Attachment 3

W.H. FORD

International Ground Water Modeling Center

Short Courses in Ground Water Modeling

Analytical Ground Water Modeling
August 16-20, 1982

Instructors:
William C. Walton and Phillip R. Davis
Geraghty and Miller, Inc.

HANDBOOK OF ANALYTICAL GROUNDWATER MODELS

by

William C. Walton
Senior Consultant
Geraghty & Miller

Butler University
Holcomb Research Institute
Indianapolis, Indiana 46208

Mine Drainage

Figure 3.17 shows a linear surface mine box cut or deep mine drift fully penetrating a uniformly porous model aquifer overlain and underlain by aquicludes. The nonleaky artesian aquifer is homogeneous, isotropic, infinite in areal extent, and constant in thickness throughout. As the box cut or drift is excavated in the aquifer, a portion becomes unconfined and the distance to which the unconfined portion extends into the aquifer becomes larger with time.

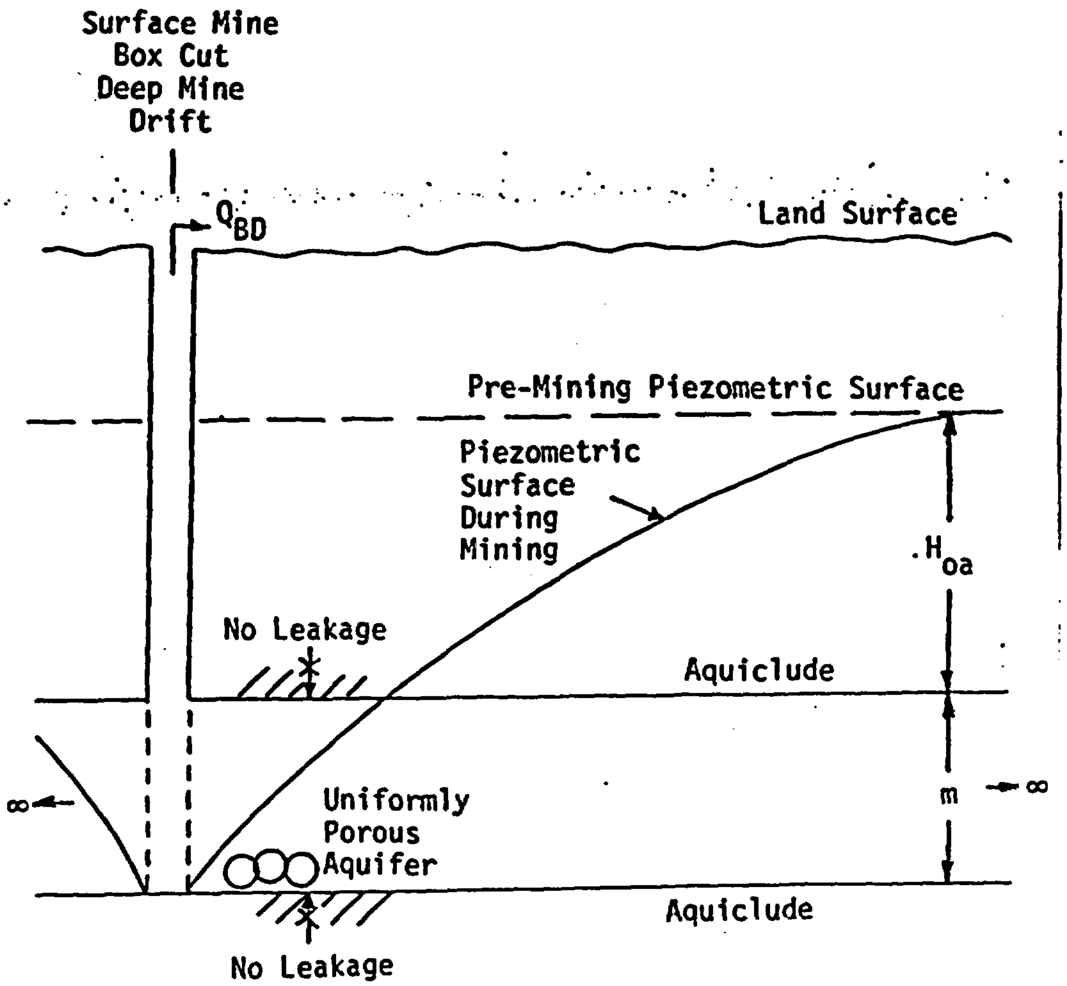

Figure 3.17. Uniformly porous nonleaky artesian aquifer with constant thickness and fully penetrating surface mine box cut or deep mine drift.

With the box cut or drift having an infinitesimal width and therefore no storage capacity and the length of the box cut or drift increasing linearly with time, the equations governing the discharge to the box cut or drift are (McWhorter, 1981)

when $t \le \frac{L_{BD}}{E_{BD}}$

$$Q_{BD} = 4E_{BD}\left[\frac{S_y T m^2}{12} + \frac{STH_{oa}{}^2}{4}\right]^{\frac{1}{2}} t^{\frac{1}{2}} \tag{3.44}$$

when $t \ge \frac{L_{BD}}{E_{BD}}$

$$Q_{BD} = 4E_{BD}\left[\frac{S_y T m^2}{12} + \frac{STH_{oa}{}^2}{4}\right]^{\frac{1}{2}} \left[t^{\frac{1}{2}} - \left(t - \frac{L_{BD}}{E_{BD}}\right)^{\frac{1}{2}}\right] \tag{3.45}$$

where

Q_{BD} = discharge to both sides of box cut or drift (L^3T^{-1})

E_{BD} = box cut or drift excavation rate (LT^{-1})

S_y = aquifer specific yield (dimensionless)

S = aquifer storage coefficient (dimensionless)

T = aquifer transmissivity (L^2T^{-1})

m = aquifer thickness (L)

H_{oa} = pre-mining piezometric height above top of aquifer (L)

t = time after box cut or drift excavation started (T)

L_{BD} = maximum length of box cut or drift (L)

Equations 3.44 and 3.45 apply to a water table aquifer if H_{oa} is set equal to zero.

A typical box cut or drift time-discharge graph is shown in Figure 3.18.

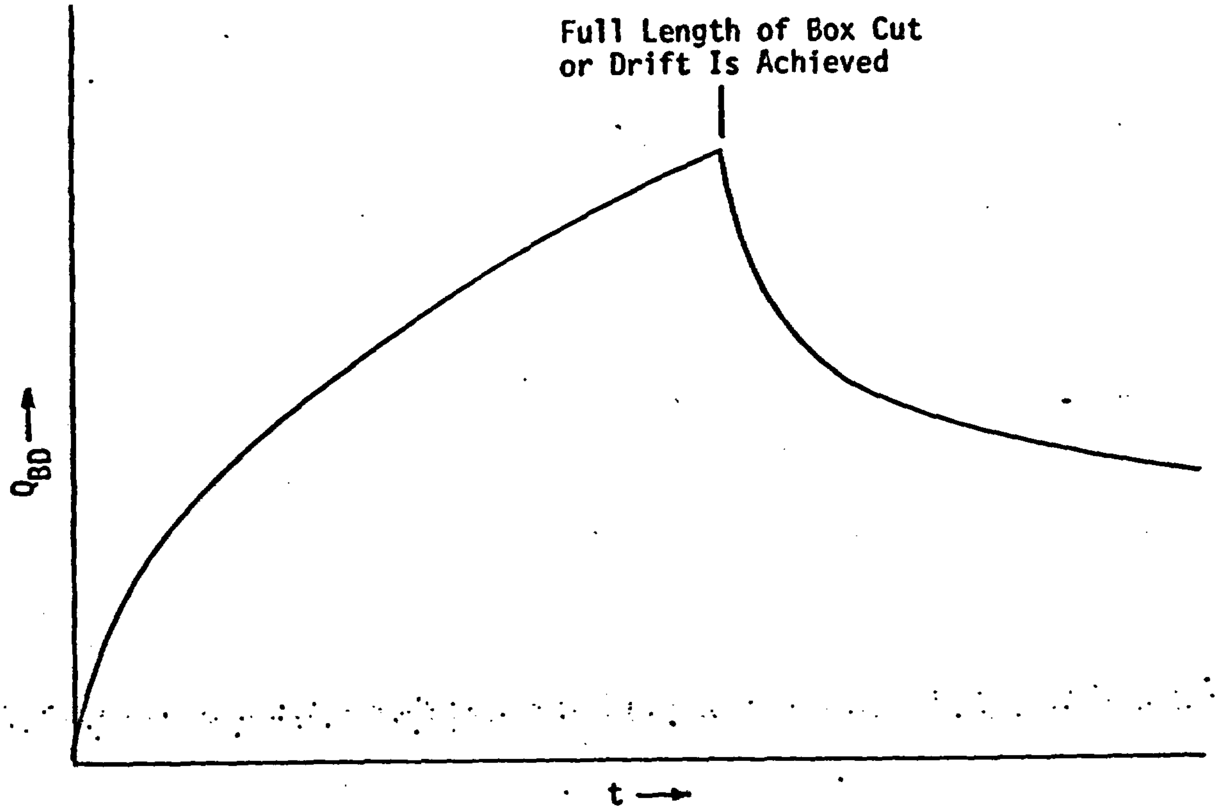

Figure 3.18. Typical time-discharge graph associated with surface mine box cut or deep mine drift excavation.

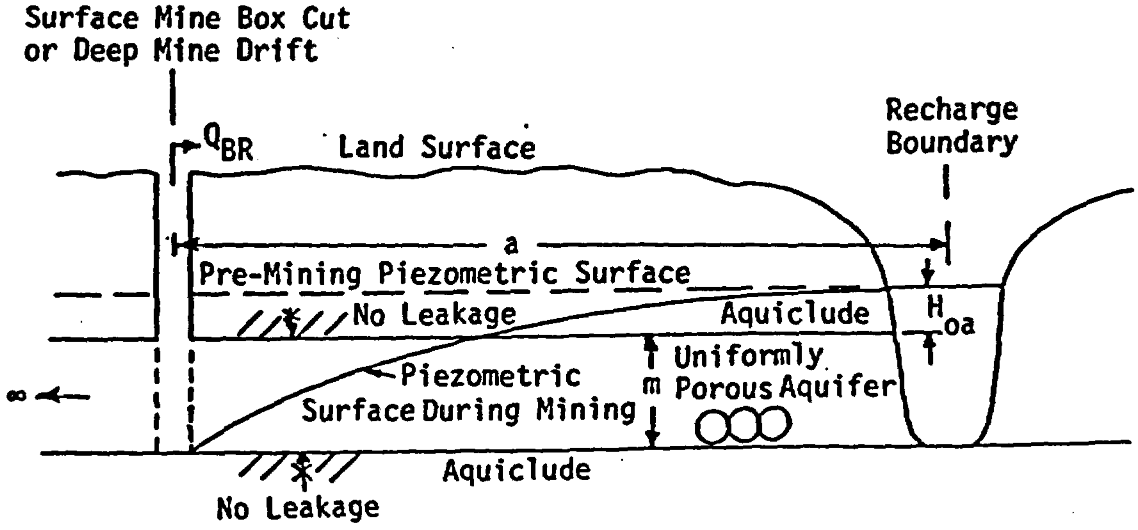

Figure 3.19. Uniformly porous nonleaky artesian aquifer with constant thickness and fully penetrating surface mine box cut or deep mine drift and nearby recharge boundary.

Suppose there is a source of recharge (recharge boundary) near the box cut or drift as shown in Figure 3.19.

The equations governing discharge to the recharge boundary side of the box cut or drift are (McWhorter, 1981)

when $t \leq \frac{L_{BD}}{E_{BD}}$

$$Q_{BR} = \frac{E_{BD} Tm}{2} \left[\frac{2H_{oa}+m}{am}\right] t \tag{3.46}$$

when $t \geq \frac{L_{BD}}{E_{BD}}$

$$Q_{BR} = \frac{Tm}{2} \left[\frac{2H_{oa}+m}{am}\right] L_{BD} \tag{3.47}$$

where

Q_{BR} = discharge to recharge boundary side of box cut or drift (L^3T^{-1})

a = distance from box cut or drift to recharge boundary (L)

Suppose there is a source of groundwater storage (alluvial valley receiving no recharge) near the box cut or drift as shown in Figure 3.20.

The equations governing discharge to the source of groundwater storage side of the box cut or drift are (McWhorter, 1981)

when $t \leq \frac{L_{BD}}{E_{BD}}$

$$Q_{BS} = E_{BD} \left(\frac{m}{2} + H_{oa}\right) b_{BD} S_y \left[1 - \exp\left(\frac{-Tt}{a_{BD} b_{BD} S_y}\right)\right] \tag{3.48}$$

when $t \geq \frac{L_{BD}}{E_{BD}}$

$$Q_{BS} = E_{BD} \left(\frac{m}{2} + H_{oa}\right) b_{BD} S_y \left\{\exp\left[-\frac{T(t - L_{BD}/E_{BD})}{a_{BD} b_{BD} S_y}\right] - \exp\left(\frac{-Tt}{a_{BD} b_{BD} S_y}\right)\right\} \tag{3.49}$$

where

Q_{BS} = discharge to source of groundwater storage side of box cut or drift (L^3T^{-1})

a_{BD} = distance from box cut or drift to source of groundwater storage (L)

b_{BD} = width of source of groundwater storage (L)

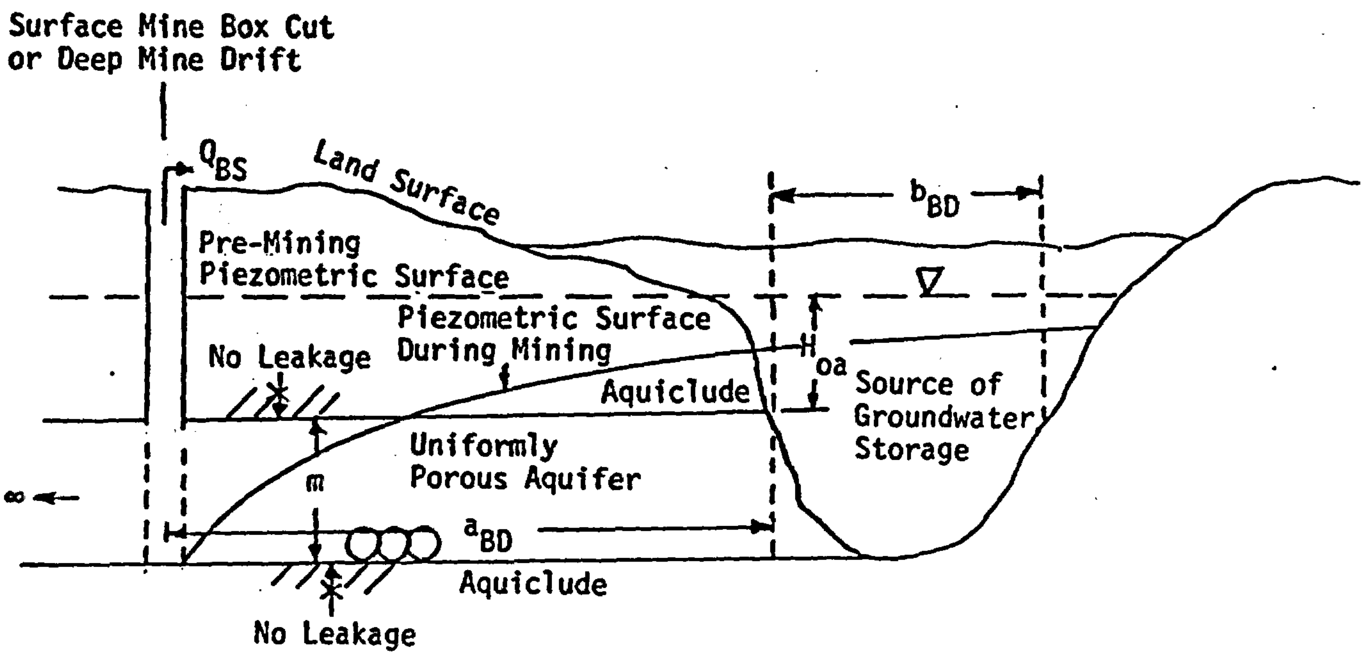

Figure 3.20. Uniformly porous nonleaky artesian aquifer with constant thickness and fully penetrating surface mine box cut or deep mine drift and nearby source of groundwater storage.

Figure 3.21 shows a linear surface mine box cut or deep mine shaft fully penetrating a uniformly porous nonleaky artesian model aquifer and a nearby observation well.

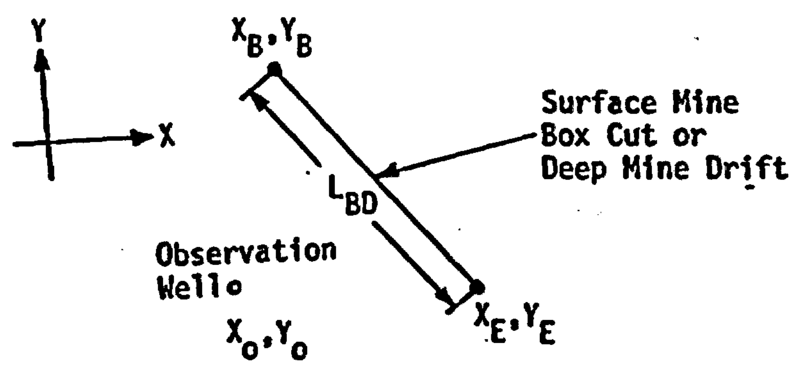

Figure 3.21. Uniformly porous nonleaky artesian aquifer with constant thickness and fully penetrating surface mine box cut or deep mine drift and a nearby observation well.

With constant discharge from the box cut or drift, the distribution of drawdown within the aquifer is given by the following equation (Prickett and Voorhees, 1981)

when observation well is $>L_{BD}/4$ away from box cut

$$s = \frac{Q_{BD}}{4\pi T(X_E - X_B)} \left\{ C \ [\alpha G(CZ+d) + \alpha G(-CZ+d) + vG(D)] \right\} \tag{3.50}$$

where

$$G(CZ+d) = W \left[\frac{S \left\{ [CZ+d - X_o]^2 + \left[\left(\frac{Y_E - Y_B}{X_E - X_B} \right) (CZ+d) + b \right]^2 \right\}}{4Tt} \right] \tag{3.51}$$

$$G(-CZ+d) = W \left[\frac{S \left\{ [-CZ+d - X_o]^2 + \left[\left(\frac{Y_E - Y_B}{X_E - X_B} \right) (-CZ+d) + b \right]^2 \right\}}{4Tt} \right] \tag{3.52}$$

$$G(d) = W \left[\frac{S \left\{ [d - X_o]^2 + \left[\left(\frac{Y_E - Y_B}{X_E - Y_B} \right) (d) + b \right]^2 \right\}}{4Tt} \right] \tag{3.53}$$

and

$$C = (X_E - X_B)/2$$

$$d = (X_E + X_B)/2$$

$$b = Y_B - Y_o - \left[\frac{Y_E - Y_B}{X_E - X_B} \quad (X_B) \right]$$

$$\alpha = 5/9$$

$$v = 8/9$$

$$Z = .7745966692$$

when $[\quad] < 0.3$

$$W[\quad] = -0.5772 - \ln [\quad] + [\quad]$$

when $[\quad] \geq 0.3$

$$W[\quad] = \left\{([\quad]^2 + .2037[\quad])/([\quad]^2 + 1.0572[\quad])\right\} /([\quad]/\exp[\quad])$$

X_B = beginning X-coordinate of box cut or drift (L)

X_E = ending X-coordinate of box cut or drift (L)

Y_B = beginning Y-coordinate of box cut or drift (L)

Y_E = ending Y-coordinate of box cut or drift (L)

L_{BD} = length of box cut or drift (L)

Discharge from a surface mine box cut, deep mine drift, or room and pillar deep mine can be estimated with equivalent well-array and successive approximation techniques. Appropriate well model aquifer equations, including those simulating nonleaky artesian, leaky artesian, water table, and partial penetration conditions, are utilized. Rectangular arrays of wells which produce required drawdowns within specified mine areas give satisfactory approximations when the wells are closely spaced. Groups of wells may be replaced with hypothetical single wells

Kanwar, R. S., and H. S. Chauhan. 1978. Non-steady spherical flow to cavity well in an infinite non-leaky aquifer. American Water Resources ASsociation WAter Resources Bulletin, Volume 14, Number 3.

Kanwar, R. S., H. P. Johnson, H. S. Chauhan. 1979. Nonsteady flow to nonpenetrating well. ASCE Journal Irrigation and Drainage Division, Volume 105, Number IR1.

Kozeny, J. 1933. Theorie und Berechnung der Brunnen, Wasserkraft and Wasserwirtschaft, Nos. 8-10.

McWhorter, D. B. 1981. Procedures for predictive analysis of selected hydrologic impacts of surface mining. Industrial Environmental Research Laboratory, Office of Research and Development, U.S.E.P.A., Cincinnati,

Mortada, M. 1955. A practical method for treating interference in water drive reservoirs. Transactions AIME, 204.

Mueller, T. D. 1962. Transient response of non-homogeneous aquifers. Society of Petroleum Engineering Journal, 33.

Mueller, T. D., and P. A. Witherspoon. 1965. Pressure interference effects within reservoirs and aquifers. Journal Petroleum Technology, Transactions AIME, 234.

Papadopulos, I. S. 1967. Drawdown distribution around a large-diameter well. Proceedings of Ground Water Hydrology Symposium, American Water Resources Association.

Papadopulos, I. S. 1966. Nonsteady flow to multiaquifer wells. Jour. of Geophys. Res. Vol. 71, No. 20.

Prickett, T. A., and M. L. Voorhees. 1981. Selected hand-held calculator codes for the evaluation of cumulative strip-mining impacts on groundwater resources. Thomas A. Prickett & Associates, Inc., Urbana, Illinois.