SEISMIC SAFETY ADVISORY COUNCIL

STATE OF UTAH

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SEISMIC STRONG-MOTION INSTRUMENTATION FOR UTAH:
CURRENT STATUS, NEEDS, AND RECOMMENDATIONS

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SEISMIC SAFETY ADVISORY COUNCIL
STATE OF UTAH

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FOREWORD

The Utah Seismic Safety Advisory Council, established in 1977 by legislative action, is charged to prepare assessments of earthquake hazards and associated risks to life and property in the State of Utah, and to make recommendations for programs or actions that might be undertaken to reduce earthquake risks to life and property. An important aspect of earthquake safety is the availability and adequacy of information about Utah's earthquake environment and earthquake effects. Information limits obviously have an influence upon the ability of the State, local governments, and the private sector to undertake effective mitigation programs or actions. Serious deficiencies in this information need to be pointed out when they are found, and programs to obtain such information need to be suggested. One such information deficiency is highlighted herein.

In this report we describe the status of earthquake strong-motion information in Utah, we identify deficiencies in both the strong-motion data base and the instrumentation systems in the State to obtain data, and we suggest programs to overcome the information deficiencies.

Strong-motion information is important in understanding the characteristics of surface ground motion resulting from seismic vibrations, especially in Utah's abundant alluvial-filled valleys where the propogation and attenuation of seismic waves is complex. Very little such data exist in Utah, and there presently are inadequate information-gathering programs in operation. Indeed, the present strong-motion program in Utah is so inadequate that it might better be described as nonexistent.

In order to provide a reasonably complete overview of strong-motion instrumentation pertinent to Utah, we have included in Section 1 some discussion on the purposes, measurements, and instrument arrays for recording seismic activity in Utah. Distinction is made between short-period seismographs used for detecting and locating earthquake activity, a capability that the State has, and accelerographs used for measuring earthquake strong motions, a capability that the State does not have. In Section 2, specific needs and uses for earthquake strong-motion data are discussed. In Section 3, alternative programs intended to meet the strong-motion information deficiency are suggested and discussed, and in Section 4, specific recommendations of the Utah Seismic Safety Advisory Council pertaining to this matter are set forth.

The report gives special attention to suggesting an optimal size and distribution of a modest strong-motion instrument array for Utah. The recommendations that are made are based upon consideration of the smallest sized instrument network that would provide the needed geographic coverage of potentially active seismic zones in Utah. Acquisition, installation, and maintenance cost data for an instrumentation program are included. The report also discusses the capability of State agencies and institutions to operate a strong-motion instrument program.

The purpose of this report is to call attention to an information void which constrains accurate seismic risk analysis and the proper design of earthquake-resistant structures in Utah and to suggest a means whereby the State effectively can participate in correcting this information void. The Advisory Council has concluded that earthquake strong-motion information needs can be met only through some sort of State participation. Hence, adoption and funding of the programs recommended herein are urged by the Seismic Safety Advisory Council.

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Section 1

STRONG-MOTION INSTRUMENTS

THE PURPOSE OF STRONG-MOTION INSTRUMENTS

Recordings from specially designed seismographs provide the basic data from which the seismicity of a region is determined and evaluated. In turn, the extent of seismic risk in an area is determined using such seismicity data along with other indicators of seismic hazards and the extent of exposure of populations and land development in that area.

Seismic recording instruments may be grouped in two classes--(1) short-period, narrow band, high magnification velocity seismographs and (2) broad-band, low-magnification, strong-motion accelerographs. In general discussions, the former are referred to as short-period seismometers and the latter as strong-motion recorders.

Short-period seismographs are used primarily to identify, locate, and characterize the source of earthquakes, typically over wide areas or regions. Such instruments are extremely sensitive so that distant and even very small local ground disturbances are recorded. From the resulting recordings, trained seismologists are able to estimate with good accuracy the location, focal depth, size or magnitude of an earthquake, type of faulting, and stress release. However, one detriment resulting from the high sensitivity characteristic of short-period seismographs is that a large ground motion from a local earthquake likely will overdrive its recording mechanism, forcing it off scale. The resulting recording, while indicating the occurrence of an earthquake, will yield little information about the ground motion caused by the earthquake. Moreover, the distorted recording will not reveal details of frequency-dependent ground motion that are of primary interest for engineering considerations.

Strong-motion seismographs are used when information is wanted about the characteristics of the ground motion produced by large earthquakes. These recorders are designed to provide a complete time history of the ground motion, typically in terms of ground acceleration, from which velocities and displacements of the motion may be derived. Strong-motion seismographs, however, are much less sensitive than short-period seismometers, and the instruments will not be triggered by moderate or distant earthquakes. Hence, strong-motion instruments are of little use for monitoring the regional or local seismicity, i.e., for routinely recording the thousands of small-magnitude earthquakes that occur annually in any active earthquake area such as Utah.

As is implied by the above descriptions, short-period seismographs and strong-motion recorders each have their particular uses and purposes. The two instrument types are not the same, and their respective purposes are different. However, together they compliment each other to provide a wide frequency response record that is necessary for a complete seismicity evaluation.

Short-period seismographs, such as those that constitute the University of Utah's seismic network in Utah, are primarily for sensitive detection and accurate location of earthquakes throughout a broad belt of seismicity in the State. The network is a sophisticated research tool for studying details of earthquake occurrences in time and space (related, for example, to earthquake hazards evaluations, earthquake prediction, regional tectonics) and of earthquake wave propogation (for crustal structure and classical seismology). But, again, data from these instruments are inadequate for evaluating strong ground shaking from moderate to large nearby earthquakes.

Strong-motion recorders, on the other hand, are designed to yield detailed information about the ground motion. They are calibrated to record large ground motions and vibration frequencies which affect the behavior of structures. Their ultimate purpose is to provide data useful in the engineering design of structures and to aid in understanding and characterizing the effects of soil response on the behavior of structures. Such information is essential for the design of structures which are to be earthquake-resistant, and seismic design standards are developed from such ground-motion data.

Because short-period velocity seismographs are distinctly different from the strong-motion accelerometers both in frequency and in amplitude response, they cannot be used interchangeably. When both kinds of data are needed, as is the case for moderate to strong earthquakes, two types of instruments must be used.

GROUND-MOTION MEASUREMENTS

Measurements of ground motion induced by earthquakes are essential for the design of earthquake-resistant structures and for other studies of soil conditions which may pose hazards to life and property when earthquakes occur.

Forces are imposed upon structures as a result of ground accelerations, and soil behaviors also are affected by such motions. These forces must be resisted by a structure if damage to the building or its collapse are to be avoided. Characteristics of these forces are derived from measurements of ground movement during earthquakes. Such measurements are made with strong-motion instruments which chart directions of the forces and time histories of the ground accelerations. From these measurements, load factors are established or calculated and used as the basis for earthquake-resistant design of structures.

Ground response due to earthquakes is influenced by the underlying soil and rock conditions in the region between the earthquake epicenter and the point of measurement. Since subsurface soil and rock conditions are variable, the earthquake-induced ground motions at various locations will differ for the same earthquake. Knowledge of these variations is important, if not essential, in the design of structures to properly resist the earthquake-induced forces. Accordingly, strong-motion earthquake records for several earthquake events and at a number of different locations are needed in order to establish amplitude and frequency parameters for earthquake-resistant design. Although each earthquake event will have a unique motion, the soil and rock attenuation characteristics are relatively constant under similar earthquake forces. Hence, once the soil and rock behavior characteristics are known, ground response can be estimated, and such data can be combined with an assumed design-basis earthquake to fully describe the expected forces on a building at a given site.

In contrast to short-period seismographs which typically operate continuously (background "noise" may be recorded even if earthquake activity is not present), strong-motion instruments are designed to record intermittently when ground motions exceed a predetermined level. Hence, strong-motion instruments are activated infrequently and when large ground motions are present. They are insensitive to small motions which do not activate the recorder.

Strong-motion measurements have two-fold value. The first is for characterizing the source behavior of large earthquakes in a region. (Within a few miles of an earthquake source, ground motion is greatly influenced by the dynamics of the fault region.) The second is for evaluating ground response in an area to nearby strong earthquakes. Each of these two kinds of information has importance for earthquake-resistant construction, and both kinds of information are needed to develop earthquake design criteria that are valid for the Utah region.

SEISMIC INSTRUMENTATION IN UTAH

Continuous monitoring of seismicity in Utah currently is carried on by the University of Utah Seismograph Stations, which is operated by the Department of Geology and Geophysics, by means of a network of short-period seismographs located throughout Utah, Southern Idaho, and Western Wyoming. The network consists of 52 separate stations (as of July, 1980), each with its own instrument. Figure 1 indicates these instrument site locations in Utah. Table 1 gives more specific data about the network ([1], plus updated information from the Seismograph Stations).

Seismic data received by nearly all of the stations are telemetered to the Seismograph Stations laboratory at the University of Utah for central recording, processing, and interpretation. The instrument package at each remote station of the network typically includes a vertical-component, short-period (1.0 Hz) velocity seismometer and associated amplifiers and other electronics to produce a frequency-modulated (FM) audio tone. The FM data are continuously transmitted by radio and/or telephone links to Salt Lake City. Through 1979, recording was limited to analog 16-mm film recorders and paper drum recorders. Early in 1980, a sophisticated computer system, provided by the U.S. Geological Survey, was installed for the digital recording and semi-automated processing of the telemetry network data, processing of all regional earthquake data, and all other aspects of seismological research.

Earthquake information is reviewed by University staff and faculty, processed or interpreted as may be necessary, and disseminated to interested parties as may be appropriate. In addition to allowing earthquake surveillance for public safety and information, the voluminous seismic data are used by researchers at the University of Utah and elsewhere "for assessing earthquake hazards, for studying the feasibility of earthquake prediction, for studying the seismo-tectonics of the southern Intermountain region, and for seismological and geothermal research." [1] The basic earthquake data are essential to various federal, State, and local agencies involved in earthquake hazards assessment, as well as to interested scientists, engineers, businessmen, and the general public for a host of purposes.

Instrumental data about Utah seismicity first was obtained in the 1930's. However, prior to the 1950's seismicity information primarily was obtained from non-instrumental intensity data derived from reports of felt earthquakes that date back to 1850. Since the installation of a skeletal instrument network beginning in 1962, instrumental data have been available on a statewide basis, and since 1974, seismic data have been available from a dense high-gain network of telemetered stations chiefly concentrated in the Wasatch Front area. Evidently, Utah's data base on seismicity is improving significantly over that obtained in past years, although in a geologic time frame the data still cover a very brief period for assessing long-term seismicity.

The University of Utah Seismograph Stations currently receives funding support for the instrument program from a combination of sources, including the U.S. Geological Survey, the State of Utah, and the National Science Foundation.

STRONG-MOTION RECORDERS

Utah has almost no data about ground response to nearby large earthquakes. Moreover, there presently are inadequate numbers of strong-motion instruments in place to obtain such data if a strong earthquake were to occur, and there are no definite plans at the present time to gather such information by means of instrument arrays.

As of 1980, there were just ten strong-motion instruments installed in Utah, of which 7 instruments are located at federal dam sites. The oldest, installed in about 1939, is located in the basement of the Administrative Building (Old Main) at the Utah State University in Logan. There are two other instruments in the main building of the Veterans Administration Hospital in Salt Lake City, one in the basement and one at the top story (7th story). The other instruments include one at the Flaming Gorge Dam in northeastern Utah, one at the Hyrum Dam in northern Utah, 3 at the East Canyon Dam, and 2 at the Dear Creek Dam, both just east of the Wasatch fault zone. Instruments at the last three dam sites named were just recently installed. The existing strong-motion instrument sites are listed in Table 2. Figure 2 indicates the locations of existing strong-motion instruments.

The U.S. Water and Power Resources Service (formerly U.S. Bureau of Reclamation) has placed strong-motion accelerographs at several dam sites in the last two years and replaced the 1960-vintage instrument at Flaming Gorge Dam (see Table 3 and Figure 3). These instruments are in conjunction with that agency's responsibility for the safety of federal dams. Additional instruments likely will be placed in other dams in future years, according to plans discussed by personnel of the agency. However, it must be noted that these instruments at dam sites all are in mountainous areas east of the Wasatch fault and are not expected to contribute much information about seismic wave propogation in extensive valley alluvial deposits to the west side of the Wasatch Mountains where information is so lacking.

Only one strong-motion earthquake record has been obtained to date from the in-place instruments. A Richter magnitude 5.7 earthquake in Cache Valley in 1962 triggered the instrument in Old Main. Data from this earthquake recently were analyzed by the University of Utah, and the horizontal and vertical spectral responses have been published. This is the only spectral data for anywhere in Utah and the surrounding region that can be used for engineering purposes. The same instrument was triggered again by the 1975 Malad, Idaho, earthquake, but the instrument malfunctioned, and no record was obtained. Thus, very little useful data have been obtained from the in-place instruments. One reason for this lack of data, a reason more significant than the one case of equipment malfunction, is that since installation of these instruments, just two earthquakes have occurred at a location sufficiently close to one to cause ground motions above the threshold level of instrument sensitivity. However, several earthquakes have occurred in the State in recent years of strength sufficient to activate strong-motion instruments if more instruments were installed over a wider area. It is evident to most researchers that the present strong-motion instruments are inadequate in number and distribution to provide the Statewide coverage needed to obtain ground response data for the State.

It is useful to contrast the instrument situation in Utah, as described above, with that in California. In that state, as a result not only of the greater amount of seismicity but also as a result of a state-mandated instrumentation program, there are several hundred strong-motion instruments in place, both in free-field locations and in buildings. Consequently, California in recent years has accumulated considerable data about ground response unique to the subsurface conditions that are present there. Further, nearly all of the technical community's present data on building response have come from California records.

Section 2

STRONG-MOTION INSTRUMENT NEEDS IN UTAH

Deficiencies relating to strong-motion records and ground response data in Utah have been noted in the previous section. Other seismology experts knowledgeable about the Utah situation have observed similar deficiencies and also have made observations which argue for more and wider distribution of strong-motion instruments in the State.

Seismologists and engineers recognize the importance of strong-motion instruments as the source of data for evaluating the effects of earthquakes. In the preface of a booklet titled Strong-Motion Engineering Seismology it is stated that "...the key to an efficient hazard-reduction program is an adequate understanding of the destructive seismic forces involved--or, in other words, of the characteristics of the strong ground motions of earthquakes." [2] That same report, prepared by a committee of the National Academy of Sciences, recommends an immediate and substantial increase in the number of strong-motion instruments throughout the U.S. and worldwide.

Seismology experts representing a number of nations and organizations have assessed favorable locations for strong-motion instrument arrays worldwide and have identified 29 areas as the most likely to yield useful earthquake records in the near term [3]. The report prepared from that assessment notes that "(b)ecause damaging earthquakes are widely distributed in time and space, the choice of favorable sites for strong-motion instrument arrays must be guided by the principal needs of the users of the records obtained." (Cf. [3], p. 10). Five criteria were established by these experts for selection of favorable site locations for such arrays (Cf. [3], pp. 11-12).

(1) High probability of recording a potentially damaging earthquake (6.5 Richter Magnitude or greater) within the next 10 years.

(2) The need to record the near-field ground motion for very large earthquakes ($\sim$ 8 Richter Magnitude). (In Utah, data are needed for damaging earthquakes in the Richter magnitude range from 6.5 to 7.5.)

(3) The need to obtain data from a variety of source mechanisms.

(4) The need for good operational conditions (access to the area, technological assistance, etc.).

(5) Where feasible, proximity to important industrial and population centers with structures of engineering significance.

It is noteworthy that the Wasatch fault in Utah is among the 29 most suitable sites worldwide which were determined by the study group to fit the above criteria for placing arrays of strong-motion instruments. It is one of three sites within the United States and one of two sites within the contiguous 48 states, the other being near Palmdale, California. Thus, the scientific community apparently places great importance upon locating strong-motion instruments in areas of Utah.

Within Utah, similar views are held by the scientific and technical communities regarding the need for instrumental data on strong ground motions. This need is highlighted by the near-absolute lack of ground-motion data and the absence of sufficient instruments to give a reasonable chance that data can be obtained from those infrequent, but inevitable, strong earthquakes.

In a report on criteria for seismic risk mapping for Utah prepared for the Seismic Safety Advisory Council by the geotechnical engineering firm of Dames and Moore (San Francisco office), it is noted that "(t)here is no current information about attenuation relationships which might specifically describe the ground motions developed in Utah, either for the state as a whole or for various tectonic regions within the state." ([4], p. 6). Lack of such data is due entirely to lack of instrumented strong-motion records. Owing to this lack of ground motion data, the Dames and Moore report states that currently available geologic and seismic data for the State are not sufficient for preparation of risk maps to be used at the local planning level. The report implies that such mapping at county scale is about as detailed as is presently possible. Thus, for reasons relating to seismic safety planning at the local level, the need for strong-motion records once again is forcefully argued.

In summary, the case has been presented on the need for strong-motion instrumentation in Utah. The need is recognized both by the scientific community and by those who would apply the information in seismic hazards reduction programs.

Section 3

ALTERNATIVE STRONG-MOTION INSTRUMENT PROGRAMS

INSTRUMENT SITES

Accepting that strong-motion instruments are needed in Utah, in this section we set forth and discuss various alternatives to accomplish their acquisition and operation.

The first point to be examined is, of course, what the extent of an array of strong-motion instruments in Utah should be. A committee of the Seismic Safety Advisory Council, after extensive technical review, has concluded that a minimum strong-motion instrument array would include both free-field and building instrument sites distributed more densely in areas of probable higher seismicity and relatively heavily populated, but also spread throughout the length of the Intermountain Seismic Belt in Utah at intervals close enough together so that some data would be obtained from any moderate or large earthquake along the north-south central region of the State.

Criteria for selecting instrument sites were established based upon the priority of data needs, the exposure of existing populations and land development, and the likelihood of an earthquake sufficiently large to trigger the instruments. These criteria are as follows.

- o Sites in regions of relatively high seismicity in the State.
- o Sites offering a variety of soil and bedrock conditions, including valley alluvial deposits.
- o Site proximity to population centers and developing areas of the State.
- o Buildings offering several types of construction and heights.
- o Siting availability and accessibility for servicing of instruments, with preference given to established sites of the existing seismologic network in the State.

Given these criteria, a minimum strong-motion instrument array in the State of Utah would consist of not less than 17 new instruments total at 11 different sites. Five sites include more than one instrument. These 17 instruments do not include the existing instruments in the State; although the three located in buildings have been considered in the array layout. Recommended instrument locations are indicated in Figure 4. Table 4 furnishes more specific information about the instrument sites.

The minimum instrument array described above could be increased in size beneficially, but any reduction in the number would result in possible voids in the array and consequent possible voids in the data to be gleaned.

In addition to the 17-instrument array described above, consideration also should be given to acquisition of a few portable strong-motion instruments that can be moved promptly to the site of a moderate or large earthquake for the purpose of obtaining data from large aftershocks. The flexibility afforded by portable instruments provides a cost-effective alternative in Utah where large earthquakes are infrequent and a dense network of strong-motion instruments is neither feasible nor suggested.

Further effective utilization of the strong-motion instrument network might be achieved by setting some of the instruments at low triggers that are in active seismic areas such as Hansel Valley, Cache Valley, Elberta, etc. Multiple use of the instrument array thus could be achieved, combining research and utilitarian purposes for the data. In a study titled "Recommendations for a New National Network" soon to be published by the National Academy of Sciences, major importance is given to linking a national program in strong-motion seismology ultimately with the new National Seismographic System through the regional computer centers. The recently installed computer center at the University of Utah Seismograph Stations is one of those regional centers, and so there is opportunity in Utah to benefit from such a national linkage. It is reported that some regional centers already are tying strong-motion instruments to on-line short-period seismographs and recording both types of data simultaneously by computer.

These additional research aspects of a strong-motion instrument program in Utah merit careful consideration. However, further details on the actual workings of such extended uses are not discussed in this report due to our lack of knowledge regarding research objectives. It is enough here to note the presence of other valuable uses for a strong-motion instrument program.

Some seismology experts employed by the U.S. Geological Survey (USGS) have suggested that a smaller array of instruments would be workable in the State. In particular, the suggestion has been put forth that the recommended new strong-motion instruments in buildings could be eliminated in an initial program, and that the number of free-field instruments could be reduced to one instrument at each site. The instruments would be spaced evenly more or less along the center line of the State, mostly in the same locations as suggested in the plan proposed by the Utah Seismic Safety Advisory Council. A plan proposed by R.B. Matthiesen [5] consistent with this notion would involve 10 new instrument sites plus the existing instruments (See Figure 5). While such an array as suggested by Matthiesen would provide areawide coverage in the State, some potentially useful data that might be acquired about building response for Utah soil conditions very likely would be lost because of voids in the suggested array. The Advisory Council, therefore, has misgivings regarding the array suggested by Matthiesen.

As a comparison, it again is pointed out that the 17-instrument array suggested by the Council for Utah is minor in size relative to the several hundreds of strong-motion instruments presently in place in California.

INSTRUMENT INSTALLATION AND MAINTENANCE COSTS

Strong-motion recorders, such as the SMA-1 or SMA-2 strong-motion accelerographs manufactured by Kinemetrics, today cost just less than $3,000.00 each.

Instrument installation requirements and costs will vary for different site conditions. For "free field" sites, the principal requirements are a slab, some sort of weatherproof enclosure, such as a drum or secure box, and a source of power supply. For building installations, a secure room or closet is preferred, but no other special arrangements are needed, other than a power source. It has been estimated that an installation allowance of $3,000 should be provided for each "free field" instrument. The cost for installing an instrument in a building normally will be lower than this.

Strong-motion accelerographs require routine, although not frequent, maintenance. Primarily this is to ensure that they will be functional when that infrequent earthquake event occurs. Since the instruments operate only when triggered by an earthquake event, and since they are automatic, both in start-up and shut-down, frequent maintenance service is unnecessary. One indication of cost for maintenance of a strong-motion instrument array comes from the U.S. Geological Survey. That agency, which maintains its own instruments plus many others under contract arrangements, currently estimates its annual maintenance costs at approximately $750 per instrument, and the USGS has stated it uses that figure for negotiating maintenance contracts with others.

Given the above cost data, the following estimates are obtained for the recommended 17 new strong-motion instruments plus a suggested 3 portable instruments which would comprise a minimum network in Utah.

Instrument Purchase	$ 60,000
Instrument Installation	$ 51,000
Total Initial Cost	$111,000
Long-Term Maintenance Cost	$ 12,750 Yearly

The costs indicated above likely will increase in future years, but such inflationary increases are not examined further in this report.

FUNDING OPTIONS

Three alternatives for obtaining and funding a strong-motion instrument network in Utah have been identified and are discussed in this report.

- o Installation and maintenance by a federal agency.
- o Installation through a federal grant, with long-term maintenance assumed by the State.

- Installation and maintenance through a State program.

Unique situations are found to exist for each of these alternatives which require further discussion. The most attractive among them, from a State fiscal point of view, clearly would be a program funded and managed by a federal agency, such as the U.S. Geological Survey. Still, that alternative also has disadvantages to the State, of which the most critical is an uncertainty regarding federal interest or funding. Accordingly, we here examine the program workings, advantages, and disadvantages for each alternative, from which recommendations have been drawn by the Seismic Safety Advisory Council.

Federal Funding

The U.S. Geological Survey, assisted with funding from the National Science Foundation, currently manages a strong-motion instrument program comprising about 200 accelerographs and 300 seismoscopes for studies of ground motion and building response. These instruments do not include several hundred instruments owned by others which the USGS maintains and services under contract. Various working papers obtained from the USGS indicate no discernable pattern for the decision-making process regarding locating and distributing the instrument arrays that they own in selected regions, although the expected degree of seismicity is an evident consideration. Working papers obtained from the USGS also indicate that there are divided views among technical staff internally within that agency regarding which locations the arrays should be expanded into. At the present time, most of the USGS strong-motion instruments are sited throughout California. Plans for adding more arrays outside California presently are being reviewed internally by the USGS. However, this process has been underway for several years, and there still is no indication of what will be done, if anything, to enlarge the instrument system.

The USGS strong-motion instrumentation program is constrained by the fact that the agency operates it under annual agreements with the National Science Foundation (NSF), which is the major source of program funds. Accordingly, there are several levels and agencies of review for the strong-motion instrument program within the federal government. Further, the strong-motion instrument program must compete with other science priorities for its funds.

Within the framework described above, Utah's strong-motion instrument and data needs have been assessed and reassessed several times by the USGS and NSF. Instrument needs in Utah also have been brought to the attention of USGS and NSF by the university-based scientific community as well as by the Utah Seismic Safety Advisory Council in recent years. None of these efforts has resulted in specific action by the federal agencies--either acceptance or outright rejection of recommendations that have been made. Undoubtedly, a major influence causing such indecision is the lack of federal resources to meet all identified needs. However, it also is the view of the Utah Seismic Safety Advisory Council that organizational management structures peculiar to the USGS and NSF have brought about some of the confusion in the USGS strong-motion program regarding installation of instruments.

Given the indecisive situation in the federal agencies regarding strong-motion instrumentation plans for Utah, it is the view of the Seismic Safety Advisory Council that plans for establishing an instrument array in the State must proceed independently of the federal government. To place total reliance upon the prospect that federal involvement may be forthcoming in the future is deemed a gamble not in the interests of the State. However, such plans that the State may develop should be suitably flexible to benefit from future possible federal involvement.

Federal/State Funding

A second alternative for a strong-motion instrument program in Utah is instrument acquisition and installation through a federal grant with long-term maintenance funded by the State.

Federal grants have been awarded to several university researchers in other states for conducting strong-motion research. The cost of purchasing and installing the instruments has been included as a part of the grants. Most recently, engineers and seismologists at a university in Southern California obtained 81 strong-motion instruments for an elaborate research effort. The twenty or so strong-motion instruments needed in Utah to provide a basic array are insignificant when measured against the instruments provided under such research grants as described above. Hence, given the recommendations of their own advisory groups, as cited above, federal agencies would be strongly pressured to respond favorably to a grant request from the State of Utah or one of its universities.

Maintenance of strong-motion instruments requires continuing and long-term funding. It is this long-term commitment that distinguishes an array such as is suggested for the State of Utah from research arrays such as are indicated above. Commitments to research typically are for relatively short time periods, and this fits well with the erratic nature of federal support. In contrast, a permanent instrument array in Utah may be in place for many years before an earthquake event is recorded. During this period, the instruments require regular maintenance so that they will be operable when the event occurs.

Based on these considerations, we favor the second alternative for obtaining a strong-motion instrument array in Utah, in which the instruments might be acquired and installed using federal funds obtained through a grant and maintained by a long-term commitment for funding from the State. Such a strategy would avoid the difficulty of gaining State authorization for a large initial capital outlay to acquire the instruments but would establish a commitment by the State to participate in the program by sharing the cost through paying the maintenance costs in successive years. The maintenance costs, in the long run, would probably be greater than the initial installation costs but would be spread over many years.

It might be asked why the federal government should become involved at all in assisting with the funding of a strong-motion instrument array in Utah. Although we have stressed the importance of such instruments to the State's earthquake research and data gathering program, the fact is that information obtained from any strong-motion instrument has worldwide value and would be used by many others besides the Utah program. There is ample precedent for federal involvement in placing strong-motion instrument arrays in areas likely to experience moderate to strong earthquakes. To the extent that earthquake research is recognized as a national and international problem, Utah's seismic environment and the great need for better data in the State represent convincing arguments for federal praticipation through the national earthquake hazards reduction program.

Any strong-motion instrumentation program involving the State of Utah would require that a managing agnecy be designated. There are two organizations in the State which could serve in this capacity.

The University of Utah's Seismograph Stations already is operating and maintaining a seismometer array of more than 50 stations. The program employs three PH.D seismologists and is part of an extensive research and teaching effort, including courses in engineering and earthquake seismology. Thus, staff capability could be expanded rather easily to maintain the strong-motion instrument array suggested for the State. Since the strong-motion data are primarily for long-term data collection and research purposes, the program would appear to fit well with University objectives. Dissemination of data obtained from the strong-motion instrument array to other interested State agencies and the private sector could be handled routinely in a variety of ways and even by formal agreements when special interests are involved. For example, a State agency, such as the Utah Geological and Mineral Survey, might serve as the repository for strong-motion records obtained from earthquakes in the State, an arrangement which would assure preservation and accessibility to the data and would establish a central location for utilitarian uses as distinct from research uses of the data. In such a management arrangement, the University would require annual funding to carry out the maintenance responsibilities for the instrument array. Whether or not the actual maintenance of instruments should be done by University staff or by contract to a private firm would be a decision to be made by the University.

The second organization that would appear to be capable of managing the strong-motion instrument program is the Utah Geological and Mineral Survey (UGMS). That agency presently has certain responsibilities relating to earthquake studies in the State which are geologic in nature. Thus, the additional responsibilities involved in the strong-motion program possibly could be assumed by UGMS. However, the agency presently has no staff who are knowledgeable about seismic instrumentation, and so additional staff capability would be needed in this case along with annual funding for maintenance of the instruments. Also, the possibility exists that some duplication of research activities carried on by the University of Utah's Seismograph Stations might occur.

Of the two possible managing agencies named, the University of Utah Seismograph Stations appears to be the most plausible choice--primarily because of the existing staff capabilities and because the strong-motion instrumentation program is a logical expansion of on-going seismology research activities.

State Funding

A third alternative for obtaining a strong-motion instrument program in Utah is that the State assume complete responsibility both for acquisition and installation of the instruments and for long-term maintenance. Two funding methods have been identified for this alternative.

The first, and perhaps the simplest, funding method would be by means of an initial State appropriation for acquisition and installation of the instruments followed by annual appropriations for their maintenance. Program management could be accomplished in the same way as is suggested above.

California offers a model for a second funding method that might be considered in Utah. California established a strong-motion instrumentation program in 1972 to locate recorders throughout the State in free-field situations and in buildings. The placement of instruments in certain buildings is required by law. The cost for the program is paid from an assessment against the building permits issued by local governments. Management of the program is by the California Division of Mines and Geology. More information on the California strong-motion instrumentation program appears in Appendix A of this report.

It is reported that the strong-motion instrument program in California has produced adequate funds to carry out the legislative intent through the building permit assessments. And, as a result of the program, California has achieved the most comprehensive and extensive strong-motion array in the world.

Although we do not argue here for transposing the California program to Utah, we nonetheless point to that state's program as an example of how program financing can be paid by the building industry which creates the seismic risk rather than by government. In that regard, the California program has merit. In other regards, however, it may not be appropriate in Utah. First, Utah's strong-motion instrument needs are less elaborate than are California's. Fewer instruments in Utah will meet our needs. Second, comments have been made that the California program has generated more revenue than is needed to operate the strong-motion program there. This suggests that the program costs are not as large as were projected and implies that a permanent operating revenue source may not be necessary.

When one considers the additional government regulations and accounting that would be required for a strong-motion instrument program paid from revenue assessments, and when one compares these costs with an annual outlay of just a few thousands of dollars to maintain the twenty or so instruments needed in Utah, a one-time capital outlay appropriation and annual maintenance appropriations become the more attractive financing method.

Section 4

RECOMMENDATIONS FOR STRONG-MOTION INSTRUMENTATION IN UTAH

In preceding sections of this report we have described the purposes of earthquake strong-motion instruments, the use of data derived from such instruments, the lack of data on earthquake motions in Utah, the need for such data to carry out seismic risk mapping, and alternatives for establishing a strong-motion instrument program in Utah. In this section we set forth recommendations for strong-motion instrumentation in Utah that are intended to guide State policy in this matter.

Recommendations

It is recommended that a strong-motion instrumentation program be established in Utah comprising the following elements.

1. The strong-motion instrument array should consist of a minimum of 17 new accelerographs at 11 different sites, and located in general as indicated in Figure 4 of this report.
2. The instrument array should consist of SMA-1 strong-motion accelerographs, or similar type.
3. The strong-motion instrument program should be managed and operated by the University of Utah Seismograph Stations.
4. Funding for the program should be provided by the State of Utah through a separate appropriation for the initial purchase and installation of instruments, with subsequent annual funding for management of the program and maintenance of the instruments by specific reference in the University of Utah operating appropriation.
5. Effort should be continued to obtain grant funding from the federal government for acquisition and installation of the strong-motion instruments during the time that State funding is being sought, but the State program should be continued without delay and without dependence upon federal participation.

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[2] National Academy of Sciences, Strong-Motion Engineering Seismology: A Key to Understanding and Reducing the Damaging Effects of Earthquakes (Washington, D.C.; 1973).

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Table 1

EXISTING SHORT-PERIOD SEISMOGRAPH INSTRUMENT SITES IN UTAH (1980)
OPERATED BY THE UNIVERSITY OF UTAH SEISMOGRAPH STATIONS

NO.	REFERENCE CODE	STATION NAME	GENERAL LOCATION
1.	ANU	Antelope Island, Utah	Davis County, Great Salt Lake
2.	BDU	Big Dutch Hollow, Utah	
3.	BKU	Beaver Lake Mountains, Utah	Beaver County, northwest of Milford
4.	BMUT	Black Mountain, Utah	Rich County, east of Bear Lake
5.	CCU	Cedar City, Utah	Cedar City, Utah
6.	CMU	Cedar Mountain, Utah	Emery County, southeast of Price
7.	CPU	Coon Peak, Utah	Salt Lake County, west of Magna
8.	CWU	Camp Williams, Utah	Southern edge of Salt Lake County
9.	DAU	Daniels Canyon, Utah	Wasatch County, southeast of Heber City
10.	DCU	Deer Creek Reservoir, Utah	Wasatch County, southwest of Heber City
11.	DUG	Dugway, Utah	Tooele County, in Skull Valley
12.	EPU	East Promontory, Utah	Box Elder County, Promontory Mountains
13.	ETU	East Traverse Mountains, Utah	Southern edge of Salt Lake County
14.	FDU	Ford Ridge, Utah	Carbon County, northwest of Price
15.	FPU	Francis Peak, Utah	East edge of Davis County
16.	FSU	Fish Springs, Utah	Juab County, Fish Springs Mountains
17.	GMU	Granite Mountain, Utah	Salt Lake County, Wasatch Mountains
18.	HDU	Hyde Park, Utah	Cache County, north of Logan
19.	HTU	Hoyt Peak, Utah	Summit County, northeast of Kamas
20.	HVU	Hansel Valley, Utah	Box Elder County, south of Snowville
21.	KDUT	Kidman Hollow, Utah	Cache County, west of Logan
22.	KNB	Kanab, Utah	Kane County, west of Kanab
23.	LBUT	Lower Browns Hole, Utah	Weber County, near Huntsville
24.	LTU	Little Peak, Utah	Box Elder County, south of Tremonton
25.	LVU	Levan, Utah	Juab County, near Levan
26.	MCU	Monte Cristo Peak, Utah	Southeast edge of Cache County
27.	MMU	Miners Mountain, Utah	Wayne County, Capitol Reef National Park
28.	MSU	Marysville, Utah	Northern Piute County
29.	NLU	North Lilly, Utah	Southwest Utah County, near Eureka
30.	PBU	Perry Basin, Utah	Box Elder County, near Perry
31.	PTU	Portage, Utah	Box Elder County, near Portage
32.	RBU	Red Butte Canyon, Utah	Salt Lake County, east of Salt Lake City
33.	RSU	Rock Spring, Utah	Iron County, west of Cedar City
34.	RSUT	Red Spur Mountain, Utah	Cache County, west of Randolf
35.	RVUT	Riverside, Utah	Box Elder County, north of Tremonton
36.	SAU	Saltair, Utah	Salt Lake County, shore of Great Salt Lake
37.	SGU	Sterling, Utah	Sanpete County, east of Sterling
38.	SLC	Salt Lake City, Utah	University of Utah
39.	SNU	Stansbury North, Utah	Tooele County, Stansbury Island
40.	SUU	Santaquin Canyon, Utah	Utah County, east of Santaquin
41.	WCU	Willow Creek, Utah	Sevier County, northwest boundary
42.	WHU	Wild Horse, Utah	Juab County, Fish Lake National Forest
43.	WMU	West Mountain, Utah	Utah County, southern edge of Utah Lake
44.	WVUT	Wellsville, Utah	Cache County, near Wellsville

Table 2

EXISTING STRONG-MOTION INSTRUMENT SITES IN UTAH (1980)

SITE REFERENCE	NUMBER OF INSTRUMENTS	LOCATION	INSTALLATION DATE
SM-1	1	Basement of Administration Building Utah State University Logan, Utah	1939
SM-2	2	Basement and 7th Story of Main Building, Veterans Administration Hospital Salt Lake City, Utah	1972
SM-WPR1	1	Flaming Gorge Dam Daggett County, Utah	1960
SM-WPR2	1	Hyrum Dam Cache County, Utah	1980
SM-WPR3	3	East Canyon Dam Morgan County, Utah	1980
SM-WPR4	2	Deer Creek Dam Wasatch County, Utah	1979

Table 3

EXISTING STRONG-MOTION INSTRUMENTS PLACED AT UTAH DAMS*
WATER AND POWER RESOURCES SERVICE (1980)

SITE REFERENCE	NUMBER OF INSTRUMENTS	DAM SITE	INSTRUMENT LOCATION(S)
SM-WPR1	1	Flaming Gorge Dam Daggett County, Utah	Bedrock, free field
SM-WPR2	1	Hyrum Dam Cache County, Utah	Bedrock, right abutment
SM-WPR3	3	East Canyon Dam Morgan County, Utah	Bedrock, downstream at right abutment (1) Dam crest (2)
SM-WPR4	2	Deer Creek Dam Wasatch County, Utah	Toe of dam (1) Bedrock, left abutment (1)

*Instruments are SMA-1 recorders. Additional down-hole instruments are planned for several sites, including the Hyrum Dam and Soldier Creek Dam.

Table 4

RECOMMENDED NEW STRONG-MOTION INSTRUMENT SITES IN UTAH

SITE REFERENCE	NUMBER OF INSTRUMENTS	LOCATION	SITE CHARACTERISTICS
SM-3	2	North Central Hansel Valley Box Elder County, Utah	Free Field on Bedrock Free Field on Alluvial Deposits
SM-4	2	Cache Valley	Free Field on Alluvial Deposits
SM-5	1	Ogden, Utah	Free Field on Bench Deposits
SM-6	3	Salt Lake Valley, Utah	Free Field on Deep Alluvial Deposits Free Field on Intermediate Depth Alluvial Deposits Free Field on Bedrock
SM-7	2	Salt Lake City, Utah	Basement and Top Story of Multistory Building on Valley Alluvial Deposits
SM-8	1	Provo, Utah	Free Field on Intermediate Depth Alluvial Deposits
SM-9	1	Nephi, Utah	Free Field on Bedrock
SM-10	1	Centerfield, Utah Sanpete County	Free Field on Bedrock
SM-11	2	Elsinore, Utah Sevier County	Free Field on Alluvial Deposits Free Field on Bedrock
SM-12	1	Beaver, Utah Beaver County	Free Field on Bedrock
SM-13	1	Cedar City, Utah Iron County	Free Field on Alluvial Deposits

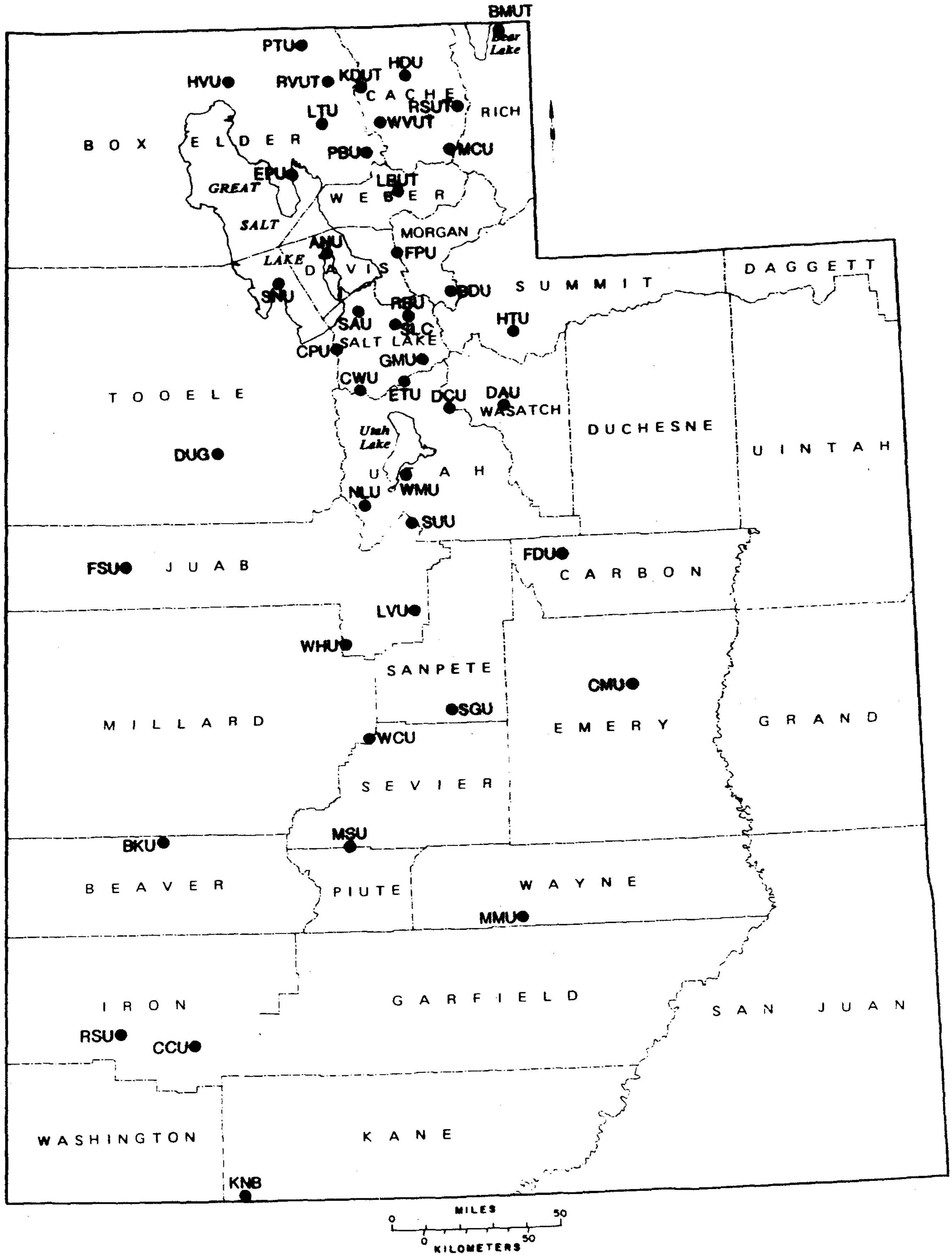

Figure 1

EXISTING SHORT-PERIOD SEISMOGRAPH INSTRUMENT SITES IN UTAH (1980)
OPERATED BY THE UNIVERSITY OF UTAH SEISMOGRAPH STATIONS

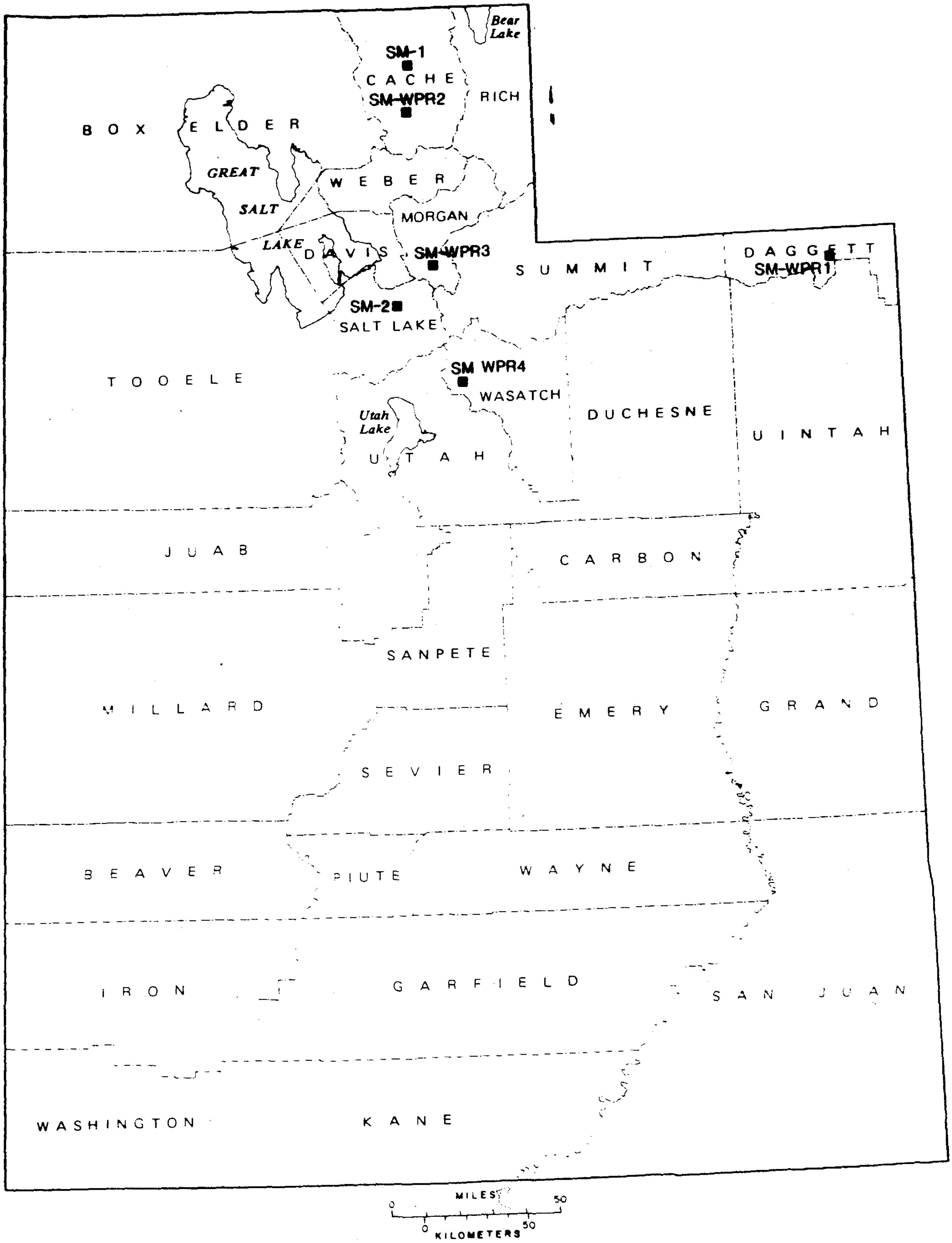

Figure 2

EXISTING STRONG-MOTION INSTRUMENT SITES IN UTAH (1980)

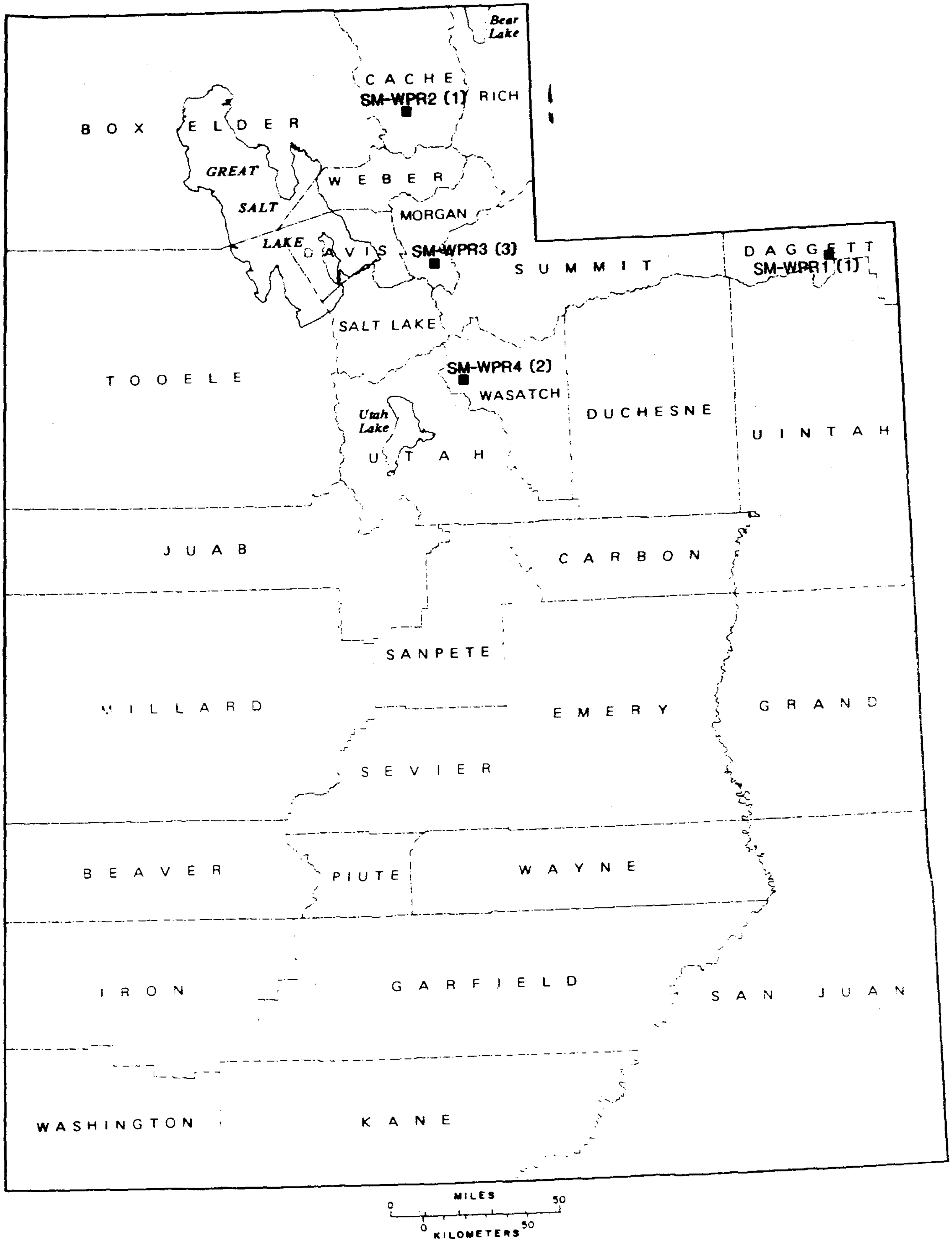

Figure 3

EXISTING STRONG-MOTION INSTRUMENTS PLACED AT UTAH DAMS

WATER AND POWER RESOURCES SERVICE (1980)

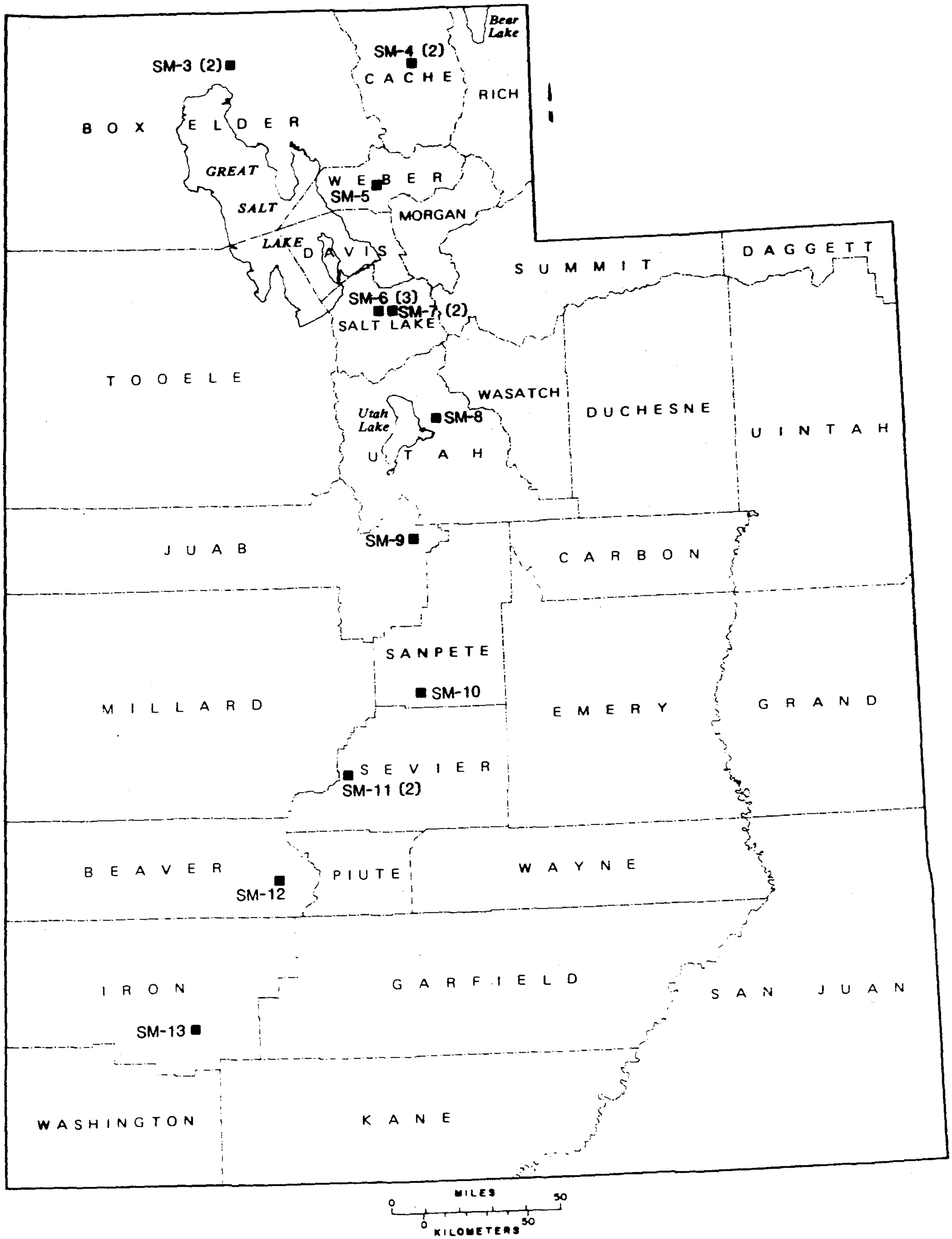

Figure 4

RECOMMENDED NEW STRONG-MOTION INSTRUMENT SITES IN UTAH

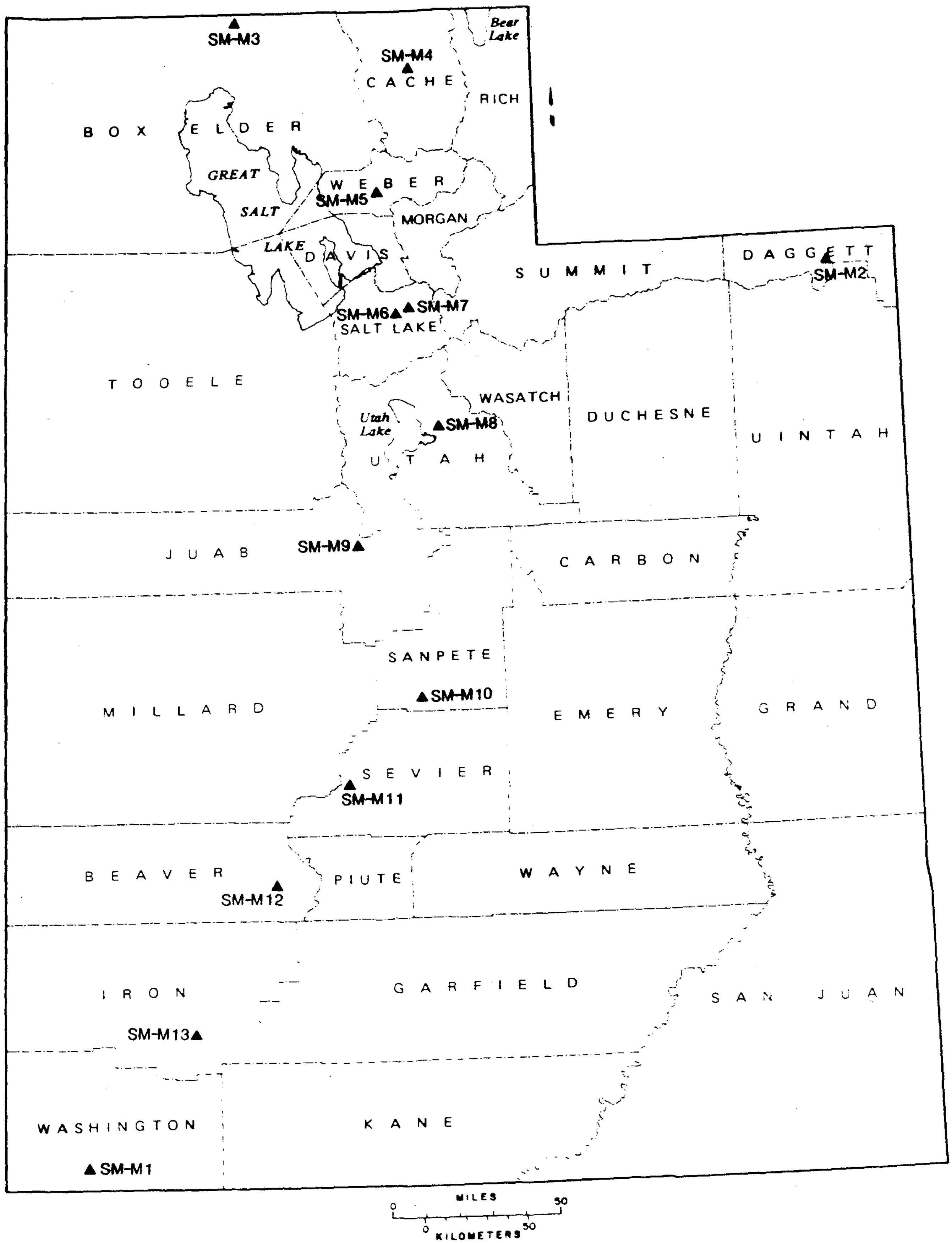

Figure 5

STRONG-MOTION ACCELEROGRAPH SITES IN UTAH

AS PROPOSED BY R. B. MATTHIESEN

Appendix A

THE CALIFORNIA DIVISION OF MINES AND GEOLOGY STRONG-MOTION INSTRUMENTATION PROGRAM

(Article taken from California Geology, April 1979, by Tom M. Wooton.)

The California Strong Motion Instrumentation Program (CSMIP) was created by an act of the State Legislature on January 1, 1972, in reaction to the San Fernando earthquake of February 9, 1971. The program was assigned to the California Division of Mines and Geology (CDMG) for management and operation. Also provided by the legislative act was an advisory board whose responsibility was to provide advice and assistance to CDMG in operational and policy-setting matters. As originally conceived, the function of CSMIP was to procure, install and maintain appropriate strong-motion recording instrumentation which was to be placed in representative structures and geologic environments throughout the state. Record processing was to be accomplished through other agencies.

Subsequent legislation added responsibilities to CSMIP for the processing of strong-motion records and dissemination of reduced data and also transferred the advisory function from the Advisory Board to the Seismic Safety Commission.

Funding to support the program is provided from a fee on building permits amounting to 7 cents per $1000 of the estimated cost of construction. This fee is collected statewide, except from jurisdictions which qualified for exemption by having their own strong-motion instrumentation programs on January 1, 1972. The fees are paid into a special fund from which appropriations can be made only to support this program. Present income into the fund is on the order of $900,000 per year.

The objectives of CSMIP, as determined by the Strong Motion Instrumentation Advisory Board and CDMG, are 1) the collection and reduction of engineering data on the response of ground and representative structures to strong motion shaking, and the dissemination of the data to the structural engineering community to be used in the development of earthquake resistant design; and 2) the study of the seismic character of ground response in representative geologic settings and the effects of the various geologic conditions along the path of energy propagation on the frequency content and amplitude of strong ground motions.

CDMG has established the Office of Strong Motion Studies headed by a Program Manager and staffed by appropriate professional, technical and clerical personnel to carry out the assigned program.

The network planning function is carried out by CDMG with the advice and assistance of its Advisory body, and in coordination with the Seismic Engineering Branch of the U.S. Geological Survey (SEB/USGS). The network plan includes the instrumentation of three categories of sites or stations: free field, buildings and lifeline facilities. The free field sites includes individual stations for evaluation of specific ground response, horizontal arrays to evaluate seismic motion propagation effects, and vertical or downhole arrays for the study of layer-effects. Buildings to be instrumented include both high-rise and low-rise, and are of representative construction types and materials. Lifeline facilities included in the program are transportation structures of all types, such as bridges, tunnels and wharfs; dams; power facilities; and water treatment and transmission facilities. It is presently estimated that the density of instrumentation required to fulfill the defined objectives will be in the order of 500 free-field sites, 400 buildings, and 150 various lifeline facilities throughout the state.

The operations function involves the selection of sites and facilities to be instrumented, the installation of appropriate instrumentation, and the maintenance of installed instruments. Collection of records is considered a function of the maintenance procedure. The data management involved until recently only preliminary evaluation for significance, frequency content, duration and peak accelerations of recorded seismic events, and preparation of records for further reduction and archiving by the SEB/USGS. CDMG, under authority provided by 1976 legislation, is formulating a plan for development of a comprehensive capability for record processing and data reduction. A system of publications designed to effectively disseminate data to the user community is also being developed. Instrumentation and operations are standardized to conform to standards of the SEB/USGS. Further, it was decided to take advantage of the latest developments in instrumentation technology within the standard framework. All instruments used in the program are battery powered accelerographs which remain in a passive state until triggered by strong ground motions, generally in excess of 1% of gravity (0.01 g). The instruments selected for surface free-field application are self-contained, triaxial accelerographs operating on electro-magnetic-optical principals and which generate photographic analog accelerograms. 147 of the accelerographs contain a WWVB radio receiver integrated into the electronic circuitry to provide a seismic event real-time code on the record.

The instrumentation used in buildings and other structures, and in downhole arrays, is a distributed system utilizing a central recorder and remote accelerometers. This system utilizes remote force-balance accelerometers and external electronic starters which are hard wired to a central recorder. This accelerograph has a useful capacity of 13 channels of data which are also recorded photographically.

In addition to the analog recording instrumentation, direct digital recording instrumentation has been developed to the production stage. CDMG will procure two or more instruments of this type for field testing in free-field application and one 21-channel structure system for installation in a vehicular tunnel during the fiscal year 1978-1979.

Current practice of installation of surface free-field sites calls for a Portland Cement concrete pad approximately four feet by four feet to which the triaxial instrument is attached. The instrument is covered by a fiberglass enclosure, which is also secured to the pad. Power to maintain battery charge is normally provided by externally mounted solar cells, although 110 VAC is used when available. A loop antenna for WWVB radio, when utilized, is located within the fiberglass enclosure for protection. The instrument is oriented with the axis of the longitudinal accelerometer aligned in the direction of the most probable seismic energy source.

Downhole arrays utilize special adaptations of the central recording accelerograph system in which triaxial packages of force-balance accler-ometers are encased in waterproof canisters and are connected to the surface mounted recorder through specially designed pressure resistant waterproof cabling. The downhole sites are selected so that sharp velocity differential interface will be encountered at a depth not to exceed 100 meters, the maximum workable depth for the accelerometer canisters.

The third type of instrumentation is that applied to buildings and other structures. A central recording system is utilized with external electronic vertical starter and accelerometers. In a typical installation, the central recorder is mounted in an accessible, secure location, generally at one of the lower levels. A triaxial accelerometer package and a vertical starter are mounted at the ground level near the estimated center of rotation of the structure. Uniaxial accelerometers are arranged to secure maximum data on building response. In structures of over four stories, it is normal practice to install an electronic horizontal starter at the roof level to maintain system activation for recording residual building motions after the seismic input motion has ceased.

Periodic maintenance is standard for all present instrument types, and consists of check for proper instrument operation, calibration check, battery and charging circuit check, and, as indicated by age or the presence of records, replacement of the recording film. If problems are encountered in any of the above checks, repairs are effected in the field whenever possible. At this time, instrument modifications which have been developed are made. The service cycle is four months at present, but is expected to be extended to six months as instrument reliability is increased through modification.

At present all record processing is carried out under interim procedures pending the development of an operational divisional capability and the acquisition of certain equipment. Record film development is presently being handled by CDMG technical staff at Department of Water Resources (DWR) dark-room facilities.

Digitizing of analog records is being carried out under contract with several vendors, one of which has a capability for automatic digitizing. The remaining vendors utilize a manual or semi-automatic system. Either method presents the disadvantage of low productivity through the single vendor in the case of the automatic system and through excessive processing time in the case of the semi-automatic systems.

The data processing function is being carried out at the Lawrence Berkeley Laboratory (LBL) under contract with the U.S. Department of Energy (DOE). Disadvantages of this arrangement are the distance from Sacramento which makes end product delivery difficult, and the necessity for non-standard working hours mandated by priority problems.

At this time minimum statewide coverage has been reached, with free-field site installations approximately 50% complete. There have been 249 surface free-field and two downhole installations completed. The remaining free-field installations will include three to four downhole arrays and additional temporary instrument installations have been completed in response to recent seismic events.

Building instrumentation is approximately 9% complete with 36 buildings having been instrumented. Instrumentation of the lifeline category of sites has been receiving increasing attention with initial emphasis placed on dams. At this time, 16 dams have been instrumented. In addition, three highway bridges have been instrumented, and plans have been completed for instrumentation of one seaport wharf. This category is 15% complete.

A total of 314 instruments and instrument systems have been installed and are operating.

In future development of the free-field system, emphasis will be shifted to carefully planned arrays designed for the study of seismic wave (or motion) propagation and physiographic effects. A continuing study also will be made into specific installation effects on motion records and modifications necessary to minimize any introduced error.

Building system installation will continue at the present rate of about ten per year, but additional emphasis will be placed on the relative seismicity of geographic locations in order to maximize the probability of record collection. Further, as understanding of building response to shaking increases, existing installations will continue to be modified to ensure the recording of essential data.

Instrumentation of dams is 53% complete, and future installation emphasis will gradually be shifted to transportation and lifeline structures. Installation rates for those structures will be about equal to that for buildings. As in the case of buildings, modifications and improvements of existing systems will be carried out continually as advances in state-of-the-art for instrumentation are made. Extensive modifications have been started and are being carried out on dams in particular.

Data management plans will be partly dependent on the conclusions of a feasibility study report now being prepared by the Department of Conservation. Long-range plans include a full range data processing capability to be developed as quickly as possible upon approval of the feasibility study report. In addition, a full service state data center will continue to be developed.