

AN INTERIM REPORT ON THE CURRENT INDUCED SEISMICITY
AT THE MANIC 3 RESERVOIR IN THE PROVINCE OF QUEBEC

by

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Beginning in mid-September, there has been a marked increase in the occurrence of earthquakes near the Manic 3 reservoir on the Manicouagan River in the Province of Québec. Several small events were recorded by the Division's telemetered station near the Manic 5 dam site on September 16, 22 and 24, and these were located slightly to the north of the Manic 3 dam. The small earthquakes were followed by somewhat larger events in October, culminating in a magnitude 4.3 event on October 23.

The filling of the Manic 3 reservoir began on August 5th and it is believed that it was within 20 metres of its 110 metre design head in the early part of October. This loading history, coupled with the nature of the seismicity and, in particular, with the many small aftershocks following the October 23 earthquake, makes it almost certain that the seismicity at Manic 3 is induced by the loading of the reservoir.

Attached to this synopsis (Appendix A) is a brief chronological listing of events since August 5th of this year and includes a summary of the advice given by Dr. Leblanc to Hydro-Québec as events have progressed. Also attached is a letter by Dr. Leblanc to Hydro-Québec on October 20th (Appendix B) warning that the events may be induced and that the responsibility of continuing with the loading of the dam was theirs and theirs alone. During the past two weeks, Dr. Leblanc has stressed the induced nature of the earthquakes, which is now virtually certain, and has stressed two further points to Hydro-Québec: first, that, while the present history would not indicate the imminence of a larger event, experience elsewhere indicates that a larger event is distinctly possible (Simpson, 1975, Appendix C); second, Dr. Leblanc has stressed to Hydro-Québec that it would

now be appropriate to make a public statement stating the induced nature of the seismicity and the possibility of a larger earthquake. He has made the point that, while we have not made such a statement ourselves at this time, we may be compelled to do so if questioned directly by the media, and in any case we may choose to do so in future.

Today, November 17, Dr. Leblanc is meeting in Montreal with Hydro-Québec officials to discuss the above. During the meeting he will deliver a letter (Appendix D) from Dr. M.J. Berry to Dr. LeComte emphasizing again the above points about a public statement.

APPENDIX A

Synopsis of events following the induced earthquakes at the Manic 3 dam site and reservoir, P.Q.

- Aug. 5 Hydro-Québec starts filling the reservoir of Manic 3, but does not notify EPB.
- Mid-Sept.
16, 22, 24 First small events are recorded at MNQ with suspicious S-P $\approx 9.5 \pm 0.5$ sec interval. Note that S-P ≈ 11 s represents blast at Manic 3 dam site. Also S-P ≈ 4 sec. (only 1) recorded.
- Oct. 2 G. Leblanc questions H-Q by phone over possibility of blasts at other sites and about a week later received a "negative" answer.
- Oct. 12 One event, larger than previous ones, recorded. Long holiday weekend.
 Hydro notified on 15th, after earthquake was located near Manic 3.
- Oct. 15 Another event.
 Hydro confirms that no blasts have taken place.
- Oct. 19. Third, larger event $M_L \approx 1.5 - 2.5$
- Oct. 20 J. Thomas (of Division) leaves with 2 portable stations.
- Oct. 20 G. Leblanc sends letter (Appendix B) to H-Q warning that the recent earthquakes may be induced by the loading process. His letter specifically states that the rate of loading is the responsibility of H-Q.
- Oct. 21 J. Thomas recalled because of death in family.
- Oct. 23 F. Kollar leaves for Manic and Seven Islands
- 5 pm Large event 4.3 occurs.
 Kollar deploys station that same night
- 7 pm -
11 pm G. Leblanc in contact with Hydro Direction. Hydro decide to reduce the rate of release of water from Manic 5, thereby slowing down the rate of filling in the Manic 3 reservoir. They decide to take men working at Manic 3 out of tunnels.

Oct. 24 G. Leblanc notified Assoc. Press and CBC of the occurrence
10 am of event, M_L 4.3, 60 miles NNW of Baie Comeau, felt by
 Hydro workers near Manic 3 and 5.

11 am Hydro makes separate press communiqué.
 Made very clear to Hydro that EPB cannot keep the event secret.

Oct. 24 F. Kollar deploys other station and gets good readings at
 nearby stations.
 Events are \approx 7 miles north of Dam and are very shallow.

Oct. 30 Third portable station sent to and deployed by F. Kollar.
 Numerous small aftershocks occur ($M_L=0.0 \approx 1.5$) \approx 40 events/day

Nov. 13 Very low level seismicity continues.
 Fewer events >1.0.

Nov. 17 G. Leblanc has meeting with Hydro officials and delivers
 attached letter (Appendix D) by Berry to LeComte.

OTHER FACTS

Oct. 27 Men were allowed back in tunnels after complete inspection
 by Hydro experts: geologists, soil mechanics, designers,
 etc.

Oct. 27 Hydro admits that this sequence very untimely, in view of
 negotiations for \$250 million loan.

 Hydro clearly told that at no time (G. Leblanc handling re-
 quests) will EPB hide scientific facts from press, including
 possibility of "induced seismicity" and its implications with
 regard to the possibility of larger events.

Nov. 13 Up to now, numerous calls from Press. Only "Le Soleil" de
 Québec has asked about possible relation of eq. to reservoir
 filling. Answer: Yes, quite possible.

APPENDIX B

Le 20 octobre 1975

6082-4-7

Dr. Paul LeComte
Service Géologique
Hydro Québec
Place Dupuis, 17^e étage
855, rue Ste-Catherine
Montréal, P.Q., H2L 4M4

Cher Dr. LeComte:

Je voudrais vous signaler, d'une façon plus formelle, le fait que depuis dix jours, la station séismographique de Manicouagan enregistre de petits séismes dont les épicentres paraissent se situer aux environs de votre barrage de Manic 3. Pour le 12 et 19 octobre, nous estimons une magnitude près de 3; pour le 15 octobre, une près de 2, et pour le 11 octobre, une magnitude plus faible.

Après avoir confirmé avec vous, l'absence d'explosions aux heures des arrivées séismiques, nous croyons donc en l'authenticité de ces séismes. De plus, comme cette crûe d'activité coïncide avec le remplissage du réservoir Manic 3, nous croyons prudent d'envisager la possibilité d'un cas de séismicité induite. Même si les annales de 1966 révèlent une activité d'un mois, dans une région assez similaire, sûrement non-induite, nous croyons que la coïncidence de cette nouvelle activité avec le remplissage presque terminé est assez grave pour déployer deux stations portatives qui permettront d'améliorer la détermination des épicentres et peut-être aussi d'obtenir une idée des profondeurs focales et en conséquence de l'origine de ces secousses.

Il va s'en dire que la responsabilité de continuer ou de ralentir le remplissage relève de votre direction.

Je compte que nous pourrons compter, comme toujours, sur votre collaboration durant le déploiement des nouvelles stations et leur opération. Je vous tiendrai au courant des résultats. De votre part, n'hésitez pas à me contacter si vous désirez de plus ample information.

Acceptez l'expression de mes meilleurs sentiments.

G. Leblanc
Division de la séismologie
et des études géothermiques

GL:lt

APPENDIX C

SEISMICITY ASSOCIATED WITH RESERVOIR IMPOUNDING

- A Pre-symposium Review -

by

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ABSTRACT

There are over twenty cases where changes in seismic activity have been related to the filling of large reservoirs. These changes range from destructive earthquakes with magnitudes greater than 6, to variations in the level of micro-earthquake activity detectable only with instruments of high sensitivity. There are, on the other hand, many large reservoirs where increased seismicity has not been observed.

There now exist more than 275 reservoirs with dam greater than 100 meters high and an additional 135 are proposed or now under construction. At least 12 of these reservoirs (including some of the world's largest) have been shown to have experienced no observable increases in seismicity.

A number of factors may contribute to the generation or absence of post-impounding seismicity. Increased stress due to the load of the reservoir, decreased effective stress due to increased pore pressure; and the action of water on particular geological formations in the reservoir region have all been suggested as possible causes. Whether or not the changes induced by the reservoir are sufficient to generate earthquake activity may be determined by the state of regional stress near the reservoir. The combined effect of increased vertical load and increased pore pressure will have the greatest tendency to increase activity in regions where the maximum compressive stress is vertical (normal faulting). In regions where the maximum compressive stress is horizontal (thrust faulting) increased stress due to a vertical load should have a minimum effect. For all of the larger reservoir induced earthquakes the stress system determined from fault plane solutions is in agreement with the pre-existing stress field in the region of the reservoir. These earthquakes are all of strike-slip or normal type, there being no large induced earthquakes with thrusting mechanisms. In the western United States, those reservoirs where seismicity has occurred are in regions of horizontal extension, whereas those in regions of horizontal compression have not shown post-impounding increases in seismicity.

INTRODUCTION

A number of reviews have already been made of reservoir induced seismic activity. Rothé (1970, 1973), Carder (1970), Bozovic (1974), Lomnitz (1974), National Academy of Sciences (1972) and Gupta et al. (1972a, b) have summarized

the activity at twenty or more reservoirs where changes in seismicity have been observed after impounding. The details of these case histories are familiar to the participants of this meeting and will not be presented in this pre-conference review. This review will consist of a series of tables and figures, intended to serve as useful reference material during the meeting.

Examples of Reservoir Induced Seismicity

In Table 1 the reported cases of induced seismic activity have been grouped into four categories.

A) Major Induced Earthquakes - There are six cases (Koyna, Kremasta, Hsinfengkiang, Kariba, Hoover, and Marathon) where earthquakes of magnitude greater than 5, accompanied by long series of foreshocks and aftershocks, have been related to reservoir impounding. In all of these cases, information on pre-impounding seismicity is lacking, so that it is not possible to establish the exact nature of the changes in the seismic regime caused by the reservoir. It is clear however that, in every case, the post-impounding seismicity, and especially the main shock, represents a major change in the seismicity of the region about the reservoir.

Figure 1 shows the water level and time and magnitude of the largest earthquakes for five of the reservoirs in this group and for Monteynard reservoir.

B) Minor Induced Earthquakes - In Table 1 are listed 12 cases where earthquakes of approximately magnitude 3 to 5 have occurred. In some cases pre-impounding seismic activity is known to have occurred and the relationship between the reservoir and seismicity is based on coincidence in time of increased activity with the filling of the reservoir (Nurek, Monteynard, Bajina-Basta, Vajont, Benmore, Mangala). In two cases (Talbingo, Kurobe) sufficient pre-impounding instrumental data were available to show that, prior to construction of the dam, no earthquakes of the size of the post-impounding earthquakes had occurred in the vicinity of the reservoir.

C) Changes in Micro-earthquake Activity - At three reservoirs where sensitive instruments were available during impounding (Grancarevo, Hendrik Verwoer and Schlegeis) no felt earthquakes were reported, but changes were observed on the microseismic level (magnitude less than 2). As Bozovic (1974) has suggested, it is very likely that activity of this type has occurred at a large number of reservoirs but has gone unobserved because of the lack of adequate instrumentation.

D) Transient Changes in Seismicity - Five reservoirs have been associated with activity which began after impounding and has since stopped. In two cases (Oued Fodda, Camarillas) it has been suggested that the readjustment of hydrological conditions in particular geological formations in the reservoir region were responsible for the seismic activity. In three cases, the activity was associated with changes in the filling of the reservoir - at Contra, the activity stopped when the reservoir was emptied and refilled; at Camarillas, the activity stopped after the water level was lowered; and, at Vouglans, the activity occurred after a rapid emptying and filling of the reservoir.

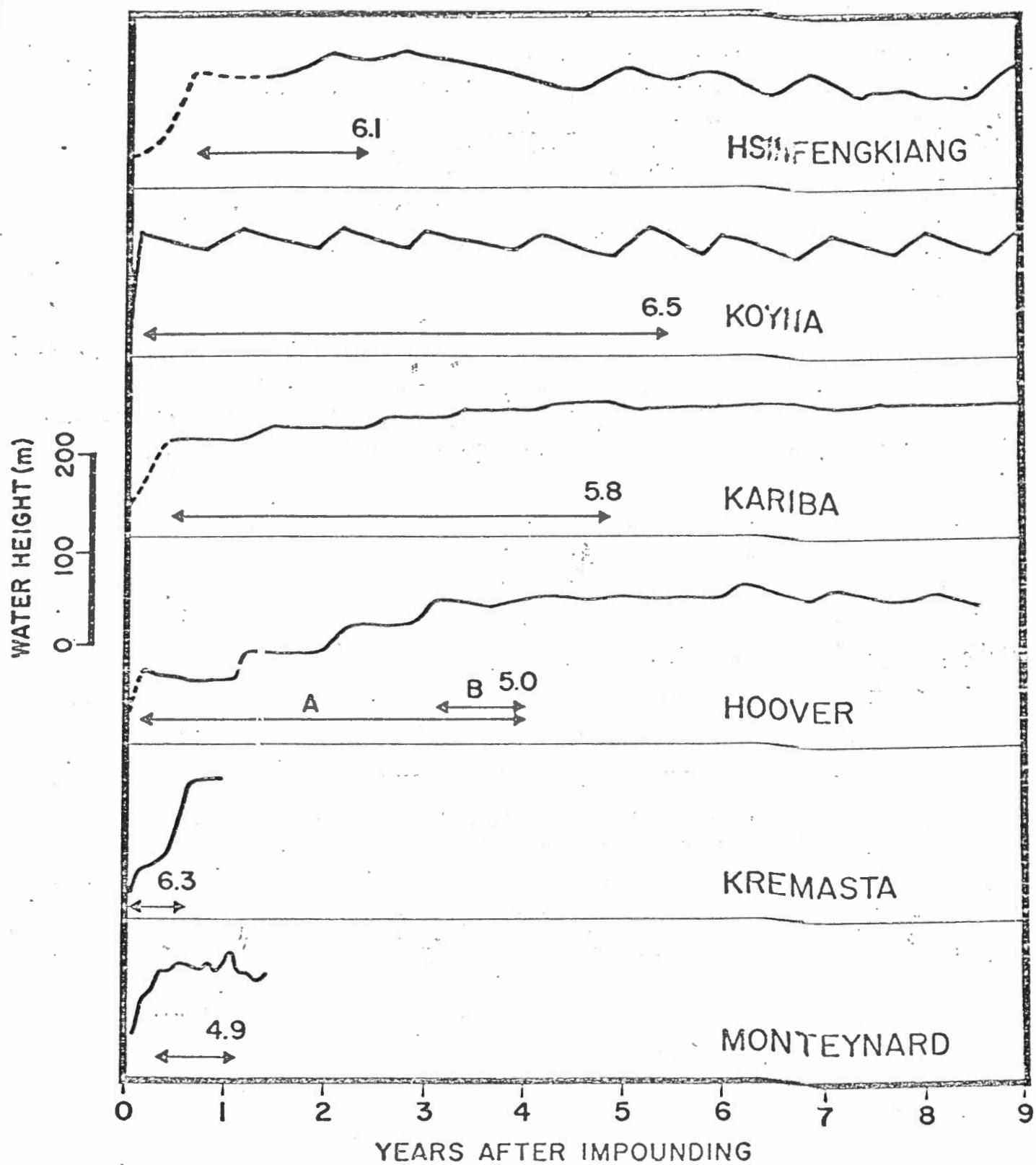


Figure 1. Filling curve and time and magnitude of the largest earthquakes for six cases of reservoir induced seismic activity.

Other Cases of Induced Seismicity - Post-impounding earthquakes have also been reported at seven reservoirs located in marginal areas of the Indian Shield, at El Grado in Spain, and at Cabin Creek, Rocky Reach, Shasta and Keer dams in the United States. Details for these reservoirs are not available.

Reservoirs Without Increased Seismicity - The following reservoirs (with heights in meters) have been reported by various sources to be free from post-impounding increases in seismicity: Oroville, U.S.A. (236); Bhakra, India (226); Glen Canyon, U.S.A. (216); Daniel Johnson, Canada (214); W.A.C. Bennett, Canada (183); Flaming Gourge, U.S.A. (153); Serre-Poncon, France (129); Bratsk, U.S.S.R. (125); Nagarjuna Sagar, India (124) and Aswan, Egypt (111).

LARGE DAMS

Since no diagnostic criteria appear to be available for determining the risk of triggering induced earthquakes, all "large reservoirs" must to some extent be considered potential sources of induced activity. Those reservoirs listed in Table 1, where activity has occurred represent only a small fraction of the total number of large reservoirs in the world. As well as considering why these reservoirs have generated seismicity, it is also important to determine why other large dams have not shown activity.

The National Academy of Sciences Report (1973) defines a large reservoir as "one with a volume of one million acre-feet ($1233.5 \times 10^6 \text{ m}^3$) or more, usually impounded behind a dam 300 feet (91.4 meters) or greater in height." The International Commission on Large Dams has published a "World Register of Dams" (ICOLD, 1973) from which the data listed in Tables 2 and 3 for all dams over 100 meters high have been obtained.

Table 2 lists by country 410 existing or proposed dams over 100 meters high, of which approximately 275 are now completed. Table 3 lists by height 93 dams over 150 meters high and 17 reservoirs with volume greater than 100 km^3 . In Figures 2 and 3 are shown the 31 reservoirs with dams greater than 100 meters high and reservoir volumes greater than 10 km^3 . Note that of the world's 5 largest reservoirs shown in Figure 2 only one (Kariba) has shown seismicity and at least three of the others (Daniel Johnson, Bratsk and Aswan) are reported to have had no observable seismicity.

CHARACTERISTICS OF RESERVOIR SEISMICITY

Rothé (1970, 1973) and Gupta *et al.* (1972a,b) have summarized the common features of the seismicity at large reservoirs.

Size of reservoir - Rothé (1973) has noted that the depth of water appears to be more important than the total volume of water, and that activity is most common in reservoirs greater than 100 meters deep. As Tables 1, 2 and 3 show, however, this is certainly not a necessary or sufficient condition - there being many reservoirs greater than 100 meters high which have had no activity and at least 5 under 100 meters where activity has been observed.

Spatial extent of seismicity - Rapid decreases in intensity from the epicenters of the larger earthquakes and audible noises associated with many of the small earthquakes indicate that reservoir related seismicity is very

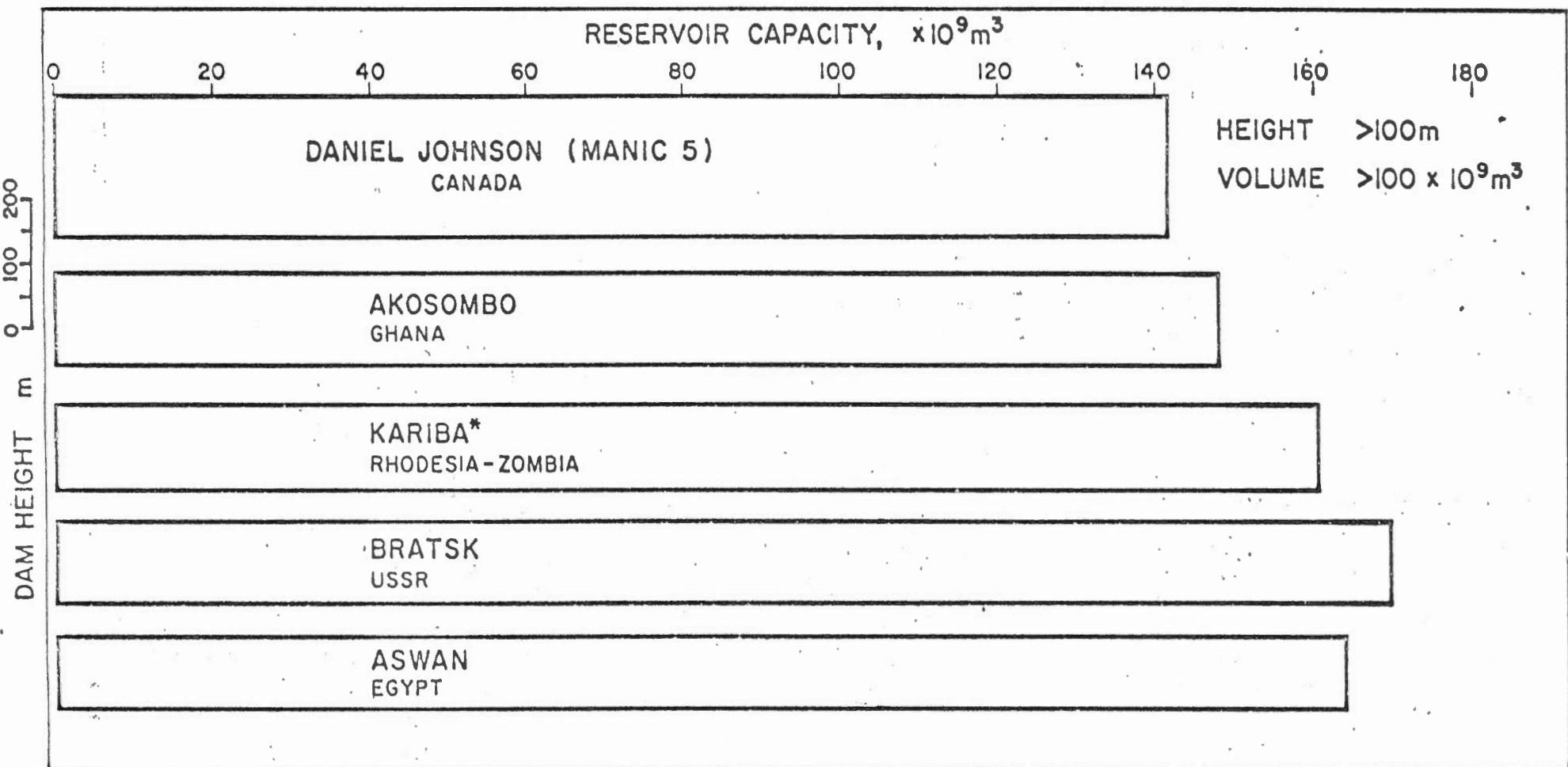


Figure 2. Dam height and reservoir capacity for five of the world's largest reservoirs. Asterisk (*) denotes reservoirs with related seismicity. For comparison Lake Superior has an average depth of 148 meters, a greatest depth of 406 meters and a volume of $22,491 \text{ km}^3$.

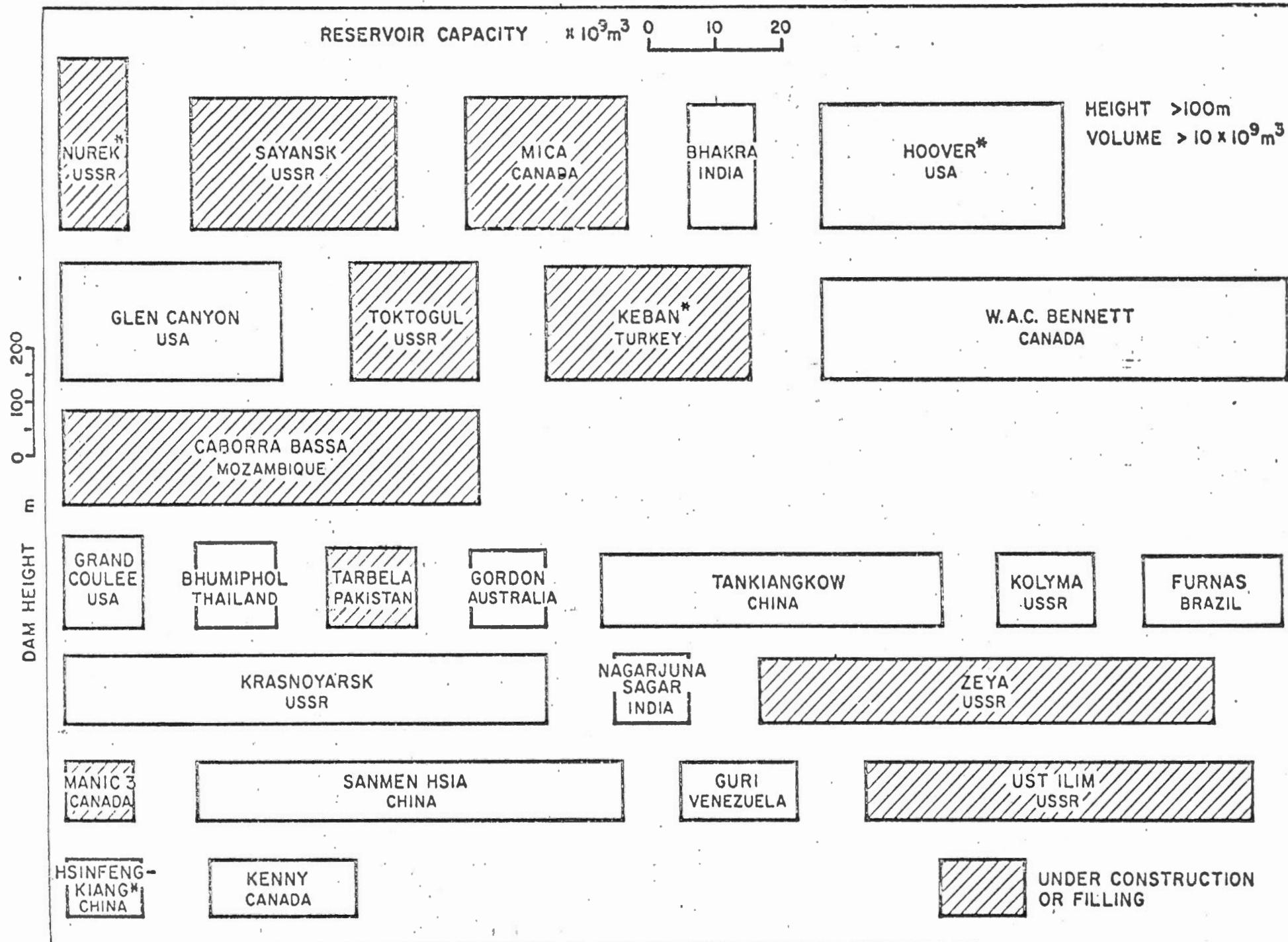


Fig. 3. Reservoirs with dams greater than 100 meters high and reservoir capacity between 10 and 100 million cubic meters.

shallow. Most of the large earthquakes have occurred directly beneath the reservoir and most activity is within 25 km of the reservoir.

Temporal character of seismicity - In most cases activity has started soon after impounding and the level of activity has increased as the water level increases. Most large shocks have occurred at or near the time of highest water level (see Figure 1). The largest earthquakes have been associated with long series of foreshocks and aftershocks. The foreshock and aftershock sequences fall into a Mogi Type II classification, indicating heterogeneous structure and non-uniform stress distribution.

Size relationship of seismicity - Gupta et al. (1972a,b) have shown that for the reservoirs with the largest earthquakes, the magnitude ratio of the largest aftershock to the main shock is high (approximately 0.9) and that both foreshock and aftershock "b values" in the frequency-magnitude relationship are high (greater than 1.0). Both of these characteristics contrast sharply with the situation for natural earthquakes in the same regions. These again suggest non-uniform stresses in a heterogeneous medium.

Geological structure and fault plane solutions - Gupta et al. (1972b) note that in the areas around Kariba, Kremasta and Koyna reservoirs there is evidence for former volcanic activity. Among the rock types near the reservoir are limestones and red clays which are easily affected by water. The fault plane solutions determined for earthquakes at these reservoirs show near-vertical fault planes with the reservoir on the down-dropped side.

ACKNOWLEDGEMENTS

Christopher Scholz, Klaus Jacob and Lynn Sykes have provided many useful comments and background material. The ideas for a "census" of large reservoirs was suggested by earlier work by W. I. Gough, who kindly provided the material she had collected.

REFERENCES

- Bozovic, A. (1974) Review and appraisal of case histories related to seismic effects of reservoir impounding. Eng. Geol., 8, 9-27.
- Carder, D. S. (1970) Reservoir loading and local earthquakes, Eng. Geol. Case Histories, No. 8, 51-61.
- Gupta, H. K., B. K. Rastogi and H. Narain (1972a) Common features of the reservoir-associated seismic activities. Bull. Seism. Soc. Amer., 62, 481-492.
- Gupta, H. K., B. K. Rastogi and H. Narain (1972b) Some discriminatory characteristics of earthquakes near the Kariba, Kremasta and Koyna artificial lakes. Bull. Seism. Soc. Amer., 62, 493-507.
- I.C.O.L.D. (1973) World Register of Large Dams. International Commission on Large Dams, Paris, 998 pp.

Lomnitz, C. (1974) Earthquakes and reservoir impounding: state of the art.
Eng. Geol., 8, 191-198.

National Academy of Sciences (1972) Earthquakes related to reservoir impounding
U.S. Nat. Acad. Sci., Washington, 24 pp.

Rothé, J. P. (1970) Seismes artificiels. Tectonophysics, 9, 215-238.

Rothé, J. P. (1973) Summary: geophysical report, in Man-made Lakes:
Their Problems and Environmental Effects, Geophys. Monogr., 17,
Amer. Geophys. Union, Washington, 441-454.

TABLE 1 RESERVOIR INDUCED SEISMICITY

| Dam Name | Country | Height (m) | Volume (x10 ⁶ m ³) | Year of Impounding | Year of Largest Earthquake | Magnitude or Intensity |
|---|-------------|---------------|--|-----------------------|----------------------------------|------------------------------|
| A) MAJOR INDUCED EARTHQUAKES | | | | | | |
| Koyna | India | 103 | 2780 | 1964 | 1967 | 6.5 |
| Kremasta | Greece | 165 | 4750 | 1965 | 1966 | 6.3 |
| Hsinfengkiang | China | 105 | 10500 | 1959 | 1961 | 6.1 |
| Kariba | Rhodesia | 128 | 160368 | 1959 | 1963 | 5.8 |
| Hoover | U.S.A. | 221 | 36703 | 1936 | 1939 | 5.0 |
| Marathon | Greece | 63 | 41 | 1930 | 1938 | 5.0? |
| B) MINOR INDUCED EARTHQUAKES | | | | | | |
| Benmore | New Zealand | 118 | 2100 | 1965 | 1966 | 5.0 |
| Monteynard | France | 155 | 240 | 1962 | 1963 | 4.9 |
| Kurobe | Japan | 186 | 199 | 1960 | 1961 | 4.9 |
| Bajina-Basta | Yugoslavia | 89 | 340 | 196 | 1967 | 4.5-5.0 |
| Nurek | U.S.S.R. | 317 | 10400 | 1972 | 1972 | 4.5 |
| Mangala | Pakistan | 116 | 7250 | 1967 | 1970 | 4.2 |
| Talbingo | Australia | 162 | 921 | 1971 | 1972 | 3.5 |
| Keban | Turkey | 207 | 31000 | 1973 | 1974 | 3.5 |
| Vajont | Italy | 261 | 61 | 1963 | | |
| Pieve de Cadore | Italy | 112 | 68 | 1949 | 1951 | |
| Grandval | France | 88 | 292 | 1959 | 19 | V |
| Canalles | Spain | 150 | 678 | 1960 | 1962 | V |
| C) CHANGES IN MICROEARTHQUAKE ACTIVITY | | | | | | |
| Grancarevo | Yugoslavia | 123 | 1280 | 1967 | | 1-2 |
| Hendrik-Verwoerd | S. Africa | 88 | 5954 | 1971 | 1971 | <2 |
| Schlegeis | Austria | 130 | 129 | 1971 | 197 | 40 |
| D) TRANSIENT CHANGES IN SEISMICITY | | | | | | |
| Oued Fodda | Algeria | 101 | 228 | 1932 | | |
| Camarilles | Spain | 44 | 40 | 1960 | 1961 | 3.5 |
| Piasta | Italy | 93 | 13 | 1965 | 1966 | VI-VII |
| Vouglans | France | 130 | 605 | 1968 | 1971 | 4.5 |
| Contra | Switzerland | 220 | 86 | 1965 | 1965 | |

| | | | | | | | |
|----|---------------------|------------|--------------|----------|------|-------|-------|
| 6R | MORROW POINT | GUNNISON | USA, COLO. | VA | 143 | 144 | 279 |
| 6B | POSSYROCK | COWLITZ | USA, WASH. | VA | 185 | 1603 | 953 |
| 6B | OKOVILLE | FEATHER | USA, CALIF. | TE | 236 | 4298 | 59639 |
| 6B | NEW BULLARDS BAR | N. YUBA | USA, CALIF. | VA | 194 | 1194 | 2064 |
| 71 | NEW DON PEDRO | TUOLUMNE | USA, CALIF. | TE | 178 | 2504 | 12914 |
| 73 | DWORSNAK DAM | CLEARWATER | USA, IDAHO | PG | 219 | 4278 | 4970 |
| 73 | LITTRY | KOOTENAI | USA, MONTAN | PG | 136 | 7216 | 3234 |
| C | AUBURN | AMERICAN | USA, CALIF. | TE | 210 | 2837 | 4590 |
| C | CARTERS LAKE | COOSANATEE | USA, GEORGIA | TE/ER138 | 583 | 10912 | |
| C | CRYSTAL | GUNNISON | USA, COLO. | VA | 107 | 31 | 104 |
| C | JUCASSEE | KERSEE | USA, S.C. | TE | 133 | 1430 | 8869 |
| C | LOST CREEK | ROGUE | USA, OREL | TE | 105 | | |
| C | NEW MELONES LAKE | STANISLAUS | USA, CALIF. | TE/ER130 | 2960 | 12035 | |
| C | PYRAMID | PIRU CK | USA, CALIF. | | 122 | 220 | 5240 |
| C | SHAKER CREEK | SHAKER CK | USA, OHIO | TE | 100 | 5 | 497 |
| P | HIGH MOUNTAIN SHEER | SNAKE | USA, IDAHO | VA | 294 | 4 | 1529. |
| P | BAGBY | HERCED | USA, CALIF. | ER | 134 | 530 | 5558 |
| P | BIG TREES | STANISLAUS | USA, CALIF. | ER | 130 | 200 | 4817 |
| P | DICKEY | ST JOHN | USA, MAINE | TE | 105 | 13048 | 47080 |
| P | FRANZ | FRANZ CK | USA, CALIF. | TE | 103 | 1850 | 5580 |
| P | HOOKER | GILA | USA, N.M. | TE | 104 | 327 | 7263 |
| P | HAACAHAA | KAACHHA CK | USA, CALIF. | TE | 116 | 1850 | 1237 |
| P | PLACITA | CRYSTAL | USA, COLO | TE | 107 | 130 | |
| P | POOR MOUNTAIN-LOWER | BACK CK | USA, VA. | ER | 113 | 50 | |
| P | POOR MOUNTAIN-UPPER | BACK CK | USA, VA. | ER | 114 | 31 | |
| P | PULLIAM CREEK | PULLIAM | USA, N.C. | ER | 100 | 54 | 4800 |
| P | ROSS HIGH | SKAGIT | USA, WASH. | VA | 201 | 4263 | 1067 |
| P | TOPA TOPA | SESPE | USA, CALIF. | TE | 176 | 339 | 13839 |
| 68 | GURI | CARDNI | VENEZUELA | PG | 106 | 17700 | 3762 |
| 67 | GRANCAREVO | TREBISNJ | YUGOSLAVIA | VA | 123 | 1260 | 376 |
| 68 | TIKVES | CRNA REKA | YUGOSLAVIA | ER | 114 | 475 | 2722 |
| 69 | RAMA | RAMA | YUGOSLAVIA | ER | 103 | 487 | 1510 |
| 69 | SPILJE | CRRI DRIM | YUGOSLAVIA | ER | 112 | 520 | 2699 |
| C | GAZIVODE | IBAR | YUGOSLAVIA | ER | 108 | 370 | 5 |
| C | KRATINJE | PIVA | YUGOSLAVIA | VA | 220 | 890 | 742 |
| C | SJENICA | UVAC | YUGOSLAVIA | ER | 110 | 190 | 2 |
| P | BAKOVICA KLISURA | TARA | YUGOSLAVIA | TE | 145 | 1380 | 5688 |
| P | BANJA LUKA | VRBAS | YUGOSLAVIA | VA | 124 | 691 | 157 |
| P | BIJELE STENE | MORACA | YUGOSLAVIA | VA | 150 | 320 | 150 |
| P | CERREN | CRNA REKA | YUGOSLAVIA | VA | 137 | 900 | 1093 |
| P | CELJICOVICI | MILJACKA | YUGOSLAVIA | ER | 104 | 19 | 1248 |
| P | KUNDJILA | PIVA | YUGOSLAVIA | VA | 200 | 416 | 426 |
| P | KONJIC | NERETVA | YUGOSLAVIA | VA | 133 | 460 | 515 |
| P | STUDENICA | STUDENICA | YUGOSLAVIA | VA | 116 | 140 | 416 |
| P | SIPOVU | PLIVA | YUGOSLAVIA | VA | 118 | 625 | 416 |
| P | TREBUSA | IDRIJICA | YUGOSLAVIA | VA | 120 | 307 | 415 |
| P | TRESKA | TRESKA | YUGOSLAVIA | VA | 166 | 650 | 550 |
| P | ULOG | NERETVA | YUGOSLAVIA | VA/PG151 | 445 | 317 | |
| P | KUUILOU | KOUILOU | ZATRE | P | 137 | 35000 | 390 |

APPENDIX D

Le 17 novembre 1975

6082-4-7

Dr. Paul LeComte
Service Géologique
Hydro Québec
Place Dupuis, 17^e étage,
855 Est Ste-Catherine
Montréal, P.Q., H2L 4M4

Cher Dr. LeComte:

Je reviens tout justement d'un bref voyage en Chine, ayant participé officiellement à une visite d'échange scientifique. A ce moment-ci, je crois opportun de vous écrire personnellement pour vous assurer que je donne mon entier support au cours d'action que mon personnel a choisi de suivre, à la suite des récentes secousses séismiques aux environs de Manic 3, et continue de vous assurer de notre entière coopération.

Je crois qu'il était vraiment indiqué, autant pour notre Division, que pour l'Hydro-Québec, de faire le communiqué de presse au sujet de la secousse principale de 4.3 du 23 octobre. A ce moment, il était encore impossible de dire avec certitude si la secousse était induite ou simplement naturelle pour cette région.

Maintenant, l'ensemble de la série d'événements séismiques, avec les chocs avant-coureur, le choc principal et les répliques multiples, ainsi que la profondeur focale infime, le tout en parallèle avec le remplissage, nous laisse aucun doute que cette activité est induite et causée par le remplissage du réservoir.

Jusqu'ici, aucune indication claire sur la nature des événements induits n'est apparue dans la presse. Toutefois, je crois que ce n'est qu'une question de temps avant que ce problème passe au public. D'ailleurs la communauté scientifique commence déjà à en être au courant. Vous comprenez, sans doute, que nous sommes dans l'obligation de respecter la vérité et de commenter, au meilleur de notre connaissance scientifique, les faits actuels et leurs implications futures.

Dans cette optique, je crois qu'il serait préférable que le public soit mis au courant de la nature des événements induits, et de la possibilité de plus larges chocs, selon la leçon à tirer des cas de séismicité induite ayant eu lieu ailleurs.

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Vous savez sans doute que seulement 26 cas de séismitité induite sont connus sur les 275 réservoirs ayant une tête d'eau de 100 mètres ou plus. De plus, sept de ces 26 réservoirs ont expérimenté des chocs de magnitude égale ou plus grande, que 5. Ces faits sont bien connus des scientifiques, et sûrement le deviendront, tôt au tard, du public, comme il le sied. A notre avis l'Hydro-Québec ne devrait pas retarder l'annonce de ces faits et possibilités au grand public.

Je continue de vous exprimer l'assurance de notre entière disponibilité durant cette période critique. Les jours qui vont suivre et le taux de séismitité observée, nous aideront à déterminer la durée de notre déploiement temporaire de stations spéciales, ainsi que la nature de nos recommandations.

Acceptez l'expression de mes meilleurs sentiments,

M.J. Berry

Directeur
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