Balancing Competing Water Resource Demands and Mining in a Coastal Environment

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ABSTRACT

The mining of mineral sands in coastal aquifers is often constrained by other land use conflicts and inappropriate controls imposed through a lack of understanding of environmental interactions and processes. The recent experience with the Tea Gardens mining operation illustrates how increasing our knowledge and understanding leads to more effective management of environmental problems.

As well as a source of heavy minerals, the Tea Gardens sand bed serves as a town water supply source. From past experience it was believed that mining could cause undesirable increases in dissolved iron concentrations in the aquifer, but the reasons and mechanisms for this phenomenon were not clear. A water monitoring program was therefore designed for the mining operation which was aimed at protecting the water supply borefield from any detremental effects.

After one year the results of the monitoring program were assessed in the light of new knowledge and understanding of iron hydrochemistry. It was found that the existing program was not achieving some of its major aims, and was therefore modified to a more effective and cost efficient program.

INTRODUCTION

The 1,500 kilometre stretch of eastern Australian coast from Wollongong in New South Wales to Rockhampton in Queensland, harbours one of the worlds greatest resource of the minerals rutile and zircon. But 40% of Australia's population also lives within this coastal strip and the area is the subject of more intense land-use than any other area of the continent. Inevitably there are many conflicts between competing interests.

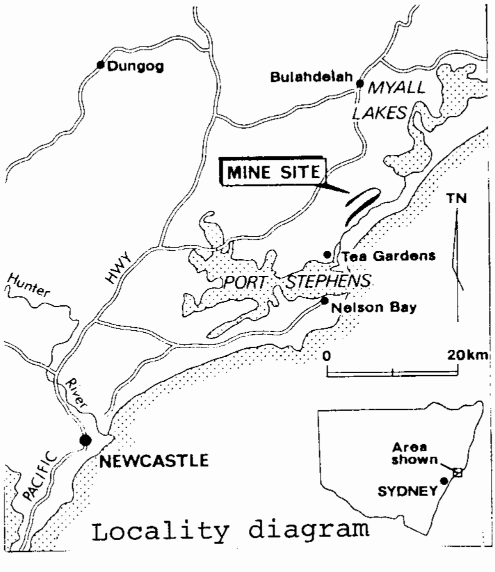
The conflicts between environmental conservation interests and the mining of heavy minerals from coastal sand beds have been particularly bitter because the operations are so visible and enroach on such a diversity of coastal environments - stable dune systems, unique sand bed forests, heathlands, fresh water wetlands etc. So much so that a multitude of environmental regulations and constraints now govern these mining operations.

Many of the constraints imposed by government agencies, particularly in regard to the aquatic environment, are probably unecessary and are symptomatic of an "overkill" situation due to a poor understanding of the interaction between mining activities and the environment, and a lack of confidence in predicting the consequences.

Nevertheless, we are continually building on our knowledge and improving our understanding through research and practical experience which leads to benefits for both the environment and the mining industry. The experiences with the Tea Gardens mining operation well illustrates this continuing process.

ENVIRONMENT

The mine is located 50 kilometres north of Newcastle between Port Stephens and the Myall Lakes.



Locality diagram

The area is a magnificent part of the New South Wales coast, and for the benefit of our overseas visitors, just a brief view of the environment. (slides)

These lakes, swamps and forests are all part of the Myall Lakes National Park which was declared at the end of a protracted, emotional and intense dispute over mineral sands mining in the area.

The present mine site is just outside the boundaries of the national park and the actual lease is dominated by the remains of an unsuccessful slash pine plantation which will be rehabilitated to native vegetation after the mining. So in this case the environment will actually benefit from the mining.

The mining lease is part of the Tea Gardens sand bed which was deposited as fluvo-estuarine sediments during the Late Pleistocene. The predominantly quartz sand, with some beds of carbonaceous sandrock, rests on a basement of Carboniferous rocks to a thickness of 10 to 30 metres (1).

Economic mineralisation occurrs as a number of parallel placer deposits within the upper 6 metres of the sand beds. About 20 km^2 of the area will be mined and the operation which began in November 1986 is expected to have a life of 10 to 12 years.

The operation uses conventional dredge techniques, that is, a suction cutter dredge floating on a water table pond pumps sand slurry to an accompanying floating concentrator plant where the heavy minerals are separated from the sand. The concentrate is pumped to a dewatering tower and later transported to an off site dry plant. The sand from the concentrator is pumped as a slurry back onto the mined area and immediately contoured, top soiled and replanted.

THE IRON PROBLEM

As is characteristic of these coastal sand beds, they are usually saturated to within 1 metre or more of the surface, they form perfect aquifers, and the ground water is often used for town water supplies (2). In this case, the local Shire Council has 15 production bores operating in the Tea Gardens sand bed, supplying water to the nearby towns of Tea Gardens and Hawkes Nest. The borefield is very close to the mining path and of course there is concern as to whether the mining operation will have a detrimental effect on the water supply.

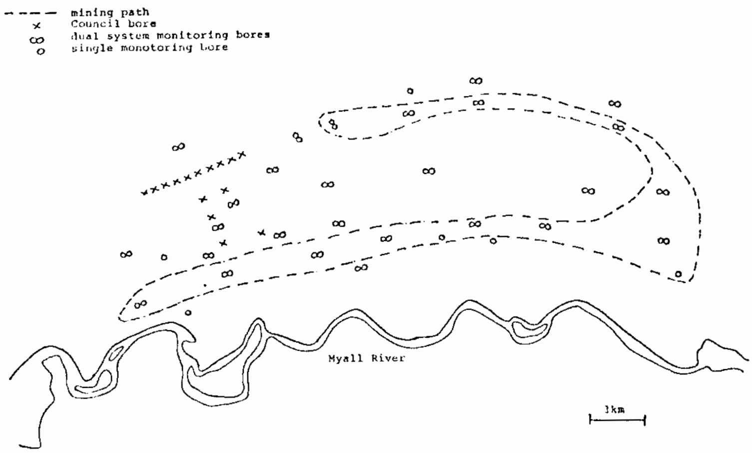
No chemicals are used in the mining process so "pollution" in terms of extraneous material is not an issue. In an analogous situation, south of Port Stephens, mineral sands have been mined from the Tomago sand beds for the past 20 years. These sand beds also provide a large portion of the water supply for the city of Newcastle and the effect of the mining on the aquifer has been under close surveillance throughout the time. What has been gained from these observations is confusion more than anything else, but there is general agreement that the mining seems to cause a rise in dissolved iron concentrations in the ground water in the mined area, although there are always individual bores which show no such trend and bores away from the mining area which show similar rises in iron concentrations.

A great deal of attention has been given to determining the reasons and mechanisms for this apparent iron mobilisation, and many theories have been advanced to explain the phenomenon, ranging from the concept of "biosoluble and non-biosoluble iron in the fine material on the bottom of the dredge pond" (3) to "a stoichiometric and thermodynamic model with vadose zone leaching through physico-chemical processes including bedrock primary weathering sites" (4). But the matter has remained largely unresolved.

MONITORING PROGRAM

High concentrations of dissolved iron are undesirable in drinking waters and increases the cost of water treatment. So a monitoring program was designed for the Tea Gardens operation which would monitor for any hydrochemical changes in the tailings zone and ascertain whether there was any vertical or lateral movement of iron towards the water supply borefield.

A network of 60 single and dual system monitoring bores, at 6 metres depth and at 20 metres depth, representing the dredging zone and production bore levels, was established over the area. The network encompassed the mining path, control areas outside the mining path, and positions up-slope and down-slope of the hydraulic gradient. The water supply borefield was encircled with dual bores intended to provide a forewarning of the enroachment of undesirable parameters so that immediate action could be taken.



Monitoring Network

The frequency of the monitoring varies for individual bores according to the proximity of the dredge pond to the Council borefield. As the mining advances and overtakes monitoring bores in the mining path, they are successively withdrawn and the replaced in their original positions in the tailings after the mining has moved on.
(slides)

So, the precept of the program was quite admirable and comprehensive, we were rigerously vigilant over the Council borefield, we were also acquiring data about long term natural variations in iron concentrations in areas which won't be mined for many years, and we were monitoring the after effects of the mining as well.

PROGRAM RESULTS

After a period of pre-mining monitoring and one year of monitoring since actual mining began, the results were reviewed and this is what was found:

(1) Wide spatial and temporal variations in ground water iron concentrations over the area.

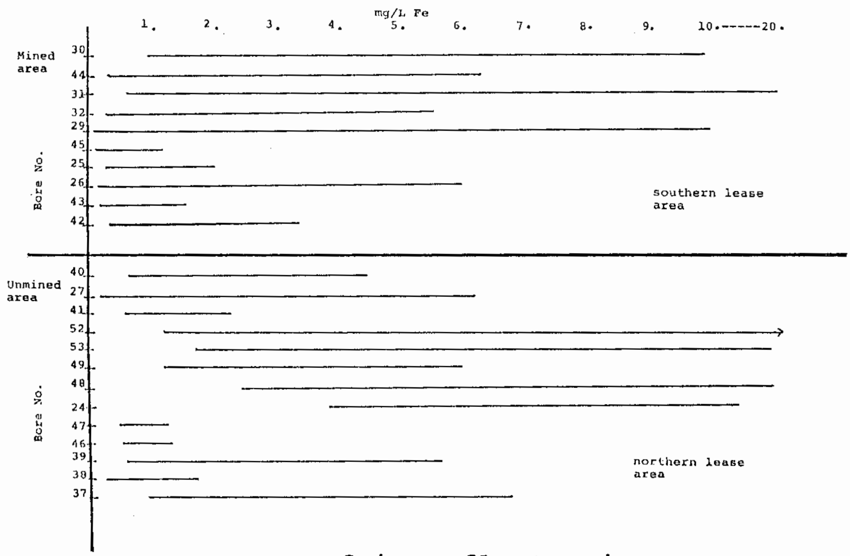
(2) Individual bores exhibited large fluctuations in iron concentrations e.g. bore 35, 6 m level, ranged from 0.1 to 45 mg/L. (this bore is outside the proposed mining path and not yet near current mining activity).

(3) There was often a large difference in iron concentrations between the two levels at the same site. eg.

	6m level	20m level		6m level	20m level
Bore 22	1.3mg/L	4.6mg/L	Bore 24	3.8mg/L	12.7mg/L
	1.9mg/L	1.1mg/L		4.1mg/L	6.5mg/L

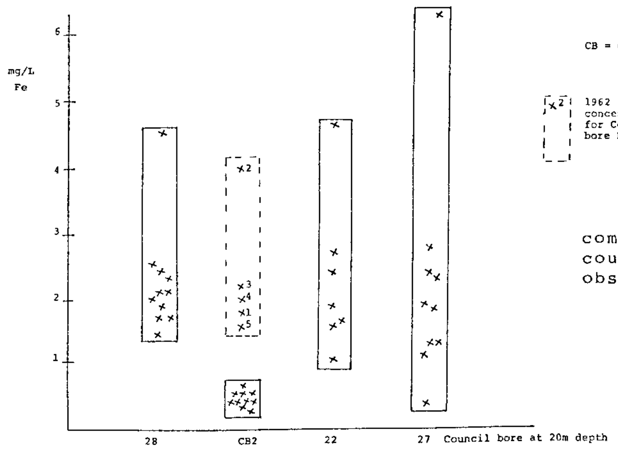
(There is some hydraulic discontinuity between the two levels due to the partial confining effect of a carbonaceous sand horizon).

(4) No increase in iron concentrations in bores in the vicinity of the mined area or in bores replaced in the tailings zone after mining, have been noted, but the range of fluctuations is so large in both mined and unmined areas that any change would have to be dramatic to be noticed.

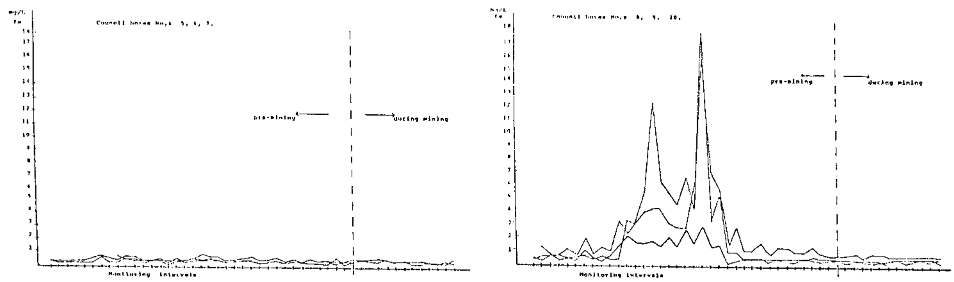


Range of iron fluctuations

(5) A most significant observation was the difference between the iron concentrations in the water supply bores compared to those from the surrounding observation bores measured during the same period.



However there is an interesting historical observation, when these water supply bores were drilled in 1962 and the water analysed for iron before they became production bores, they exhibited much higher iron concentrations, which were in fact in the same range as those from the present observation bores. Furthermore, during the pre-mining monitoring period there were occasions when a number of the Council bores suddenly gave iron concentrations similar to those from the observation bores. These high values were found to coincide with periods of shut



Iron fluctuations in Council bores

downs when the bores were not continuously pumped but operated only during sampling i.e. a similar situation to the observation bores.

IRON MOBILITY

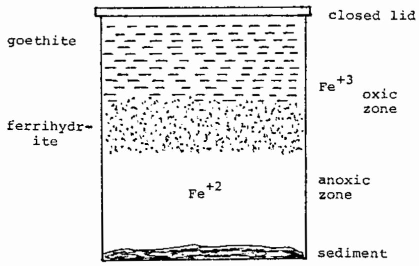
In order to successfully interpret these findings it is necessary to have an understanding of iron transformation processes in the aquifer.

In spite of the many and sometimes complicated theories on the subject, there are basically two processes through which iron is solubilised in a sand bed aquifer;
either (1) by the oxidation of reduced species of iron
or (2) by the reduction of oxidised species of iron.
Thus, you either have an aquifer environment in which reduced forms of iron such as iron monosulphide, pyrite, marcasite, are more or less stable, that is, a negative redox situation. Or, you have a more oxygenated environment in which minerals such as iron oxide, goethite, haematite, are more or less stable. In both situations the particular mineral and iron in solution, are in a quasi state of equilibrium under the prevailing environmental conditions. But this equilibrium is very easily upset by any change in the environment, and either more iron will come into solution or precipitate out of solution depending on which way the equilibrium is shifted.

There are many coastal sand beds where high iron concentrations in ground waters are the result of iron sulphide oxidation, that is, through the oxidation of reduced mineral species, and there is no doubt that in some areas of the Tomago sand beds this is the major process producing some very high iron concentrations (5). But the chemistry of the waters in the Tea Gardens sand bed indicates that the dominant process there is the reduction of oxidised species.

Iron cycling through the reduction and re-oxidation of iron is a most common process in the environment. It is taking place continually, you can see it happening everywhere. All that is
(slides)
needed is the presence of the 3 basic ingredients - water, organic matter and a source of iron. There is of course no shortage of iron in the geologic environment, sand grains and clay particles are coated with iron oxides. Organic matter as it decomposes uses up oxygen from the surroundings causing reducing conditions, the iron is reduced to the +2 state and passes into solution. This is a highly localised process. The iron is solubilised at the sediment - water interface, and as the ferrous iron encounters a higher oxygen regime away from that interface the iron is re-oxidised to Fe^{+3} and can precipitate out in a variety of forms.

The delicacy of the solid - solution equilibrium can be easily demonstrated in a beaker.



iron cycles

On standing, iron is solubilised from the sediment as Fe^{+2}. The ferrous iron is stable in the anoxic zone near the sediment. It remains in solution and the beaker wall remains clear. Further up the water column, however, there is more oxygen and the iron precipitates out in a sharply defined zone. If the beaker lid is opened, oxygen will defuse through the water column, the Fe^{+2} will be oxidised and will precipitate out and the zonation on the beaker wall will disappear.

In an aquifer there is a continual state of changing equilibria as any one or any number of a multitude of micro-environmental conditions vary. The exact mineral assemblage will vary within short distances, the amount of oxygen in the water will vary with time, the proportion of organic matter to sand will vary, the intensity of the bacterial activity involved with organic matter decomposition will vary continuously - the greater the activity the greater the amount of organic matter broken down, more anoxic conditions created at that localised spot, and therefore more iron reduced and solubilised as a consequence of the anoxic conditions. (It is important to note here that this does not involve the so called "iron bacteria" but simply the normal ubiquitous soil bacteria i.e. the iron solubilisation is an indirect effect of the activity of soil micro-organisms).

These are essentially unmeasurable parameters, they are continually changing, localised, micro-environmental effects. The factors which cause a certain concentration of iron to be in solution at a particular site to-day will be different to the combination of conditions causing another concentration of iron tomorrow, and the combination of factors at one site will be different to the combination of factors at another.

Thus the critical concept to understand is that iron does not travel conservatively through the aquifer. That is, a parcel of 5mg/L of iron does not travel from A to B as a parcel of 5mg/L of iron. By the time it gets to B the concentration in solution which is in equilibrium with the set of conditions at B, will be different.

Point A →	Point B →	Point C
One set of conditions: A particular flow rate, bacterial activity, mineral assemblage, proportion of organic matter to sand etc.	Another set of conditions: Oxygen concentration will be different, bacterial activity, the mineral assemblage etc will all be different.	
= x mg/L Fe in solution in equilibrium with these conditions	= y mg/L Fe in solution in equilibrium with this set of conditions	= z mg/L

y can be > or < x, i.e. either more iron comes into solution or some is taken up into a solid form.

This is the reason why adjacent bores in sand beds can exhibit widely different iron concentrations. The same applies to vertical distances also. A logical corollary to this is that if an enormous disturbance occurs in the environment, such as the whole turning over of the sediment through mining, just about everything in the aquifer is changed - the mineral assemblage, the proportion of organic matter to sand at a particular place, the groundwater flow rate etc. Therefore it is only reasonable to expect variations in iron concentrations in that disturbed area.

An interesting parameter which has only recently been measured in the Tomago sand beds is the organism count in sediments pre and post mining. The results so far have shown a dramatic increase in organism numbers at depth, after mining. We will now continue to monitor this at Tomago and if it is found to be a constant factor then it would certainly support the proposition that iron is mobilised indirectly through the activities of organisms degrading organic matter, particularly aerobic bacteria. The aeration of the sediments through mining may be a causative factor.

MODIFICATIONS TO THE TEA GARDENS PROGRAM

Relating these factors to the Tea Gardens monitoring program: Firstly, it is evident that since dissolved iron does not travel conservatively from point A to point B, even if high values are registered in the mined zone this will give no indication of the conditions outside that zone.

Secondly, the fact that there was such a difference in iron concentrations between the pumped water supply bores and the static observation bores, and the fact that when the water supply bores were static bores they gave results similar to the observation bores, means that the aquifer environment of a static bore is completely different from that of a continuously pumping bore. Also, that the range of iron values exhibited by a static bore, even though it is pumped for sampling, bears no relationship to the values exhibited by that same bore if it becomes part of a continuously pumping borefield. In other words, we cannot extrapolate from observation bore to pumping bore.

In the light of these considerations, it became evident that the existing monitoring program was not going to achieve the main aim of the program which was to provide a forewarning of the movement of high iron containing water from the mining path towards the water supply borefield. Therefore, as a result of a realistic appraisal, the philosophy and direction of the program was changed.

The main focus is now on monitoring the water supply borefield itself to detect any changes, although a few observation bores between the borefield and the mining path will continue to be monitored (just in case). Some long term monitoring of unmined areas and mined areas will continue to provide information on the effects of mining.

The modifications to the program, carried out with a better understanding of aquifer hydrochemistry, have resulted in major cost and energy savings to the mining company without any detriment to the environment.

It will be interesting to see what the long term monitoring will produce. It will be interesting too to see if some relationship is established at Tomago between the organism counts and the iron concentrations. Perhaps for the next Congress I will have some more answers.

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