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SEISMIC MONITORING OF THE BURDEKIN FALLS DAM - A PROGRESS REPORT TO APRIL 1989

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CONTENTS

SUMMARY

The Burdekin Falls Dam first impounded water in November 1986 and reached full supply level (FSL) in March 1988.

Seismic monitoring of the Burdekin Falls Dam commenced in 1981 with a network of three analogue recorders. Seven digital recorders were added to the network in 1984. Minor activity has been detected in the immediate vicinity of the reservoir but it remains uncertain whether this was induced by the filling of the reservoir or is a continuation of the natural activity observed in the area before the reservoir was filled. Continued monitoring will help to establish if there is any connection between observed seismicity and water level.

The events in the vicinity of the reservoir are below magnitude 2 and as such do not constitute a threat to the safety of the dam. The maximum acceleration expected from a magnitude 2 earthquake at a distance of 1 km using results such as Tynn (1987) is an order of magnitudes less than the acceleration used in the dam design (Russo et al. 1985).

The possibility of induced activity following a reduction in the water level must be considered.

It is recommended that the monitoring continue at the current level until early 1990. Monitoring at a reduced level should continue until the end of 1992, to include five years post-filling, and at a basic level for an indefinite period thereafter.

INTRODUCTION

The main aim of the monitoring of a large reservoir such as the Burdekin Falls Dam is to determine the effect of the filling of the reservoir on the local seismicity. Normal practice is to install a network several years prior to impounding so that the natural seismicity can be measured. Comparison of pre- and post-impoundment seismicity will indicate the effect of filling the reservoir.

Instrumental monitoring:-

- Allows the scientific study of reservoir induced seismicity.
  All large magnitude earthquakes associated with reservoir induced seismicity have been preceded by smaller earthquakes (Allen, 1982). Instrumental recording is the only method by which the occurrence of these low magnitude earthquakes can be verified.

- Can be used to reduce the incidence of reservoir induced seismicity.
  Instrumental recording cannot prevent reservoir induced seismicity but partial control may be possible, as suggested by Simpson and Negmatullaev (1981), if correlations between seismicity and water level or filling rate can be found.

- Allows informed public announcements.
  Should an earthquake be felt in the vicinity of the reservoir the seismic network allows informed announcements to be made regarding the location, magnitude and possible effects.

This report will detail results from the Burdekin Falls Dam network in two areas. First, the seismicity in the region surrounding the reservoir will be detailed in relation to the geological structure and then the seismicity in a smaller area around the reservoir will be studied in relation to reservoir induced seismicity.

NETWORK OPERATION

Monitoring of the Burdekin Falls Dam commenced in February 1981 with the installation of three analogue recorders. The network was upgraded and expanded in 1984 with the addition of seven triggered recorders. Details of the network configuration, instrument operation, and data analysis procedures have been detailed in Cuthbertson (1982) and Cuthbertson (1988).

The seismograph network (Figure 1 and Table 1) has continued unchanged since it was last described in Cuthbertson, 1988.

Table 1: Locations and operating periods of seismographs in the Burdekin Falls dam region

Code	Longitude	Latitude	Height	Start	End	Location
Analogue recorders						
BGRR	147.1052	-20.5492	0.16	81-02-16		Glenroy (Analog)
CVL	147.609	-20.590	0.102	85-04-30		Collinsville (Myuna)
FGT	147.7765	-20.9701	0.220	87-08-13		Fig Tree
BGC	147.1609	-20.6140	0.16	81-02-12	85-04-29	Glendon Crossing
BMG	147.0608	-20.6142	0.16	81-02-13	85-04-30	Mount Graham
BNG	147.3121	-21.3440	0.285	85-05-05	85-08-30	Bungobine
GVA	147.4827	-21.4890	0.200	86-03-18	87-06-01	Glen Eva
Digital recorders						
BGRB	147.1052	-20.5492	0.16	84-02-27		Glenroy (Digital)
BSL	146.564	-20.867	0.185	84-03-02		Bruslee
DLB	147.264	-20.151	0.070	84-04-09		Dalbeg
DNG	146.475	-20.555	0.280	84-02-29		Doongara
MCP	146.806	-20.552	0.300	84-02-23		Mt Cooper
MHP	146.802	-21.552	0.200	84-04-10		Mt Hope
UKA	147.127	-20.899	0.200	84-03-28		Ukalunda
University of Queensland recorder						
CTA	146.2550	-20.9883	0.357	62-00-00		Charters Towers (UQ)

Note: Height is in kilometres.
Start and end dates are in Year-Month-Day format.
No end date indicates the recorders are still operating.

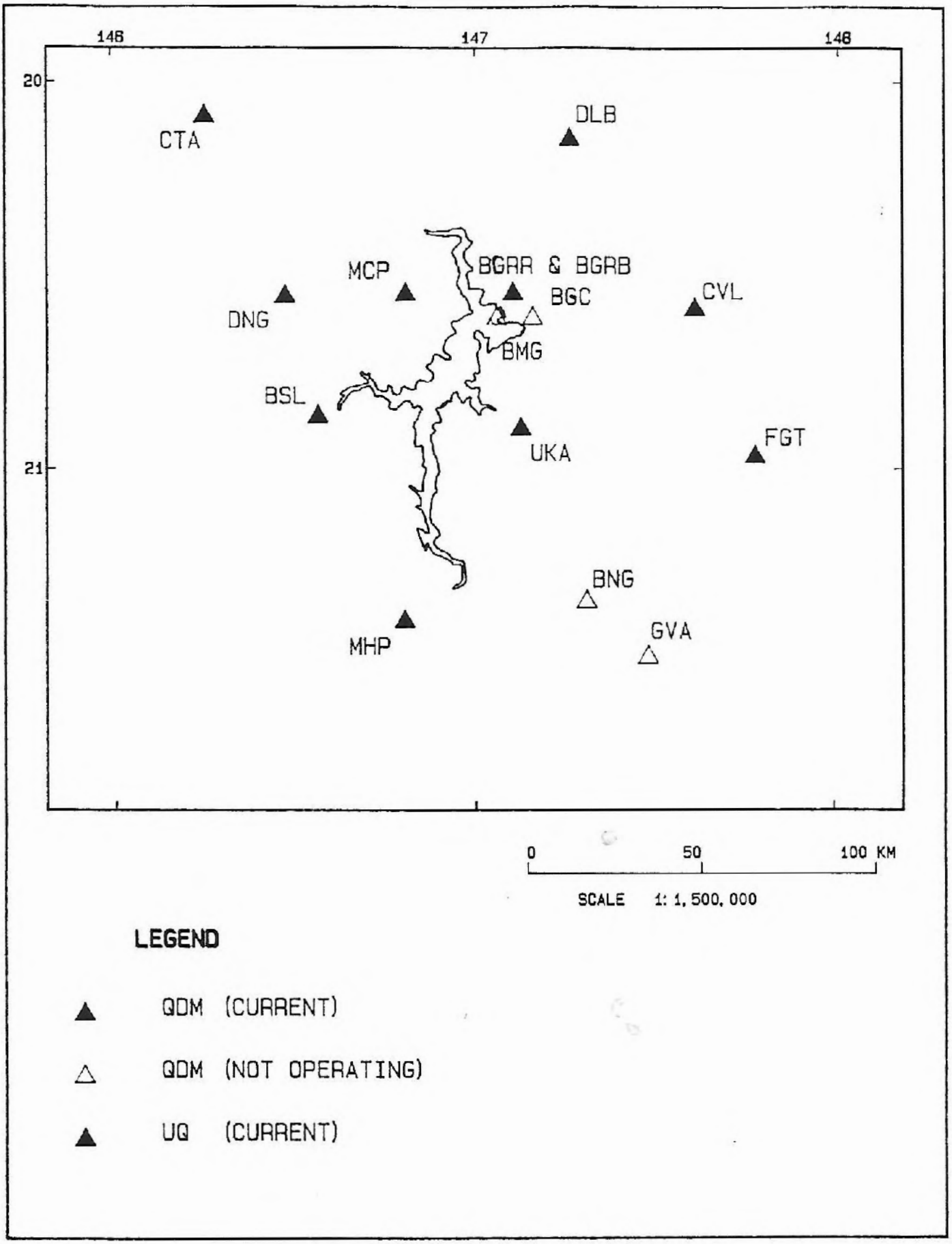

Figure 1 Seismographs in the Burdekin Falls Dam Region

There have been some difficulties with several operators leaving the district, and with one instrument which had consistent problems with battery power.

The cessation of a Telecom operated radio time signal (VNG) in October 1987 created difficulties. This signal was used to obtain absolute time for each seismograph. Accurate timing is essential in obtaining accurate earthquake locations. As an interim measure radio time signals from Hawaii (WWVH) and from Canberra (transmitted by the Royal Australian Navy) have been utilised. Unfortunately, the Hawaii signal is very weak and the Navy signal is only transmitted as an interim measure with no guarantee of continuation. The recently formed VNG Users Consortium has recommenced transmission on a new frequency but this can only be received satisfactorily in the early morning or late evening. The Users Consortium is negotiating for the transmission of VNG on two new frequencies. This would greatly improve reception and ease the problems being experienced with time synchronisation. Transmission will require financial support by the users, which will necessitate some recoupment of costs from QWRC.

In the nine years of operation the Burdekin Falls Dam network has become a vital link in the national seismograph network, recording and locating several significant earthquakes in northeast Queensland. The largest of these was a magnitude 4.7 event that occurred off the coast of Ayr in September, 1987. This event was felt quite strongly along the coast at Ayr, Home Hill and Townsville and by some people in Bowen, Collinsville, Charters Towers and Ingham.

Other significant earthquakes for which valuable data were supplied by the Burdekin Falls dam network include the large earthquakes of January 1986 at Tennant Creek in the Northern Territory, and the earthquake of March 1986 at Marryat Creek in South Australia.

REGIONAL SEISMICITY

The large extent of the Burdekin Falls dam network, brought about by the limited availability of reliable operators and limited access to suitable sites, has enabled the seismicity of a significant area surrounding the reservoir to be monitored. Study of this larger area is important in the identification of seismicity trends. These trends indicate large-scale crustal weaknesses which have a direct bearing on reservoir induced seismicity.

Figure 2 shows the earthquakes that have been located in the area of the Burdekin Falls dam. Most of these events were located using data from the Burdekin Falls Dam network. The earthquakes that occurred prior to 1981 were mostly located using felt reports and arrival times at regional seismographs (Rynn, 1987). Using this data set there appears to be an area of scattered seismicity to the west of the reservoir. In the east the seismicity is restricted to more a defined area.

In any seismicity study it is important to consider the accuracy with which the events have been located. Many of the "historical" events and some of the more recent events have large location errors. The large errors for the "historical" events are due to the large distances to the nearest recording station. Some historical events have only been located using arrival times from one seismograph and limited felt reports. Location errors for these events could be greater than 50 km. Some of the more recent events have large errors because they were only recorded on one or two of the stations in the network; either because they were very small or because some of the recorders were not operating correctly. The poorly located earthquakes are ignored when determining if there is any correlation between seismicity and geology. Figure 3 is a plot of earthquakes which have occurred since the Burdekin Falls dam network commenced in 1981, coded to indicate the degree of location accuracy.

If only the better located events are considered the scattered activity to the west of the reservoir is now seen to be broadly aligned along three trends (labelled A, B, and C). Many of the poorly located events (accuracy = 50 km) are also seen to lie along these trends.

The activity to the east of the reservoir, in the Collinsville area, is confined to the area labelled D in Figure 3.

The seismicity trends have been plotted in Figure 4 with mapped geological faults and generalised geological provinces (from Gregory, 1969, Paine and Cameron, 1972, Malone, 1969, Olgers 1969a, Clarke and Paine, 1978, Levingstone, 1981). Trend A is shown to correspond approximately with the eastern edge of the Galilee Basin while trend B correlates with the northern edge of the Drummond Basin. Trend C is seen to be parallel to several large megashears that were proposed by Olgers (1969b). The correspondence may be coincidental but it is quite possible that the same crustal feature that was responsible for the geological structure is currently influencing the observed seismicity.

The activity in zone D is confined to the northern extreme of the Bowen Basin and to the east of the Millaroo Fault zone.

The large Millaroo Fault Zone which separates the Burdekin area into two provinces of differing fault trends (Paine and Cameron, 1972) has no direct connection with observed seismicity. It does however separate the large linear seismicity trends in the west from the confined activity in the east.

The varying strikes of the trends shown in Figure 4 and the contained activity near Collinsville do not fit in with the notion of a uniform stress field. If a uniform horizontal stress field exists in north-east Queensland, as has been proposed in south-east Queensland (Cuthbertson, 1989) then only appropriately oriented faults would be activated. These faults would all have similar strikes. A uniform stress field could however exist in north-east Queensland if there are large-scale fractures in the crust that are controlling the seismicity. Focal mechanism studies of the better located earthquakes in the area will help to resolve the situation.

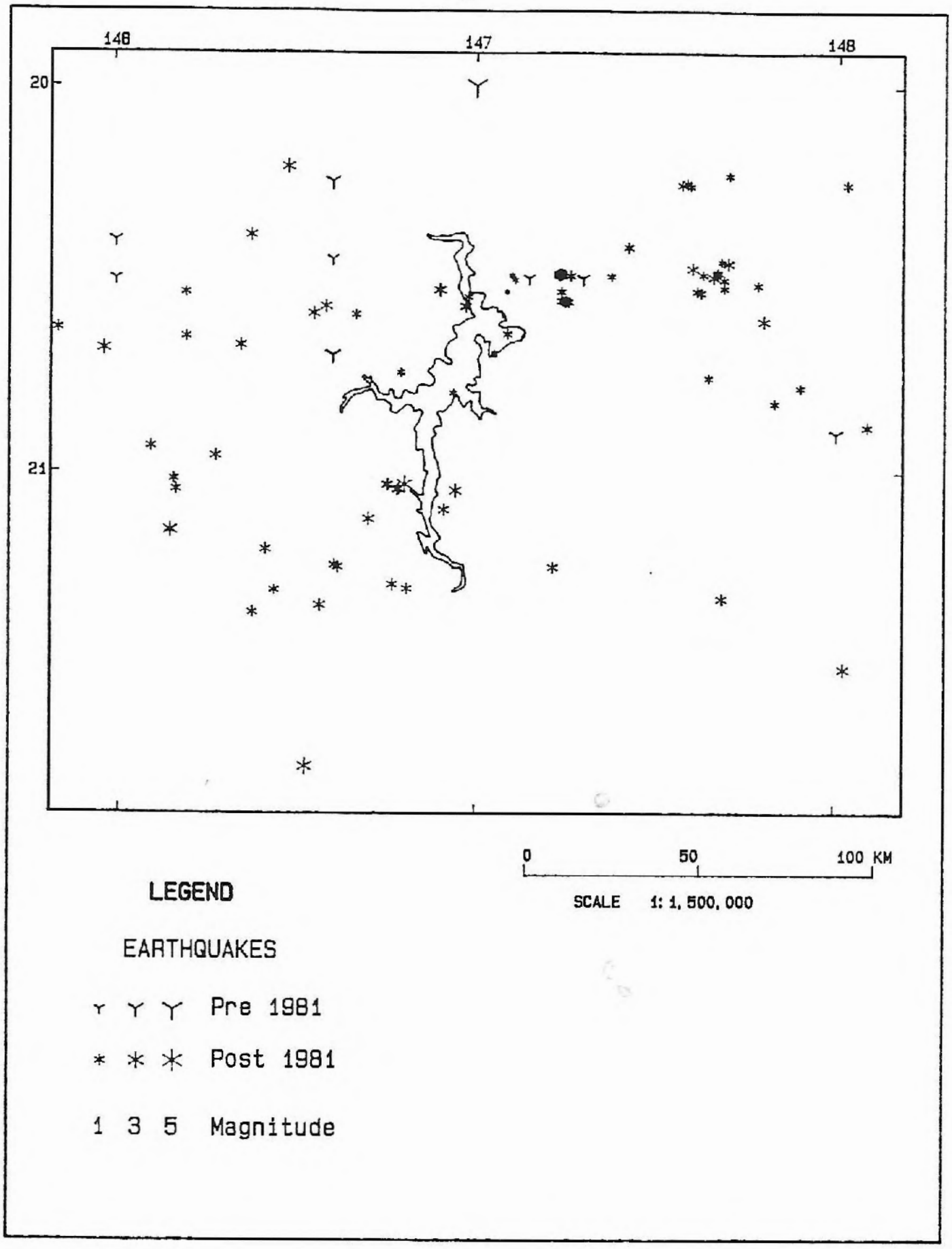

Figure 2 Earthquake Locations in the Burdekin Falls dam region

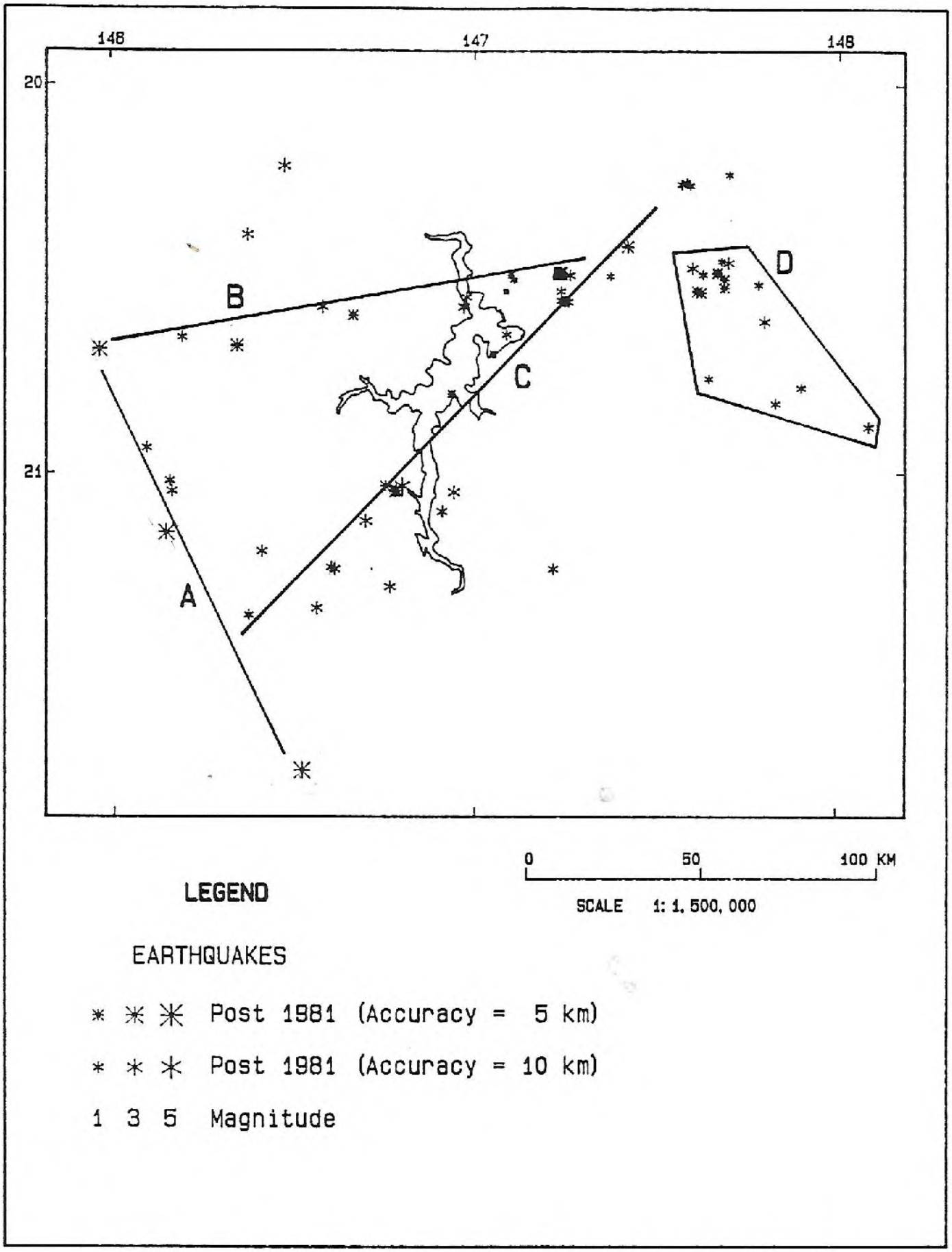

Figure 3 Earthquakes in the Burdekin Falls dam region since 1981 and interpreted seismicity lineaments

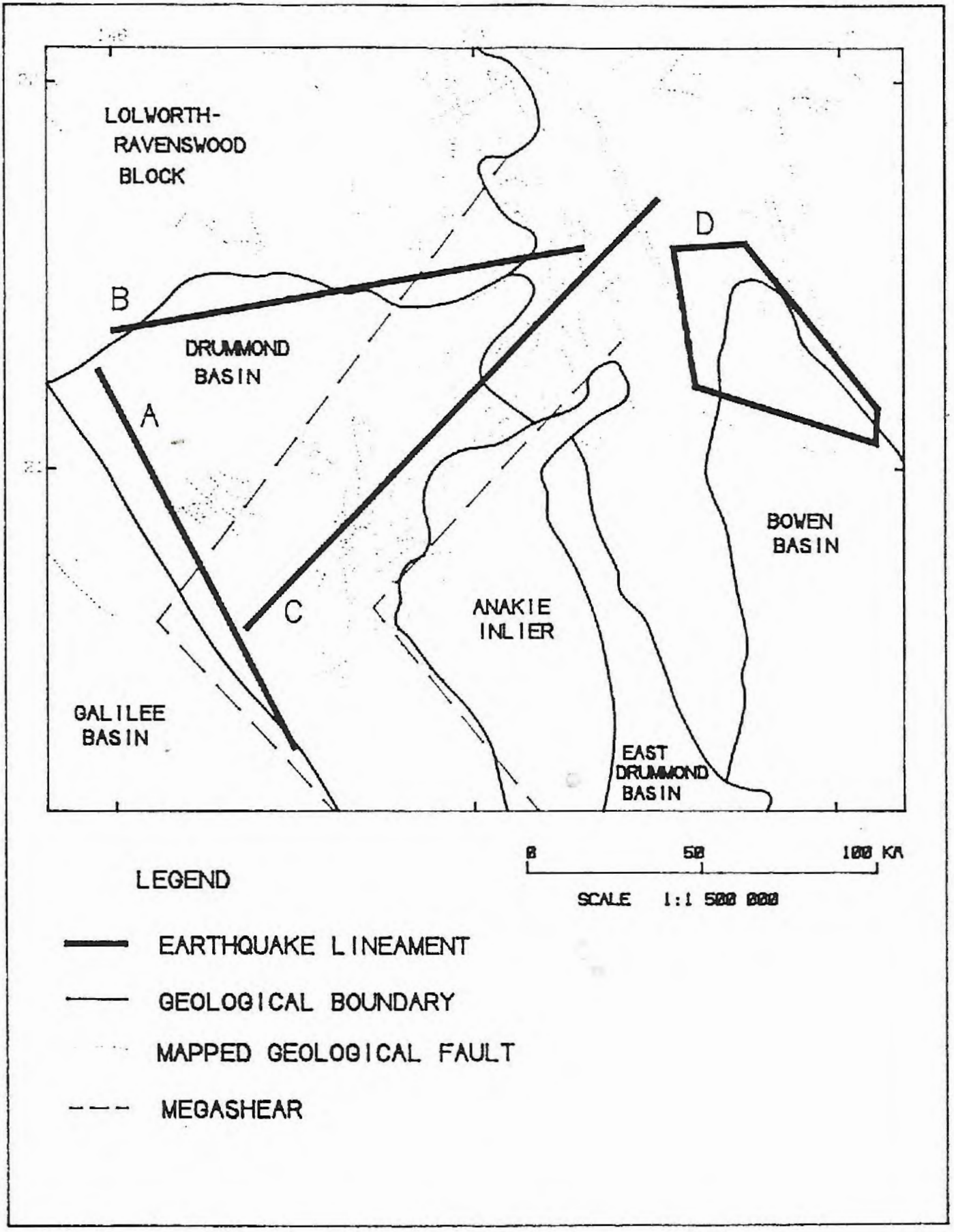

Figure 4 Seismicity lineaments and geological structure in the Burdekin Falls dam region

INDUCED SEISMICITY

Impounding a reservoir on a pre-stressed crust will cause changes in both the stress field and the pore pressure field directly beneath the reservoir and in an area immediately surrounding the reservoir. These physical changes are the mechanism by which seismic activity is induced.

Induced seismicity will be confined to the area that is influenced by the reservoir. Simple stress calculations (Poulos and Davis, 1974) show that the effect on the stress field of a circular body with a uniform density distribution is negligible at a distance of two radii from the centre of the body. The area of influence of a regularly shaped reservoir could thus be defined as the area which is twice the size of the impounded area. In practice the shallow upper reaches of a reservoir would have to be ignored in selecting a simplified shape, which would then be doubled in size to obtain the area of influence.

The choice of a factor of two is based on assumptions regarding homogeneity of the underlying crust and regularity in the shape of the impounded area. For a heterogeneous crust and an irregularly shaped reservoir the factor should be increased to ensure that all possible induced activitiy is included. Two areas of influence were chosen for the Burdekin Falls reservoir (Figure 5); one using a factor of 2 (as in Cuthbertson 1982) and a larger area obtained using a factor of 3. The smaller, inner area, with a factor of 2, will be referred to as Area I and the larger, outer area, with a factor of 3, will be referred to as Area II. Area I would enclose all activity due to a regularly shaped reservoir on a homogenous crust. Area II was chosen to ensure that it enclosed all possible activity due to an irregularly shaped reservoir on a heterogeneous crust. Note that Area I is totally contained in Area II so that all events in Area I are also in Area II.

Earthquakes that have been located inside Area I and Area II since monitoring began in 1981 are plotted in Figure 5. Comparisons of reservoir water level, water volume, earthquake magnitude and earthquake frequency are given in Figure 6 (Area I) and Figure 7 (Area II). All are plotted against a common horizontal time axis so that the effect of the impounding on the local seismicity can be studied. The water depth and water volume are plotted as a percentage of the values at FSL. For the Burdekin Falls reservoir these are 37.7m for depth and 1.86 million ML for volume.

In the 13 month period from when the reservoir filled in March 1988, to the end of April 1989, eight micro-earthquakes have occurred in Area I which has an area of 2400 km^2. This compares with seven earthquakes in the same area for the six year period to filling. For Area II, with an area of 5400 km^2, the numbers are 32 earthquakes prior to filling and 16 following filling.

In both Area I and Area II the average rate of earthquake activity has appeared to increase immediately following filling of the reservoir. However care must be taken in drawing conclusions from such small data sets. Large temporal variations in natural activity levels can be seen in Figure 7 prior to impoundment. The majority of the activity in 1988-1989 in Area II is located in close proximity to a swarm of events which occurred in 1981. The slight difference in locations between the two swarms is attributed to changes in the geometry of the recording network. In Area II the activity following impounding is simply interpreted as a continuation of the natural activity observed prior to filling.

The activity observed in 1988-1989 in Area I could however be interpreted as being induced. These events occurred in an area where previously no activity had been located and were also appreciably larger in magnitude than those recorded elsewhere in Area I prior to filling.

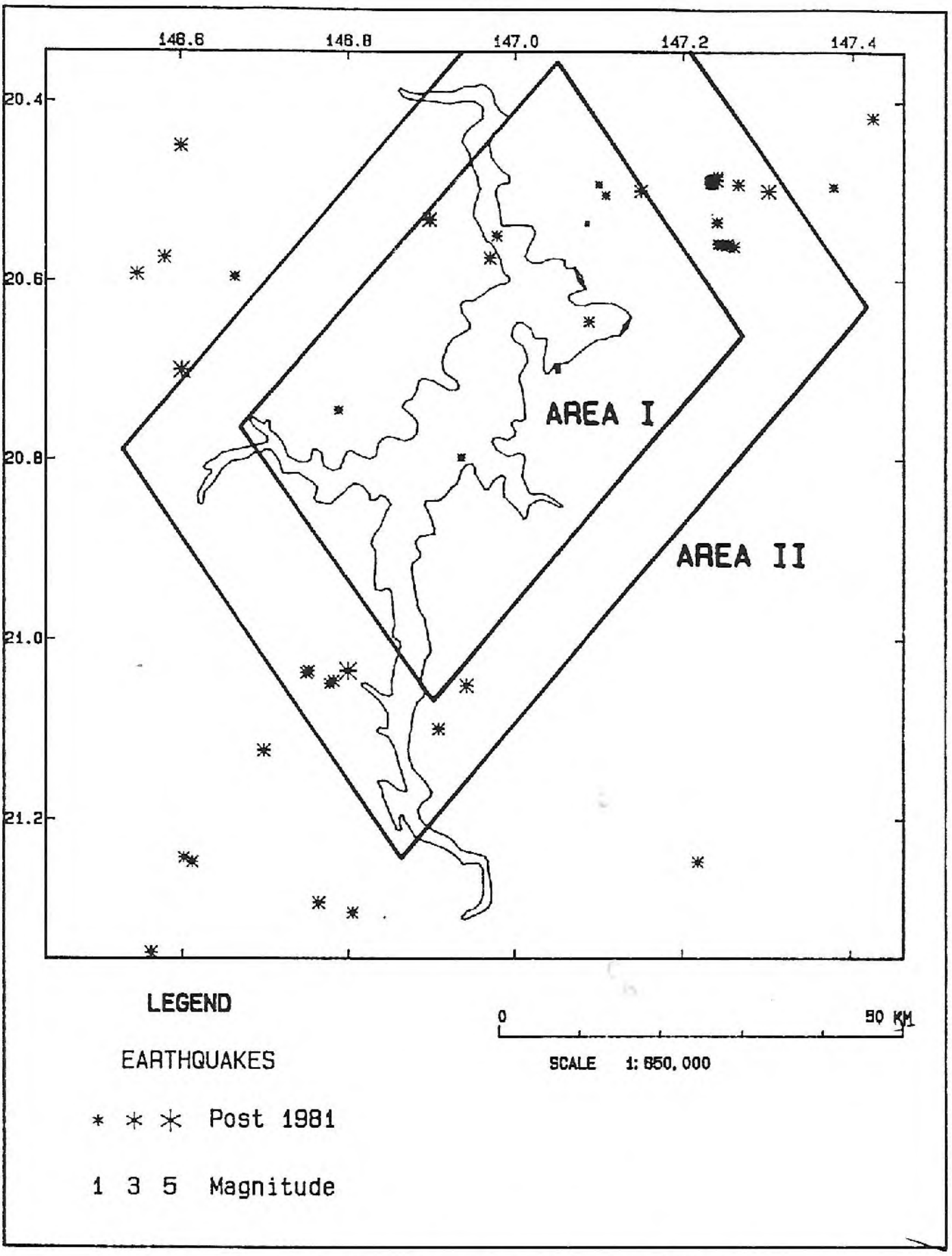

Figure 5 Earthquakes in vicinity of Burdekin Falls dam and areas of influence of reservoir

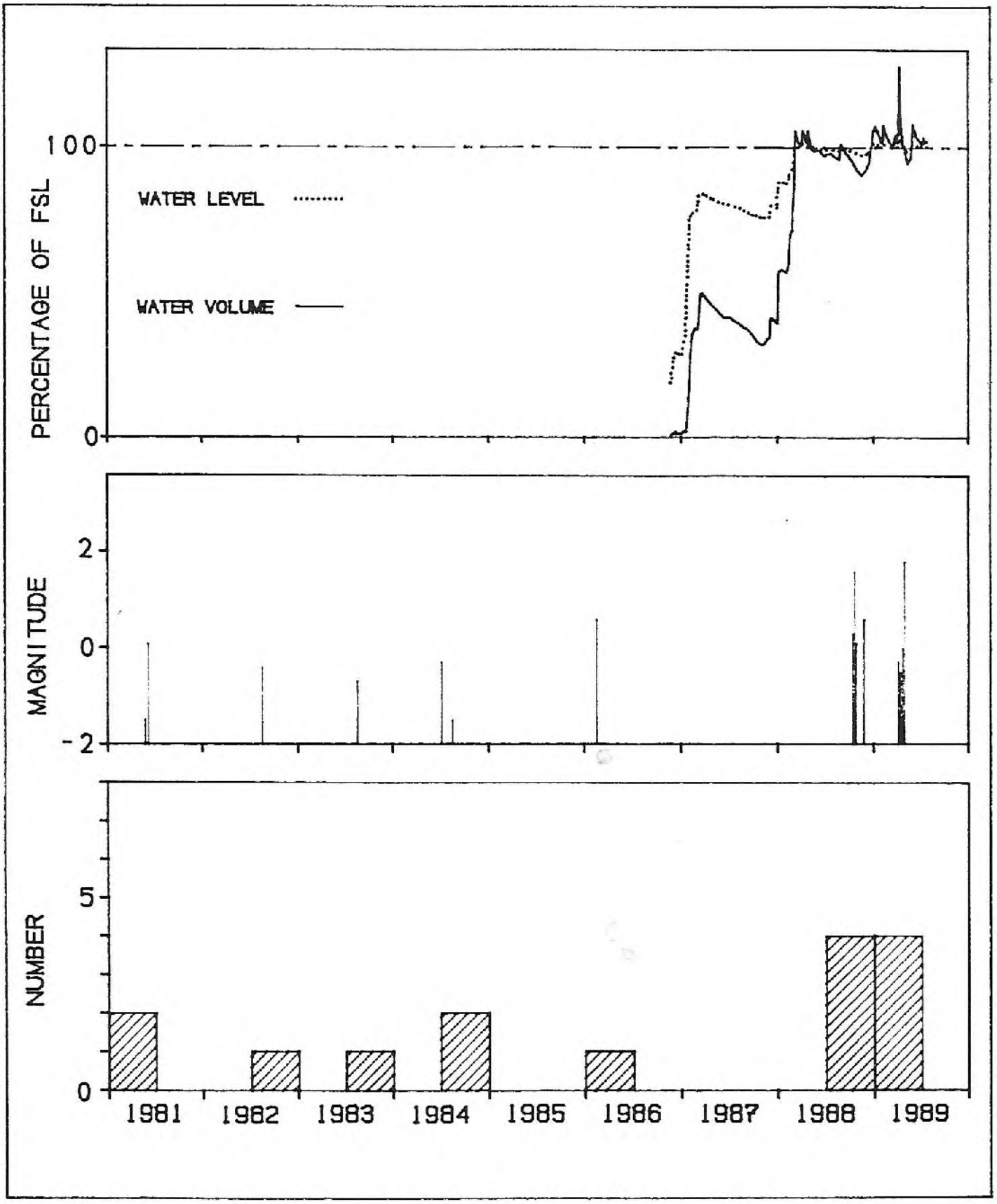

Figure 6 Earthquakes in Area I and water levels and volume, for Burdekin Falls reservoir

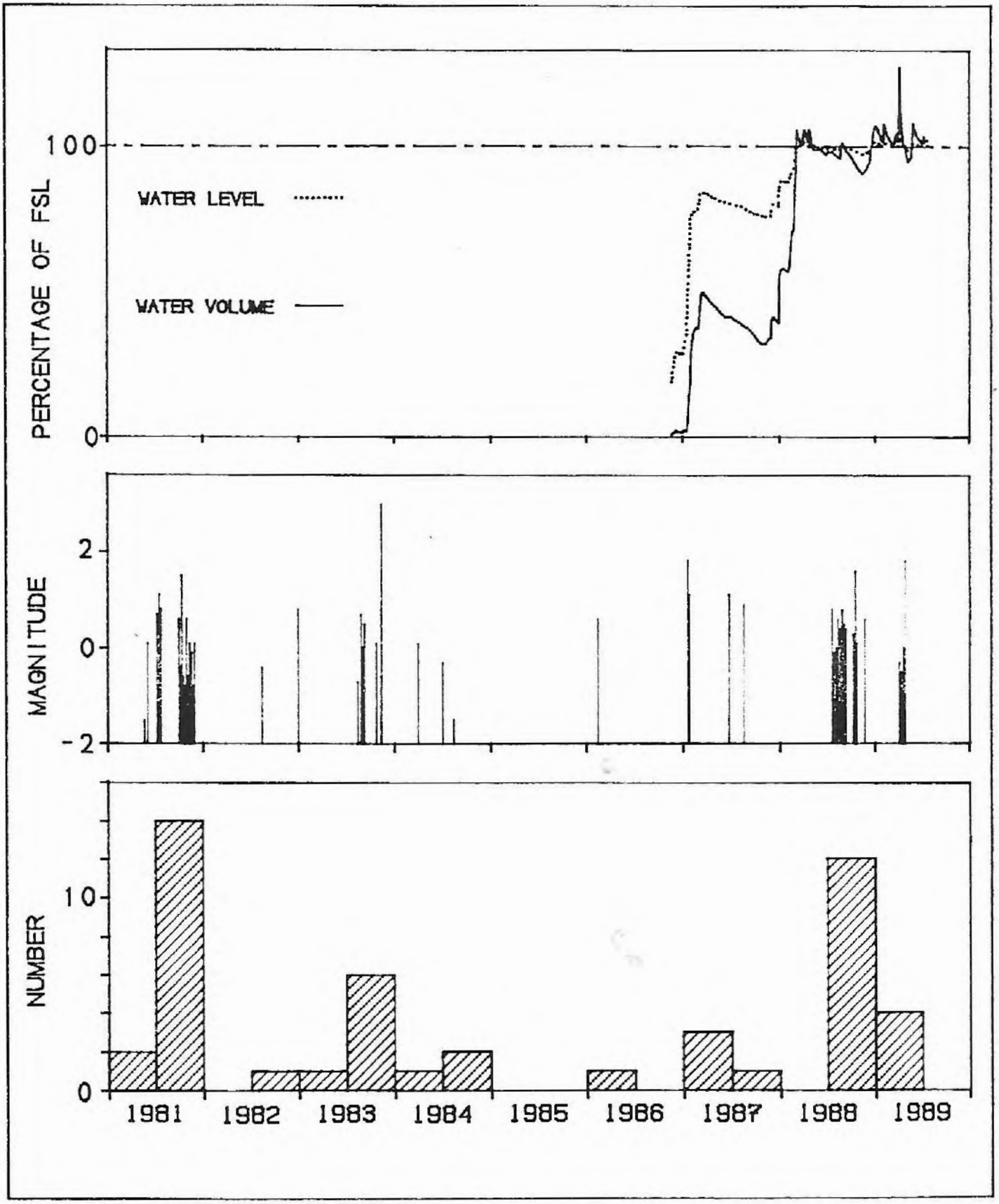

Figure 7 Earthquakes in Area II and water levels and volume for Burdekin Falls reservoir

DISCUSSION

Induced seismicity studies have shown two types of response to reservoir filling; a rapid response that occurs shortly after the first filling of the reservoir and a delayed response that occurs several years later; typically after a number of seasonal filling cycles have passed (Simpson et al, 1988). The short-term response is attributable to the weight of water, which directly increases the elastic shear stress, and indirectly increases the pore pressure due to the reduction in pore volume and increase in hydrostatic stress. The longer term response is also caused by an increase in pore pressure but due this time to the diffusion of water from the reservoir at the surface.

The occurrence of induced seismicity will depend on the state of stress in the crust beneath the reservoir. In northeast Queensland it is assumed that the crust is compressed horizontally. Seismicity studies using data from the Wivenhoe Dam network have shown that the crust in southeast Queensland is under horizontal compression (Cuthbertson, 1989). Other crustal stress studies in Australia have also found maximum compressive stress in a horizontal direction (Denham et al, 1981, Denham, 1980, Lambeck et al, 1984). Near surface stress measurements carried out during the construction of the Burdekin Dam by Bock et al (1987) also found significant horizontal compressive stresses.

The principal effect of impounding a reservoir is to increase the vertical stress directly beneath the reservoir. However the horizontal radial stress at shallow depths, in an annular area surrounding the reservoir will be reduced. Stress changes from impounding a reservoir in a thrust fault regime, where the maximum principal stress is horizontal, will stabilise existing faults in the crust beneath the reservoir (Snow, 1982). Shallow faults surrounding the reservoir will be slightly destabilised due to the decrease in horizontal stress.

It has been argued that the mechanism of reservoir induced seismicity is one of triggering due to incremental increases in existing crustal stress. The minimum shear strength for a wet vertical fracture (the weakest configuration) at a depth of 1 km is about 30 bars (Bullen and Bolt, 1985). A reservoir 50 m deep will produce a maximum shear stress of less then 2 bars which is an order of magnitude too low to induce earthquakes directly.

The activity observed in Area II since impounding is considered to be a continuation of the natural activity recorded in the area prior to impoundment. The activity in the inner area (Area I) is located in a section where no activity had been previously recorded. This activity is also generally of a larger magnitude than previous activity located elsewhere in Area I.

If the crust in northeast Queensland is under horizontal compression as is the case elsewhere in Queensland then activity due to stress changes can be induced only indirectly at shallow depths in the annular area surrounding the reservoir. The events under consideration are not unduly shallow and some are located underneath the reservoir and so fail to fit the criteria for earthquakes induced by stress changes.

There remains the possibility that the increase in activity observed in Area I is due to pore-pressure changes. The pore-pressure beneath a reservoir can be increased by changes in the stress field as well as by diffusion of water from the reservoir. The former effect will follow the loading with little or no time delay while the latter effect can lag considerably (Simpson et al, 1988). Any increase in pore-pressure will reduce the effective stress across fractures with a corresponding decrease in strength (Snow, 1982).

The activity in Area I, which commenced only 6 months after FSL was reached, would be classified as a short term response due to pore pressure increases caused by stress field changes. The induced earthquakes in this case do not have to be shallow and so the activity observed in Area I could be considered to be reservoir induced.

Whether or not the activity has been induced by the reservoir, the level and magnitude is such that there is little concern for the safety of the dam. The maximum acceleration expected from a magnitude 2 earthquake at a distance of 1 km using results such as Rynn (1987) is an order of magnitude less than the acceleration used in the dam design (Russo et al. 1985).

There exists the possibility that activity will be induced upon the lowering of the reservoir water level. In a thrust fault regime lowering of the water level will cause instability due to the increased pore pressure (Snow, 1982). To induce activity this lowering would have to be relatively rapid to prevent fluid migration which would significantly reduce pore pressure.

RECOMMENDATIONS

It is recommended that monitoring continue at the current level until early 1990 at which stage, if no significant induced activity has occurred the network could be reduced by removing one analogue and two digital recorders from service. Monitoring at this reduced level should continue until the end of 1992, to include five years following filling of the reservoir, and then at a basic level for an indefinite period thereafter.

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