Baseline Data Requirements for Assessing and Predicting Environmental Effects of Open Pit Mining

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ABSTRACT

Baseline data are required if the effects of open pit mining on local and regional groundwater and surface water conditions are to be predicted in advance or assessed during the course of mining. In a country such as Australia, which has a very variable climate, a major problem in most mining situations is the relatively short time span available for collecting detailed data on pre-mining groundwater and surface water conditions.

This paper provides a current review of the monitoring and interpretation of groundwater and surface water fluctuations around a limestone mine in Queensland, Australia. The mine has had a significant local effect on both groundwater and surface water. However, fears of widespread effects on the water table and associated environmental effects outside the limestone have proved groundless.

The absence of a very long period of baseline records makes it difficult to separate the effects of mining and drought in marginal areas. It has also been found difficult to convince all interested parties that drought, not mining, is the cause of falls in the water table in more distant areas.

Typical data collected over the past fifteen years are presented in graphical form. Use of the data to distinguish between natural effects and the effects of mining at several locations is discussed. In this instance the monitoring results and knowledge of the geology of the area have proved invaluable in determining equitable solutions in cases of loss of access to natural water supplies by farmers due to unnatural depression of the water table.

It is concluded that with the generally shorter time available for baseline data collection for many mining projects, separation of the effects of mining and natural variations might frequently be even more difficult than in the case discussed.

INTRODUCTION

It has become common practice for regulating authorities to set environmental monitoring conditions on the granting of mining leases. The data collected should allow the effects of mining to be distinguished from the effects of naturally occurring variations in environmental conditions. Any potential changes which might affect the appreciation and utilisation of natural resources by humans as well as those which might affect the natural animal and plant habitat need to be considered.

Groundwater can have both a direct and indirect influence on the environment. Changes in the water table and groundwater quality which are caused by mine dewatering and waste disposal directly affect conditions at the land surface outside the area of mining or waste disposal unless the capillary fringe above the water table lies below the root zone of the deepest rooted plants, usually trees. If the water table falls below safe pumping levels in wells used to extract groundwater for agricultural purposes there may be an indirect effect caused by a change in land use resulting from the change in available water supply. Changes in the groundwater regime may also affect surface water by altering the quantity or quality of base flow in streams.

Surface water conditions can also be altered by the discharge of mine water into watercourses, surface drainage diversions, and surface water abstractions for mineral processing and dust suppression. These can also lead to direct and indirect environmental changes.

In Australia changes in the groundwater or surface water regimes are normally expected by both "environmentalists" and farmers to be detrimental. However this is not universally the case since mine dewatering might drain a waterlogged area and increase its value to a farmer. However, to an "environmentalist" this would represent a loss of wetland habitat for some animal and plant life and thus be detrimental.

Monitoring groundwater and surface water conditions around a mine site is not difficult. A network of existing wells, new observation boreholes, streamflow measuring stations and rain gauges and a central weather station allows appropriate data to be collected, albeit at some considerable cost. The main problem is that usually the monitoring system is set up too short a time before mining commences. This is a consequence of the approval process which links environmental monitoring to mining approval and not to earlier phases of the prospecting and mining investigation process. Whether it would be practical to require the earlier establishment of a monitoring program would be the subject of an interesting discussion.

This paper outlines the current status of a program to collect baseline groundwater and surface water data and use it in an assessment of the effects of dewatering a limestone mine. Details concerning the setting up of the monitoring network have been presented previously by Dudgeon [1,2].

Data has been collected for a period of 15 years in three mining leases not yet affected by mining. In a fourth lease in the same area mining commenced shortly after the monitoring program was established so only a short record of baseline data specific to that site is available for investigating the effects of mine dewatering. Fortunately geological and climatic conditions in the lease being mined are almost identical to those in the three unmined leases so baseline data trends observed in the latter can be used to differentiate between naturally occurring and mine-induced changes in the former.

The problem of distinguishing between the effects of mining and drought conditions in lowering the water table level and depleting both groundwater and surface water supplies is discussed. The length of baseline record required, types and frequency of measurement and problems which have been encountered are all reviewed.

EAST END LIMESTONE MINE

Regional geology

The East End mine near Gladstone, Queensland, Australia is operated by Queensland Cement Ltd to provide limestone for a large cement manufacturing plant. The reader is referred to the paper by B.A. Dudgeon and C.R. Dudgeon in the Congress Proceedings for details of the geology of the region surrounding the mine. It will suffice to say here that the open pit is situated in an elongated limestone body originating from a coastal coral reef deposit tightly folded into metamorphosed Devonian sediments which are mainly of volcanic origin. Sills, dykes and other larger volcanic intrusions occur extensively. This deposit of limestone and others situated in the 11 km × 8 km area covered by the monitoring network are generally steeply dipping, well fractured, and surrounded by hard fractured rocks of relatively low permeability. They occur mainly in valley floors because of their relatively high susceptibility to weathering and erosion in comparison to surrounding rocks and are largely covered with a layer of clayey soil overlying clay which fills the depressions in the very irregular weathered limestone surface. The vertical extent and interconnections of deposits at depth are unknown.

Groundwater and streamflow monitoring system

Figure 1 shows the mining leases and area over which monitoring of groundwater and surface water conditions is required by lease conditions.

A monitoring network of more than one hundred permanent water supply wells and bores and specially constructed observation bores is used to measure water table levels and take water samples. Measurements are supplemented at times by water levels taken in blast holes drilled near pit boundaries.

Six measuring weirs are used to measure flows in several streams which originate in or pass through the monitoring area. A seventh weir at the outlet from settling ponds is used to measure the discharge of water from the mine.

Two pluviometers at weir sites and four storage rain gauges sited within the boundaries of the four limestone leases are used to measure rainfall while a weather station at the mine records other weather data.

Groundwater levels and conductivities are measured quarterly with additional measurements at some locations when unusual conditions exist. Rainfall which is collected by the storage rain gauges and stored in underground reservoirs is also measured quarterly while rainfall rates are measured by the pluviometers and superimposed on two of the continuous streamflow records whenever rainfall occurs. Stream flows and mine water discharge are measured continuously by water level recorders at weirs which are provided with standard sharp edged rectangular notches. Conductivity measurements are made quarterly at all weirs and additional more frequent measurements of conductivity, pH, and turbidity are taken at the settling pond outlet and in streams which receive or might in future be used to receive water pumped from a mine. The frequency of the additional measurements varies from weekly in "wet" weather to monthly in "dry" weather.

Baseline data collection

The four limestone mining leases were granted to provide a sufficient resource to justify capital expenditure on a large cement making plant. Only one lease is currently being mined. The time frame for mining in the other leases is uncertain because of the uncertainty of market growth and possible increase of recoverable reserves in the lease being mined.

Baseline data has now been collected for the three unmined leases for 15 years. Mining commenced in the lease being mined shortly after monitoring commenced but the rate of mining and dewatering was slow enough to allow the early groundwater measurements made at all but a few locations close to the mine to be treated as baseline data.

Results of groundwater monitoring program to date

Mining commenced not long before the onset of one of the longest and worst periods of drought on record. During the 10 year period from 1979 to 1989 only three significant groundwater recharge events temporarily halted the gradual decline in water table levels. Above average rainfall in 1989 and 1990 returned water table levels to near maximum values but a short, intense drought then caused levels to fall even lower, probably to the lowest levels in more than 70 years in many places. No written records are available to confirm that the drought has caused the water table to fall to its lowest level since wells were constructed in this area following the issue of miner's homestead leases about 1920. However, many of the hand dug wells were progressively deepened to follow the water table down during droughts and it can be expected that the existing bottom levels give good indications of previous lowest water table levels observed. This argument backs up stories of well construction from surviving long term residents.

Figure 2 shows typical records of water table levels in 100m deep observation holes in the limestone deposit being mined. Rainfalls measured in nearby rain gauges are also plotted. Figure 3 shows comparable plots for locations which are remote from and separated by rock of low permeability from the limestone being mined. Figures 4 to 6 are plots of data for several pre-existing water supply wells located near the boundaries of limestone deposits. The particular records have been selected to illustrate the difficulty of separating the effects of drought and mining if a sufficient length of record is not available.

It can be observed from Figures 2 to 6 that falls in the water table remote from the mine are of the same order as those in the limestone being mined. Comparable falls have been recorded over a much wider region in this part of Queensland and are clearly attributable to natural drainage of the aquifers during drought.

Use of data to separate the effects of drought and mining

Most of the permeability and storage in the fractured rock aquifers being dealt with occurs near the surface. This is particularly the case in the limestone aquifers in which the solution channelling is most evident in the range of recent water table fluctuations. While the water table is high this results in a rapid draining of the limestone aquifers in response to lack of recharge during drought. The data presented indicates that the natural rate of fall of the water table can greatly exceed the incremental rate of fall induced by mine dewatering. This presents a problem when an attempt is made to separate the component of water table fall caused by mining from the total fall over a given period. The more rapid and greater the range of the natural water table fluctuations the more difficult the problem becomes.

Apart from a locally deeper depression of the water table in the fractured limestone at the mine the eventual consequences of drought and mine dewatering in this case are almost identical. Even the locally steep drawdown and internal seepage face which is assumed to occur in the low permeability hard rock where it abuts the limestone being mined will be the same regardless of the cause of dewatering of the limestone. Thus a comparison of the general shape of the water table surface away from the mine before and during mining is unlikely to show differences great enough to enable a decision to be made as to whether the water table has or has not been affected by mining at a particular monitored location.

The cumulative effect of mine dewatering and recharge should show up as a long term decline of maximum water table levels achieved after recharge events. Comparisons of peak water table levels after major recharge events and the shapes of recession curves have been used in this investigation to separate water table falls due to mine dewatering from those which would have occurred due to drought in the absence of mining. Only four such events have occurred in the fifteen years of monitoring so the need for a long period of baseline data in these circumstances is evident. Only by comparing the behaviour of the water table around the mine with that in similar areas remote from the mine has it been possible in this case to differentiate between the effects of mine dewatering and drought. When mines are established in the other three leases there will be an adequate length of record in each to allow direct comparison of groundwater conditions before and after mining.

Results of surface water monitoring program

Disposal of mine water and diversion of surface runoff around the mine has altered flows in the creek downstream from the mine but only to the benefit of adjoining landholders who now have a stable water supply. Previously salinity rose to very high levels as the creek dried up during a severe drought.

The absence of a long period of baseline measurements in the creek has not been a serious disadvantage in this case although such a record could have prevented the delay which occurred in the issue of a discharge licence for mine water. This had to await the collection of a necessary minimum amount of data on the properties of the receiving stream and mine water.

Since most of the creeks in this area cease to flow during severe droughts and water quality has a big range it is important to collect data over a long period. This data is required both to determine whether mining has affected base flows and to investigate the effect of disposal of water into the creeks from future mines. The creeks do not have the same degree of similarity as do the limestone aquifers and surrounding rocks. Two of the creeks which are monitored have their sources outside the monitoring area and have much larger catchments than do the others which have their sources in limestone in the monitoring area. For this reason it will not be as simple to use data from one creek as baseline data for another as was done with groundwater data from similar limestone deposits.

Response of environment to altered water regime

The monitoring program does not include quantitative measurements of the effect on plant and animal life of changes in the groundwater and surface water regimes. However visual observation indicates no obvious detrimental change over the past 15 years in comparison with areas remote from the mine which are unaffected by water table and streamflow changes. It has been observed in observation boreholes lined with slotted PVC casing that eucalyptus tree roots have followed the water table near the mine down 10m and that the health of the trees does not seem to have suffered. This is probably not surprising for species adapted to an environment in which water table falls of this order can occur naturally during prolonged droughts. Shallow rooted species which depend on soil moisture provided by rainfall appear no different. Downstream from the mine an area of clayey soil which displayed a salty, poorly vegetated surface as a result of evaporation of water containing 1500mg/L of sodium chloride seeping upwards from the confined water table below has been drained by the mine dewatering, flushed by rainfall and cleared and grassed by an appreciative farmer.

Discharge of mine water into a creek via a lagoon has stabilised the level of the lagoon which used to dry out during a drought and put a relatively stable base flow of about 20L/s into the creek which formerly dried up to a series of pools. Both farm animals and wildlife seem not to have been disturbed by the change.

When mining ceases and the water table reverts to its higher average but more variable level in the remaining limestone, visual observations and photographs should provide at least some record from which to judge whether the water table rise has a detrimental effect on trees which lowered their roots to follow the falling water table.

DISCUSSION

Adequacy of baseline data

It is evident from inspection of Figures 2 to 6 that without the control data available from monitoring in the adjacent unmined leases it would not be possible to apportion falls in the water table between drought and mine dewatering. This points to the importance of selecting control locations where hydrogeological and climatic conditions are as close as possible to those at points of interest in the area likely to be affected by mining.

The length of record required to differentiate between natural groundwater and surface water fluctuations and those induced by mining depends on the variability of climatic conditions at the mine site. Rainfall records for the area around the East End mine show significant recharge of the limestone aquifers can be expected on average only every two or three years. Long periods of heavy monsoonal summer rain occurred only five times in approximately 55 years of record indicating that near maximum groundwater levels can be expected with an average frequency of about 10 years.

In this case 55 years of rainfall records together with a 15 year record of dry weather streamflows and groundwater levels and quality for a range of locations which represent different hydrogeological conditions give a reasonably accurate picture of natural variations.

The availability in this instance of reliable local rainfall records and weather data from an official weather station 30 km away is a bonus which would not be available in more remote locations.

The question of whether the data would be adequate to set up a model to predict the effect of mining at locations not monitored is more difficult to answer. The groundwater monitoring locations are either existing water sources (wells and bores) or observation holes intended for a comparative study of water level changes. They were not selected for developing or calibrating a regional model. Many of the water sources which the lease conditions require to be monitored are on elevated ground and affected only by local recharge and use. If regional modelling were required, a more comprehensive set of observation bores would be required. The frequency and types of measurement are considered appropriate for regional modelling in this area.

The types and frequency of measurements to define water table level, groundwater quality, stream flow and surface water quality variations have proved adequate. The quarterly read rainfall storage gauge results give a broad picture of rainfall but do not provide an adequate record of conditions favouring recharge. The pluviometer data recorded on two of the streamflow record charts are not quickly or easily accessible. Advances in digital pluviometers since the network was set up will allow for relatively cheap and effective upgrading in the future.

Two main problems have been encountered in setting up and operating the monitoring network. The first is the initial lack of co-operation and at times obstruction on the part of some landowners opposed to mining. The second is interference with observation boreholes, despite protection by steel pipes and caps, and damage to weirs and rain gauges. Both problems have diminished with time and are now rare. Major factors in improving the relationship between local landholders and the mining company (and the consultant responsible for the monitoring) have been the sensitivity of the mine management to local issues and the use of monitoring personnel who can deal effectively with landholders. The importance to a monitoring program of developing relationships with the local community from the outset is emphasised.

The future

Most of Australia and many other countries in which mining is an important industry have very variable climates. With increasing emphasis on environmental protection it will become necessary to begin to collect baseline data well in advance of mining to prevent delay to the approval process.

Collection of streamflow data worldwide to provide a sound basis for river development began many decades ago. The collection of groundwater data to assist the rational use of groundwater resources has also been carried out for a long period. Perhaps it is now time to consider a program of baseline data collection aimed at mining in those areas where there is a high probability of the establishment of mines in the future. This could possibly be organised in conjunction with detailed exploration programs.

ACKNOWLEDGEMENTS

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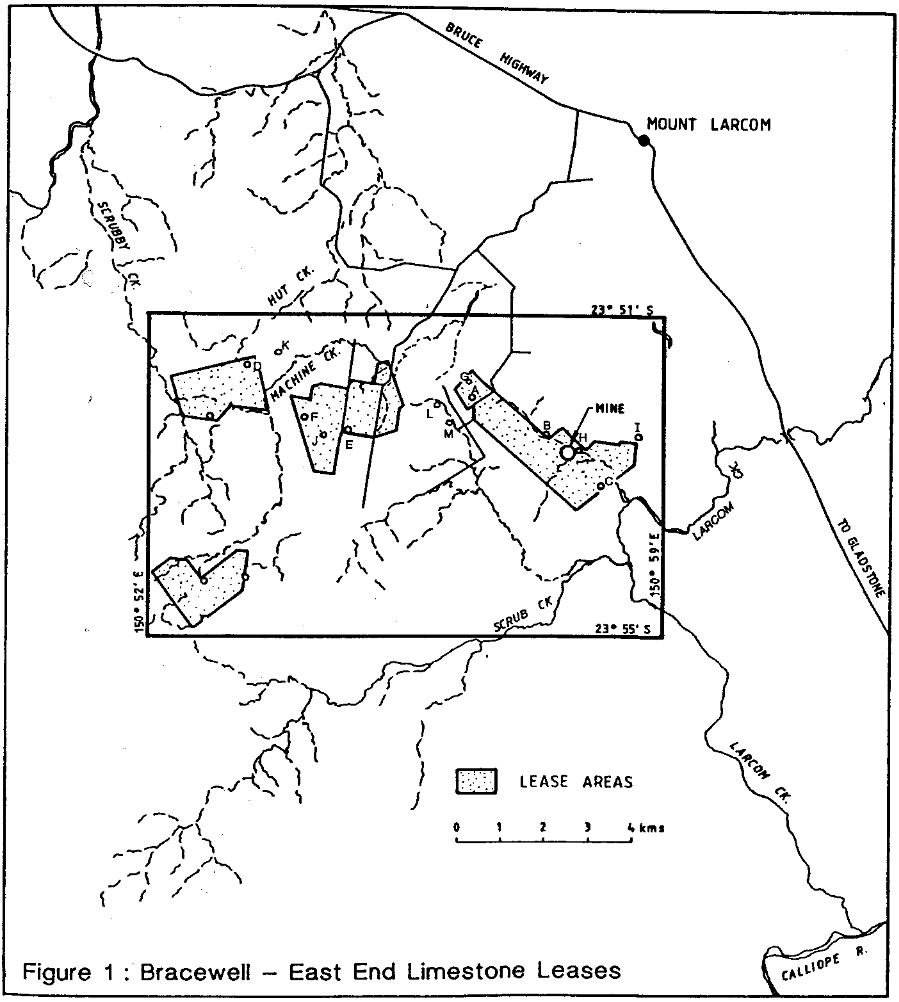

Figure 1 : Bracewell – East End Limestone Leases

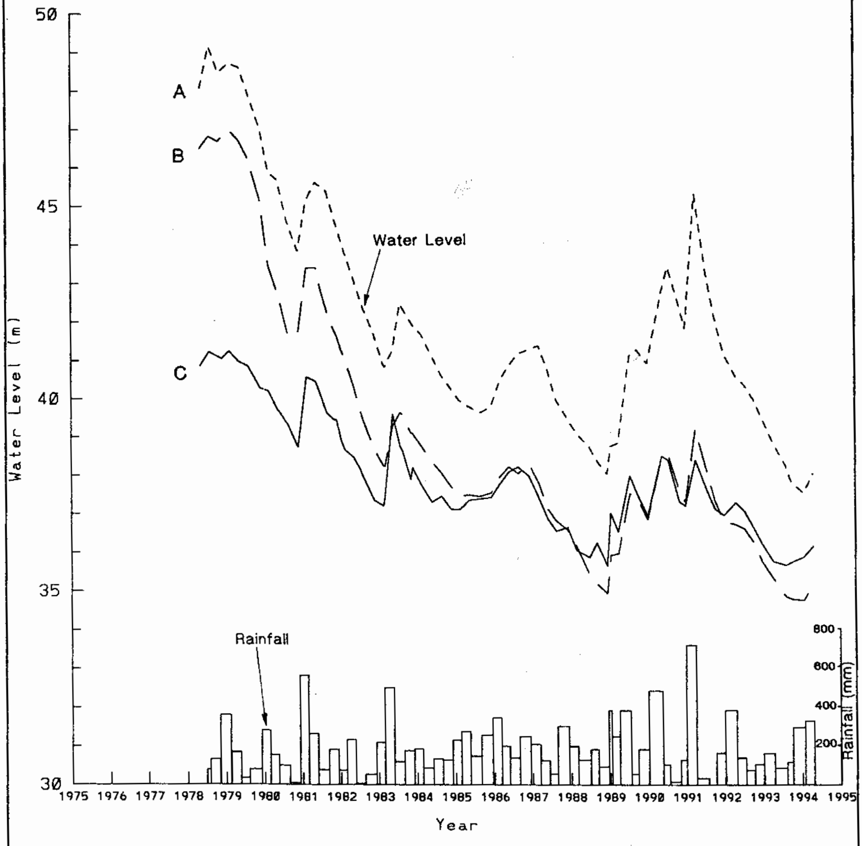

Figure 2 : Water Table Levels – Observation Holes in Limestone being Mined

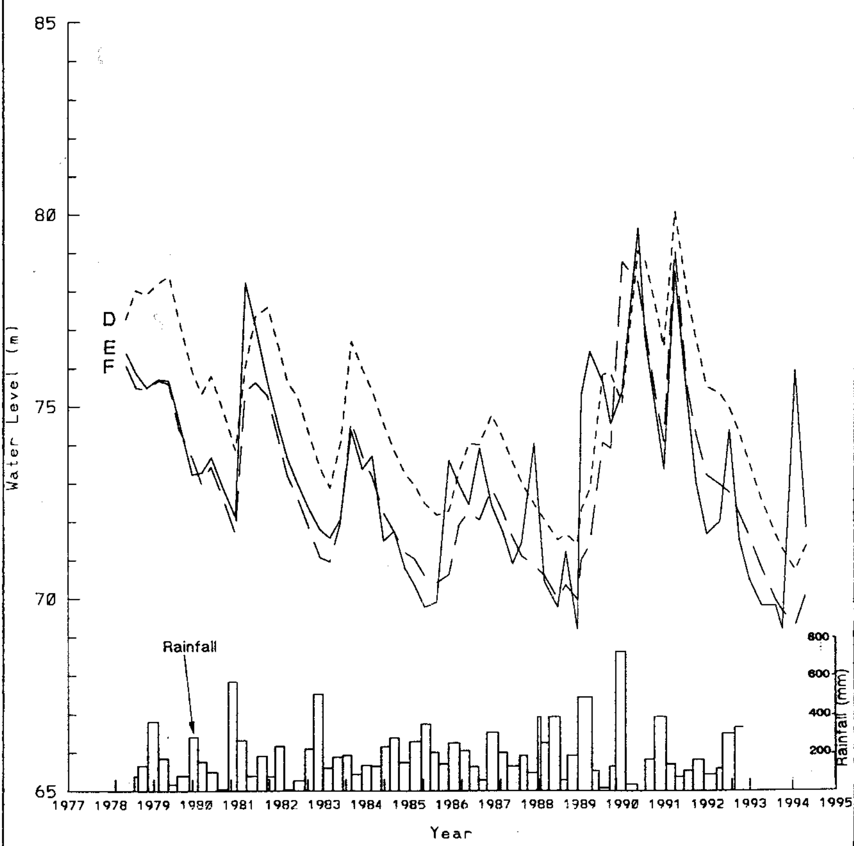

Figure 3 : Water Table Levels – Observation Holes in Limestone Remote from Mine

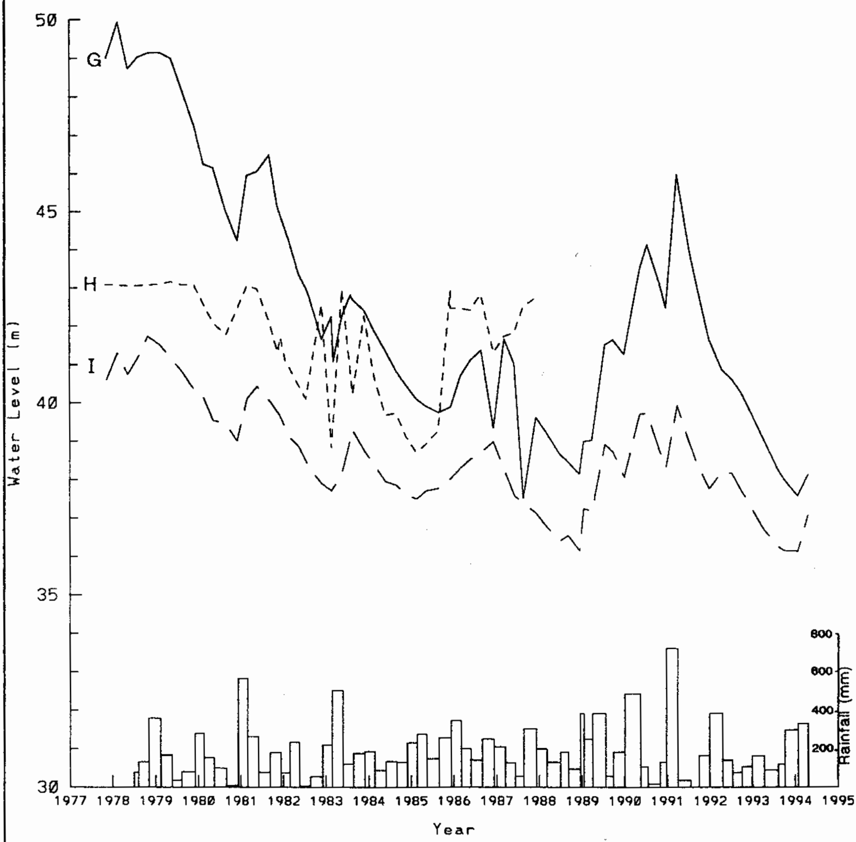

Figure 4 : Water Table Levels – Water Sources near Limestone Boundaries

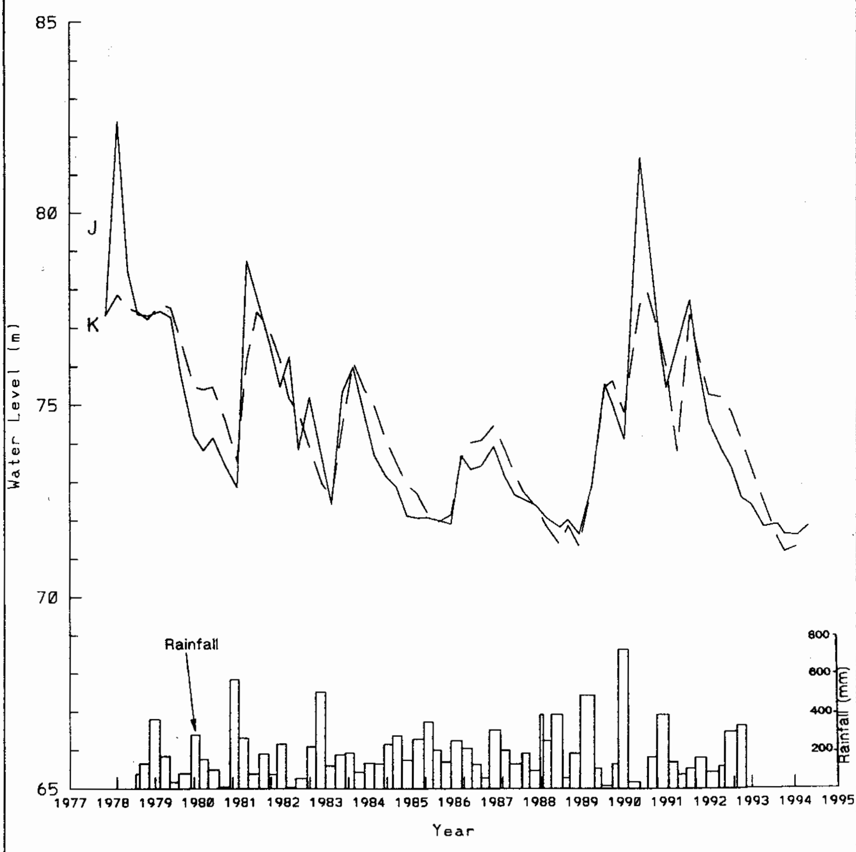

Figure 5 : Water Table Levels – Water Sources near Limestone Boundaries

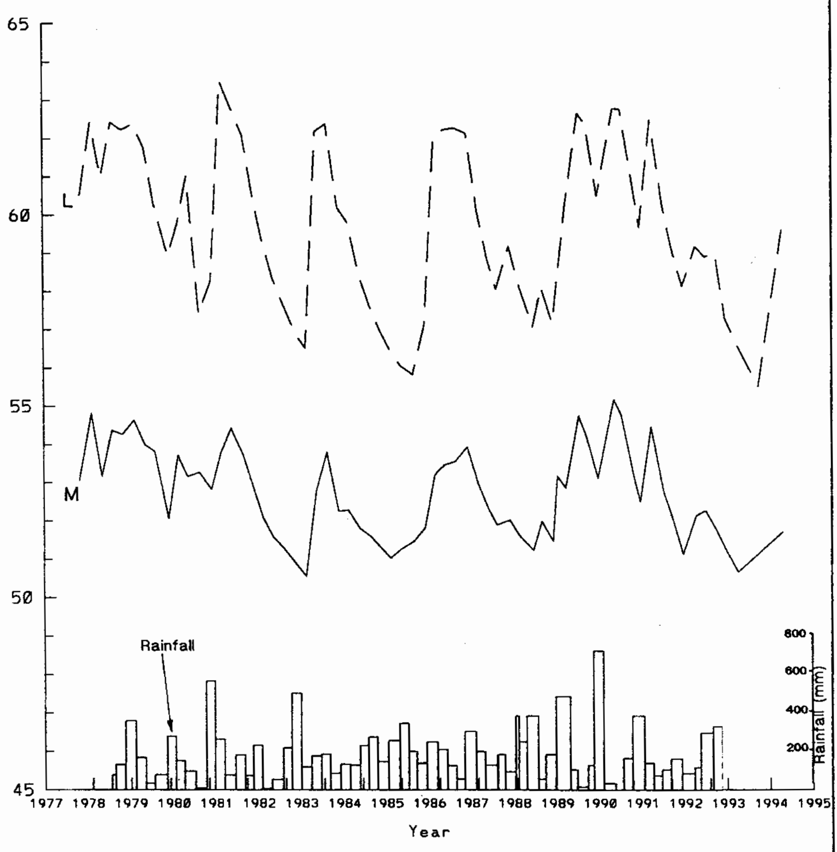

Figure 6 : Water Table Levels – Water Sources near Limestone Boundaries