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TECHNICAL ARTICLE

Ground Water Control Techniques for Safe Exploitation of the Neyveli Lignite Deposit, Cuddalore District, Tamil Nadu, India

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Abstract Dewatering in deep opencast mines generally focuses on extraction of seepage water from the phreatic zones above the ore/mineral deposits and storm water that collects in mine pits. But at the Neyveli lignite deposit in the Cuddalore District, there was a danger of the mine floor bursting due to the hydrostatic head pressures in the underlying thick confined aquifers, a problem not previously encountered anywhere in India. Hydrogeological studies established the feasibility of mining the lignite by maintaining a constant cone of depression (pressure relief) in the surrounding aquifers below the mine by continuous pumping through a pre-planned network of wells. This depressurizing process had to be designed to tackle multi-layered confined aquifers and water table conditions. This paper traces the multi-faceted evolution in developments to control ground water at the Neyveli Mines.

Keywords Confined aquifer · Dewatering · Hydrostatic pressure · Lignite · Mine floor · Neyveli mines

Introduction

Neyveli, a remote hamlet in Cuddalore District, Tamilnadu, India, occupies a prominent place in the industrial and power map of India. The Neyveli lignite field extends over an area of 470 km^2 with a geological reserve of 4,150 million tonnes (t) (Fig. 1). The Neyveli Lignite Corporation (NLC), a Government of India Enterprise, is a major lignite mining and lignite-based power generation company. NLC has two large open cast mines (Mines I and II) in the Neyveli area, with a production capacity of 24 million tonnes/annum (MTPA), which supports two pit-head thermal power stations (TPS-I and II), and another mine, mine IA, which has a production capacity of 3 MTPA and provides fuel to a captive thermal power plant. NLC plans to expand the total production capacity of the three mines to 29 MTPA.

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Stratigraphy of the Neyveli Area

The general stratigraphy of the area is listed in Table 1. Of particular note are the aquifer sands of this huge basin and the associated formations (including the lignite), which belong to the Upper Miocene age of the Tertiary era. In the lignite field, the typical stratigraphical sequence of the basin consists of an uppermost layer of 2–3 m of topsoil (lateritic loam) underlain by 40–50 m of argillaceous sandstone. The sandstone is underlain by a discontinuous seam of white sandy clay (1–2 m thick). The sandy clay is sometimes underlain by 2–10 m of semi-confined sand. Below this is the lignite seam, which ranges from 12 to 20 m in thickness. The lignite is generally underlain by a seam of ball clay 1–2 m thick. This is underlain by a confined sand formation that is about 400 m thick, which is the main aquifer of the basin. Clay seams ranging in thickness from 0.50 to 3.0 m occur within the aquifer formation.

The Hydrological Characteristics of the Neyveli Ground Water Basin

The Neyveli ground water basin is a syncline with a maximum thickness of about 400 m of water-bearing sand

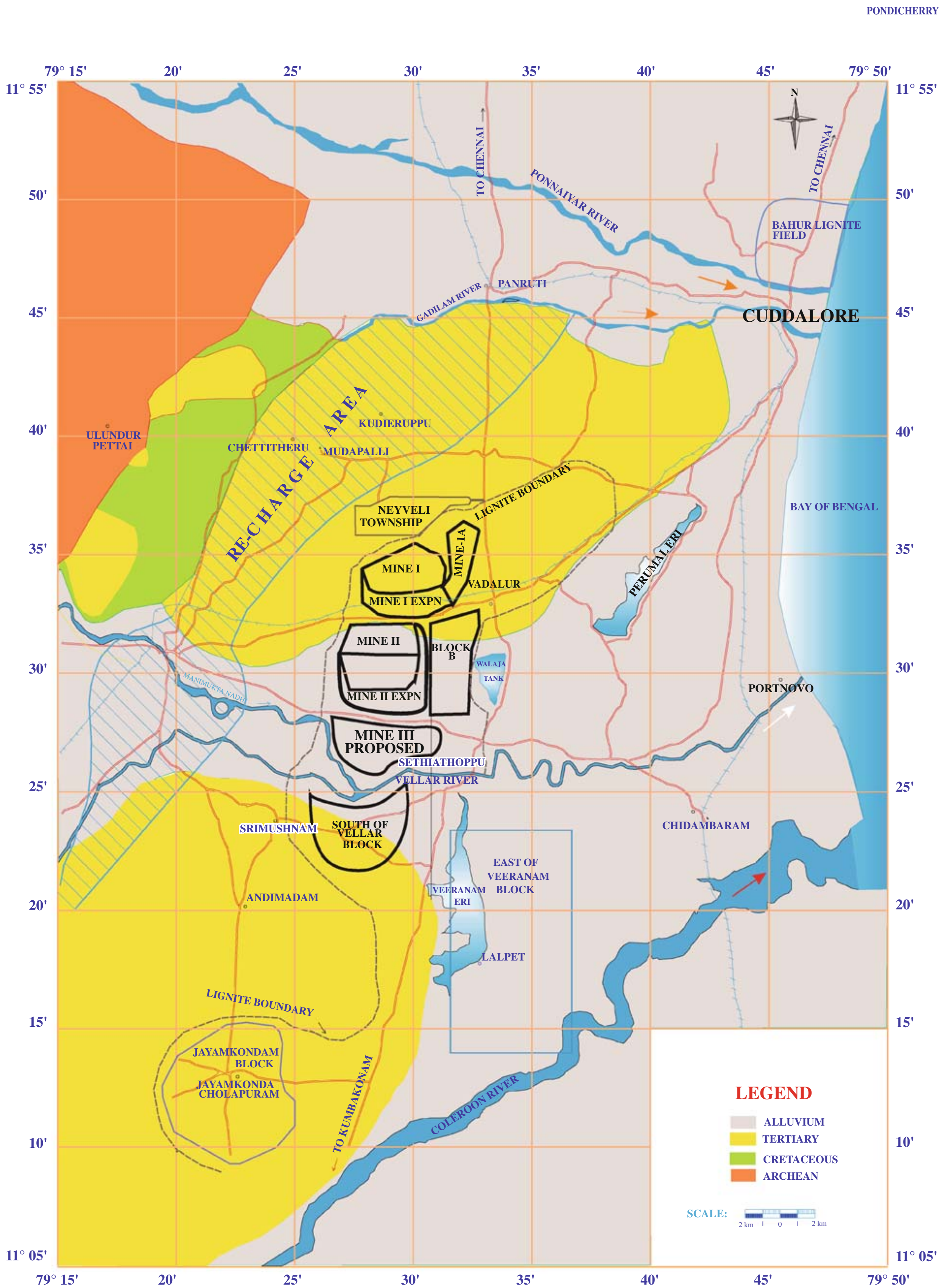

Fig. 1 Geological plan of the Neyveli lignite field

Table 1 Stratigraphy of the Neyveli area

Era	Period	Epoch	Lithology
Cainozoic	Quaternary	Recent	Soils, alluvium, laterite, kanker, brown sands
	Tertiary	Upper Miocene (Cuddalore formation)	Argillaceous sandstone, pebble-bearing sandstone, sandy clays, unconsolidated sandstone, sand (semi-confined aquifer zone), lignite, sand (confined aquifer zone) with clay intercalations; black clays or shales, grey sandstone, calcareous sandstone, and siliceous limestone with fossils
Unconformity			
Mesozoic	Cretaceous	(Ariyalur formation)	Shell limestone, siliceous limestone and marls, etc.
Unconformity			
Pre-Cambrian	Archean		Intrusive dolerite, pegmatite, quartzite, granitoid gneisses

Source: GS1 1969

in the central portion; it pinches to 50 m in the west, with a gentle rise towards the east and the sea-coast. The aquifer sands are mostly medium- to coarse-grained and highly permeable, with a porosity of 30%. The permeability normally ranges between 2×10^{-4} and 5×10^{-4} m/s. The sand formation above the lignite seam is under semi-confined conditions and the sand formations below the lignite seam are under confined conditions.

The static pressure head of the aquifer prior to commencement of ground water control (GWC) operations in Mine I (in 1961) varied from 15 to 35 m above MSL (+15 and +35 m) (Balasundar 1968) and in Mine II (in 1982) varied from 15 to 16 m above MSL (+15 and +16 m) (Gowrishankaran 1980). However, the dynamic conditions (brought about by pumpage from Neyveli Mines) and other discharges from the basin for irrigation have naturally affected the pressure head and gradient. A schematic section of the basin is shown in Fig. 2.

Within the lignite field, about 40–50 m of thick sand occurring immediately below the lignite seam is designated as the upper confined aquifer and the lower sand formation (300–350 m thick and separated from the upper aquifer by a 3–4 m thick clay seam) is designated as the lower confined aquifer.

The Neyveli artesian aquifer characteristics have been deciphered from various short and long-term pumping tests carried out by the Geological Survey of India (GSI), M/s. Powel Duffryn Technical Services Consultants, United Nation Development Project, M/s Otto Gold Co., and NLC Ltd since the early 1960s, both prior to commencement of the massive mining operations and subsequently during exploitation. These aquifer tests revealed that the Neyveli basin is one of the most complex ground water systems in India, comprising a sequence of multi-layer aquifer zones interconnected through low permeability layers. Pumping tests indicated that the upper aquifer zone has a

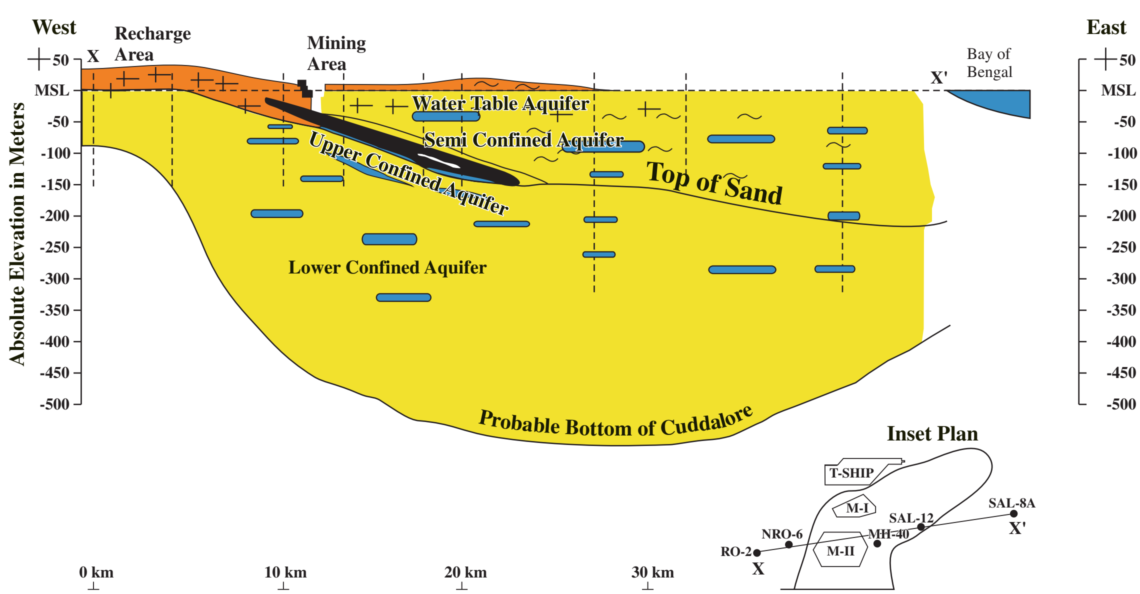

Fig. 2 West–East cross section of the Neyveli hydrogeological basin

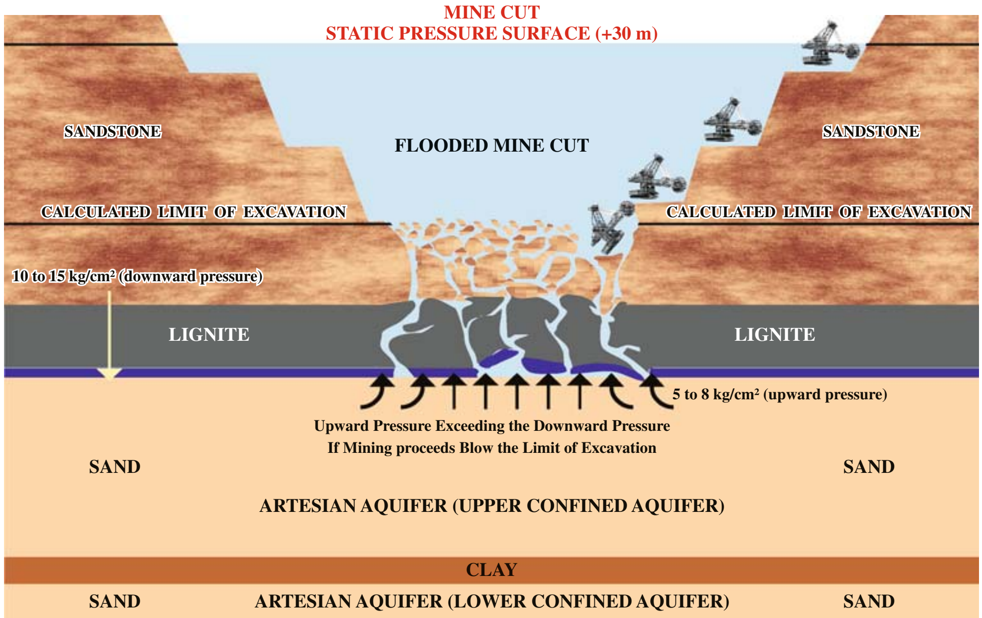

Fig. 3 Scenario without depressurization of the aquifer during lignite mining

transmissivity (*T*) value of about 1,000–1,500 m^2/day and a storativity value (*S*) of about 3×10^{-4} (GSI 1969; Kruseman and Redder 1970). The upper- and lower-confined aquifers below the lignite seam appear to merge into a single aquifer system outside the lignite field.

Mining in the Neyveli lignite field is complicated by the confined ground water in the artesian aquifers below the seam, which exerts an upward hydrostatic head pressure of 50–100 t/m^2 at the base of the lignite seam and would, if not carefully controlled, jeopardize mining operations (Fig. 3). The only force that prevents water from bursting through the lignite seam is the downward thrust exerted by the formations above the aquifer. But when the overburden is excavated, the downward thrust of the overburden is progressively reduced. It is evident that upward pressure could cause heaving and bursting of the mine floor and ultimate flooding of the mine.

Hydrogeological investigations and pumping tests indicated that the most practical solution to this problem was depressurization of the confined aquifer to maintain the pressure head below the lignite seam (initial technique) or just above the lignite seam (positive head, a better technique). Depressurization was achieved by large scale continuous pumping using a series of large diameter pump wells located at pre-planned/calculated distances from the active excavation zone (Fig. 4). Based on the pump tests, it was concluded in the late 1950s that large-scale pumping (as much as 40,000–50,000 gallons per minute (GPM) (3,030–3,790 L/s) would be necessary to achieve the desired pressure surface at the mine pit. A specially designed 1,000 GPM pump well, with a well screen that would prevent sand migration, was developed to keep the total number of pump wells in operation to around 40–50 during the initial mine cut operations of Mine I. Step-by-step operations towards the implementation are listed in Table 2. A typical depressurization operation is depicted in Fig. 5 below.

To control the ground water situation in this area, a methodology for constructing the pumping wells has evolved over the years. With particular reference to Mine I and Mine II, various experiments were performed and modifications were made to improve the state-of-the-art, as discussed briefly in subsequent paragraphs.

Mine I

As mining continued, it became clear that depressurization using a recognized grid pattern of wells was suitable for safe mining. However, based on field experience and considering the hydrological and mechanical aspects, the well construction methodology had to be modified time and time again to:

- Suit the available site/bench condition and the nature of the strata.
- Increase the life expectancy of the well.
- Establish good discharge—drawdown relationship.
- Achieve maximum permissible drawdown for optimum discharge, given the probable mutual interference between wells.
- Improved quality control to avoid well failures.

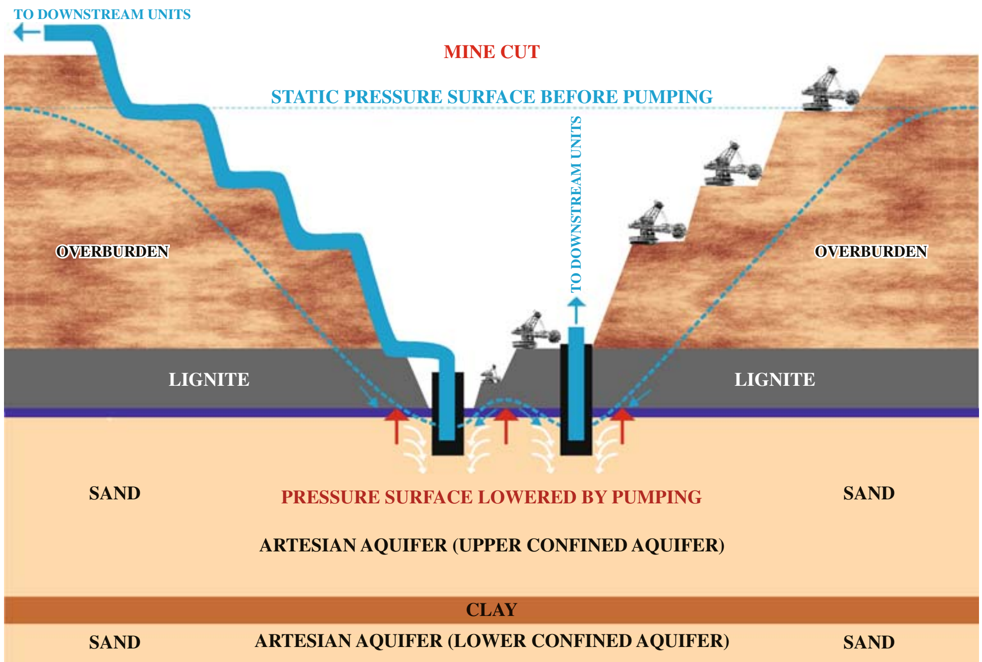

Fig. 4 Scenario after depressurisation of the aquifer during lignite mining

Table 2 Salient details of ground water control at mine I

Zone of depressurization	Pumping wells established as partial penetration wells, i.e., only the top 30–40 m of the aquifer to be penetrated
Method of drilling	Reverse circulation drilling (R.C. drilling)
Diameter of borehole	910–1,015 mm (36–40 inch)
Depth of borehole	130–140 m from the surface level, which varies depending on the location
Diameter of casing/slot pipes	0.508 m or 20 inch
Effective length of screen pipe	15–18 m
Size of slot	Length 0.07 m, width 0.003 m; conventional methods to choose the slot size could not be used as the Neyveli aquifer sand (within top 50 m) ranged between d_{40} and d_{90} retention sizes. A 3 mm width slot size was selected based on the indigenously possible methods of manufacturing the slots
Slot percentage	16–18%
Wall thickness of plain and slot pipe	Based on the quality of water (pH 6–7.5), the wall thickness was selected as 8 mm mild steel plate to withstand corrosion
Size of graded pebbles (gravel)	Graded pebbles of ≈6–8 mm packed in the area around the aquifer zone to allow entry of non-turbulent water into the well
Optimum entrance velocity of water into the well	About 0.03 m/s
Planned discharge/well	1,000 GPM
Pump capacity	175 (or) 250 HP submersible pump set with a 120/150 m head
Electrical installation	Electricity supplied through an 11 Kv pliable land line cable through H.T. skid and stepped down to 400 v by 11 Kv/400 v, 250 KVA capacity before the pump

- Standardize the methodology so that it could be adopted on a long-term basis.

Establishment of Pump Wells in the Mine I Spoil Bank: Initially, pump wells were established at the land surface and benches; later, wells had to be brought closer to the excavation face to keep pace with the mine advancement. This meant that the wells had to be placed in the mined out area, which had been refilled with overburden (loose sand, sandy clay, and sandstone spoil). Drilling of large diameter wells in the unconsolidated soil posed problems like caving, collapsing of boreholes, and subsidence of soil around drilling equipments.

Fig. 5 Depressurisation strategy adopted in the Neyveli lignite mines (*Source*: Gowrishankaran 1980)

Several experiments were carried out to improve the consistency of the bentonite drilling mud slurry (by maintaining 8% maximum concentration with a specific gravity of 1.05, and increasing settling time to enhance viscosity). But due to degradation in specific gravity and non-uniform drilling mud quality, it was decided to case the top section at a depth of 7.5 m. The sequence of operation was:

Stage I

Operation Phase 1

- The surface casing (1.5 m in diameter) was set to a depth of 1.25 m and concreted.
- A dry hole (1.37 m diameter) was drilled to a depth of 7.5 m.
- A 1.27 m diameter casing was set to a depth of 7.5 m and concreted.

Operation Phase 2

- The hole was filled with bentonite mud to about 2 m from the surface and allowed to settle for 48 hrs.
- A hole 1.2 m diameter was drilled, without circulation, through the mud, to the bottom of the spoil and up to 0.5 m into the in situ clay.
- A 1.016 m diameter casing was lowered into the hole to rest on the clay.
- The annular space between the casing and the wall of the hole was concreted.

Operation Phase 3

- The hole was extended about 30–40 m into the aquifer with a rotary coredrill, creating a 900 mm diameter hole.
- A 0.508 mm slotted casing that extended to the surface was lowered into the hole.
- The annular space was packed with graded 6–8 mm pebbles (gravel).

Stage II

The next stage of the evolutionary process was deployment of an auger hole, which has been used widely in the USA for sinking caisson foundations over which multi-story buildings have been built. A Cal Weld drilling machine was imported and used to drill dry boreholes to the bottom of the spoil (7.5–10 m). This was very effective because:

- The operation was quick and could be completed within 4 days; the old method took 2 months.
- Seepage problems and caving of soil was controlled by pumping of established wells in the surrounding area, which lowered piezometeric levels of the area below the bottom of the spoil. This allowed dry drilling without mud and meant that the use of intermediate casing (7.5 m) was only required 1–2 m from the drilling platform.

Sealing of High Pressure Pump Wells

Even though only 40–50 m of the sand separated by thick clays were considered, there were local patches where the unrelieved artesian pressure of the deeper confined aquifer affected operations due to some hydraulic continuity between the aquifers and due to absence or thinning of the clays. Wells constructed in these areas had problems caused by the pressure of the lower aquifer. This was first observed at well C/706 in Mine-I, drilled at 18 m above MSL or about 16 m from the ground level of the spoil bank bench. Upon completion, the water rose to the surface and flowed through the annular space (gravel pack); adding long casing pipe did not stop it. Ordinary methods like adding clay balls, pumping bentonite mud, cement sealing, etc. all failed to arrest the flow.

The flow in this well was sealed using "mud technology" especially designed for the problem. Adding bentonite drilling mud did not have the desired effect since the pressure of the lower aquifer was higher than the static pressure of the mud column. The specific gravity of the fluid in the borehole had to be increased to 1.6 to compensate for the differential head. Hence, high specific gravity mud mixed in pre-determined proportions of barytes (specific gravity 4.5) were pumped into the well in batches. This high viscosity mud was heavy enough to permeate into the annulus gravel pack and seal it slowly. Cement slurry (specific gravity 1.8, with 50% water) was used to seal the bottom portion of the well in an attempt to isolate the lower aquifer. Retarders like cutch (highly viscous bentonite drilling mud) and tartaric acid (5% solution) were added in pre-determined proportions to the cement slurry to delay its settling. After 24 hrs of settling time, the well was developed using dispersing agents to remove the partial clogging of the cement particles in the upper zone slots. On development, the well reacted like a typical upper aquifer well, indicating that the high-pressure lower aquifer had been effectively sealed off. This sealing technique was subsequently used at other wells whenever this problem was encountered.

Chimney Wells: Redundant lignite wells that extended into the spoil bank were sometimes successfully converted into wells by adding casing pipes as the soil/spoil was replaced. These wells were locally designated as "chimney wells". When successful, this saved money and time, but it was not possible where the cased holes had lost their verticality as the soil/spoil was dumped.

Mine II

With the advent of Mine II in December, 1982, the well construction methodologies that had proven successful in Mine I were initially adopted straightaway. However, again the methodologies had to be modified to suit Mine II strata conditions, even though hydrogeologically the aquifer was continuous, with very similar flow parameters. The wells in this area were established to varying depths depending on the location/bench (Table 3).

At places, the depth varied due to the local geology or the elevation of the bench formation. Well construction evolved around certain salient aspects such as:

- Dewatering of the semi-confined zone above the lignite seam.
- Depressurization of the upper confined aquifer zone only.
- Assuming that the 0.5 m thick clay below the top zone of the confined aquifer would act as a barrier and guarding it from being punctured.
- Handling contrasting type of strata, i.e., semi-confined fine- to medium-grained sands and medium- to coarse-grained confined sands, in the same wells.
- Maintaining constant vigil for factors that would contribute to well failure, such as the slot cutting pattern, optimum entrance velocity of water entering the well, and regulation of a sand-free discharge.

Table 3 Well details at mine II

Area/zone	Bench/location	Depth of bore hole (m)
South flank	Lignite/bottom	60–70
North flank	Middle/top	80–100
Advancing side	Middle/top	80–95

Some important modifications in the pumping and well construction methodologies that were adopted at Mine II, in addition to the techniques that were adopted at Mine I, have been highlighted and discussed below.

Modification 1

Drilling of Pump Wells in the Alluvial Soil: The first problem encountered in Mine II that required a modification in technique was due to the Quaternary deposits that capped part of the area (northern sector), comprising alluvial clay (up to 20 m and more in thickness) and loose unconsolidated sandstone. The clays were expansive, changing volume depending on the degree of moisture, and highly plastic in nature (clays had a tendency to shrink in volume when dry and expand when they took up water; Neyveli clays had low cohesive values (1.1–3.3 kPa), a high swell factor (1.6–1.7), and high dry linear shrinkage strength). This resulted in soil movement, flow, sliding, caving, etc.

Given these conditions, in the initial stages of Mine II, all attempts to start reverse circulation drilling (R.C. drilling) straight away from ground level proved futile as the soil caved in and wells had to be abandoned below 10 m. This necessitated the establishment of starter holes to the bottom of alluvial clays before commencement of R.C drilling. Furthermore, in order to avoid areas collapsing around the drilling platforms, endangering the safety of the rig, caissons (large diameter pipe, about 4 m) had to be provided. In addition to the above, properly treated bentonite mud was used to prevent wells from collapsing.

Modification 2

In the early stages of Mine II, we decided to handle the semi-confined aquifer sand separately by pumping through separate wells. Semi-confined wells 42 inch/36 inch (1.06 m/0.914 m) were drilled and 20 inch (0.508 m) pipes were lowered by screening the semi-confined zones in the advancing side of mine. Confined wells were established closer to the operation area by exclusively screening only the upper aquifer zone and sealing the top of the zone. Pumping the semi-confined zone exclusively through separate wells proved failed due to the natural hydraulic gradient within the mine. Instead, first, the top zone of the semi-confined aquifer was pumped, and then the entire zone was dewatered by seepage, leaving the wells dry. Thus, separate semi-confined aquifer well drilling and pumping had to be dispensed with.

Modification 3

Later, with expertise development, we thought that both the semi-confined and confined zones could be screened and gravel packed in the same well, avoiding separate drilling and the necessary infrastructures. However, the different sand grain sizes of the two zones led to well and pump failures. As the top zone of the semi-confined aquifer became de-saturated, water and fine sand would trickle and drip into the well from around the slotted zone, interfering with smooth operation of the pump and damaging the casing and column pipes. A second problem was that when the wells were dry and the pump was not operating, the water levels would gradually rise, re-saturating the de-saturated semi-confined zones; again, on pump starting, fine sand was brought in due to sudden lowering of the water levels, leading to pump failure. It became increasingly difficult to continuously operate the wells, leading to additional modifications (see modifications below).

To maintain the sustained water entry at an optimum critical velocity, the length of screening of the aquifer zone was increased to 22.5 or 25 m, depending on the available slot percentage (15–16% or 12–13%, respectively).

Modification 4

At locations, such as the flanks, where it was anticipated that the wells would be semi-permanent, the semi-confined slotted pipes were covered with wire mesh to a size smaller then the 2–4 mm semi-confined sand size, thus preventing fine sand entry. This method of construction was found to be effective and is now being used in both north flank and surface wells.

At locations, such as the top and middle bench, where the initially established well only has to be pumped to the same level as the advancing mine, the semi-confined zone is only gravel packed, avoiding screening the zone and allowing the water to percolate through the gravel pack by gravity and to be dewatered through the confined zone. This has proved to be useful as long as the wells being operated are on the advancing side of the mine cut.

Modification 5

Optimization of pumpage strategy involves achieving maximum drawdown with the minimum number of pumps. To achieve this, a ‘partial penetration well concept’ was tested in a few wells. This involved drilling through only 20–25 m of the upper confined aquifer, which generated/induced more drawdown in the well than the conventional method of penetrating the entire thickness. These partial penetration wells caused operational problems, such as fine sand entry, due to the turbulent action created around the well by the increased entrance velocity. This led to short well life expectancy. However, this type of well construction proved useful in the zones where the wells would have a limited life requirement.

Modification 6

Another modification introduced was the concept of drilling wells in the advancing face and subsequently reviving them by cutting, cleaning, and developing the wells in the in situ lignite bund (in the non-shifting side of the lignite bench). It was discovered that at some wells, it was no longer necessary to lower the pipe above the top of the lignite horizon, which enabled the area above the lignite horizon to be free of casing pipe, and trouble-free excavation while negotiating the borehole location. This has been tried in a few wells and proved to be successful in saving about 30–35 m (only if drilled from the top bench) of pipe length for each well. This method can be adopted for all the wells that are being drilled from advancing top benches.

Quality Control Modifications

Certain construction modifications were adopted for quality control as well and are detailed below.

1. To effectively maintain sustained pumping operations, pumps were initially extracted for maintenance after working for 8,000 hrs, but this became increasingly difficult as mining progressed, the number of pumps increased, and equipment required for pump extraction was increasingly unavailable. In addition, the movement of the equipments to extract the wells frequently damaged the approach roads and increased sand entry into the wells. To overcome this technical difficulty, a plain portion of 1 m immediately above the ‘bull nose zone’ was introduced to be used as a settling zone, above which the usual slotted portion commences. This modification proved highly practical and is now being used for all the wells.
2. The concept of drilling wells in the advancing side and subsequently cutting and reviving in the lignite bench (modification 6, above) was formulated in early 1995 with a spacing between the bunds of 200 m apart for optimization of pumpage and to bring the wells closer to the excavation face. It was observed that as these wells were cut for revival, movement of mining equipment caused the wells and especially the slotted portion to be choked with silty soil, which lengthened cleaning operations and sometimes required secondary development. To avoid this, a

plate, termed a "dummy plate," slightly lesser than well diameter (20 inch) was introduced at a depth just above or near the top of the lignite seam while the casing pipe was lowered after drilling. This prevented the entry of bottom bench soil and is now being done in all the wells drilled in the advancing side and subjected to cutting and revival.

3. Another practical problem being faced was the entry of sump water through the gravel pack into the well in the bund wells, where the gravel was packed to the top or even a few meters above the top of the lignite. When these wells were revived in the lignite bench just a few meters below the top of the lignite, the gravel pack just around the top of the casing allowed the sump water to enter into the well, leading to contamination and an operational hazard. This was overcome by gravel shrouding just to the bottom of the lignite or even below it, subject to the availability of a clay layer above the aquifer zone. Subsequently, the zone above the gravel pack was cement-sealed for 1–2 m, thus making an impermeable seal. This quality control practice has proved effective and is now used routinely.

Phases in the Development of the GWC Pumping Pattern

When the GWC operation first commenced, all of the pump wells were distributed in four grids on the surface, north, west, south, and east of the mine cut. The total pumpage ranged between 24,000 and 28,000 GPM, maintaining the pressure head at 6–8 m below the bottom of the lignite. With further development to deeper levels, pump wells were also brought to the benches, with a total discharge of about 45,000 GPM, allowing lignite production of 4.7 MTPA from both Mine I and Mine II by maintaining the pressure head at 3–4 m below the bottom of the lignite level (Fig. 6).

As the mine advanced, an inside spoil bank was formed by refilling the area already excavated for lignite. Wells were established on the spoil bank (as discussed above) to maintain an effective distance from the deep-cut line. The total discharge was maintained around 40,000 GPM, allowing lignite production of 6.5 MTPA by maintaining the pressure head at the bottom of the lignite level. The wells in the rear row, far away for the deep cut, were progressively made redundant.

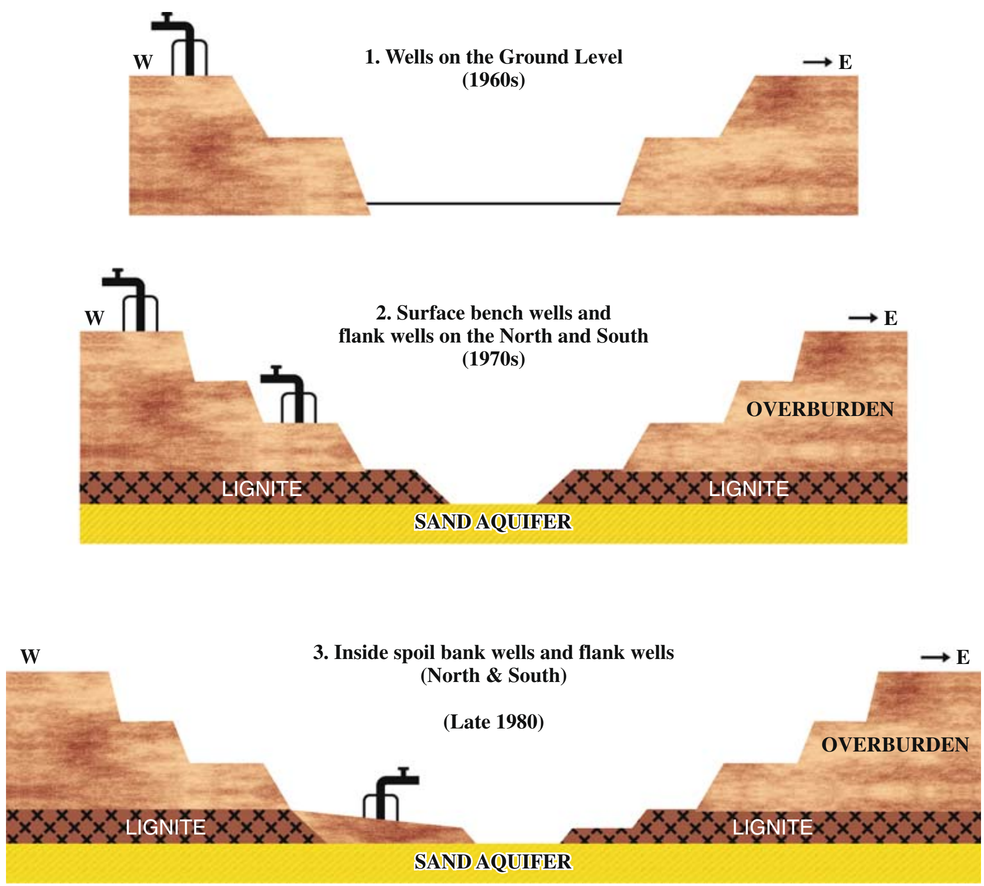

Fig. 6 Evolution of ground water control operations in the Neyveli mines—1960 to 1980

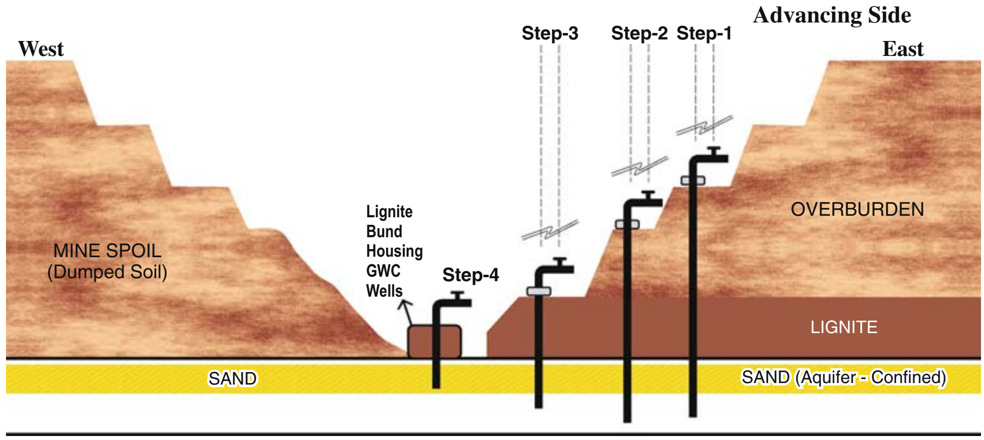

Fig. 7 Evolution of groundwater control operation—present

With the progressive dip of the bottom of the lignite and the advent of new mine cuts, the required draw down increased, especially in localized patches, and the draw down had to be planned more meticulously. In this phase, the pump wells were brought to the level of the lignite with marginally changed distances between the wells, enabling more draw down in the excavation zone. This gave two advantages:

- Drilling depth was reduced by moving the wells from the surface to benches and then to the lignite seam level.
- Water levels were sufficiently depressed using wells that partially penetrated the aquifer.

As mining expanded, the concept of optimization of ground water pumping had to be introduced. Instead of maintaining the water table a few meters below the lignite (initial phase), the number of wells and their depth were scaled back, resulting in lignite mining under a positive pressure condition (i.e., maintaining the depressed pressure level of the confined aquifer to the equivalent to a water table that would inundate 20–25% of the lignite seam). This positive pressure concept has been found to be effective in optimizing the ground water discharge from the basin (in all 3 mine cuts), but has resulted in additional handling of storm water since the mine floor is saturated. Presently, mining is being carried out by regulating the discharge to about 25,000 GPM (Mine I) and 30,000–32,000 GPM (Mine II) (Fig. 7).

Criteria for Planning GWC Measures

Based on the above discussions, the main criteria in formulating the GWC measures are:

- Mine position and mine advancement (for planning the location of pumping grids).
- Structural disposition of the lignite seam congruent to mine movement (for drawdown assessment).
- Achieving the maximum pressure relief at the point of excavation by altering the pumping combination in the proximity of the mine cut.
- The mutual effect of pumping from different wells.
- Assessment of optimization of pattern and pumpage for each mine.
- The nature of the strata and the depth of the wells.

Effective and continuous monitoring of GWC operations is necessary. The voluminous and complex hydrogeological data are analyzed using mathematical models (IIT 1975) and sometimes, the underlying aquifer parameters have to be modified to optimize GWC. Ground water management models were developed for the for Neyveli ground water basin by different organization under the detailed regional ground water management plan. Ground water modelling (NLC 1988, 1992) has allowed us to simulate future scenarios by taking into account the effect of large-scale withdrawal from the basin and changes in flow parameters, if any, in the region as a consequence of extended operation.

Conclusions

From the above discussion, it is clear that NLC has made significant strides in the management of its hydrogeological problems. Some of the noteworthy milestones achieved are:

- The concept of maintaining the confined pressure head 6–8 m below the level of the working lignite seam was progressively raised, first to the level of the bottom of the seam and now at a positive pressure of 3–4 m above the lignite bottom (i.e., at a level of 20–25% of lignite thickness above the bottom horizon).

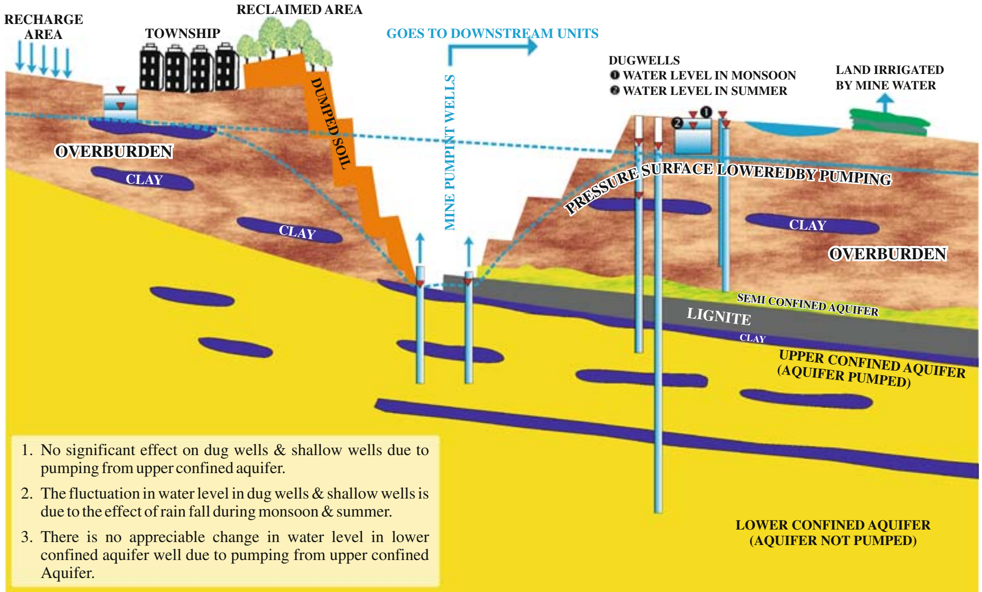

Fig. 8 Hydrogeological conditions before and after mining

- Networking of the pump well grid pattern for depressurizing was scaled back from the initial concept of establishing wells at surface level to benches in the spoil bank (the refilled area) and then to the level of the lignite bench (lignite top horizon).
- Initially, the area covered through the network of wells at the surface level was extensive, the depth drilled was greater, and the impact on lowering the water levels was less. Shifting the wells to the benches and closer to the excavation face decreased interspacing between the pump wells (from 100 to 75 m), while reducing the amount of drilling and the amount of pumpage.
- As the mine advanced, the initial pumpage of 24,000–25,000 GPM during the initial mine cut of Mine I was enhanced to 45,000 GPM. Production increased to 4.7 MTPA at both Mine I and Mine II; at Mine I, this was further increased to 6.5 MTPA, with a pumpage of 70,000 GPM. Recently, the GWC pumpage was scaled back to about 50,000–55,000 GPM from both mines while producing 21 MTPA. A comparison before and after exploitation of lignite is shown in Fig. 8.

Over a period of four decades, it has been possible to reduce the pumpage of ground water by one-third (from a level of 25–30 kL to a level of 10 kL for each tonne of lignite mined), thereby helping to reduce the cost of mining. NLC's success in ground water management was brought about by successive experimentation with grid spacing, location, and pressure head, while at all times being conscientious of mine safety. We are open to further improvements and are optimistic that as mining continues to expand, it should be possible to continue to improve our practices.

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