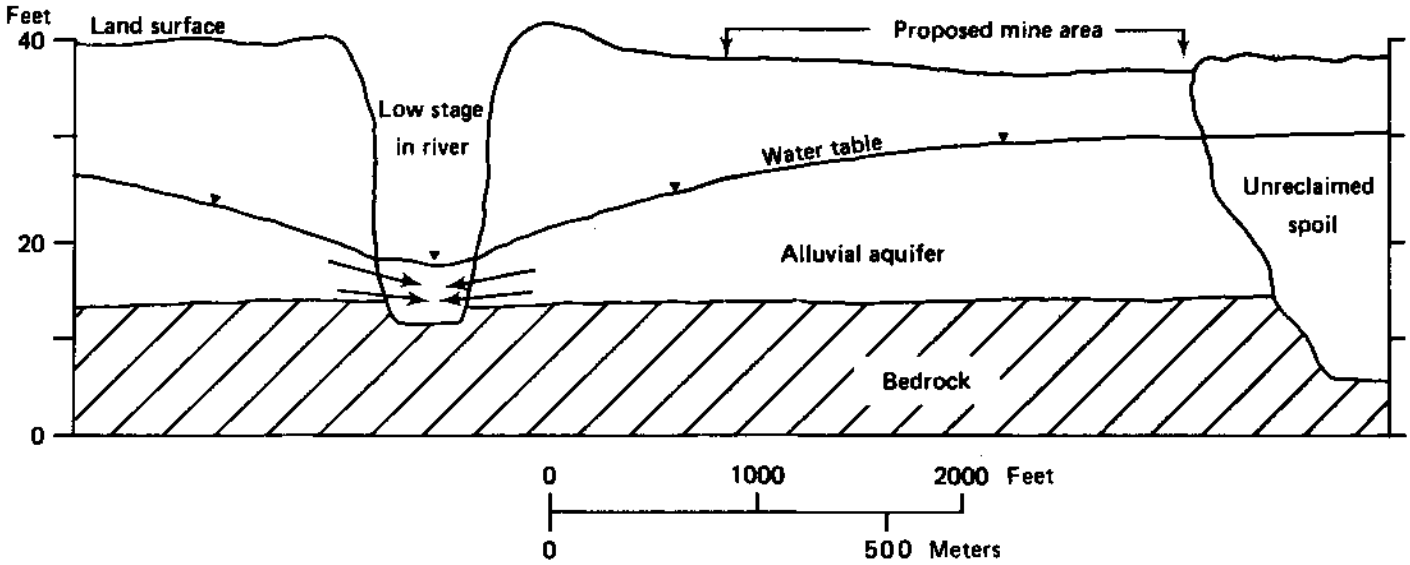

Figure 3.4-1.— Cross-section showing flow from the alluvial aquifer to the river during low-flow stage.

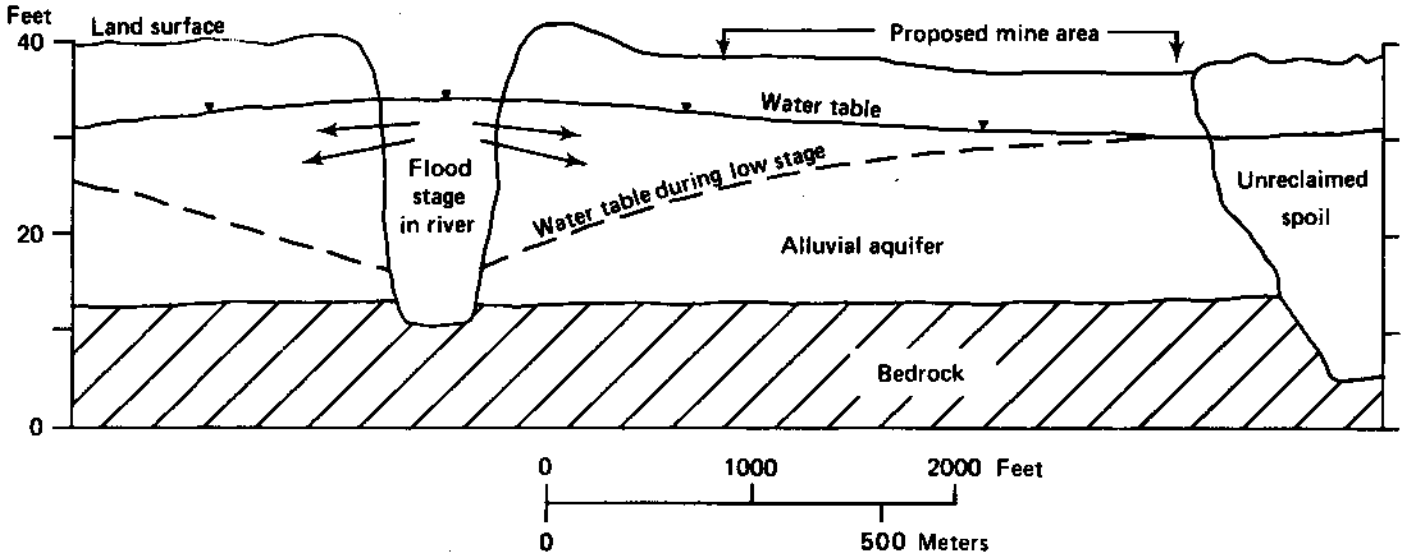

Figure 3.4-2.— Cross-section showing flow from the river to the aquifer during flood stage.

4.0 PROBABLE HYDROLOGIC IMPACTS OF MINING

4.1 GROUND-WATER DISCHARGE INTO EXCAVATION

GROUND-WATER INFLOW TO A MINE EXCAVATION THAT INTERCEPTS THE WATER TABLE NEEDS TO BE ESTIMATED PRIOR TO EXCAVATION

Ground water will discharge into a mine excavation that intercepts the water table of an aquifer. A seepage face will develop on the walls of the excavation. Fireclay will be graded onto the river side face of the excavation in an attempt to reduce ground-water inflow.

The size, shape, location, rate of excavating and hydrogeologic properties of the soil or rock are factors which affect the rate of ground-water inflow. The mine will be excavated through alluvium and shale bedrock to the Herrin No. 6 coal seam. The alluvium is a sand with a median grain size of 0.25-0.30 millimeters; the unit ranges in thickness from 10 to 22 feet. The depth to coal ranges from 20 to 45 feet and averages 30 feet.

The coal will be surface mined by a box-cutting operation. The first cut will be excavated from 'L1' to 'M1' (fig. 4.1-1); this cut will be 6,000 feet long, 800 feet from the river, and about 2,000 feet west of the mine boundary. Subsequent cuts will reverse the direction of excavating from the preceding cut, as the open pit will advance eastward. The pit dimensions of the first cut are 6,000 feet long, 30 feet deep, and 60 feet wide at the base with 1:1 slopes. The calculated mining rate is 1,500 linear feet per month, or 4 months to open the first cut.

Water in the alluvial aquifer is under water-table conditions when the river is at the mean annual stage. Figure 3.2-1 shows the water-table contours in and adjacent to the site on June 12, 1981. As the first cut is made, hydraulic gradients will begin to slope toward the excavation, inducing inflow toward the excavation. A seepage face will develop on both sides of the excavation.

The excavated face is depicted as being vertical (fig. 4.1-2) to simplify the conceptual hydraulic model. In figure 4.1-2, FC may be specified as a constant head boundary; DC and HI are impermeable boundaries. The water table EF meets the outflow boundary GD at E. The assumption is made that flow through the unsaturated part of the system, the area between EF and HI, is negligible.

Control of ground-water flow to the excavation will be necessary to minimize the pumping required to dewater the pit. Dewatering the excavation will lower ground-water levels in the aquifer near the pit, reducing pore pressures on the walls and thus improving slope stability. Dewatering can be accomplished with drains, drainage trenches, or pumping wells.

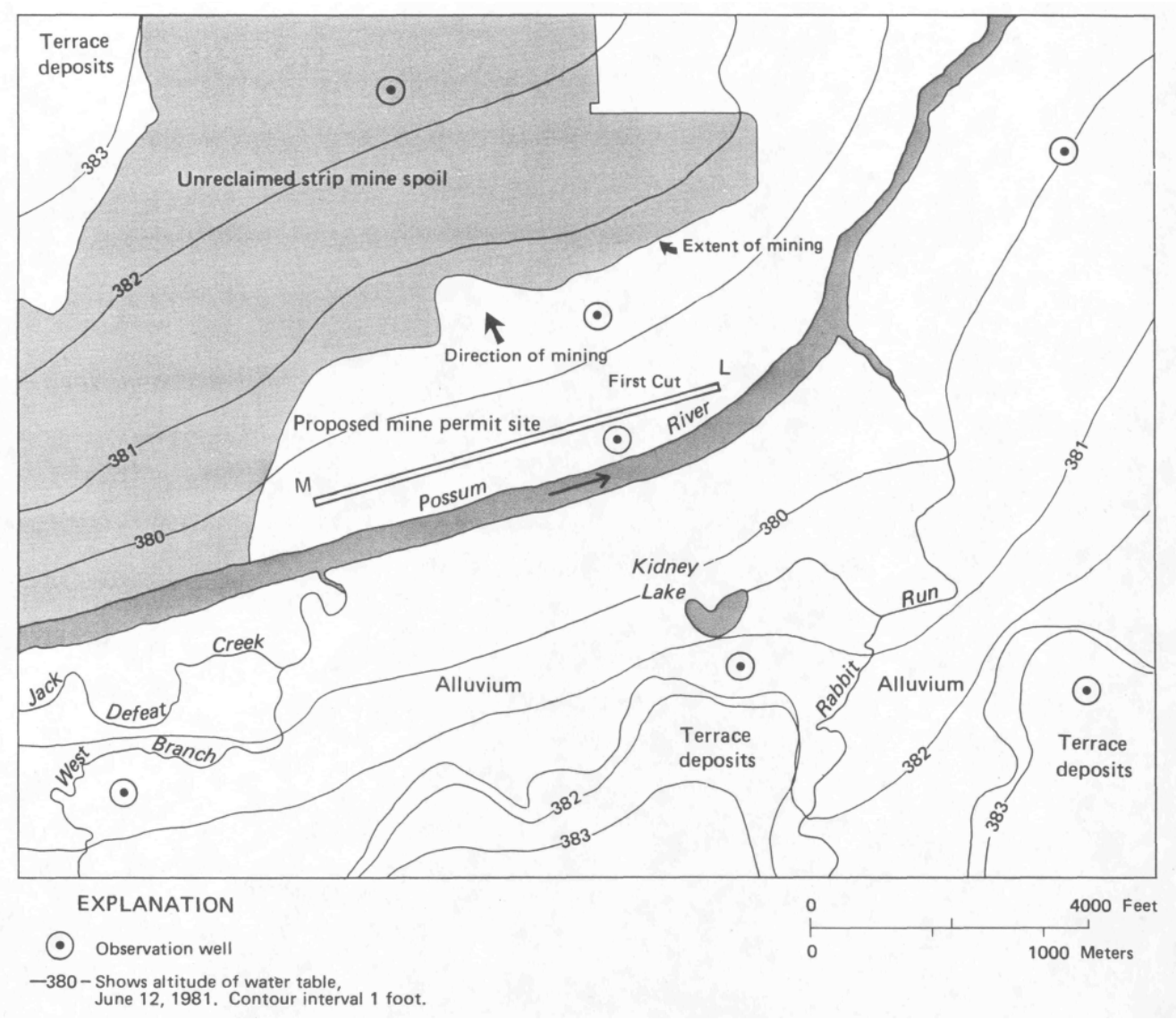

Figure 4.1-1.— Proposed mine and adjacent area showing location of first mine cut, direction of mining, and water-table contours.

A different method to reduce inflow is being considered for this mine. Some of the fireclay would be excavated in the first section of the cut and graded onto the excavation face nearest the river. As the clay is laid down, it would be covered with spoils material to provide additional support for the clay barrier against hydraulic pressures resulting from rising ground-water levels behind the barrier (fig. 4.1-3).

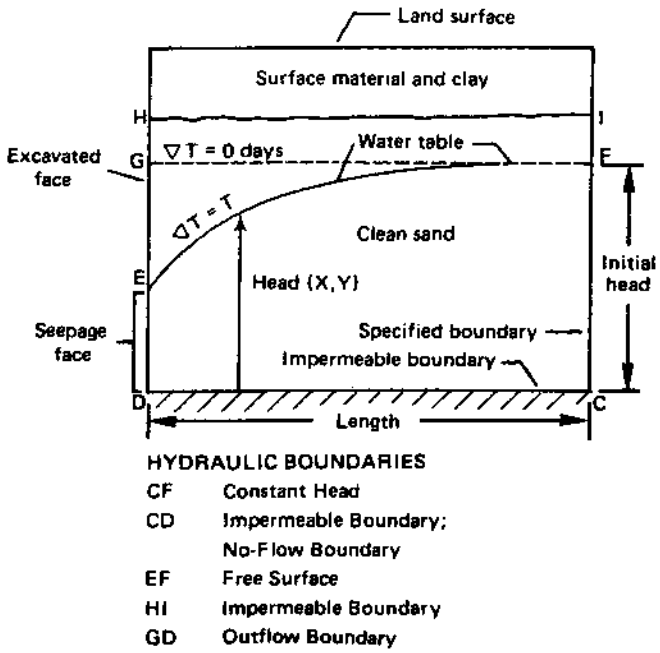

Figure 4.1-2.— Cross section of pit showing drainage to seepage face.

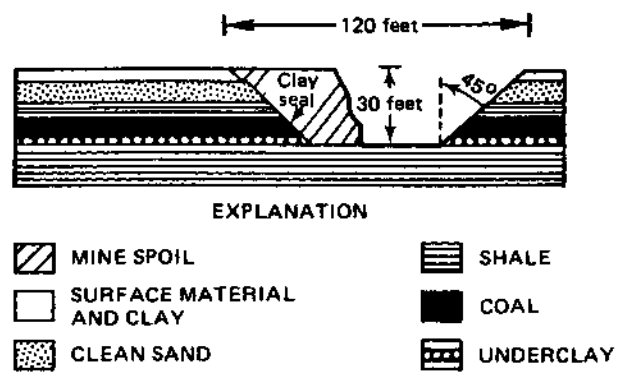

Figure 4.1-3.— Cross section through first cut showing clay seal supported by layer of mine spoil

4.0 PROBABLE HYDROLOGIC IMPACTS

4.2 PREDICTIVE ANALYSIS OF GROUND-WATER INFLOWS INTO EXCAVATION

GROUND-WATER INFLOW RATES CAN BE ESTIMATED FROM ANALYSES OF PREVIOUS INVESTIGATIONS

Ground-water discharge depends on the hydraulic boundaries. The ground-water discharge, on the river side of the excavation, reaches steady state in about 30 days. The ground-water discharge from the abandoned mine side approaches zero after more than a year.

The geohydrologic cross section from figures 2.1-1 and 2.1-2 is presented in figure 4.2-1(a). To calculate the ground-water discharge into the excavation for this setting, the following simplifying analytical assumptions (8) are made:

1. The river fully penetrates the sand unit and is not separated from it by a confining layer.
2. The sand unit is horizontal and of uniform thickness.
3. Water in the aquifer is unconfined. (For the analysis, the initial saturated thickness of the aquifer and the river stage is 20 feet. Stream-gaging records for Possum River at Iona show that the mean daily river stage exceeds 20 feet less than 4 percent of the time.)
4. Drainage to the excavation will be at right angles to the length of the cut.
5. Recharge to the aquifer from infiltration or leakage through 'surface material or clay ' is negligible.
6. The hydraulic boundaries of the aquifer are a constant line source on the river side and an impermeable boundary on the other.
7. The alluvial aquifer is considered to be homogeneous, isotropic, and of infinite extent in a direction parallel to the river.

These assumptions provide a larger than expected value of ground-water flow into the excavation.

Following the solution for transient drainage of ground-water flow from a constant-head boundary (Possum River) to an outflow reservoir (the floor of the excavation) (16), the water-table profiles between the River and the excavation are shown in figure 4.2-2. The altitude of the water table between the excavation and the River approaches steady state after about 30 days.

Ground-water inflow from the river side of the excavation initially is greater than 1000 gal/d per linear foot of length of excavation. However, the discharge declines to a steady-state value of 155 (gal/d)/ft at 60 days after coal excavation begins (fig. 4.2-3).

The water-table profiles between the mine-floor excavation and the abandoned mine are shown in figure 4.2-4. The ground-water inflow from the abandoned-mine side of the excavation is initially greater than 300 (gal/d)/ft and gradually decreases with time, as shown in figure 4.2-5. After 400 days of surface mine excavation, the transient discharge is about 34 (gal/d)/ft.

The total ground-water inflow is the sum of discharges from figures 4.2-3 and 4.2-5 for the respective times. Ground-water profiles in the alluvial aquifer after 90 and 400 days are shown in figures 4.2-1b and 1c.

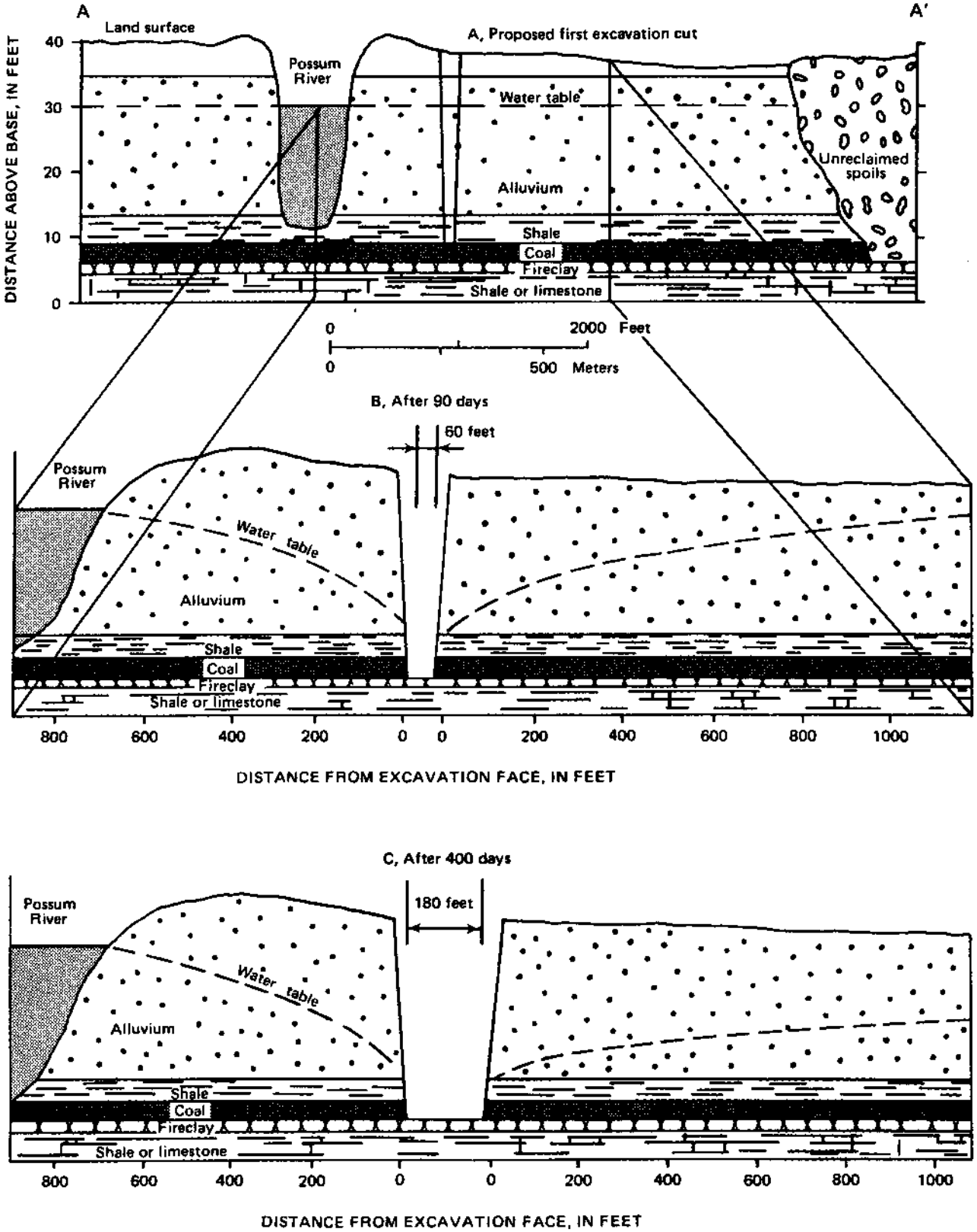

Figure 4.2-1.— Water profiles in alluvial aquifer after 90 and 400 days from the start of surface mining operations.

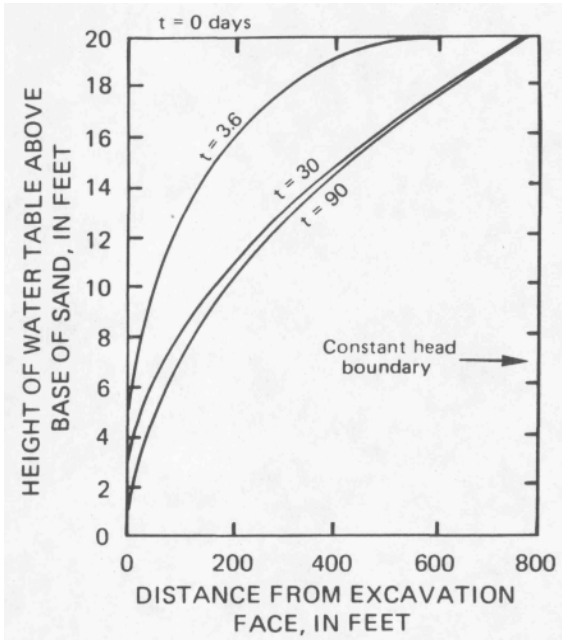

Figure 4.2-2.— Response or water table between mine pit and Possum River.

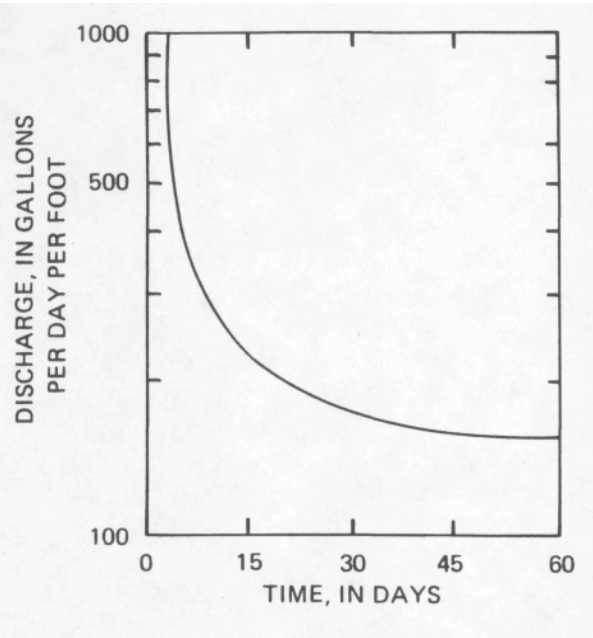

Figure 4.2-3.— Ground-water inflow hydrograph for river side of pit.

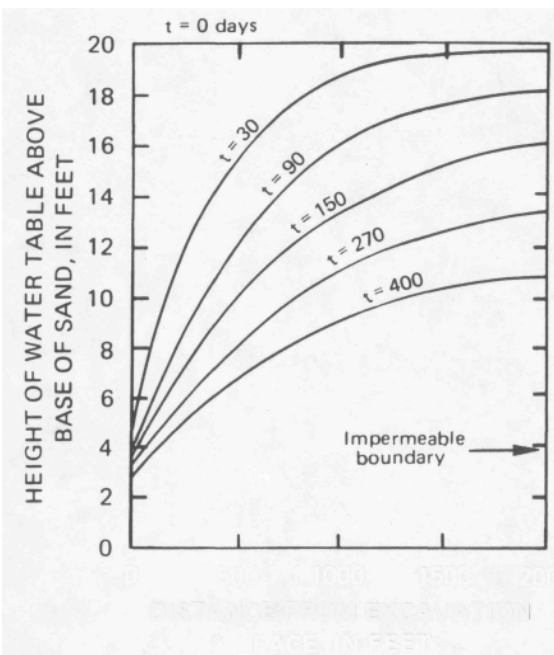

Figure 4.2-4.— Response of water table between mine pit and abandoned mine.

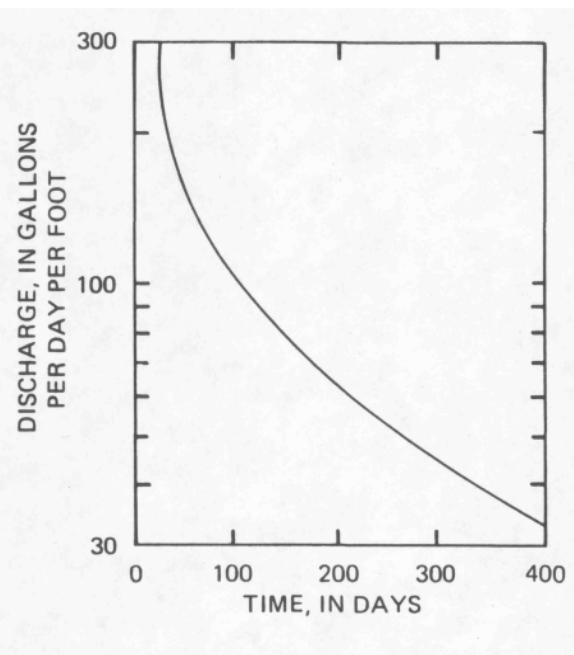

Figure 4.2-5.— Ground-water inflow hydrograph for abandoned mine side of pit.

4.0 PROBABLE HYDROLOGIC IMPACTS

4.3 HYDRAULIC ANALYSIS OF GROUND-WATER INFLOW TO FIRST CUT

GROUND-WATER INFLOW FROM EITHER SIDE OF FIRST CUT MAY BE USED TO ESTIMATE THE DRAINAGE DURING EXCAVATION

Ground-water inflow to the excavation reaches a maximum as the first cut is completed. The effect of sealing the river side of the first cut to reduce ground-water inflow becomes more significant later during opening of the excavation.

The maximum inflow of ground water will occur when the first cut is completed. Although the excavation rate will be 1,500 linear feet per month, it is assumed in the analysis that four sections, each 1,500 feet in length, will be opened instantaneously at 1-month intervals. Each 1,500-foot section allows an equivalent length and height of aquifer to drain from both the river and abandoned-mine side of the cut. Excavation of the second cut begins at the end of the fourth month. Simulation of ground-water flow to the second cut is not made.

The rates of inflow through both faces have been evaluated at monthly intervals for each open 1,500-foot section (fig. 4.3-1). Inflow increases as the length of the open pit is increased. The decreasing slope of the hydrograph with time results primarily from the slowing rate of inflow from the abandoned-mine side of the cut.

The analysis considers ground-water inflow into the excavation with sealing of the seepage face on the river side of the cut. It is assumed that the seal is applied instantaneously over each 1,500-foot section, 1 month after the section is completed. Sealing the seepage face at this frequency leaves only 1,500 feet of open face to drain on the river side of the excavation at any time. Based upon hydrologic analyses the sealing of the river side seepage face causes (1) a 20-percent reduction of ground-water discharge at the end of the second month of excavation, (2) about 40-percent reduction at the end of the third month, and (3) about 60-percent reduction at the end of the fourth month.

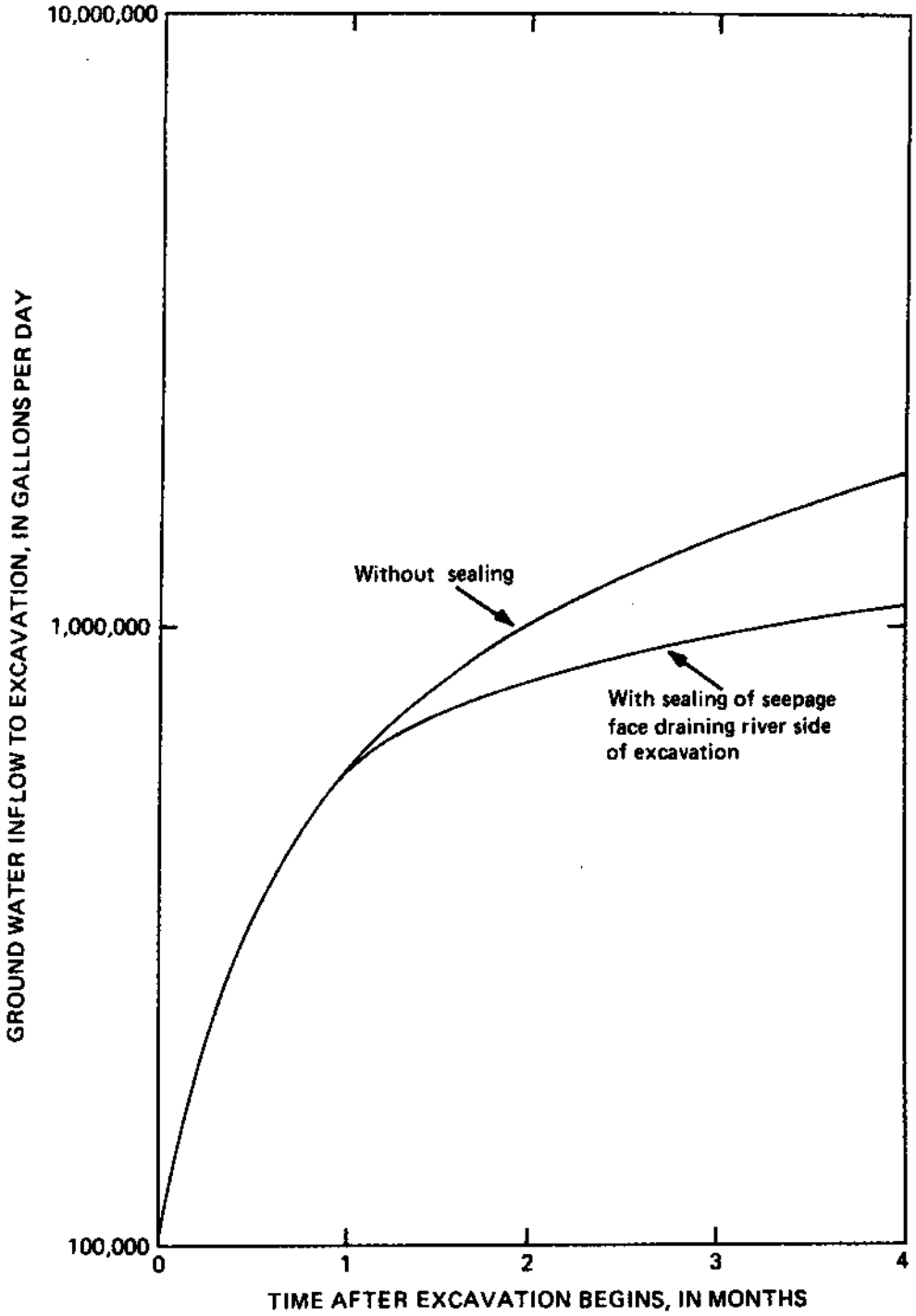

Figure 4.3-1.— Ground-water inflow hydrographs for first cut, with and without clay barrier.

4.0 PROBABLE HYDROLOGIC IMPACTS

4.4 GROUND-WATER-QUALITY CONSIDERATIONS

WATER IN ALLUVIAL AQUIFER MAY BE IN CONTACT WITH POTENTIALLY ACIDIC AND VERY MINERALIZED WATER

Lack of adequate buffering capacity in the spoils to neutralize acid water produced from oxidation of pyrite and marcasite in the spoils may result in acidic and very mineralized ground water. Water in the spoils will eventually discharge to the river, where dilution by river water will minimize the effects on river water quality.

The major effect of mining on the ground-water quality will result from the mine spoils being in contact with the alluvial aquifer. The spoils will consist of silty clay, clean sand, and shale. There will be two to three times, by volume, more sand than either clay or shale. The silty clay, derived from the more recent alluvial deposits above the sand unit, has been subjected to leaching by infiltrating water over many years, and consequently, would not contribute significantly to the mineralization of the water in the spoils. The shale associated with the coal seam has an abundance of pyrite and marcasite, which are likely to be sources of acid production in the spoils. Buffering capacity of the spoils material is small. The potential exists for the formation of an acidic and very mineralized water in the spoils.

Following the recovery of water levels in the alluvial aquifer and spoils, ground-water flow will most likely be from the mine spoils toward the river. However, the direction of flow will depend on the river stage. Discharge of the acidic, mineralized spoils water will probably have a minimal effect on the river water quality because of dilution by the river water. A less likely but possible alternative would be for the ground water to flow from the spoils through the alluvial aquifer toward the river in a downstream direction. Water from the spoils then might flow toward a municipal well field and contaminate that water supply.

5.0 GROUND-WATER MONITORING NETWORK

PRE-, DURING, AND POST-MINING GROUND-WATER MONITORING CAN BE USED TO EVALUATE IMPACTS OF MINING

Wells or borings completed during the permitting process may be used for monitoring. Other wells will have to be installed to complete the monitoring system.

A monitoring system needs to provide sampling points for monitoring surface-water and ground-water quality and for determining the rate of ground-water drawdown and recovery in and adjacent to the mined area. The number of sampling points required to adequately monitor the effects of mining on an alluvial aquifer will depend on the distribution of hydraulic gradients and complexity of the hydrogeology. Wells for water sampling and measurement of water levels need to be installed both within, and adjacent to, the mine site.

Records of premining ground-water and surface-water quality are necessary as background data in a monitoring program (fig. 5.0-1). Historical data are needed to determine if changes take place during mining. The monitoring system is designed to account for contamination by sources outside of the site. If not accounted for, these contaminants might inadvertently be attributed to the mining.

Geologic and hydrologic data gathered as a part of the permitting process will provide a basis for the design of a monitoring program. Monitor wells can be located between the pit and river and between the abandoned mine and the pit to monitor changes in water levels as mining progresses (fig. 5.0-2). The quality of the water collecting in the pit during mining will be monitored prior to discharge to the river.

Once mining has been completed, ground-water levels will recover to near the premining level. Water levels need to be measured periodically to determine rate of recovery and direction of flow in the spoils. After mining, water that infiltrates the surface and enters the ground water may leach minerals from the spoils. Monitoring the ground-water quality on the river side of the mined area will be necessary to determine whether or not the quality has been altered (fig. 5.0-3).

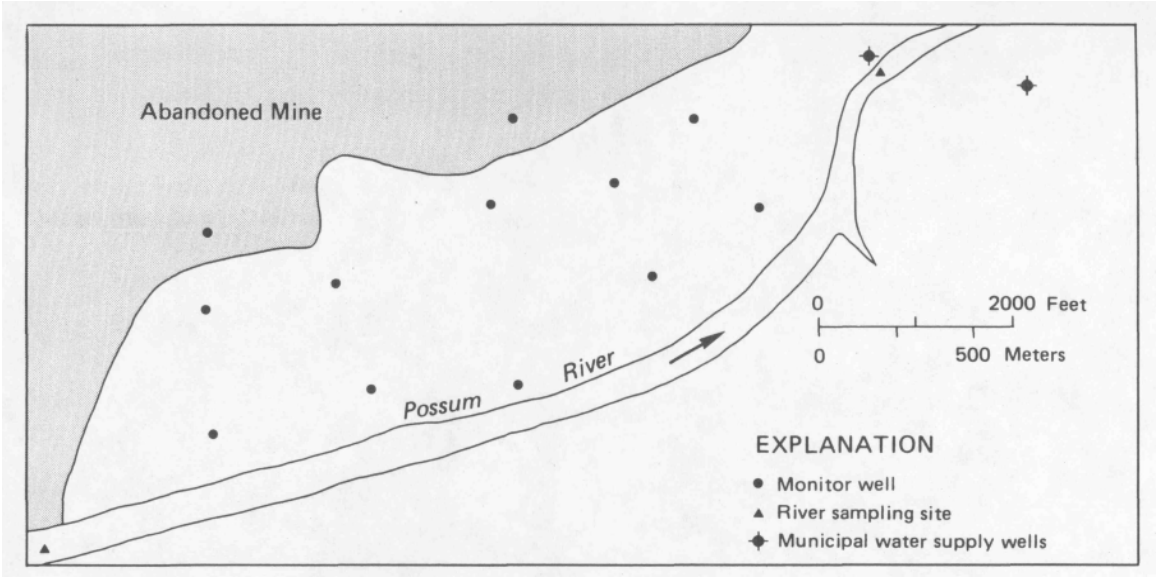

Figure 5.0-1— Distribution of pre-mining monitoring wells and river-quality sampling sites.

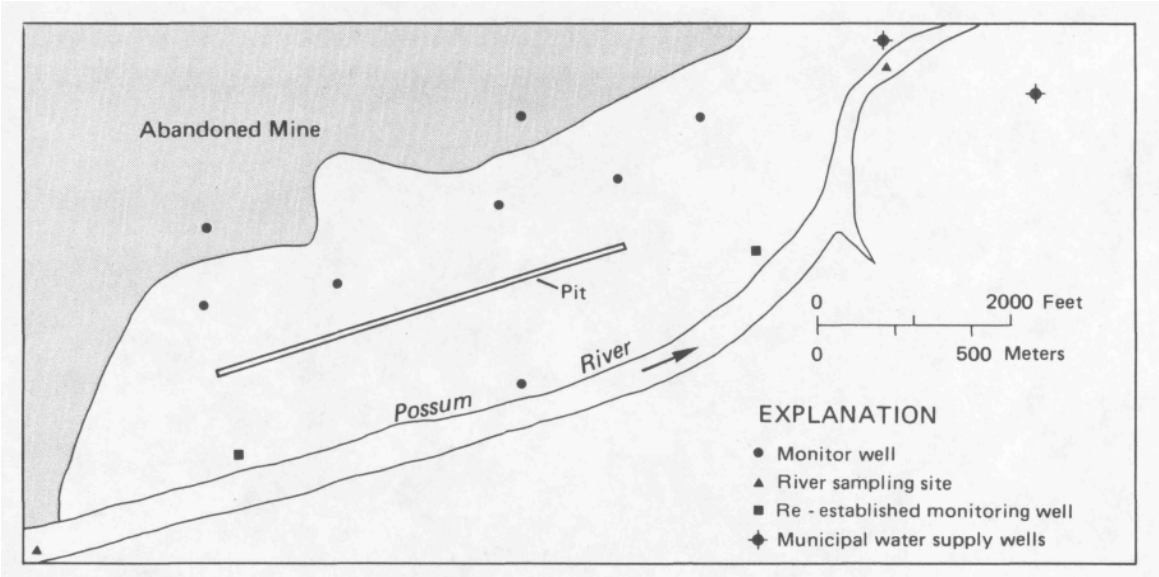

Figure 5.0-2.— Distribution of monitoring wells and river quality sampling sites during mining.

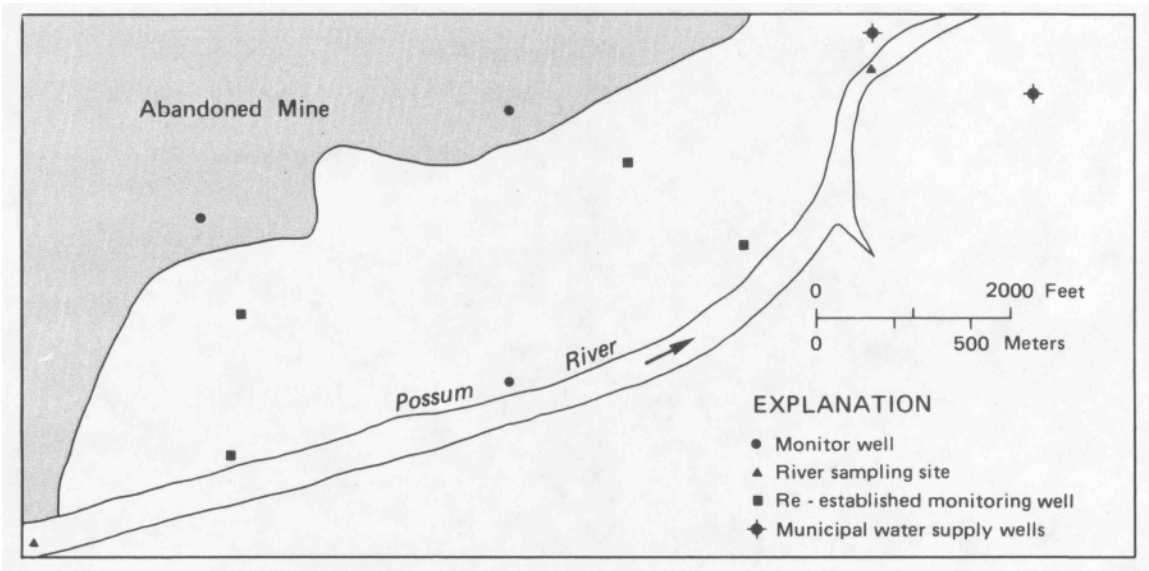

Figure 5.0-3.— Distribution of post-mining monitoring wells and river-quality sampling sites.

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