Hydrogeological Issues Concerning the Thar Lignite Prospect

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Abstract

The paper is concerned with the hydrogeological appraisal of the proposed mining operations in the Thar lignite field in Sindh, Pakistan. The Thar coalfield covers an area of approximately 9000km^2 and contains three lignite seams lying at depth of 130m to 250 m. In the Thar lignite field, the presence of three main aquifers induces pore pressure in the rock mass surrounding the lignite seams and makes high wall slopes potentially unsafe. It is, therefore, necessary to dewater the rock mass before commencing mining excavations. The paper describes the proposed mine dewatering scheme to facilitate depressurising of the rock mass surrounding the mining excavations. Inflow prediction of groundwater to the surface mining excavation was carried out using a SEEP/W finite element software package. The simulation results show that the ground water inflow from the Top aquifer is 114m^3/d, from the Intermediate confined aquifer is 141m^3/d and from the Bottom confined aquifer is 1.28 x 10^5 m^3/d. These results were compared with the analytical solutions which indicated that the relative error of estimation of inflow quantities varies from 3.4 % to 6.4%.

Keywords: Open cut mining, hydrogeology, aquifers, Thar lignite mine, advanced dewatering, pumping out tests, mine water inflow

1-Introduction

Water inflow to the mine workings carrying out below the groundwater table creates a number of water related problems affecting the design and economic viability of the mining operations. This inflow requires installation of an effective drainage scheme to keep the mine workings dry and create a broad and prolonged cone of depression [1]. To design a dewatering facility, hydrogeological investigation around the mine is a major task.

The Thar lignite/coal field situated in the Eastern part of Sindh province in Pakistan is considered to be the seventh largest lignite deposit in the World containing some 193 billion tonnes (Bt) of lignite resources. This paper is concerned with the hydrogeological appraisal of the proposed mining operations in this lignite field. A finite element (FE) SEEP/W [2] computer software has been used to calculate dewatering quantities from three aquifers associated with the lignite seams under consideration; one unconfined aquifer and two confined aquifers; one under artesian conditions. This will facilitate the dewatering of rock mass surrounding the open cut mining excavation, thus ensuring excavation stability and the economic viability of the mining operations. A paper containing the results of a slope stability analysis of high walls using the software "SLIDE" version 5 is being published elsewhere.

2-Thar lignite/coalfield

The Thar lignite/brown coalfield is located in the South Eastern part of Sindh province at a distance of some 400 kms from the city of Karachi (Figure 1 a). The lignite field was first discovered in 1994, and since then feasibility studies have been separately carried out in blocks I and II by RWE Power International, Germany [3] and a Shenhua group from China. Figure 1 shows the location of Thar coalfield

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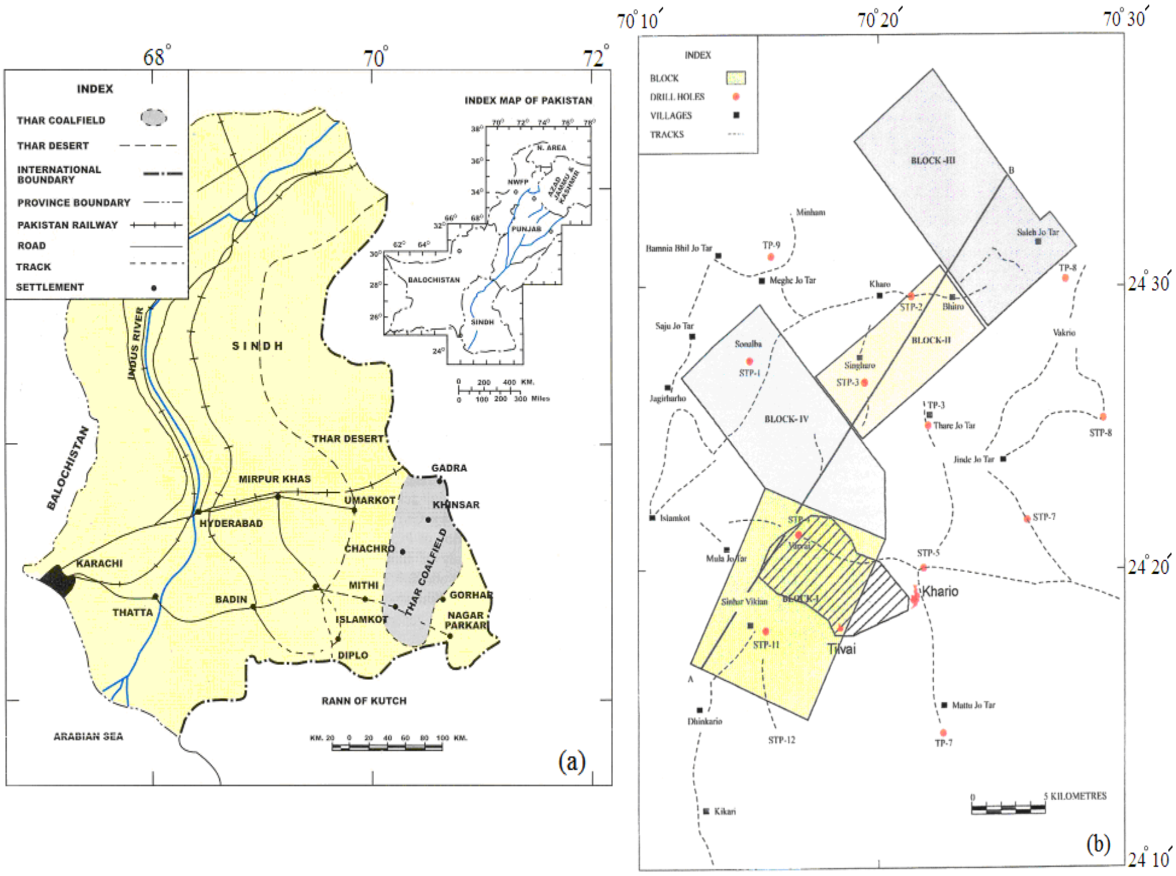


Figure 1. Location of Thar lignite/brown Coal field and its division into four mining blocks. (a) Location of Thar lignite/ brown coal deposit, (b) Mining blocks in Thar Coalfield [3, 4].

together with its division into eight mining blocks (Figure 1. b)

2-1-Stratigraphic section and lithology of Thar coalfield

A stratigraphic section and lithology of the Thar coalfield are shown in Figure 2 that indicates that lignite seams there occur in the Bara formation belonging to the Palaeocene/Eocene age [5]. The Bara formation consists of 90m of thick sandy/silty claystone and sandstone strata with depths varying from 125m to 200m. The carbonaceous clay-stone in the Bara formation contains carbonaceous petrified roots and rare sandy resin globules. There are number of brown coal/lignite seams of varying thickness, ranging from 1.452 to 28.6 metres, at an average depth of 170m. The rank of coal ranges from lignite-B to sub-bituminous-A containing 47% moisture, 17% fixed carbon, 23% volatile matter, 6% ash, 1% sulphur and a calorific value of 10,900 Btu/lbs [6]. Underlying the Bara formation is basement rock that is light to grey medium compacted granite comprising fine to coarse quartz grains. Above the Bara formation is the sub-recent formation comprising inter-bedded carbonaceous sandstone, siltstone and clay-stone up to 65m thick lying at a depth of 52-125m. Overlying the sub-recent formation is 50m of thick dune sand which is a recent formation comprising fine to medium grained sand, yellow greyish in colour containing Ferro-magnesium minerals [5]. Eight major mining blocks in the Thar coalfield contain 6.03.00 Bt of measured reserves, 10.9 Bt indicated reserves, 2.414. Bt of inferred reserves and 180Bt of hypothetical reserves [7].

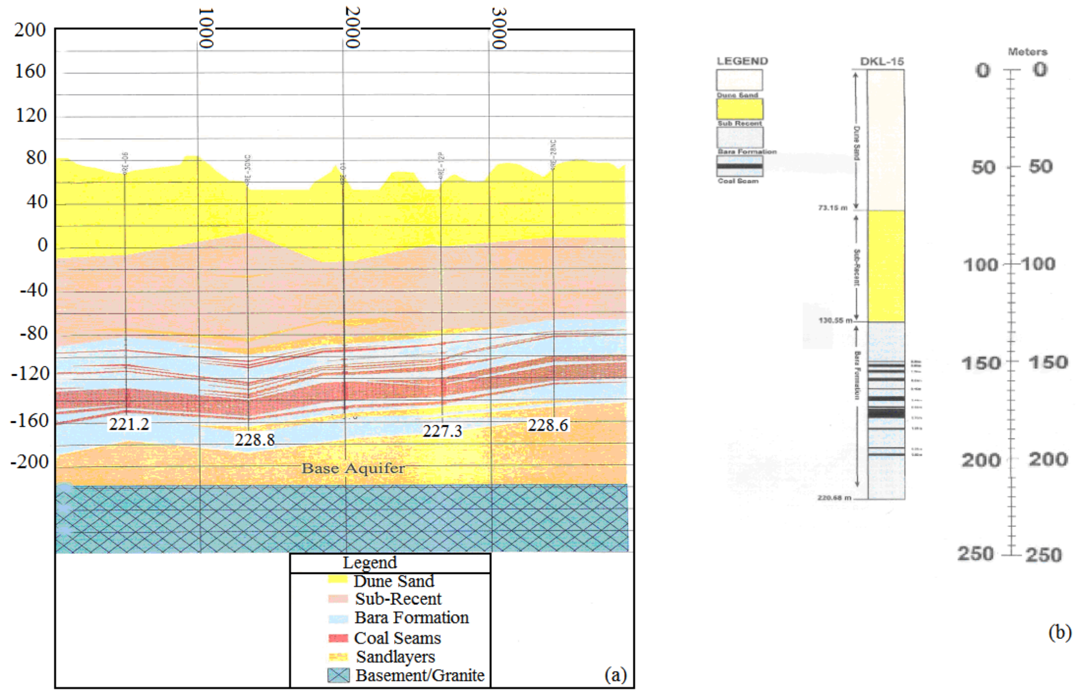


Figure 2. Ground water regimes in Thar lignite prospect [8, 9].

2-2-Hydrogeology

There are three major aquifers in the Thar coalfield designated as *Top* aquifer, Intermediate aquifer and *Bottom* aquifer. The *Top* aquifer (TA) is located at the base of the dune sand and extends all over the Thar Desert. In the mining prospect, the Top aquifer has a water column up to 5m and the water table is 10 to 12m above the mean sea level. The permeability coefficient of the top aquifer is $3x10^{-7}$ m/s. The *Intermediate* aquifer (IA) comprises scattered lenses in sub-recent and Bara Formations with the permeability coefficient varying from 10^{-5} to 10^{-7} m/s with water table 10-20m above mean sea level.

The Bottom aquifer (BA), which is the most dominant aquifer in the Thar coal field in terms of thickness, lateral extension and permeability, is located at the base of the lignite seams and reaches down to the granite basement. The Bottom aquifer, in the vicinity of bore hole RE-25, is 50-60m thick and increases in thickness westwards. This aquifer is an artesian aquifer with the piezometric head 25m above mean sea level. This aquifer is of significance before opening the mine because it is necessary to depressurize the aquifer before the open pit excavation reaches a mining depth of 100m to avert the danger of floor rupture and collapse of high wall slope.

2-3-Pumping tests and evaluation of aquifer parameters

Pumping out tests were conducted in boreholes RE-51 and RE-52 in the *Bottom* aquifer at a constant pumping rate over a period of 24 hours. Bore holes were equipped with ‘Grungfos SP 30’ submersible pumps 150mm in diameter with a maximum pumping capacity of 14 litres/m and delivery head of 40m. Drawdown of the aquifer as a consequence of pumping out was monitored on the observation piezometers RE12P and RE-22. The results of pumping out tests on RE-51 well and RE-52 well are presented in Figure3.

2-3-1-Pumping out test in Bore hole RE-51

Figure 3 (a) presents the pumping out test results on bore hole RE-51 with the observation of drawdown in the piezometer borehole RE12P installed at a radial distance of 25m. Transmissivity of the Bottom aquifer is calculated from the draw down curve in Figure 3(a) using the Cooper-Jacob equation as follows [10, 11]:

$$T = \frac{2.3 x Q}{4 \pi \Delta S} \quad (1)$$

where,
Q= Pump discharge rate = 13 litres/s ($0.013 m^3/s$)
ΔS= Drawdown per logarithmic scale as shown in Figure 3(a) = 1.35 m
Thus, the average transmissivity of the aquifer is calculated as follows:

$$T = \frac{2.3 x 0.013}{4 x 3.14 x 1.35} = 1.76 \text{ x } 10^{-3} \text{ m}^2/\text{s}$$

The average permeability of the aquifer can be expressed as:

$$K = T/m \quad (2)$$

where,
m= permeable thickness of the aquifer (m=30m)
S= average storage coefficient
T= transmissivity in m^2/s
K_{RE-51}= permeability coefficient = 1.76 x $10^{-3}/30$ = 5.88 x 10^{-5} m/s
t_0= intersection of draw down line with time axis in Figure 3(a)
r= radial distance from the test well in m= 25m
S= 2.25 T x t_0/r^2= [2.25 x 2.3 x 10^{-3} x 43]/25^2 = 3.56 x 10^{-4}

2-3-2-Finite Element model of Pumping out test on well RE-51

The finite element model using SEEP/W package [2] was used to simulate the pumping out test conducted on pumping well RE-51 and the observation well RE-12 [12]. Detailed theoretical aspects of SEEPW/ software are described elsewhere [1, 13, 14, 15, 16]. Figure 4(a) shows a finite element grid incorporating 253 nodes and 50 elements in a single 30m thick layer of the bottom aquifer with a model length of 2000 m. The rectangular mesh consisted of eight-nodded elements with an infinite element at the right-hand outer boundary of the aquifer. An axi-symmetrical analysis was carried out by simulating a radial flow to the well assigning 24 time steps to simulate transient flow conditions. The following boundary conditions were assigned to the model: (i) No flow boundaries at the upper and lower layers of the aquifer. (ii) A head boundary on the right hand side of the model. (iii) A flux boundary at the left hand side of the model next to the dewatering well. The input parameter to the computer models were (i) Hydraulic conductivity-7.3 x 10^{-5} m/s, (ii) Storage coefficient 2.9 x 10^{-4}, (iii) the initial hydraulic head of 160m, (iv) Thickness of confined aquifer 30m,(v) pumping out rate 0.014 m^3/s and (vi) the well radius 0.075 m.

Figure 4 (b) shows the hydraulic heads at the observation piezometers as a function of distance (from 0 to 2000 m) from the axis of the pumping out well RE-51 during the well dewatering operation. Time steps simulated were t=0, t=60s, 600s, 1200s, 3000s, 6000s, 9500s, 19000s, 40000s, 60000s, 80000s and 100000s. Figure 4(c) shows the field draw downs observed data at piezometer RE-12P at a distance of 25m from the RE-51 well. The simulation results by numerical modelling indicate a close agreement in the results of the two methods.

Figure 4(d) compares the residual draw downs predicted by the numerical model with those with those observed at piezometer RE-12P showing a close agreement. The input parameters in this simulation were a permeability of 7.3 x10^{-5}m/s, a storage coefficient 2.0 x 10 $^{-4}$ with no flow boundary conditions for the upper and lower surfaces of the aquifer and a head boundary condition at the right side of the model.

2-3-3-Pumping out test in bore hole RE-52

Figure 3 (b) shows the pumping out test results on bore hole RE-52 with the draw downs observed in the piezometer RE22 installed at a radial distance of 25m.

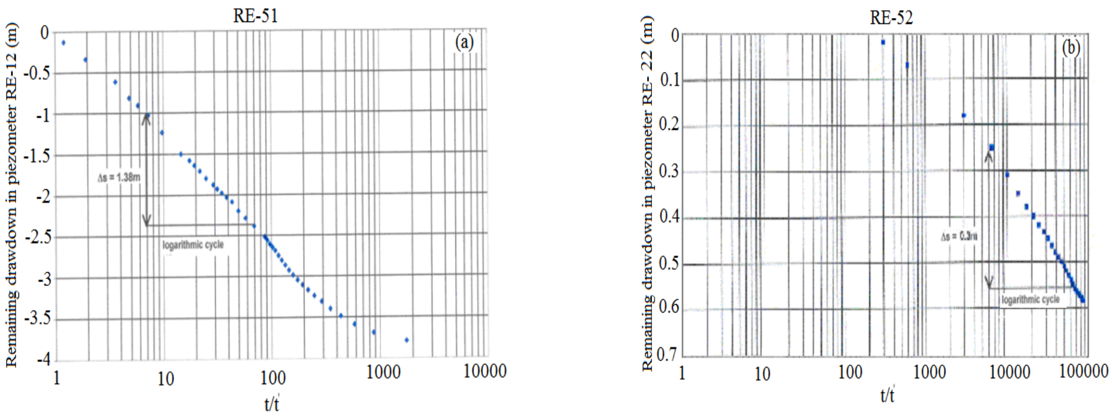


Figure 3. Results of pumping out tests in Thar lignite Prospect. (a) Pumping out Well RE-51W-recovery well RE-12P, (b) Well RE-52-recovery well RE-22 [3].

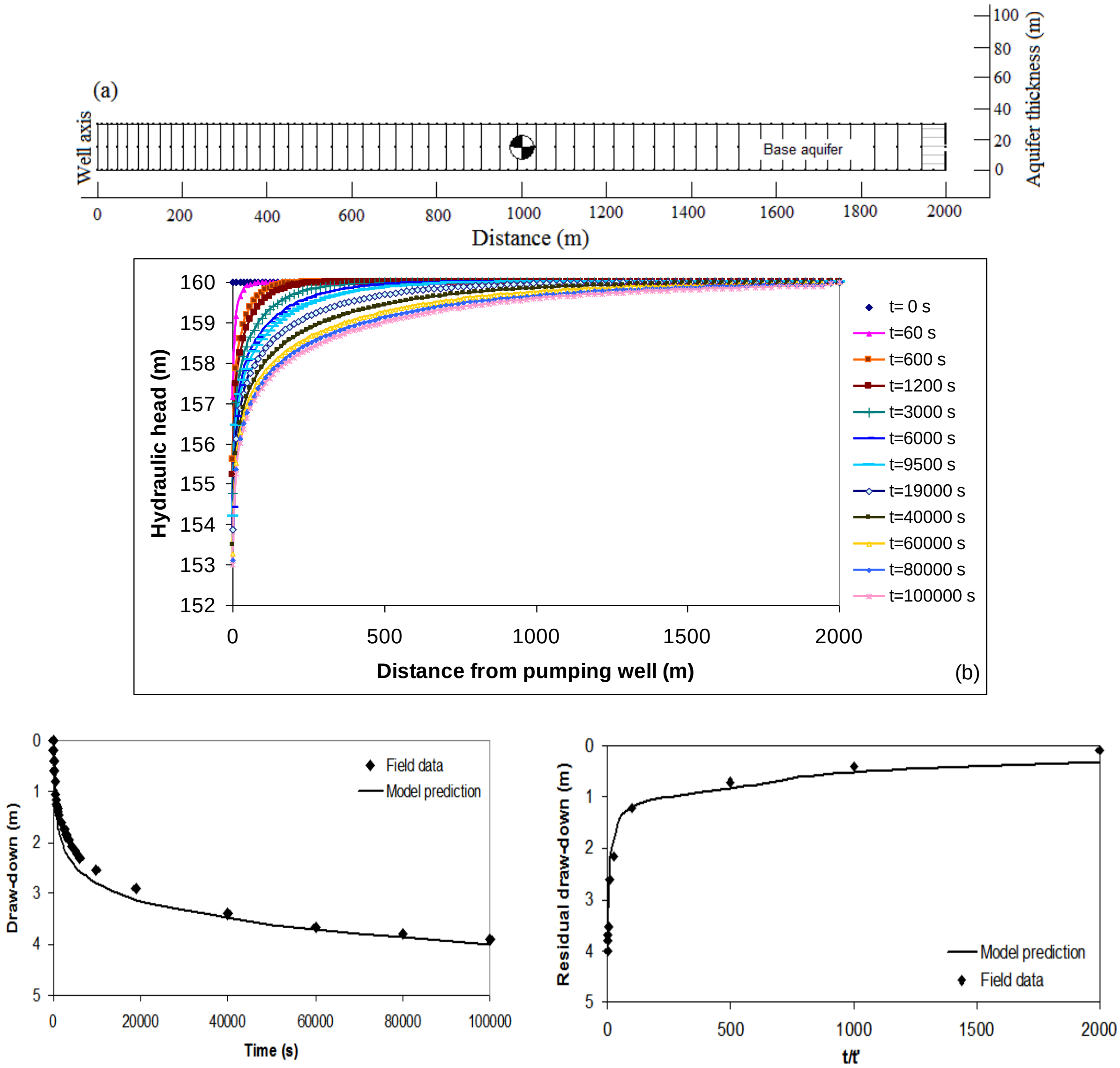


Figure 4. Comparison of field data with the computer model of pumping out test on well RE-51. (a) Finite element model of pumping well RE-51 in the Bottom aquifer, (b Hydraulic head vs time for pumping out well RE-51 and Piezometric well RE-12P, (c) Comparison of model results with field data in RE-51

pumping test, (d) Residual draw down as a function of time predicted at 25m radial distance from RE-51 well.

Transmissivity of the Bottom aquifer is calculated from the draw down curve in Figure 3(b) using the Cooper-Jacob equation as follows:

$$T = \frac{2.3 \times Q}{4\,\pi\,\Delta S} \quad = 2.3 \text{ x } 0.013 / 4 \text{ x } 3.14 \text{ x } 0.3$$

$$= 7.9 \text{ x } 10^{-3}\ m^2/s$$

where,

Q= pump discharge rate = 13 litres/s (0.013 m^3/s)

ΔS= drawdown per logarithmic scale in Figure 3(b) = 0.3 m

K= average permeability of the aquifer can be

expressed as K = T/m

$K_{RE\text{-}52}$= 7.9 x 10^{-3}/30 = 2.63 x 10^{-4} m/s

m= permeable thickness of the aquifer =30m

S= average storage coefficient

T= transmissivity in m^2/s

t_0= intersection of draw down line with time axis in Figure 3(a)

r= radial distance from the test well in m= 30m

$$S = \frac{2.25\,x\,T\,x\,t_0}{r^2} = = \frac{2.25\,x\,2.63x10^{-4}\,x\ 43.}{25^2} = 2.7 \text{ x } 10^{-3}$$

2-3-4-Finite Element Simulation of pumping out well RE-52

The second pumping out test was conducted in well RE-52. The finite Element model is shown in

Figure 5. The FE model consists of 258 nodes, 51 elements in single layer of 60m thickness and 2000m length as shown in Figure 5a. The rectangular mesh contained eight nodded elements with an infinite element at the outer boundary of the aquifer. It can be seen in Figure 5a that the grid spacing increases from the well to the outer boundary. The simulation of transient flow conditions was modelled in this analysis. The input parameters to the model were hydraulic conductivity= 1.8 x 10 $^{-4}$ m/s; storage coefficient= 3.5 x 10^{-3}; aquifer thickness= 60m; dewatering rate= 0.013m^3/s and time steps=7. Figure 5 (b) shows the hydraulic head at various distances of piezometers from the pumping out well RE-52 for elapsed times of t=0, 300s, 2000s, 10000s, 20000s, 60000s and 100000s. The draw down predicted by the finite element model compared to that measured during field investigations is shown in Figure 5(c), indicating a reasonable agreement.

2-4-The finite element simulation of a hypothetical pumping out test to examine the effect of major parameters on the drawdown curves

Figure 6 (a) shows the hypothetical pumping out well comprising 253 nodes and 50 elements in a 60m thick single layer with model length of 5000 m. The rectangular mesh had eight nodded elements with an infinite extent of the confined aquifer at the outer boundary. No flow boundary conditions were assigned to the upper and lower boundaries of the model with a piezometric head of 160m at the right side of the model and a flux boundary condition at the left side of the dewatering well. The input parameters to the finite element model of the confined aquifer were; hydraulic conductivity as 8.0 x 10^{-5}m/s, storage coefficient as 2.7 x 10^{-3}, initial hydraulic head of 160m, thickness of confined aquifer 60m, pumping out rate of 0.014 m^3/s and well radius of 0.075m. Figure 6 (b) shows the simulated hydraulic heads as a function of distances between the pumping out well and the observation well for ten time steps from t=1 hr, 5hrs, 10 hrs, 1 day, 1 month, 6 months, 1 yr, 2 yrs, 5yrs, and 10 yrs. In order to examine the sensitivity of the computer model to various parameters, the values of hydraulic conductivity, storage coefficients and pumping rates were changed. The conductivity of the aquifer ranged from 2 x 10^{-5} m/s to 1 x 10^{-6} m/s, the storage coefficient from 2.0 x 10^{-5} to 8.0 x 10^{-5} and the dewatering rate from 40 l/s to 200 l/s. Figure 6(c) shows the hydraulic head vs time { 0 to 3500 days} curve for the bottom confined aquifer for permeability values of K= 8 x 10^{-5}m/s , 6 x 10^{-5}m/s , 4 x 10^{-5}m/s , 3 x 10^{-5}m/s and 2 x 10^{-5}m/s. Figure 6(d) shows the hydraulic head Vs time from t=0 to 3500 day for storage coefficients varying between 3.5 x 10^{-4}, 8.5 x 10^{-4}, 1.5 x 10^{-3}, , 3.5 x 10-^{3} and 6.5 x 10^{-3}. Figure 6(e) shows hydraulic head vs time in the dewatering well for t= 0 to 3500 days for differing pumping rates from 40 l/s to 200l/s with 12 pumping rate steps increasing with steps of 20l/s.

Figure 6 (f) shows hydraulic head vs distance from the dewatering well to observation wells between 0 to 4500m in 14 time steps of t= 0 to 10 years.

The results indicate that the modelling results are highly sensitive to the hydraulic conductivity of the aquifer.

3-Mine dewatering arrangements for the Thar prospect

Mine dewatering arrangements comprise of the following main elements as shown in Figure 7.

i. Surface dewatering ditches to divert water from the surface hydrological cycle.

ii. First stage pumping out of wells to dewater unconfined aquifer

iii. Second stage pumping out of wells to depressurize intermediate aquifer

iv. Third stage pumping out of wells to depressurize the base aquifer.

3-1-Surface Dewatering Ditch

A review of the rainfall data from Mithi district indicates that a daily maximum precipitation of around 100mm /day is expected during the months of July and August [18]. This will lead to some flooding of the lowest mine bench without hampering the mining operations on the upper benches. It is expected that during unexpected rainfall the entire operation of the mine may close for a period of two days. The peak flow to the surface drainage system can be calculated, using the rational formula, as follows [19]:

Q = 2.78 K A I= 2.78 x 463.77 x 0.58 x 100 = 7.5 x 10^4 litres/s

where,

Q = peak flow in litres/s

A= catchment area in hectares= 463.77 hectares

K= run-off coefficient in decimal=0.58

I= rainfall intensity in mm/h=100mm/h

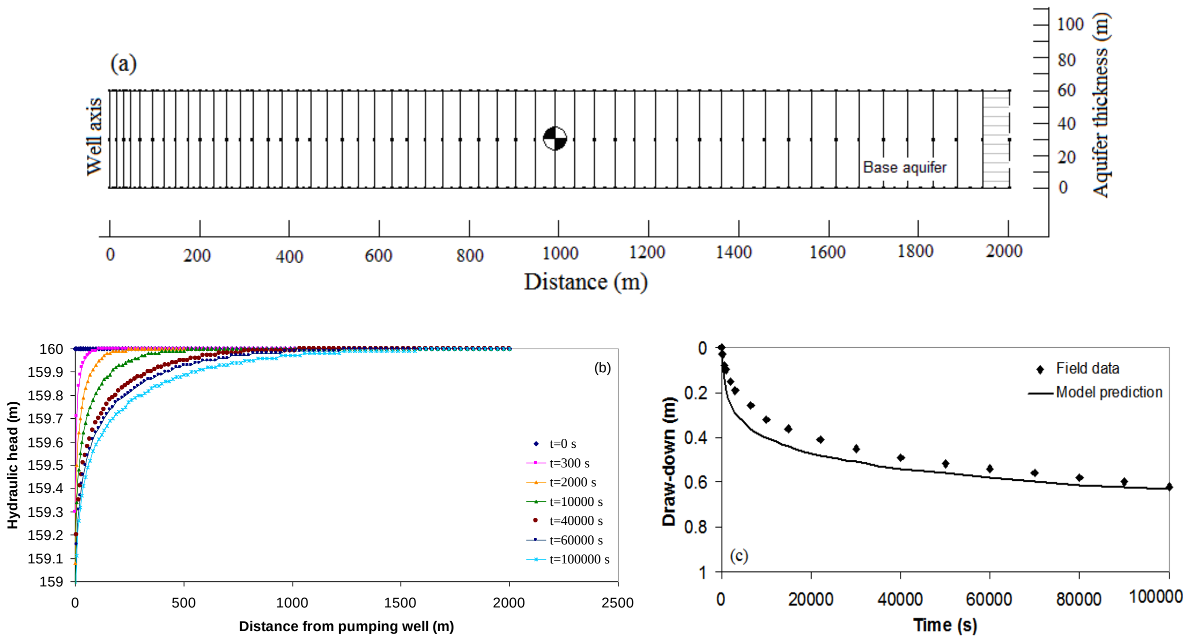
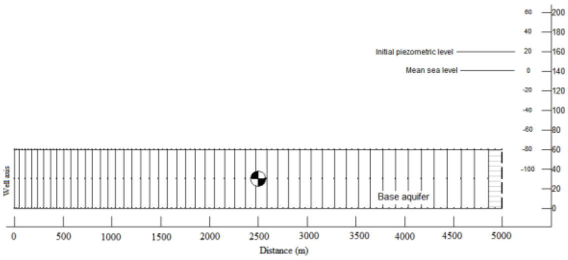
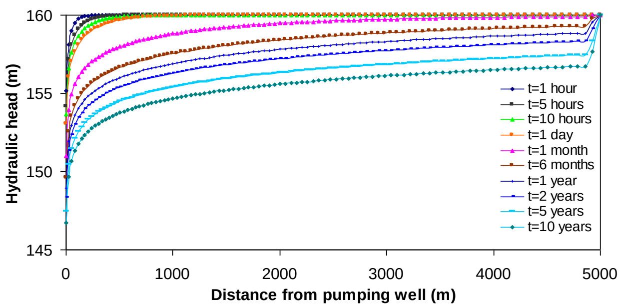


Figure 5. FE model of a pumping out well RE-52 with observation well RE-22 and the results of simulation. (a) Finite element model of well RE-52 Intersecting the Bottom aquifer, (b) Hydraulic head

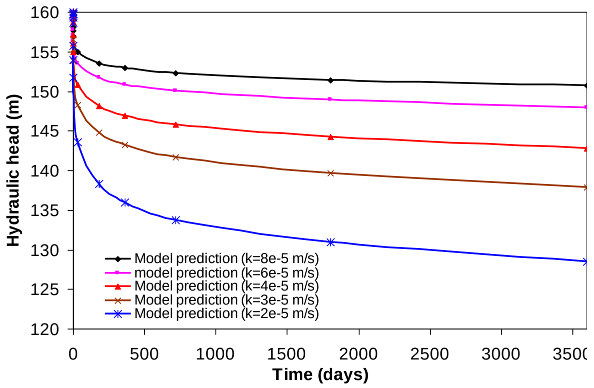
versus draw down of pumping well RE-52 at different radial distances, (c) Comparison of field and predicted results of FE model of RE-52 well.



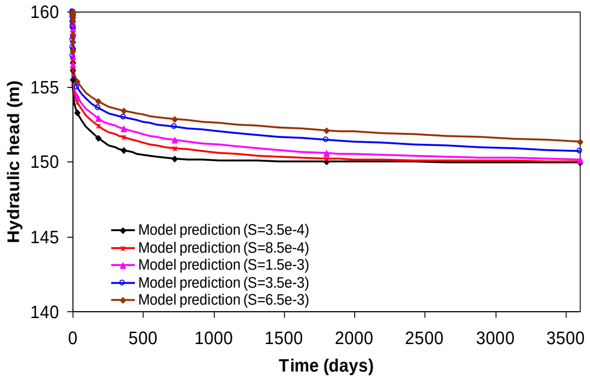
(a) Finite Element model of Thar Bottom aquifer



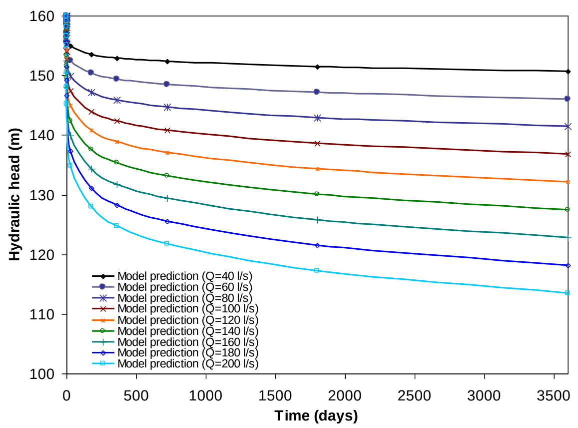
(b) Hydraulic head vs distance for pumping out test for various elapsed times on Bottom confined aquifer



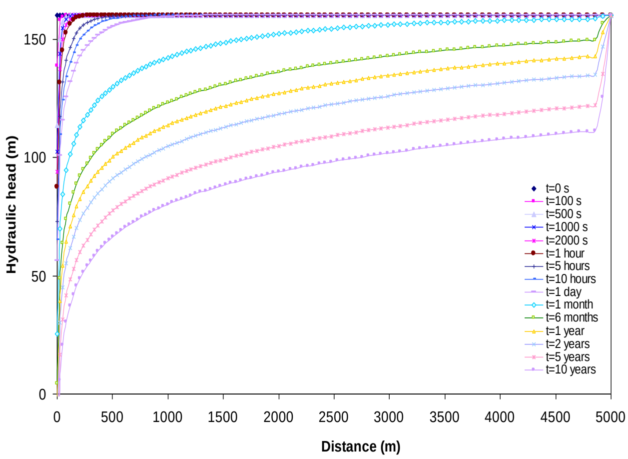
(c) Hydraulic head vs time for different permeabilities



(d) Hydraulic head vs time for different storage coefficient



(e) Hydraulic head vs time for different Pumping out rates



(f) Hydraulic head vs distance for various elapsed times

Figure 6. Finite element model of a pumping test on a hypothetical well in to the Bottom confined aquifer predicting Hydraulic head at 50 m from the dewatering well for various factors.

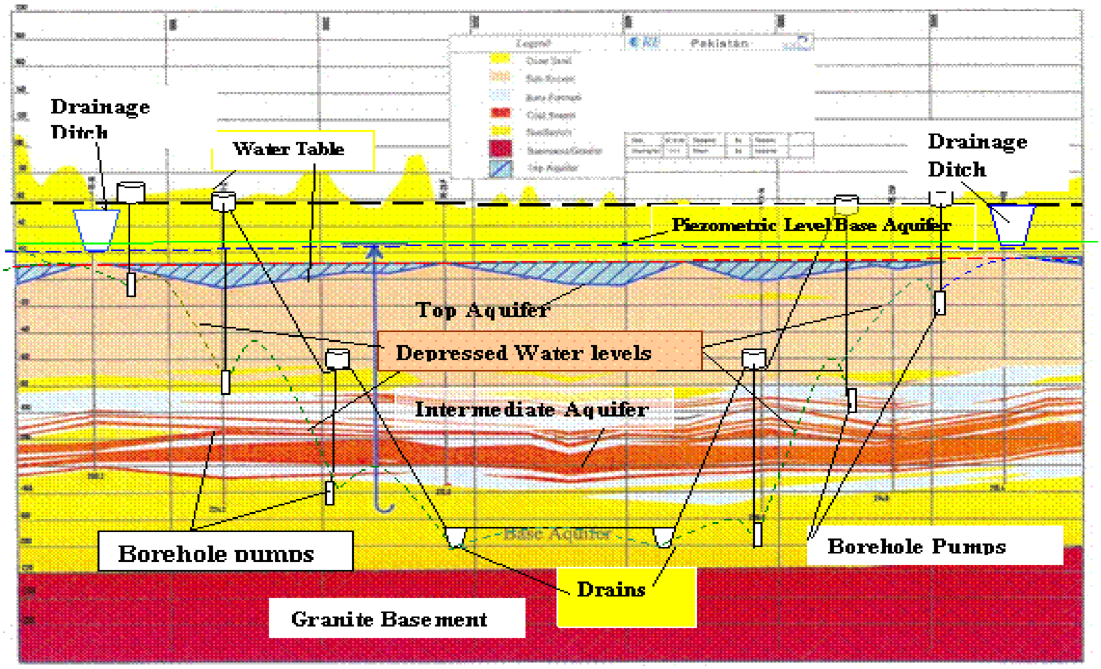


Figure 7. Dewatering arrangement of three aquifers in Thar lignite deposit [17].

Table 1. Dewatering predictions of Thar aquifers using equivalent well approach (based on Pathan et al [17]).

Aquifer Characteristics	Pumping calculations	Results
Top aquifer Aquifer thickness, L= 5m Drawdown, D = 20m Drawdown radius, r = 1100m Radius of influence, R = 1300m k= 3 x 10^{-7} m/s = 0.0259 m/d T = 0.0259 x 5 = 0.13 m^2/d h= 12m H=20	**Unconfined steady state linear aquifer** Modified Dupuit equation [21]: $Q_{TA} = \dfrac{\pi k\left(H^2 - h^2\right)}{\ln\left\{\dfrac{R}{r}\right\}}$ $= \dfrac{3.14\,x\,0.0259\,x\left(20^2 - 12^2\right)}{\ln\left\{\dfrac{1300}{1100}\right\}} = \dfrac{21}{0.18}$	=116 m^3/d
Intermediate aquifer Scattered lenses K= 10^{-6} m/s = 0.086 m/d Drawdown required D = 80+20 = 100m Thickness of aquifer, L= 10m Radius at drawdown, r = 1050m Radius of influence, R= 2500m	$Q_{IA} = \dfrac{2\pi k L D}{\ln\left\{\dfrac{R}{r}\right\} - \dfrac{n}{2}}$ Peterson Equation $= \dfrac{2\,x\,\pi\,x\,0.086\,x\,10\,x\,100}{\ln\left\{\dfrac{2500}{1050}\right\} - \dfrac{0.5}{2}}$	=147 m^3/d =0.1 m^3/min =17 l/min
Base Aquifers k_{RE-51}=5.88 x 10^{-5}m/s k_{RE-52}=2.63x10^{-4} m/s Drawdown =205+55=260m Aquifer thickness L=55m Radius of draw down r=750m Radius of influence R= 2050m (assumed) n=0.5	$Q = \dfrac{2\pi k L D}{l_n\left\{\dfrac{R}{r}\right\} - \dfrac{n}{2}}$ Peterson Equation (1954) $Q_{RE-51} = \dfrac{2x3.14x5.88x10^{-5}x55x260}{\ln\left\{\dfrac{2050}{750}\right\} - \dfrac{0.5}{2}}$ $= 0.699x10^6\ m^3/d$ $Q_{RE-52} = \dfrac{2x3.14x2.63x10^{-4}x55x260}{\ln\left\{\dfrac{2050}{750}\right\} - \dfrac{0.5}{2}}$ $= 8.64x10^6\,m^3/d$	=0.7 x 10^6 m^3/d =8.64x10^6 m^3/d

3-2-Prediction of aquifers pumping rates

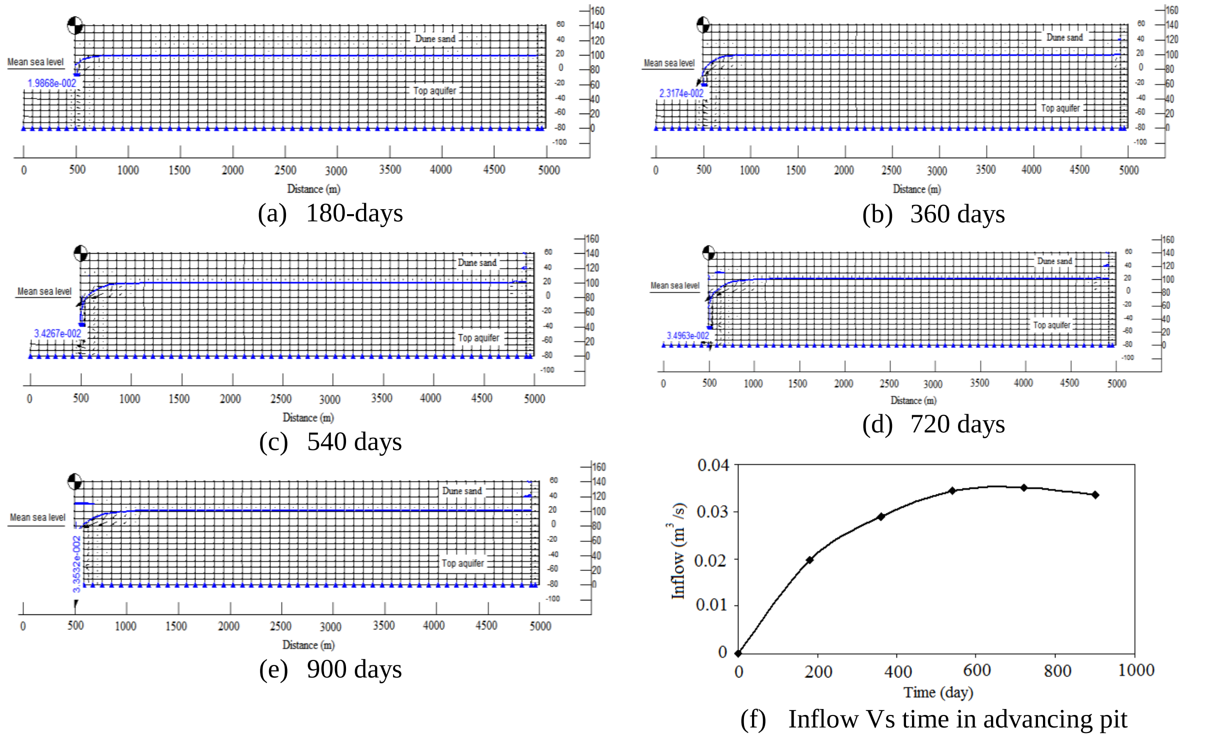
Pumping rates from the three aquifers at the Thar prospect have been calculated using the equivalent well approach by the Pathan et al [20] as summarized in Table 1. Table 1 indicates that the permeability coefficients of the base aquifer as calculated by pumping out tests on boreholes RE-51 and RE-52 differ considerably presenting a large difference in predicted inflow quantities at the different part of the pit.

4-Finite element simulation of water inflow from aquifers in Thar Coalfield during pit advancement

4-1-Inflow simulation from Top aquifer

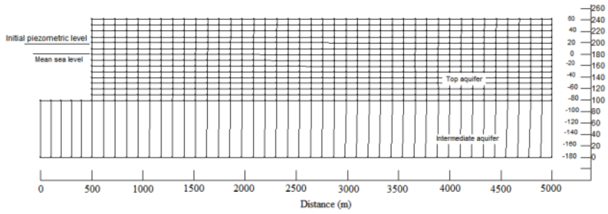
Figure 8 shows the finite element model for predicting inflow to the partially penetrating pit into the Top unconfined aquifer, using SEEP/W software, for the various stages of pit advancement from 180 days – 900 days of progress in 5 time-steps. The FE model comprises a grid with 1033 nodes, 896 elements and 16 bedding planes making a 140m thick and 5000m long aquifer layer [12]. Input parameters to the model were hydraulic conductivity 3 x 10^{-7} m/s, saturated porosity 0.45 with an initial water level of 90m. The base of the Top aquifer was presumed to be impermeable, imposing a no-flow boundary condition at the bottom of the model. An infinite boundary condition was assigned to the outer boundary of the model to simulate indeterminate extension of the aquifer from the mining excavation. The pit advance was simulated by assigning a constant head at the radius of the pit corresponding to specified pit depths at various stages of mining operations. The hypothetical mining operation was idealized as a cylindrical pit with a radius of 500m, advancing 32m per year for a maximum duration of 2.5 years.

Figure 8 (f) shows the model prediction of ground water inflow vs time into the advancing pit in an unconfined aquifer at the Thar lignite mine. Figure 8 (f) indicates that the inflow increased linearly from 0 to 200 days to 0.02 m^3/s, then gradually from time 200 days to 540 days to 0.035m^3/s, then decreasing gradually to 0.0335 m^3/s after 900 days of simulation.

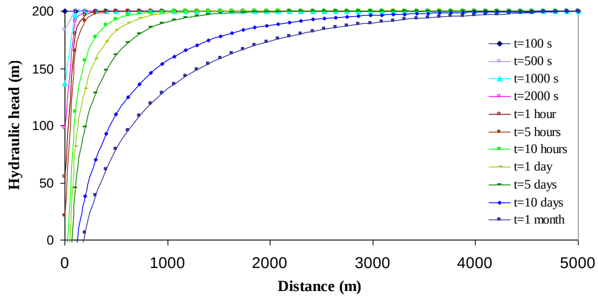


(a) 180-days
(b) 360 days
(c) 540 days
(d) 720 days
(e) 900 days
(f) Inflow Vs time in advancing pit

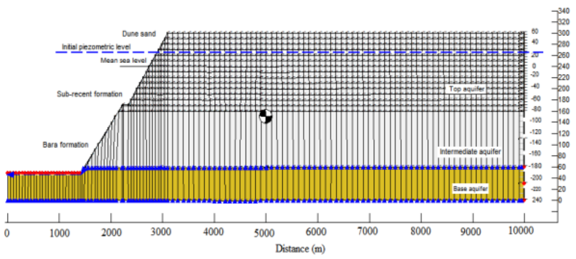
Figure 8. Model prediction of ground water inflow from the Top unconfined aquifer to Thar lignite mine at various stages of advancing pit.



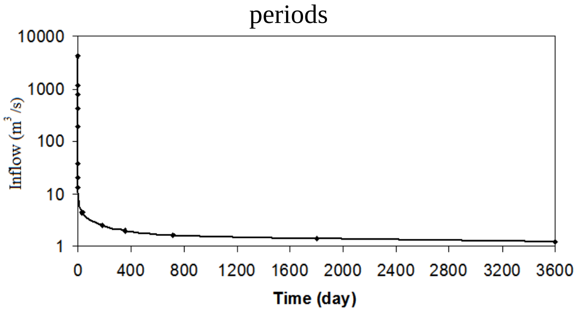
(a) Finite Element mesh of Intermediate aquifer



(b) Hydraulic head versus distance for various time periods



(c|) Finite Element mesh of bottom aquifer



(d) Inflow Prediction Vs t (days) in confined bottom aquifer

Figure 9. Prediction of groundwater inflow to the advancing pit at Thar lignite mine by the Intermediate and bottom confined aquifer

4-2-Inflow simulation from the Intermediate aquifer during pit advancement

Figure 9(a) shows the model simulation of dewatering the Intermediate aquifer at Thar lignite mine, the aquifer being assumed to be a confined aquifer. The finite element grid comprised 92 nodes and 45 elements creating a single layer of 100m thick and 5000m long aquifer. The input parameters to the model were conductivity $5x10^{-6}$m/s ; storage coefficient $2.0x10^{-4}$, initial hydraulic head of 200m, thickness of confined aquifer 100m, pumping out rate 0.03 m^3/s and well radius 0.075m. Figure 9(b) shows the hydraulic head at various distances to the observation wells from pumping well axis in the Intermediate confined aquifer as a function of time from 100 seconds to one month in 11 time steps.

4-3-Inflow prediction from the Bottom confined aquifer during pit advancement

For numerical modelling of inflow prediction from the Bottom confined aquifer to the Thar mine, a finite element asymmetric grid was constructed embodying 246 nodes, 120 rectangular elements making a single layer, 60m thick and 10000m long, aquifer. The input parameters to the model were 60m, being the thickness of the aquifer, 5.0 x 10-5 m/s as aquifer conductivity, 2.7 x 10^{-3} storage coefficient and 265m initial hydraulic head. Figure 9(c) shows the finite element grid of the model. No flow boundary conditions were assigned to the upper and lower boundaries of the aquifer. A boundary head of 265m was assigned to the right hand side and a value of 48.5m head to the left side of the model. An infinite boundary condition was maintained at the outer boundary of the model to simulate extending the aquifer to an infinite distance from the pit edge.

An initial piezometric surface was used as an initial condition for the transient simulation of the inflow problem. This will generate a uniform total head distribution of 265m throughout the entire aquifer before transient simulation with 14 time steps and 100 iterations. The model was run for a simulation time of 10 years. Figure 9(d) shows the inflow quantity versus time predicted by the FE model indicating a negative exponential decrease in inflow rate at the early stage of simulation, followed by a very low rate of decrease in flow during the remaining time.

5-Inflow prediction into fully penetrating pit using steady state flow condition

The following three different FE simulations were carried out to predict inflow by the Top, unconfined aquifer, Intermediate confined aquifer and the Bottom aquifer in a fully penetrating pit under steady state flow regime.

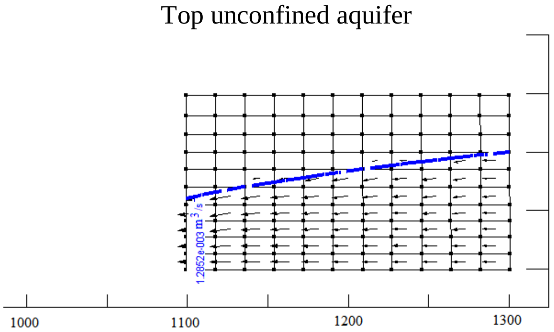
5-1-Unconfined Top aquifer under steady state flow condition

The open pit in the unconfined aquifer was modelled as a fully penetrating pit with vertical walls with a constant head of 20m at the outer boundary of the model at a radial distance of 1300m. The radius of drawdown was 1100 m, a constant head of water was 12m at the pit, and permeability was 3.0x 10^{-7} m/s. Figure 10(a) shows the FE model consisting of 132 nodes, 110 elements and 10 layers of 3m thickness each. Figure 10 (b) shows the modified conductivity function assigned to the aquifer. The numerical results indicate that the inflow to the fully penetrating pit in top aquifer in steady state flow condition is 112 m^3/d.

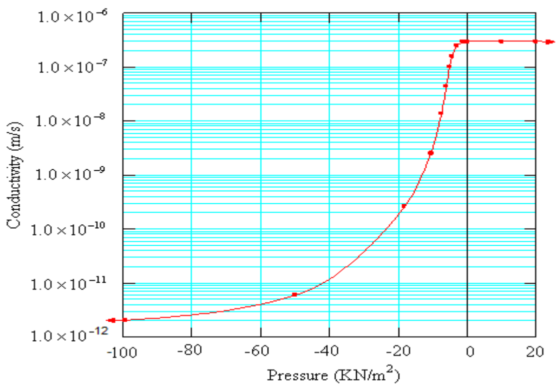
5-2-Inflow from confined Intermediate aquifer under steady state flow condition

The FE model of the intermediate aquifer consisted of 55 elements, 116 nodes and a single layer 10m thick as shown in Figure 10(c). The input parameters to the model were: thickness of aquifer 10m, hydraulic conductivity 1.0x 10^{-6}m/s, drawdown required 100m, the radius of drawdown 1050m and radius of influence 2500m. The numerical result predicted by the model was the inflow quantity of 141 m^3/d.

Top unconfined aquifer

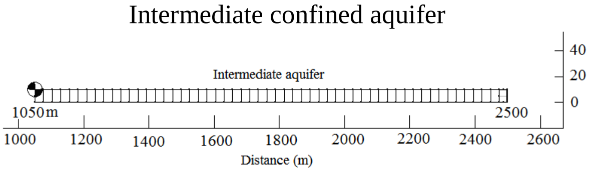


(a) Finite Element grid, velocity vectors and water table of the top unconfined aquifer



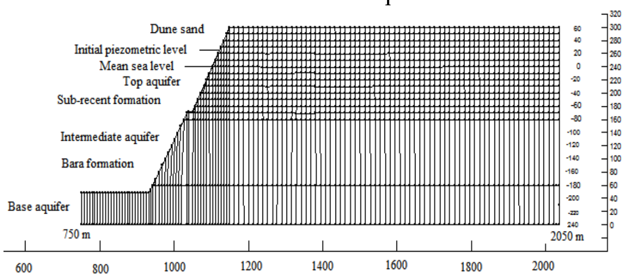
(b) Modifies hydraulic conductivity of the top unconfined aquifer

Intermediate confined aquifer



(a) FE grid of intermediate Aquifer

Bottom confined Aquifer



(b) FE grid of the bottom confined aquifer.

Figure 10. Steady state flow analysis in a fully penetrating open pit in Thar lignite mine intersecting the Top, Intermediate and Bottom aquifers.

Table 2. Comparison of analytical and numerical results of mine water inflow to the fully penetrating pit into three aquifers in the Thar lignite mine under steady state flow conditions.

Aquifer	Inflow Rate (m^3/d)		% Error
	Analytical solution	Numerical Solution	
Top unconfined aquifer	116	112	3.4%
Intermediate confined aquifer	147 Peterson equation	141	4.1%
Bottom confined aquifer k= 2.19×10^{-3}m/s k= 1.3×10^{-4}m/s	Peterson equation 2.25×10^{7} 1.34×10^{6}	2.34×10^{7} 1.4×10^{6}	6.4% 4.5%

5-3-Inflow from the Bottom confined aquifer under steady state flow condition

This simulation was performed to predict the ground water inflow from the Bottom aquifer to the fully penetrating pit to the Thar lignite mine under steady state flow condition as shown in Figure 10d. The FE model comprised an axisymmetric grid consisting of 246 nodes, 120 rectangular elements in a single layer, 55m thick and 2050m long aquifer. The main input parameters assigned to the model were: thickness of aquifer 55m, hydraulic conductivity 2.19×10^{-5}m/s, drawdown required 260m, radius of drawdown 750m and radius of influence 2050m. The simulated inflow quantity to the fully penetrating pit was 1.28×10^5 m^3/d. If the hydraulic conductivity was changed to 1.3×10^{-4} m/s as calculated from the pumping well test on Well -RE52, the predicted inflow quantity to the pit was $1.4 \times 10^5 m^3/d$ against $1.34 \times 10^5 m^3/d$ calculated by the analytical method. Table 2 presents a comparison of analytical and numerical inflow results at Thar lignite mine for a fully penetrating pit into three aquifers under steady state flow conditions.

This simulation result indicates that 20 pumping-out wells equipped with 150mm diameter submersible motor pumps, type Grudfos SP30, will be required with a discharge rate of 30 l/s over a period of 10 years to dewater the aquifer. The overall dewatering rate for top aquifer will be $0.6 m^3/s$. For Intermediate and Bottom confined or leaky aquifers high head borehole pumps with suitable ratings are needed.

6-Conclusions

This paper outlines a numerical axi-symmetric finite element model utilizing the SEEP/W software to analyse pumping out data in well RE-51 and RE-52 from an infinite confined aquifer in the Thar lignite prospect located at 400km South East of city Karachi, Sindh, Pakistan. After evaluating and verifying the pumping test simulation with the results obtained from the analytical methods and field data, a model simulation of a hypothetical pumping out well carried out a sensitivity analysis of various factors affecting ground water inflow. It was indicated that the model is sensitive to permeability of the aquifer as an input data. The model was then used to predict ground water inflow to Thar lignite prospect during the open cut mine advancement at various time periods and also to predict inflow into fully penetrating pit into the three aquifers using the steady state flow condition. It is concluded that the results of inflow can provide significant information for the design of an effective dewatering system for all stages of mining.

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