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Technical Communication

Assessment and Management of Water Resources for a Lignite Mine

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Abstract. A water resource management study was carried out for the proposed exploitation of lignite in Gujarat, India. The main source of water in the region is monsoon rainfall, which averages 567 mm/yr. The mine will be excavated in benches below groundwater level. Depth of water from the surface varies from 2-5 m. Total groundwater available within the leasehold area is 485 m^3/day and water demand for mining purposes will be around 120.5 m^3/day (25% of the available groundwater).

During the monsoon season, an estimated pumping capacity of 236 L/s should take care of groundwater seepage and rainwater when the maximum excavated area exists. After rehabilitation and backfilling, a water body will be created in the mined out pit, which will act as a water reservoir and enhance groundwater recharge. The mine should not significantly affect the region's water resources as long as the recommendations outlined in this paper are adopted.

Key words: Khadsaliya; management of water; water balance; water quality; water resources

Introduction

The proposed Khadsaliya lignite mine is situated about 31 km south-southeast of Bhavnagar, in the state of Gujarat, near the west coast of India. Based on the geology of the area and design parameters, the open pit has to be excavated below the superjacent groundwater level. Therefore, it will be necessary to pump water out of the pit. The broad objectives of this study were to assess the surface and groundwater resources in and around the mine site, evaluate the water balance, quantify water availability vis-a-vis the pump requirements, analyse the physico-chemical properties of the surface and groundwater, and formulate a water management strategy.

To fulfil these objectives:

a) Supporting data regarding drainage pattern, geology, mining details, rainfall, ground and surface water resources, water balance, etc. were collected.

b) Rainfall pattern and intensity was analysed to evaluate runoff characteristics. Long term groundwater data were analysed for pre- and post-monsoon water level fluctuations (Adamovski and Hamory 1983; Weeks and Boughton 1987; Soliman et al. 1997).

c) Geological structure and stratigraphy were analysed from borehole data and geological cross-sections of the mine (Karaguzal et al. 1999; Chaulya et al. 2000; Chakraborty et al. 2001).

d) Aquifer parameters were determined by pumping tests. Required pump capacity was estimated based on field studies and supporting data (Rao and Rao 1985; Drawson and Istok 1992; Kresic 1997; Singh et al. 1999; Bell and Maud 2000; Umar and Ahmad 2001).

e) The water resource potential was calculated based on rainfall, evaporation, infiltration, land use, soil characteristics, etc. (Bradon 1986; Lyle 1987; Karanth 1990; Tolman 1993; Abu-Taleb 1999; Feng et al. 2000). The water balance was analysed, based on availability and demand (Brawner 1986; Basu and Basu 1999; Berger 2000; Reddy et al. 2000).

f) Water quality was analysed per standard methods (Down and Stocks 1977; Dominico and Schwart 1990; AWWA 1992; Lee et al. 2001).

g) A water management strategy was formulated, based on technical and economic factors (ASCE 1972; Aral 1995; Abu-Taleb 1999; EI Ouali et al. 1999; Graniel et al. 1999; Yang et al. 1999; Farah et al. 2000; Reddy et al. 2000).

Description of the Study Site

The mine site is about 3 km from the western coast of the Gulf of Khambat. The area is characterised by a flat to moderately undulating topography, which gently slopes towards the east and south-east. The surface cover is alluvium, coastal dunes, mud flats, and beach sands. The elevation ranges from 66 m in the NW to 27 m in the SE.

In general, there are three seasons: Monsoon, from late June to October; Winter, from November to February; and Summer, from March to June. The relative humidity reaches over 94% during the monsoon, while the rest of the year is comparatively dry. Most vegetative growth occurs during the monsoon. The post-monsoon period is hotter, with very high temperatures. Most vegetation dries out during this period and the ground looks almost barren. Winters are mild. The monthly variation of average rainfall from 1979 to 2000 at the Bhavnagar meteorological station is depicted in Figure 1. The average annual rainfall is 567.2 mm.

The total leasehold area is 171 ha, of which about 75% is government gochar land (land used for animal grazing) and the rest is private agricultural land. The anticipated land use at the end of mining operations is indicated in Table 1. Of the total leased area, 165.42 ha (96.4%) will be disturbed by mining. Most of the disturbed areas will be reclaimed (including the formation of a water body) before abandonment. The south pit will be fully backfilled and reclaimed while the north pit will be left with a 40-50 m deep water body (reduced by rehandling waste into the north pit after excavating the lignite fully) over a 39 ha area. The overburden will be dumped in a place devoid of lignite, where it should not cause a problem for the adjacent property or human settlement.

The leased area is part of the Saurashtra Peninsula, which is bounded by the sea except on the north-east, where it is flanked by alluvial plains and formations ranging from Jourocretaceous to Recent coastal deposits. About 65% of the Peninsula is covered by basaltic lava flows (Deccan Trap). In the northern part of the Peninsula, the trap rock overlies upper Mesozoic sediments; at the coastal fringe, the trap rock underlies Tertiary-Quaternary sediments. The lignite seams, as revealed by boreholes, are associated with greenish gray clays and carbonaceous clays, probably of Eocene age. The lignite was encountered at depths from 28.65-67.71 m.

The leased area can be divided into two blocks and worked as two separate pits. There are 6.82 Mt of recoverable reserves for opencast mining (Table 2). Geological and recoverable reserves are limited to a life of 17-18 years at 0.40 Mt/yr. The life of the mine can be increased and stripping ratios can be improved somewhat if some additional reserves (about 8 Mt) in the adjoining lignite-bearing area are made available in the future.

Water Regime

The drainage pattern is sub-dendritic to dendritic and the drainage density is medium. The drainage direction is mostly to the east and south-east. The only river of significance in the area is the seasonal Ramdasiya River, which flows to the Gulf of Cambay. A canal passes beside the lease area and flows from south to north.

The Ghogha formation consists of thinly bedded grits, conglomerates, and limestone. Due to its porous

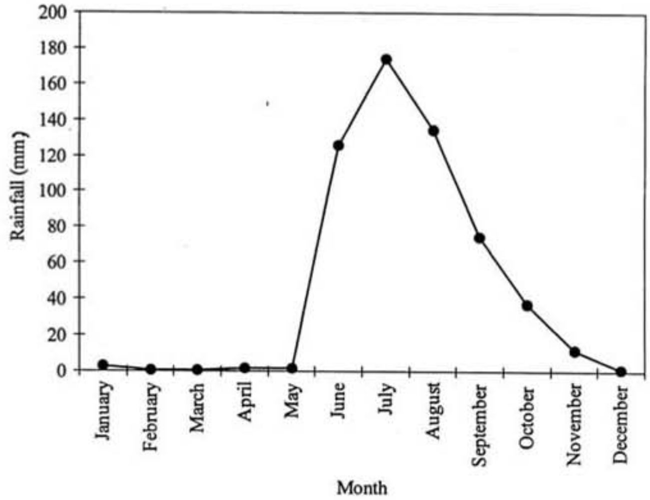

Figure 1. Monthly rainfall during 1979-2000

nature, it is a good aquifer, but there are few wells in these formations because the salinity increases with depth. The Gaj limestone contains beds of clay and so has low yields and poor groundwater quality.

Unlike the sedimentary formations, the trap rocks do not have primary porosity. The dug (open) wells in these formations yield only 1-2 thousand m^3/yr, which is only sufficient for domestic use and limited irrigation. Due to deficit rainfall, the water levels of these wells have declined. The water quality is good.

Pumping tests

Determination of aquifer characteristics is essential for estimating the groundwater potential of any region, which in turn allows an understanding of the water balance (Drawson and Istok 1992). Two pumping tests were conducted near the proposed mine site (in the villages of Badi and Hoidad), maintaining a 40 m^3/day discharge in the first well and 293 m^3/day discharge in the other well. Both tests were conducted in open wells in Ghogha beds/formations with pumping durations of 200-280 minutes. The test data revealed that the specific capacity varies from 0.026-0.069 m^3/min/m, which is quite low. Permeability and transmissivity values are also relatively low. The Badi well was able to sustain a pumping rate of about 300 m^3/day for nearly 5 hours. With vertical boreholes drilled beyond the bottom of the well, the water potential could be improved and pumping duration could be increased.

Water Balance

Total groundwater recharge or availability for the Khadsaliya leasehold area was calculated to be 0.174 million m^3 using the infiltration method or 0.177 million m^3 using the specific yield method. The

Table 1. Post-mining land use of the leasehold area

Description of area	Land use (ha)					% of total area
	Plantation	Water body	Public use	Undisturbed	Total Area	
Top soil dump	5.35	0	0	0	5.35	3.13
External dump	11.58	0	0	0	11.58	6.77
Excavation	105.89	39.29	0	0	145.18	84.90
Roads	0	0	2.50	0	2.50	1.46
Infrastructure	0	0	0.23	0	0.23	0.14
Greenbelt	4.72	0	0	0	4.72	2.76
Undisturbed area	0	0	0	1.44	1.44	0.84
Total	127.54	39.29	2. 73	1.44	171.00	100.00

Table 2. Salient parameters and recoverable reserves

Particulars	South Mine Block		North Mine Block		Overall
1. (a) Minimum Pit Depth (m)	33.0		45.0		33.0
(b)Maximum Pit Depth (m)	73.0		78.0		80.0
2. Overburden Thickness (m)					
(a) Minimum	23.0		44.0		23.0
(b) Maximum	64.0		78.0		78.0
3. Seam Thickness (m)	Range	Average	Range	Average	
(a) Composite Seam	9.15-2.12	5.92	4.87-1.51	3.425	4.98
(b) Top Spilt	6.20-1.61	4.28	3.14-1.42	2.575	3.97
(c) Middle Spilt	1.87-0.50	1.33	1.53-0.30	1.015	1.22
(d) Bottom Spilt	1.52-0.61	0.97	1.22-0.20	0.71	0.91
4. Parting between					
(a) Top & Middle	5.53-0.20	1.72	4.28-0.30	2.195	2.00
(b) Middle & Bottom	4.17-0.90	2.57	3.67-2.74	3.205	2.75
5. Floor Gradient	1:30		1:10		
6. Pit Area (ha)					
(a) Floor	63.26		31.64		94.91
(b) Surface	89.37		55.82		145.19
7. Recoverable Reserves ('000 t)	5115		1705		6820
8. Waste Quantity ('000 m^3)	39141		24762		63903
9. Stripping Ratio (t/m^3)	1:7.65		1:14.52		1:9.36

Table 3. Water demand for the Khadsaliya Mine

Activities	Water requirement (m^3/day)
Dust suppression @ 68,040L/day/Mt annual production of lignite	27.24
Workshop @ 6,804 L/day/Mt annual production of lignite	2.72
Plantation watering @ 8 L/tree/day	80.00
Potable water at pit head	10.53
Total	120.49

Table 4. Location of water sampling stations

Location/village	Remarks
W1 Morchand (Bore well)	Drinking water
W2 Khadsaliya (Open bore well)	Drinking water
W3 Khadsaliya (Well in core zone)	Drinking water
W4 Thalsar (Well water)	Drinking water
W5 Hathab (Bore well)	Drinking water
W6 Padwa (Open bore well)	Drinking water
W7 Sea water	Surface water

groundwater yield on this recharge = 485 m^3/day. Water demands for the mine are summarized in Table 3, based on the norm for each category. Total groundwater available within the leasehold is 485 m^3/day and the average water demand for the various mining purposes is around 120.5 m^3/day. Only 25% of the available groundwater resource within the leasehold area will be used by the mine, which should minimally impact the regional water resources.

Water Quality

Water samples were collected from seven locations. Total hardness ranged from 168 to 5600 mg/L while Ca hardness varied from 28 to 768 mg/L, with higher values recorded at well 5 (Hathab) (Tables 4 and 5).

Management of Water Resources

Mine water control is an integral part of any opencast operation. Flooding can affect the movement of machinery, excavation of soil, and ultimately

Table 5. Summary of water test results

Characteristics	IS:10500	Water test results						
		W1	W2	W3	W4	W5	W6	W7
Suspended solids (mg/L)	-	16-26	18-23	24-26	18-29	14-44	19-32	22-40
Dissolved solids (mg/L)	500	480-738	1408-1519	1160-1354	431-638	1485-12185	408-517	22815-30014
Cl (mg/L)	250	47-224	383-544	104-612	48-64	514-5478	48-98	12436-19674
Total hardness as $CaCO_3$ (mg/L)	500	203-432	636-800	470-680	272-363	436-5600	168-228	736-5400
BOD (mg/L)	-	1.2-2.2	1.2-2.2	1.4-2.0	1.0-3.0	0.8-2.2	0.6-2.2	1.2-2.4
COD (mg/L)	-	8-16	10-14	18-22	6-12	10-18	6-14	12-19
Ca hardness (mg/L)	75	44-112	131-257	89-211	75-91	104-768	28-57	228-672
Mg (mg/L)	75	26-36	37-73	34-40	19-28	32-883	20-26	38-892

production, apart from the safety aspects. As such, water control should be included in mine planning and dovetailed to the progress and advancement of mining at every stage. The sources of water that require consideration in an opencast mine are: seepage water; confined ground water; surface water; and rain water. Based on the available sub-surface hydrological data, ground water within the mine area is under phreatic (unconfined, non-artesian) conditions. Therefore, only seepage water, runoff, and rain water have to be considered.

Seepage water from overburden strata

Seepage from the overburden strata is bound to occur during mining. The amount and flow velocity depend on characteristics like permeability, specific yield, and transmissivity of the strata and the surface area exposed. This in turn depends on the shape, size, and dimensions of the mine cut, the hydrological conditions of the soil, and the season of the year. The stratigraphy and rainfall distribution pattern indicate that seepage from the overburden and lignite during the non-monsoon season will be negligible; during the monsoon, seepage will be significant. To design sump capacity and plan water control operations, the maximum inflow of water due to seepage in a period of 24 hours during the monsoon season has to be estimated. We assumed that 10% of the rainfall inflow will enter the mine as seepage from the overburden (based on CMRI 2001).

The seepage water has to be led to a sump in the mine floor by means of toe-drains cut along the bench slopes. Sumps should also be constructed at the down-gradient end of each bench; these should be inter-connected by a well-planned piping/delivery system. It is essential to periodically desilt the toe-drains. As the mine advances, new drains will have to be established, and the old ones abandoned.

Seepage water from the internal dump

In any opencast mine, initially the overburden is dumped outside as an external dump. Back-filling can commence only after the initial mine cut is completely excavated and the mine has sufficiently advanced so as to have adequate floor width. In the proposed mine, back-filling is expected to start two years after the opening of the initial mine cut. Seepage from the internally dumped material will vary depending on the sequence of operation, the gradient and degree of consolidation of the dump, etc. We assumed that 10% of the rainfall will infiltrate and then emerge as seepage, including seepage from the internal dump (based on CMRI 2001).

When the backfill attains the surface level or the original ground level, the surface of the dump area should be properly dozed, levelled, graded, and consolidated so as to maintain the slope away from the active mining zones.

Revegetation/forestation of the dump surface as early as possible will help arrest soil erosion and gully formation and will also reduce the amount of seepage from the dumps.

Surface water

Surface runoff water during the monsoon season is a potential problem. The ground surface gradient is from west to east and south-east, so it is likely that runoff from the Deccan trap area, west of the mine, could enter the mine on rainy days. As a rough estimate, for every 25 mm of rainfall, runoff from a 1 km catchment area will total about 15,000 m^3 under normal topographical conditions. It is absolutely necessary to prevent such runoff from entering the mine. This can be achieved by constructing a diversion or garland canal around the mine. With this arrangement, all the surface runoff water with potential to flow towards the mine will be intercepted. The canal will require periodic desilting.

As an additional precautionary measure for arresting the runoff water, embankments 2-3 m high should be constructed at the periphery of the mine at appropriate places. The soil that is excavated in the construction of the canal should be utilised to the extent possible for the construction of the embankment. It is desirable to strengthen and stabilise the embankments by proper consolidation and turfing. As the mine advances, it will be necessary to periodically abandon a part or all of the garland canal and embankments at one location and then reconstruct the same at a new location.

Unlike surface runoff water, water due to rainfall cannot be avoided or prevented. However, prior to the onset of the monsoon, mine slopes should be trimmed and the benches should be properly levelled and graded so that the water falling on the slopes and benches flow towards the toe-drains, which will ultimately drain the entire water to the main sump situated at the lowest elevation of the mine floor.

Calculation of mine water inflow

More than 90% of the total annual rainfall occurs from June to October. Daily intensity during the rainy days of the monsoon normally ranges from 20-80 mm. However, to estimate the maximum amount of water that will accumulate in a mine, one generally considers the maximum rainfall recorded in a 24 hour period during the proceeding 50 years. The maximum recorded intensity for 24 hours was 306.5 mm. However, it is impractical to account for such a high level of rainfall because doing so would require very elaborate pumping arrangements that would remain idle most of the time, since rainfall is negligible for seven months of the year. Other than the one intense storm of 306.5 mm in 24 hours, recorded 24 hour maximum rainfall has ranged between 105.7-242.5 mm. Therefore, the decision was made to plan for a maximum rainfall event of 250 mm in 24 hours.

Mine water control arrangements

The normal practice is to plan to pump out the quantity of water that will accumulate in 24 hours of rainfall within about 100 hours, depending on the prevailing mining conditions, position of equipment, production schedule, etc. However, to minimise disruption of mining, it was felt that arrangements should be planned to pump out the accumulated water within 48 hours. Accordingly, the following parameters were selected:

a) Rainfall intensity =250 mm in 24 hours
b) Time for pumping the water from the sump=48 hr
c) Area of mine during Stage I-lignite exposure stage (3 months after mining starts)=30,000 m^2
d) Area of mine during Stage II-lignite deep cut stage (1 year after after mining starts)=96,000 m^2
e) Area of mine during Stage III-full production stage (2 years after after mining starts)=1,48,360 m^3
f) Level at the deepest portion of Stage I = + 8 m
g) Level at the deepest portion in Stage II = - 6 m
h) Level at the deepest portion in Stage III = - 12 m
i) Elevation where water will discharge = + 28 m

Based on these parameters, pumping capacity, water accumulation, etc. were calculated (Table 6).

Pumping set up

It is advisable to establish a temporary sump on each bench, with suitable pumping arrangements, to reduce the amount of inflow into the main sump on the mine floor. However, one should presume that all the water falling in the mine will ultimately reach the main sump, which should be constructed at the deepest part of the mine. In case the mine floor level/gradient does not permit easy flow of water to the main sump, it may be necessary to have intermediate sumps for water collection and resort to staged pumping. The sumps should be periodically desilted so that the designed storage is always available. The foot valve should be graded with a net of small mesh. Pumping capacity and water disposal must be maintained at every stage of mine progress/ advancement.

Pumping capacity and the number of pumps required are enumerated in Table 6. At full production, 850 m^3/hr of water will require five pumps: two 150 m^3/hr and two 300 m^3/hr pumps, with an additional 150 m^3/hr (40 L/s, 50 m head) standby pump. The centrifugal pumps should be mounted on floating platforms (pontoons) to avoid submergence. Power and electrical connections have to be provided, along with a standby diesel generator for running at least one 80 L/s capacity pump in case of power failure. Delivery pipe lines should be laid from the sumps to the surface to transport the pumped water to a surface drain. A flexible hose of about 10 m length should be provided at the delivery outlet of each pump as a part of the pipeline system. This will provide sufficient flexibility in the first portion of the delivery pipelines to account for the rise and fall of the water level in the sump. As the water pumped to the surface from the sumps should be of good quality except for suspended solids, the water could be used for irrigation, fire fighting, spraying, etc. with proper storage and supply/delivery systems. The success of mining operations will depend to a large extent on

Table 6. Detail of pumping arrangement for Khadsaliya lignite mine

Particulars	3 months after the start of mining	At the end of the 1st year	At the end of the 2nd year
Area of catchment (m^2)	30,000	96,000	148,360
Rainfall in 24 hours (m)	0.25	0.25	0.25
Quantity of water accumulated due to rainfall (m^3)	7,500	24,000	37,090
Quantity of water due to seepage (m^3)	750	2,400	3,710
Total quantity of water to be pumped in 48 hours (m^3)	8,250	26,400	40,800
Pumping capacity required (m^3/hr)	172	550	850
Number of pumps required to discharge pit water:			
150 m^3/hr (40 L/s, 50 m head) capacity pump	2	2	2 + (1)
300 m^3/hr (80 L/s, 100 m head) capacity pump	0	1	2

Note: Area of catchment is based on the mine plan of the respective period/year; number of pumps include standby, which is given in brackets ( ); the number indicates how many pumps should be available at each stage and not the additional requirement over the previous stage.

proper mine water control arrangements and so, to reiterate, it is essential that the mine water control system be integrated with mine planning at each stage of mine advancement. By doing so and by adopting the various measures outlined above, it should be possible to maintain the targeted production from the Khadsaliya Mine without any problem due to water.

Conclusions and Recommendations

The location of the proposed lignite mine is in an area with very little annual rainfall. The source of water during excavation will be primarily from precipitation. The preliminary hydrological study revealed no high-yield aquifer horizons. Groundwater occurs under phreatic conditions. The mine will onlyuse 25% of the groundwater resources available within the leasehold area, and the loss of water due to mining operations should not significantly affect the inhabitants of the area.

Because rainfall during the monsoon season can be intense at times; garland drains and protective 2-3 m embankments will be constructed around the mine excavations. Drainage ways will be constructed for the mine benches, and check dams will be provided.

Two 40 L/s capacity pumps with 50 m head and two 80 L/s capacity pumps with 100 m head, along with a standby 40 L/s capacity pump are proposed for mine dewatering during the operational stage. A standby generator will be necessary, particularly during the rainy season. Sumps of adequate capacity will be provided. The excavation and transport machinery will be sited over the lignite bench top and will not be affected by water accumulation.

During rehabilitation, a water body will be created in the mined out pit; this will act as a reservoir for improving groundwater recharge.

By implementing all of these management strategies, the proposed mine should not cause any significant impact on the water resources of the region.

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