A Study Into the Effects (Including Environmental) of Mineral Sand Mining on the Tomago Sandbeds Aquifer at Newcastle N.S.W.

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SUMMARY. The Tomago Sandbeds contain two valuable resources, water and heavy minerals. Water is abstracted from pumping stations within the gazetted catchment area and at the time of the study two areas outside the gazetted catchment area were being mined for heavy minerals. The development of the existing water supply scheme is outlined and the factors pertinent to mineral sands mining operations are noted. Under the general headings of geology/stratigraphy, groundwater/hydrology, chemistry and the vegetation/environment, the possible changes due to mining on the use of the aquifer are assessed. Finally, conditions are set out under which mining might proceed within the gazetted catchment area, without adversely affecting the quality and quantity of water available and its abstraction.

1 INTRODUCTION

The Tomago Sandbeds contain two valuable resources available for the use of man, water and heavy minerals. The former is replaceable through the forces of nature but the latter is irreplaceable: thus one is of long term value and vital to the continuing life of the community regionally, while the other is of considerable but transient economic value to the country.

The Tomago Sandbeds are located to the north east of Newcastle and cover an area of approximately 130 square kilometres. The sandbeds are contained within the area bordered by the Hunter River, the southern boundary of Grahamstown Reservoir, Pipeclay Creek around the bays of Port Stephens to Tilligerry Creek, and across to Fullerton Cove off the Hunter River. Over most of the area the ground lies between RL 6 m and RL 9 m and tends to be flat or gently undulating.

The Tomago Sandbeds are utilised by the Hunter District Water Board (the Board) as one of the three major sources of water supply for the Newcastle region and were first brought into use in 1939. The area of the sandbeds controlled by the Board and designated the gazetted catchment area, is approximately 100 square kilometres in extent. The majority of this area is utilised and owned by the Board for the purposes of water supply. The storage potential of the sandbeds may be gauged by considering that the weighted mean high ground water level has been estimated at approximately RL 6.67 m: depending on the limit criteria used this represents a storage of 110 to 160 x 10^9 litres. The Board's investments in capital works associated with the sandbeds and located on the sandbeds have amounted to approximately $A 5 million; however, present day or replacement values would be considerably in excess of this sum.

Exploratory work undertaken by mining companies indicates that an appreciable portion of the sandbeds contain heavy minerals and that the commercially viable leads are generally within about the top 25 feet. No official estimate has been placed on the value of the heavy minerals but with the recent increases in value of rutile, illmonite, zircon and monozite, indications have been given that the deposits have a value in excess of $A 70 million.

2 DEVELOPMENT OF SANDBEDS WATER SUPPLY SCHEME

The first phase of the scheme was a shallow development one operating on a suction lift. By 1941, 15 pump stations commanding a large extent of the sandbeds had been installed: these electrically operated stations each drew water from 60 tube wells penetrating to depths of 13.5 m: the maximum rated capacity of each station was 115 ℓ/s. Conceptually, the second phase undertaken in the mid nineteen fifties differed from the first stage by being a deep well pumping development comprising bore pumps (7.5 to 9.5 ℓ/s maximum rated capacities) in wells penetrating to depths of about 20 m and interconnected in groups of 8 to 16 wells to a station: a booster pump was installed in the more remote stations. Additionally, in this phase five of the original stations were converted into deep well bore pump stations. All the pumping stations are connected to a large diameter header main traversing over 20 km of the sandbeds and feeding into treatment works: the latter have a rated combined capacity of 80 Mld (with an overload capacity up to 110 Mld). An authoritative description of the scheme has been provided by the Board (Ref. 1).

3 POSSIBLE EFFECTS OF MINING

Mineral sand mining has been undertaken in Australia for many years, but not in other areas where the sand forms an aquifer being used as a major source of water supply; it is the latter feature that makes the Tomago Sandbeds area unique. Thus when it was realised that it was likely that applications to mine within the gazetted Tomago catchment area would be lodged by mining companies and at a time when perimeter areas outside the gazetted catchment were already being mined, it became apparent that further investigation and assessment of the area was necessary in order to ensure that the existing water resources were not jeopardised in any way either quantitatively or qualitatively. Also if mining was to be permitted, it would be necessary to formulate controls which would have to be imposed to safeguard the aquifer and the environment.

With these objectives in mind, it may be said that the investigations set out to evaluate and answer the following questions:-

- What does mining involve?
- What are the existing conditions relating to the nature of the sandbeds, the hydrology and the related chemistry as well as the vegetation in the area?
- What changes occur or may occur as a result of mining?
- Is the mining of the mineral sands compatible with the use of sandbeds as an aquifer or alternatively can the mining be regulated in a manner such that the interests of the water authority may be safeguarded?

4 THE MINING OPERATION

Two forms of sand mining are used along the east coast of N.S.W., dredge mining and open cast mining. At Tomago, the level of the water table is generally relatively high with respect to the base of the mineral leads and dredge mining has been the only method under consideration.

The typical mining cycle (after initial development of a dredge pond) may be summarised as follows:-

(i) Clear and burn trees and undergrowth.
(ii) Strip and then stockpile the topsoil.
(iii) Mine forward by cutter suction working along and undercutting the front sand face of the pond, the upper material being removed after it has fallen on to the floor of the pond.
(iv) The dredged material is pumped back along a flexible pipeline, supported on floats, to a pontoon mounted concentrator plant.
(v) Preliminary screening of the dredged material to remove oversize coarse (say > 6 mm) and organic material, depositing this material back into the pond.
(vi) Gravity separation of the heavy minerals is undertaken on the concentrator plant.
(vii) The heavy minerals are pumped ashore to a stockpile where the concentrate is de-watered and temporarily stored before removal offsite for mineral sorting.
(viii) The remaining material (i.e. the mineral reduced sand) is ejected hydraulically at the rear of the pond as tailings.
(ix) The tailings are levelled off or contoured, the topsoil replaced and revegetation measures put in hand.

The stages noted above are shown diagrammatically below:-

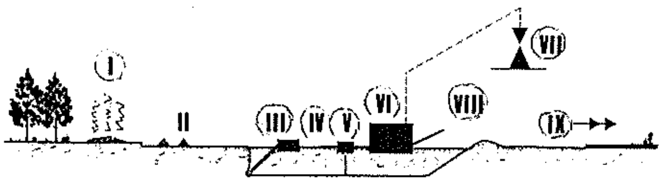

Fig. 1 Diagrammatic representation of mining cycle

5 THE EXISTING CONDITIONS

In order to study the effects of mining disturbance, it was a pre-requisite to obtain knowledge of the present geohydrological and chemical conditions. This then became the background against which to judge the changes brought about by mining which in turn established the basis to assess the effects on the aquifer and determine measures necessary to control and/or alleviate any adverse effects of mining.

The general characteristics and conditions of the existing environment were determined by a carefully planned and wide ranging programme of field and laboratory work having regard to each of the main factors involved, namely:

Geology Stratigraphy	To investigate the extent of the aquifer and variability of the stratification within it.
Groundwater Hydrology	To determine the permeability, porosity of the sandbeds and the regional water table and to develop a mathematical water balance model for the aquifer.
Chemistry	To ascertain the quality of the groundwater and related insitu chemical constituents in the soil.
Vegetation Environment	To classify and map the natural vegetation and landform.

(a) Geology

The following stages were deduced in the geological development of the area. An elevated surface formed of Permean sediments, consisting of interbedded siltstones and mudstones comprising part of the Tomago Coal Measures, was eroded until by late Pleistocene times a quite irregular land surface existed. Submergence of this surface then took place, whereby the Tomago Basin was formed. This was later cut off and closed by a sand bar which resulted from prevailing currents, assisted by a further drop in sea level. Sedimentation occurred within this basin from stream borne and sea borne deposits with intertongueing occurring. The sediments were mostly soft to stiff grey clays and silt, Tomago clays with occasional gravel and did not cover completely the Permean base. Re-entry of the sea followed and deposition of sand occurred on the ocean beach front. The heavy minerals were deposited during this period. A further fall in sea level and deposition of wind blown sand occurred to form dunes as the beach retreated south eastwards. Thereafter fluctuations in ground water level led to the development of Podsol profiles in the sands. A few swamp deposits exist on the present surface of the sands in isolated low lying parts.

(b) Stratification of Sandbeds Aquifer

The study was concerned primarily with the sandbeds aquifer itself. The base of the aquifer was found to be clay and/or rock: the base was plotted and contoured and is shown on Fig. 2.

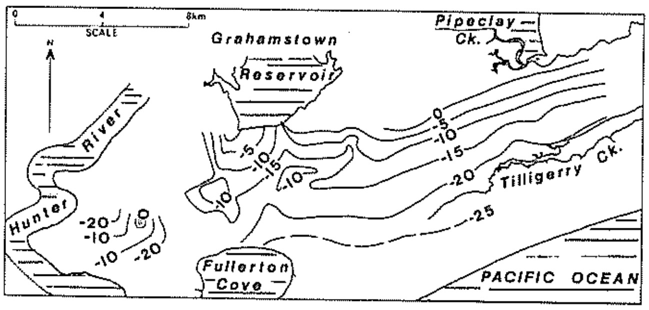

Fig. 2 Base of aquifer contours

From a study of the 325 sandbed samples taken by driving 6.35 mm nom. dia. tubes (Ref. 2 and 3) and obtained throughout the sandbeds, it was found that a convenient correlation existed between individual strata and the colours of the tube samples immediately on recovery. In general, the profile consisted of the upper light sand (ULS), the dark sand (DS), the lower light sand (LLS) and the under lying grey sands (GS). The dark coloured sand representing the B horizon of a typical podsol profile, was found to be occasionally cemented, and in this condition is known locally as "Wooloomooloo rock". It is equivalent to the "coffee rock" of West Australia reported upon by Andrews (Ref. 4). A typical section through the sandbeds is shown on Fig. 3.

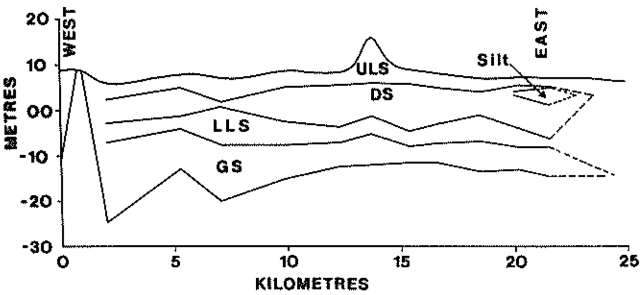

Fig. 3 Central section through long axis of sandbeds

Mechanical properties of the sands in the various strata were examined and Fig. 4 shows the average gradings of the upper three strata are almost identical, with the grey sand being distinctly finer than the overlying strata. Mineralogical examination showed mostly rounded to subrounded quartz for all strata except the GS whose larger grains were angular.

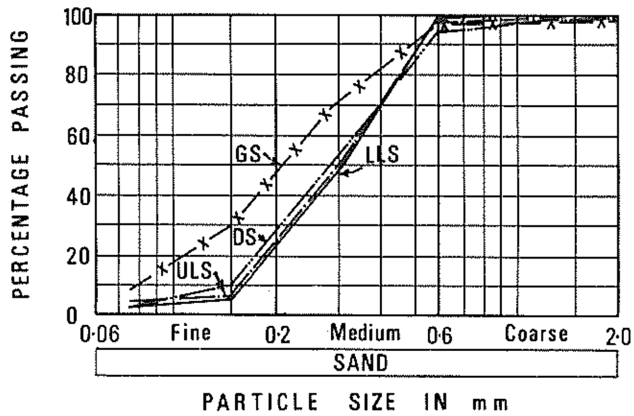

Fig. 4 Average gradings of sand strata

Extensive measurements on the density of the sand in the various strata were made using the air injection sampler. The average results obtained above and below the water table were all within the range 1600 to 1630 kg/m^3, with the exception of the DS above the water table where an average density of approximately 1550 kg/m^3 was obtained. These densities represent porosities of approximately 39%.

As a matter of routine, SPT values were obtained but their use for ascertaining satisfactorily the changes in density was indeterminate due to the presence of cemented zones.

(c) Hydrology of the Aquifer

Initially, a network was established of groundwater observation holes, the majority of which were related to but remote from the water supply abstraction points to minimise interference. Comprehensive ground water contour maps of the area were drawn up and these are continuing to be made at monthly intervals in order to observe seasonal and yearly variations. The main factors affecting changes in the ground water levels in the catchment area are climatic conditions and the Board's abstractions. An analysis of the rainfall data showed that it varied from 1000 mm per year near the Hunter River to 1300 mm per year for the eastern zone. Abstractions of water by the Board have been carefully recorded from the commencement of pumping operations in 1939. The peak value abstracted in any one year was approximately 26×10^9 litres.

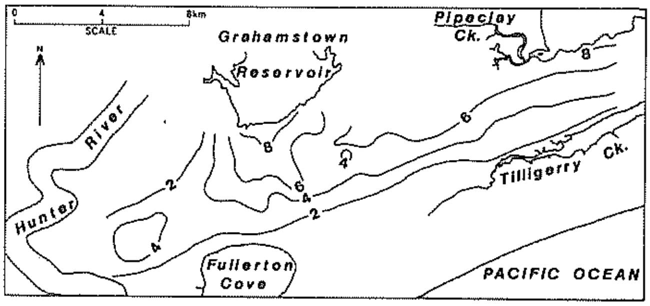

Fig. 5 Typical ground water contour plan

Prior to this study, large scale pumping tests had been carried out near the western border of the sandbeds and these have been reported by Herzog and Gerard (Ref. 5). They indicated in natural ground (unmined) an average coefficient of permeability of approximately 2.5×10^{-2} cm/sec. During this study, an extensive programme was undertaken of individual permeability tests (constant head above ground water level and rising/falling head below ground water level): results were obtained from 100 locations from over 40 positions in plan over the area of the sandbeds. The overall average estimated probable permeability was 1.5×10^{-2} cm/sec and location averages lay within the range 0.02×10^{-2} to 4.5×10^{-2} cm/sec. No definite pattern was observed for any concentration of high or low results in any particular area although the light sand strata were on average, the most permeable. Comparing the different types of tests confirmed the normally higher value for the rising head technique indicated by experience, although precautions were taken to minimise uplift. The constant head test generally gave consistently lower results probably due to the different environment for these tests.

In order to obtain an assessment of the relative behaviour of the hydrological factors affecting water movements within the aquifer, a mathematical water balance model was developed utilising the monthly data from a selected 6 year period. The catchment was divided into three parts and each was considered separately. The mathematical model was then developed from the following equation:-

$$G_{i+1} = G_i - a'G^n_i - b'E_{pi} + c'(R_i - X_i) \qquad (1)$$

In the equation, G_{i+1} and G_i are respectively the volumes of ground water stored at the end and start of each month, R_i and X_i are respectively the measured rainfall and abstraction during month i, E_{pi} is the evaporation measured in an "Australian" type evaporimeter, $a'\,G^n_i$ represents the net seepage losses and a', b', c' and n are dimensionless constants.

(d) Chemistry of the Aquifer

This was examined with relation both to the soil profile and the ground water. It had been found already that iron is the parameter of crucial importance to the operation and management of the aquifer: therefore, a definite part of the work was directed towards identifying and ascertaining the variations in iron across the aquifer, and also the transformation mechanisms occurring causing the solubilisation of the iron.

The results of the chemical analyses on the soil samples from the four main sand strata were plotted out across the length of the aquifer to examine regional variations. A plot of interest is that of the chemistry of the sand, comparatively by strata (see Fig. 6). The high iron in the grey sand is considered to be a factor warranting further consideration in the future development of the area as a water resource, although the level of the grey sand is generally such that it is unlikely to be affected by a mineral sand mining operation.

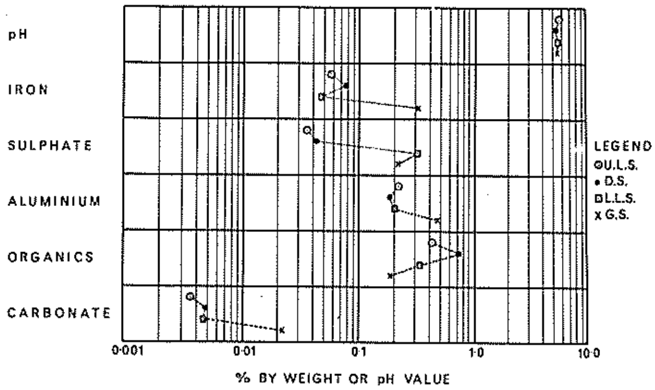

Fig. 6 Soil chemistry by strata

The water quality was investigated by testing samples from the network of sampling points established during this study and by consideration of results of tests obtained from integrated samples from the Board's pumping stations. Fortunately, with respect to the latter, detailed records have been maintained by the Board throughout the period of use of the sandbeds. The groundwater is acidic throughout the sandbeds and some correlation was indicated between the groundwater abstracted and the base level of abstraction with relation to the level of the grey sand.

It was considered that some change might occur when sampling from the water supply wells, due to chemical transformation mechanisms especially with respect to the iron content. A point of considerable interest with respect to the iron and the groundwater is the mechanism whereby iron is brought into solution from insoluble compounds. The mechanism which is most favoured depends upon the introduction of air into previously submerged iron bearing strata (Ref. 6) causing the initial dissolution of iron by oxidising the insoluble sulphide to soluble ferrous sulphate: the process may, however, be extended by further oxidation to produce insoluble iron hydroxide. The reactions may be shown simply as follows:-

$$FeS_2 \xrightarrow{+O_2} FeSO_4 \xrightarrow{+O_2} Fe(OH)_3 \qquad (2)$$

The oxidation of the sulphide generally occurs through the agency of, and can be greatly accelerated by, sulphur oxidising bacteria. It is, of course, this first reaction above which is of prime importance. The implications of the above hypothesis have been examined in relation to the use of the aquifer. It was noted that an indication exists between pumping rates and the pumped water quality (Board's records) and that the worst effects on the quality (i.e. high iron content) occurs nearly one year after heavy pumping.

(e) Landform/Vegetation

By means of aerial photo interpretation and field visits, a survey of the vegetation was undertaken. Six main vegetation classes were identified and mapped. The classes were: heathland, shrub savannah, woodlands, forest, swamp and cleared land.

6 CHANGES RESULTING FROM MINING

In considering the changes resulting from mining, it was advantageous to the study that mining was already taking place in the sandbeds area outside the gazetted catchment: one operation was at the western end and the other near the eastern end of the sandbeds. The latter was adjacent to a salt water boundary and in an area where the sandbeds were comparatively shallow: here the mining was undertaken down to the level of the clay base of aquifer. The western area on the other hand was reasonably typical of the sandbeds and this site provided valuable information.

The western area, in particular, was studied as an active mining area in much greater detail than the remainder of the catchment; although detailed attention was given also to two prospective mining areas within the gazetted catchment area where mining might first be permitted to take place on an experimental basis.

More obvious changes resulting from mining are apparent from the description of the mining operation in Section 4, i.e. elimination of the existing vegetation and soil structure. Questions which arise from the sand resorting operation are:

- is the restructuring of the sand deposits of significance?
- is the pattern, rate of flow or storage of ground water affected?
- is the quality (chemically) of the water affected?
- how can the changes in vegetation be minimised?

The answers to most of these questions follow on from consideration of changes in soil structure and factors affecting the ground water, hydraulically and chemically and finally by considering vegetation requirements.

(a) Soil Structure Changes

The main feature of concern identified was an extensive layer of mainly fine material termed "slime" deposited on the base of the mining pond. The significance of this layer is commented on further in the paragraphs following. In size, it was mainly less than 0.15 mm, passing AS sieve No. 100, and was found to be rich in iron and organics. Aggregated thicknesses of up to about 300 or 600 mm in places were measured in holes put down through the restored mined-over ground.

(b) Factors Affecting the Groundwater Hydraulically

The slimes layer at the base of the pond level was found to be relatively impermeable (i.e. approx. range 10^{-5} to 10^{-6} cm/sec). Hence it could seriously inhibit any vertical flow through it and might therefore affect the recharge of the sandbeds.

The results of a few large scale pumping tests and multiple local (small scale tests) indicated that the permeability of the tailings (above the slimes layer) was greater than that of the undisturbed ground by a factor of some 50%.

The average density of a limited number of sand samples obtained from the tailings by means of the air sampler was not significantly different from that obtained from the unmined ground.

Gradings of samples from the tailings indicated that there was a marked reduction in the percentage of fines passing AS sieve No. 100. This is consistent with the formation of the predominantly minus AS No. 100 slimes layer at the base of the pond level and the increased permeability.

(c) Factors Affecting the Groundwater, Chemically

Two important features emerged in the chemistry survey. Firstly, a high concentration of iron was found in the slimes layer at the base of the pond, and secondly, the groundwater in the mined-over area showed notable increases in soluble iron several months after mining had occurred nearby. It may be noted that the latter observation is in keeping with the delay effect described previously in a comparative analysis of water chemistry and heavy abstractions of groundwater. Laboratory tests undertaken support the hypothesis that increases in soluble iron are related to the presence of the slime layer.

(d) Vegetation Changes

Changes must occur from the removal of the trees and topsoil. Their effect is summarised in the following list of objectives of revegetation:-

(i) Stabilisation of the ground surface against future erosion.
(ii) Prevention of increased water losses.
(iii) Prevention of deterioration in water quality.
(iv) Re-establishment of a stable fire resistant eco-system.

7 TECHNICAL SAFEGUARDS

Considerations of the findings of the study led to the conclusion that it should be possible to permit limited mineral sand mining operations to be undertaken by the dredge process in a manner whereby the interests of the Board would not be adversely affected providing certain safeguards were incorporated in the mining process and appropriate detailed and carefully monitored control measures were adopted. These considerations would be subject to progress reviews as mining proceeded. The main technical control measures are outlined below:-

(i) Local conditions - investigation of ground conditions and groundwater to be ascertained in the area to be mined to check that no new factor exists which requires attention e.g. local silt formations.
(ii) Slimes - the slime separated out by the mining process should be removed from the pond and catchment area.
(iii) Organics - organic matter should not be permitted to accumulate in the pond.
(iv) Groundwater - the quality of the groundwater in the area should be checked regularly to obtain a verification of the efficacy of the measures and controls adopted, particularly with the passage of time.
(v) Vegetation and Landform - the nature of the vegetation and landform existing before mining should be ascertained in some detail and measures should be taken to re-establish the pre-mining landform including the topsoil and the indigenous species to the extent practically possible.

To achieve the above a detailed control and monitoring system is required to provide regular and constant checks on the performance of the operation, and should adverse effects attributed to mining be detected, powers should exist to enable the Board, if necessary, to stop operations in the area until adequate remedial measures are taken and until a satisfactory operating procedure is established.

As a point of current interest, it may be noted that mining is proceeding satisfactorily now on a lease area within the gazetted catchment area in accordance with the detailed conditions set out and noted in principle in this paper.

8 CONCLUSIONS

The mining of mineral sands by the dredge process in the Tomago aquifer causes changes which, if not carefully controlled, could result in effects detrimental to the aquifer as a source of water supply. Therefore, in order to safeguard the aquifer, it is imperative that suitable controls are adopted for any mining operations which are permitted. To verify the compliance with and adequacy of the measures, a monitoring system is required. A contractual basis for the work is necessary giving the Board adequate powers to enforce the safeguards formulated. Subject to these provisos, it should be possible for restricted mining to proceed in the Tomago catchment area without detriment to the Board's interests.

9 ACKNOWLEDGEMENTS

The study described was a multi-disciplinary one involving many experts and organisations. Unfortunately space does not permit individual acknowledgements. The authors, however, are grateful to the Hunter District Water Board for permission to publish this paper.

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