PROBLEMS IN SEPARATING THE EFFECTS OF DROUGHT AND MINE DE-WATERING IN A FARMING AREA SURROUNDING A LIMESTONE MINE

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ABSTRACT

Groundwater monitoring to determine the effects of de-watering an open pit limestone mine operated by Queensland Cement Ltd. (QCL) near Gladstone, Queensland, Australia has been carried out for the past 20 years. Recently imposed environmental restrictions will prevent QCL from continuing to dredge raw material from Moreton Bay near Brisbane for its Darra cement plant. As a consequence, the Gladstone cement plant will be expanded rapidly and the rate of increase in the size of the open pit will be approximately trebled. Despite this, the life of the mine is still expected to be about 50 years. The expansion proposal coincided with a long period of drought that has caused water table levels in Central Queensland to fall below previously recorded levels. Actual and perceived problems of groundwater depletion due to mine de-watering have been used by local landholders as arguments against approval of the expansion. Consequently, considerable attention has been focussed on the monitoring arrangements and apportionment of the water table falls between the effects of mine de-watering and lack of recharge due to drought. QCL has had to expend considerable resources on expanding the monitoring network to improve its coverage of doubtful areas and to commission more comprehensive analysis of the results of past measurements in an attempt to increase the level of confidence in the analysis. The problems with landholders have been exacerbated by government authorities allowing land use near the mine to alter from farming to rural residential. Another factor which has influenced the level of attention paid to objectors to the project is the location of the mine and cement plant in the electorate of the independent member of the Queensland Parliament who holds the balance of power between the two major parties.

The paper is intended to draw the attention of others involved in long term projects in comparable environments to factors which may be overlooked or which may change over the duration of mining.

The effects on the monitoring, assessment and remediation program of unexpected developments in this case are discussed.

INTRODUCTION

In many countries, unconfined groundwater levels vary greatly over long periods of time as a result of very variable rainfall. This is particularly true in and near recharge areas and in very permeable aquifers. Such large natural variations make it difficult to distinguish between the effects of drought and mine de-watering unless a very long record of pre-mining conditions is available.

At the 5th IMWA Congress, a paper was presented by Dudgeon [3] to describe a case study in which data on water table levels and groundwater quality had been collected for more than 15 years around an open pit limestone mine. The monitoring system has been described in detail in another paper by Dudgeon [2]. The mine is at East End near Gladstone, Queensland, Australia and supplies limestone for a cement plant. It is situated in one of four mining leases granted to Queensland Cement Ltd. (QCL) in 1977. The location of the mine is shown in Figure 1.

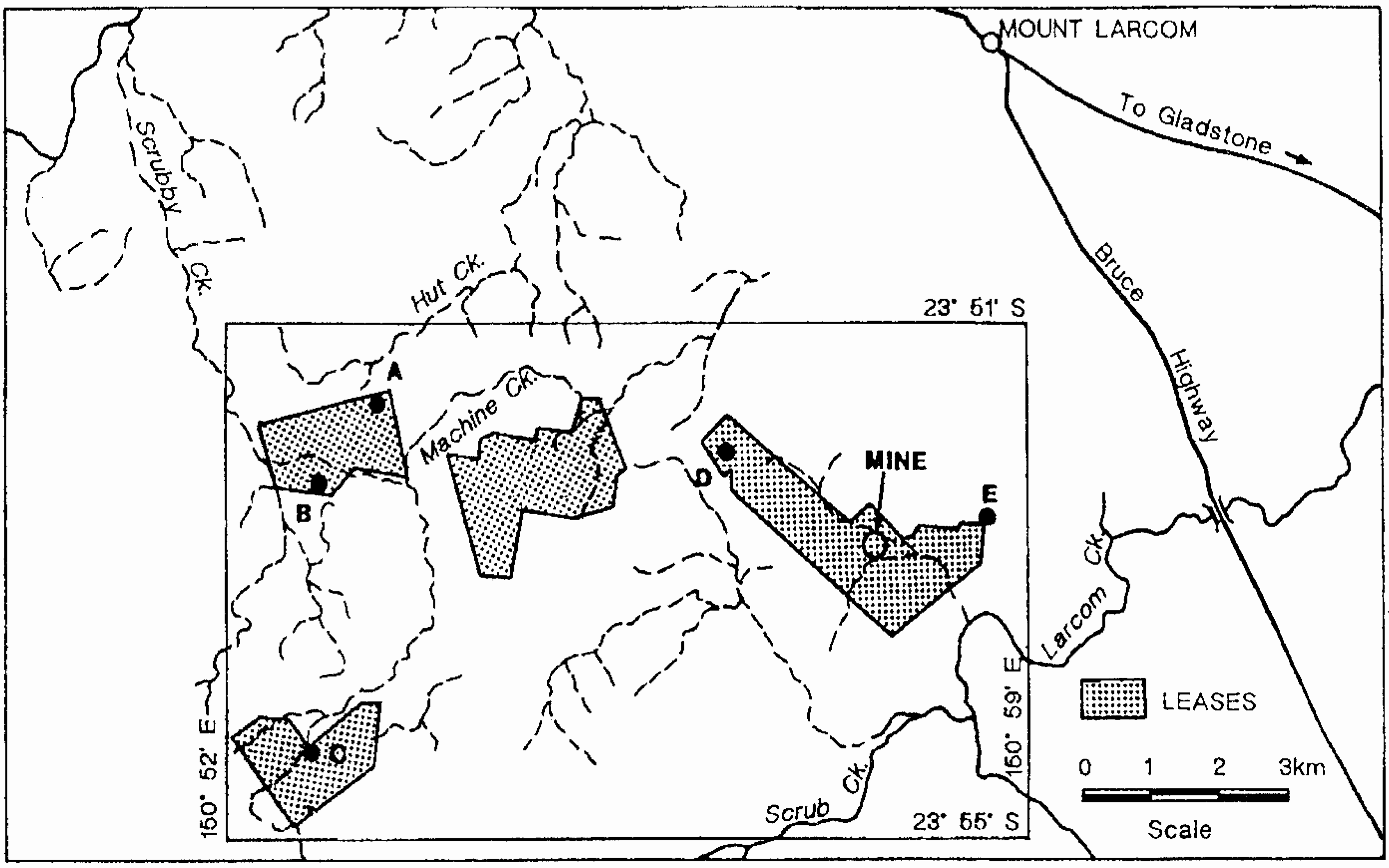

Figure 1 : Location of QCL's East End Limestone Mine

The current paper describes problems which have arisen over the past two years in apportioning recorded falls in the groundwater table between the effects of mine de-watering and those of an ongoing regional drought. The problems are concerned as much with satisfying the local action group set up to oppose further mine development as they are with technical difficulties. The assessment of current groundwater depletion by mine de-watering, and prediction of future depletion of groundwater supplies as mining continues, probably for the next 50 years, has become a very hot issue in the local community. A rapid expansion of the output of the cement plant in Gladstone by a factor of about three has been forced on the cement company by the refusal of the Queensland Government to allow the continuation of dredging raw material from Moreton Bay for the company's Darra (Brisbane) cement plant. The expansion has been vigorously opposed by local interests. The Government's decision has effectively removed a political/environmental problem from the Brisbane area and made more acute a problem in another area.

An interesting aspect of the current situation is that the mine is situated in the electorate of an independent member of the Queensland Parliament who holds the balance of power between the two major political parties. Because of this, the local landholders have been able to bring to bear considerable political leverage on the determination of the Government's response to landholders' objections and the resolution of disputes between landholders and the company. To complicate the issue further, Queensland Cement Ltd. is now owned by a Swiss based company which operates cement plants in many parts of the world, so the situation falls into the emotionally sensitive category of one involving the interests of a large foreign multinational versus those of small local landholders.

The data on which this paper is based are those supplied to the Queensland Department of the Environment (Water Resources) to meet mining lease conditions. The information is freely available to the public. The opinions expressed in this paper are those of the author and may not coincide with those of Queensland Cement Ltd. or other participants in the struggle over mine expansion.

Groundwater Conditions Attached to Mining Leases

When the mining leases were granted, conditions were attached requiring the mining company to monitor groundwater conditions, surface water base flows in streams and rainfall in an 11.3km x 8.0km rectangle surrounding the four limestone mining leases (see rectangle in Figure 1). It was also stipulated that the company should provide landholders with alternative supplies of water if water supplies were depleted. Additional conditions were imposed subsequently in relation to a licence to discharge water from the mine to the surface water system. These set upper limits on the quantity, salinity, solids content and turbidity of the discharged water and are not directly related to the company's responsibility for supplementing depleted groundwater supplies. However, an indirect relation occurs because of the possibility of using the water to supplement depleted water supplies.

Geologic and Hydrologic Conditions

The geology of the area around the mine and its effect on inflow of groundwater to the mine is described in detail in an earlier IMWA Congress paper by Dudgeon and Dudgeon [4]. The mine is situated in a limestone body formed from coral reef deposits folded into a sedimentary series which includes many volcanoclastic beds and volcanic intrusions.

Because of the intense folding of the series, permeability characteristics are strongly anisotropic, particularly at depths up to about 15m where preferential solution channelling has taken place along the fold axis/strike direction which runs approximately north west to south east. There is a strong contrast between permeabilities and storage coefficients in the limestone and surrounding rocks, especially at shallow depths. Because of the very variable conditions, yields from groundwater sources (bores, wells and a few springs) are very variable. [In Australia, a drilled water well of relatively small diameter is referred to as a bore; use of the term well is restricted to dug or augered wells with circular or rectangular cross sectional dimensions of the order of 1 to 1.5 metres.]

Groundwater quality is also very variable, with conductivities encountered in bores ranging from about 1 000µS/cm to 40 000µS/cm within a few kilometres from the mine. Sodium chloride is the main dissolved solid. Groundwater pumped from the mine currently has a conductivity of approximately 3 100µS/cm whereas when mining commenced in 1979 the conductivity of discharged water exceeded 4 000µS/cm. Approximately 2km north of the mine, water which is saltier than most sea water occurs within a few hundred metres of a strip of land from which groundwater with a conductivity less than 2 000µS/cm is pumped. The better quality water, presumably from local recharge, occurs between the saline water and the mine. Other instances of relatively abrupt changes in water quality with distance are common around the monitoring area. They demonstrate the highly variable nature of the geology, sources of dissolved solids and rates of movement of groundwater. It is clear that there are significant barriers to the movement and mixing of water in some directions.

Hydrologic conditions are controlled by a very variable temporal pattern of rainfall. The mine is less than 50km south of the Tropic of Capricorn in the coastal zone of Central Queensland. It is in an area which suffers extremes of climate, being affected by dry continental conditions and occasionally by cyclones (typhoons) which move down the coast from the tropics bringing heavy rain. Rainfall records collected near the mine site over a period of 40 years prior to the commencement of mining and data collected at four sites in the monitoring area over the subsequent 20 years indicate that major recharge events which will bring groundwater levels up to maximum values occur about once in 10 years on average. Typical conditions for such major recharge are an exceptionally wet summer monsoon period which includes a cyclonic disturbance. In the intervening years, water table levels decline steadily, with significant partial recovery every few years except in unusual conditions such as those which have prevailed since early in 1991. Although rainfall has not been extremely low over all of this period, rainfall has been such that very little of it has reached the water table.

PROBLEMS WHICH HAVE ARISEN

Mining commenced in 1979, some two years after the mining leases were granted. During the next 15 years only minor problems caused by abnormally low water table levels near the mine had to be investigated. These were dealt with amicably by individual negotiation between the company and the affected landholders. Remedial action was based on comparison of the recorded variation of the water table in the particular water source with records for remote sources and observation bores. Remedial action included cleaning out bores, lowering pumps and the construction of one new bore. The company also purchased some additional land close to the mine which might have been affected by mine de-watering. Unfortunately, the company did not see fit, in the early years of mine development, to buy all of the land most likely to be affected and which was available for purchase. Nor did it move quickly enough more recently to acquire land already known to be affected by a significant fall in water table level when it was offered for sale.

When the company announced its plans for rapid cement works and mine expansion, the situation changed. The potential for accelerated groundwater depletion was seized upon by local landholders as a major reason why the permitting authority should refuse planning permission for the expansion of the cement works. A local "action group" was set up to oppose the expansion. It is noteworthy that landholders who had unsuccessfully opposed the intrusion of limestone mining into their domain nearly 20 years earlier were in the forefront of the opposition. Because of the political situation referred to in the introduction, this group has had exceptional influence on the project. Any attempt to raise cost-benefit arguments in relation to the cost of investigations and remedial action has been stifled. The cost of monitoring, investigations and remedial action to date, estimated to be between 0.5 and 1 million US$, has far exceeded the value of production from affected land and the value of lost water supplies. It will continue to do so in the future unless a more rational approach is taken.

The potential for conflict over groundwater issues has been increased by Queensland and Local Government authorities' handling of local land tenure matters. Prior to the granting of the limestone mining leases, most of the land likely to be adversely affected by mine de-watering was held as miner's homestead leases. These 32.4 hectare (80 acre) leases date back to the 1920's when prospecting and gold mining took place in the hills to the west. They were intended to provide a place of residence and subsistence for the families of miners. Long before limestone mining started, many of the leases had been sold to form larger aggregate land units and dairy farms had been established. By the time mining commenced, many of the dairies had been abandoned and much of the land was used for the grazing of beef cattle. The level of original farm improvements was generally confined to fencing and a basic house and dairy. Land values were relatively low (of the order of US$120/ha) at the time mining commenced. As a result of political pressure following the granting of the limestone mining leases, the homestead leases were converted by the Queensland Government to freehold. The authorities also allowed this land surrounding the mine to be subdivided into small parcels (16.2 hectares) which are of an uneconomic size for farming in the absence of large supplies of water suitable for irrigation. Because of the upgrading by the State Government of the shortest road to the expanding industrial port city of Gladstone, this land is now only a half hour's drive from this centre of employment, so many of these newly created blocks of land have been purchased by newcomers to the area who obtain their income by working in Gladstone. New houses have been built and the land use has effectively changed from farming to rural residential. Land values for small blocks have increased by a factor of about twenty in the 20 years since the mining leases were granted whereas the price of larger parcels of land in Central Queensland valued solely on the basis of potential for farm production has been relatively stable over this period. The change in land use has caused the demand and dependence on groundwater supplies to increase as a consequence of increased domestic demand and increased use of water for irrigation for hobby farming. Unfortunately there is only one narrow band of groundwater near the mine with conductivity between 1 500μS/cm and 2 000μS/cm and the residential development straddles this band. The water table in this band has been lowered by mine de-watering. These new landholders purchased land knowing it to be close to a mine which would operate for a long period and yet expect to be compensated for effects which are an inevitable consequence of mining. It is a similar situation to that which occurs when a new airport remote from housing is built, developers are allowed to come in and build houses near the airport and then the occupiers expect compensation for airport noise. The irony of the situation in this case is that, as a contribution to regional infrastructure when the cement plant in Gladstone was first established, Queensland Cement Ltd. was required to provide funds for a major bridge and part of the road which is now used by landholders who live near the mine and object to the mine expansion. If the road had not been built, living near the mine and travelling to Gladstone to work would have been a much less attractive and economic prospect.

PROBLEMS IN EVALUATING EFFECTS OF MINE DE-WATERING

When the monitoring system was set up, it was envisaged that during the early years of mining there would be little effect of mine de-watering on water table levels except in a zone close to the mine. It was expected that during this period the measurement of water table level changes in more distant areas which might be affected later, and in remote areas which would not be affected, would allow the effects of mine de-watering and aquifer depletion due to natural gravity drainage to be separated with sufficient accuracy when the zone of influence of the mine extended further. An underlying assumption was that natural water table fluctuations would occur within historic limits during this period of baseline data collection. Unfortunately, since 1990 the worst recharge conditions on record have occurred in Central Queensland. Water table levels have fallen below previously recorded minimum levels and are still at very low levels.

In some instances of groundwater sources near the mine, comparison of recession and recharge limbs of groundwater hydrographs with those for equivalent sources remote from the mine shows quite clearly that water table lowering due to mine de-watering has prevented recharge occurring to normal levels. The problem then becomes one of quantifying the water table fall due to mine de-watering and determining the corresponding reduction in discharge available from the affected source. The latter task is much more difficult than the former in the absence of pumping test data for the low water table levels being experienced. Since, in this case, natural water table levels have fallen below historic lows there is no possibility of this information being available. In any case, none of the water sources in question has ever had a proper pumping test performed on it, even at the time of construction. This is typical of conditions in Australia, and in many other parts of the world.

For a newly constructed bore in the zone close to the mine, where there will be a continued lowering of the water table below natural levels during, and for some time after the life of the mine, it is not possible to determine what the maximum short term and long term yield of the bore would have been in the absence of the mine.

A more difficult problem to resolve occurs when a landholder who has a water source in a location and at an elevation where it is almost certainly not subject to any effect of mine de-watering claims that the water source is affected by the mine. Since water table levels generally have fallen below previously recorded values it is very difficult to prove conclusively that the water table level at the particular location would have fallen to the same extent in the drought, even in the absence of the mine. Then, of course, there are the marginal cases for which it is difficult to determine if there is a significant effect or not.

Comparison of water table fluctuations in affected and unaffected bores

Measurements of the water table level and groundwater conductivity are taken at more than 100 observation points in the monitoring area surrounding the mine. The data indicate the response of the groundwater system to natural recharge and drainage, extraction by landholders and mine de-watering. Figures 2 to 5 are included to demonstrate typical behaviour of the water table in limestone over the full period of record and, in particular, the problem of determining how much of the continuing fall in the water table during the ongoing drought is due to natural effects and how much can be attributed to mine de-watering. Note that all levels shown in figures are from the same datum.

Figures 2 to 4 show the variation of the water table in three observation bores drilled to a depth of 100m in two limestone bodies well separated from the limestone being mined. The locations are shown in Figure 1. The plots show how variable the response can be in similar topographic situations. Such factors as the distribution of interbedded and intruded rocks of low permeability which act as barriers to flow and the proximity to recharge areas can alter the local response of the aquifer greatly. Figures 2 and 4 clearly represent conditions at points where the aquifer recharges and drains freely whereas Figure 3 is for a point where local rises caused by recharge dissipate quickly and groundwater drains to a level which is fixed by some encircling barrier to further outflow. Two features are common to the three plots. The first is the rise in the water table following the major recharge of 1990/1991 to levels higher than those which occurred during the wet period at the start of the record. The second is the general decline in the level since that major recharge event.

Figure 5 is a water table variation plot of the type obtained for observation bores and water sources in the limestone body which is being mined. This particular plot is for a 100m deep observation bore situated in the limestone about 3km up strike from the mine, as shown in Figure 1. Unfortunately, because of access difficulties and intermittent pumping, the records for most bores used as water sources are less complete and more complex than those for unpumped observation bores such as that to which Figure 5 refers. The characteristic feature of plots of this type is the failure of the water table to recover fully during the 1990/1991 recharge. The deficit is attributed to the effect of the removal of water from the aquifer by mine de-watering. The recharge clearly did not occur in sufficient quantity and/or at a high enough rate to make up for the water removed and then restore the aquifer to its "full" condition as it did in other unaffected locations. It is from plots such as this that it has been necessary to estimate how much lower the water table is at a given time than it would have been in the absence of the mine. It has also been necessary to estimate the reduced pumping capacity of water sources corresponding to the estimated water level deficits. In the absence of other information it has been considered prudent to take a conservative approach and assume that drawdown and yield should both be interpolated and extrapolated by linear proportioning even though the rate of reduction of both drawdown due to mine de-watering and the proportional effect on yield must both decrease as the natural water table level falls. The fall in the water table between the highest level recorded in the wet period at the start of monitoring and the peak water level recorded during the 1990/1991 recharge has been taken as a base to be adjusted by extrapolation. Unfortunately, the urgent need for investigation brought on by QCL's expansion plans has come before the occurrence of another major recharge event. Such an event would have allowed current water table depression due to mine de-watering to be estimated more confidently.

Regional numerical modelling

Because of the occurrence of non-Darcy flow near the pit (Dudgeon [1]) and a variable and poorly defined seepage face at the pit boundary, development of a combined regional flow and local pit inflow model would be very expensive and time consuming. Although a finite element model with the capability of handling both the three dimensional non-Darcy anisotropic flow near the pit and the regional Darcy flow is available, the cost of applying it in this instance is not considered to be justified. Its implementation would also require a great deal more detail to be added to current knowledge of the aquifer close to the mine.

Since groundwater inflow to the mine can be deduced from records of mine water discharge collected over the past 15 years by deducting surface water components, and records of regional water table variations are available for periods up to 20 years, it is possible to model the regional flow over 15 years without having to attempt to model the details of local flow near the pit. Such a model has been commissioned by Queensland Cement Ltd. and may increase the average accuracy of separating the existing and past effects of mine de-watering from natural water table fluctuations.

The prediction of future effects will be much less satisfactory unless the near-pit flow regime, which controls inflow to the pit, is modelled correctly. In many mining operations the pit is kept free of water by pumping from bores outside the pit. This is not necessary in this instance as the groundwater inflow can be dealt with easily and more economically within the pit. The limestone being mined is hard and there is no problem working machines on the mine floor. A serious disadvantage of de-watering by pumping from bores outside the pit would be increased discharge and increased drawdowns away from the pit. When free inflow to the pit is allowed, as in the case being discussed, the inflow, and thus the amount of water being extracted from the regional aquifer, must be computed in the modelling process. This makes the modelling more difficult than modelling for a situation where the discharge from the aquifer is controlled by pumping from a borefield.

An added difficulty of predicting the effect of the mine on regional groundwater levels is introduced by the uncertainty of rainfall and recharge in an area where long term climatic fluctuations might have a time scale of the same order as the life of the mine, currently anticipated to be about 50 years. Records and local experience are available for an even greater period yet it appears that minimum natural groundwater levels have not been experienced in this time. In the absence of sufficient record, the selection of recharge information to insert into a model to predict either the probability of certain outcomes or extreme effects can only be arbitrary. The possibility of significant induced climatic change, considered by many as certain to occur within the next 50 years, makes the `prediction of long term effects even more uncertain.

Estimation of Reduced Yields of Water Sources

Since unconfined fractured rock aquifer permeability generally decreases with depth, particularly in limestones, and is not linearly related to depth, estimation of the decrease in the yield from bores and wells due to a fall in the water table is very difficult unless extensive relevant pumping test results are available. In the absence of such data, making such estimates is very subjective and may be subject to large errors. In an extreme case, the yield of a bore producing most of its water from a single fissure or zone of fractures or solution channels part way down the bore will fall to zero when the water table falls below this source of inflow. Unless the location of such a fissure or zone is known from drilling records or hydraulic logging of the bore, or can be inferred from pumping test results, estimation of the yield for a particular water table level can be grossly in error. Fortunately, for reasons of cost, most bores in the area being discussed are drilled only a short distance deeper after a major source of water is encountered. However, if the yield does not satisfy requirements, further drilling may be ordered and may result in a bore with several entry points for water at different levels or a dominant inflow from a level well above the bottom of the bore. The only way of obtaining sufficient data to allow accurate estimation of the yield versus water table level relationship would then be to determine the vertical distribution of inflow by flow metering in the borehole in conjunction with pumping tests. It would be difficult to justify the cost of such an investigation in the case of most farm water supply bores.

The Future

Problems encountered in separating the effects of drought and mine de-watering in this case have led to the construction of over 20 additional observation bores to allow the extent of the area significantly affected by mine de-watering to be more closely defined. The drilling of these holes provides valuable information on geology as well as allowing more intensive monitoring of water table and groundwater quality variations. If future effects are to be predicted with a greater level of confidence, appropriate procedures to predict the free inflow into the mine as it expands must be incorporated into the regional model which has already been developed to model the effect on water table levels of mine water inflows measured in the past.

It is difficult to judge whether an even more comprehensive program of monitoring in the past would have resulted in certain resolution of disputes. In an area where the art of water divining appears to be given greater credence than the science of hydrogeology, the chance of satisfying all existing landholders is probably slim. It is hoped that the information provided in this paper and earlier papers referred to will allow others involved in similar investigations be better prepared for possible eventualities such as those which have arisen over the past 20 years in this case.

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4. Dudgeon B.A. and Dudgeon C.R. The importance of geological investigations in modelling the effects of de-watering open-pit mines. IMWA, 5th Congress, Nottingham, UK, Sept.1994.

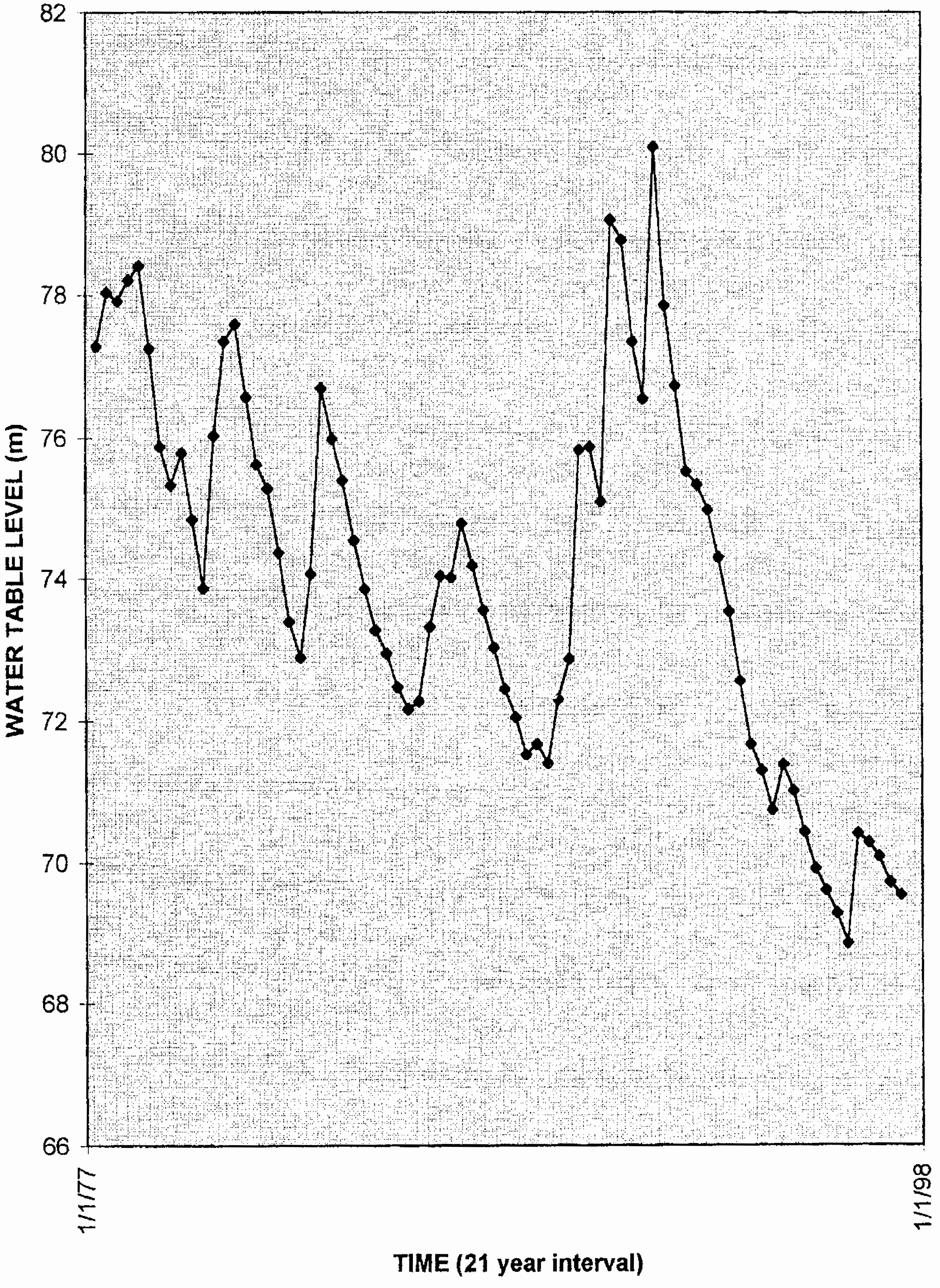

Figure 2 : Water Table Variation in Limestone Remote from Mine (Observation Bore A in Figure 1)

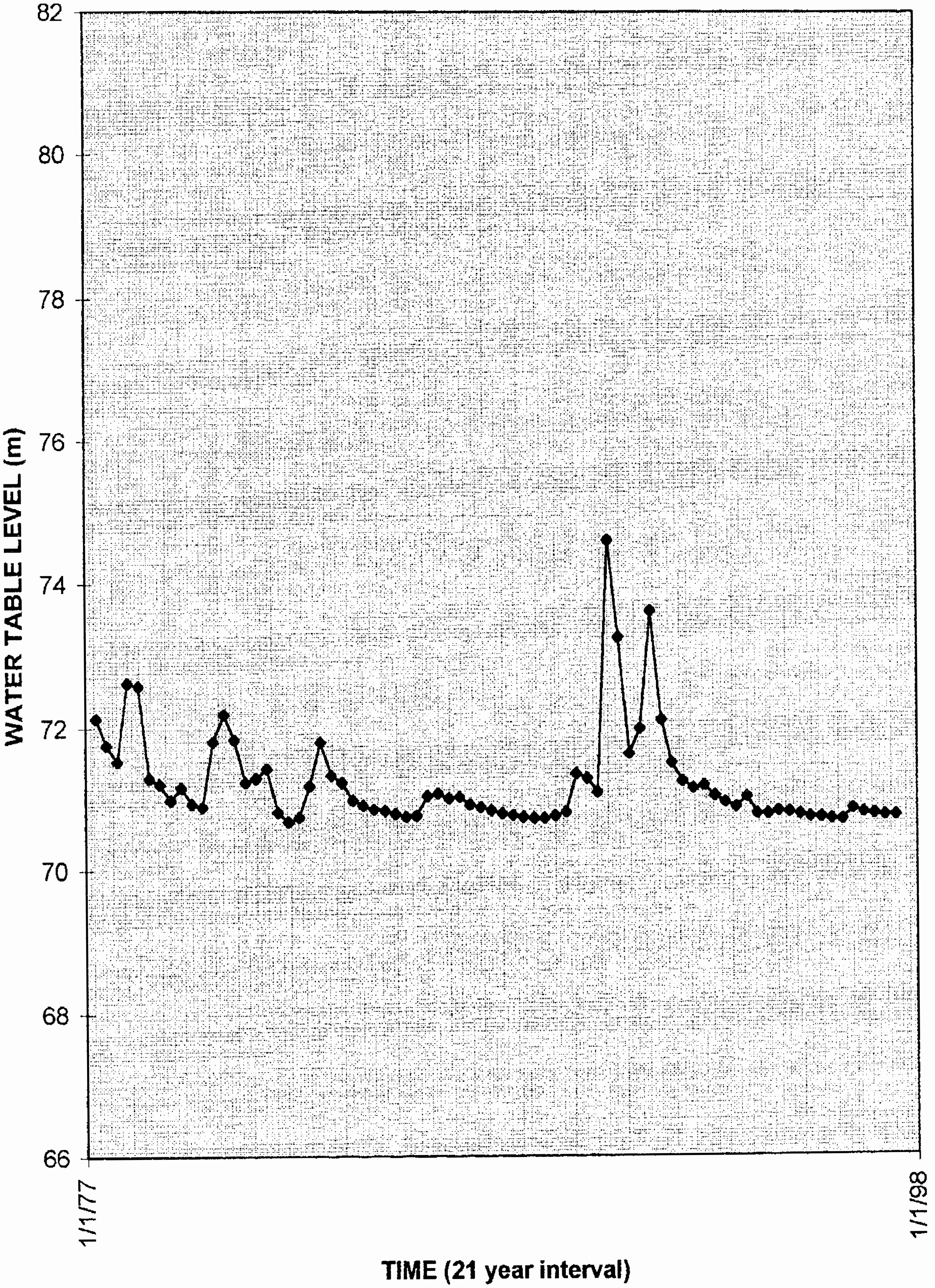

Figure 3 : Water Table Variation in Limestone Remote from Mine (Observation Bore B in Figure 1)

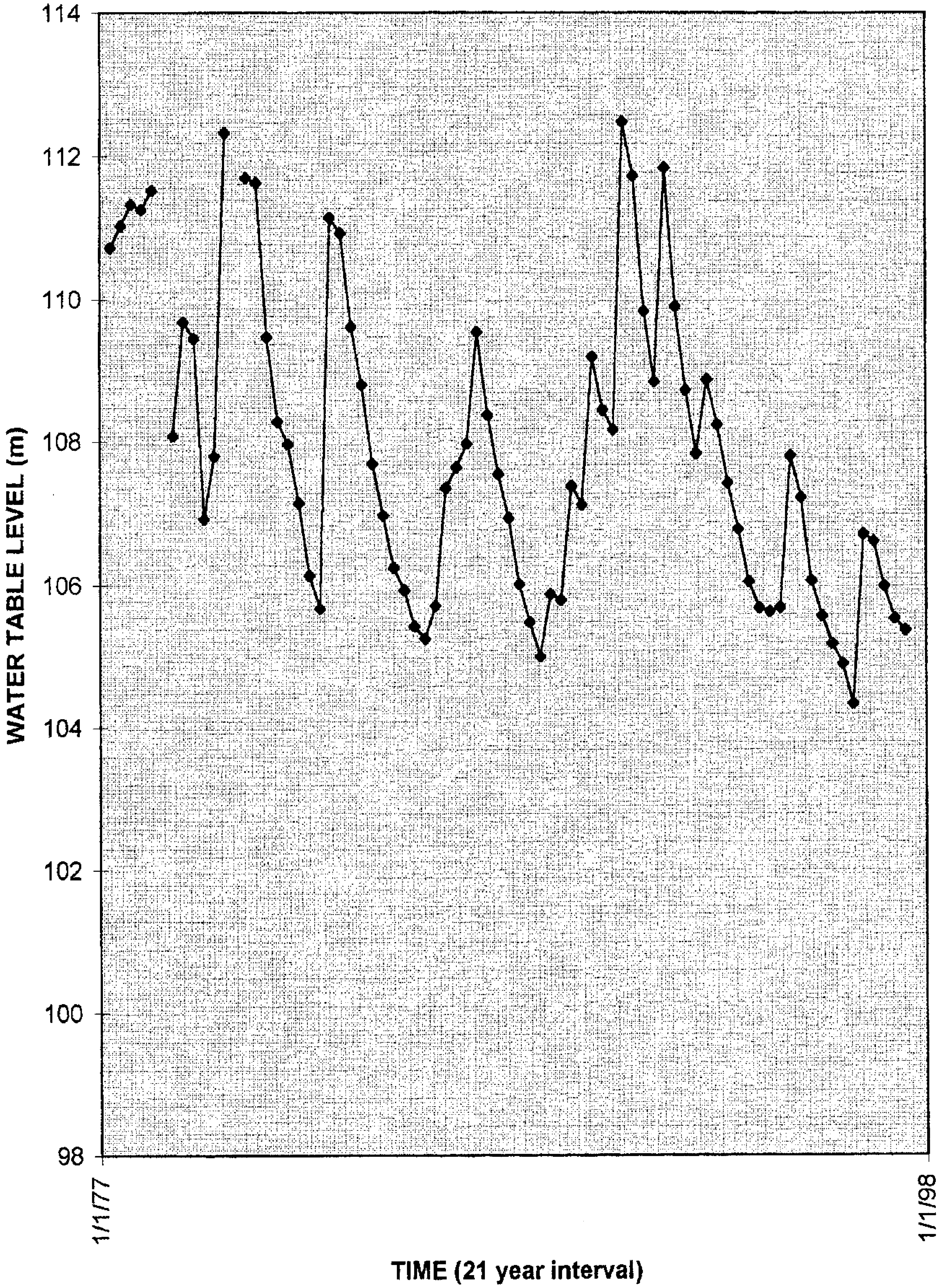

Figure 4 : Water Table Variation in Limestone Remote from Mine (Observation Bore C in Figure 1)

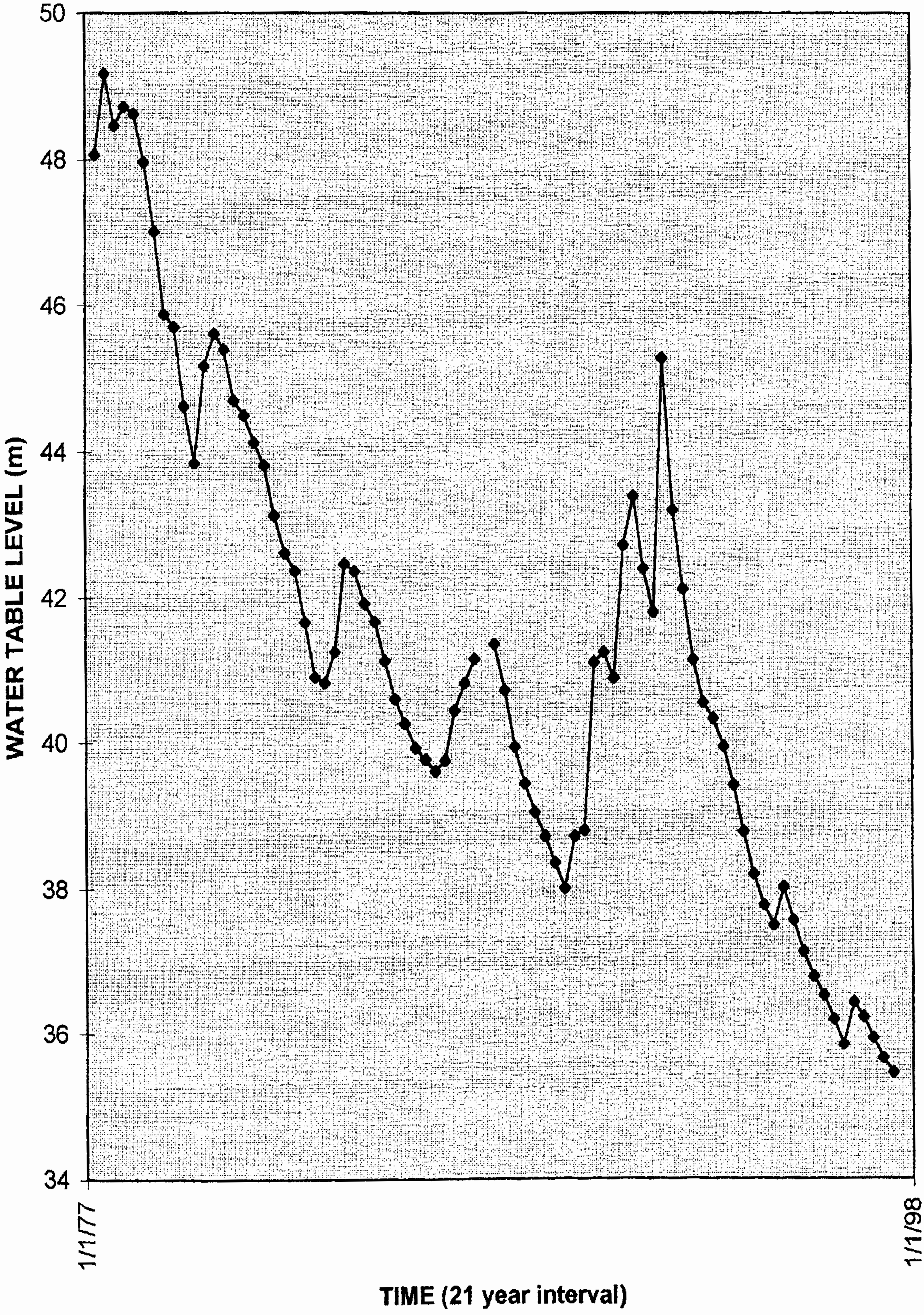

Figure 5 : Water Table Variation in Limestone being Mined (Observation Bore D in Figure 1)