

TECHNICAL REPORT 93-4

**SEISMIC ACTIVITY NEAR THE
V.C. SUMMER NUCLEAR STATION**

FOR THE PERIOD
OCTOBER-DECEMBER, 1993

BY

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Principal Investigator

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COLUMBIA, SOUTH CAROLINA 29208

CONTRACT NO. N622702

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INTRODUCTION

Analysis of the seismic activity near the V.C. Summer Nuclear Station in South Carolina between October 1 and December 31, 1993 is presented in this report. During this period, four events were recorded and located in the vicinity of the Monticello Reservoir. All were of relatively low magnitude.

A compilation of the locatable seismic activity and station performance for the year 1993 is also included in Appendix VII pages 15-23.

SEISMIC NETWORK

Earthquakes during this period were recorded on stations of Monticello Reservoir and South Carolina Seismic Networks. The configuration of stations utilized to locate Monticello Reservoir events is shown in Figure 1 and station coordinates are listed in Appendix I. The operational status of the network is given in Appendix II.

DATA ANALYSIS

Hypocentral locations have been determined using the computer program HYPO71 (Lee and Lahr, 1972). The velocity model used in the earthquake locations is given in Appendix III. The format of the HYPO71 output is given in Appendix IV. The event magnitude was determined from the signal duration at JSC using the following relation:

$$M_L = -1.83 + 2.04 \text{ Log } D,$$

where D is the signal duration (seconds).

An estimate of daily energy release was determined using a simplified magnitude (M_L) - energy (E) relation by Gutenberg and Richter (1956):

$$\text{Log}_{10} E = 11.8 + 1.5 M_L$$

OBSERVED SEISMICITY DURING OCTOBER-DECEMBER, 1993

Four events were recorded and located during the fourth quarter of 1993. All events occurred to the southeast of the Monticello Reservoir and only one event was located within the confines of the reservoir proper (Figure 2). All locations were good to fair (B-C; Appendix V).

The earthquake occurrences were spaced throughout the quarter and ranged in magnitude from $M_L = -0.68$ to $M_L = 0.28$. The largest event occurred on October 1, 1993 at 16:28 UTC and was the one event located within the confines of the reservoir (Figure 2). The final three events were spaced throughout the rest of the quarter and were located in a fairly tight cluster to the southeast (Figure 2). The long term decline in seismicity observed at Monticello Reservoir is continuing (Figure 3) and the cumulative seismicity has shown relative flattening since 1985-86 (Figure 4).

CORRELATION OF WATER LEVEL WITH SEISMICITY

Monticello Reservoir is a pumped storage facility. Any decrease in the reservoir level associated with power generation is recovered when water is pumped back into the reservoir. There can be normal variations up to five feet per day between maximum and minimum water levels. The water level has been monitored to see if there is any correlation between the daily or seasonal changes in the reservoir level and the local seismicity. Water levels are compared with seismicity in Figure 5. The top panel shows the average water level; the error bars show the maximum and minimum water levels each day. The second panel shows the change in water level from day to day. The number of events per day and the log of energy released are shown in the lower histograms. These charts include all reported earthquakes listed in Appendix V. The average water level, daily changes in water level, number of earthquakes and energy release are given in Appendix VI. No systematic correlation was observed between the seismicity and reservoir level fluctuations.

CONCLUSIONS

Seismicity during the fourth quarter of 1993 was lower than that of the third quarter and occurred in the southeastern section of the reservoir. There was no unusual seismic activity and the activity was scattered temporally. No systematic correlation was observed between the reservoir level fluctuations and the seismicity.

REFERENCES

- Gutenberg, B. and Richter, C.F. (1956). Magnitude and energy of earthquakes, *Ann. Geof.* 9,1-15.
- Lee, W.H.K. and Lahr, J.C. (1972). A computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes, revisions of HYPO71, U.S. Geological Survey, Open-File Report, 100 pp.

Monticello Reservoir Seismic Network

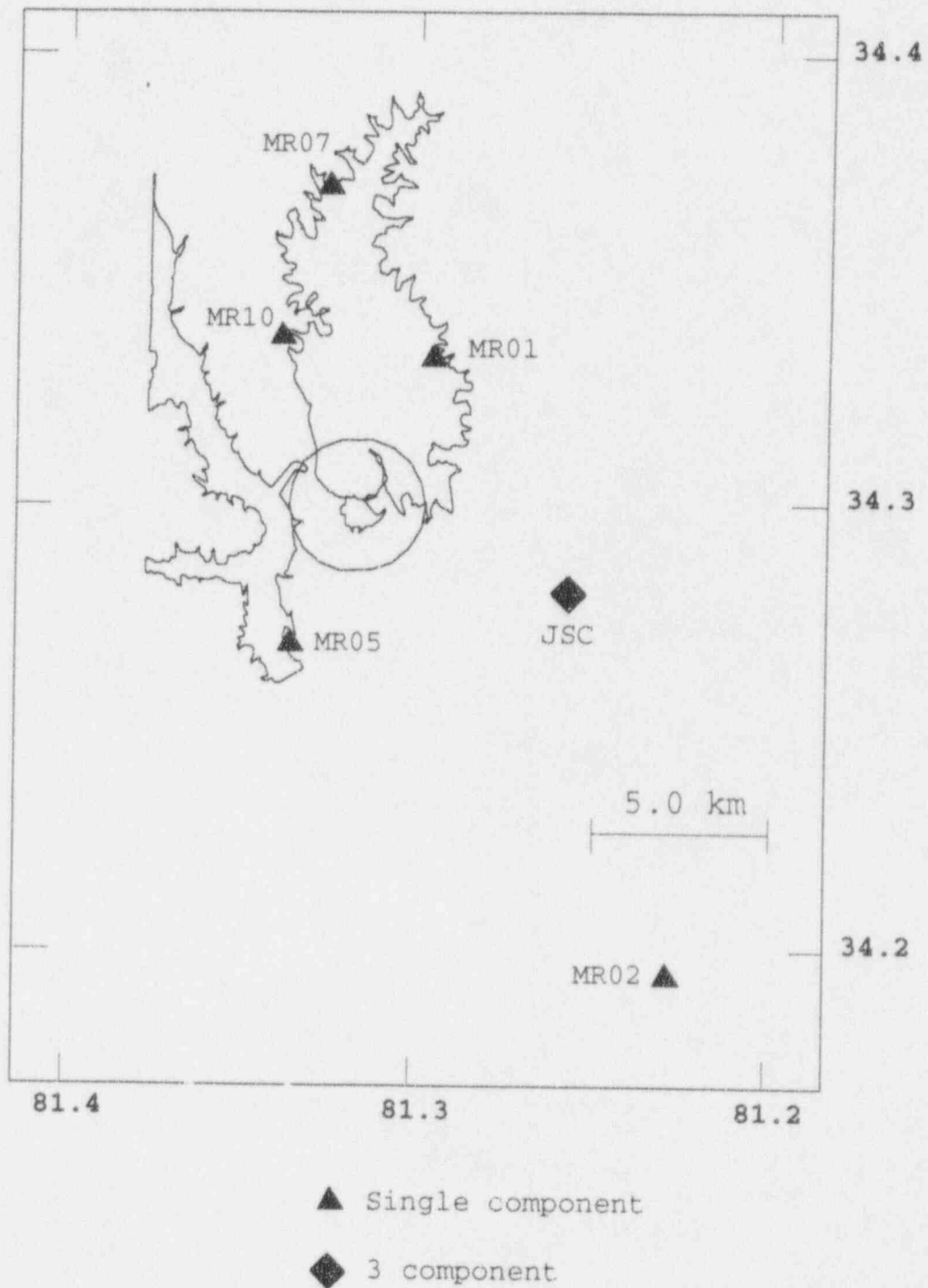


Figure 1 Location of Monticello Reservoir seismic stations.

Monticello Reservoir Seismicity

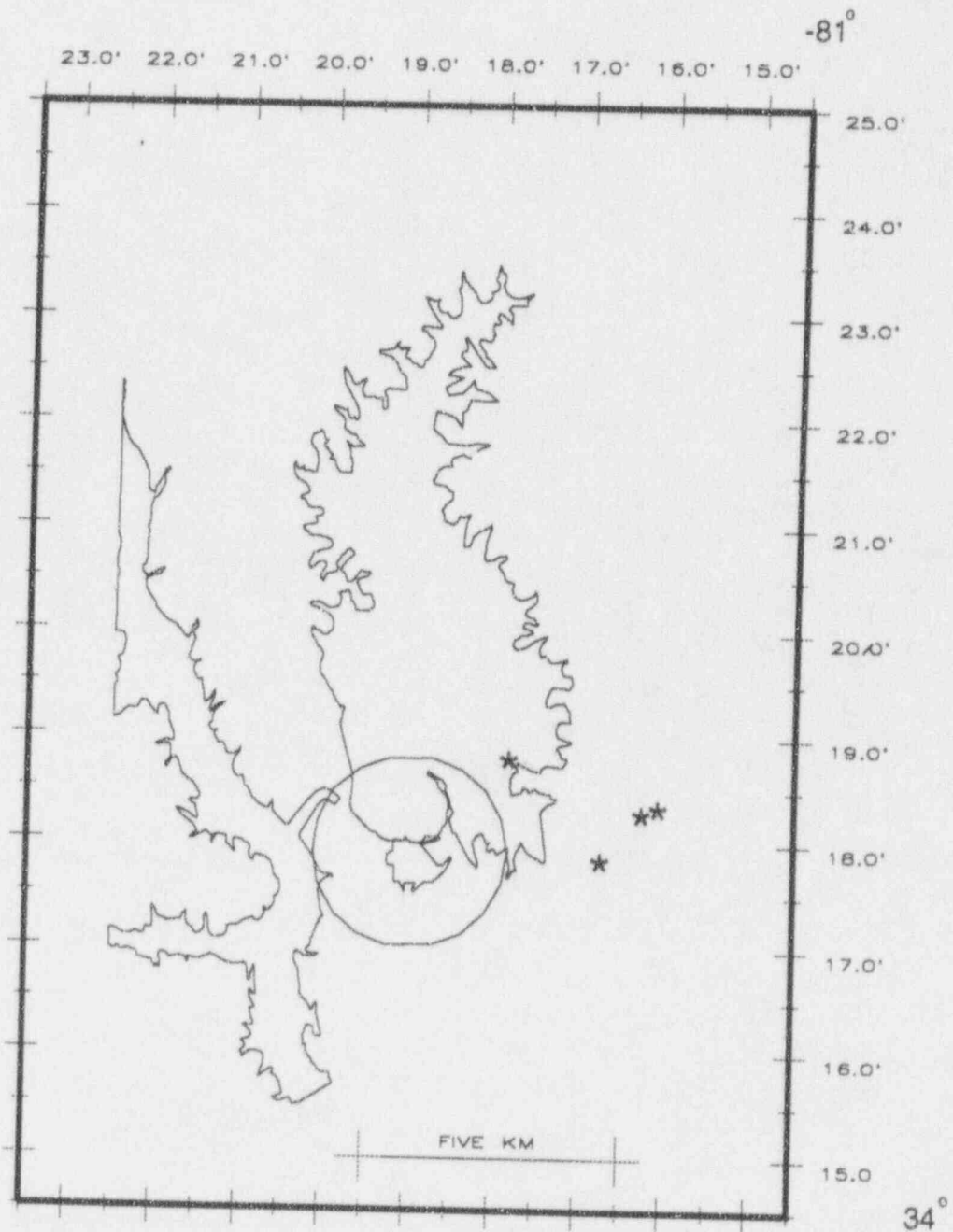


Figure 2. Events located near Monticello Reservoir during the period October - December, 1993 (stars)

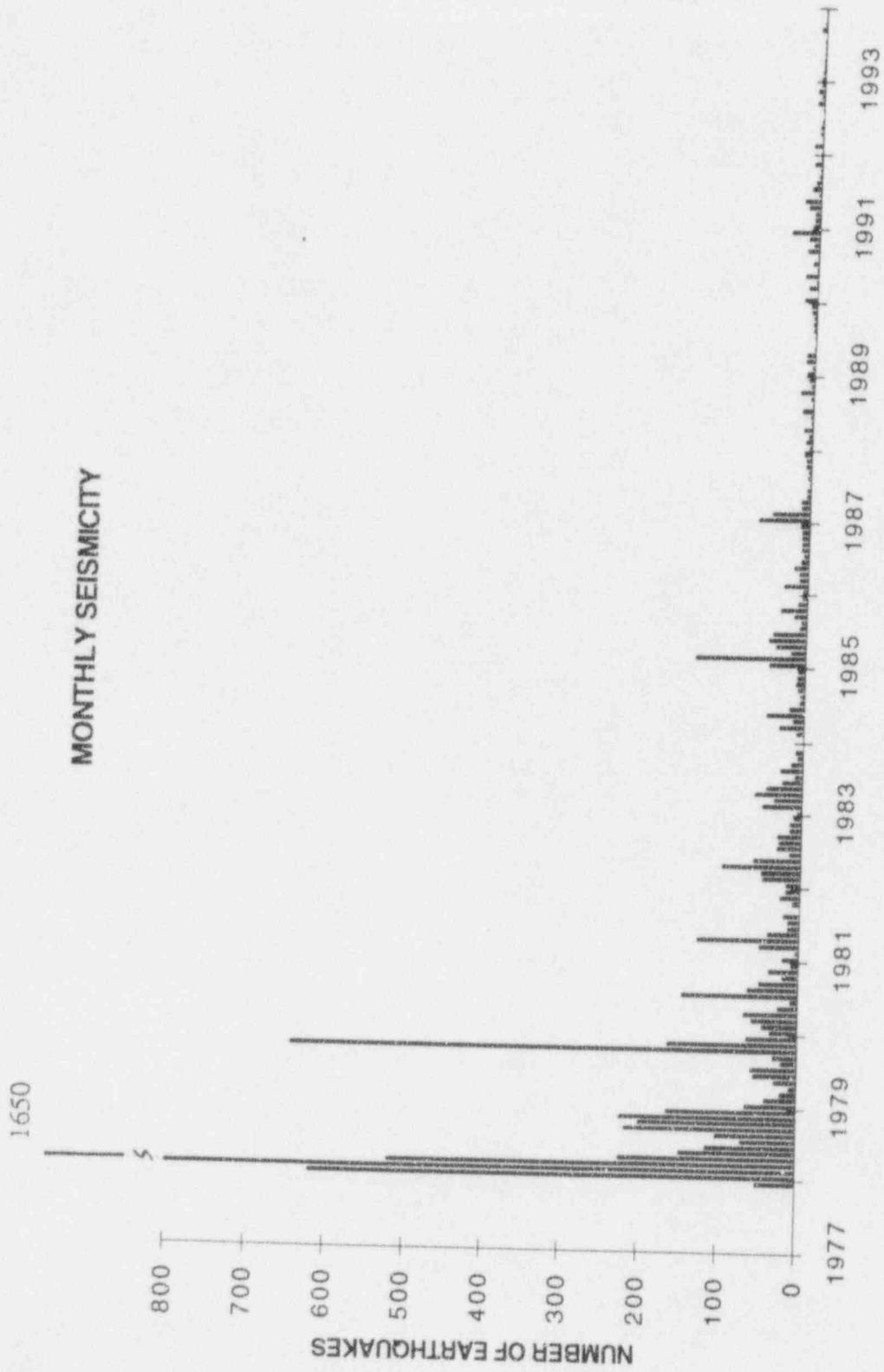


Figure 3. Earthquakes between impoundment and December, 1993.

CUMULATIVE SEISMICITY

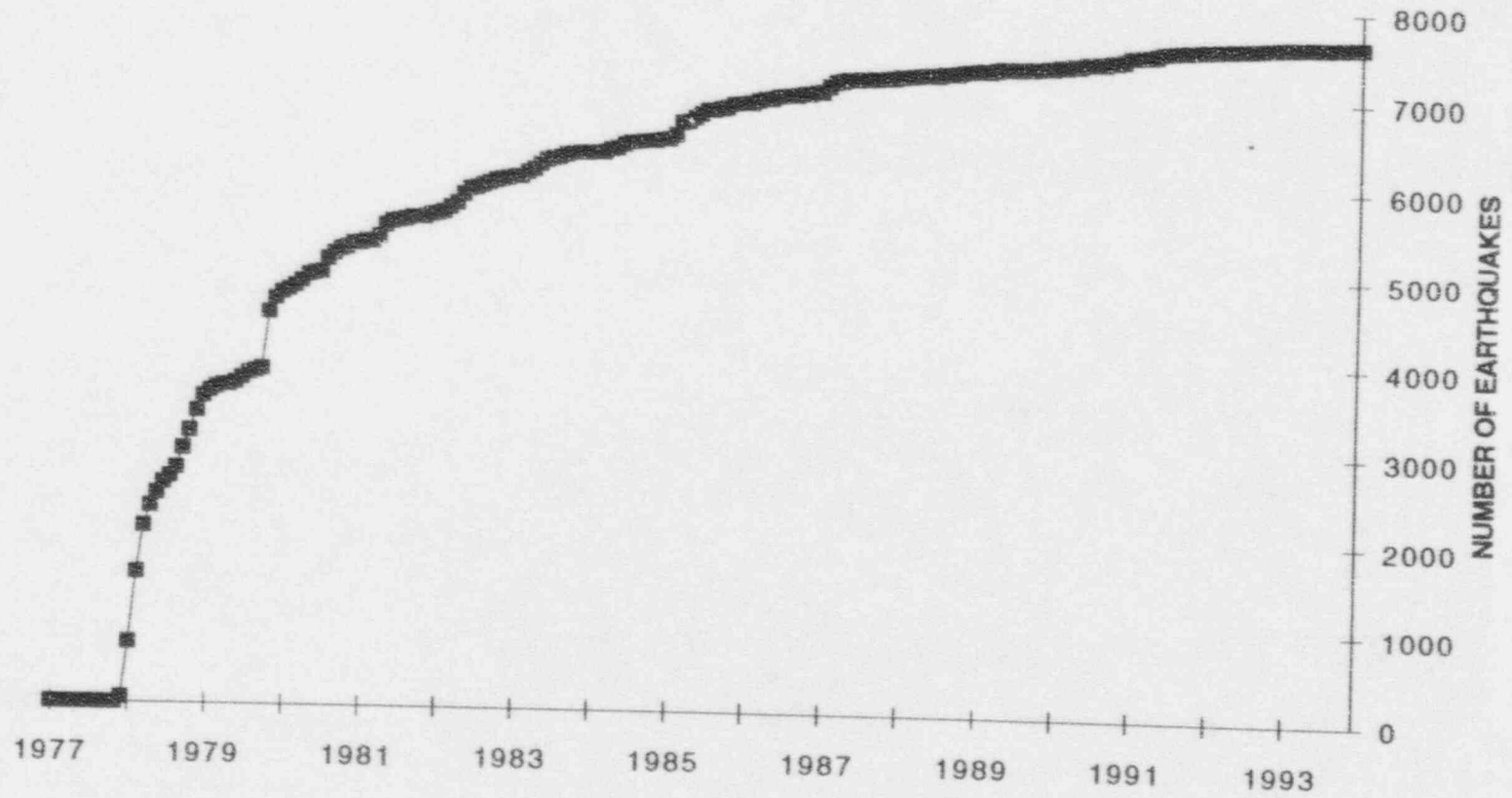


Figure 4. Cumulative seismicity near Monticello Reservoir since impoundment.

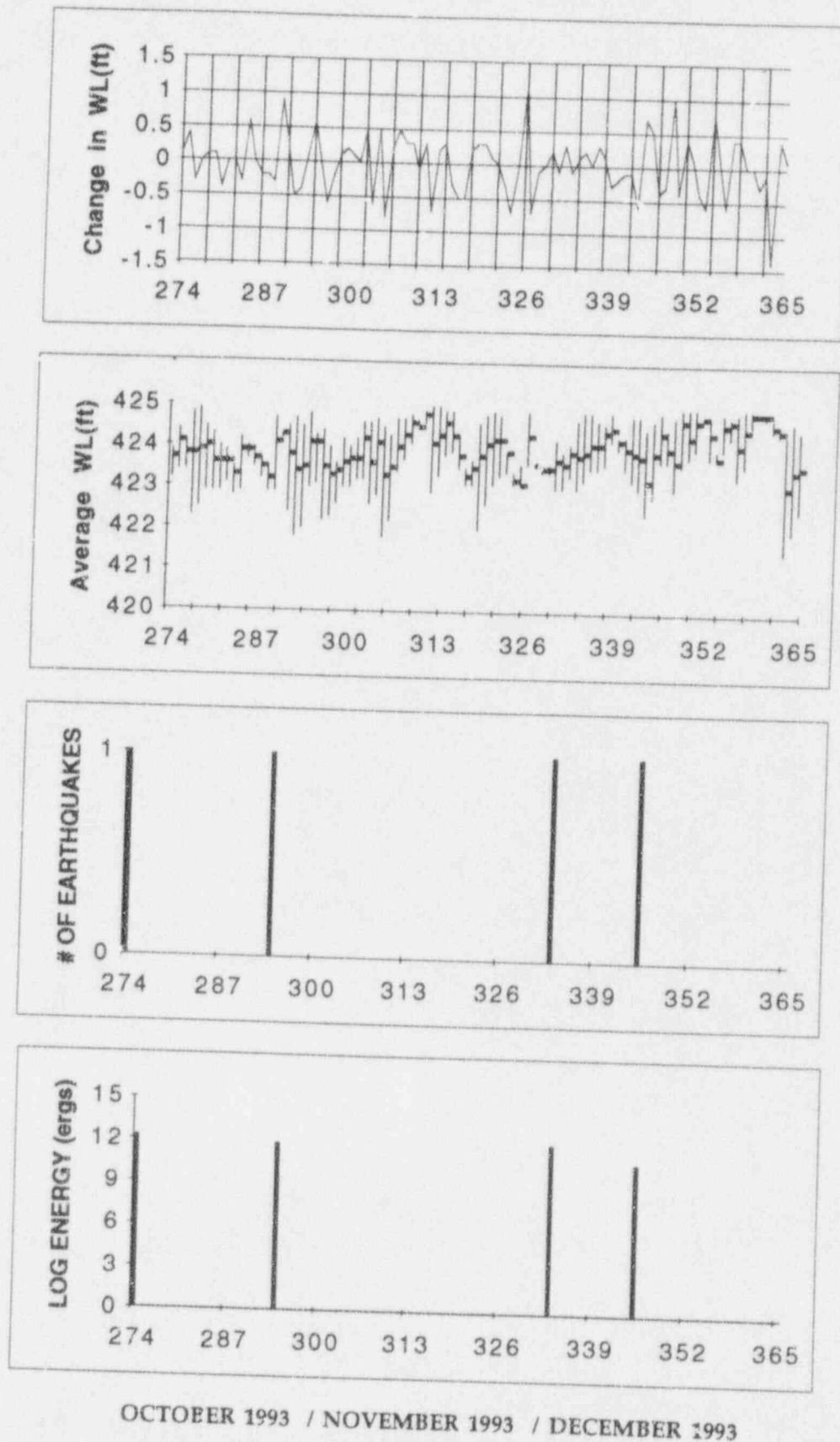


Figure 5. Comparison of daily lake level, changes in lake level, number of earthquakes and the log of energy release in ergs per day at Monticello Reservoir. Error bars in the top panel indicate daily fluctuations in water level.

APPENDIX I
STATION LOCATIONS

STATION	LAT° N	LONG °W
JSC	34°16.80'	81°15.60'
MR01	34°19.91'	81°17.74'
MR02	34°11.58'	81°13.81'
MR05	34°16.05'	81°20.05'
MR07	34°22.23'	81°19.50'
MR10	34°20.18'	81°20.25'

APPENDIX II
SEISMIC STATION OPERATIONAL STATUS
OCTOBER 1 - DECEMBER 31, 1993

STATION	PERCENT DOWNTIME
MR01	17.4
MR02	20.6
MR05	17.4
MR07	17.4
MR10	17.4
JSC	6.5

APPENDIX III
MONTICELLO RESERVOIR
VELOCITY MODEL

Velocity km/sec	Depth to top km
1.00	0.00
5.40	0.03
5.90	0.18
6.10	0.46
6.30	0.82
8.10	30.00

APPENDIX IV
MONTICELLO EARTHQUAKES
HYPO71 FORMAT

Column 1	Date
Column 2	Origin time (UTC) h.m.sec.
Column 3	Latitude (N) degrees, min.
Column 4	Longitude (W) degrees, min.
Column 5	Depth (km).
Column 6	Local duration magnitude.
Column 7	No. of station readings used to locate event. P and S arrivals from same stations are regarded as 2 readings.
Column 8	Largest azimuthal separation in degrees between stations.
Column 9	Epicentral distance in km to nearest station.
Column 10	Root mean square error of time residuals in sec. RMS = R_i^2/No , where R_i is the time residual for the i^{th} station.
Column 11	Standard error of the epicenter in km*.
Column 12	Standard error of the focal depth in km*.
Column 13	Quality of the epicentral location.

* Statistical interpretation of standard errors involves assumptions which may not be met in earthquake locations. Therefore standard errors may not represent actual error limits.

Note: If ERH or ERZ is blank, this means that it cannot be computed, because of insufficient data.

APPENDIX V
MONTICELLO RESERVOIR EARTHQUAKES
OCTOBER- DECEMBER, 1993

DATE	ORIGIN	LAT N	LONG W	DEPTH	MAG	NO	GAP	DMIN	RMS	ERH	ERZ	QM
931001	1628 49.43	34-18.81	81-17.84	2.28	0.28	8	133	2.0	0.04	0.3	0.6	B1
931021	829 38.85	34-17.81	81-16.72	2.37	0.03	10	159	2.5	0.15	0.9	1.9	C1
931129	1729 20.70	34-18.35	81-16.21	0.63	0.15	12	197	3.0	0.03	0.2	0.3	C1
931211	2248 46.90	34-18.31	81-16.35	0.77	-0.68	8	191	3.0	0.03	0.2	0.3	C1

APPENDIX VI

Maximum and minimum water levels, change in water level, number of earthquakes and log of energy release per day at Monticello Reservoir during October 1 - December 31, 1993. Dates are given in Julian Calendar.

J.DATE	WL (max)	WL (min)	WL (avg)	WL (ch)	# of eqs	Energy
274	423.9	423.2	423.7	0.1	1	12.22
275	424.4	423.4	424.1	0.4	0	0
276	424.1	423.4	423.8	-0.3	0	0
277	424.8	422.3	423.8	0	0	0
278	424.9	422.5	423.9	0.1	0	0
279	424.5	422.9	424	0.1	0	0
280	424.3	422.9	423.6	-0.4	0	0
281	424	422.9	423.6	0	0	0
282	423.9	423.1	423.6	0	0	0
283	423.5	422.8	423.3	-0.3	0	0
284	424.2	422.9	423.9	0.6	0	0
285	424	423.7	423.9	0	0	0
286	423.8	423.5	423.7	-0.2	0	0
287	423.7	423.2	423.5	-0.2	0	0
288	423.5	422.9	423.2	-0.3	0	0
289	424.7	422.9	424.1	0.9	0	0
290	424.3	424.2	424.3	0.2	0	0
291	424.5	422.4	423.8	-0.5	0	0
292	424.7	421.8	423.4	-0.4	0	0
293	424.5	422	423.5	0.1	0	0
294	424.8	423	424.1	0.6	1	11.85
295	424.3	423.1	424.1	0	0	0
296	424.4	422.2	423.5	-0.6	0	0
297	424	422.3	423.3	-0.2	0	0
298	423.6	422.6	423.4	0.1	0	0
299	424.2	423	423.6	0.2	0	0
300	424	423	423.7	0.1	0	0
301	424.2	423.2	423.7	0	0	0
302	424.6	423.2	424.2	0.5	0	0
303	424.6	422.6	423.6	-0.6	0	0
304	424.7	422.8	424.1	0.5	0	0
305	424.5	421.8	423.3	-0.8	0	0
306	424.3	422.2	423.5	0.2	0	0
307	424.7	423.4	424	0.5	0	0
308	424.7	423.7	424.3	0.3	0	0
309	424.8	424.1	424.6	0.3	0	0
310	424.5	424.5	424.5	-0.1	0	0
311	424.9	424.6	424.8	0.3	0	0
312	425	422.9	424.1	-0.7	0	0
313	425	423.3	424.3	0.2	0	0
314	424.9	423.8	424.6	0.3	0	0
315	424.9	423.9	424.3	-0.3	0	0

APPENDIX VI (continued)

J.DATE	WL (max)	WL (min)	WL (avg)	WL (ch)	# of eqs	Energy
316	424.3	423.5	423.8	-0.5	0	0
317	423.5	423.1	423.3	-0.5	0	0
318	423.7	423.1	423.5	0.2	0	0
319	424.6	422	423.8	0.3	0	0
320	424.8	422.6	424.1	0.3	0	0
321	424.9	423.1	424.2	0.1	0	0
322	424.8	423.3	424.2	0	0	0
323	423.9	423.4	423.9	-0.3	0	0
324	423.4	423.1	423.2	-0.7	0	0
325	423.6	423.1	423.1	-0.1	0	0
326	424.9	423.6	424.3	1.2	0	0
327	423.6	423.6	423.6	-0.7	0	0
328	423.6	423.4	423.5	-0.1	0	0
329	423.6	423.4	423.5	0	0	0
330	424.2	423	423.7	0.2	0	0
331	423.9	423	423.6	-0.1	0	0
332	424.1	423.3	423.9	0.3	0	0
333	424.7	423	423.8	-0.1	1	12.03
334	424.9	423.2	423.9	0.1	0	0
335	424.9	423.5	424.1	0.2	0	0
336	424.7	423.5	424.1	0	0	0
337	424.6	423.6	424.4	0.3	0	0
338	424.9	424.2	424.5	0.1	0	0
339	424.3	424	424.2	-0.3	0	0
340	424.3	423.5	424	-0.2	0	0
341	424.8	423.2	423.9	-0.1	0	0
342	424.8	423	423.8	-0.1	0	0
343	424.5	422.4	423.2	-0.6	0	0
344	424.7	422.8	423.9	0.7	0	0
345	424.9	423.7	424.4	0.5	1	10.78
346	424.5	423.7	424	-0.4	0	0
347	424.8	423	423.7	-0.3	0	0
348	425	423.6	424.7	1	0	0
349	425	423.8	424.3	-0.4	0	0
350	425	424	424.7	0.4	0	0
351	424.8	424.8	424.8	0.1	0	0
352	424.8	423.8	424.4	-0.4	0	0
353	424	423.8	423.8	-0.6	0	0
354	424.9	424	424.6	0.8	0	0
355	424.8	424.3	424.7	0.1	0	0
356	424.9	423.3	424.1	-0.6	0	0
357	425	423.6	424.5	0.4	0	0
358	425	424.6	424.9	0.4	0	0
359	424.9	424.9	424.9	0	0	0
360	424.9	424.8	424.9	0	0	0
361	424.8	424.5	424.6	-0.3	0	0
362	424.5	424.4	424.5	-0.1	0	0
363	424.4	421.5	423.1	-1.4	0	0
364	424.7	422	423.5	0.4	0	0
365	424.5	422.5	423.6	0.1	0	0

APPENDIX VII

Monticello Network and Seismicity During 1993

STATION OPERATION STATUS

The operational status of the Monticello Network During 1993 is presented in Figures 7 and 8. The generally high downtime for the Monticello Network during the fourth quarter (Figure 8) is due to loss of power at Parr Tower which made the data relay for the network inoperative, accounting for 17.4% of the fourth quarter downtime at each of the MR Stations.

SEISMICITY

During 1993 twenty-six events were recorded (Appendix VIII and IX) around the Monticello Reservoir of which twenty-two were located. Of the twenty-two located events (appendix VIII) two were blasts at Blair Quarry and have not been plotted in Figure 6. The events were scattered throughout the area of the reservoir but generally can be separated into two groupings, one in the northwest and the other in the southeast (Figure 6). Every month but August had locatable events (Figure 9) with duration magnitudes ranging from $M_L = -0.68$ to $M_L = 1.02$ (Figure 6 and Appendix VIII) and occurring at depths from 0.15 to 3.87 km (Figure 11). Eighteen of the twenty located events had magnitudes less than $M_L = 1.0$ (Figure 10) and most were of good to fair quality (B or C) with only two of poor quality (D) (Appendix VIII).

Seismicity around the Monticello Reservoir in 1993 continued at the relatively low level that has been observed since 1987. Compared to the 1992 seismicity (Figure 12 and Appendix X) more activity was found to the south and southeast and north northwest with no earthquakes located in the center of the reservoir (Figure 6). The greater percentage of good quality locations can be attributed to improved operation of the network and increased efforts to incorporate digital recording techniques.

Monticello Reservoir Seismicity

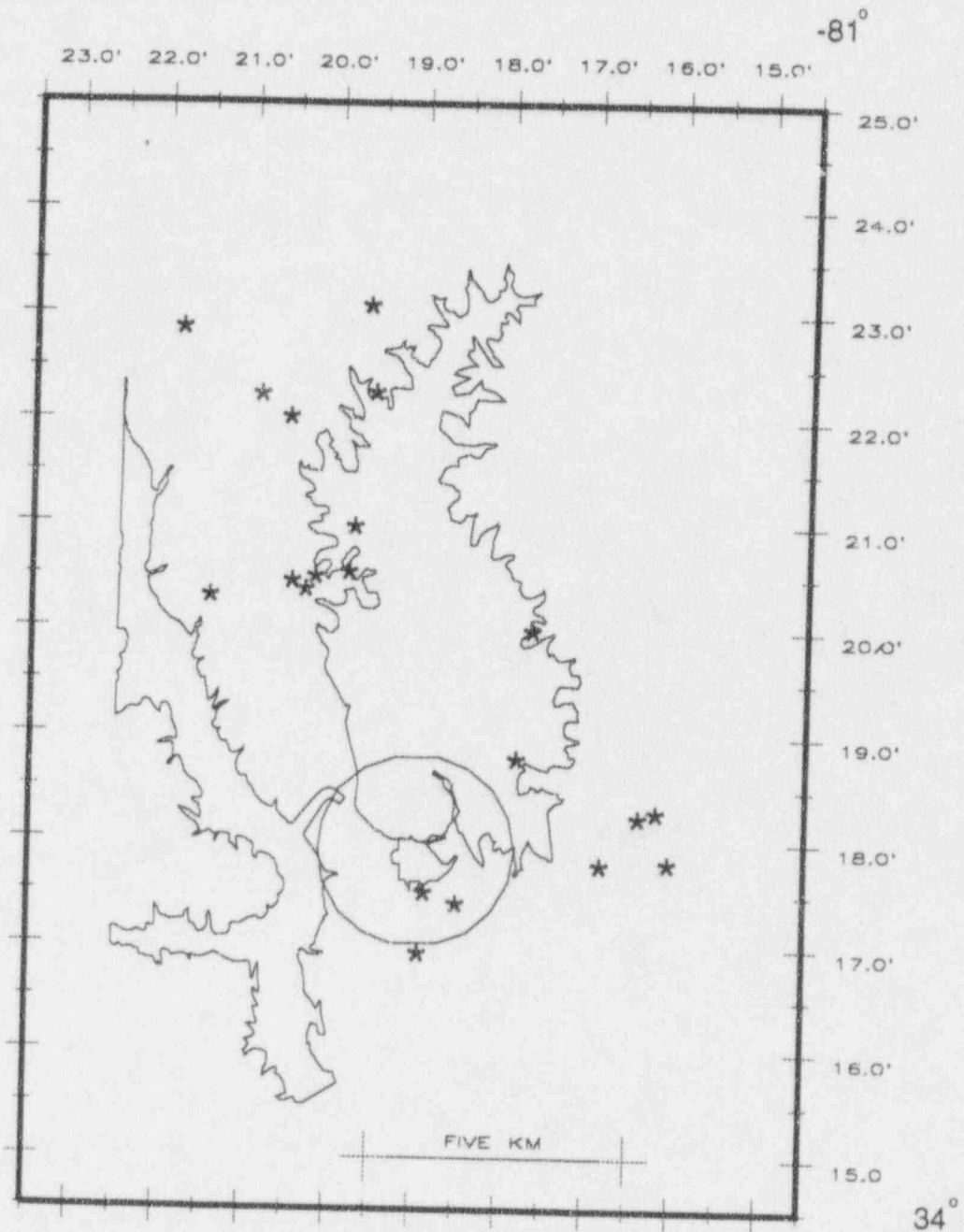


Figure 6. Events located near Monticello Reservoir during the year 1993 (stars)

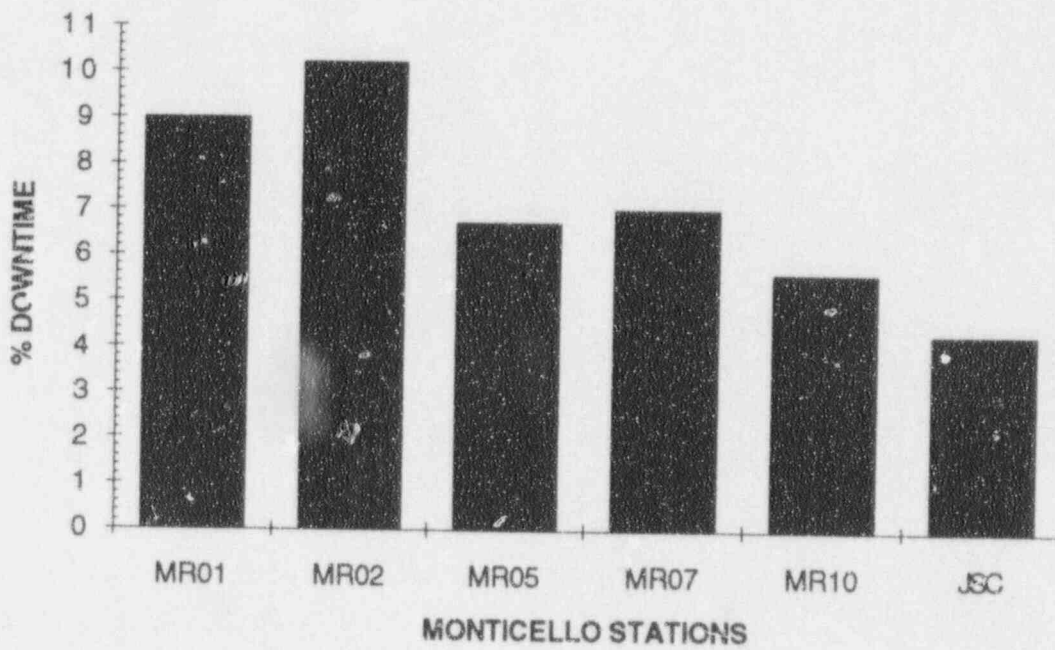


Figure 7. Operational status of Monticello Reservoir seismic sub-network stations for 1993.

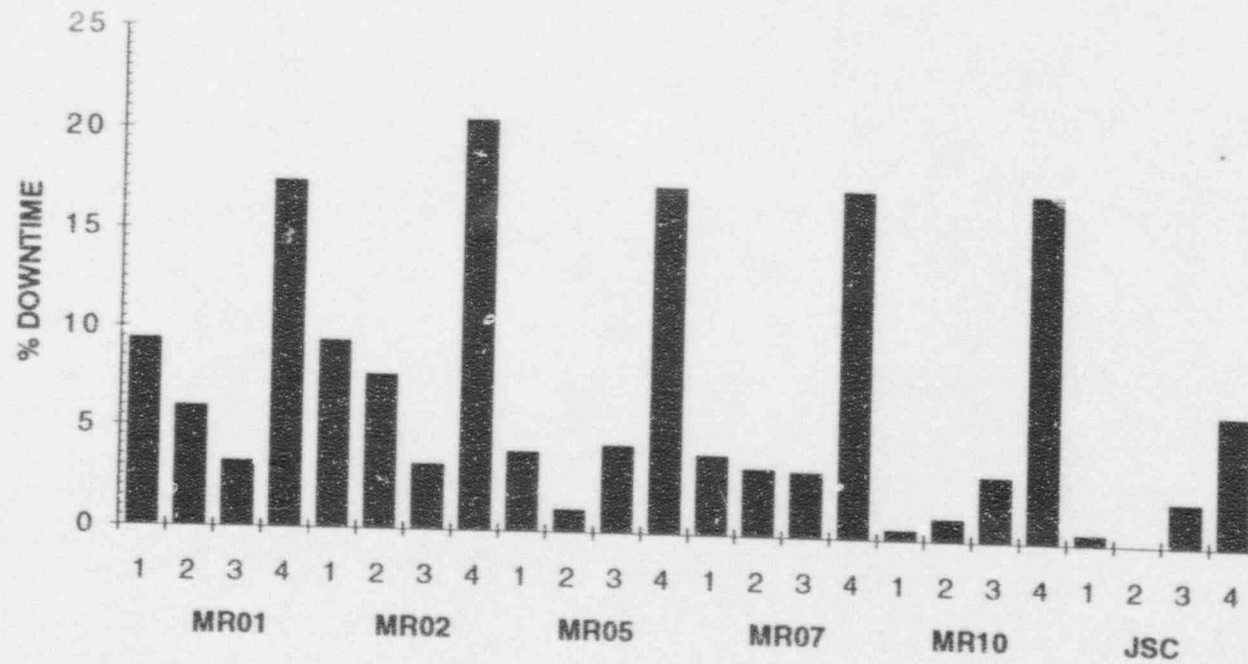


Figure 8. Operational status by quarter of Monticello Reservoir seismic sub-network stations during 1993. Quarters and stations designated.

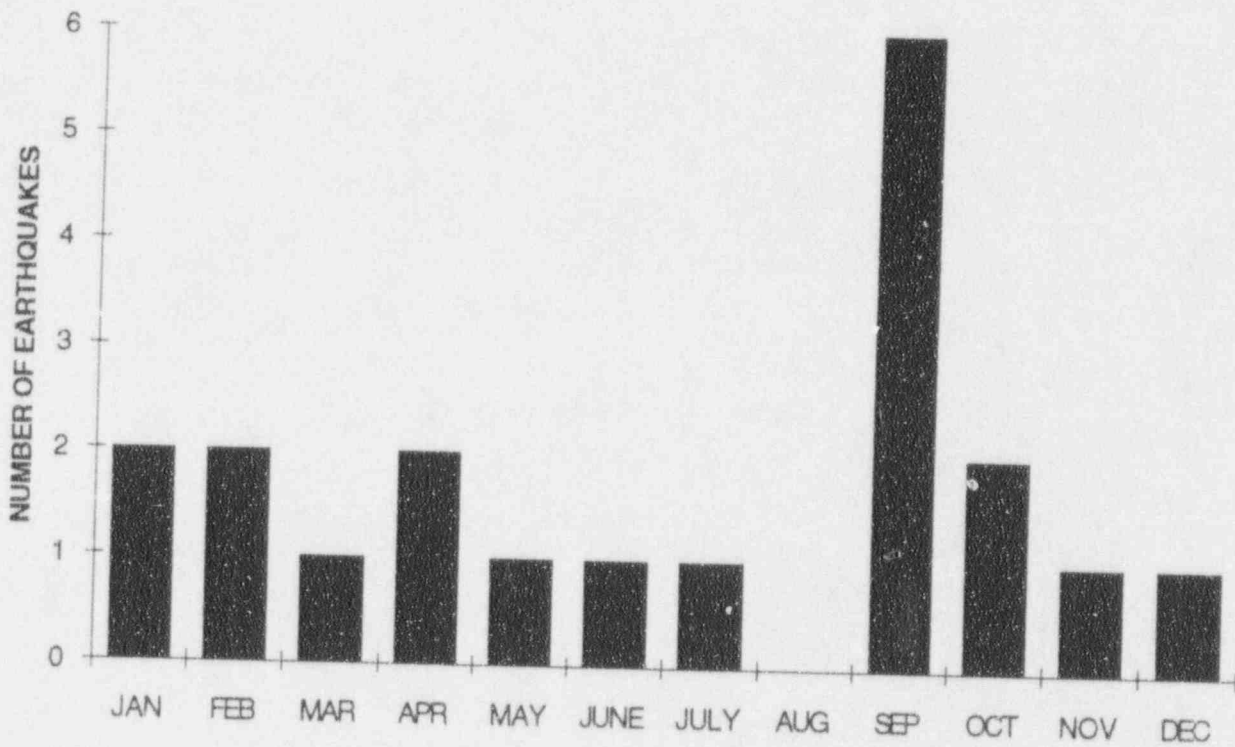


Figure 9. Monthly distribution of located earthquakes at Monticello Reservoir during 1993.

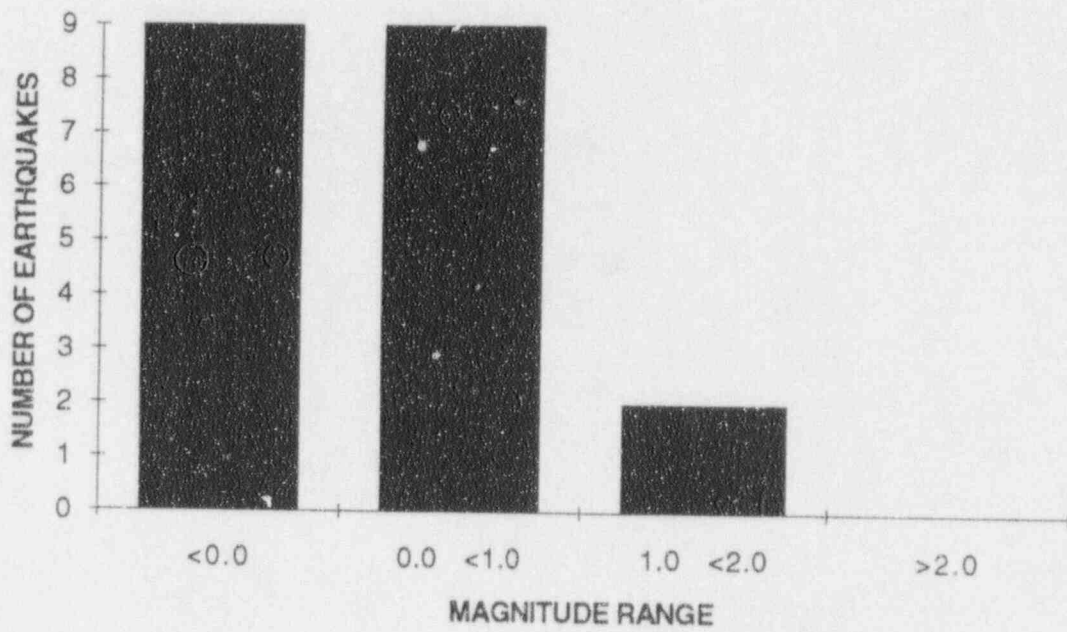


Figure 10. Magnitude ranges of located earthquakes at Monticello Reservoir during 1993.

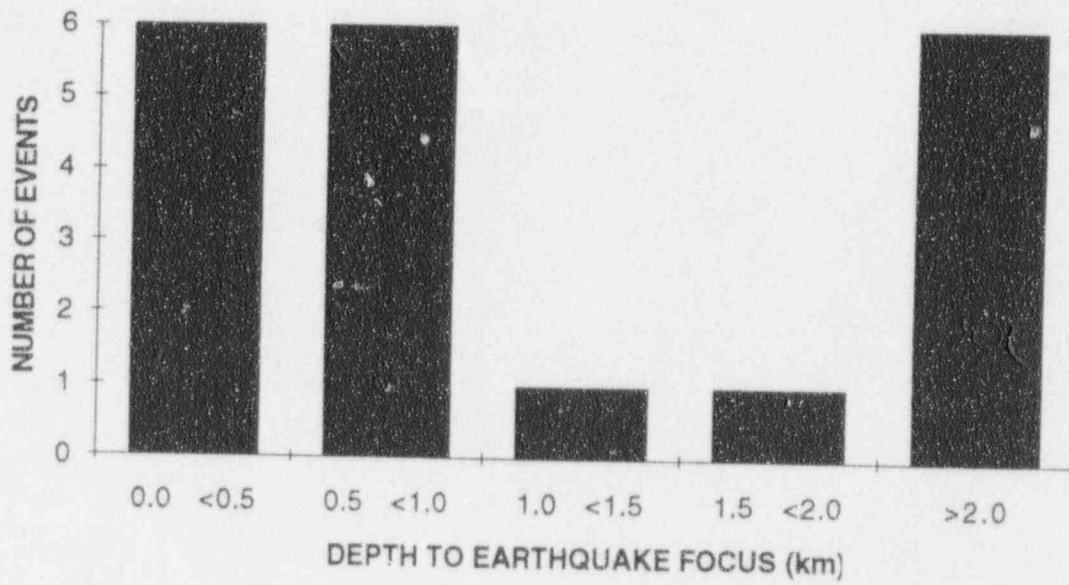


Figure 11. Depth distribution of located earthquakes at Monticello Reservoir during 1993.

Monticello Reservoir Seismicity

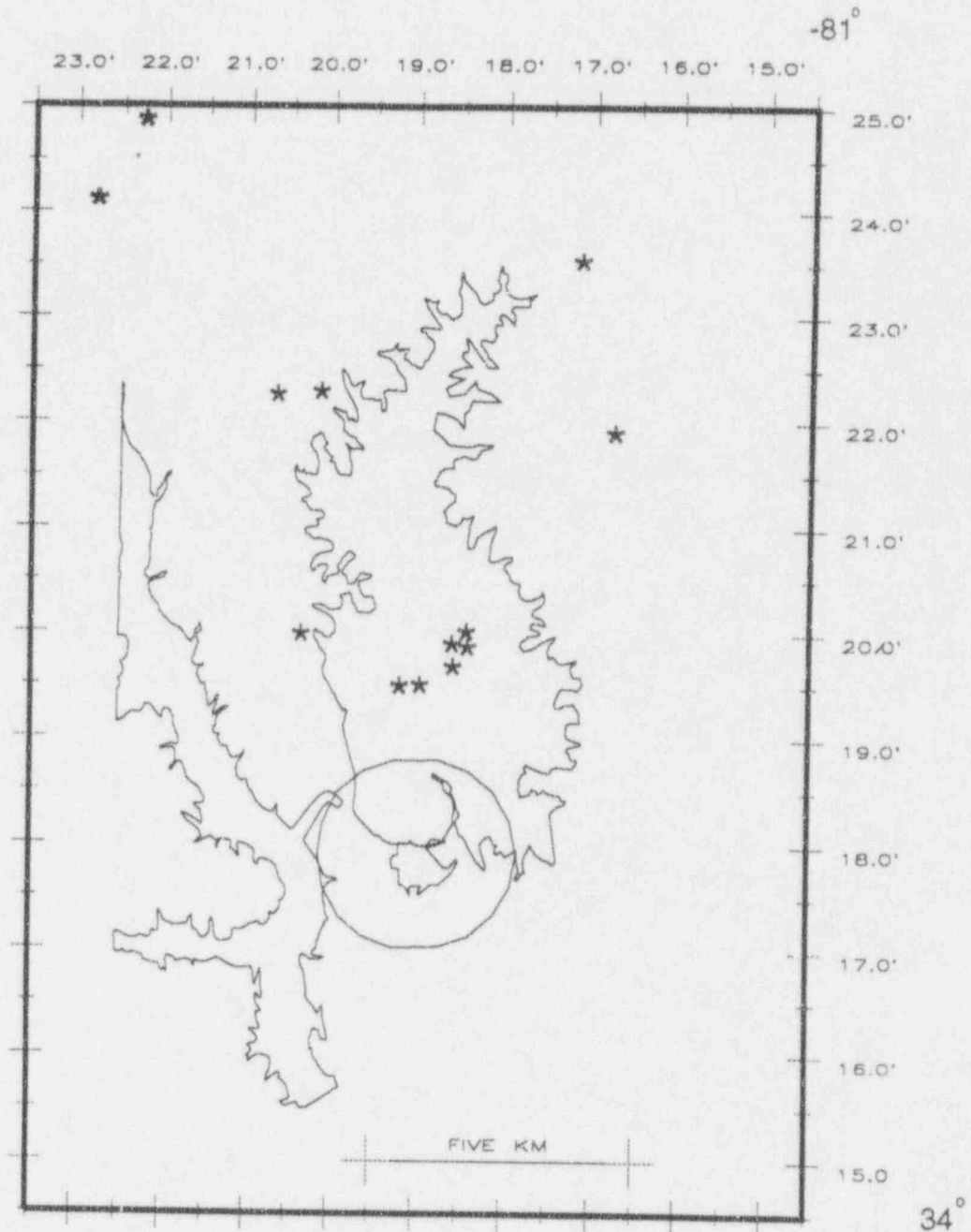


Figure 12. Events located near Monticello Reservoir during the year 1992 (stars)

APPENDIX VIII
MONTICELLO RESERVOIR EARTHQUAKES
JANUARY - DECEMBER, 1993

DATE	ORIGIN	LAT N	LONG W	DEPTH	MAG	NO	GAP	DMIN	RMS	ERH	ERZ	QM
930111	2227	43.49	34-16.90	81-19.03	3.64	0.82	7 120	2.3	0.04	0.3	0.5	B1
930112	043	25.39	34-17.52	81-18.93	0.24	-0.40	12 126	3.2	0.06	0.3	0.9	B1
930211	1736	46.55	34-22.33	81-19.60	1.94	-0.11	4 307	0.2	0.04			C1
930219	2051	47.72	34-22.33	81-20.95	0.82	1.02	6 282	2.2	0.08	9.8	8.1	D1
930219	2103	39.42	34-25.06	81-22.71	3.44	0.82	8 339	7.2	0.03	0.6	0.6	C1 *
930318	1753	15.06	34-25.25	81-22.72	6.55	0.57	8 341	7.4	0.08	1.6	0.8	C1 *
930322	1855	9.95	34-17.90	81-16.00	0.42	1.02	10 199	2.1	0.08	0.5	0.8	C1
930428	550	29.53	34-23.09	81-19.60	1.00	0.01	8 322	1.6	0.16	2.6	1.8	D1
930430	1615	12.49	34-22.09	81-20.72	0.26	0.21	4 274	1.9	0.01			C1
930524	1622	57.02	34-22.87	81-21.89	0.20	0.82	5 300	3.9	0.02	3.0	1.8	D1
930618	355	10.29	34-20.98	81-19.77	0.66	0.01	7 164	1.6	0.10	1.0	1.9	B1
930714	2006	13.27	34-20.01	81-17.71	2.31	0.16	10 185	0.2	0.05	0.3	0.3	C1
930906	1122	6.58	34-20.24	81-21.51	0.47	0.00	12 236	1.9	0.10	0.7	2.0	C1
930906	1246	37.07	34-20.50	81-19.85	0.05	0.00	7 144	0.8	0.07	0.4	0.9	B1
930906	1542	35.05	34-20.52	81-20.20	0.12	0.00	8 192	0.6	0.03	0.2	0.3	C1
930906	1659	37.11	34-20.49	81-20.43	0.48	0.00	8 229	0.6	0.05	0.5	0.5	C1
930906	1717	4.29	34-20.41	81-20.29	0.04	0.00	6 291	0.4	0.02	0.4	0.4	C1
930911	345	12.04	34-17.38	81-18.49	3.87	-0.27	10 121	3.4	0.25	1.2	2.5	B1
931001	1628	49.43	34-18.81	81-17.84	2.28	0.28	8 133	2.0	0.04	0.3	0.6	B1
931021	829	38.85	34-17.81	81-16.72	2.37	0.03	10 159	2.5	0.15	0.9	1.9	C1
931129	1729	20.70	34-18.35	81-16.21	0.63	0.15	12 197	3.0	0.03	0.2	0.3	C1
931211	2248	46.90	34-18.31	81-16.35	0.77	-0.68	8 191	3.0	0.03	0.2	0.3	C1

* Blair quarry blasts which are not plotted on figure 6

APPENDIX IX

List of Unlocatable Events With (S-P) \leq 2.5 Seconds Recorded Around Monticello Reservoir During 1993

No	DATE	STATION	P-Arrival HR MIN SEC	S-P SEC	Ep. Distance(km) (S-P) x 8.5	DUR SEC	MAG
1	93 01 04	JSC	06:46: 59 0	1.5	12.8	12	0.37
2	93 01 11	JSC	23:47: 53.5	0.6	5.1	5	-0.4
3	93 02 05	JSC	10:89: 06.0	0.8	6.8	4	-0.6
4	93 03 22	JSC	21:46: 52.0	0.4	3.4	5	-0.4

APPENDIX X
MONTICELLO RESERVOIR EARTHQUAKES
JANUARY - DECEMBER, 1992

DATE	ORIGIN	LAT N	LONG W	DEPTH	MAG	NO	GAP	DMIN	RMS	ERH	ERZ	QM
920225	1337	42.78	34-20.00	81-18.64	1.18	1.02	10 159	2.5	0.08	0.5	1.9	B1
920226	1010	10.46	34-19.79	81-18.74	1.31	0.21	10 153	2.4	0.10	0.4	1.3	B1
920315	8 0	47.48	34-20.07	81-18.68	0.97	0.82	10 159	2.4	0.06	0.3	1.7	B1
920402	1714	29.62	34-22.33	81-20.66	1.00	1.02	7 281	1.8	0.15	2.9	4.5	D1
920429	1810	2.98	34-23.60	81-17.18	4.90	0.82	7 292	4.4	0.15	3.6	2.7	D1
920521	1431	33.09	34-20.01	81-18.79	0.42	0.21	7 111	1.6	0.08	0.8	2.1	B1
920529	1654	44.12	34-24.09	81-22.80	2.79	1.02	8 333	6.1	0.07	1.2	1.6	C1
920825	1704	57.66	34-24.50	81-24.40	0.69	1.02	7 333	8.6	0.23		5.4	D1 *
920908	1755	43.74	34-21.98	81-16.80	2.00	0.82	6 253	4.2	0.08	1.2	3.6	D1
921005	1959	1.06	34-24.89	81-23.27	1.32	1.18	6 339	6.5	0.01	0.2	1.0	C1
921025	1142	19.73	34-19.64	81-19.23	0.74	-0.11	6 170	1.9	0.08	7.6	11.8	D1
921029	542	54.20	34-19.64	81-19.08	0.42	1.15	8 147	2.0	0.12	1.2	2.6	C1
921107	321	40.11	34-22.33	81-20.11	2.46	1.12	8 278	1.0	0.09	1.0	0.7	C1
921209	2148	49.10	34-19.98	81-20.35	1.50	0.44	8 230	0.4	0.10	1.2	0.8	C1

* Blair quarry blast which is not plotted on figure 12