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Ground Water Basin Management at the Neyveli Lignite Mines

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Abstract Water conservation and water management practices have been adopted at Neyveli to ensure proper hydrologic balance. These practices are important because ground water pumping is a prerequisite for lignite mining in the Neyveli basin. This paper delineates some of these practices and the scientific studies undertaken by the Neyveli Lignite Corporation to develop and implement them. Optimal water utilization would be achieved by maintaining the ground water recharge (input) and the ground water extraction (output) ratio in the basin.

Keywords Ground water basin management · Neyveli lignite mine · Water conservation practices

Introduction

The Neyveli lignite mines of India contain large reserves and represent a unique mining venture in southeastern Asia. The 3,500 km^2 hydrogeological basin in which these mines lie contain multiple aquifers under hydrostatic pressure. There are three identified aquifers in the Neyveli basin: a water table aquifer, a semi-confined aquifer, and a deep confined aquifer. Within the lignite field, the lignite acts as an aquiclude, and it overlies the confined aquifer. The Neyveli Lignite Corporation (NLC) has had to practice controlled dewatering to reduce the water pressure since the inception of these mines; this has also necessitated water management and conservation.

The Neyveli area can be broadly divided into four physiographic divisions: two that are relatively high, in the northwest and central portion, and the Gadilam-Ponniyar and Vellar-Manimuktha Nadhi alluvial plains. The northwestern high land lies in the western part of Neyveli passing between Senthanadu and Vridhachalam in a northeast-southwest direction. The elevation ranges between 30 and 100 m above mean sea level. The central high area stretches roughly north-northeast to south-southwest in the center of the Neyveli field.

Thorough understanding of geology, physiography, and hydrology is critical to plan and design ground water conservation practices in a large ground water basin like the Neyveli. The geology and hydrological characteristics of the basin have been discussed in detail in the two papers by Anandan et al. in this issue. This paper describes the resource conservation and ground water basin management practices for Neyveli, emphasizing the ground water mining (extraction) aspects. An analysis of water mining vis-a-vis lignite mining for optimum resource utilization and management is the central theme of this article.

The Neyveli basin has met the total water requirement of the region for agriculture, industry (thermal power plant), drinking water, and other miscellaneous uses for the past five decades. As said earlier, the confined aquifer is under artesian condition below the lignite seam; therefore, the aquifer has to be essentially depressurized at Mines I, IA, and Mine II. The details of pumping for depressurization in the mines, township, power plant, and other uses are summarized in Tables 1, 2, 3 and 4.

Pumping for strata depressurization has been a continuous process by NLC for the last five decades. Detailed analysis of the pumping scenarios at the NLC mines

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Table 1 Ground water pumping in Neyveli mines for progressive depressurization

Mine	Capacity (MT/A)	Period	Quantum, MCM/A	Explanation
Mine I	4.7–10.5	July 1961–2007	100–34	Initial pumping was high to stabilize the aquifer system and to depressurize strata below the seam level
Mine II & expansion	4.7–10.5	Dec. 1982–2007	6.8–54	Positive head depressurization
	10.5–15	Beyond 2009	60–90	Positive head depressurization
Mine IA	3.0	March 2006–07	14	Positive head depressurization

Source: Compiled from various NLC technical reports, *MCM* million cubic metres, *MT* million tonnes, *A* Annum

Table 2 Ground water pumping for the NLC township

Area, km^2	Blocks	Dwellings	Population	Period	Quantum MCM/A	Explanation
27	30	20,000	1.5 lacs	1961–2006	2–14	Of 14 MCM, around 10 MCM is being compensated by treated storm water, subject to its availability.

Source: NLC (Status report of Neyveli township), *MCM/A* million cubic metres per annum

Table 3 Ground water pumping for NLC thermal plants

Period	Quantum, MCM/Year	Power Generation, MW
1961	01	600
1986	05	1,230
2007	28	2,490

Source: NLC, *MCM* million cubic meters

Table 4 Ground water pumping for other purposes

Source	Period	Quantum (MCM/A)	Explanation
Agriculture	1961	18	Government schemes like free electricity and soft loans have accelerated pumping activity
	1986	50	
	2007	78	
Industries	1990	5	
	2007	17	
Drinking water for villages and towns	1961	3	–
	2007	21	Includes ≈ 15MCM/year to the Chennai Metro water supply

Source: NLC, *MCM/A* million cubic metres per annum

revealed that optimal pumping for mining lies at around 170 MCM/annum. However, NLC is shouldering the responsibility of socio-economic development of the area as well as its environmental responsibilities. This has necessitated ground water monitoring of the region as a whole, as discussed below. Extraction from the Neyveli basin by NLC for depressurization of the three mines and use by the thermal plants and the township is around 130MCM/a. Ground water extraction by other agencies for purposes like irrigation, drinking water for towns and villages, and industrial use totals about 110 MCM/a.

Recharge and Water Management

Various scientific studies were undertaken by NLC to determine the recharge area and recharge quantities based on the geological features of the basin and related hydrological parameters. As discussed elsewhere in this issue, these recharge assessment studies established the aerial extent of the recharge area (420 km^2) and average rainfall recharge percentage (15.5%). Based on physiography, lithology, ground water flow pattern, and water level fluctuations (WLF), total recharge was calculated to be about 111 MCM a year (Gupta and Thangarajan 1986). Studies by various research organizations and institutes, such as the National Geophysical Research Institute (NGRI), the VEB Industrie Consult (Berlin), the Indian Institute of Technology, and the Ministry of Coal have been discussed in the other two NLC technical papers appearing in this issue and contributed significantly to our understanding of various aspects of ground water recharge and water management. Actual field implementation was done by NLC.

In May, 2006, the NLC and Central Ground Water Board (CGWB) entered into a 5 year memorandum of understanding to further develop the Neyveli hydrogeological basin based on scientific principles and more intense regional monitoring. Various scientific studies are being undertaken jointly with a view of developing a well-defined ground water development plan for the entire basin and an action plan for sustainable management of the available water resources. The NLC regional ground water

Table 5 Salient details of ground water monitoring wells

Aquifer type	Area spread, km^2	Depth, in m	# of wells	Type of formation
Phreatic (water table)	3,500	10–50	150	Recent and tertiary
Confined	3,500	120–450	100	Tertiary

Source: NLC (regional monitoring plan)

monitoring strategy for the aquifers in this area includes the monitoring of dug wells constructed by agencies like the Tamil Nadu State Government (Ground Water Survey and Development Agency) and the CGWB in 16 different sectors (Table 5) spread over the entire 3,500 km^2 region. Water levels and water quality are monitored seasonally for determination of pH, TDS, temperature, hardness, chloride, and other water quality parameters using portable water sampling kits. Water samples are analyzed at the Tamil Nadu Water Supply and Drainage Board Laboratory (Chennai) and at NLC's in-house centre for applied research and development (CARD).

Seasonal monitoring of the wells penetrating the water table (phreatic) aquifer in the region have indicated that ground water pumping from the deep confined aquifers have had no significant impact on the phreatic aquifers of the region. Also, so far, no noticeable surface subsidence has been observed in the area.

Development of a Regional Ground Water Model

Ground water models describe ground water flow and transport processes. Depending on the nature of the equations involved, these models can be classified as empirical, probabilistic, or deterministic. Visual MODFLOW (a computer package developed by Waterloo Hydrogeologic, Canada) is the most popular, complete and easy-to-use ground water modeling package for practical applications in three-dimensional groundwater flow and contaminant transport simulations. This fully integrated package (with various options and capabilities for simulating, calibration and powerful graphical interface) has been utilized extensively for the regional ground water model development of the Neyveli aquifer.

Numerical ground water models previously developed for the Neyveli aquifer studied the aquifer response and the regional effects of mine pumping. The first modeling effort, which assumed steady state dynamics, was a two dimensional (2-D) ground water flow model that considered only the upper confined aquifer (Gupta and Thangarajan 1986). The leakage and upward flow were calculated approximately and entered into the model. This model development study indicated that there would be a considerable decline in the piezometeric level in the future. The entire 16 km^2 area was divided into a square grid pattern. This regional model was calibrated in two stages. First, the model had to suggest a plausible transmissivity pattern, starting with the transmissivity distribution. Second, model results from June 1956 to June 1986 were compared with field observations. Downward leakage from the phreatic aquifer to other aquifers and sub-surface inflow across the southwestern boundary was indicated in these models as sources of input to the aquifer system. Similarly, various components of ground water withdrawal from the aquifer system were taken into account, especially the pumpage for irrigation in the northern, southern, and southwestern regions. They recommended the need for additional data, such as a detailed geological map, water level monitoring wells in different aquifer zones, exploration by gamma ray logging to delineate the thickness of clay lenses, regular monitoring of water quality in the coastal area, quantification of sub-surface inflow from the recharge area and outflow towards the northern boundary, and the development of a hydrogeological database for creating a three dimensional (3-D) model.

Later, in 1992, NLC developed a single layer model as a continuation of its earlier 1986 model (Gupta and Thangarajan 1992). The changes made were variable grid spacing instead of constant grid spacing and extension of the model area up to the sea. Simulations and analysis were conducted for the period from 1988 to 1992. Different scenarios were analyzed, including: seepage to the aquifer from the township; industrial and agricultural pumping effects on draw down; pumping from the mines (to achieve desired extraction pressure of aquifer at the lignite bottom); and the effect of starting additional mines (It was proposed to start Mine III with a pumpage of 25,000 gpm and impact due to expansion of mining activity was the need). The model results indicated that township pumping should be reduced and recommended a positive pressure of 5 m in the mines, instead of depressurization below the lignite bottom, in order to optimize the mine pumpage.

Laubag Consulting and Dresden University (1995) developed a 3-D finite difference model (FDM) for the Neyveli aquifer system. The model was calibrated with data from 1958 to 1988 and simulations were run until 2005. This was the first systematic study conducted for the Neyveli aquifer. The results from this study revealed the downward trend of the pressure surface in the upper confined aquifer and suggested that additional data such as hydrogeological exploration data between the mining area and the sea, quantification of upward and downward leakage, and quantification of outflow towards the north and flow from the recharge area are required for accurate modeling of the aquifer system.

Ramani and Dhar (1998) constructed a two layer confined aquifer model separated by a clay layer. At the western side, a recharge boundary was given; the northern side had no flow boundary and at the southern and eastern sides, a constant head boundary was assigned. Their simulations indicated that mine pumping has considerably decreased head. They recommended additional work to incorporate the effects of the Coleroon, Gadilam, Vellar, and Manimuktha rivers and stressed the necessity of modeling the fresh water-salt water interface. They also recommended additional boreholes near the coast, monitoring wells in the water table and the semi-confined and lower confined aquifers, and, in general, more reliable borehole information for a more extensive area.

In the work done by Ramani and Dhar (1998), the southern side was assigned a constant head boundary without temporal variation, which creates problems for future predictions since pumping effects may affect this boundary condition. Also, since the model considered only the upper and lower confined aquifers, it was not clear how leakage from the upper layers were considered. The volume of leakage from the lower confined aquifer into the upper confined aquifer was represented by a straight line equation based on the amount of mine pumping, which is an over-simplification of the problem.

Another regional geo-hydrological model (Gutt 1989) for the Neyveli ground water basin was also a 3-D FDM meant to identify the long-term effects of ground water depressurization from Mines I and II and the proposed Mine III. The possibility of salt-water intrusion from the Bay of Bengal was examined and suggestions were made for maintaining the ground water balance.

To plan the depressurization and to assess the influence of the ground water extraction on the surroundings, a model based prediction of ground water flow during the mine life was felt extremely necessary. A reliable prognostic pumping plan for mine water pressure control was developed and assessed by the regional effects of mine pumping (Agrawal and Mohan 2004; Mohan et al. 2006). The ground water balance for the confined aquifer was computed for 2005–2006, which showed that the recharge to the confined aquifer system was about 249 MCM and the total extraction from the basin was about 263 MCM. Of the 263 MCM/a, NLC's pumping (from three operational mines, township, and power station) was about 144 MCM/a. The remaining annual withdrawals included agricultural pumping (80 MCM), pumping by industries (20 MCM), drinking water (21 MCM, which includes 16 MCM to Chennai metro), and outflow towards the sea (about 3 MCM). Thus, there was a deficit in the ground water balance of 14 MCM (Mohan et al. 2006).

Also, for resource conservation and management, different ground water flow models were developed with specific emphasis on basin management, considering the existing and future lignite mines. The model output, i.e. an areal discretization plan of the Neyveli ground water basin, was drawn (Fig. 1). The model was calibrated for 10 years and was validated for 3 years, considering 1990 as the base year. For future prediction, optimized values were obtained for ground water control pumping and predictions up to 2008.

All of the recommendations indicated by the modeling studies were accepted by the Central Groundwater Authority and the Ministry of Environment and have been implemented. The expansion schemes (discussed elsewhere in this issue) incorporated the findings of these studies. Other relevant results from the developed model are given below:

- The model results indicate no significant changes in the water levels of the water table aquifer, semi-confined, and lower confined aquifers due to ground water extraction from the upper confined aquifer.
- The quantity of water pumped by NLC has ranged from 150 to 170 MCM/a; all other users together withdraw an approximately equal amount. As a result, the radius of influence has increased from 5,000 m in 1990 to 10,000 m in 2008. NLC increased its annual withdrawal by 20 MCM to lower the pressure surface in the mining area by 2–3 m. However, this has only resulted in an additional drawdown of 1 m near the seaside.
- Detailed analysis of the pumping scenarios in the NLC mines reveals that the optimal pumping is about 170 MCM/year.
- The model simulation studies for recharge to the upper confined aquifer indicate that in the area close to the water divide (assuming a series of 12 water injection wells, each 100 GPM capacity, running round the clock), the impact would be 5 m near the sea in 3 years. Similarly, in the recharge area on the western side, assuming eight injection wells of 100 GPM capacity, 1 m of improvement in the water level could be noticed in 3 years. A detailed study is warranted to ascertain the basic parameters as there could be litho-structural problems encountered during actual field conditions.
- While the lowering of water levels in the active mining zone is essentially due to the depressurization activity of NLC, drawdown in the coastal area is primarily due to pumping by industry and agriculture (for irrigation).
- The results of simulation studies indicate that there is no seawater intrusion towards the land. However, additional R&D should be conducted on the potential effects of these changes on the salt water/fresh water interface.
- Considering the expansion schemes of the mine (and the stipulated pumpage from the confined aquifers), NLC needs to devise alternative sources to meet the drinking

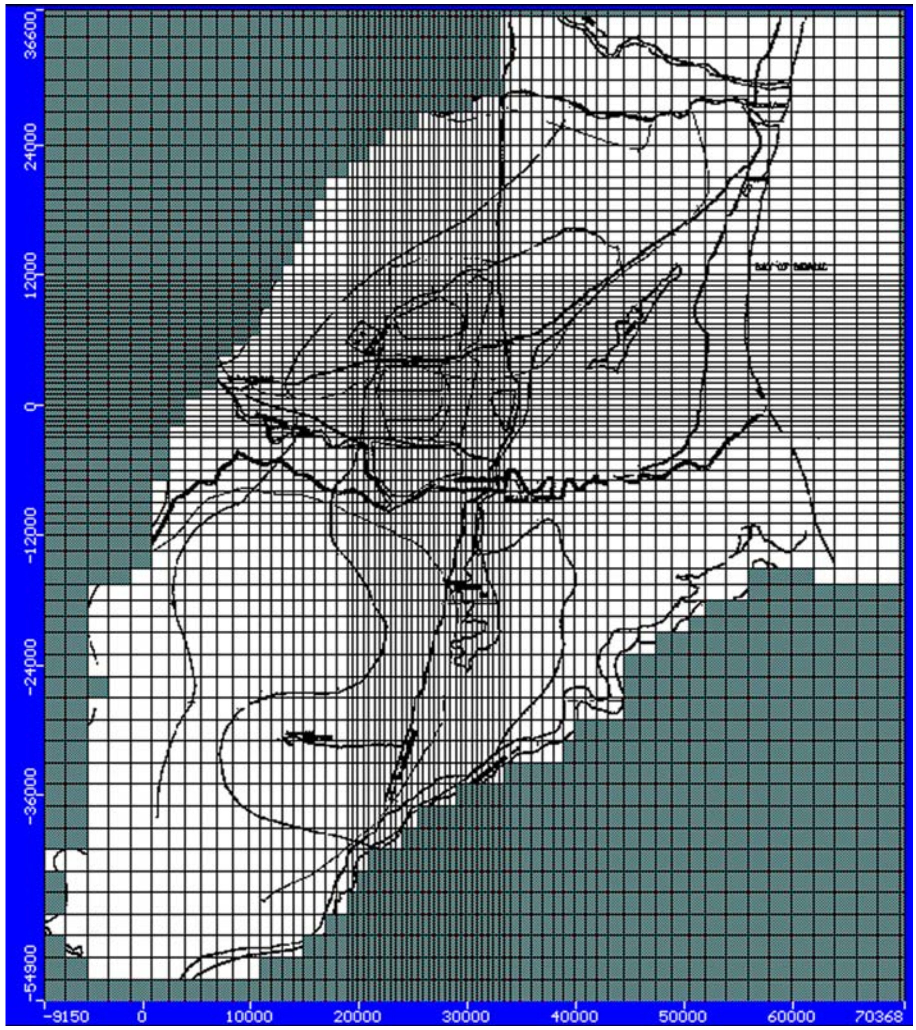

Fig. 1 Areal discretization of the Neyveli ground water basin with active and inactive cells

water requirements for the mines and the populace and cooling water requirements for the power station.

- Artificial recharge experiments should be undertaken using injection wells or other methods in the field.
- To periodically assess regional ground water variations, monitoring of dug and tube wells should be continued.
- Collaborative projects should be undertaken in the future to decipher the aquifer geometry, assess the distribution of potentiometric heads under different stress conditions, assess sector-wise impact of ground water withdrawal, and simulate ground water flow for varying stress conditions with the additional data generated. This will result in a well defined and more comprehensive ground water development plan of the basin.

Water Conservation Measures

To safeguard the region against water scarcity, an effective ground water management system is essential. The following steps are being taken, based on the discharge computations and recharge resources (Agrawal et al. 2004).

1. Optimizing the ground water extraction from the mines: the ground water control operational plans for all three mines have been drawn to restrict the water withdrawal within 170 MCM/a to enable lignite excavation under a positive head mining of 5–8 m.
2. Water savings at various key points has been summarized in Table 6. The quantity is significant from a water conservation angle and is given only for NLC industrial establishments where the consumption of water is high.
3. Other measures: A high level standing committee was constituted to monitor ground water/storm water extraction, utilization, and conservation in Neyveli industrial units. The committee will also identify additional conservation measures and implement them through NLC management. One such measure is the use of treated sewage water for horticulture (lawns, etc.) and afforestation of mined areas and mine spoil slopes.

Table 6 Water conservation measures at NLC

Conservation measures	Savings in ground water, MCM/year
Introduction of dry ash disposal system in thermal power stations	09
Substituting the treated storm water from mines for the raw water requirement of thermal power station–II and expansion unit.	35
Staggering the working hours of pumping in township by about 2 hours a day (Stage I)	04
Substituting the treated storm water for township drinking water supply (Stage II)	10

Source: NLC

Conclusions

Over the years, NLC has developed expertise for ground water conservation and management with specific reference to the Neyveli Basin. Ground water models have been extremely useful for the hydrogeological basin water mangement studies, which are being undertaken by NLC through ground water monitoring, controlled pumping, and improved/refined ground water recharge techniques, such as injection wells. The recharge for the entire Neyveli hydrogeological basin to the confined aquifer system was computed to be about 249 MCM and the total extraction from the basin was about 263 MCM for the year 2005–2006. This means that there is a deficit of 14 MCM in the ground water balance.

NLC efforts for water resource conservation and management, which include mines and other industrial establishments, e.g. power plants, are planned scientifically, with local as well as regional ground water management (basin studies). NLC has already taken necessary steps to optimize the mine pumpage, reduce pumpage for township water supply, and water consumption at various key points.

Anticipating the withdrawal of ground water by other sectors/agencies, NLC intends to strengthen implementation of the adopted methodologies to augment future recharge to the basin. NLC's successful attempts to replenish ground water, which is an ongoing process, have been appreciated by the Indian mining industry.

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