THE EFFECTS OF COAL EXTRACTION ON THE OVERLYING GROUNDWATER REGIME ADJACENT TO CATARACT RESERVOIR, NEAR SYDNEY, AUSTRALIA

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ABSTRACT

Following long controversy, including a Judicial Inquiry, on whether coal mining should be permitted under a number of water supply storages near Sydney, Australia, the New South Wales Dams Safety Committee agreed to a pilot program of panel and pillar mining adjacent to and partly under one of them, Cataract Reservoir. Among other conditions, it stipulated that piezometers be installed at various levels at each of three sites prior to the commencement of panel extraction. The major object of these was to monitor the distribution of head of groundwater in the strata and to ascertain the effect of mining and whether it led to loss of water from the reservoir. In this locality, the Bulli coal seam is at a depth of about 300m, and the deepest piezometer at each site is located at about 100m above the coal.

The results of the monitoring are reviewed from the commencement in January 1981, and are considered in relation to the progress of mining and to the water levels in Cataract Reservoir. The data from the deepest piezometers, set in aquicludes, reflect the pore pressure regime responding to the first workings acting as a sink, and more complex effects as varying stress conditions occurred during panel extraction. These effects were much attenuated in the piezometers at intermediate levels. In the shallowest piezometers, set in aquifers above the full storage level of the reservoir, the head variations reflect only the controls of climate and topography.

The data do not indicate any appreciable loss of water from the reservoir to the underlying strata or to the mine. This conclusion is supported by data on water entry to the mine workings.

INTRODUCTION

On the surface over the Southern Coalfield, south of Sydney, are five major water storages, owned and operated by the Metropolitan Water Sewerage and Drainage Board (MWS&DB) and complementing the supplies to the cities of Sydney and Wollongong (Figure 1).

The question of mining under such storages has long been controversial and since its establishment in 1924, the MWS&DB has been in conflict with mining companies. This led, in 1974, to a Judicial Inquiry led by Mr Justice Reynolds and in his report (Reynolds 1976) he made recommendations which would have allowed restricted mining under storages and within Marginal Zones, but not under the structure.

Subsequently, the New South Wales Dams Safety Committee (DSC) was constituted under the Dams Safety Act 1978, and it has statutory functions under both this and the Coal Mining Act. Its development and workings are detailed by Cantwell and Wilson (1982), Cantwell and Whitfield (1984) and Ramsland and Holla (1986).

A mining company must apply to the DSC with details of its mining proposal. The DSC then recommends the extent and dimensions of mining permitted and associated monitoring conditions which may include surface and/or underground geological mapping, measurement of water movement within the mine, monitoring of surface subsidence and strain, as well as inspections of the dam structure and measurement of seepage from, and phreatic surface within, the dam structure. The monitoring is assessed regularly and action taken as necessary.

BULLI MONITORING PROGRAMME

Although the Reynolds guidelines specified only bord and pillar development within a 35° Marginal Zone and under a storage, the DSC recommended approval of an application by Bulli Colliery, of Australian Iron & Steel Pty Ltd, for panel and pillar mining of the 2.5m thick Bulli seam partly under the 94300ML storage of Cataract Reservoir.

The conditions of approval included provision for extensive surface and underground monitoring including the determination of vertical strains and groundwater levels in a number of boreholes at each of three sites located in the pillar between two of the panels to be extracted (Figure 1).

Development work located two dyke zones transecting the proposed workings and extending under Cataract storage. Although no dyke material was found on the surface, their location corresponded with a major lineament determined from aerial photographs. The DSC was concerned that mining in the vicinity of the dyke zones might result in concentrated strain resulting in surface fracturing and a substantial loss of water from the storage or overlying strata into the mine workings.

An extensive study was therefore initiated to establish the groundwater regime prior to mining and to determine the changes caused by development of headings and extraction of panels. A cored hole was drilled to the base of the Bulli seam and pressure tested using downstage single packer pump-in techniques at stages of approximately 18m to define the hydraulic properties of the strata. Originally a single hole with multiple piezometers was envisaged at each of three sites but ground conditions, principally in the claystones and shales, made this impractical. The decision was made to drill individual holes with single piezometers located at differing depths but similar stratigraphic levels (Figure 2).

Details of the construction and installation of the piezometers are given in Cantwell and Wilson (1982). In brief each hole contains a single 28mm diameter, 1m long Casagrande type porous pot piezometer in a 10m sand filter connected to the surface by ABS tubing. Subsidence and strain measuring points consisting of ring magnets were fitted at approximately 12m intervals to the outside of the piezometer tube in the deepest borehole at each site. All boreholes were geologically and geophysically logged. Following piezometer installation, all holes were grouted from the sand filter to the surface.

The mining comprised development and extraction of three panels, approximately 80m wide and 400 to 730m long, separated by 65m wide pillars at a depth of cover of 230 to 300m. First workings in this area commenced in 1979 and the panels were extracted at intervals over the period April 1983 to March 1986, as shown in Figures 3a), 4a) and 4c).

Monitoring of the boreholes at Site 1 commenced in January 1981 whereas Sites 2 and 3 were not fully operational until April 1982. Water level measurements were taken on a monthly basis except during periods of panel extraction when measurement increased to fortnightly.

In parallel with the surface monitoring, measurement of water movement within the mine workings was also required. This comprised weekly measurement of intake and return ventilation moisture, coal moisture, water piped into the working area and excess water piped, pumped or flowing out of the area.

RESULTS OF MONITORING

The results of water level measurements in the piezometers at the three monitoring sites for the period January 1982 to August 1986 are presented in hydrograph form in Figures 3 and 4, and the distribution of groundwater head as at August 1986 for some selected stratigraphic levels is included in Figure 2.

In considering the data on groundwater heads at the various piezometers, important factors are:

(i) the hydrogeological environment, being a stratified sequence of sedimentary rocks in an area of high relief, is in a recharging zone in the regional groundwater regime so in its natural state the groundwater head will be at a progressively lower level with depth. [This relationship is confirmed by data from other bores, including water supply bores, in unmined areas in the district (Williamson, 1974, 1978)].

(ii) with the probable exception of the Hawkesbury Sandstone, in which piezometers 2E and 3E are set, the strata in which the remaining piezometers are located are all essentially aquicludes in their undisturbed state. [The pressure testing at twelve 18m zones in the deepest bore at Site 1 gave permeabilities mostly less than

1×10^{-6}cm/sec (Cantwell & Wilson, 1982)]. With such low permeabilities, the rate of flow into or out of the monitoring bores in response to changes in head will also be very low. Consequently, substantial changes in stress on the strata may be reflected by only gradual changes in water level and with considerable time lag. However, reversals of stress, eg: from tensional to compressional, will be reflected relatively rapidly because they will reverse the trend of water level movement.

(iii) Stress induced fractures of significance in relation to vertical hydraulic connection would result in rapid water level change.

With these aspects in mind, the hydrographs in Figures 3 and 4 will be discussed with particular reference to the effects of mining.

Site 1 Piezometers

At this site, the early influence of first workings, which allow the mine to act as a sink and effect pore pressure reduction, is evident in the two deepest piezometers 1B and 1A. This would have begun even before monitoring commenced in January 1981, there being first workings only 120m WNW from directly under the site in September 1980. The downward trend in water level due to this effect was accelerated when first workings came to within 20m of under the site in June-July 1982, as evidenced by the steepened gradient of the hydrograph of 1B at this time and to a lesser extent in 1A. In consequence, the water level in 1B had fallen at least 12.3m before extraction of the first panel, 1SW, began in April 1983. It was less affected in 1A, falling only 2.9m. (Figure 3a).

Within three weeks of the start of extraction of panel 1SW, the water level in 1B had fallen a further 0.9m, but then, when the extraction front was adjacent to under 1B, the trend reversed to slowly rise 3.8m over the next 11 months. In 1A, it had started to rise by March 1983, but rose 6.7m in 10 months, taking it 1.5m above the then Cataract storage level.

In both 1B and 1A, the water levels had begun falling again a few months before extraction of 2SW panel started in July 1984. They continued to fall, in 1B only 1.5m but in 1A 15.1m, accelerating markedly when the extraction front was closest to Site 1 in August-September 1984.

In 1B, the level started rising again four months before extraction of 2SW finished and was still continuing as at August 1986, the last data reviewed in this paper. On the other hand, the level in 1A reached its lowest recorded point in July 1985, nearly four months after the end of extraction of 2SW panel and two months after the start of extraction of 3SW panel. The level then rose, peaking in November 1985, from whence it continued to fall slowly.

At the end of the period of record, the level of 1A was only 1.1m above that in 1B, though in March 1981 it was 4.0m. Over the monitoring period, the level in 1B finished 5.4m lower than its initial highest recorded point in March 1981, and that in 1A 8.3m lower. However being the deeper, at least some of this difference may be due to 1B being more affected by the pore pressure reduction occasioned by the first workings present before monitoring began.

The water levels in 1C and 1D show broadly similar behaviour patterns though with relatively small amplitude and some time lag (Figure 3a). Initially, the levels were in their expected relative positions, with that in 1C below that in 1D. However, within a month of the start of extraction of 1SW panel in April 1983, the level in 1C rose above that in 1D and stayed there till February 1984. The levels in these piezometers then fluctuated about each other, usually within a metre and with that in 1C more often the higher, but from December 1985, 5 months after extraction of 2SW panel, it remained above that in 1D. From about mid-1985, soon after the extraction of 3SW panel started in May, the hydrograph of 1C shows a pronounced parallelism to that of 1A. Both rose to peak in November 1985, and from then both were still falling as at August 1986. The level in 1C rose to above the Cataract storage level, to as high as 1.0m above FSL during October-December 1985, the highest water level achieved in any of the Site 1 piezometers.

The amplitude of variation in water level in 1D was more subdued than in 1C, mostly within a range of 2.0m. However, from November 1985, its level has been on a slowly rising trend whereas that in 1C has been slowly falling. As at August 1986, they were about 1.0m apart and since they are on reverse trends and panel extraction has ceased, it is anticipated that the water levels in 1C and 1D will ultimately resume their expected relative positions, with that in 1D the higher.

Considering the behaviour of water levels in the piezometers at Site 1, it is evident that, allowing for attenuation and lag effects, there is a general sympathetic relationship. The behaviour is consistent with the effects of pore pressure variations due to shifting stress conditions in the strata as a result of the mining. All of the piezometers showed water level increases as the extraction of 1SW panel progressed past Site 1, which is consistent with compressional effects as the strata under the site received additional load. Conversely, with the extraction of 2SW panel, the small amount of surface subsidence (maximum 60-65mm) over both panels would give tensional conditions under Site 1, which are reflected by the reduction in water levels. Climatic variations, especially rainfall, or variations in the level of Cataract storage, do not appear to have any appreciable influence on the water levels (Figure 3b). There appears no evidence to suggest that the changing head conditions in the piezometers indicate any significant change in the degree of hydraulic connection between the storage, the monitored zones and the mine, or that there has been appreciable loss of water from the storage to the strata or the mine.

Site 2 Piezometers

As evident in Figure 2, Site 2 is about 24m higher than Site 1 and, because of the increased thickness of Hawkesbury Sandstone there, one of the piezometers, 2E, is located in that formation.

Prior to the start of extraction of 1SW panel, the water level in 2B was falling slowly, probably influenced by the earlier first workings close to under its site in June 1982. When the panel extraction commenced, the rate of fall increased, indicating tensional effects. But once the extraction front passed Site 2 in July 1983, there was a change to compressional effects, leading to a rise in water level of 9.2m over the next three months. This trend reversed abruptly when the panel was completed and, from September 1983, the level fell a total of 21.0m at a progressively declining rate until a month after the start of extraction of 2SW panel in July 1984. It slowly rose 1.2m by November 1984, when the extraction front reached near under the site. There then commenced an even more dramatic fall, 36.6m in about four months, indicating a substantial tensional regime. Within a month of completion of 2SW panel in April 1985, the level started to recover and was still doing so as at August 1986 (Figure 4a). By then it had recovered 25.6m but it was still some 38m lower than the level in 1B, which is on about the same stratigraphic horizon, as compared with being about 17m lower than it in April 1981.

In relation to the water level behaviour in 2B, it seems significant that the zone of maximum surface subsidence after extraction of the three panels is in the vicinity of Site 2. Maximum subsidence as at August 1986 was 114mm.

In piezometer 2C, for reasons unknown to us, the water level was left artificially very high on completion, some 53m above Cataract FSL. Consequently, over the period of monitoring it fell gradually, though at a progressively reducing rate and any effect due to the extraction of 1SW panel was masked. However, during the initial extraction of 2SW panel its rate of fall lessened appreciably, from 0.4m to 0.2m per month, until the extraction front was close to Site 2. There followed a tensional effect causing an increase in the rate of fall to 1.1m per month and this continued till September 1985. From then its rate of fall progressively reduced and was only 0.1m per month as at August 1986. Its level had fallen below Cataract FSL in May 1985, and by August 1986 it was 7.5m below FSL.

The water level in 2D was also left very high on completion but it fell to a low in mid-June 1983, at which time the extraction front of 1SW panel was closest to under Site 2. A slow rise, totalling 1.9m, ensued over the next 6 months and from then on only minor gradual fluctuations. Its behaviour has been very much attenuated compared with the deeper piezometers at this site. Also, its water level has consistently remained above that of Cataract FSL, though only 0.8m above it as at August 1986.

The base of the monitored zone in 2E is in the Hawkesbury Sandstone and some 25m above Cataract FSL. Its water level has remained over 40m above FSL and its behaviour is consistent with that of a perched aquifer and is topographically and climatically controlled. Allowing for time lag, the significant rises in level correlate with major rainfall events, eg: the rise of about 3.7m over November 1984 to February 1985 is considered due to recharge from the high rainfall of 381.5mm over 4-12 November, 1984, which also led to a 2.0m rise in Cataract storage at that time (Figures 4a and 4b). There appears no correlation of the water level in 2E with the mining events at depth.

As for Site 1, the data on water level behaviour relevant to Site 2, other than for 2E, are considered consistent with the effects of pore pressure variations due to changing stress conditions in the strata as a result of mining. The effect are pronounced in piezometer 2B, and evident in 2C during 1985, but very much attenuated in 2D. In 2E, such effects are not evident.

Site 3 Piezometers

Location of site 3 was originally envisaged to be outside the influence of mining and to therefore act as a control. However, alteration of the mine layout after the holes were completed, bringing development headings closer to the site, negated this objective.

Interpretation of the data from piezometers 3B, 3C and 3A has also been handicapped. The zones monitored have such low permeabilities and the completion water levels were left so high that the levels have generally been falling over the period of monitoring (Figure 4c). When this situation became apparent in various piezometers, consideration was given to bailing the water down to a more reasonable level, though the true head was not known. However, the main object of the monitoring is to ascertain whether any mining-induced fractures or other openings allowed loss of water from Cataract storage, and since any substantial disturbance to the groundwater regime would become readily evident, it was decided to leave conditions as they were. Thus, in spite of the disadvantage of artificially high water levels, their consistent behaviour indicates there not to have been any significant change in the degree of hydraulic connection between the monitored zones, the storage and the mine.

Of the above three piezometers, the water level in 3B as at August 1986 was 3.0m below that in 1B, and since there have been first workings within 20m of under 3B since January 1982, its level is now probably valid, the aquiclude draining under pore pressure reduction due to the first workings acting as a sink.

For 3C, it was expected that its head would be lower than that in 3D, but as at August 1986 its water level was 5.8m above that in 3D (Figure 4c). However, the rate of fall in 3C is such that its level should eventually reach its expected relative position of being below that in 3D.

The water level in 3D shows behaviour similar to that in 2D, fluctuating only very slowly and with amplitude within 2.5m. In spite of the 250m distance of Site 3 from the limits of panel extraction, it seems significant that its periods of low level have been during the extraction of each of the three panels. It is considered that, as for 2D, the water level behaviour in 3D is more likely to represent attenuated pore pressure effects due to mining rather than climatic or other effects.

As in 2E, the behaviour of water level in 3E is consistent with topographic and climatic control (Figure 4b). Its variations are within a range of 2.5m and the greater time lag and attenuation of water level change compared to those in 2E is considered due mainly to its monitored zone being about twice the depth of that in 2E, relative to the surface. As at August 1986, the level of 3E was 59.0m above Cataract FSL and 18.0m above that in 2E, an expected relationship. The hydraulic gradient for the E horizon depicted in Figure 2 clearly indicates that groundwater from the Hawkesbury Sandstone contributes to Cataract Storage.

It is concluded that at Site 3, the mining has not caused any significant change in the degree of hydraulic connection between the monitored zones, the storage and the mine.

WATER ENTRY TO MINE

The history of mining the Bulli seam in this coalfield has been that the mines are virtually dry, with only small inflows from the strata, commonly temporary, and this also applies in the present case. The data on water movement between strata and mine workings during the mining show that there was some water make during extraction of all three panels. However, even then the make was negligible, the maximum recorded being only 1120L/hr in June 1983 during extraction of 1SW panel. This is in accord with the conclusions from the piezometric data and indicates that the source of the make during extraction was relatively localised groundwater.

CONCLUSIONS

It is concluded that:

(i) the piezometric data from the three monitoring sites reflect the effects of pore pressure variations occasioned by mining. Initially, these were reductions in pore pressure due to first workings acting as a sink and causing slowly declining water levels, generally more evident in the deepest piezometers. With panel extraction, the pore pressure regime was compounded by changing stress conditions set up in the overlying strata, so that both increases and decreases in pore pressures were effected in response to compressional and tensional conditions at different times and locations; and

(ii) the mining layout has allowed panel extraction of the Bulli seam close to and under Cataract storage, with minimal surface subsidence and without causing significant change in the degree of hydraulic connection between the storage, the zones monitored in the upper two-thirds of the overburden strata, and the mine, or appreciable loss of water from Cataract storage.

ACKNOWLEDGMENT

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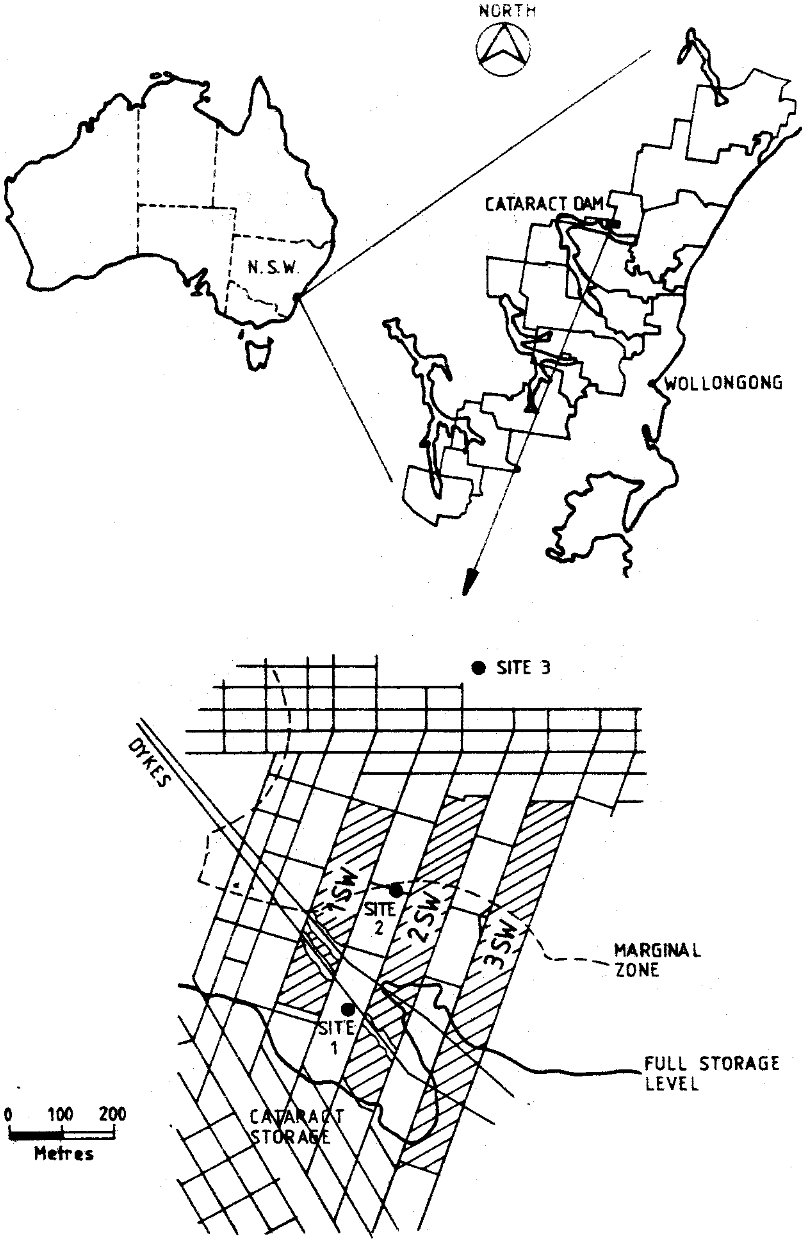
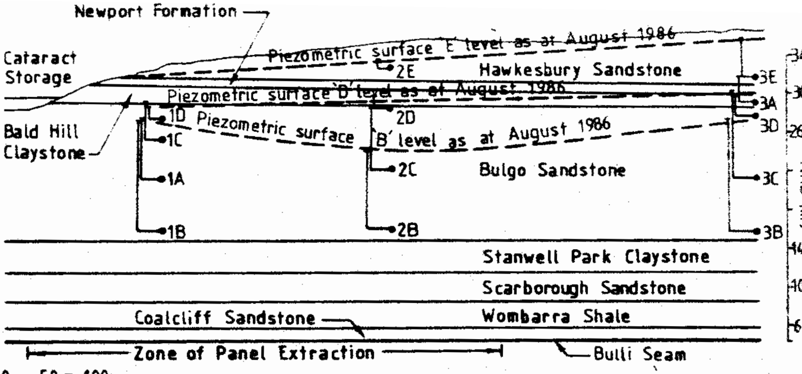
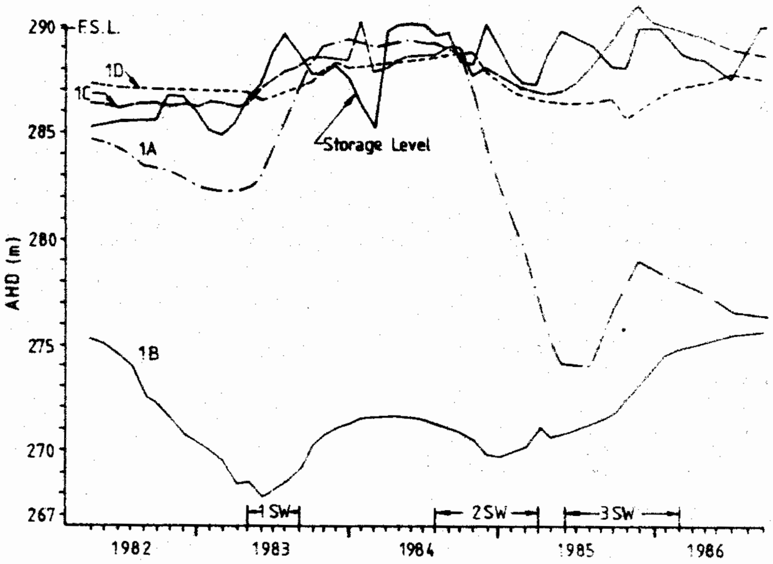


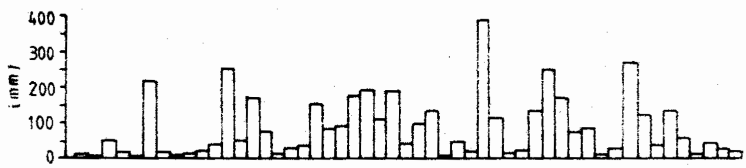
LOCATION AND LAYOUT OF MINING. FIGURE 1



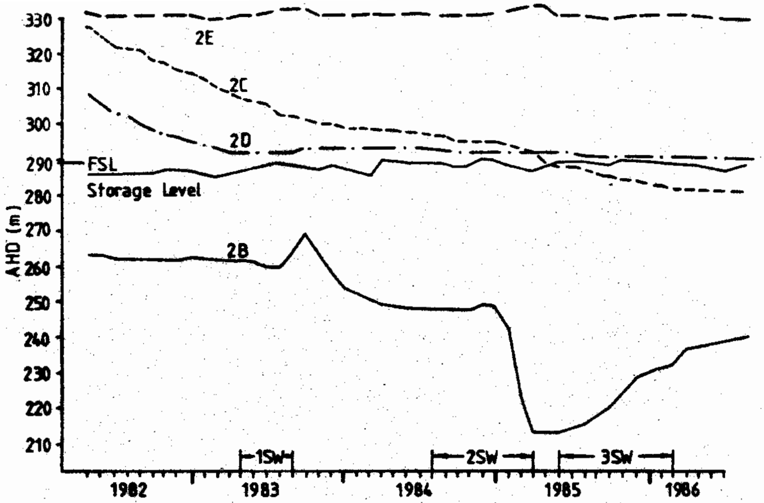
STRATIGRAPHIC SECTION AND LOCATION OF PIEZOMETERS. FIGURE 2.



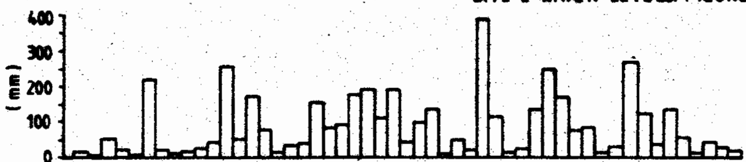
SITE 1 WATER LEVELS. FIGURE 3(a)



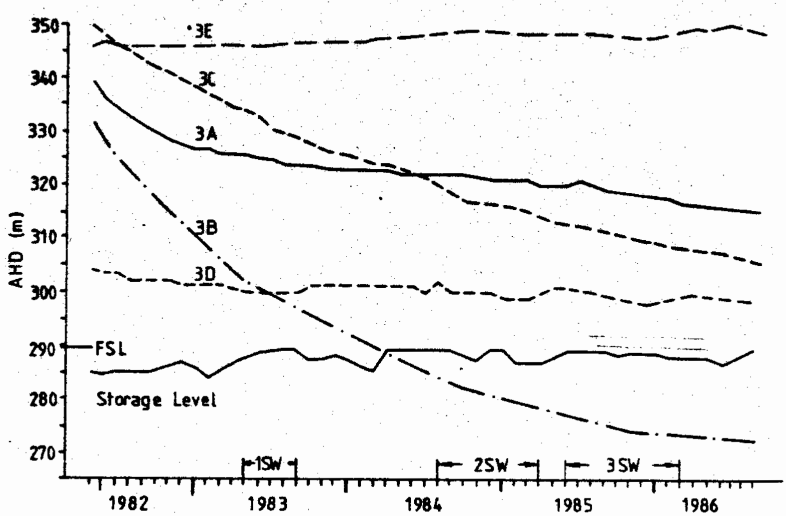
RAINFALL FIGURE 3(b)



SITE 2 WATER LEVELS. FIGURE 4 (a)



RAINFALL. FIGURE 4 (b)



SITE 3 WATER LEVELS. FIGURE 4 (c)