NUREG/CR-6625

Automated Seismic Event Monitoring System

Multimax, Inc.

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

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Manuscript Completed: April 2000
Date Published: May 2000

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Washington, DC 20555-0001
NRC Job Code W6094

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC), as part of its actions for insuring public safety, wishes to be able to monitor seismic activity in near-real time. To help achieve this capability, a data recording, processing, and archiving system was constructed to detect seismic signal arrivals, calculate epicenters and seismic magnitudes, and issue alerts whenever a strong earthquake is determined to have occurred near the site of a nuclear power plant. This system takes as its input raw waveforms that have triggered signal detectors at stations of the U.S. National Seismographic Network (USNSN) and that have been re-broadcast via satellite from the U.S. Geological Survey (USGS) to a Very Small Aperture Terminal receiver at NRC, so the system is able to perform its calculations within minutes of the earthquake. The epicenters that are calculated by the system are crude, however, so as soon as improved event locations are calculated by USGS they are downloaded via the Internet and used in place of the epicenters that had been calculated at NRC in near-real time. Seismograms that were not received at NRC via the satellite link are also retrieved via the Internet, sometimes months after the event, and they are then added to the permanent seismogram archive.

In addition to determining earthquake epicenters and magnitudes automatically, the software system permits the seismograms to be studied off-line by means of stand-alone seismic data analysis packages that are operated by a scientist or data analyst using interactive graphics on a UNIX workstation. One of these stand-alone packages permits the seismograms recorded at the USNSN stations to be used to estimate the Cumulative Absolute Velocity (CAV) at nearby nuclear power plant sites. These calculations make use of tables of frequency-dependent site effects that were computed for power plant sites on the basis of local geologic structures. Another part of the off-line software is a Geographic Information System that permits the newly computed epicenters, the locations of the seismic stations, and the power plant sites all to be displayed on the workstation in interactive maps that show a detailed context of the geologic and geophysical data sets which affect seismic wave propagation and other important physical phenomena.

The software for near-real time seismic analysis has recently been re-written in the Java programming language. As a part of this re-writing of the code, a graphical interface has been developed that permits information about recent and archived events to be displayed via tables and that permits the raw waveforms to be viewed and manipulated graphically in both the time and frequency domains. The seismograms can be displayed as soon as they are received from the satellite or after the events have been detected and located. Because both the analysis and graphics modules are written in Java, this new version of the near-real time seismic monitoring system is platform-independent.

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1. OVERVIEW OF THE AUTOMATED SEISMIC EVENT MONITORING SYSTEM

1.1 Project Background

The U.S. Nuclear Regulatory Commission (NRC), as part of its role in licensing nuclear power plants and assuring public safety, is interested in determining the effects of earthquakes on nuclear plant structures and safety systems. In order to identify seismicity and seismic hazards in the United States, the NRC has cooperated with the U.S. Geological Survey (USGS) to establish the U.S. National Seismograph Network (USNSN). The USGS operates the network, which uses state-of-the-art equipment to detect and record seismic signals over a broad frequency band and with a high dynamic range. The USGS archives and analyzes the data and then re-broadcasts the raw waveforms over a satellite. The NRC has the capability to receive satellite re-broadcasts and access the data stream, so that those same seismograms that are processed by USGS can be analyzed by NRC also.

1.2 Project Motivation

The purpose of this redundancy is that NRC wishes to monitor seismic activity in near-real time. If an earthquake occurs in the central or eastern USA, NRC wants to be able to estimate whether structural damage may have occurred at a power plant site, without waiting for reports from the site itself (which are likely to be disrupted by communications outages caused by the earthquake) and without waiting for information from USGS about the exact location and magnitude of the earthquake. NRC has therefore initiated the construction of a seismic monitoring system at its own facility, using the raw waveforms that are re-broadcast from USGS. This monitoring system is intended to calculate (at least to a rough approximation) the location of the earthquake that generated the waveforms that are retrieved from the satellite and then to determine whether the earthquake was strong enough, and close enough to a power plant, to have caused damage. This proactive determination of potential seismic damage would of course be invaluable if damage had in fact occurred but had not yet been reported (or possibly even detected) from the power plant site. A system was therefore desired to conduct seismic monitoring in the eastern and central United States, a region with over 60 nuclear power plants and a history of significant earthquakes causing widespread damage, but a region which is nevertheless under-represented in terms of seismic monitoring studies in comparison to the more seismically active western USA.

1.3 Project History

To implement these plans for a near-real time seismic monitoring system, NRC awarded contract NRC-04-94-043 to Multimax, Inc., in 1994. The first phase of work was to activate the data downlink of the seismogram re-broadcasts from USGS. The seismograms (in compressed USNSN format) are received on a Very Small Aperture Terminal (VSAT) antenna located on the roof at NRC headquarters in Rockville, MD. Originally, the data were transmitted via a multiplex (mux) connection to a Sun workstation in a separate part of the NRC headquarters facility, although that connection was eventually upgraded to a copper wire connection with a line amplifier and modems at each end. The VSAT itself was moved in 1997 to be oriented to a different satellite, and the system was off-line until the VSAT resumed operation in its new position in 1998.

Once waveforms were being transmitted to the Sun workstation, it was determined that data were being lost due to a failure of the workstation's input system (a serial port) to keep up with the

data rate from the mux. An external serial buffer was therefore installed to accumulate data while downloading waveforms to the workstation. This solution proved effective, but frequently the system would get hung up, and it was necessary to recycle the serial buffer whenever that happened.

When the VSAT came back online in 1998, the serial buffer was replaced with a new unit, and data transmission problems resulted. For a period of several months, data were no longer being recorded and processed by the system. However, by that time the Sun workstation itself had been upgraded to a SPARCstation-5, and the workstation was now able to download data directly from the modem without falling behind the data transmission rate. The external serial buffer was thus no longer necessary, and it was disconnected. The workstation was then once again able to receive waveforms from the VSAT. The current hardware configuration therefore no longer includes an external serial buffer.

During the 1997 – 1998 hiatus when first the VSAT was inoperative and then the serial buffer was malfunctioning, waveform data could not be retrieved from USGS via the satellite re-broadcasts. However, it was possible to request seismograms over the Internet from USGS via the AutoDRM protocol. Of course, this could be done only after data windows for the waveforms were identified, so this could not be done until USGS or some other agency had already detected the earthquake, and hence data retrieved in this manner could not be used for a first-alert system. Nevertheless, it was felt that it would be valuable for off-line research purposes to retrieve the data even as late as months after the earthquakes, since these seismograms could be used to help calibrate ground motion calculations and to determine seismicity more accurately. Data were retrieved over the Internet not only from USGS but also from the Incorporated Research Institutions in Seismology (IRIS) and from certain universities that operated local seismic networks. A huge archive of waveforms for earthquakes in the central and eastern United States was thus accumulated by transmitting AutoDRM requests and parsing the results, as is described in Chapter 2 of this report. An appendix describes the program *reqdata* that was used to expedite the formatting of these data requests and monitoring the responses.

The plan for the near-real time analysis of the seismic waveforms was to use as much freely available code as possible, either from USGS or from universities. The system was intended to write the waveforms and the analysis results into a permanent archive, so that a scientist or data analyst could later retrieve them off-line for additional study. The system would thus consist of software for performing automated signal detection, event location, and ground motion estimation that would be performed in near-real time, whether or not an operator was present, and a detailed scientific analysis software package that could be used for subsequent studies carried out on the archived data. This design was implemented as the Seismic Data Analysis and Event Selection (SDAES) system, using code garnered from USGS and universities for performing most of the data-processing tasks and using code developed by Multimax for integrating the data analysis, archival, and retrieval systems.

The SDAES automated processing system decompressed the USNSN waveforms, ran a signal detector on them, calculated P- and S-wave arrival times and polarizations, then used those values to calculate the distance and azimuth of the earthquake from the detecting station, and in turn used the distance and azimuth to calculate a single-station event location. If data from multiple stations were available for the event, the location could be improved by using the distances computed from each station separately and finding the intersection of the circles having as their radii those computed distances.

As is well known, single-station event locations are often quite poor, particularly for small events where noisy seismograms make it difficult to pick accurately the signal arrival times (especially when using automated detectors) and where noise contamination of the waveforms makes the measurement of polarization unreliable. The near-real time analysis can thus compute an approximate location that can serve as the basis of an earthquake alert system, but reliable calculations of ground motion at power plant sites require epicenters that are better determined than those that were produced using the single-station location method. A function was therefore incorporated into SDAES that would use the UNIX "finger" command to query the on-line seismic event bulletin at USGS regularly and download the values of the epicenters for all newly located events in the bulletin. The USGS locations, which are based on signals detected by an extensive network of seismic stations, are assumed to be the best available near-real time locations of these events. The single-station locations that were calculated by SDAES would then be replaced by the network-determined locations from USGS. However, this process could take from a half hour to several hours, so there was still need of the near-real time locations computed by SDAES, which although less accurate than the USGS location could nevertheless be used to trigger an alert system.

In many cases no event could be found in the USGS bulletin that corresponded to the event located by SDAES. Probably in most cases those "events" were in fact spurious ones created by the SDAES's using arrival times from waveform noise excursions that were mistaken for signals by the automatic detector software. Perhaps some of the events that could not be matched were real, but they were too small to be located reliably, being detected at local distances by only a single USNSN station, so no corresponding matches could be found in the USGS event list. It turned out that many of the events detected by SDAES were not in the central or eastern USA at all; instead, they were teleseisms, whose signal arrivals were misinterpreted by the automatic system as regional phases. The problem of automatically associating individual signals with events on a global basis is well known to all creators of seismic bulletins. If no match could be found for an SDAES event in the USGS on-line bulletin, then the "unconfirmed" event was deleted from the system. Because a match could possibly be created much later, on the basis of delayed data that were not processed at USGS until days afterwards, all calculated events were kept in the system for a full week, and every time the on-line bulletin was queried via an automated "finger" command (which was conducted by SDAES every few minutes), the bulletin would once again be searched for a matching event. If none was found within a week, the event was then deleted from disk. If a match was found, however, then all seismograms detected by SDAES from the "confirmed" event were archived (in SAC waveform format) in the permanent database of waveforms associated with located events.

The core software for data recording was an endless loop of two C-language programs, vsatsav and vsatrd. These two programs read the data that was input to the Sun workstation from the VSAT, decompressed the data from USNSN format, wrote the waveforms to disk, and then read the waveforms back into memory for automated processing. These two programs had been written in the 1980s and were tailored to operate on a hardware platform marked by slow performance and limited memory. The programs served well to overcome those limitations, but they were unreliable, since the endless loop of these two programs' running in tandem frequently got hung up. In fact, it eventually proved necessary to run a UNIX *cron* job that would check every 5 minutes to see whether they were still running and re-start them if they were not! Of course, data would be lost in the interim period between when the programs stopped and when the *cron* job re-started them. It was decided that using the loop of these two programs was unsatisfactory, and in light of the speed and memory of a modern Sun workstation, they were unnecessary.

Although the original plan was to use off-the-shelf software from universities and the Government for all the data processing modules, it was decided to re-write most of the system to improve its reliability. This re-writing of the code took place in 1998, when the VSAT transmissions were being received (without the serial buffer) from the new orientation of the antenna. The C and FORTRAN code written by universities and the USGS were replaced mainly by a Java application developed by Multimax. The same signal detection and event location algorithms were implemented in the new code (although some improvements were made to features such as the pre-detection filtering), but the endless loop of the vsatsav and vsatrd processes was completely eliminated in favor of a much more straightforward approach that accomplished both of these processes in a single step. The performance of this Java-based application proved entirely satisfactory on the SPARCstation-5 *res18*, so the elimination of the off-the-shelf software that had been written for 1980s-era hardware was justified. In fact, unlike the previous system which had to be checked every 5 minutes to insure that it was still running, the current system has *never* crashed, except when the workstation was brought down for a re-boot.

Because the new software system replaced the university-developed FORTRAN and C code with Java code developed by Multimax (although a few new C-language elements are also used) and because the fundamental processes for waveform recording and reading have been replaced with a new technique, it was felt appropriate to rename the system. Although many data files and other program elements still bear the original designation SDAES, the new system is called the Automated Seismic Event Monitoring System (ASEMS). This new designation better reflects the new capabilities that were added to the system when the Java code was written. The old UNIX command-line interface and certain X-windows displays (based on Motif widgets) were replaced with new routines (employing Java graphics) that offer much more capability for *monitoring* the system's operations than just examining the lists of signal detections and even locations. The new software permits the waveforms themselves to be displayed and manipulated interactively. This is an important capability for a genuine seismic monitoring system, so the new name ASEMS is an appropriate one.

1.4 Off-Line Data Analysis

As the original acronym SDAES (Seismic Data Analysis and Event Selection) suggests, archived data retrieval (*i.e.*, "Event Selection") was an important part of the software for off-line data analysis, and it remains so in the ASEMS software. The seismic data archives are intended to serve as the basis of intensive studies of events of particular interest, using interactive analysis software packages such as SAC, *geotool,* and PITSA. The original SDAES software allowed an archived waveform to be retrieved by issuing a series of UNIX shell command-line prompts, to which the user would enter responses from the keyboard to identify the desired data, event, station, and data channel(s). This interface was tedious to use, and it provided the scientist or data analyst with no real information about the event other than just the raw waveforms themselves. When the SADES software was replaced by the ASEMS software package, this command-line interface was replaced with a Java-based graphical interface. The ASEMS interface displays a table that presents information about the event / station /channel combinations that are available in the waveform archive. The seismograms can then be retrieved from the graphical interface that displays the table, and the waveforms can immediately be displayed on the workstation by ASEMS without relying on stand-alone seismogram viewing programs such as SAC, *geotool*, or PITSA.

The waveforms are stored in the data archive in SAC format. Each seismogram is a separate data file. The seismograms are organized into a UNIX directory tree, grouped by a hierarchy of year, month, and event. The files for each event are labeled using the epochal time (*i.e.*, the seconds after Jan. 1, 1970) of the origin time of the event, with file suffixes to identify both the seismic station and the data channel. Waveforms recorded by the VSAT and by the off-line data retrieval process performed by submitting AutoDRM requests over the Internet are all stored in the same data archive. When data have been retrieved over the Internet for the same events /stations / channels as had already been downloaded from the VSAT, the VSAT data are deleted in favor of the seismograms retrieved via AutoDRM, since the latter waveforms may span a longer time window and since they are free of the data drop-outs that can be introduced by the satellite re-broadcasts.

An important calculation that is conducted off-line by a scientist or data analyst is the estimation of the Cumulative Absolute Velocity (CAV), a measurement of ground motion that has significant implications for structural damage, at the sites of nuclear power plants. The CAV is estimated based on spectra of the earthquake as observed at the USNSN stations, corrected for attenuation, and "propagated" to the power plant sites using empirical relationships developed in previous investigations of other measurements of ground motion. This procedure is examined in Chapter 5. The program *Predspec* permits the operator to choose graphically the particular seismograms to use for these calculations, the time windows in which the spectra are to be computed, and the spectral bands in which the signal-to-noise ratio is sufficiently high for the calculations to be meaningful. This program was written for use with SDAES, and it still uses the X-windows and Motif interface. It should now be integrated within the ASEMS application instead of existing as a stand-alone off-line program.

The final stage in the calculation of ground motion at the power plant sites is the application of frequency-dependent corrections for local geological structures at the power plant sites. These local crustal structures can amplify vibrations at certain frequencies through resonances, based on the thicknesses of the crustal layers and the elastic parameters of each layer. A table has been constructed of these corrections at the sites of power plants in the central and eastern United States, at frequencies ranging from 1.25 to 10.0 Hz. The construction of this table is explained in Chapter 4. It should be noted that this table was constructed using values of the geologic structure measured at locations in some cases distant from the actual power plant sites, so these values should be regarded as suspect, especially at the highest frequencies. Purely local measurements of the geological structures would yield more nearlyreliable results.

Although the waveform archive can be used for interactive seismic analysis conducted using off-line programs such as SAC, *geotool*, PITSA, and *Predspec*, the new version of the automated monitoring system offers many of these same capabilities, but now in near-real time. Specifically, ASEMS allows a scientist or data analyst to view seismograms (either from the data archive or as soon as the waveforms are downloaded from the VSAT and decompressed) graphically on the workstation, to perform interactive manipulations on them (such as applying filters), and to make graphical measurements on them in the time and frequency domains. These same operations are key to the operation of the off-line analysis programs, so there is now less need for those stand-alone programs under ASEMS than there was under SDAES.

1.5 Geographic Information System

A stand-alone software package that is of special importance is the *ArcView* Geographic Information System (GIS), which is described in detail in Chapter 3. The GIS allows maps to be constructed interactively that can display (along with a great many other data layers, or

"Themes") the epicenters or newly detected and archived earthquakes, the locations of the USNSN stations that detected (or failed to detect) chosen events, and the locations of nearby nuclear power plants. It is especially useful to put that information into the proper geological and geophysical context by adding "Themes" that display topography, rock types, crustal thicknesses, seismic velocities, faults, and other data that affect the generation, propagation, attenuation, and scattering of seismic waves. These detailed maps present significant information that will aid the operator in assessing the possibility of structural damage to the power plants from the earthquakes. However, constructing maps interactively, by specifying the data "Themes" to display, is only part of the utility of a GIS. The real power of this software lies in its architecture as a graphical (*i.e.,* map) interface to an underlying database. Queries that can be posed to relational databases can also be posed to *ArcView*, and the results of those queries will be displayed in tables, graphs, or maps. This makes the GIS be a valuable tool for managing and accessing data as well as for displaying the data on maps constructed interactively.

The ArcView system at NRC makes use of two special extensions to the standard *ArcView* software, namely the *Spatial Analyst* tool and the *3-D Analyst* tool. *Spatial Analyst* allows complex calculations involving geographical relationships to be performed. Of particular use in this project are the tools for constructing and mapping continuous contours of data sets that are sampled at discrete and irregularly spaced locations. Several examples of data contours constructed using this tool are shown in Chapters 3 and 4. The *3-D Analyst* tool allows 2-D (surface) map data to be extended into the third dimension, adding a depth or elevation component to the data sets. This is valuable for displaying topography (which has a significant effect on the scattering of seismic surface waves), but it is even more valuable for displaying the effects of sub-surface geology on the propagation and amplification of seismic body waves. Unfortunately, the detailed 3-D models of local geology at power plant sites which should be displayed and analyzed using this tool are currently unavailable.

ArcView currently communicates with ASEMS via shared data files. ASEMS has its own internal mapping program for displaying simple maps showing epicenters, seismic stations, and power plant sites, but without the detailed geological and geophysical data sets that can be displayed using *ArcView*. This internal mapping capability makes the use of *ArcView* necessary only for detailed off-line interactive analysis. However, that analysis could be expedited by the addition of "hot link" capabilities to the *ArcView* maps that would communicate more directly with ASEMS than just by sharing data files (which the operator must identify explicitly).

1.6 System Weaknesses and Suggested Improvements

The preceding discussion has identified a number of areas in which the performance of ASEMS could be strengthened. We herein summarize those areas and suggest future work that could be performed to enhance the utility to NRC of the seismic monitoring system:

1) The event locations are often inaccurate because the signal picks (*i.e.,* the times identified as the arrivals of P and S waves) are often in error. These poor signal picks could be improved by using a detection algorithm that is "tuned" to each USNSN station by applying a station-specific pre-detection filter that compensates in an optimal fashion for the particular spectrum characterizing the earth noise measured at that station. As a starting point for conducting the study that would be required for tuning the signal detectors at each station, a detailed examination should be performed of all the signal picks (correct and incorrect) performed at each station to see why the detector makes the picks that it does. The near-real time waveform display capabilities of ASEMS offer the necessary capabilities to perform

that study, since unlike the earlier SDAES software ASEMS allows the examination of waveforms that are not associated with events that have been "confirmed" by USGS.

2) Detailed crustal models of the geology at nuclear power plant sites should be assembled so that they can be displayed and analyzed using the *ArcView 3-D Analyst* tool and so that these local structures can be used to obtain more meaningful values of the frequency-dependent site amplification coefficients than those that are tabulated in Chapter 4.

3) The off-line calculations of CAV that are performed by the stand-alone program *Predspec* (which unlike the rest of the system still uses an interface based on X-windows and Motif) should be ported to the ASEMS application itself. The operator could thus use a single program for seismic monitoring and CAV calculation. Moreover, the CAV calculations could then be automated and performed in near-real time, although these results would of necessity be less reliable than those that would be obtained by the interactive manipulations performed by the scientist or data analyst.

4) There should be stronger linking between *ArcView* and ASEMS than just the sharing of data files. Now that ASEMS is written in Java, an object-oriented programming language, complete data objects instead of just data files should be communicated between these two programs. This communication could be implemented within *ArcView* using "hot links".

5) The interactive waveform display and measurement capabilities of ASEMS have eliminated the need for many of the features of the stand-alone seismic analysis programs SAC, *geotool*, and PITSA. Even more of the functionality of these analysis programs should be ported to ASEMS (which would be straightforward to do, given its object-oriented architecture) so that the need to rely on these stand-alone programs would be eliminated entirely.

6) Because ASEMS is written in Java, it is portable to Windows platforms as well as to UNIX systems. In particular, the graphics can be displayed on any platform. It would therefore be valuable to exploit this platform independence by constructing a viewer application that allows a PC user on the same local-area network as *res18* to see tabular displays of the latest signal detections and event locations and to view and manipulate the raw waveforms on the PC instead of on the UNIX workstation. Such a viewer application could be implemented easily using the existing Java code for ASEMS.

2. ARCHIVE OF SEISMIC WAVEFORM DATA AT NRC

2.1 Background

An important task in this project was the collection of a large database of seismograms and ancillary data, such as instrument responses, for earthquakes in the central and eastern United States. This data archive was created by storing the waveforms for the events that were detected by the automated processing system and supplementing them with additional waveforms from other seismic stations and with waveforms for events that the automated processing system failed to detect. The composite archive thus contains waveform data from a large seismic network, not just those stations that transmit their data via satellite to NRC, and from a large number of earthquakes, including those that were too small to be detected by the automated system.

The period spanned by the data requests that contributed to the historical archive is January 1995 through August 1998. Since then, events have continued to be detected by the automated system, and the waveforms for those events that are downloaded at NRC from the satellite have continued to be added to the waveform archive, but no additional data for these events have been requested yet from any other data sources such as USGS.

There are a total of 232 events in the data set, all of them with epicenters within the central and eastern United States. The seismic network that contributed to the data set consists of 219 stations. Not all of these stations are themselves located in the central or eastern United States, but almost all of them were within regional distances (*i.e.*, less than 1500 km) from those particular central or eastern US earthquakes for which they reported data. (The few exceptions were stations at larger distances than 1500 km from some 14 events that occurred in 1996, when a rather less stringent data-collection policy was used in this project.) Over 98% of the waveform data in the archive were recorded at stations nearer than 1500 km from the epicenters of the events, since the seismograms that are of principal interest in this project are those that recorded regional phases such as Lg. The 2% of the waveforms that were recorded at distances of more than 1500 km correspond either to data for the 14 aforementioned events in 1996 or to data that were downloaded from the satellite and were then determined by the automated processing, or by the USGS bulletin, to have come from events with distant epicenters (sometimes as far as 2500 km from the stations). A policy decision was made to retain those data that had already been downloaded and saved by the automatic processing system, even though in those particular cases they turned out not to have come from events at regional distances.

The data from stations that do not transmit via satellite to USGS and the data from events that were too small to be detected by the automated processing system were acquired in most cases by submitting data requests in "AutoDRM" format over the Internet. A program known as *reqdata* was used to expedite the formatting of the data requests, to keep track of the requests and the responses (which could be a waveform, a message that no data were available, or no response at all), and to parse the E-mail responses into waveform format and store them in the data archive. A description of the *reqdata* program is provided as an appendix to this report.

Over half of the requests for waveform data were generated as AutoDRM requests and transmitted via E-mail in "GSE2.0" format to USGS, since most of the seismic stations transmit their data to USGS. However, almost one-third of the data were retrieved by AutoDRM requests that were submitted not to USGS but either to the Incorporated Research Institutions in Seismology [IRIS] Data Management Center in Seattle, Washington, or to the International Data

Center in Arlington, Virginia, since some stations report data to those agencies but not to USGS. An additional 9% of the waveform data, including waveforms from some small events that were detected only by local-area seismic networks and not by the USNSN, were collected from MIT, Virginia Tech, and Lamont-Doherty Earth Observatory of Columbia University via FTP downloads over the Internet. Finally, less than 1% of the data in the archive of events in the period January 1995 – August 1998 represents waveforms that were downloaded at NRC from the satellite. As will be explained below, most of the waveforms that were downloaded from the satellite were subsequently replaced by "duplicate" waveforms (which might, however, be of higher quality than the satellite data) that were retrieved from USGS via AutoDRM requests. A breakdown of the data sources that contributed to the waveforms in the archive is as follows:

USGS (AutoDRM requests)	58.5%
IRIS (AutoDRM requests)	29.2%
MIT (FTP downloads)	4.4%
IDC (AutoDRM requests)	3.1%
Virginia Tech (FTP downloads)	3.0%
Lamont-Doherty (FTP downloads)	1.3%
Downloads at NRC from satellite	0.5%

Epicenters and origin times for some events that were not reported in the USGS seismic bulletin were taken from the bulletin of the International Data Center [IDC] in Arlington, Virginia. Like the seismograms themselves, the seismic bulletins were downloaded over the Internet in response to data requests.

The USNSN stations that transmit data via satellite to NRC also transmit data to USGS. The data become available at USGS only after the bulletins are created, however, so those data can be retrieved by submitting AutoDRM requests only after a significant delay. During that period the data that were downloaded from the satellite at NRC are stored in the data archive. Once the waveforms are made available to be downloaded from USGS, however, AutoDRM requests are submitted for those same seismograms that were already downloaded via satellite. These duplicate data are retrieved because they may span longer time windows or may be free of dropouts and other transmission errors. The policy that was used in formulating the AutoDRM requests was that time windows spanning from 180 sec prior to the predicted P-wave arrival to twice the predicted (LR arrival - origin time) interval would be requested. Extending the requested time window to twice the time required for the arrival of the surface wave LR means that the requested window will contain a lengthy interval of the LR coda, which is usually not the case with the waveforms that are downloaded from the satellite. The data that are retrieved in response to the AutoDRM requests are then used to replace the data in the archive that had been downloaded from the satellite. Similarly, the epicenters and origin times for the events that are associated with the waveforms are those that were taken from the seismic bulletins produced by USGS, the IDC, or the university operating the local-area network, since these are more reliable than the ones that were calculated by the automated data processing on the basis of a far smaller network.

It should be noted that many of the waveforms retrieved by the AutoDRM requests do not contain detectable signals. For every station, a time window in which the signal should arrive is calculated on the basis of the epicenter and origin time of the event as reported in the bulletin, and the AutoDRM request is submitted for any available waveform within that time window. Many, and for the smaller events probably most, of the waveforms thus contain only noise and no visible signals. Nevertheless, these noisy data are still valuable since they help set an upper limit to the magnitude of the event, namely that it was of a size such that the signal (attenuated

by the propagation path distance and by the effects of anelasticity and scattering) had to be smaller than the detection threshold (*i.e.*, the measured ambient earth noise level) at every station that failed to detect it. This negative evidence is a valuable tool to use in determining accurately the magnitude of the earthquakes and, in turn, the seismicity rate (i.e., the exponential increase in the number of events as a function of decreasing magnitude). This is important, since the seismicity rate is extrapolated backwards to large magnitudes to estimate the probability that earthquakes above a certain magnitude threshold will occur within a given time interval.

The waveforms with no detected signals are also valuable, of course, since improvements in the signal detection algorithms may permit low-amplitude signals to be detected within the noisy waveforms at some future date. These improvements in the detection algorithms are likely to come about by the fine-tuning of the bandpass filters that are applied to the signals at each station. Currently in this project the same filter is applied to the data from every station, but fine-tuning the detector algorithms would permit station-dependent filters to be applied that are optimal for reducing the effects of the earth-noise spectrum that is dependent on the local geological (and meteorological, and industrial) environment at every station.

2.2 Inventory of Events in the Seismic Data Archive

Table 1 presents a list of the 232 seismic events for which waveform data were collected in this project. The columns of this table are:

Epoch — The "epochal time" (*i.e.*, seconds after Jan. 1, 1970, in accordance with a standard UNIX timekeeping convention) of the event. The Epoch is used as an index to identify the event uniquely.

Date — The calendar date of the event.

Origin — The hour, minute, and second (in Universal Time) of the event. Note that the Epoch is redundant with the combination of the Date and the Origin.

Lat — The latitude of the epicenter, in decimal degrees. A positive value indicates the Northern Hemisphere.

Lon — The longitude of the epicenter, in decimal degrees. A negative value indicates the Western Hemisphere.

Depth — The depth in kilometers of the hypocenter. Usually when the depth cannot be determined accurately a default value is used. The default value is 0.0 km for events that were located by the IDC by restraining the depth to the surface. The default value that is usually used by the USGS for apparently shallow events is 10.0 km. A default value of 33.0 km is conventionally used for events that can be determined only to be shallower than the Moho.

Mag — The seismic magnitude of the event. For the largest events, a teleseismic body-wave magnitude (designated in Table 1 as "Mb") is used, since this is the most reliable magnitude. For smaller events that were detected only at regional distances, a regional-phase body-wave magnitude (designated in Table 1 as "Ml", for "local" magnitude) or a regional-phase surface-wave magnitude (designated in Table 1 as "Lg", for the seismic wave that is measured by this magnitude) is used in place of the more reliable "Mb" magnitude that could not be measured. A designation "u", for "unknown magnitude type", indicates that the seismic bulletin reported a value for the magnitude but did not identify what

type of magnitude it was. If the magnitude was too small to be measured, a default value of −1.0 is used in Table 1.

Src — The data center that is the source of the epicenter and origin time information listed in Table 1 for that event. The bulletins produced by USGS, the International Data Center, MIT, and Virginia Tech were all used.

Sta — The total number of stations from which data for that event are stored in the seismic waveform archive at NRC.

Table 1

The 232 Events in the Seismic Waveform Archive at NRC

Epoch	Date	Origin	Lat	Lon	Depth	Mag		Src	#Sta
789998721	01/13/95	12:05:21	43.37	-70.94	7.2	2.6	Ml	MIT	5
790444299	01/18/95	15:51:39	34.77	-97.60	5.0	4.2	Ml	USGS	11
792607471	02/12/95	16:44:31	44.27	-70.25	5.0	2.8	Md	USGS	21
792863637	02/15/95	15:53:57	45.90	-75.04	18.0	3.5	Ml	USGS	18
792983596	02/17/95	01:13:16	44.17	-70.24	8.0	2.7	Md	USGS	19
793198626	02/19/95	12:57:06	39.12	-83.47	10.0	3.6	Ml	USGS	27
793531933	02/23/95	09:32:13	41.87	-80.83	5.0	2.9	Ml	USGS	21
794505997	03/06/95	16:06:37	29.18	-101.33	0.0	3.9	Mb	IDC	4
794909752	03/11/95	08:15:52	36.96	-83.13	1.0	3.7	Mb	USGS	28
794915404	03/11/95	09:50:04	37.00	-83.19	5.0	3.3	Lg	USGS	2
795536670	03/18/95	14:24:30	43.33	-71.61	8.1	2.8	Ml	MIT	5
797615976	04/11/95	15:59:36	43.83	-68.44	13.3	3.1	Ml	MIT	5
797819576	04/14/95	00:32:56	30.29	-103.35	18.0	5.6	Mb	USGS	14
797821908	04/14/95	01:11:48	30.30	-103.35	10.0	2.7	Ml	USGS	5
797825666	04/14/95	02:14:26	30.30	-103.35	10.0	2.8	Ml	USGS	9
797825978	04/14/95	02:19:38	30.30	-103.35	10.0	3.3	Ml	USGS	8
797831322	04/14/95	03:48:42	30.30	-103.35	10.0	2.6	Ml	USGS	6
797832676	04/14/95	04:11:16	30.30	-103.35	10.0	2.4	Ml	USGS	8
797838819	04/14/95	05:53:39	30.30	-103.35	10.0	2.7	Ml	USGS	9
797845176	04/14/95	07:39:36	30.30	-103.35	10.0	2.4	Ml	USGS	7
797848032	04/14/95	08:27:12	30.30	-103.35	10.0	2.8	Ml	USGS	8
797853778	04/14/95	10:02:58	30.30	-103.35	10.0	2.9	Ml	USGS	8
797857040	04/14/95	10:57:20	30.30	-103.35	10.0	2.3	Ml	USGS	8
797956409	04/15/95	14:33:29	30.27	-103.32	10.0	4.0	Ml	USGS	11
798126357	04/17/95	13:45:57	32.95	-80.07	10.0	3.9	Ml	USGS	21
799746695	05/06/95	07:51:35	47.00	-66.60	5.0	3.9	Mb	USGS	11
799827310	05/07/95	06:15:10	43.38	-70.95	5.8	2.8	Ml	MIT	5
801411752	05/25/95	14:22:32	42.99	-78.83	5.0	3.0	Ml	USGS	27
801604270	05/27/95	19:51:10	36.17	-89.43	6.0	3.8	Ml	USGS	23
802219472	06/03/95	22:44:32	47.02	-76.29	18.0	3.4	Mb	USGS	22
802474031	06/06/95	21:27:11	36.22	-89.47	5.0	3.6	Ml	USGS	21
803304791	06/16/95	12:13:11	44.29	-71.92	5.0	3.8	Ml	USGS	24
804126977	06/26/95	00:36:17	36.75	-81.45	5.0	3.1	Mb	USGS	34
804418040	06/29/95	09:27:20	36.55	-89.78	10.0	3.1	Lg	USGS	1
804830344	07/04/95	03:59:04	36.25	-104.81	5.0	3.8	Ml	USGS	26

Table 1 (Continued)

Epoch	Date	Origin	Lat	Lon	Depth	Mag		Src	#Sta
804953804	07/05/95	14:16:44	35.37	-84.21	10.0	3.7	Ml	USGS	28
804955321	07/05/95	14:42:01	43.34	-71.44	4.0	2.2	Ml	MIT	4
805150867	07/07/95	21:01:07	36.35	-81.33	5.0	3.0	Lg	USGS	1
806206234	07/20/95	02:10:34	36.50	-89.67	5.0	3.2	Lg	USGS	2
807455224	08/03/95	13:07:04	37.40	-76.68	5.0	2.9	Ml	USGS	25
807464873	08/03/95	15:47:53	48.09	-92.34	0.0	-1.0	u	IDC	11
808701530	08/17/95	23:18:50	36.10	-89.41	5.0	3.1	Ml	USGS	23
808935326	08/20/95	16:15:26	45.41	-73.28	18.0	3.3	Ml	USGS	16
810342081	09/05/95	23:01:21	38.36	-89.04	4.0	2.9	Ml	USGS	22
810878345	09/12/95	03:59:05	45.61	-74.43	18.0	3.7	Ml	USGS	21
811125093	09/15/95	00:31:33	36.87	-98.69	5.0	4.1	Ml	USGS	21
811724607	09/21/95	23:03:27	45.08	-74.21	18.0	3.1	Ml	USGS	19
812431061	09/30/95	03:17:41	43.28	-71.59	6.9	2.9	Ml	MIT	5
813309560	10/10/95	07:19:20	46.42	-78.77	18.0	3.5	Ml	USGS	21
814149202	10/20/95	00:33:22	28.38	-100.60	0.0	4.2	Ml	IDC	5
814156181	10/20/95	02:29:41	44.40	-70.84	8.7	2.8	Ml	MIT	5
814204638	10/20/95	15:57:18	45.79	-96.86	5.0	3.7	Ml	USGS	12
814219481	10/20/95	20:04:41	38.05	-81.41	0.0	2.9	Mb	IDC	31
814295065	10/21/95	17:04:25	42.85	-77.92	5.0	-1.0	u	USGS	6
814667848	10/26/95	00:37:28	37.05	-83.12	1.0	3.9	Mb	USGS	32
816198359	11/12/95	17:45:59	30.30	-103.35	10.0	3.6	Ml	USGS	10
816221523	11/13/95	00:12:03	44.30	-68.00	5.0	3.0	Ml	MIT	5
816686614	11/18/95	09:23:34	43.01	-71.92	0.9	2,5	Ml	MIT	5
817329332	11/25/95	19:55:32	42.83	-70.74	0.9	2.2	Ml	MIT	5
817679311	11/29/95	21:08:31	38.38	-80.66	0.0	2.7	Lg	USGS	32
817828660	12/01/95	14:37:40	35.06	-99.34	5.0	2.9	Ml	USGS	14
817940928	12/02/95	21:48:48	37.81	-82.20	33.0	2.9	Lg	USGS	30
818387006	12/08/95	01:43:26	44.09	-71.24	13.0	2.9	Ml	MIT	5
819022600	12/15/95	10:16:40	36.07	-83.64	5.0	2.6	Lg	USGS	21
819701508	12/23/95	06:51:48	38.73	-104.92	5.0	3.5	Mb	USGS	19
820370258	12/31/95	00:37:38	38.72	-104.91	5.0	2.8	Ml	USGS	17
821139327	01/08/96	22:15:27	38.03	-81.68	0.0	3.6	Lg	USGS	29
823603562	02/06/96	10:46:02	42.82	-71.37	7.1	-1.0	u	MIT	5
823619428	02/06/96	15:10:28	42.51	-97.54	5.0	3.6	Ml	USGS	34
823622917	02/06/96	16:08:37	43.98	-103.73	5.0	3.7	Lg	USGS	24
824322541	02/14/96	18:29:01	38.00	-81.62	0.0	3.9	Lg	USGS	39
824796797	02/20/96	06:13:17	45.96	-74.78	18.0	-1.0	u	USGS	3
826800146	03/14/96	10:42:26	45.99	-74.43	18.0	-1.0	u	USGS	48

Table 1 (Continued)

Epoch	Date	Origin	Lat	Lon	Depth	Mag		Src	#Sta
827526132	03/22/96	20:22:12	41.69	-71.24	12.0	3.5	Lg	USGS	36
827736227	03/25/96	06:43:47	35.61	-102.60	5.0	-1.0	u	USGS	35
827763350	03/25/96	14:15:50	32.13	-88.67	5.0	3.5	Lg	USGS	30
828193541	03/30/96	13:45:41	44.92	-73.48	10.0	-1.0	u	USGS	8
828338407	04/01/96	06:00:07	42.11	-70.56	6.9	-1.0	u	MIT	5
829018088	04/09/96	02:48:08	43.07	-104.10	5.0	3.7	Ml	USGS	26
829259698	04/11/96	21:54:58	34.97	-91.16	5.0	3.3	Ml	USGS	20
829903814	04/19/96	08:50:14	36.98	-83.02	0.0	3.9	Mb	USGS	25
830169870	04/22/96	10:44:30	41.68	-71.06	5.0	2.6	Ml	USGS	13
830931231	05/01/96	06:13:51	44.42	-69.98	19.0	-1.0	u	MIT	5
830999980	05/02/96	01:19:40	42.55	-71.47	6.7	-1.0	u	MIT	5
831109672	05/03/96	07:47:52	43.05	-104.02	5.0	3.1	Ml	USGS	28
831145140	05/03/96	17:39:00	44.40	-69.95	18.4	-1.0	u	MIT	5
833348823	05/29/96	05:47:03	43.71	-71.20	5.0	-1.0	u	MIT	5
835063109	06/18/96	01:58:29	42.16	-71.06	9.5	-1.0	u	MIT	5
836076643	06/29/96	19:30:43	37.19	-81.95	1.0	4.1	Mb	USGS	19
836602630	07/05/96	21:37:10	35.20	-84.00	5.0	2.8	Ml	USGS	4
838084800	07/23/96	01:20:00	44.45	-74.03	5.0	2.8	Ml	USGS	14
838333756	07/25/96	22:29:16	37.30	-98.50	5.0	2.2	Ml	USGS	13
838878263	08/01/96	05:44:23	37.40	-104.25	5.0	3.8	Ml	USGS	23
838878954	08/01/96	05:55:54	37.38	-104.20	5.0	3.2	Ml	USGS	20
839787470	08/11/96	18:17:50	33.58	-90.87	10.0	3.5	Ml	USGS	9
840171406	08/16/96	04:56:46	49.21	-82.92	18.0	3.6	Ml	USGS	10
840305923	08/17/96	18:18:43	37.94	-81.45	0.0	3.0	Mb	IDC	17
840614054	08/21/96	07:54:14	44.18	-71.35	10.0	3.8	Ml	USGS	32
843012988	09/18/96	02:16:28	33.74	-82.10	5.0	2.8	Ml	USGS	13
843183353	09/20/96	01:35:53	42.43	-72.22	7.8	-1.0	u	MIT	5
843269040	09/21/96	01:24:00	35.70	-84.00	5.0	2.0	Ml	USGS	9
843853300	09/27/96	19:41:40	37.63	-81.20	0.0	3.0	Mb	IDC	20
844290731	10/02/96	21:12:11	37.80	-81.03	0.0	3.2	Mb	IDC	20
844372087	10/03/96	19:48:07	42.67	-104.35	0.0	3.6	Mb	IDC	20
845205084	10/13/96	11:11:24	35.88	-89.99	5.0	2.8	Ml	USGS	14
845552608	10/17/96	11:43:28	39.74	-76.05	5.0	2.3	Ml	USGS	9
846485979	10/28/96	06:59:39	40.27	-76.14	5.0	2.6	Ml	USGS	12
846611423	10/29/96	17:50:23	43.43	-71.54	6.0	-1.0	u	MIT	5
846817768	11/01/96	03:09:28	37.35	-104.23	5.0	3.2	Ml	USGS	23
846954487	11/02/96	17:08:07	37.41	-79.84	0.0	3.1	Mb	IDC	23
847764213	11/12/96	02:03:33	38.00	-90.40	5.0	2.7	Ml	USGS	12

Table 1 (Continued)

Epoch	Date	Origin	Lat	Lon	Depth	Mag		Src	#Sta
848746458	11/23/96	10:54:18	35.04	-100.50	5.0	3.0	Ml	USGS	10
849132348	11/27/96	22:05:48	38.31	-81.42	0.0	3.4	Mb	IDC	20
849246094	11/29/96	05:41:34	35.92	-89.93	20.0	4.3	Ml	USGS	22
849264429	11/29/96	10:47:09	36.29	-89.37	5.0	3.6	Ml	USGS	18
850418025	12/12/96	19:13:45	43.58	-71.29	7.3	-1.0	u	MIT	5
850634397	12/15/96	07:19:57	36.03	-89.84	1.0	2.8	Ml	USGS	9
850701511	12/16/96	01:58:31	39.50	-87.40	5.0	3.1	Ml	USGS	13
851012998	12/19/96	16:29:58	35.08	-97.65	5.0	2.5	Ml	USGS	9
851234177	12/22/96	05:56:17	39.20	-76.90	5.0	2.3	Ml	USGS	9
851761728	12/28/96	08:28:48	43.32	-69.74	6.1	-1.0	u	MIT	5
852029804	12/31/96	10:56:44	46.54	-75.95	10.0	-1.0	u	USGS	8
852385082	01/04/97	13:38:02	43.71	-69.43	5.0	-1.0	u	MIT	5
852779246	01/09/97	03:07:26	33.20	-92.60	5.0	2.8	Ml	USGS	6
853625078	01/18/97	22:04:38	39.25	-104.50	0.0	3.3	Mb	IDC	11
853627550	01/18/97	22:45:50	39.21	-104.27	0.0	2.5	Mb	IDC	8
853648573	01/19/97	04:36:13	39.42	-104.49	0.0	3.2	Mb	IDC	10
855432792	02/08/97	20:13:12	43.35	-104.97	0.0	3.6	Mb	IDC	16
855531133	02/09/97	23:32:13	42.62	-72.27	5.0	-1.0	u	USGS	5
855791591	02/12/97	23:53:11	34.95	-100.89	5.0	3.0	Ml	USGS	12
855997740	02/15/97	09:09:00	34.93	-100.96	0.0	3.5	Mb	IDC	11
858087031	03/11/97	13:30:31	34.72	-97.50	5.0	2.5	Ml	USGS	14
858539248	03/16/97	19:07:28	34.21	-93.44	5.0	3.4	Ml	USGS	15
859242695	03/24/97	22:31:35	27.58	-98.03	0.0	3.9	Mb	IDC	4
860042652	04/03/97	04:44:12	45.98	-72.33	5.0	3.5	Ml	USGS	14
860674076	04/10/97	12:07:56	41.02	-69.53	18.2	-1.0	u	MIT	5
860829701	04/12/97	07:21:41	48.14	-79.93	0.0	3.5	Mb	IDC	10
860847096	04/12/97	12:11:36	48.19	-79.82	5.0	3.6	Mb	USGS	9
861375464	04/18/97	14:57:44	26.51	-87.08	28.2	3.7	Mb	IDC	7
862305831	04/29/97	09:23:51	44.48	-70.34	18.9	-1.0	u	MIT	5
862717153	05/04/97	03:39:13	31.00	-87.40	5.0	3.1	Ml	USGS	9
864071134	05/19/97	19:45:34	34.78	-85.44	5.0	2.9	Ml	USGS	15
864392700	05/23/97	13:05:00	43.25	-71.17	1.5	-1.0	u	MIT	5
864499927	05/24/97	18:52:07	46.08	-74.49	0.0	3.5	Mb	IDC	25
865049201	05/31/97	03:26:41	33.18	-95.97	5.0	3.4	Ml	USGS	12
867347731	06/26/97	17:55:31	36.61	-89.64	10.0	2.5	Lg	USGS	20
868543071	07/10/97	13:57:51	45.04	-74.83	18.0	2.8	Lg	USGS	15
869331994	07/19/97	17:06:34	35.06	-84.81	10.0	3.5	Lg	USGS	25
870016236	07/27/97	15:10:36	38.67	-78.39	5.0	2.4	Lg	USGS	19

Table 1 (Continued)

Epoch	Date	Origin	Lat	Lon	Depth	Mag		Src	#Sta
870265763	07/30/97	12:29:23	36.44	-83.51	5.0	3.8	Lg	USGS	20
870333330	07/31/97	07:15:30	43.62	-75.37	5.0	3.2	Lg	USGS	12
871148764	08/09/97	17:46:04	41.80	-97.19	5.0	3.4	Lg	USGS	49
871927912	08/18/97	18:11:52	44.06	-104.87	0.0	4.0	Ml	IDC	49
872068324	08/20/97	09:12:04	47.53	-70.29	18.0	3.2	Lg	USGS	10
873589081	09/06/97	23:38:01	34.66	-96.44	5.0	4.2	Lg	USGS	16
874180232	09/13/97	19:50:32	38.29	-89.71	16.0	2.5	Lg	USGS	14
874520192	09/17/97	18:16:32	35.62	-90.46	5.0	3.8	Lg	USGS	18
874734950	09/20/97	05:55:50	37.18	-90.92	5.0	3.1	Lg	USGS	16
875074825	09/24/97	04:20:25	36.55	-89.82	5.0	3.2	Ml	USGS	14
875362449	09/27/97	12:14:09	36.20	-89.48	5.0	3.1	Lg	USGS	17
875555110	09/29/97	17:45:10	38.70	-77.50	5.0	1.4	Md	USGS	20
876644902	10/12/97	08:28:22	44.91	-74.55	14.0	2.5	Lg	USGS	8
876784000	10/13/97	23:06:40	44.36	-74.97	4.0	2.7	Lg	USGS	10
877259532	10/19/97	11:12:12	32.33	-103.40	0.0	3.3	Mb	IDC	47
877682118	10/24/97	08:35:18	31.12	-87.34	10.0	4.8	Mb	USGS	19
877908432	10/26/97	23:27:12	31.10	-87.30	10.0	3.7	Lg	USGS	17
878029211	10/28/97	09:00:11	31.10	-87.30	10.0	3.0	Lg	USGS	11
878035006	10/28/97	10:36:46	37.16	-82.03	1.0	3.4	Lg	USGS	22
878039058	10/28/97	11:44:18	47.67	-69.91	12.0	4.8	Mb	USGS	12
878193743	10/30/97	06:42:23	36.70	-80.92	10.0	2.0	Lg	USGS	19
878227180	10/30/97	15:59:40	36.72	-80.93	9.0	1.8	Lg	USGS	16
878418070	11/01/97	21:01:10	42.78	-70.01	12.1	-1.0	u	MIT	5
878783673	11/06/97	02:34:33	46.80	-71.41	23.0	4.8	Mb	USGS	22
878784939	11/06/97	02:55:39	46.78	-71.39	18.0	2.8	Ml	USGS	11
878785557	11/06/97	03:05:57	46.76	-71.37	18.0	2.9	Ml	USGS	6
879000566	11/08/97	14:49:26	46.78	-71.37	23.0	2.3	Lg	USGS	9
879479051	11/14/97	03:44:11	40.15	-76.25	5.0	2.8	Lg	USGS	13
880712924	11/28/97	10:28:44	36.01	-89.72	5.0	2.3	Lg	USGS	13
881106076	12/02/97	23:41:16	36.53	-89.47	10.0	2.8	Lg	USGS	17
881434166	12/06/97	18:49:26	42.88	-104.65	0.0	3.8	Mb	IDC	30
881840097	12/11/97	11:34:57	37.10	-98.48	5.0	2.7	Lg	USGS	9
881916138	12/12/97	08:42:18	33.38	-87.29	1.0	3.8	Mb	USGS	21
882911357	12/23/97	21:09:17	43.37	-104.72	0.0	4.1	Ml	IDC	33
882988332	12/24/97	18:32:12	33.20	-92.75	5.0	2.6	Lg	USGS	9
883756036	01/02/98	15:47:16	37.83	-103.41	5.0	3.4	Ml	USGS	26
883887922	01/04/98	04:25:22	36.46	-83.33	0.0	2.7	u	VTECH	4
884234052	01/08/98	04:34:12	42.85	-70.04	25.0	2.9	Ml	USGS	14

Table 1 (Continued)

Epoch	Date	Origin	Lat	Lon	Depth	Mag		Src	#Sta
886025112	01/28/98	22:05:12	36.10	-89.76	11.0	2.7	Ml	USGS	23
886488444	02/03/98	06:47:24	37.31	-80.50	0.0	0.5	Md	VTECH	3
887276269	02/12/98	09:37:49	36.12	-89.71	10.0	3.0	Ml	USGS	26
887390170	02/13/98	17:16:10	43.85	-71.26	8.0	2.7	Ml	USGS	22
887897127	02/19/98	14:05:27	36.54	-89.58	9.0	2.6	Ml	USGS	21
888459027	02/26/98	02:10:27	36.38	-89.58	10.0	2.5	Ml	USGS	18
888502831	02/26/98	14:20:31	46.07	-76.36	18.0	3.7	Ml	USGS	12
889419958	03/09/98	05:05:58	46.49	-81.07	1.0	3.9	Mb	USGS	12
889945006	03/15/98	06:56:46	36.43	-89.52	5.0	2.6	Ml	USGS	21
890252528	03/18/98	20:22:08	35.20	-84.20	5.0	2.5	Ml	USGS	18
891021595	03/27/98	17:59:55	47.44	-93.46	0.0	3.2	Mb	IDC	5
892059409	04/08/98	18:16:49	36.94	-89.02	14.0	3.2	Ml	USGS	24
892098821	04/09/98	05:13:41	36.40	-89.50	7.0	2.7	Lg	USGS	19
892310552	04/11/98	16:02:32	43.09	-104.66	0.0	3.3	Mb	IDC	19
892461371	04/13/98	09:56:11	34.61	-80.47	5.0	3.9	Ml	USGS	29
892636422	04/15/98	10:33:42	30.19	-103.30	10.0	3.6	Ml	USGS	10
892839916	04/17/98	19:05:16	43.23	-104.64	0.0	3.5	Mb	IDC	33
892916572	04/18/98	16:22:52	45.57	-74.99	18.0	4.1	Ml	USGS	32
893201306	04/21/98	23:28:26	38.17	-78.57	8.0	2.6	Ml	USGS	31
893438802	04/24/98	17:26:42	47.48	-92.78	0.0	3.2	Ml	IDC	5
893690566	04/27/98	15:22:46	35.45	-102.38	5.0	3.2	Ml	USGS	19
893772782	04/28/98	14:13:02	34.78	-98.42	5.0	4.2	Ml	USGS	17
894543881	05/07/98	12:24:41	32.37	-88.11	10.0	2.8	Ml	USGS	13
894874034	05/11/98	08:07:14	36.88	-89.07	8.0	2.6	Ml	USGS	19
895629208	05/20/98	01:53:28	38.76	-78.42	3.0	2.4	Ml	USGS	23
896111222	05/25/98	15:47:02	46.46	-81.17	1.0	3.9	Ml	USGS	11
896249092	05/27/98	06:04:52	36.11	-89.01	5.0	2.4	Ml	USGS	20
897013862	06/05/98	02:31:02	35.48	-80.82	5.0	3.2	Ml	USGS	24
897382431	06/09/98	08:53:51	44.75	-73.72	5.0	3.4	Ml	USGS	9
898070423	06/17/98	08:00:23	35.93	-84.41	10.0	3.6	Ml	USGS	26
898187198	06/18/98	16:26:38	42.62	-103.00	5.0	3.4	Ml	USGS	31
898701601	06/24/98	15:20:01	32.50	-87.95	5.0	3.4	Ml	USGS	18
898805307	06/25/98	20:08:27	42.93	-104.67	0.0	3.5	Mb	IDC	28
899708044	07/06/98	06:54:04	25.02	-93.63	10.0	3.4	Mb	USGS	4
899837084	07/07/98	18:44:44	34.72	-97.59	5.0	3.2	Ml	USGS	19
899949133	07/09/98	01:52:13	44.73	-73.68	0.0	2.5	Ml	USGS	4
900260930	07/12/98	16:28:50	43.55	-101.11	5.0	3.1	Ml	USGS	23
900394729	07/14/98	05:38:49	35.34	-103.47	5.0	3.0	Ml	USGS	17

Table 1 (Continued)

Epoch	Date	Origin	Lat	Lon	Depth	Mag		Src	#Sta
900476691	07/15/98	04:24:51	36.69	-89.52	13.0	3.1	Ml	USGS	21
900486484	07/15/98	07:08:04	47.02	-66.61	5.0	4.0	Ml	USGS	5
901145517	07/22/98	22:11:57	37.65	-90.20	18.0	2.7	Ml	USGS	19
901216337	07/23/98	17:52:17	48.59	-104.15	0.0	3.5	Mb	IDC	19
901683119	07/29/98	03:31:59	48.37	-104.71	5.0	3.8	Mb	USGS	19
901789041	07/30/98	08:57:21	46.17	-74.72	18.0	4.0	Lg	USGS	15
903114312	08/14/98	17:05:12	27.74	-99.86	0.0	3.8	Mb	IDC	4

2.3 Stations Contributing to the Seismic Waveform Archive

Table 2 presents a list of the 219 seismic stations that recorded the waveform data in the archive at NRC. The columns of this table are:

Sta	The 3- or 4-byte station code that serves as a unique identifier for the station.
Lat	The latitude of the station, in decimal degrees. A positive value indicates the Northern Hemisphere.
Lon	The longitude of the station, in decimal degrees. A negative value indicates the Western Hemisphere.
Elev	The elevation of the station, in kilometers above mean sea level.
Type	A designation "3C" in Table 2 indicates that the station reports "3-component" data, *i.e.*, separate data channels for north-south, east-west, and vertical seismometers. A designation "1C" indicates that the station reports data from only the vertical seismometer. A designation "4C" indicates that a fourth data channel is recorded, probably from a separate high-frequency vertical seismometer. These data were taken from the "site" table at one of the same data centers that provided the waveform data themselves. An underscore indicates that the "site" table did not indicate how many components of data are recorded at this station.
# Evt	The number of events in Table 1 for which this station recorded data that are stored in the seismic waveform archive at NRC.

Table 2

The 219 Stations Contributing to the Seismic Waveform Archive at NRC

Sta	Lat	Lon	Elev	Type	#Evt
AAM	42.299721	-83.656110	0.249	3C	41
ABL	34.850811	-119.220800	1.981	1C	2
AHID	42.765388	-111.100300	1.960	3C	10
ALQ	34.942501	-106.457400	1.849	3C	48
ANMO	34.946201	-106.456700	1.840	3C	54
ARN	37.349331	-121.532600	0.628	1C	2
ARNY	41.303200	-74.114500	0.430	-	4
ARUT	37.787998	-113.440300	1.646	1C	13
BGR	44.828800	-74.374200	0.297	-	7
BINY	42.199310	-75.986100	0.498	3C	61
BLA	37.211300	-80.420990	0.634	3C	82
BLUE	43.894001	-74.454000	0.601	3C	9
BMN	40.431469	-117.221700	1.500	3C	3
BMW	46.474998	-123.228000	0.870	1C	1
BONR	37.955189	-118.301600	2.582	1C	2
BRC	44.427500	-75.583000	0.083	-	4
BW06	42.777779	-109.555500	2.200	3C	15
CALA	40.113400	-108.535800	2.345	-	3
CALI	40.365299	-108.567000	2.085	-	3
CBKS	38.813999	-99.737380	0.677	3C	57
CCM	38.055672	-91.244580	0.223	3C	87
CEH	35.890831	-79.092780	0.152	3C	54
CHIP	44.798000	-75.195000	0.097	-	3
CLER	44.383999	-74.245000	0.498	3C	5
CRNY	41.311800	-73.548200	0.293	-	4
CSD	40.436401	-108.279100	1.931	-	3
CSP	34.298031	-117.357400	1.268	1C	1
CTU	40.692501	-111.750300	1.731	3C	10
CVL	37.981392	-78.460830	0.167	1C	69
CWPT	36.009109	-89.626380	0.076	1C	14
DAU	40.412498	-111.255800	2.771	1C	16
DLAR	35.809700	-90.008000	0.067	1C	12
DNH	43.122500	-70.894800	0.024	-	42
DOUG	40.570301	-108.688600	2.153	-	3
DPW	47.870640	-118.202800	0.892	1C	6
DRLN	49.256001	-57.504200	0.238	3C	5
DRY	40.699501	-108.536600	2.059	-	3

Table 2 (Continued)

Sta	Lat	Lon	Elev	Type	#Evt
DUG	40.195000	-112.813300	1.477	3C	17
DXB	42.061000	-70.699200	0.008	-	34
EDIT	35.862999	-89.554310	0.148	1C	8
ELK	40.744831	-115.238700	2.210	3C	10
ELN	37.228300	-80.751700	0.634	-	10
EMUT	39.813999	-110.815300	2.268	1C	19
EYMN	47.946190	-91.495000	0.475	3C	12
FFC	54.724998	-101.978300	0.338	3C	3
FINE	44.265000	-75.167000	0.000	-	1
FLET	44.722700	-72.951700	0.366	-	6
FRD	33.494701	-116.602200	1.164	-	1
FVM	37.984001	-90.426000	0.310	3C	5
FWGP	40.964199	-108.768000	2.077	-	3
FWV	37.581700	-80.811700	0.756	-	10
GAC	45.703300	-75.478300	0.062	5C	42
GHV	37.794170	-78.107330	0.107	1C	44
GLA	33.049999	-114.830000	0.000	-	1
GLD	39.750561	-105.221300	1.762	1C	55
GLO	42.640300	-70.727200	0.015	-	42
GLST	36.269112	-89.287690	0.122	1C	34
GMW	47.547920	-122.786300	0.506	1C	2
GOGA	33.411190	-83.466610	0.150	3C	79
GPD	41.017700	-74.460800	0.360	-	2
GRAI	43.809310	-111.335700	2.231	1C	4
GRAN	41.108398	-108.641900	2.164	-	3
GWDE	38.825611	-75.617110	0.019	3C	25
HAWT	36.225609	-89.659600	0.081	1C	13
HAYW	43.639580	-110.332500	2.835	1C	11
HBF	32.933060	-80.377670	0.010	1C	47
HBVT	44.362300	-73.065000	0.342	-	5
HELL	41.047001	-108.576600	2.153	-	3
HIAW	41.014801	-108.734400	2.105	-	3
HKSI	40.596700	-74.122000	0.107	-	1
HKT	29.950001	-95.833340	-0.121	3C	50
HMR	38.154671	-121.800300	0.065	1C	2
HRV	42.506390	-71.558320	0.180	3C	61
HVU	41.779671	-112.775000	1.609	1C	8
HWUT	41.607310	-111.565000	1.720	3C	12

Table 2 (Continued)

Sta	Lat	Lon	Elev	Type	#Evt
IKP	32.648830	-116.108000	0.957	1C	2
ISCO	39.799720	-105.613400	2.743	3C	24
JFWS	42.914890	-90.248800	0.318	3C	33
JNMT	40.459202	-108.020300	2.231	-	3
JSC	34.278889	-81.258050	0.120	1C	60
JWM	40.571701	-108.603800	2.077	-	3
KEEN	44.264999	-73.821990	0.485	3C	12
KINN	41.180099	-108.592500	2.292	-	3
KNB	37.016609	-112.822400	1.715	3C	8
KNW	33.714100	-116.711800	1.507	-	1
KVN	39.050999	-118.099900	1.829	1C	2
LANG	40.873100	-108.290600	2.258	-	3
LBFM	41.347000	-121.890300	1.982	1C	2
LBNH	44.240108	-71.925880	0.367	3C	55
LDS	37.242500	-113.351400	1.102	3C	7
LGPM	40.912498	-122.828600	1.290	1C	2
LHS	34.479172	-80.808320	0.120	1C	61
LIME	40.871399	-108.785800	2.371	-	3
LKWY	44.565189	-110.400000	2.424	3C	10
LNOR	45.871059	-118.285000	0.768	1C	2
LON	46.750000	-121.809900	0.854	1C	2
LOOK	40.863400	-108.482300	2.415	-	3
LOZ	44.620000	-74.580000	0.482	-	8
LSC	40.532799	-108.441300	1.802	-	3
LSCT	41.678391	-73.224380	0.318	3C	41
LTX	29.333891	-103.666900	1.013	3C	23
LVA2	33.351601	-116.561500	1.435	-	1
MANY	41.222000	-73.868600	0.133	-	4
MAYB	40.482800	-108.192800	1.888	-	3
MCW	48.679668	-122.832300	0.693	1C	1
MCWV	39.658112	-79.845610	0.280	3C	69
MDV	43.999200	-73.181200	0.134	-	4
MEMM	37.666328	-118.939100	0.000	1C	5
MIAR	34.545700	-93.572990	0.207	3C	98
MIV	44.074700	-73.534000	0.317	-	6
MM01	42.317501	-72.711700	0.122	-	19
MM02	42.166000	-73.718690	0.134	-	22
MM03	42.038799	-74.846190	0.670	-	24

Table 2 (Continued)

Sta	Lat	Lon	Elev	Type	#Evt
MM04	41.853001	-76.197990	0.473	-	21
MM05	41.653000	-76.921990	0.701	-	25
MM06	41.391499	-78.126190	0.647	-	23
MM07	41.257130	-79.135000	0.518	-	28
MM08	41.109501	-80.068190	0.381	-	29
MM09	40.791100	-81.205590	0.357	-	30
MM10	40.614700	-82.303100	0.346	-	23
MM11	40.221401	-83.194700	0.283	-	26
MM12	40.043900	-84.372490	0.305	-	25
MM13	39.831699	-85.311400	0.337	-	24
MM14	39.549435	-86.394760	0.290	-	21
MM15	39.294521	-87.313460	0.191	-	15
MM16	38.921902	-88.304570	0.165	-	21
MM17	38.669441	-89.325540	0.144	-	21
MM18	38.528679	-90.568600	0.186	-	17
MNV	38.432800	-118.153100	1.524	3C	1
MO18	38.514381	-90.564370	0.161	-	3
MRCM	37.671669	-118.506300	2.030	1C	1
MSAR	35.784170	-90.146860	0.069	1C	6
MSNY	44.998300	-74.862000	0.055	-	7
MSU	38.513329	-112.174100	2.141	1C	18
MTUM	37.353329	-118.563400	1.810	1C	1
MYNC	35.073891	-84.127890	0.550	3C	53
NA12	37.983060	-77.879450	0.125	1C	18
NAV	37.316669	-80.793050	0.610	1C	25
NDH	40.370602	-108.136300	1.957	-	3
NEE	34.823002	-114.596000	0.139	-	10
NEW	48.263329	-117.120000	0.760	3C	4
NMMO	36.588001	-89.552000	0.090	1C	4
NOQ	40.652500	-112.120300	1.622	3C	5
ONH	43.279200	-71.505600	0.280	-	41
OXF	34.511810	-89.409180	0.101	3C	54
PACK	43.535000	-73.818030	0.287	3C	4
PAL	41.004200	-73.909200	0.091	3C	5
PD31	42.766701	-109.557800	2.214	-	20
PEC	33.891941	-117.160600	0.616	1C	1
PFO	33.609169	-116.455200	1.280	3C	2
PHAM	35.835999	-120.398400	0.455	1C	1

Table 2 (Continued)

Sta	Lat	Lon	Elev	Type	#Evt
PINI	43.507600	-111.345700	1.932	1C	3
PINR	40.363400	-108.368400	2.097	-	3
PIT	44.169200	-74.241700	0.311	-	1
PKEM	36.061501	-120.109000	0.288	1C	3
PLG	41.004200	-73.909200	0.091	-	3
PLM	33.353439	-116.861600	1.692	1C	3
PNH	43.094200	-72.135800	0.659	-	6
PNY	44.834200	-73.555000	0.177	-	5
PRM	34.083328	-82.363320	0.254	1C	12
PTI	42.870331	-112.370100	1.670	1C	8
PTN	44.570000	-74.981900	0.197	-	8
PV08	38.576309	-108.647000	2.940	1C	38
PV09	38.498661	-109.133400	2.652	1C	38
PV10	38.376339	-109.038800	2.316	1C	40
PWLA	34.979970	-88.063670	0.204	1C	23
QUAR	35.643940	-90.649140	0.115	1C	23
REDW	43.362390	-110.851800	2.192	1C	10
RELT	36.033199	-89.302190	0.107	1C	12
RMW	47.459690	-121.805300	1.024	1C	2
RRE	41.168701	-108.732300	2.353	-	3
RRW	41.138901	-108.858900	2.320	-	3
RSNY	44.548328	-74.529990	0.396	3C	6
RSSD	44.120419	-104.036100	2.060	3C	32
RW3	38.250170	-107.687000	2.603	1C	8
RW4	38.156830	-107.615700	2.739	1C	11
RW5	38.080000	-107.832500	2.991	1C	4
SADO	44.769402	-79.141700	0.243	4C	14
SCHQ	54.831902	-66.833600	0.501	3C	10
SFTN	35.357498	-90.018750	-0.022	1C	23
SGS	33.192670	-80.511830	0.024	1C	32
SMR	40.721699	-108.302800	1.900	-	3
SND	33.551899	-116.612900	1.358	-	1
SRU	39.110828	-110.523800	1.804	1C	23
SSK	34.210670	-117.693000	1.683	1C	2
SSPA	40.635811	-77.888000	0.158	3C	85
STEW	44.049720	-110.681700	2.316	1C	9
STLK	44.223500	-75.015000	0.513	-	1
SUTT	40.578701	-108.285800	1.852	-	3

Table 2 (Continued)

Sta	Lat	Lon	Elev	Type	#Evt
SWB	40.654202	-108.380600	1.815	-	3
TANK	40.405300	-108.737000	2.441	-	3
TBR	41.141700	-74.222200	0.261	-	4
TKL	35.658001	-83.774000	0.351	-	13
TMI	43.305561	-111.918000	2.179	1C	13
TNP	38.082001	-117.218000	1.932	1C	2
TPH	38.075000	-117.222500	1.884	3C	1
TPNV	36.928669	-116.223600	1.600	3C	1
TRO	33.523399	-116.425600	2.628	-	1
TUC	32.309719	-110.784100	0.906	3C	30
TWAR	35.361389	-90.559690	0.061	1C	16
TWIN	40.755600	-108.384400	1.883	-	3
TX00	29.333799	-103.667000	1.013	-	26
TYS	38.526001	-90.566000	0.195	1C	10
ULM	50.249901	-95.875000	0.281	3C	15
VGB	45.515671	-120.777400	0.729	1C	1
VMCK	41.078899	-108.709800	2.136	-	3
VMSC	40.928398	-108.648300	2.006	-	2
WADM	36.366112	-89.795890	0.078	1C	16
WCC	41.058500	-73.791800	0.100	-	1
WCI	38.229000	-86.293800	0.500	3C	45
WFM	42.610600	-71.490600	0.088	-	42
WMC	33.573601	-116.674600	1.271	-	1
WMOK	34.737888	-98.780990	0.486	3C	66
WMV	37.108500	-80.970500	0.000	-	10
WVOR	42.433941	-118.636700	1.344	3C	3
WVT	36.130000	-87.830000	0.153	3C	44
YSCF	40.428902	-108.430000	1.966	-	3
YSNY	42.475811	-78.537490	0.628	3C	53
ZENO	40.602798	-108.824500	2.302	-	3

2.4 Master Table of Stations for Each Event

Table 1 is a summary table showing how many of the 219 stations recorded waveforms for each of the 232 events, and Table 2 is a summary table showing how many of the 232 events were recorded at each one of the 219 stations. In addition to these summary tables, there is stored on-line a master table showing all seismograms archived. Each entry represents a unique event / station / channel record. This file is viewable in ArcView as a table. The information contained in this ArcView table consists of: Year, Month, Epoch, SAC File, Size (bytes), Station, Channel, Source, Distance (degrees), and Calibration (Y or N). The Year, Month, and Epoch are sufficient to identify the directory path where the SAC File containing the waveform data is located on the file system of the workstation *res18*. The Size of the SAC File is expressed in bytes. The Source field shows from which data center the seismogram was retrieved. The Calibration field indicates whether the waveform is calibrated for ground motion, and the value of this field is either "Y" or "N". This field was included solely because about 22% of the USGS data had missing calibration factors. Thus it is only USGS data that will have a value of "N" in this field. It is strongly recommended that records with "N" in this field not be used for ground motion studies that require accurate amplitude values. These waveforms are nevertheless useful for spectral analyses where the *relative* amplitudes at high and low frequencies, rather than the absolute amplitudes, are significant.

This master table is 8533 lines long, since there is an entry for each event / station / channel combination that is present in the waveform archive. The table is in ASCII format, so it can be read by the ArcView Geographic Information System [GIS]. Importing this table into ArcView permits maps to be drawn showing the geographic distribution of the stations that reported waveform data for any selected event. This station distribution can then be used to answer queries about the distances from the epicenter to every station, to show the geological environments along the propagation path to each station (which is important for understanding the attenuation of the seismic waves), to show the topographic relief along the path (which is important for understanding the scattering of the seismic waves), and of course to show the relative proximity of each station to power plant sites, so that the seismograms can be identified which best predict the ground motion at those sites.

3. DESCRIPTION OF DATA INSTALLED IN THE ARCVIEW GEOGRAPHIC INFORMATION SYSTEM AT NRC

3.1 Data Types

The ArcView Geographic Information System constructs maps from overlapping data layers known as "themes". Each theme corresponds to a separate feature in the map legend. For instance, soil type, land cover usage, population density, governmental divisions such as states and counties are all example of polygonal themes; rivers, streets, power lines, and boundaries between governmental divisions are all examples of line (actually, arc) themes; and city centers, building locations, seismic stations, and earthquake epicenters are all examples of point themes, since they are usually represented on a map using only a single value of the latitude and longitude. Whether a theme is a polygon, a line, or a point, ArcView stores the geographic information about its spatial location in the form of a "shapefile". In order to construct a geographic database, themes must be converted from their native data format into shapefiles. For point themes, this is a straightforward process of reading in a table of latitudes and longitudes and saving them as a shapefile. For line and polygon data sets, the conversion is more complicated. Fortunately, certain data formats that are used by agencies such as the U.S. Geological Survey can be converted to a format that ArcView can handle, and then they can be stored on the disk as shapefiles. We now describe three of those important data formats that were used to construct the ArcView database, namely Digital Elevation Models, Digital Terrain Elevation Data, and Digital Line Graphs.

3.1.1 Digital Elevation Models (DEM) - 7.5 minute quadrangles, 1:24000 (large) scale

Digital Elevation Models (DEM) provide elevation data which may be useful in studying surface characteristics such as slope and surface roughness, or providing a base map. An attempt was made to collect all available large-scale (1:24000) 7.5 minute quadrangles for the 69 nuclear power plant sites in the central and eastern U.S. Online data was retrieved for 59 nuclear plant sites from the USGS Geo Data web and FTP site:

http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html .

Occasionally, two nuclear plants were located on the same quadrangle.

DEMs consist of an array of equally spaced elevation values in raster form. Large (1:24000) scale DEMs have 30 x 30 meter data spacing, and are projected in the Universal Transverse Mercator (UTM) coordinate system. Elevation values may be in units of either meters or feet. In the ArcView project installed on the system at NRC, called "sdaes.apr", DEM themes are displayed along with Digital Line Graph (DLG) data in six display view windows, one for each UTM zone. All selected DEMs are based on the 1927 North American Datum (NAD) which uses the Clarke 1866 spheroid. Therefore, a custom UTM projection, rather than standard, was chosen. ArcView's standard projection uses the more recent GRS 1980 spheroid and is based on the 1983 NAD.

On-line 1:24000 scale DEMs from USGS are only available in Spatial Data Transfer Format (SDTS) which must be converted to "dem" format before importing into ArvView3.0a. Conversion software exists at the following Bureau of Land Management (BLM) FTP site:

ftp://blm.gov/pub/gis/sdts/dem .

Program "sdts2dem" was used to convert SDTS to .dem format (a DOS PC copy resides in the NRC project directory /sdts/dem). ArcView3.0a often exhibited a bug, however, when attempting to import USGS DEMs, resulting in a failure to load the data. This is a known bug, however, and was usually overcome by exiting and restarting ArcView, sometimes numerous times. For a detailed description of SDTS DEM file structure, see the USGS publication "The Spatial Data Transfer Standard Mapping of the USGS Digital Elevation Model", available by FTP at

ftp://sdts.er.usgs.gov/pub/sdts/datasets/raster/dem

in either portable document file format (demmap.pdf) or Word Perfect format (demmap.wp).

3.1.2 Digital Terrain Elevation Data (DTED – Level 0)

Digital Terrain Elevation Data (DTED) Level 0 consists of a 1-degree by 1-degree elevation model with data sampling of 30-arc-second spacing (approximately 1 km). The data is available by FTP at the National Imagery and Mapping Agency (NIMA) web site (formerly Defense Mapping Agency) at the following URL:

http://www.nima.mil/geospatial/products/DTED .

Elevation values are in units of meters. Level 0 DTEDs represent a thinned dataset extracted from the NIMA DTED Level 1 holdings that have spatial resolution of 3-arc-sec. The 3-arc-second Level 1 data is equivalent to the 1-degree DEMs (1:250,000 scale) available from the USGS Geo Data web and FTP site:

http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html ,

except that the header and data formats differ. Only the NIMA DTED Level 0 (30-arc-sec) data files were installed in the ArcView project. Additional documentation is also available at the above Internet web sites.

3.1.3 Digital Line Graphs (DLG) – 7.5 minute quadrangles, 1:24000 (large) scale:

The USGS also makes Digital Line Graph (DLG) files available by anonymous FTP at the USGS Geo Data web site described above. DLGs are digital vector representations of cartographic features such as hydrography and roads, and may provide useful information when overlaid on top of DEMs. Only the 1:24000 (large) scale 7.5 minute quadrangles were retrieved for available nuclear power plant sites. These were installed along with DEMs in six display view windows of ArcView project "sdaes.apr" according to UTM zone. In some cases, a DLG may exist even if the corresponding DEM is unavailable.

Since ArcView3.0a cannot import either SDTS or DLG-3 formats directly, a detailed procedure was followed to convert SDTS format to shapefiles and link the attribute data. The on-line 1:24000 (large) scale DLGs are available only in SDTS format (both SDTS and DLG-3 formats may be available on CD-ROM). First, SDTS files (.DDF suffix) must be converted to DLG-3 optional format using program "sdts2dlg". Then an Avenue script ("DLGShape") is used to convert DLG-3 files to shapefiles within ArcView. Other software extracts attribute data and links them. For complete instructions, the U.S. Fish and Wildlife Service web pages maintained by Deb Southworth offer an excellent overview and additional links at the following URLs:

http://www.fws.gov/data/gisconv/sdtsovr.html and

http://www.fws.gov/data/gisconv/sdts2av.html .

Software programs and documentation for SDTS conversion are available by FTP at the Bureau of Land Management (BLM) FTP site:

ftp://blm.gov/pub/gis/sdts/dlg .

A full description of DLG-3 SDTS file structure and attribute codes can be found in the publication "DLG-3 SDTS Transfer Description" available on-line by anonymous FTP at the following USGS site:

ftp://sdts.er.usgs.gov/pub/sdts/datasets/tvp/dlg3 ,

either in PostScript file "dlg3sdts.ps" or Word Perfect file "dlg3sdts.wp".

The SDTS conversion tools for DLGs were developed for the 1:24000 (large) scale data and have worked with 1:100,000 scale DLG files also. However, the software has not been thoroughly tested and may fail to link all attributes. For example, the elevation contour values of the hypsography layer were not linked since they are stored in another SDTS attribute file.

On-line large scale DLGs in SDTS format are packaged as compressed tar files containing a set of SDTS module files for a given data category or layer. Several layers may be available, including:

1) Boundaries – political and administrative boundaries;
2) Hydrography – flowing water, streams, shorelines, and related features;
3) Hypsography – elevation contours of surface topography;
4) Man Made Features
5) Non-vegetative features – naturally occuring features such as sand beaches.
6) Transportation – consists of 3 layers: roads, railroads, and miscellaneous transportation such as power stations and transmission lines.

Not all layers are available for each 7.5 minute quadrangle. Furthermore, conversion software performed inconsistently, and it frequently failed on layers such as man made and non-vegetative features. Few attributes were linked in the boundaries layer and, as stated above, no elevation contour values were linked in the hypsography layer. Results were significantly improved for the hydrography and transportation layers. Attribute look-up tables, which were used to link descriptions with attribute codes, were either downloaded from web sites or manually edited, and are saved under the NRC project directory "GIS/DLG/lookup".

3.2 ArcView Project File

An ArcView "project" file is, a loose sense, a set of instructions describing how various data sets should be grouped into different "views" of the database and exactly how those "views" should be displayed graphically on the computer console as interactive maps. All of the GIS data that have been installed on the NRC computer system for the current contract are managed through a single project file, "SDAES.apr". This project file contains 20 separate views. We now describe each one of these views in turn, and for each type of view (i.e., each different kind of interactive map) we

show an ArcView "layout" map that illustrates the view. The different data "themes" that make up each view are described in the text and are also indicated in the map legends on the layouts. However, not all themes can be shown for every view, since some themes (*i.e.*, data layers) completely cover up other themes. Of course, on the interactive views on the computer, the SDAES system user has complete control of which themes to make visible or invisible and in which order to display the overlapping data layers.

3.2.1 "Central U.S. – Seismic Hazards" View

This view shows selected database themes from USGS Open File Report 95-0241, "Elements of Infrastructure and Seismic Hazard in the Central United States – Database", and was digitally compiled by Susan Rhea (rhea@gldvxa.cr.usgs.gov).

The Modified Mercalli Intensity Scale shows outlines of hypothetical values fromMmi = VI through X for great earthquakes that might occur along the New Madrid Seismic zone. Digitized by USGS from Algemissen and Hopper (1985), original scale about 1:6,670,000.

Nuclear facilities shown as black squares represent 44 facilities housing significant nuclear material.

The portion of the "Geologic Map" shows boundaries of Quaternary and Cenozoic-Mesozoic Units. Digitized by USGS from King and Biekman (1974), original scale 1:2,500,000.

FTP site: greenwood.cr.usgs.gov (136.177.48.5) in /pub/open-file-reports/ofr-95-0241.

References:

1) Algermissen, S.T., and Hopper, M.G. 1984, Estimated maximum regional seismic intensities associated with an assemblage of great earthquakes that might occur along the New Madrid seismic zone, east-central United States: U.S. Geological Survey Miscellaneous Field Studies Map MF-1712, 1 sheet, scale about 1:3,770,000.

2) King and Biekman, Geologic Map of the United States (exclusive of Alaska and Hawaii): U.S. Geological Survey 1974, 3 sheets, scale 1:2,500,000.

3) Wheeler, R.L., Rhea, Susan, and Tarr, A.C., 1994, Elements of infrasructure and seismic hazard in the central United States, in Shedlock, K..M., and Johnston, A.C., Eds., Investigations of the New Madrid seismic zone: U.S. Geological Survey Professional Paper 1538-M, 3 plates, scale 1:2,500,000, 61p.

View Projection:

1) Albers Equal Area Conic (Conterminous U.S.)
2) Spheroid: Clarke 1866
3) Central Meridian: -96.0
4) Reference Latitude: 37.5
5) Parallel 1: 29.5
6) Parallel 2: 45.5
7) False Easting: 0.0
8) False Northing: 0.0

Map Units: meters

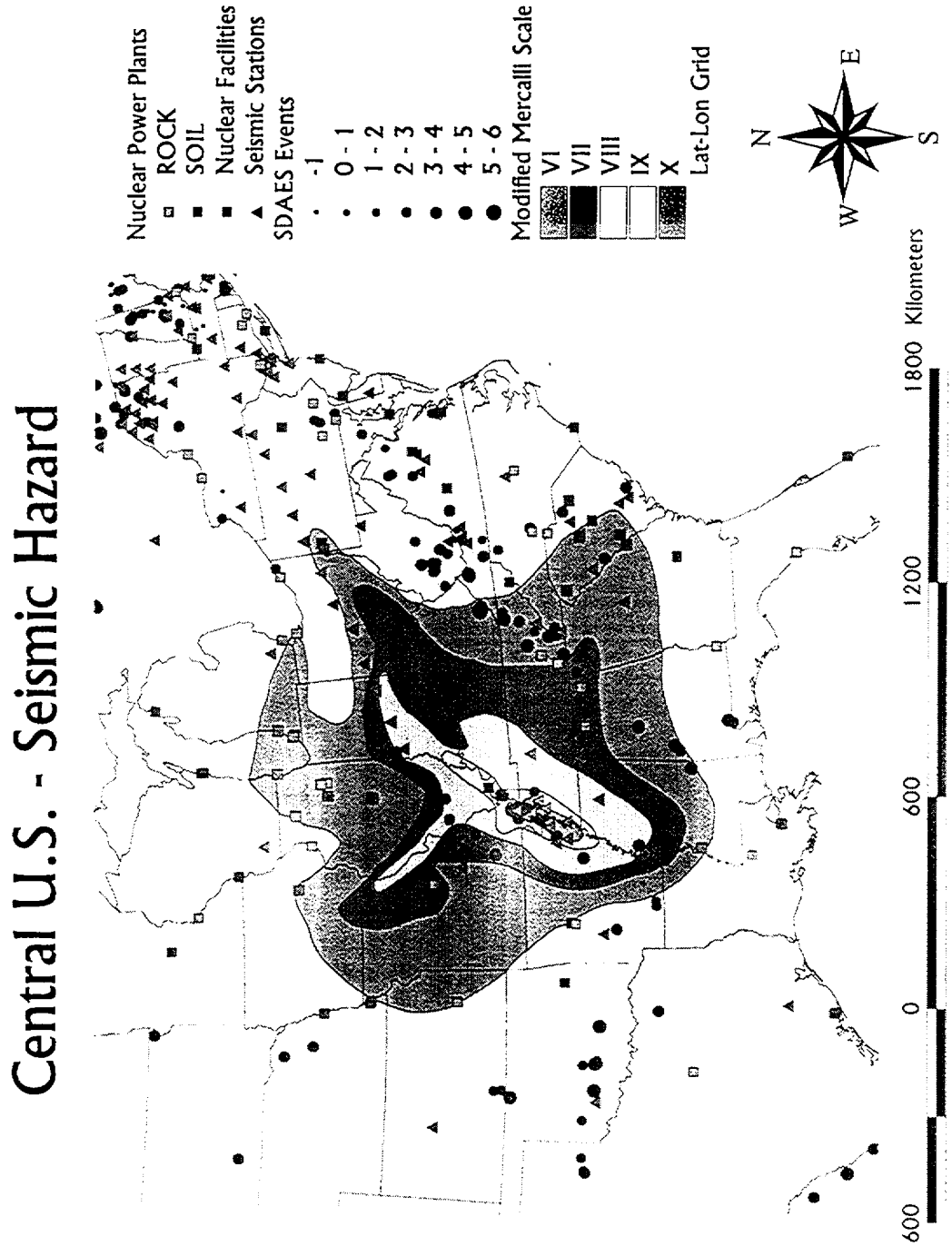

Figure 1. "Central U.S. – Seismic Hazards" View. Map showing Mercalli Intensities estimated from a hypothetical New Madrid earthquake.

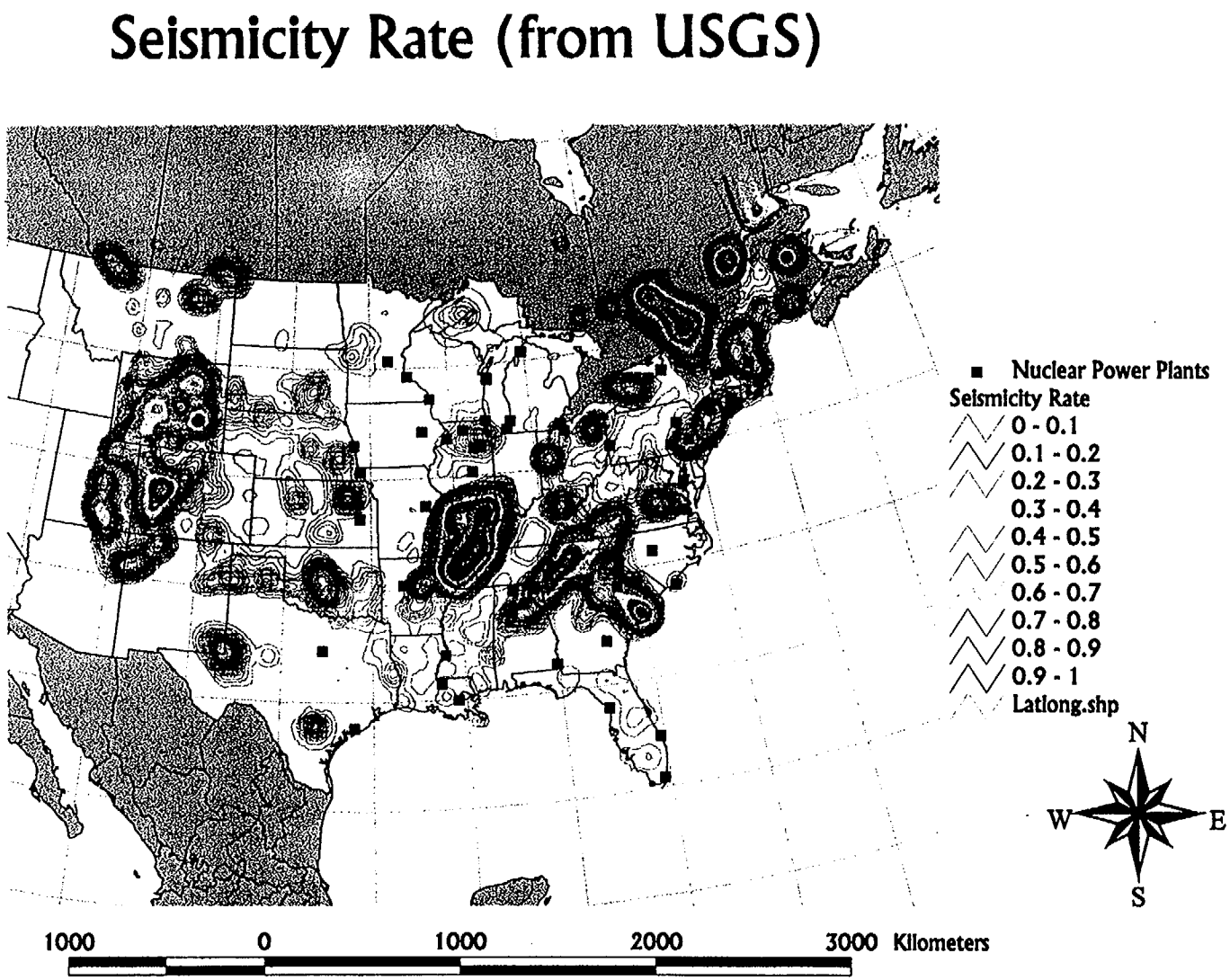

Figure 2. "Central U.S. – Seismic Hazards" View. Map showing the seismicity rate.

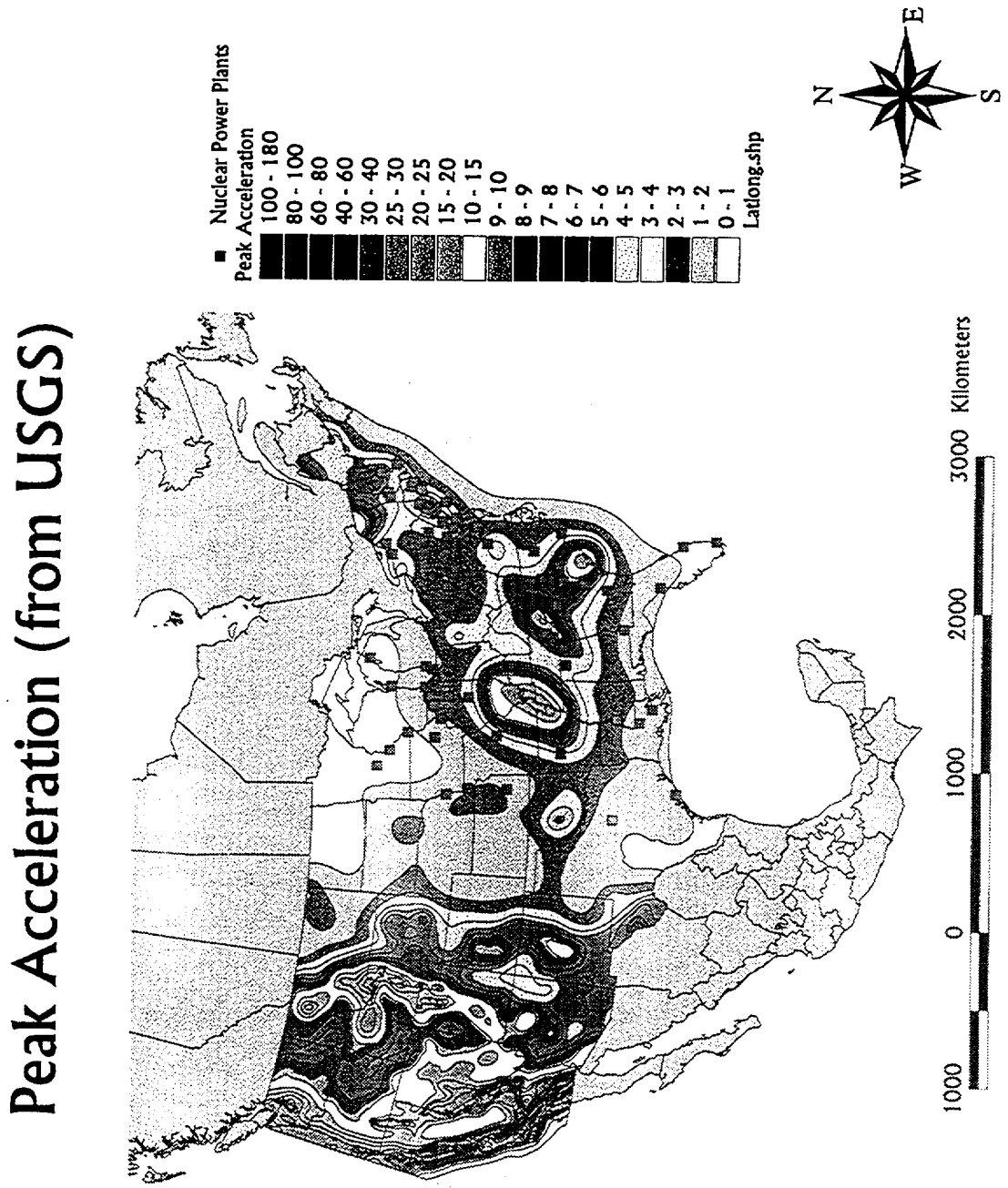

Figure 3. "Central U.S. – Seismic Hazards" View. Map showing the estimated peak acceleration from a hypothetical New Madrid earthquake.

3.2.2 "CRUST5.1 Model and Elastic Parameters" View

The CRUST5.1 model was developed as a 5x5 degree global crustal model by Walter Mooney (USGS), Gabi Laske, and Guy Masters (1998). The global model is composed of 139 key 1D-profiles (the crustal types) where one of these profiles is assigned to each 5x5 degree cell. Each individual profile is a 7 layer 1D-model consisting of:

1) ice
2) water
3) soft sediments
4) hard sediments
5) upper crust
6) middle crust
7) lower crust

Parameters Vp, Vs and rho (density) are given for the lower 5 of these 7 layers as well as for the mantle below the Moho. The overlying ice and water layers, although explicitly tabulated in the CRUST5.1 model, are not shown in this View since they are not important for the conterminous United States, which is the area of interest for the Geographic Information System at NRC.

The data for the 139 different types of crustal profiles used in the CRUST5.1 model were gathered from seismic experiments and then averaged globally for similar geological and tectonic settings (such as Archean, early Proterozoic, rifts, etc.). These averages were used to assign structures to those regions for which no seismic data were available.

The CRUST5.1 model differs from previous models in that the thickness and seismic/density structure of sedimentary basins is taken into account more completely. The velocity structure of these basins was estimated using a significantly larger database of crustal structure than in previously published models. The compressional wave, shear wave, and density have been explicitly specified using newly available constraints from field and laboratory studies. The velocity structure of the crystalline crust and uppermost mantle is estimated from the statistical average of regions with a similar crustal age and tectonic setting.

A map that is related to the one in this View is the global digital map of sediment thickness that was produced by Laske and Masters (1999), two of the authors of CRUST5.1. This newer map incorporates sediment thickness for continental areas (including the shelves) obtained by digitizing data provided by the EXXON production research group, and it is digitized on a scale that is 25 times finer than CRUST5.1 (*i.e.*, using a 1x1 degree grid rather than a 5x5 degree grid). The CRUST5.1 model had been completed before the new higher-resolution model became available. We suggest that in the future the new 1x1 degree map should be used to replace the CRUST5.1 map in this View, since both the higher resolution and the incorporation of the data from EXXON will be valuable in improving the accuracy of any geophysical calculations made using the data taken from this View. An example of a calculation that is highly sensitive to the thickness of the crust is the modeling of the propagation of Lg waves, so any improvement in the accuracy and resolution of the model presented in this View will be quite useful in performing the geophysical interpretations that the Geographic Information System at NRC is intended to facilitate.

FTP site: carp.ucsd.edu (132.239.154.12)

References:

Laske, G., and G. Masters, A global digital map of sediment thickness. Published on the Internet at the Web site http://mahi.ucsd.edu/Gabi/sediment.html in June, 1999.

W.D. Mooney, G. Laske and G. Masters, CRUST 5.1: A global crustal model at 5x5. J Geophys. Res., 103, 727-747, 1998.

directory: /pub/gabi/crust

View Projection:

1) Albers Equal Area Conic
2) Spheroid: Clarke 1886
3) Central Meridian: -96.0
4) Reference Latitude: 37.5
5) Parallel 1: 29.5
6) Parallel 2: 45.5
7) False Easting: 0.0
8) False Northing: 0.0

Map units: meters

Theme Descriptions:

1) Crustal Thickness (km) – Interpolated surface derived from a global 5x5 degree grid of lat, lon, and thickness values stored in ASCII file "crthick.txt". Interpolation parameters: Inverse Distance Weighting (IDW), nearest neighbors = 12, exponent (power) = 3. Extent of coverage clipped at display window showing continental U.S. Additional information is contained in the "Theme Properties" window.
2) Elevation (km) – Interpolated surface of global topography (5x5 deg grid) based on ASCII file "topo.txt".
3) Sediment Thickness (km) – interpolated surface derived from "sed.txt".
4) P Velocity, S Velocity, and Rho – elastic parameters for each of 5 layers (soft sediments, hard sediments, upper crust, middle crust, and lower crust) based on 5x5 degree global grid.

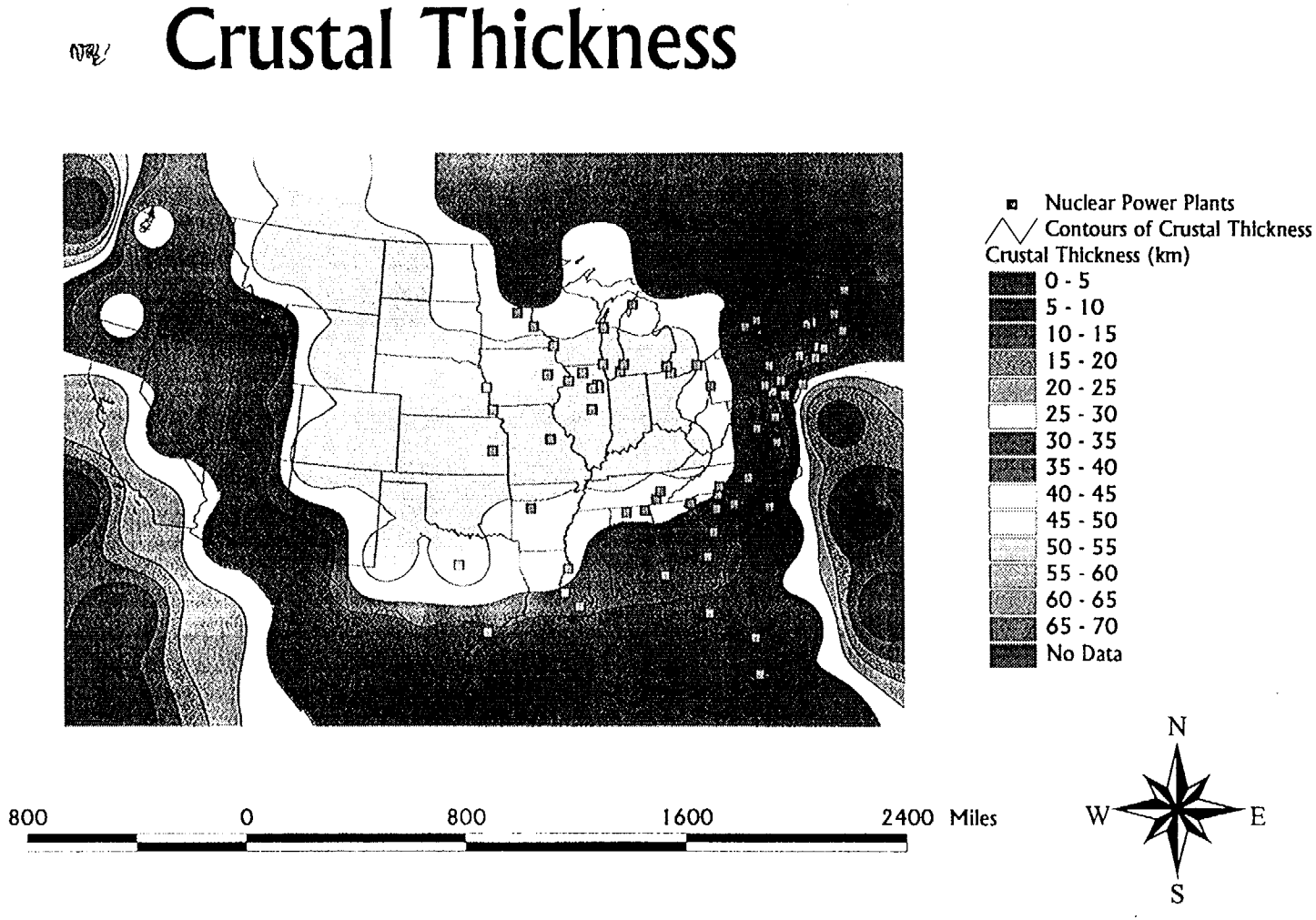

Figure 4. "CRUST5.1 Model and Elastic Parameters" View. Map showing the crustal thickness for the CRUST5.1 earth model.

3.2.3 Digital Chart of the World

The Digital Chart of the World (DCW) was originally developed by ESRI for the Defense Mapping Agency (DMA), and is currently available over the internet at Pennsylvania State University. The compiled DCW contains several data layers for each region, and is based on DMA aeronautical charts at a small (1:1,000,000) scale. Data layers include digital line graph coverages such as drainage, roads, rails, utilities, and hypsography, plus others. Only data for North America was installed in this ArcView project, covering all 29 eastern and central U.S. states in which nuclear power plants are located. Not all data layers were retrieved (7 of 25 possible layers were downloaded), and the user may wish to download other point, line, or polygon coverages, or additional states, available from the FTP site below. For more information, see the file "README.txt in directory "Lookup".

Attribute tables for each theme contain only an identifier (number) which can be used to join records to descriptions in the appropriate "lookup" table. Once joined, these descriptions may be useful for identifying features and/or symbolizing the legend in the theme's table of contents. Sample "lookup" tables can be found in the directory named "DCW/Lookup" as dbase (.dbf) files. The user would join the first field (e.g., "RDLNTYPE" in lookup table roads.dbf) with the same field in the theme's attribute table. These lookup tables were simply compiled from the information in the file "README.txt" in directory "Lookup". README.txt contains additional information about these and other layers which can be used to create more detailed lookup tables.

Data files were originally in ARC/INFO export (*.e00) format and later converted to ARC/INFO coverages with program "import71" before loading into ArcView. Only line themes are displayed, although some layers such as drainage are actually "networks" containing polygon, line, and point features. The user may wish to display these other features by adding a new theme with the desired theme type selected.

Filenames for the ARC/INFO coverages and lookup tables were chosen to be more descriptive than the original layer names given in the README.txt file. For example, the name "roads" was given to the original "rdline" layer. The following filenames were used:

1) bound = PONET (political/ocean boundaries network: polygon, point, and line).
2) utilities = UTLINE (utility line features such as transmission lines or pipelines).
3) rails = RRLINE (railroad line features).
4) roads = RDLINE (road line features).
5) drainage = DNNET (drainage network: polygon, point and line features).
6) hypnet = HYNET (hypsography network; usually 1000 ft. contours).
7) hypso2 = HSLINE (hypsography supplemental line features).

Web Site:

1) http://www.maproom.psu.edu/dcw
2) http://www.lib.ncsu.edu/stacks/gis/dcw.html

The color shaded relief map was created from 15 arc-second DEM data which were resampled from the original USGS 3 arc-second DEM data. The data was processed in ARC/INFO GRID format, multi-directional hillshading applied, projected to Albers conic equal area meters, and converted to a 60 MB TIFF image file named "us15a468m.tiff" with

resolution of 468 m. Finer resolutions with correspondingly larger TIFF image size may be available from USGS.

View Projection:

1) Albers conic equal area
2) Spheroid: Clarke 1866
3) Standard Parallel 1: 29.5 N
4) Standard Parallel 2: 45.5 N
5) Centeral Meridian: -96.0 W
6) Reference Latitude: 23.0 N
7) False Easting: 0.0 meters
8) False Northing; 0.0 meters

Map units: meters

Note that all themes of the Digital Chart of the World are in geographic coordinates (decimal degrees) which may be projected onto the color relief map image using the above projection.

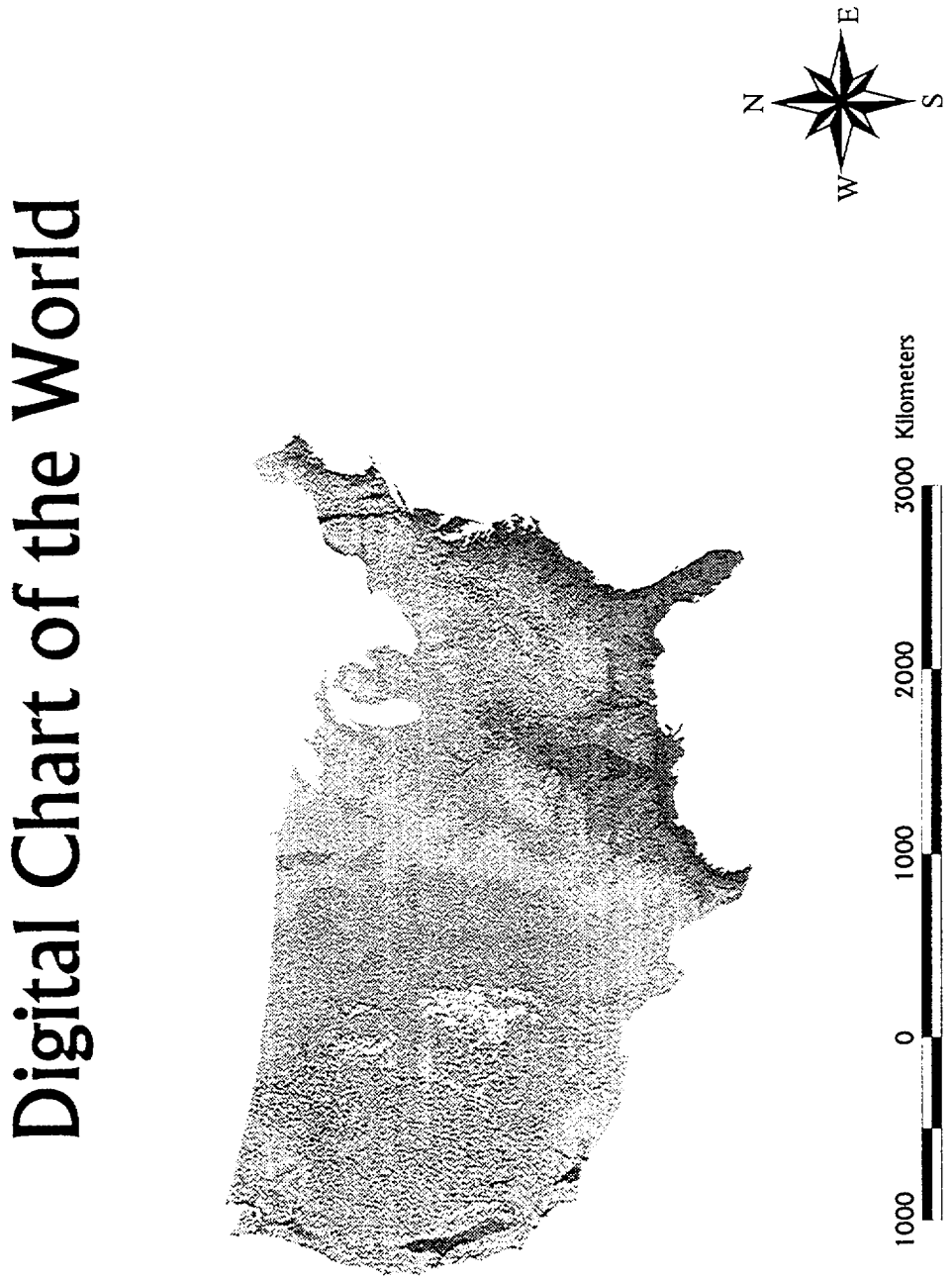

Figure 5. "Digital Chart of the World" View. Map showing the resolution of the View at the scale of the conterminous United States.

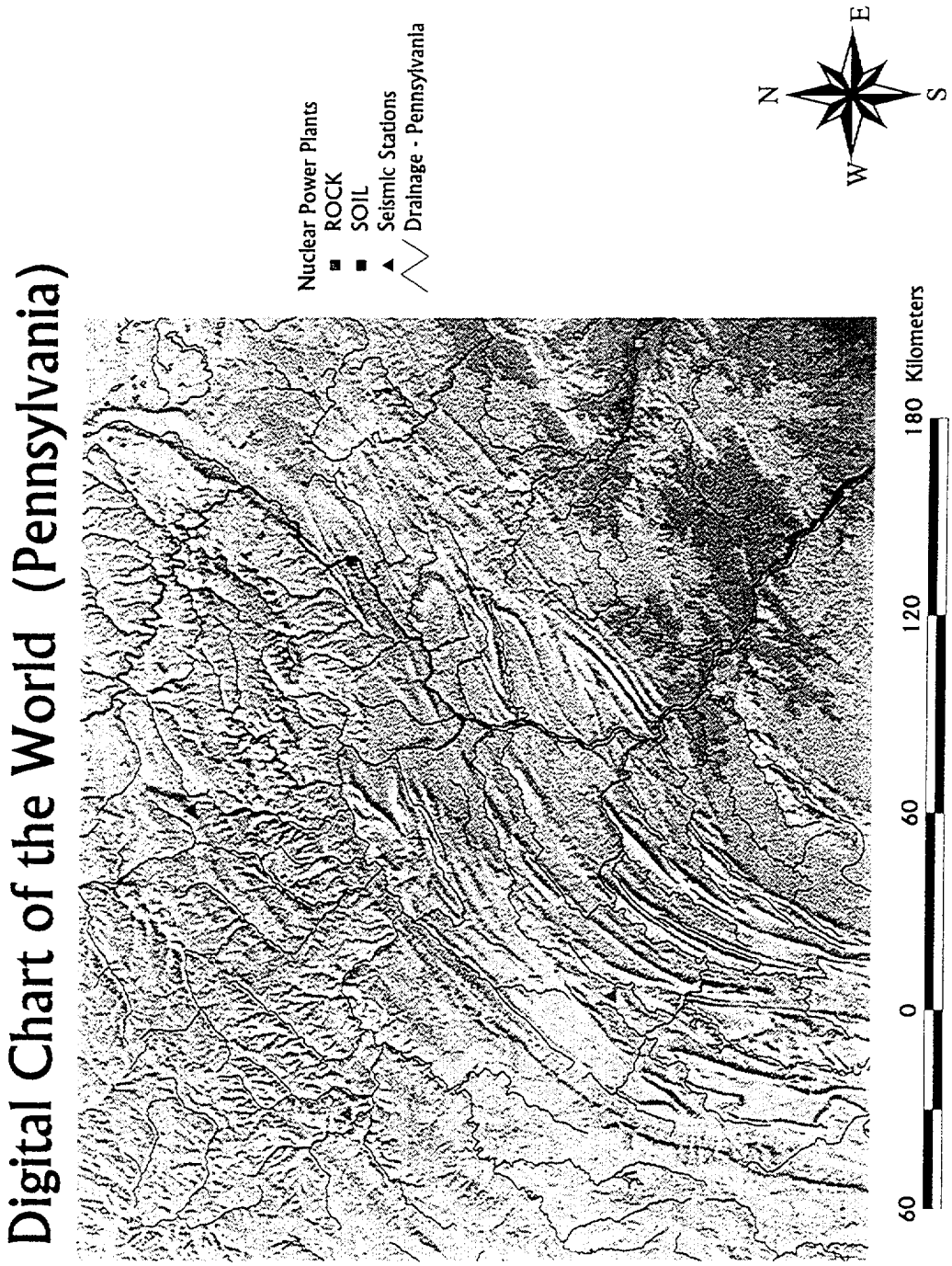

Figure 6. "Digital Chart of the World" View. Map showing the resolution of the View at the scale of a single state (Pennsylvania).

3.2.4 "DEM/DLG, UTM Projection, Zone 14" View (99°W Longitude)

Digital elevation models (DEM) for 7.5 minute quadrangles were downloaded from the USGS "Geodata" web site for 3 available nuclear power plant sites:

1) Comanche Peak, TX
2) Fort Calhoun, TX
3) South Texas Station

Digital Line Graph (DLG) data were also downloaded from the same web site and converted to shapefiles with no projection (*i.e.*, geographic coordinates in decimal degree units) by using the ArcView "Projector!" extension.

View Projection:

1) Universal Transverse Mercator (UTM), Zone 14
2) Spheroid: Clarke 1866
3) Central Meridian: -99.0
4) Reference Latitude: 0.0
5) Scale Factor: 0.99960
6) False Easting: 500000.0
7) False Northing: 0.0

Map units: meters

Web site: http://edcwww.cr.usgs.gov/doc/edchome/ndcdb.html

FTP site: ftp://edcftp.cr.usgs.gov

3.2.5 "DEM/DLG, UTM Projection, Zone 15" View (93° W Longitude)

Digital Elevation Models (DEM) for 7.5 minute quadrangles (scale 1:24000) were downloaded from the USGS "Geo Data" web site for 11 nuclear plant sites in Zone 15 (90W – 96W longitude) of the Universal Transverse Mercator projection.

Digital Line Graph (DLG) data were also downloaded from the same web site, and converted to shapefiles with no projection (i.e., geographic coordinates in decimal degree units) by using the ArcView "Projector!" extension.

View projection:

1) Universal Transverse Mercator (UTM), Zone 15
2) Spheroid: Clarke 1866
3) Central Meridian: -93.0
4) Reference Latitude: 0.0
5) Scale Factor: 0.99960
6) False Easting: 500000.0
7) False Northing: 0.0

Map units: meters

Web site: http://edcwww.cr.usgs.gov/doc/edchome/ndcdb.html

FTP site: ftp://edcftp.cr.usgs.gov

3.2.6 "DEM/DLG, UTM Projection, Zone 16" View (87° W Longitude)

Digital Elevation Models (DEM) of 7.5 min. quadrangles, scale=1:24000, for 16 nuclear power plant sites in UTM Zone 16 (84W – 90W longitude).

Digital Line Graphs (DLG) at same scale for available nuclear power plant sites. DLG data was converted to shapefiles with geographic coordinates (decimal degrees) by using the ArcView "Projector!" extension.

View Projection:

1) Universal Transverse Mercator (UTM), Zone 16
2) Spheroid: Clarke 1866
3) Central Meridian: -87.0
4) Reference latitude: 0.0
5) Scale Factor: 0.99960
6) False Easting: 500000.0
7) False Northing: 0.0

Map units: meters

Web site: http://edcwww.cr.usgs.gov/doc/edchome/ndcdb.html

FTP site: ftp://edcftp.cr.usgs.gov

3.2.7 "DEM/DLG, UTM Projection, Zone 17" View (81° W Longitude)

Digital Elevation Models (DEM) of 7.5 min quadrangles, scale 1:24000, for nuclear power plant sites in UTM Zone 17 (78W – 84W longitude).

Digital Line Graphs (DLG) at same scale for available nuclear power plant sites. DLG data were converted to shapefiles with geographic coordinates (decimal degrees) by using the ArcView "Projector!" extension.

View Projection:

1) Universal Transverse Mercator (UTM), Zone 17
2) Spheroid: Clarke 1866
3) Central Meridian: -81.0
4) Reference Latitude: 0.0
5) Scale Factor: 0.99960
6) False Easting 500000.0
7) False Northing: 0.0

Map units: meters

Web site: http://edcwww.cr.usgs.gov/doc/edchome/ndcdb.html

FTP site: ftp://edcftp.cr.usgs.gov

3.2.8 "DEM/DLG, UTM Projection, Zone 18" View (75° W Longitude)

Digital Elevation Models (DEM) for 7.5 min. quadrangles, scale = 1:24000, for nuclear power plant sites in UTM Zone 18 (72W – 78W longitude).

Digital Line Graph (DLG) for available nuclear power plant sites at same scale. DLG data have been converted to shapefiles with geographic coordinates (decimal degrees) by using the ArcView "Projector!" extension.

View Projection:

1) Universal Transverse Mercator (UTM), Zone 18
2) Spheroid: Clarke 1866
3) Central Meridian: -75.0
4) Reference Latitude: 0.0
5) Scale Factor: 0.99960
6) False Easting: 500000.0
7) False Northing: 0.0

Map units: meters

Web site: http://edcwww.cr.usgs.gov/doc/edchome/ndcdb.html

FTP site: edcftp.cr.usgs.gov

3.2.9 "DEM/DLG, UTM Projection, Zone 19" View (69° W Longitude)

Digital Elevation Models (DEM) of 7.5 min quadrangles, scale 1:24000, for nuclear power plant sites in UTM Zone 19 (66W – 72W longitude).

Digital Line Graphs (DLG) at same scale for available nuclear plant sites. DLG data have been converted to shapefiles with geographic coordinates (decimal degrees) by using the ArcView "Projector!" extension.

View Projection:

1) Universal Transverse Mercator (UTM), Zone 19
2) Spheroid: Clarke 1866
3) Central Meridian: -69.0
4) Reference Latitude: 0.0
5) Scale Factor: 0.99960
6) False Easting: 500000.0
7) False Northing: 0.0

Map units: meters

Web site: http://edcwww.cr.usgs.gov/doc/edchome/ndcdb.html

FTP site: ftp://edcftp.cr.usgs.gov

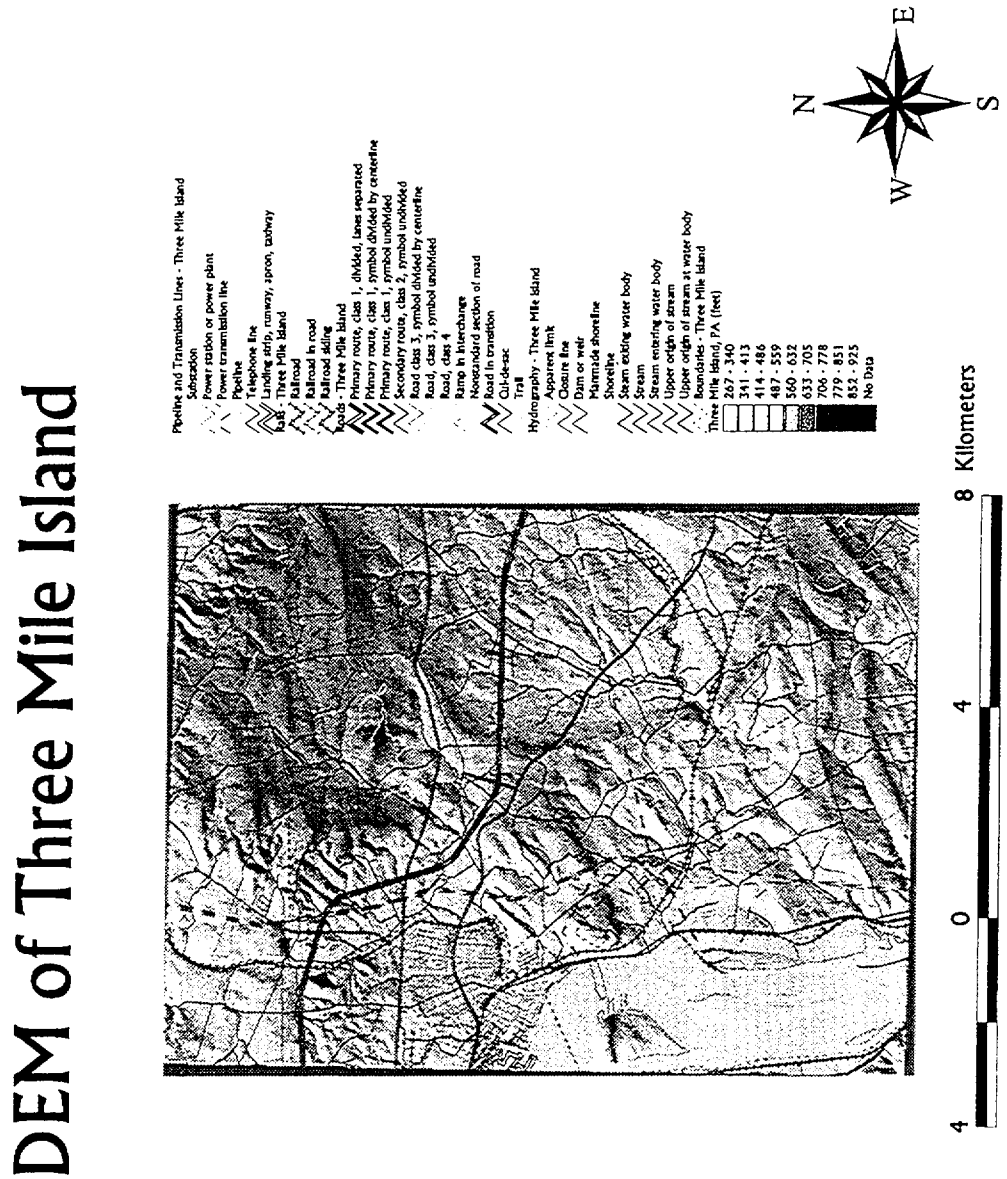

Figure 7. View showing a Digital Elevation Model (DEM) for a particular 7.5-minute quadrangle in Universal Transverse Mercator (UTM) Zone 18.

3.2.10 "DTED (Digital Terrain Elevation Data)" View, 1:250,000

Digital Terrain Elevation Data (DTED Level 0) were freely downloaded from the National Imagery and Mapping Agency (NIMA) web page:

http://www.nima.mil/geospatial/products/DTED

These data are the same as the 1-degree USGS DEM (scale 1:250K) data also available from USGS, except that the header and data formats differ.

All elevations are in units of meters.

Since the original data are stored in geographic coordinates with arc-sec units, the script "Spatial.DTEDShift" was used to import the DTED into ArcView and convert to decimal degree units. This step allows other themes which are stored in decimal degrees to properly align when overlaid.

The script "Spatial.DEMShade" was used to generate hill-shading rather than the default "Compute Hillshade..." option under the Surface menu (Spatial.Hillshade) due to corruption when using converted DTED (or 1-deg DEM) data.

Projection parameters: geographic coordinates (decimal degrees)

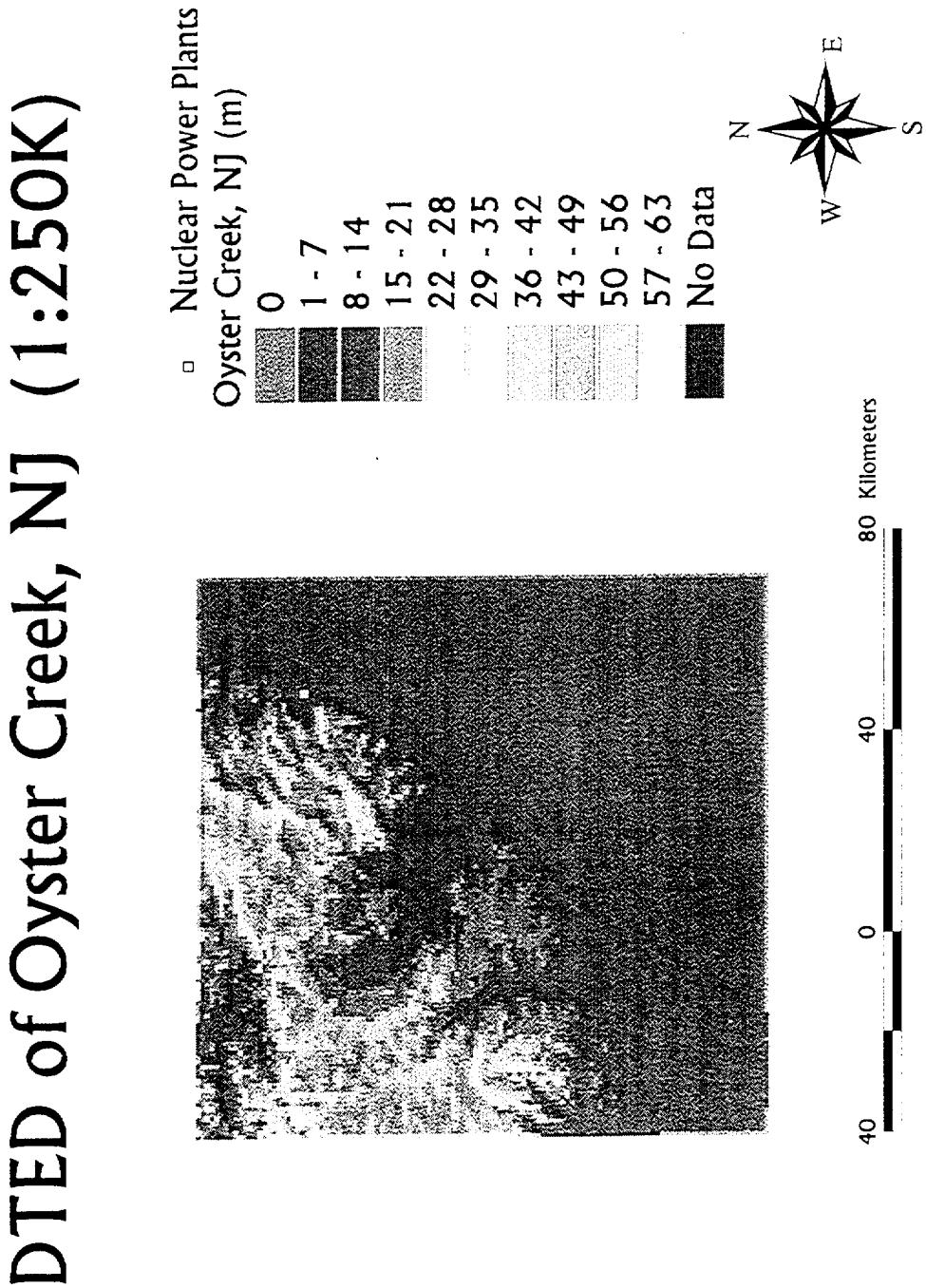

Figure 8. View showing a 1:250,000 scale Digital Terrain Elevation Data (DTED) representation of topography. Elevations are in meters.

3.2.11 "U.S. Geologic Map" View

The geologic map of the U.S. is based on King and Beikman (1974) originally published at a scale of 1:2,500,000. Faults and glacial line themes are available as well as the geology polygon theme. The data files are unprojected in units of decimal degrees (*i.e.,* geographic coordinates).

Web sites:

1) http://minerals.er.usgs.gov/kb (the data and publication reside here)
2) http://atlas/geo/cornell.edu/geoid/metadata/htmls/geology/us_geology.html

The Cornell University Web site referenced above contains the metadata description.

References:

1) Geology of the Conterminous United States at 1:2,500,000 Scale – A Digital Representation of the 1974 P. B. King and H. M. Beikman map (1994), U.S. Geological Survey Digital Data Series, DDS-11.

2) Explanatory Text to Accompany the Geologic Map of the United States (1974), by Philip B. King and Helen M. Beikman, Geological Survey Professional Paper 901.

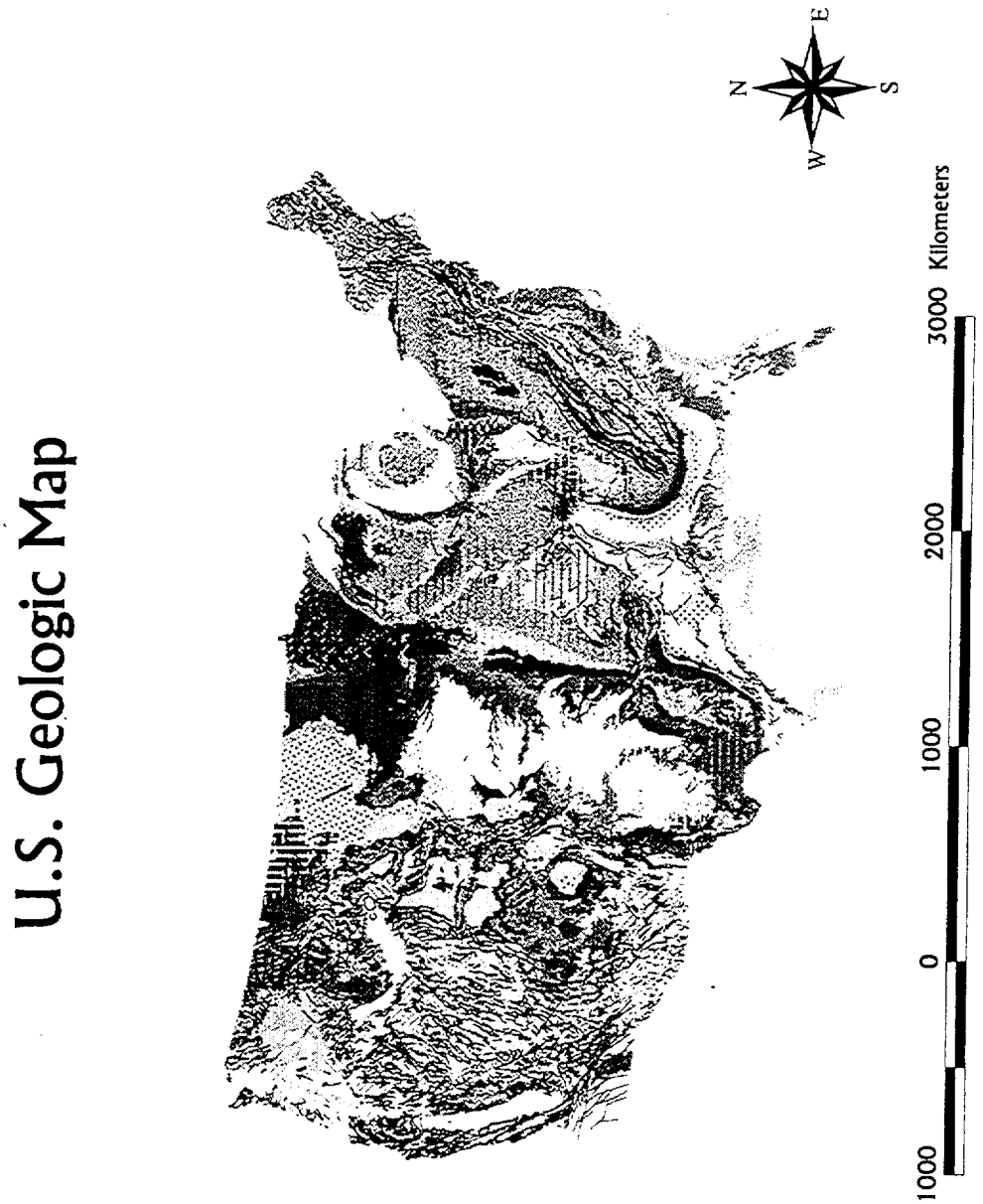

Figure 9. Map showing the "U.S. Geologic Map" View at the resolution of the entire conterminous United States.

3.2.12 "Heatflow and Sediment Thickness" View

The Heatflow map is based on the geothermal database developed for the Geological Society of America Decade of North American Geology (DNAG) Geothermal Map of North America (Blackwell and Steele, 1992; Blackwell et al., 1989, 1991).

The Sediment Thickness map was digitized from a 1x1 degree grid and is based on the work of Laske and Masters (1997). Only the grid data for 25° N to 50° N latitude and 65°W to 125° W longitude were retrieved.

Elastic parameters Vp, Vs, and rho (density) are also displayed for 3 sediment layers, where the top layer is a maximum of 2 km thick and the second layer is a maximum of 5 km thick.

View Projection:

1) Albers Equal Area Conic
2) Spheroid: Clarke 1866
3) Central Meridian: -96.0
4) Reference Latitude: 37.5
5) Parallel 1: 29.5
6) Parallel 2 45.5
7) False Easting: 0.0
8) False Northing: 0.0

Map units: meters

Web sites:

1) http://www.smu.edu/~geothermal
2) http://geothermal.id.doe.gov/geothermal/fy96/explorat/exp-02.html
3) http://mahi.ucsd.edu/Gabi/sediment.html

FTP site: ftp://carp.ucsd.edu)

References:

1) Blackwell, D.D., K.W. Wisian, and J.L. Steele, Geothermal resource evaluation based on heat flow and thermal conductivity for the United States, from DOE Geothermal Energy Technical Site web page http://geothermal.id.doe.gov/geothermal/fy96/explorat/exp-02.html, 1996.

2) Blackwell, D.D., and J.L. Steele, editors, DNAG geothermal map of North America, 1:5,000,000, 4 sheets, Geol. Soc. Amer., Boulder, CO, 1992.

3) Blackwell, D.D., J.L Steele, and L.S. Carter, Geothermal resource evaluation for the eastern United States based on heat flow and thermal conductivity distribution, Geothermal Res., Council Trans., 17, 97-100, 1993.

4) G. Laske and G. Masters, A Global Digital Map of Sediment Thickness, EOS Trans. Amer. Geophys. U., 78, F483, 1997.

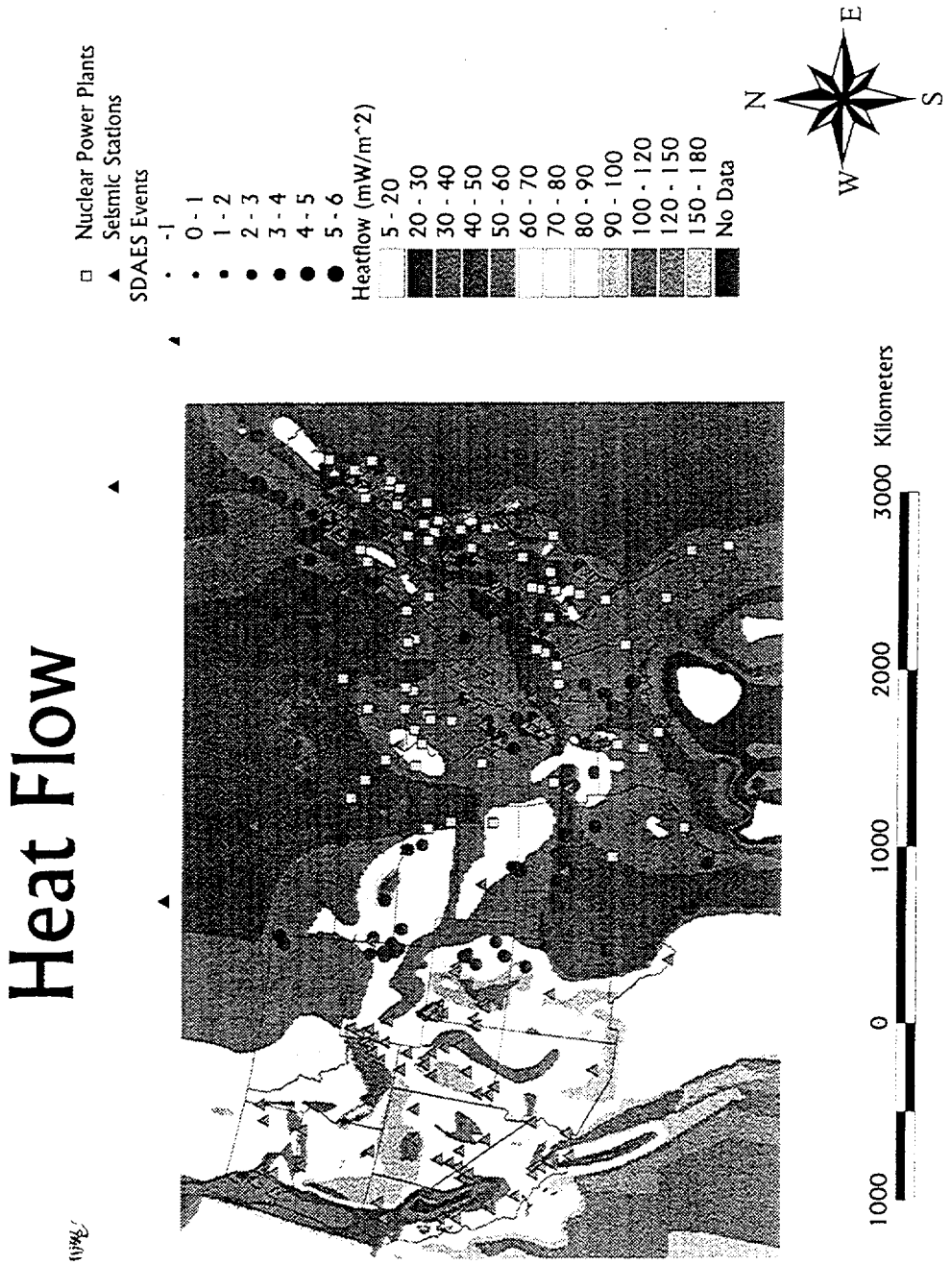

Figure 10. Map of heat flow, generated from the "Heatflow and Crustal Thickness" View.

3.2.13 "Frequency-Dependent H/Z Contours" View (from EPRI Data)

Mean horizontal/vertical (H/Z) station terms based on bandpass filtered Lg amplitudes for seven frequency bands from 1.25 to 7 Hz were dervied by a multivariate least squares inversion procedure using more than 50 stations of the LRSM and RSTN networks and 107 eastern and central U.S. events (90 earthquakes, 17 explosions). These results, part of a seismic wave attenuation study in eastern North America, were interpolated using the IDW method in ArcView to create contours for each frequency band. Higher values indicate greater horizontal or shear motion relative to vertical component, and may be associated with sediment sites. The Soil Amplification Factors provided for each nuclear power plant were derived by doing a spatial join between the "Nuclear Power Plants" point theme and each H/Z contour line theme so that the closest H/Z value was assigned to a nuclear power plant location. Then the antilog of H/Z was calculated (the H/Z terms are in log units) and a constant adjustment factor was added only to the plant sites with soil type.

The "H/Z Stations" theme marks the locations of LRSM and RSTN stations at which H/Z values were derived. Note that contours appear more tightly wrapped around these points due to the relative sparcity of grid points elsewhere.

Reference:

Gupta, I.N., K.L. McLaughlin, R.A. Wagner, R.S. Jih, and T.W. McElfresh (1998). Seismic Wave Attenuation in Eastern North America, prepared for Electric Power Research Institute, NP-6304, Research Project 2556-9.

3.2.14 "Lake Superior Geologic Map" View

This View is based on USGS Open-File-Report 97-455, "Digital Geologic Map and Mineral Deposits of Minnesota, Wisconsin, and Michigan" (Cannon et al., 1997). Files were downloaded from USGS's Mineral Resource Data System (MRDS) in ARC/INFO shapefile format. The data are stored in geographic coordinates (decimal degrees).

Web site: http://minerals.er.usgs.gov/pubs/of97-455/superior.html

Reference:

Cannon, W.F., T.H. Kress, D.M. Sutphin, G.B. Morey, and J. Meints, 1997. Digital Geologic Map and Mineral Deposits of the Lake Superior Region: Minnesota, Wisconsin, Michigan. USGS OFR 97-455.

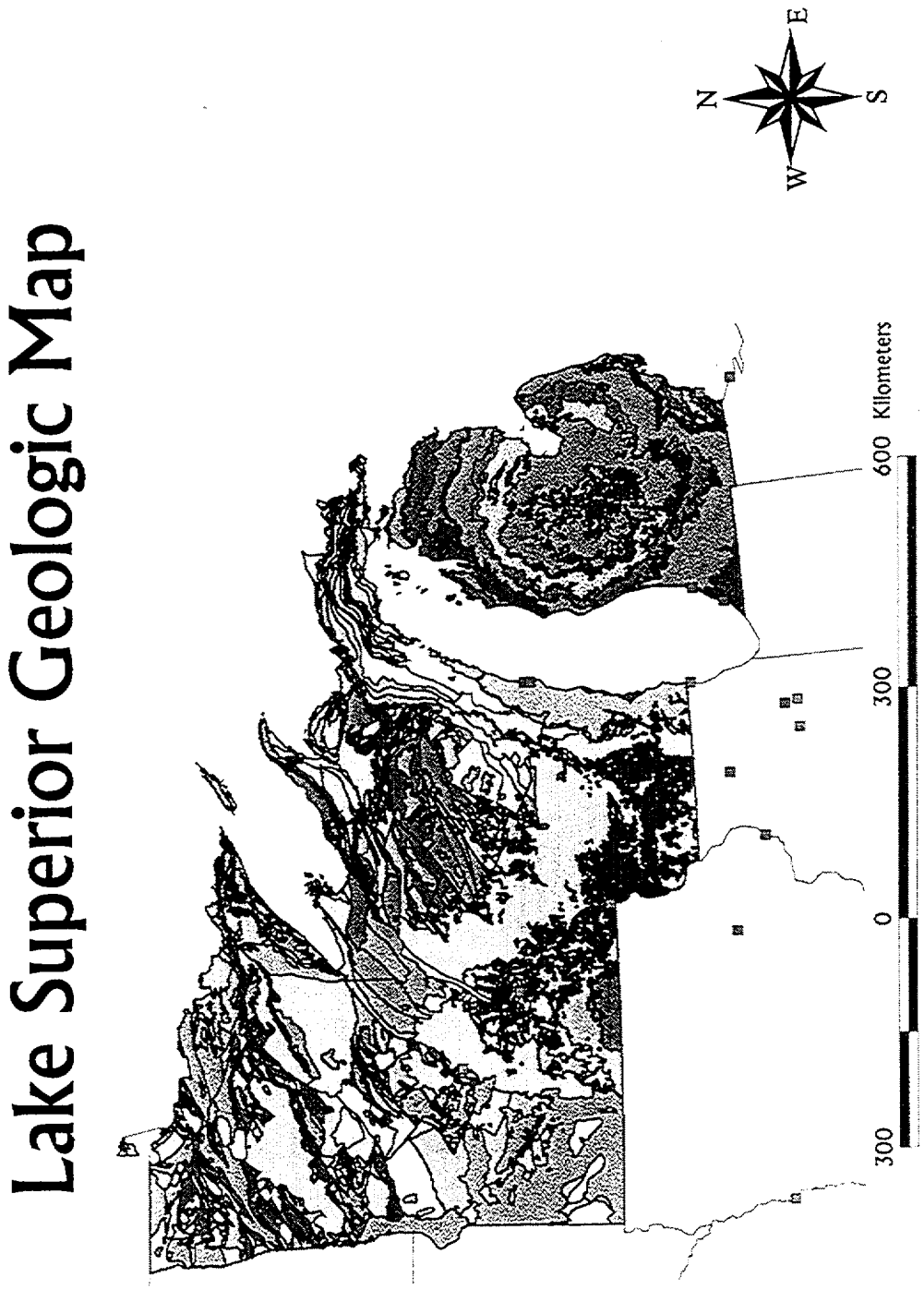

Figure 11. Map showing the "Lake Superior Geologic Map" View at the resolution of the entire area spanned by the data set.

3.2.15 "Nebraska Sample Maps" View

The excellent Web site http://csd.unl.edu/csd/gisdata.html contains many types of digital maps for Nebraska. Selected maps include a geologic bedrock map, gravity, magnetic and depth to Precambrian layer. Files were downloaded in ARC/INFO export format and converted to shapefiles using the "Projector!" extension, which was also used to convert from Lambert Conformal Conif projection to decimal degrees.

View Projection:

1) Lambert Conformal Conic
2) Spheroid: Clarke 1866
3) Central Meridian: -100.0
4) Reference Latitude: 0.0
5) Parallel 1: 40.0
6) Parallel 2: 43.0
7) False Easting: 0.0
8) False Northing: 0.0

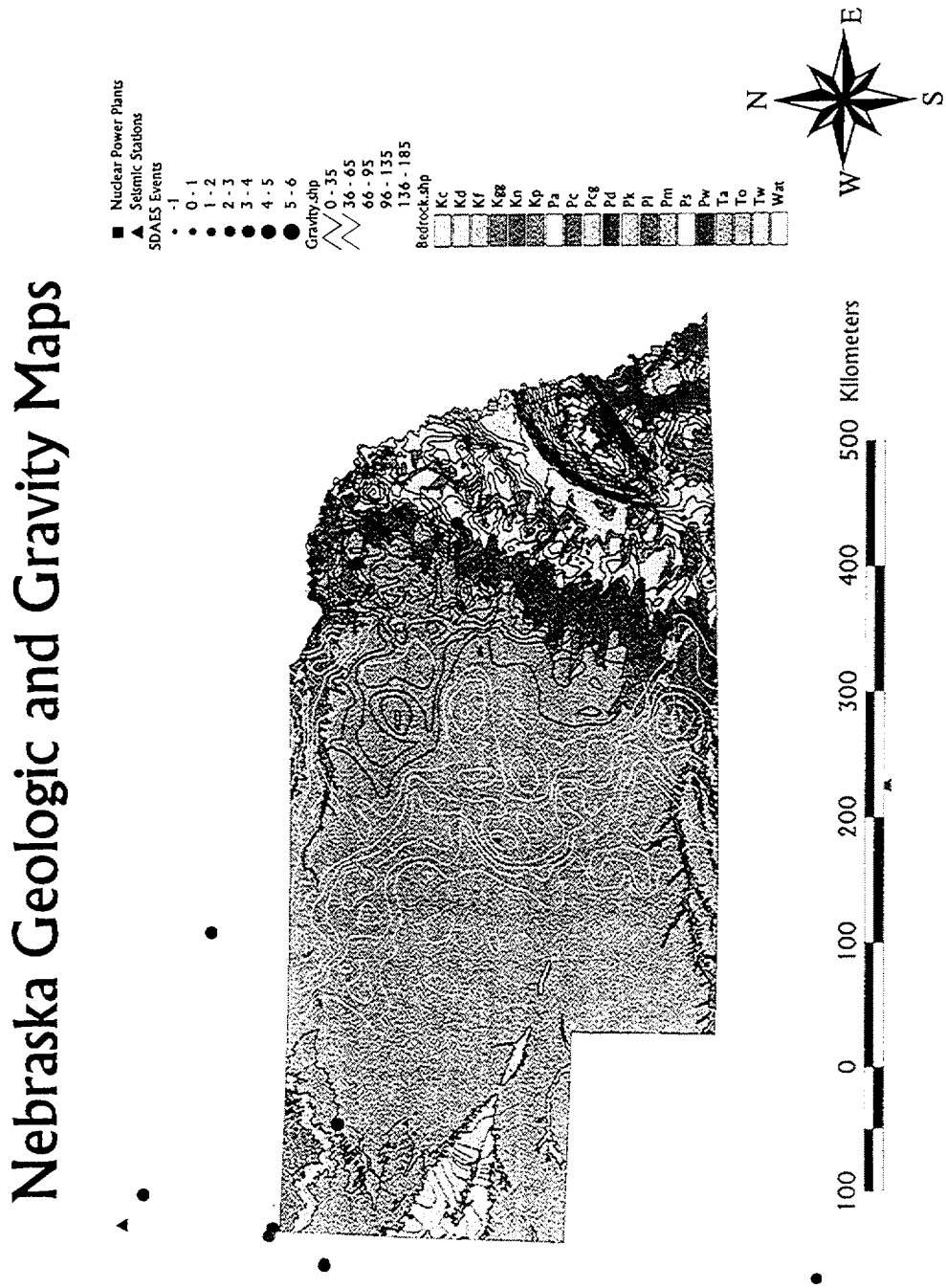

Figure 12. Map showing selected data sets from the "Nebraska Sample Maps" View.

3.2.16 "New Madrid Seismotectonic Map" View

Selected database themes for the New Madrid region were copied from USGS Open-File-Report 95-0574, "Seismotectonic Maps in the Vicinity of New Madrid, Missouri Database", which was digitally compiled originally by Susan Rhea (rhea@gldvxa.cr.usgs.gov). Files were downloaded by anonymous FTP from a USGS data server named "greenwood.cr.usgs.gov" in directory /pub/open-file-reports/ofr-95-0574. Upon request, the maps were unprojected to decimal degree units and made available as ARC/INFO export files (*i.e.*, a file format denoted by the suffix *.e00).

Web site: http://greenwood.cr.usgs.gov

Open file reports are available at http://greenwood.cr.usgs.gov/maps/map.html

Theme Descriptions:

1) Faults -- locations of faults located by geologic observation.
2) Subsurface Ruptures 1811-1812 Eqks. -- File "enrgcen" represents locations of probable subsurface ruptures of the 1811-1812 earthquakes, as defined by sandblow distribution (Obermeier, 1989). Obermeier describes the zones as "energy centers" of those earthquakes, rather than the more spatially limited concept "epicenter".
3) Depth to Paleozoic Surface – File "pzcon" refers to Paleozoic surface depth contours from Dart (1995).
4) Depth to Magnetic Basement – File "magdep" is depth to magnetic basement (Hildenbrand and Hendricks, 1995).
5) P Velocity (0-5 km deep) – P velocity contours for shallow depths of 0 – 5 km (Al-Shukri and Mitchell, 1987).
6) P Velocity (5-14 km deep) – P velocity contours for depths of 5 – 14 km (Al-Shukri and Mitchell, 1987).
7) Structrures Identified From Gravity Field – structures identified from gravity field data (Langenheim, 1995).
8) Axial Gravity Anomaly – axial gravity anomaly (Langenheim, 1995).
9) Base Hydrography – selected hydrography, selected on the basis of significant ground-shaking or liquefaction potential.
10) Mississippi River – polygon coverage of the Mississippi River extracted from the Base Hydrography.

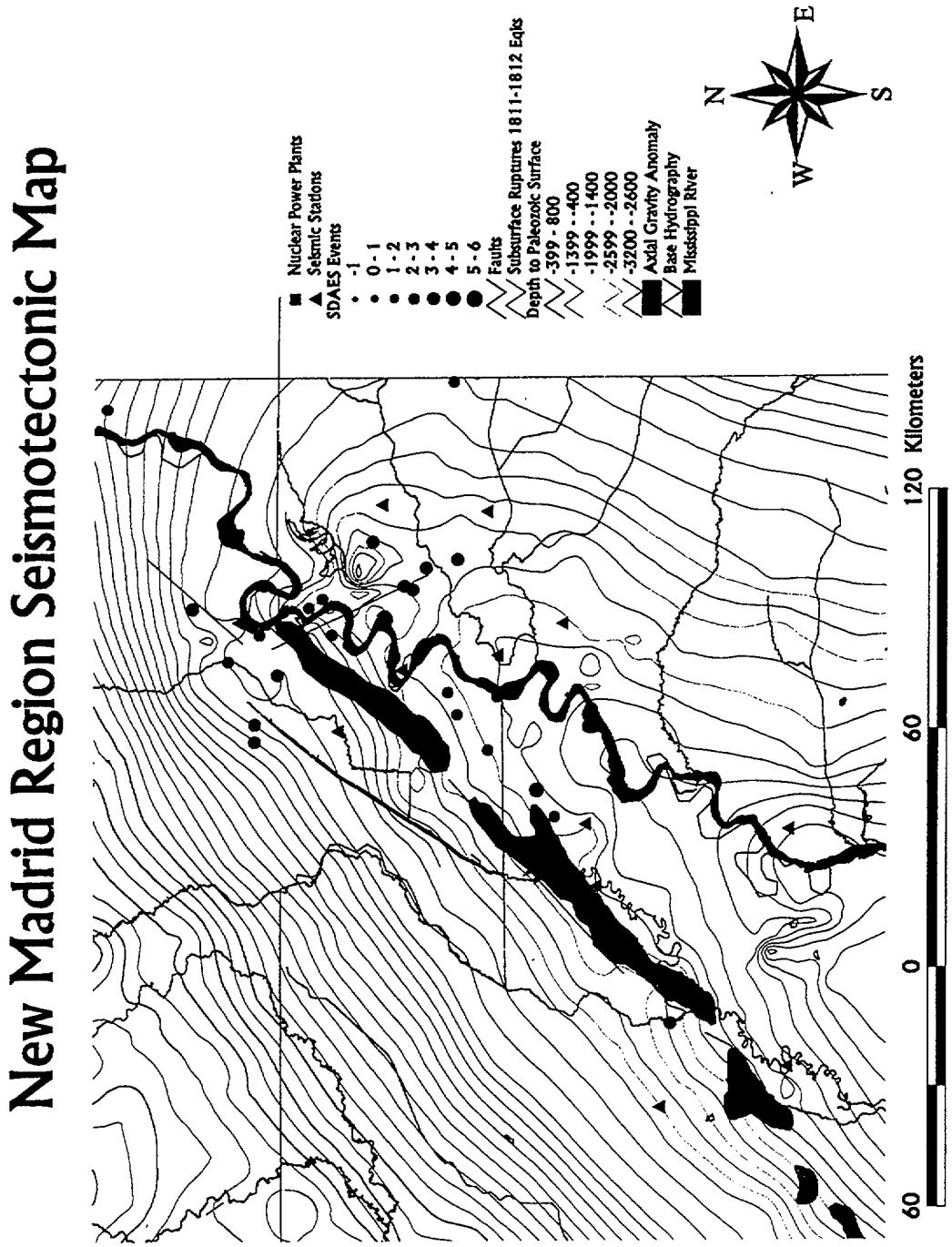

Figure 13. Map showing selected data Themes from the "New Madrid Seismotectonic Map" View.

3.2.17 SDAES General View

A map of the U.S. was created to show themes related to nuclear power plants, seismic data collection efforts during 1995-1998, historical seismicity, and geophysical crustal parameters. The nuclear power plants theme consists of 69 sites in the eastern and central U.S. with locations given in the attribute table derived from the NRC web page. In addition, "soil amplification factors" were derived from the nearest H/Z values to each plant site and corrected by calculating the antilog and applying a constant factor to soil sites. The H/Z contours are described in more detail on the appropriate view.

A complete listing of seismic stations is given for those earthquakes in the eastern and central U.S. (25° N to 50° N latitude, -65° W to –105° W longitude) for which waveform data was retrieved within about 10 degrees distance. The "SDAES Events" theme also lists all the earthquakes for which waveform data was recovered.

Historical seismicity between 1973-1998 is shown in the "NEIC Eqks" theme for comparison and provides a more complete coverage, although data collection was not based on this listing.

Pn Velocity contours are based on Braile (1989). The contour interval is 0.1 km/sec.

Mean Crust P Velocity contours represent the average seismic velocity of the crust. Contour interval is also 0.1 km/sec (Braile, 1989).

Crustal Thickness contour map shows thickness in kilometers measured from the surface to the inferred Moho discontinuity. Contour interval is 5 km (Braile, 1989).

Reference:

Braile, L.W., Hinze, W.J., von Frese, R.R.B, and Keller, G.R., 1989. Seismic properties of the crust and uppermost mantle of the conterminous United States and adjacent Canada, in Parkiser, L.C., and Mooney, W.D., Geophysical framework of the continental United States: Boulder, Colorado, Geological Society of America Memoir 172.

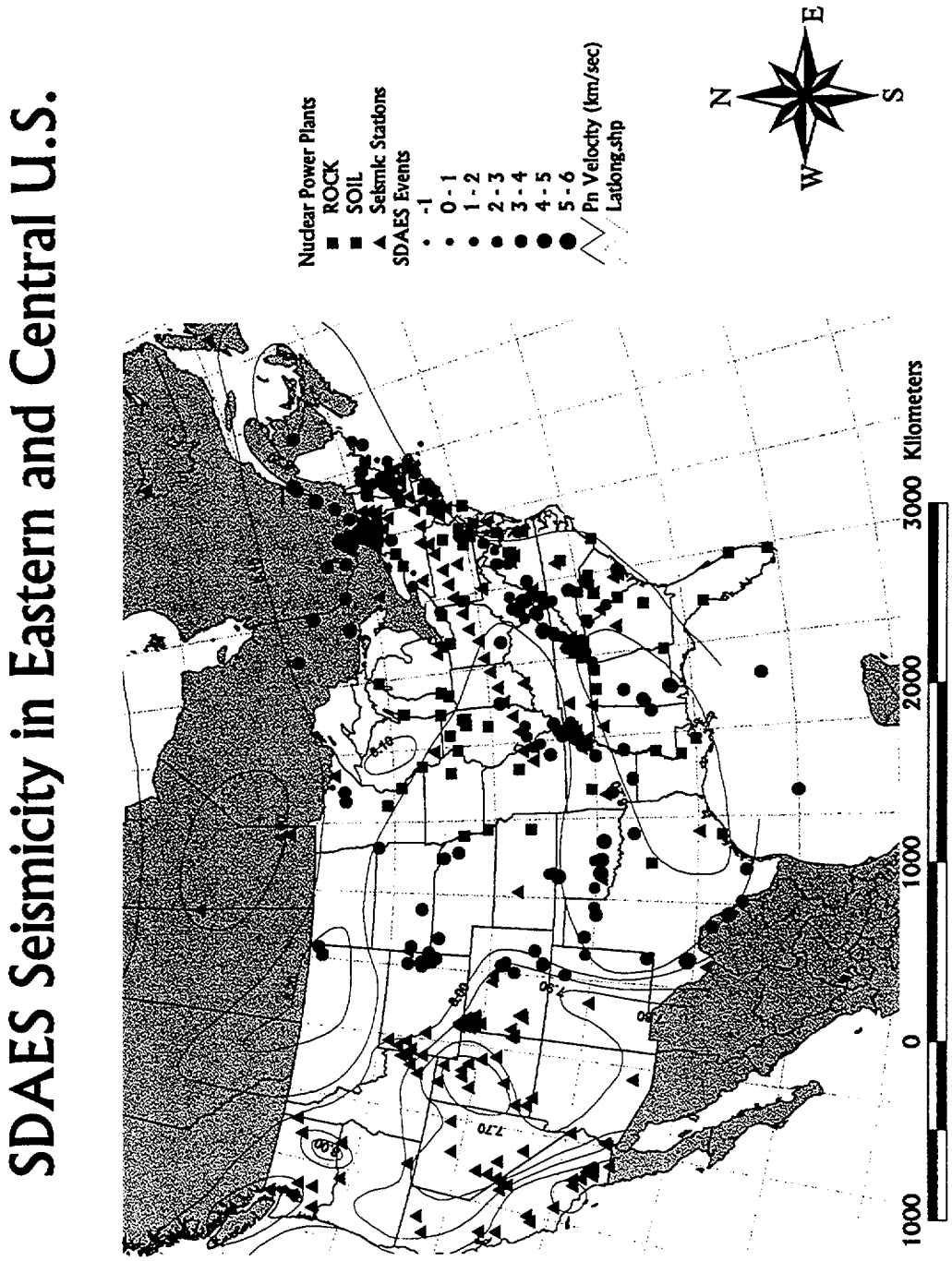

Figure 14. Map generated from the SDAES General View.

3.2.18 "Soils Map (STATSGO)" View, Scale = 1:250,000

Soils maps for 29 eastern and central U.S. states from the STATSGO database were freely downloaded from the Natural Resources Conservation Service (NRCS) ftp site (formerly Soil Conservation Service). Each map covers an entire state with a scale of 1:250,000. All 69 nuclear power plants are located within these 29 states. The original ARC/INFO coverages were converted to shapefiles with the ArcView "Projector!" extension with output units of decimal degrees, *i.e.*, unprojected in geographic coordinates. This step allows other themes in decimal degree units to properly align when overlaid.

Several tables in *dbase* format accompany each soils map theme. Each table consists of multiple fields or attributes derived from the Map Unit Interpretation Database (MUIR), which describe various soil characteristics or interpretations for a soil survey area, and its map units and components. Tables can be linked or joined on common attributes. For example, the "muid" (mapunit id) field is common to most tables. For a complete description of the tables and their attributes, please refer to the following web sites and publication below:

Web sites:

1) http://www.ftw.nrcs.usda.gov/stat_data.html
2) http://www.stalab.iastate.edu/soils/muir
3) http://www.fws.gov/data/gisconv/soiltool.html

FTP site: ftp://ftp.ftw.nrcs.usda.gov/pub/statsgo

A complete description of attributes can be found in Appendix B of the following publication. This is also available by FTP in "portable document file" (pdf) format from the first web site above.

Reference:

U.S. Department of Agriculture, 1994, State soil geographic (STATSGO) data base – data use information, miscellaneous publication number 1492 (rev. ed.): Fort Worth, Texas, Natural Resources Conservation Service.

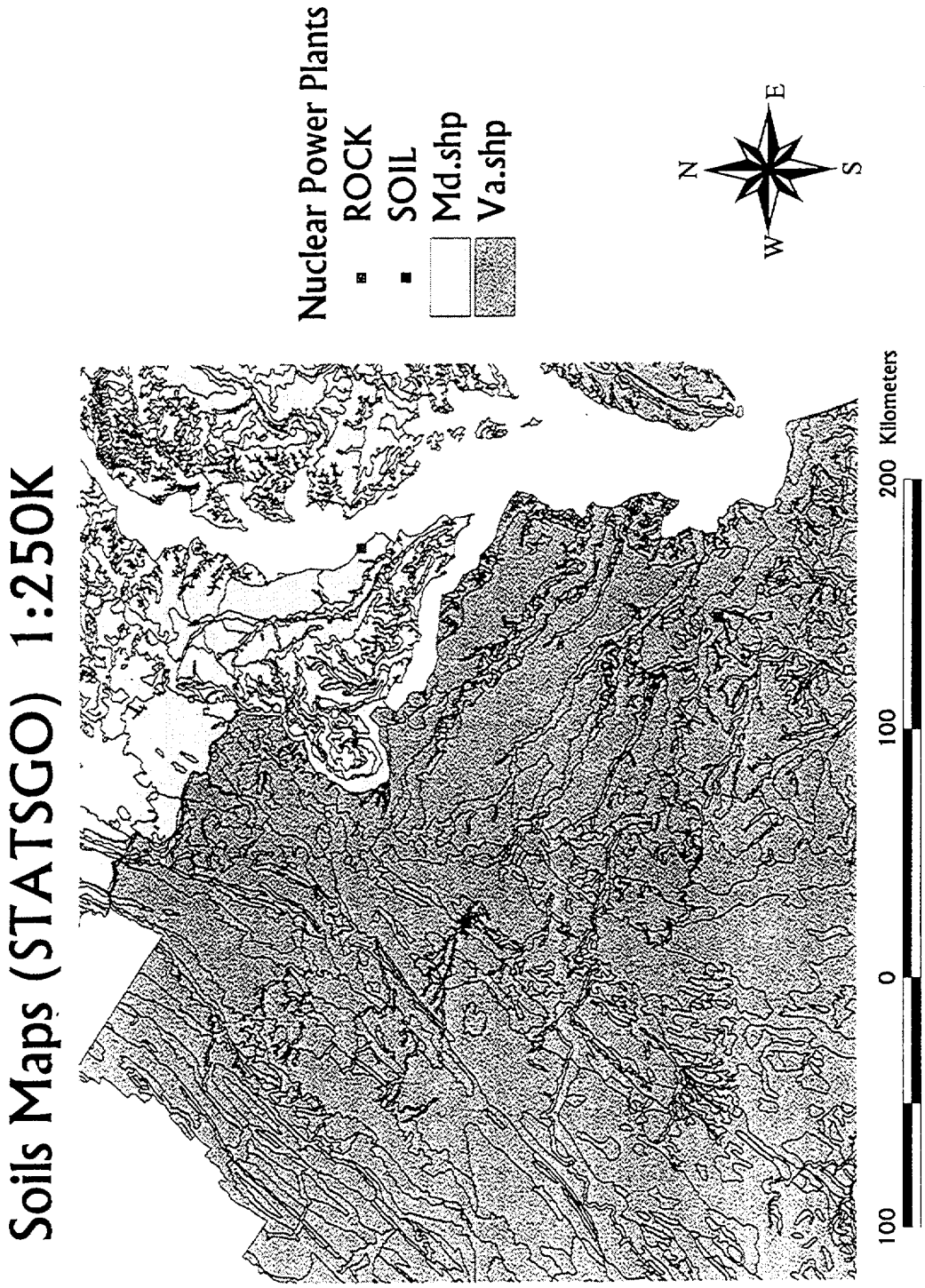

Figure 15. Two states (Maryland and Virginia) from the "Soils Map (STATSGO)" View.

3.2.19 "Topographic Maps (DRG) – Nebraska" View

Digital Raster Graphics (DRG) of topographic maps for two nuclear power plant sites in Nebraska were downloaded as TIFF files from the Conservation and Survey Division of the University of Nebraska – Lincoln Web site.

The map scale is 1:24000 based on a 7.5 minute quadrangle.

Web Site: http://csd-esic.unl.edu/index.html

View projection parameters should be set separately for each quadrangle:

View Projection:

1) Fort Calhoun, NE

Projection:	UTM Zone 14
Spheroid:	Clarke 1866
Scale Factor	0.9996
Central Meridian;	-99.0
Reference Latitude:	0.0
False Easting:	500000.0
False Northing:	0.0

2) Cooper Station, NE

Projection:	UTM Zone 15
Spheroid:	GRS 1980
Scale Factor:	0.9996
Central Meridian:	-93.0
Reference Latitude:	0.0
False Easting:	500000.0
False Northing	0.0

3.2.20 "Topographic Maps (DRG) – Pennsylvania" View

Digital Raster Graphics (DRG) for 5 nuclear power plant locations in Pennsylvania were downloaded from the Pennsylvania Spatial Data Access (PASDA) Web page.

These are essentially scanned raster images of 7.5 minute topographic quadrangle maps at a scale of 1:24000 in the form of "tiff" files.

Web Site: http://www.pasda.psu.edu/discover/data-types.shtml

View Projection:

1) Albers Equal Area Conic
2) Spheroid: Clarke 1866
3) Central Meridian 78.0
4) Reference Latitude 39.0
5) Standard Parallel 1: 40.0
6) Standard Parallel 2: 42.0
7) False Easting: 0.0
8) False Northing 0.0

Map units: meters

3.2.21 "Topographic Maps (DRG) – Texas" View

Digital Raster Graphics (DRG) of 7.5 minute topographic maps for two nuclear plant sites in Texas (scale=1:24000) were downloaded from the Texas Natural Resource Conservation Commission (TNRCC) web site.

Web Site: http://www.tnrcc.texas.gov/gis/raster.html

View projection parameters should be set separately for each quadrangle:

View Projection:

1) Comanche Peak, TX

Projection:	UTM Zone 14
Spheroid:	Clarke 1866
Scale Factor:	0.9996
Central Meridian:	-99.0
Reference Latitude:	0.0
False Easting:	500000.0
False Northing	0.0

2) South Texas

Projection:	UTM Zone 14
Spheroid:	GRS 1980
Scale Factor:	0.9996
Central Meridian:	-99.0
Reference Latitude:	0.0
False Easting:	500000.0
False Northing	0.0

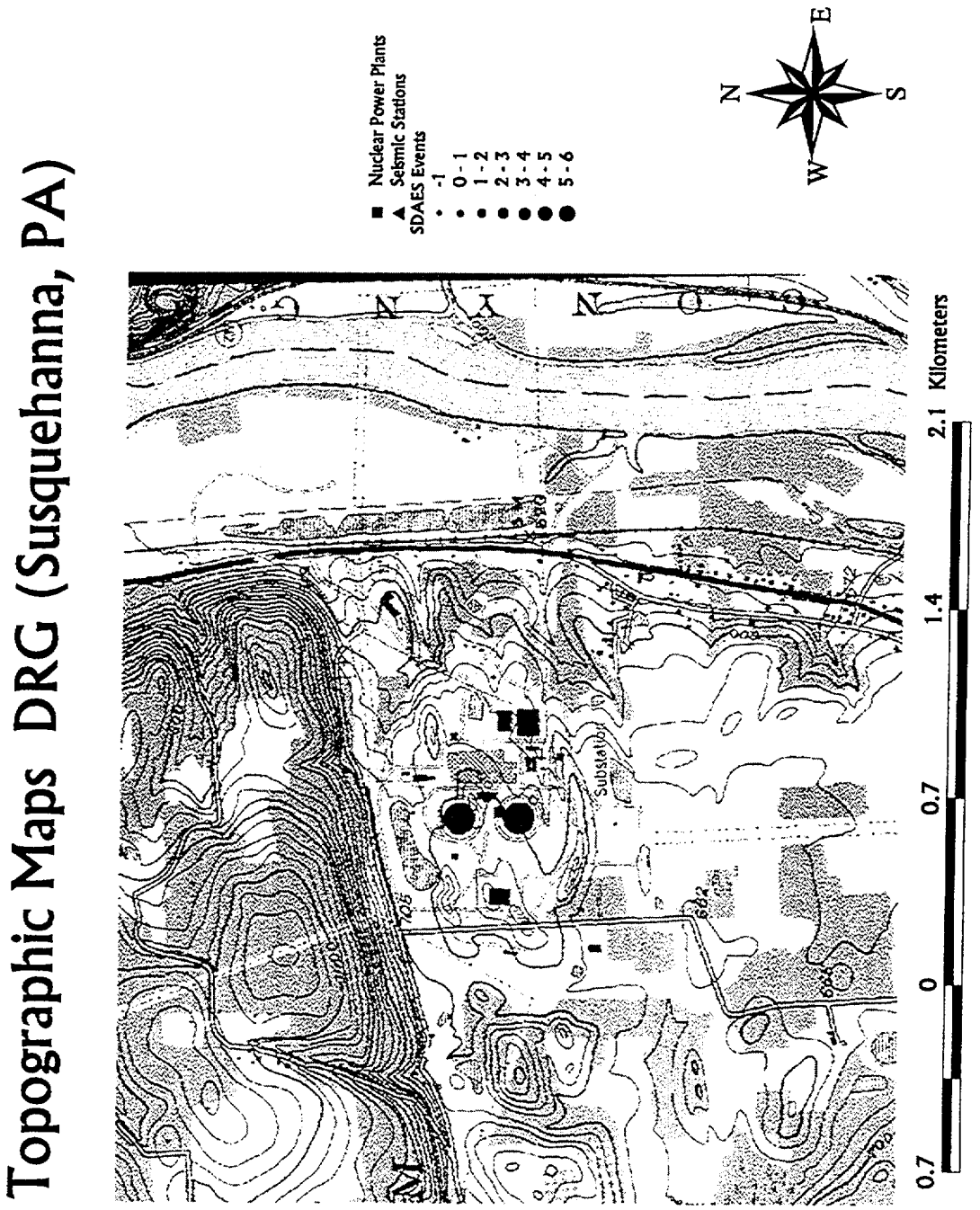

Figure 16. Digital Raster Graphics (DRG) map produced from the "Topographic Maps DRG – Pennsylvania" View for a particular 7.5-minute quadrangle.

3.2.22 "Wabash Region Seismotectonic Map" View

Selected maps from USGS Open-File-Report 97-681, "Seismotectonic Maps in the Vicinity of the Lower Wabash Valley, IL, IN, and KY – Digital Spatial Database" by Susan Rhea (1997) show line themes of faults and depth to basement in this region of the central U.S. The data files were originally in ARC/INFO export (e00) format and are available by anonymous FTP in "greenwood.cr.usgs.gov". Upon request, the data were unprojected into decimal degrees (*i.e.*, geographic coordinates).

Descriptions of the individual themes can be found under the Theme Properties window.

Web Site: http://greenwood.cr.usgs.gov/maps/maps.html

FTP site: ftp://greenwood.cr.usgs.gov/pub/open-file-reports/ofr-97-0681

Reference:

Rhea, Susan B., Seismotectonic maps in the vicinity of the Lower Wabash Valley, IL, IN, and KY – Digital Spatial Database (1997), Open-File Report 97-681, U.S. Geological Survey.

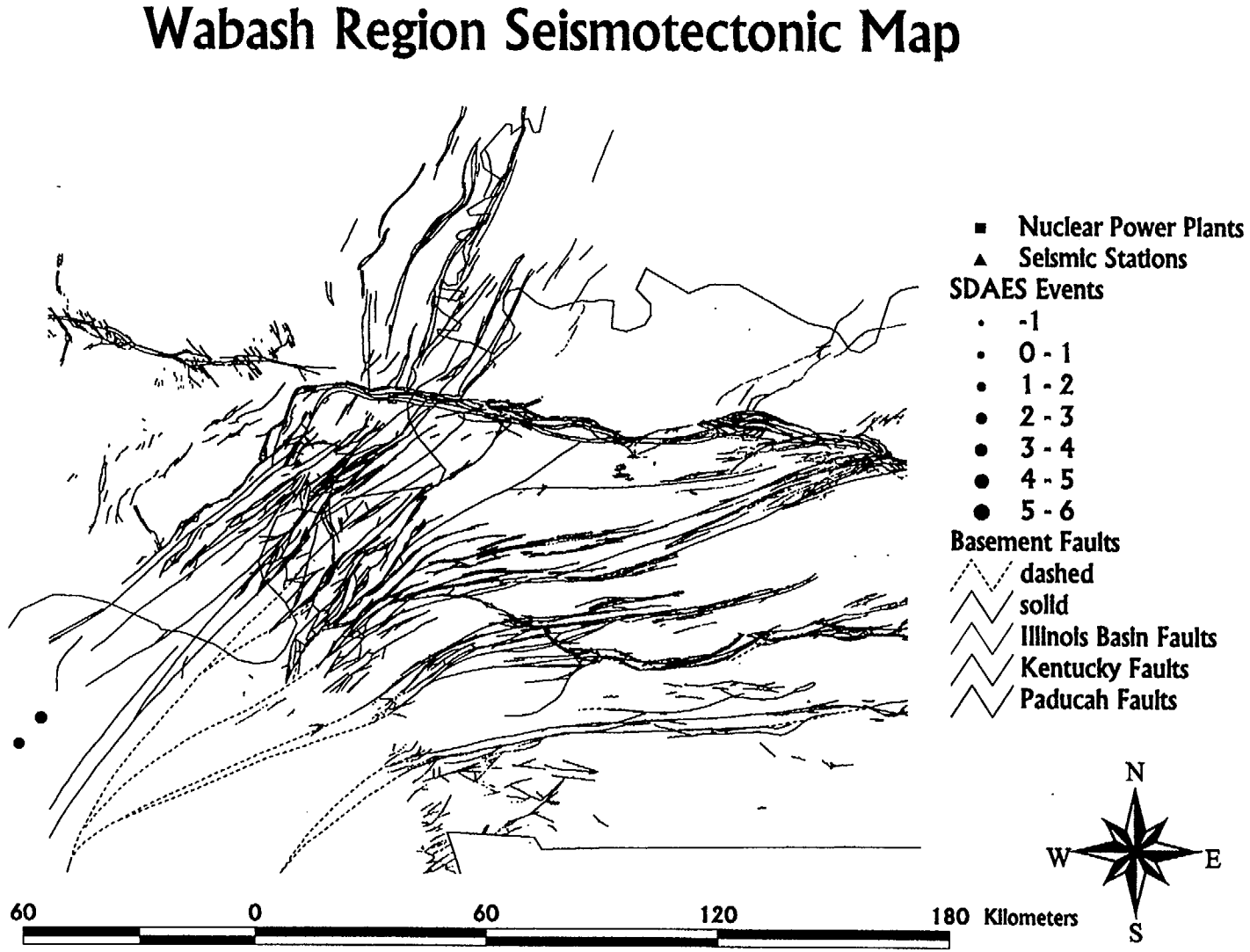

Figure 17. Map displaying selected data themes from the "Wabash Region Seismotectonic Map" View.

3.2.23 "World Stress Map (1997)" View

The World Stress Map (WSM 97-1) was developed under the WSM Project and is currently maintained by the Geophysical Institude of Karlsruhe University, Germany. Initially, the World Stress Map was based on the compilation of tectonic stresses for the United States by Mary Lou and Mark Zoback (Zoback and Zoback, 1980). Only data for North America are shown (25° N to 55° N latitude, -55° W to –125° W longitude).

Web Site:

http://www-gpi.physik.uni-karlsruhe.de/pub/wsm/index.html

A complete summary of the table attributes can be found in:
http://www-gpi.physik.uni-karlsruhe.de/pub/wsm/contribute/fieldswsm.html

FTP Site:

gpiwse3.physik.uni-karlsruhe.de (129.13.133.59)

directory: /pub/geoappl/wsm
file: wsm97-1.dbf (or wsm97-1.dbf.gz)

References:

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2) Zoback, M.L., Burke, K., 1993. World Stress Map. EOS, Trans. Amer. Geophys. U..

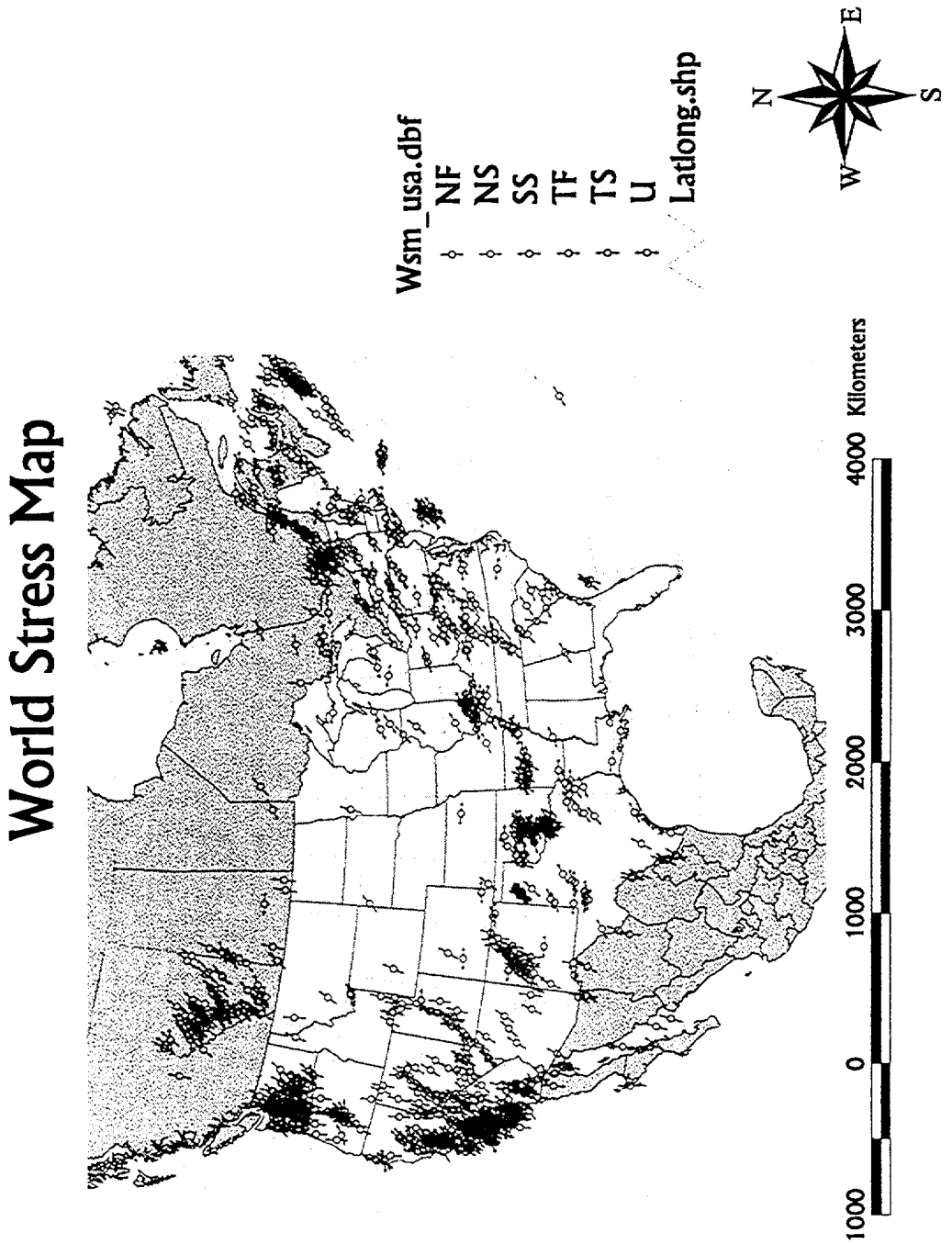

Figure 18. View displaying the "World Stress Map (1997)" for North America.

4. CALCULATION OF FREQUENCY-DEPENDENT SITE EFFECTS

4.1 Introduction

The ground motion at a given nuclear power plant (NPP) site, due to an earthquake, depends on several factors, including magnitude of the earthquake, its distance from the plant site, the attenuation characteristics of the wave propagation path, and frequency-dependent site effects. Theoretical analysis, based on detailed knowledge of the subsurface structure (e.g. layer thicknesses, their P and S velocities, and densities), can provide a fairly good estimate of the site effects. However, by visiting the NRC library facilities and examining several Final Safety Analysis Reports (FSAR), it was found that such information is not available for most, if not all, NPP sites.

Figure 19 shows 67 different locations of all Nuclear Power Plant (NPP) sites in the central and eastern United States. The NPP sites are classified as rock or soil sites, on the basis of information provided to us by Mr. Roger M. Kenneally of the Structural and Seismic Engineering Branch of the NRC. A comparison with the tectonic map of the United States (Figure 20, after Braile et al., 1989; Figure 9) clearly shows that the separation of the NPP sites into rock and soil is not directly related to the physiography of the region. For example, the three NPP sites in Florida, which lies within the Coastal Plain region with relatively lower seismic velocities, are classified as both rock (2) and soil (1). Similarly, out of the three closely-located NPP sites in Illinois, two are classified as rock and one as soil. This means that the classification of NPP sites in Figure 5 is based on shallow, near-surface material. The estimation of NPP site response should therefore be determined by considering a combination of two parts: shallow (a few hundred meters) and deep subsurface structure. Such an approach has been recommended and used in several studies (*e.g.* Rogers et al., 1985; Benz and Smith, 1988; Hill et al., 1990).

4.2 Site Effects Due to Shallow Structure

The shallow structure under a NPP influences the site effects mostly at the higher frequencies, whereas the deeper structure has significant influence mainly at lower (less than about 2 Hz) frequencies (or on relatively taller structures). We made use of Mr. Roger M. Kenneally's database in order to determine whether a given NPP site was on rock or soil. In order to be consistent with the software *Predspec*, which is already in use at the NRC workstation and makes use of attenuation relations from Atkinson and Boore (1995), we use the frequency-dependent rock versus soil site effects given by Atkinson and Boore (1995, Table 3, p. 24). The multiplicative soil amplification factors range from 1.9 to 0.93 for the frequency range of 0.5 to 20.0 Hz.

4.3 Site Effects Due to Deeper Structure

For the evaluation of site effects due to deep subsurface structure, we used two different approaches:

(a) Theoretical Modeling of Site Effects

In this method, we consider the crustal structure under various NPP sites and estimate the frequency-dependent amplification by theoretical methods. The NPP sites lie within several physiographic-tectonic provinces of the eastern United States (*e.g.* Fox, 1970; King and

Beikman, 1974; Braile *et al.*, 1989; Pakiser and Mooney, 1989), each of which may have distinct crustal structure (Toro *et al.*, 1997). There appears to be no single source for these crustal models. A search of the available literature suggested that the best approach would perhaps be to use the regionalized crustal structure models for the central and eastern North America (CENA), as developed by Woodward Clyde for the Electric Power Research Institute (EPRI, 1993). The regionalized crustal structure models for the central and eastern United States, as developed by Woodward Clyde for EPRI, consist of 16 different regions so that the site effects for a particular region can be approximated by those observed at a recording station lying within the same region.

A test of the theoretical method was carried out for its usefulness in obtaining meaningful results consistent with known empirical observations of site effects. Dr. Robert Herrmann's wavenumber integration code for deriving synthetic seismograms for various crustal structures and focal mechanisms (Herrmann and Wang, 1985) was first implemented. For each crustal model, for a hypocentral depth of 10 km and a source-receiver distance of 100 km, synthetic seismograms for three fundamental focal mechanisms (strike-slip, dip-slip, and 45° dip-slip), along two different azimuthal directions (0° and 90°), and for three components of motion (vertical, radial, and transverse) were obtained (a total of 18 seismograms). The sampling interval was 0.05 sec so that results up to 10 Hz can be determined. As a test of the method for providing realistic estimates of frequency-dependent amplification, a comparison of the ground motion for two significantly different crustal structures, Gulf Coastal Plain and Mid-continent, was made. Note that the P-velocities in the uppermost layer for these two structures are 4.0 and 4.9 km/sec, respectively. Frequency-dependent amplification, obtained by taking the ratio of ground motions for sources in the Gulf Coastal Plain and Mid-continent regions and averaged over six synthetics for each region, are shown in Figure 21a,b,c for the vertical, radial, and transverse components, respectively. The ratio of average horizontal to vertical is shown in Figure 21d which indicates values larger than 1 only for mostly very low (less than about 0.5 Hz) frequencies.

According to several studies (*e.g.* Gupta *et al.*, 1982; Gupta and McLaughlin, 1987; Gupta *et al.*, 1989; Lermo and Chavez-Garcia, 1993; Field and Jacob, 1995; Theodulidis *et al.*, 1996), the ratio of the observed horizontal and vertical component S waves or Lg provides a fairly good estimate of the frequency-dependent site effects at a recording station. The theoretical result in Figure 21d implies no amplification of ground motion for most frequencies larger than about 0.5 Hz. However, observational results of ground amplification due to lower velocity medium generally indicate amplification over a fairly large frequency band (*e.g.* Phillips and Aki, 1986). It seems therefore that the theoretical results in Figure 3 are not consistent with generally accepted observations and should not be used. A possible reason for the discrepancy is the dominance of surface waves in the theoretical model (Castro *et al.*, 1997). The theoretical approach for determining frequency-dependent site effects was therefore abandoned because it led to results inconsistent with observations.

(b) Empirical Methods

In view of the large amount of waveform data already acquired by the SDAES system (Figure 22), it was considered more appropriate and useful to derive the frequency-dependent site effects based on analysis of the recorded three-component waveforms than on purely theoretical methods which require several unrealistic assumptions (such as plane parallel, homogeneous layers). In a comparison of various site-response estimation techniques, Field and Jacob (1995) concluded that horizontal- to vertical-component ratios of shear wave spectra reveal the overall frequency dependence of site response. This means that an estimate of the frequency-dependent

site effects at a recording site can be made by simply obtaining the average ratio of horizontal and vertical component S waves or Lg.

We developed software for conveniently obtaining the average horizontal/vertical ratio of Lg from three-component data from several events recorded at a common station. All Lg spectra are corrected for noise by obtaining spectra of a sample of noise preceding the first arrival, Pn. Spectral ratios of each of the two horizontal (north-south and east-west) to the vertical component are obtained by using only those data points in their spectra which meet a minimum specified signal/noise level. Results from two recording stations OXF and BLA, lying within two different crustal regions, have already been obtained.

Work on frequency-dependent site effects was continued by analyzing three-component data from several additional stations, each recording three or more events with satisfactory signal/noise ratios. A comparison of the average horizontal/vertical ratio of Lg from three-component data recorded at a common station with that obtained by using noise samples (prior to the arrival of P waves) showed remarkable similarity. This means that a fairly good estimate of the average horizontal/vertical ratio of expected ground motion at a station can be made even when the available recordings do not include a seismic event. This result also indicates that the average horizontal/vertical ratio of Lg is not much influenced by source effects and is truly representative of the recording site.

4.4 Frequency Dependent Site Amplification Maps

As mentioned earlier, the ratio of the observed horizontal (H) and vertical component (Z) of Lg, i.e. H/Z, has been known to provide a good estimate of the frequency-dependent site effects at a recording station. It was therefore decided to make use of the available H/Z data from as many as 53 locations based on three-component data from 107 seismic events in the central and eastern United States (EPRI, 1989). These data for seven different frequencies (1.25, 2, 3, 4, 5, 6, and 7 Hz) are contoured and the site effects for each NPP site are obtained by interpolation, using the Spatial Analyst (ArcView). The results are shown in Figures 23a, b, c, d, e, f, g. The final amplification factors for each of the 69 NPP locations, obtained by correcting all soil sites by additional soil amplification factors from Atkinson and Boore (1995, Table 3, p. 24), are listed in Table 3.

4.5 References

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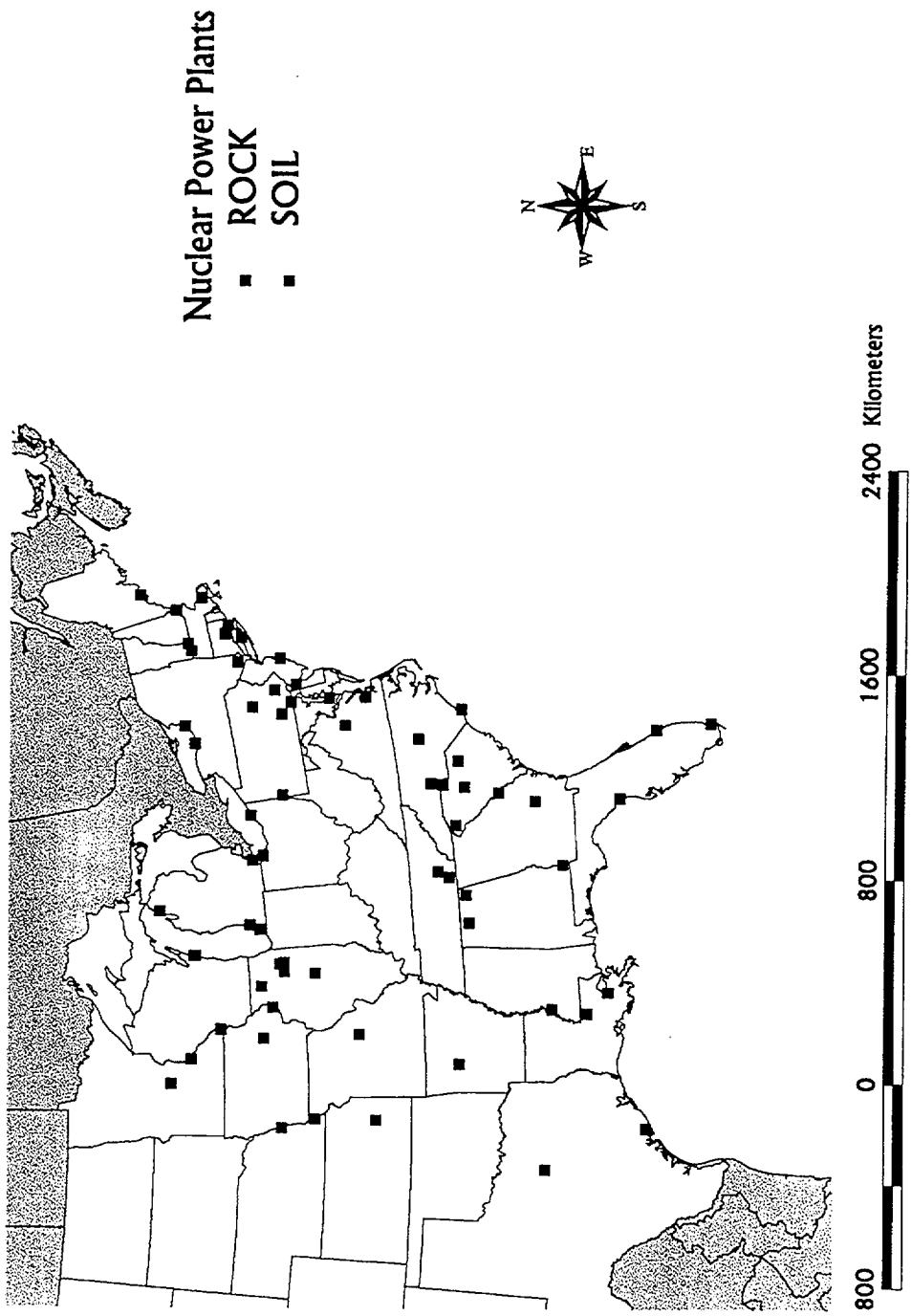

Figure 19. Locations of 67 Nuclear Power Plants in the central and eastern United States.

Figure 20. Index map of eastern North American continent showing the principal tectonic units, geologic provinces, and locations of major basins and uplifts (after Braile *et al.*, 1989, Figure 9).

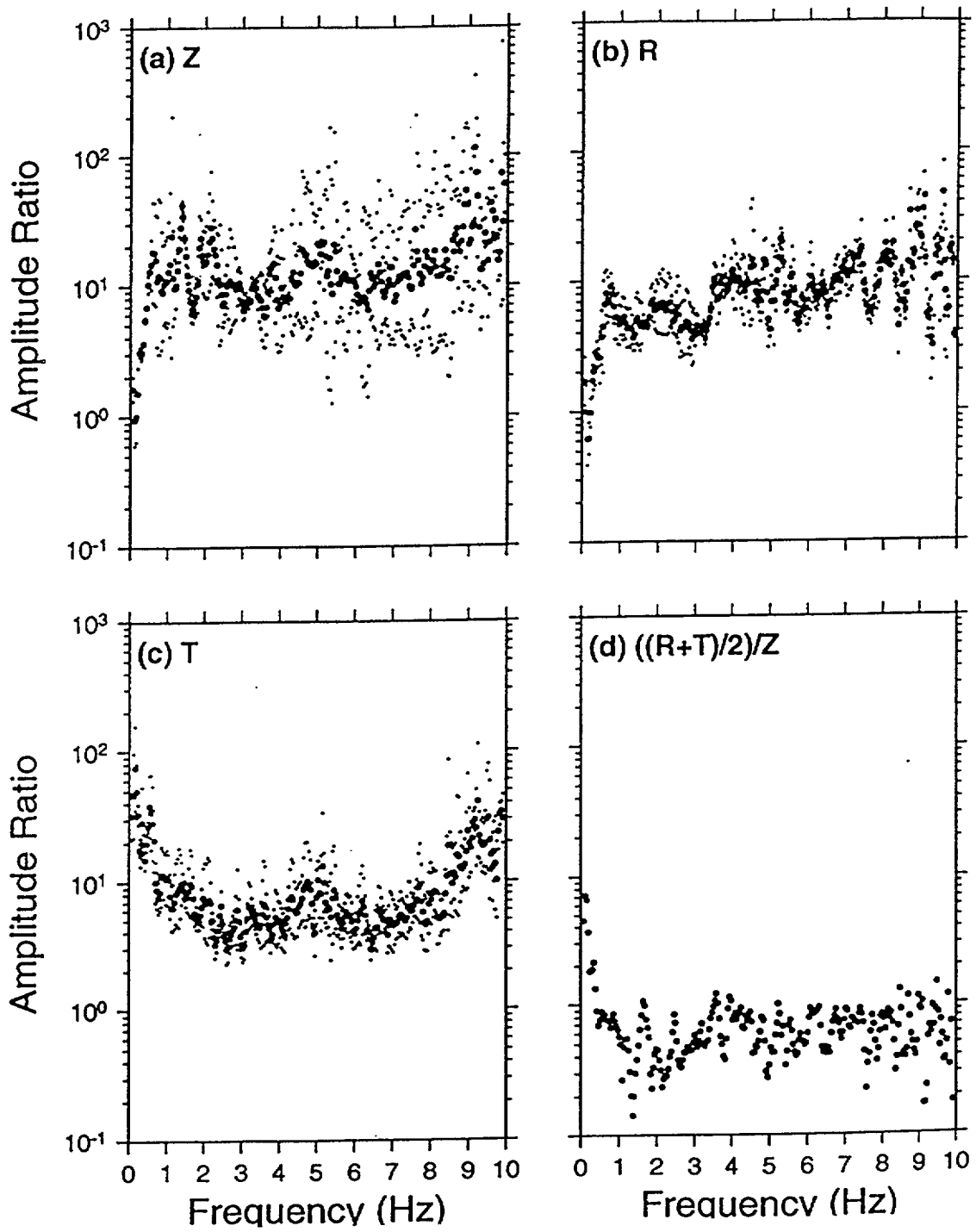

Figure 21. Theoretical average amplification (ratio of ground motions for sources in the Gulf Coastal Plain and Mid-continent regions) for (a) vertical, (b) radial, (c) transverse components, and (d) ratio of average horizontal to average vertical, indicating values larger than 1 only for mostly very low (less than about 0.5 Hz) frequencies. These theoretical results appear to be inconsistent with observed results, and therefore they are not used.

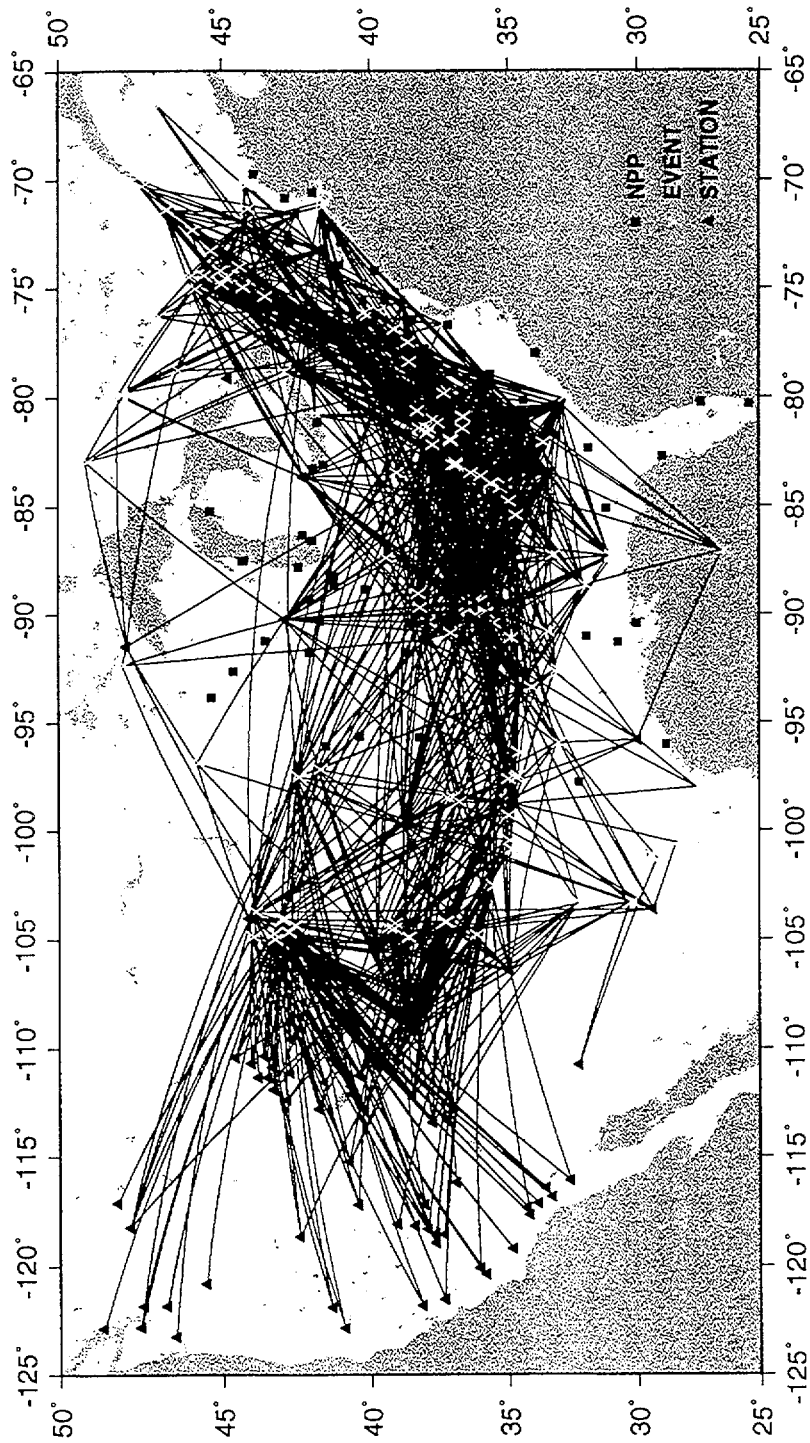

Figure 22. Large volumes of waveform data have been collected by the SDAES system, as is indicated by a map of the paths connecting 148 seismic events recorded at 112 stations. The locations of 67 Nuclear Power Plants are also shown.

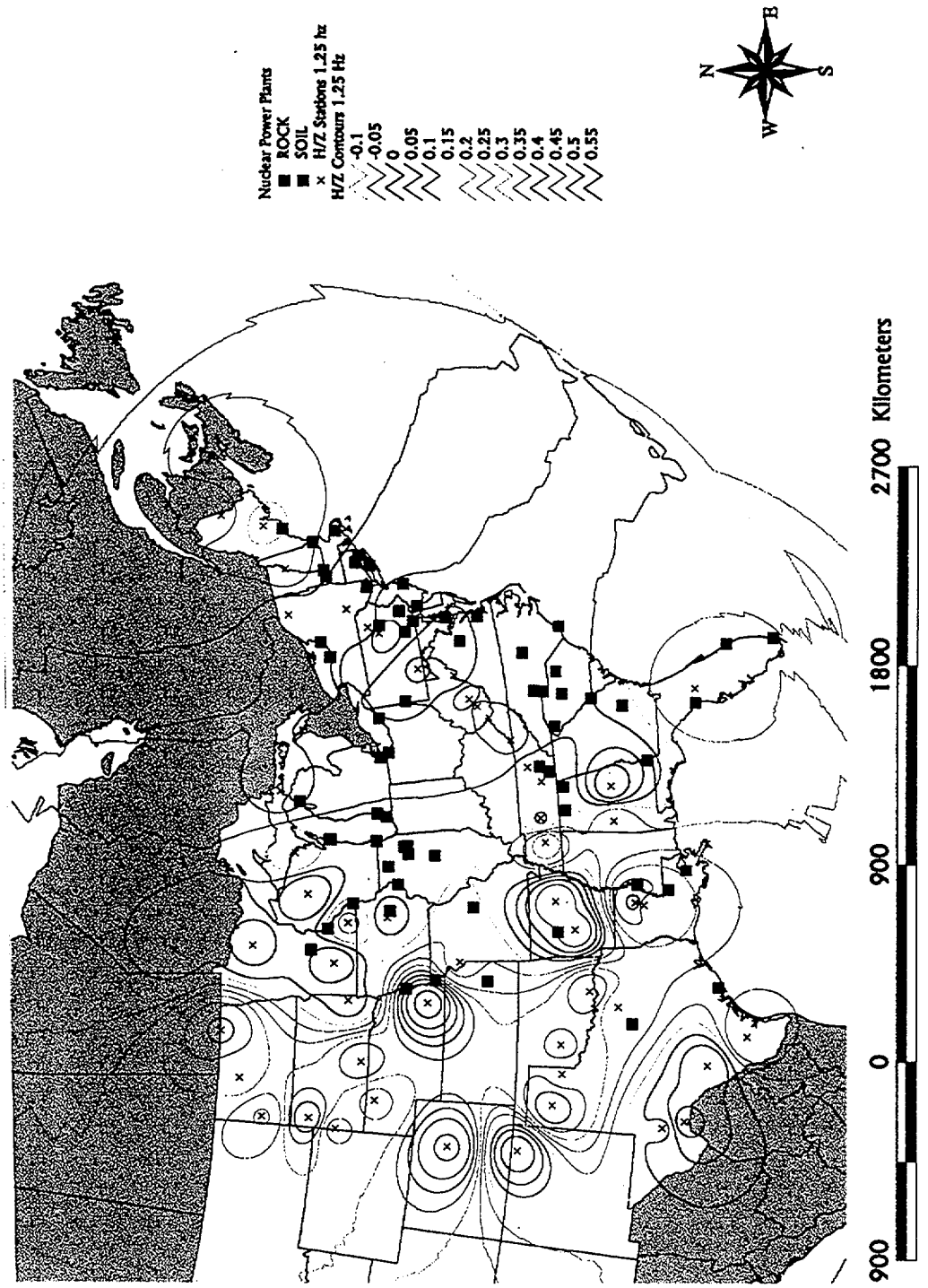

Figure 23a. Frequency-dependent site effects based on the ratio of the observed horizontal (H) and vertical (Z) components, H/Z, from EPRI (1989), for mean frequency of 1.25 Hz.

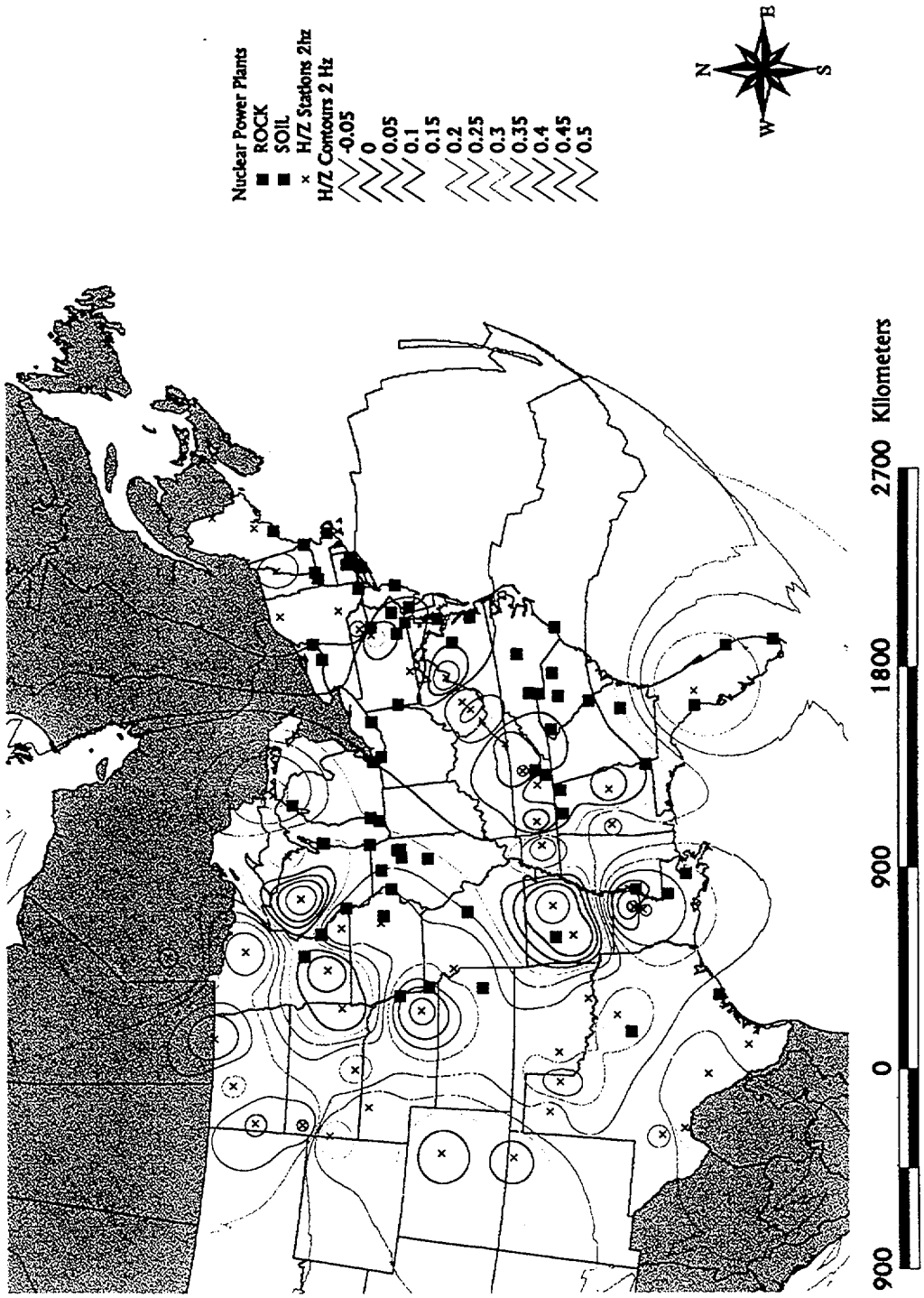

Figure 23b. Frequency-dependent site effects based on the ratio of the observed horizontal (H) and vertical (Z) components, H/Z, from EPRI (1989), for mean frequency of 2.0 Hz.

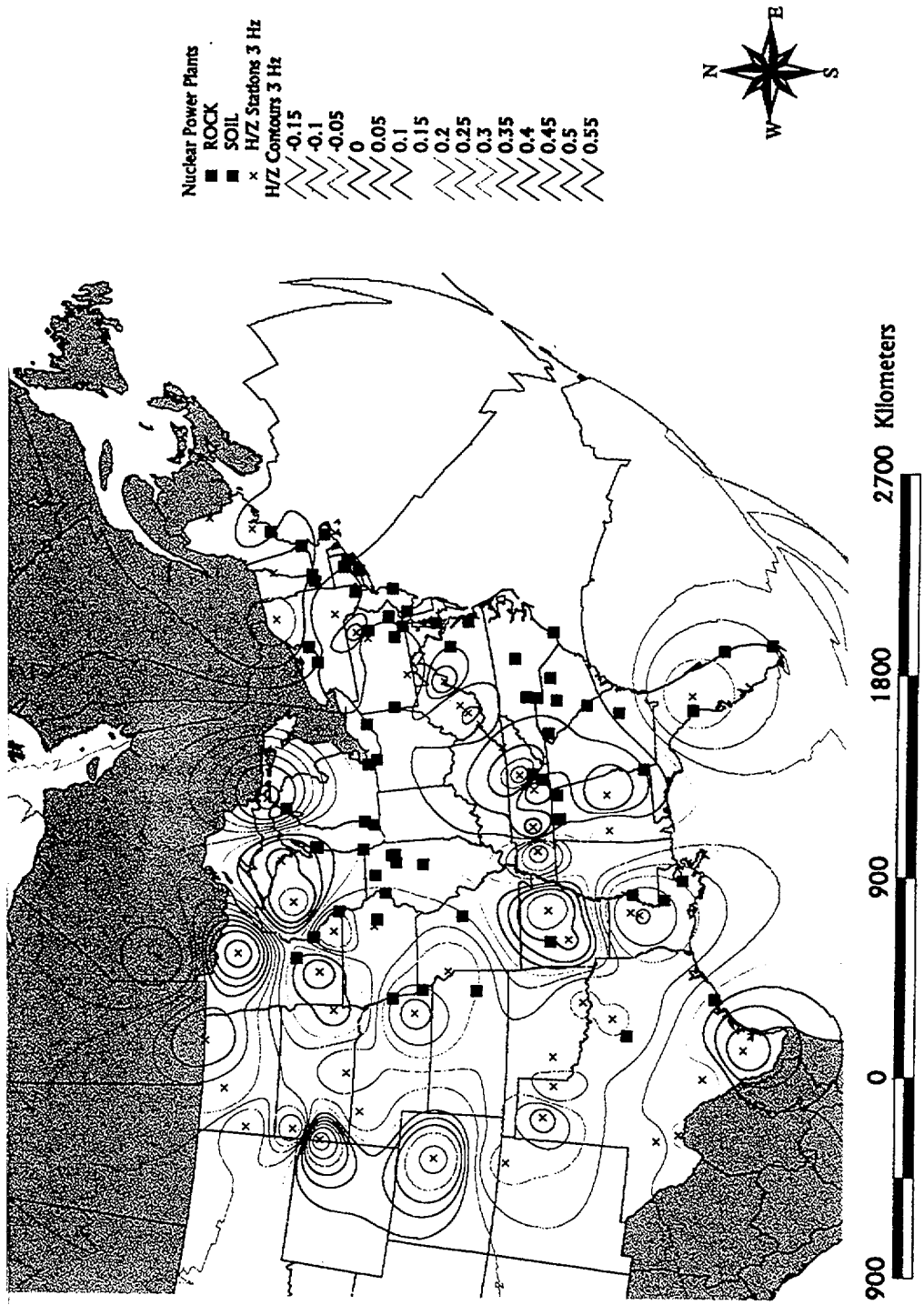

Figure 23c. Frequency-dependent site effects based on the ratio of the observed horizontal (H) and vertical (Z) components, H/Z, from EPRI (1989), for mean frequency of 3.0 Hz.

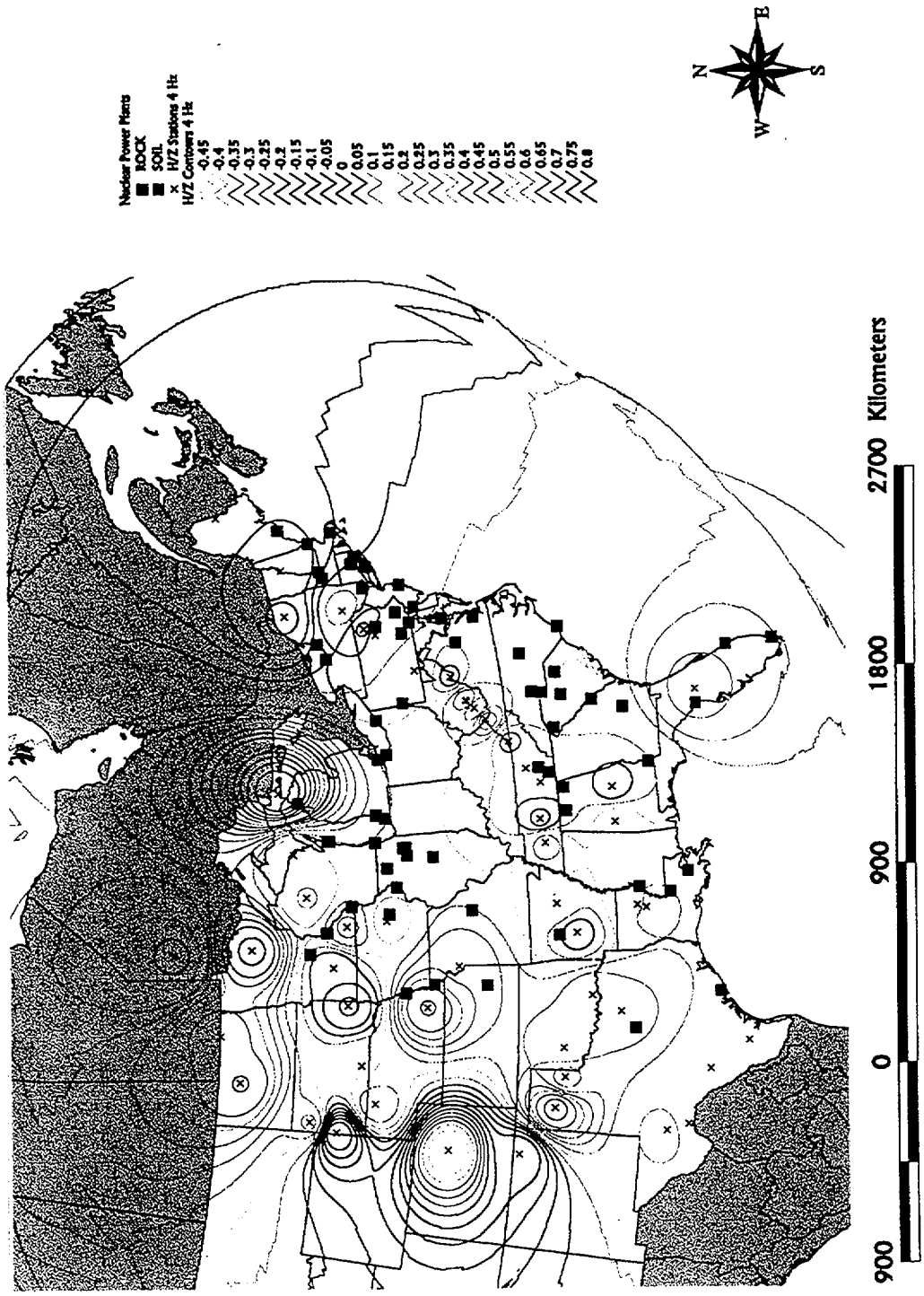

Figure 23d. Frequency-dependent site effects based on the ratio of the observed horizontal (H) and vertical (Z) components, H/Z, from EPRI (1989), for mean frequency of 4.0 Hz.

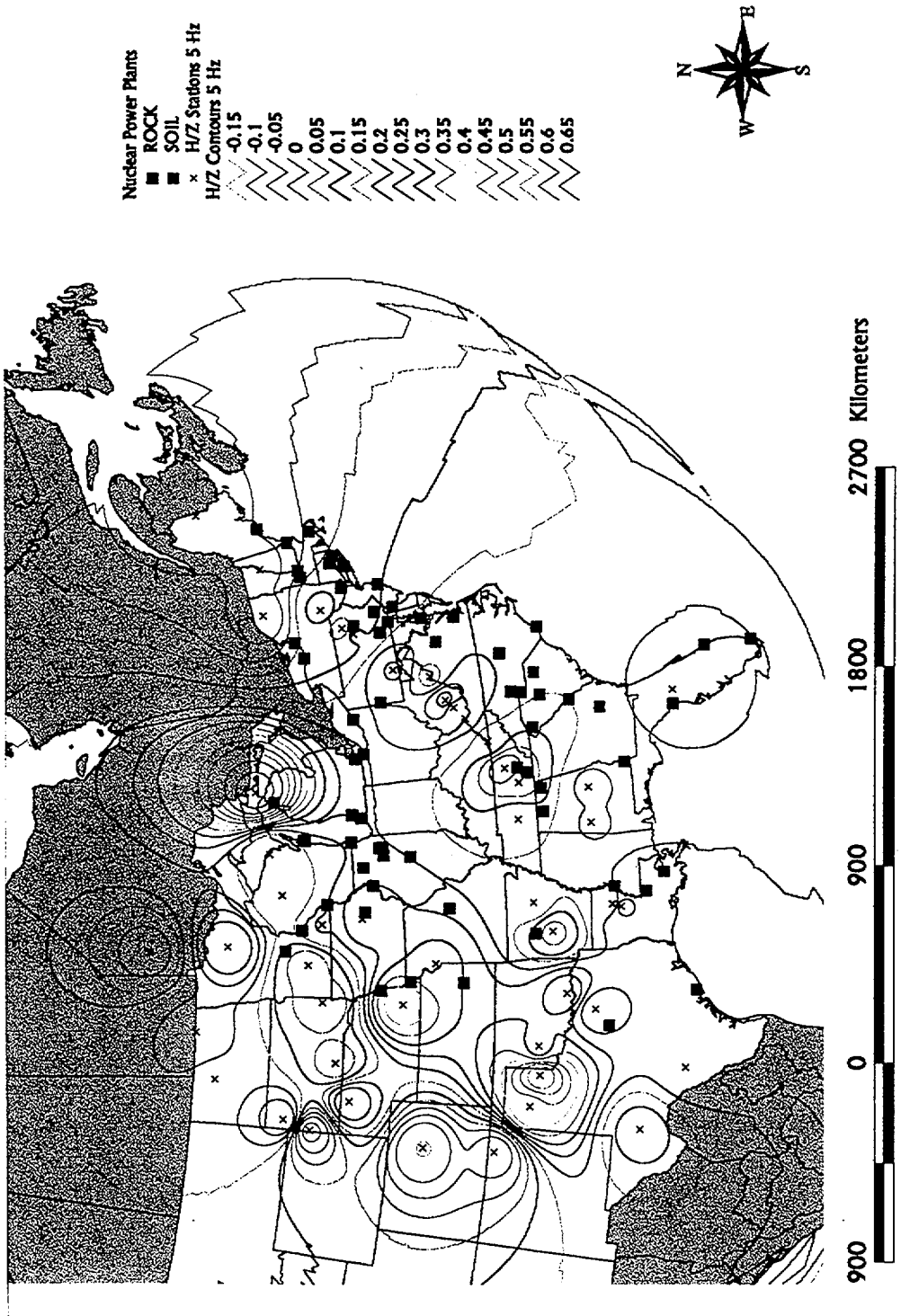

Figure 23e. Frequency-dependent site effects based on the ratio of the observed horizontal (H) and vertical (Z) components, H/Z, from EPRI (1989), for mean frequency of 5.0 Hz.

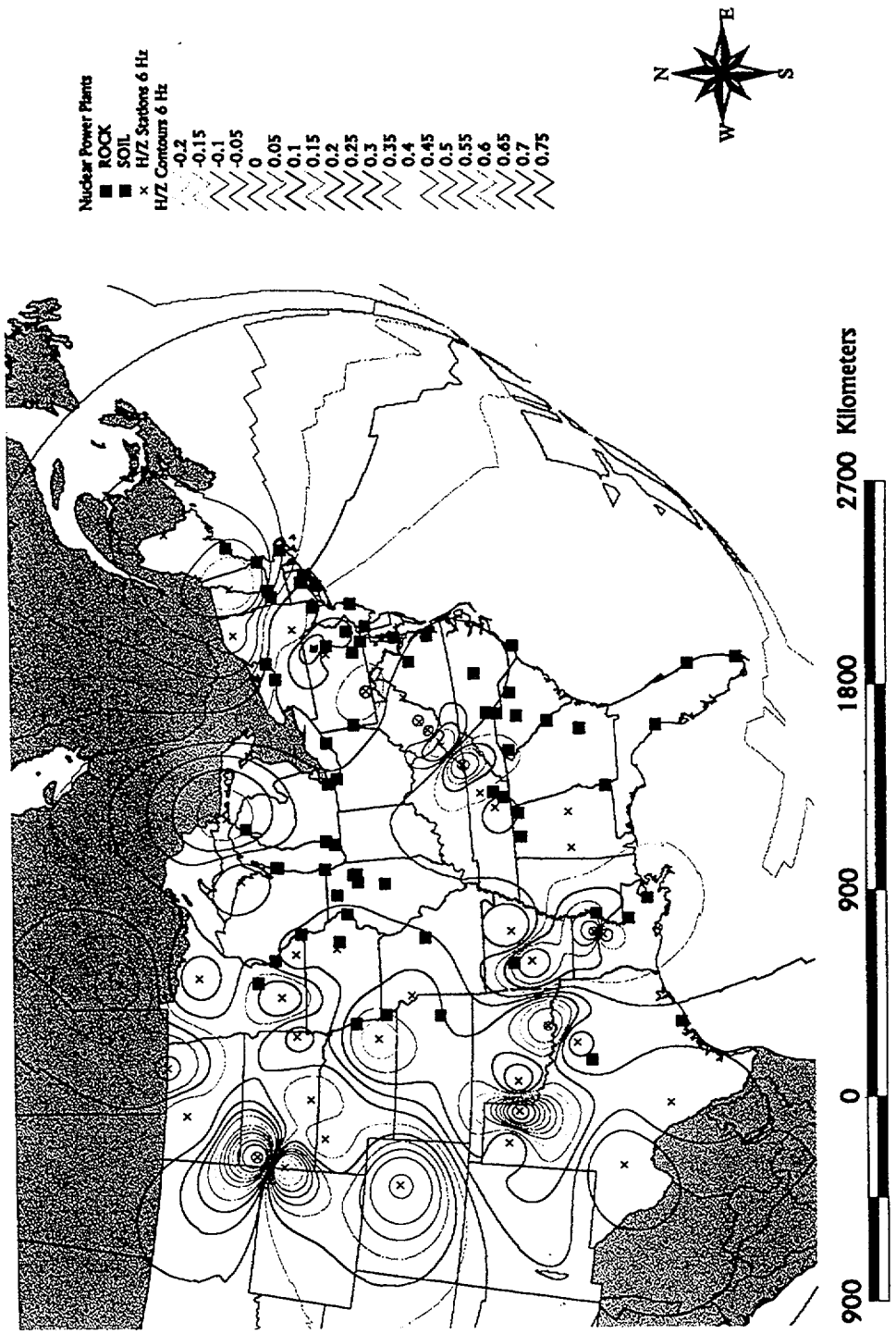

Figure 23f. Frequency-dependent site effects based on the ratio of the observed horizontal (H) and vertical (Z) components, H/Z, from EPRI (1989), for mean frequency of 6.0 Hz.

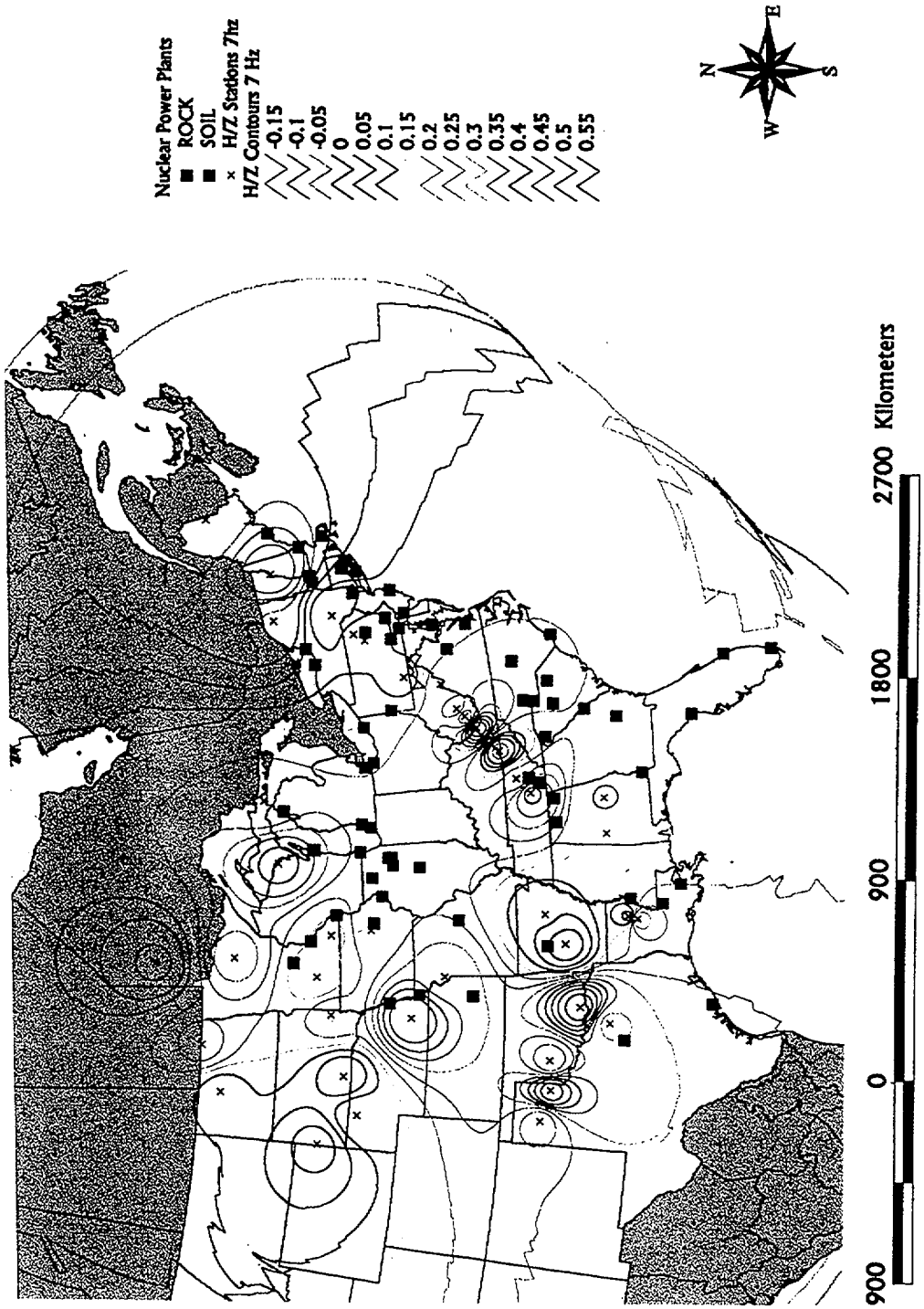

Figure 23g. Frequency-dependent site effects based on the ratio of the observed horizontal (H) and vertical (Z) components, H/Z, from EPRI (1989), for mean frequency of 7.0 Hz.

Table 3. List of 69 Nuclear Power Plants with frequency-dependent site amplification factors.

No.	Plant	State	Lat	Lon	Fdn	SAF_1.25hz	SAF_2hz	SAF_3hz	SAF_4hz	SAF_5hz	SAF_6hz	SAF_7hz
1	Arkansas	AR	35.226667	-93.230833	ROCK	1.00	1.00	1.00	1.15	1.17	1.07	1.00
2	Beaver_Valley	PA	40.621944	-80.433889	SOIL	2.00	2.24	2.40	2.51	2.82	2.40	2.19
3	Bellefonte	AL	34.708889	-85.926667	ROCK	1.38	1.17	1.20	1.17	1.17	1.58	2.14
4	Big_Rock_Point	MI	45.359167	-85.194722	SOIL	2.09	3.72	4.79	10.47	7.08	3.72	2.63
5	Braidwood	IL	41.243611	-88.228889	ROCK	1.35	1.48	1.45	1.51	1.58	1.70	1.70
6	Browns_Ferry	AL	34.704167	-87.118611	ROCK	1.41	1.17	1.20	1.17	1.35	1.51	1.78
7	Brunswick	NC	33.958333	-78.010556	SOIL	2.24	2.34	2.29	2.57	2.57	2.63	2.51
8	Byron	IL	42.075000	-89.281944	ROCK	1.32	1.58	1.51	1.48	1.66	1.74	1.70
9	Callaway	MO	38.758333	-91.781667	ROCK	1.45	1.58	1.62	1.58	1.74	1.82	1.78
10	Calvert_Cliffs	MD	38.434722	-76.441944	SOIL	2.09	2.14	2.24	2.34	2.51	2.57	2.24
11	Catawba	SC	35.051389	-81.069444	ROCK	1.17	1.17	1.17	1.41	1.45	1.55	1.66
12	Clinton	IL	40.171944	-88.834167	SOIL	2.57	2.82	2.69	2.63	2.75	2.82	2.63
13	Comanche_Peak	TX	32.297778	-97.785000	ROCK	1.86	2.09	1.95	1.86	1.55	1.62	2.00
14	Cook	MI	41.976111	-86.566389	SOIL	2.40	2.75	2.57	2.88	2.82	2.75	2.69
15	Cooper_Station	NE	40.361944	-95.641111	SOIL	4.90	4.79	4.37	4.37	4.07	3.89	4.17
16	Crystal_River	FL	28.957222	-82.698889	ROCK	1.70	2.19	2.04	2.04	1.62	1.45	1.48
17	Davis_Besse	OH	41.597222	-83.086389	ROCK	1.17	1.23	1.32	1.51	1.58	1.58	1.55
18	Dresden	IL	41.389722	-88.271111	ROCK	1.35	1.48	1.45	1.51	1.62	1.70	1.70
19	Duane_Arnold	IA	42.100556	-91.777222	SOIL	2.29	3.63	3.09	2.51	3.39	3.02	2.69
20	Enrico_Fermi	MI	41.963333	-83.258611	ROCK	1.17	1.26	1.35	1.58	1.62	1.62	1.55
21	Farley	AL	31.222778	-85.112500	ROCK	1.17	1.29	1.12	1.26	1.55	1.45	1.35
22	Fitzpatrick	NY	43.523889	-76.398333	ROCK	1.07	1.00	1.07	1.05	1.10	1.26	1.15
23	Fort_Calhoun	NE	41.520833	-96.076667	SOIL	5.25	4.79	4.17	4.17	3.98	3.89	4.17
24	Ginna	NY	43.291667	-77.308889	ROCK	1.10	1.05	1.12	1.12	1.17	1.41	1.20
25	Grand_Gulf	MS	32.007500	-91.048056	SOIL	4.37	5.37	4.37	2.88	2.75	1.74	2.24
26	Haddam_Neck	CT	41.481944	-72.499167	ROCK	1.05	1.00	1.12	1.12	1.15	1.26	1.17
27	Harris	NC	35.633333	-78.956111	ROCK	1.17	1.17	1.23	1.45	1.55	1.66	1.70
28	Hatch	GA	31.934167	-82.344444	SOIL	2.51	2.75	2.45	2.63	2.57	2.45	2.40
29	Hope_Creek	NJ	39.467778	-75.538056	SOIL	2.14	2.24	2.29	2.19	2.29	2.57	2.04
30	Indian_Point	NY	41.271389	-73.952500	ROCK	1.10	1.00	1.17	1.20	1.23	1.45	1.32
31	Kewaunee	WI	44.343056	-87.536111	SOIL	2.51	2.75	2.19	2.82	2.57	2.69	3.47
32	La_Crosse	WI	43.560000	-91.228333	SOIL	2.75	3.47	3.55	3.02	2.75	2.95	2.29
33	Lasalle	IL	41.243889	-88.670833	SOIL	2.51	2.95	2.75	2.69	2.82	2.82	2.69
34	Limerick	PA	40.220000	-75.590000	ROCK	1.20	1.17	1.23	1.17	1.23	1.62	1.26
35	Maine_Yankee	ME	43.950556	-69.696111	ROCK	1.00	1.00	1.00	1.00	1.00	1.00	1.00
36	McGuire	NC	35.432222	-80.948333	ROCK	1.17	1.17	1.17	1.45	1.51	1.58	1.70
37	Millstone	CT	41.308611	-72.168056	ROCK	1.05	1.00	1.12	1.12	1.15	1.23	1.15
38	Monticello	MN	45.333333	-93.848333	SOIL	2.14	2.40	2.40	2.19	2.09	2.19	2.19
39	Nine_Mile_Point	NY	43.522222	-76.410000	ROCK	1.07	1.00	1.07	1.05	1.10	1.26	1.15
40	North_Anna	VA	38.060833	-77.790556	SOIL	2.04	2.00	2.09	2.29	2.63	2.69	2.51

41	Oconee	SC	34.791667	-82.898611	SOIL	2.29	2.14	2.00	2.34	2.24	2.29	2.40
42	Oyster_Creek	NJ	39.814167	-74.206389	SOIL	2.09	2.14	2.19	2.14	2.19	2.51	2.04
43	Palisades	MI	42.322222	-86.315278	SOIL	2.40	2.75	2.63	3.02	2.88	2.82	2.69
44	Peach_Bottom	PA	39.758889	-76.269167	ROCK	1.17	1.20	1.26	1.20	1.32	1.55	1.29
45	Perry	OH	41.801111	-81.143333	ROCK	1.12	1.17	1.29	1.41	1.55	1.51	1.41
46	Pilgrim	MA	41.944444	-70.579444	SOIL	1.74	1.86	1.91	1.78	1.78	1.62	1.51
47	Point_Beach	WI	44.280833	-87.536111	SOIL	2.51	2.75	2.19	2.82	2.57	2.69	3.47
48	Prairie_Island	MN	44.619444	-92.633056	ROCK	1.45	1.62	1.78	1.58	1.48	1.70	1.41
49	Quad_Cities	IL	41.726111	-90.310000	ROCK	1.29	1.74	1.62	1.45	1.78	1.82	1.70
50	River_Bend	LA	30.757222	-91.331667	SOIL	3.98	4.57	4.27	2.88	2.95	2.19	2.69
51	Robinson	SC	34.405278	-80.158611	SOIL	2.24	2.29	2.24	2.57	2.57	2.63	2.63
52	Salem	NJ	39.462778	-75.535833	SOIL	2.14	2.24	2.29	2.19	2.29	2.57	2.04
53	Seabrook	NH	42.898056	-70.851389	ROCK	1.00	1.00	1.00	1.00	1.00	1.00	1.00
54	Sequoyah	TN	35.223333	-85.087778	ROCK	1.45	1.17	1.20	1.17	1.07	1.58	2.34
55	Shoreham	NY	40.960000	-72.870000	SOIL	2.00	1.95	2.14	2.09	2.09	2.24	1.95
56	South_Texas	TX	28.795000	-96.048056	SOIL	3.16	3.31	2.45	2.75	2.88	2.75	2.88
57	St_Lucie	FL	27.348611	-80.246389	SOIL	3.09	3.98	3.55	3.55	2.82	2.45	2.40
58	Surry	VA	37.165556	-76.698333	SOIL	2.09	2.14	2.19	2.40	2.63	2.63	2.45
59	Susquehanna	PA	41.091667	-76.148611	SOIL	2.40	2.63	2.45	2.14	2.14	2.69	2.00
60	Three_Mile_Island	PA	40.153056	-76.725000	ROCK	1.23	1.26	1.29	1.20	1.32	1.55	1.26
61	Turkey_Point	FL	25.435000	-80.331389	ROCK	1.58	1.91	1.78	1.78	1.58	1.45	1.55
62	Vermont_Yankee	VT	42.780278	-72.515833	ROCK	1.00	1.00	1.02	1.00	1.00	1.00	1.00
63	Virgil_C.Summer	SC	34.295833	-81.320278	SOIL	2.24	2.29	2.19	2.51	2.45	2.51	2.51
64	Vogtle	GA	33.141944	-81.764722	SOIL	2.34	2.40	2.24	2.45	2.45	2.45	2.45
65	Waterford	LA	29.995000	-90.471111	SOIL	3.63	4.07	3.63	2.82	2.82	2.19	2.51
66	Watts_Bar	TN	35.602778	-84.790278	ROCK	1.35	1.00	1.00	1.23	1.00	1.45	1.86
67	Wolf_Creek	KS	38.238889	-95.688889	ROCK	1.70	1.91	2.00	1.91	2.00	2.00	2.09
68	Yankee_Rowe	MA	42.728056	-72.924722	SOIL	1.86	1.86	2.00	1.91	1.86	1.74	1.62
69	Zion	IL	42.445556	-87.802222	SOIL	2.45	2.82	2.63	2.82	2.75	2.82	2.75

Table 3 (continued). List of 69 Nuclear Power Plants with frequency-dependent site amplification factors.

5. CALCULATION OF CUMULATIVE ABSOLUTE VELOCITY (CAV)

5.1 Background

Damage to structures due to earthquakes is a complex function of amplitude, frequency and duration, and it varies with the type of structure. Small earthquakes in the eastern United States have occurred with Peak Ground Acceleration (PGA) or Pseudo-Acceleration (PSA) exceeding Operational Basis Earthquake (OBE) criteria but without sustaining damage to structures of nuclear power plants. Several parameters that relate measured ground motion to potential structural damage have been introduced (Reiter, 1990, P. 170). One was *Arias Intensity* (*AI*) defined as:

$$AI = \frac{\pi}{2g}\int_0^{t_0} a^2(t)dt \qquad (1)$$

Where $a(t)$ is acceleration recorded from the onset of the record to a time t_0 when strong motion ceases. The other measure that did well was one called *Cumulative Absolute Velocity* (*CAV*), where

$$CAV = \int_0^{t_0} |a(t)|dt. \qquad (2)$$

It was concluded in EPRI (1988) that *CAV* is the best single parameter for determining the damage threshold of earthquakes.

One task of the development of the SDAES and then the ASEMS seismic monitoring systems is *CAV* prediction at sites of nuclear power plants. The *CAV* dependence on distance was supposed to be derived from synthetic seismograms. However, this task was eventually modified to change the method from using synthetic seismograms to using observed waveforms, after our initial work on this project showed that the latter approach was more nearly effective. The relationships of PGA and response spectra PSA versus magnitude and distance, which were determined by Atkinson and Boore (1995) for eastern North America, are used in the software that we developed. These relationships do not include *CAV*. We therefore made efforts to determine the relationship of CAV from the seismic data recorded by SDAES. However, most of the data recorded by the VSAT system during the period 1995 – 1996 from earthquakes in the eastern United States were from small events, so the recordings have low signal-to-noise ratios. The lack of ground motion data in eastern North America is well known. So far all the relations of ground motion attenuation in this area are determined using hybrid methods (semi-empirical, semi-theoretical, and stochastic; *cf.* Reiter, 1990). In light of these restrictions, we chose to derive the *CAV* attenuation from the existing relations of PSA given by Atkinson and Boore (1995) for the eastern United States. This process involves a conversion of the relations in the frequency domain to corresponding relations in the time domain.

5.2 Prediction of AI

We use *AI* as an intermediary variable for *CAV*, because it can easily be connected with spectra by means of the Parseval relation:

$$\int_{-\infty}^{\infty} |\phi(f)|^2 df = \int_{-\infty}^{\infty} |x(t)|^2 dt \tag{3}$$

where $x(t)$ has Fourier transform $\Phi(f)$ (Kaplan, 1981). The right-hand side of (3) is similar to (1), the expression for AI. The integration from 0 to t_0 must include most of the energy in full range. Atkinson and Boore (1995) provide the relations for PSA in this form:

$$\log PSA = c_1 + c_2(M-6) + c_3(M-6)^2 - \log R - c_4 R \quad , \tag{4}$$

for the frequencies 0.5, 0.8, 1.0, 1.3, 2.0, 3.2, 5.0, 7.9, 10.0, 13.0, and 20.0 Hz. Using these relations, we can make predictions for response spectra at those frequency points for any power plant, so long as we have the value of PSA obtained from the records at one or more seismograph stations. In the case of prediction, the magnitude M is the same for the recording site and the site where we make the prediction. Therefore, the prediction value can be determined simply from the recorded PSA value and the $\log R + c_4 R$ term. We can approximate the spectral integration in the left-hand side of (3) as

$$S = \sum_{i=1}^{N} \phi_i^2 (f_{i+1} - f_i) \tag{5}$$

where Φ_i is the value of the Fourier spectrum of an acceleration record and where f_i stands for a particular frequency.

If AI_1 is AI at a seismograph station, AI_2 is that at a power plant, S_1 and S_2 are the results of the corresponding spectral integration in the frequency domain, then from (3) we obtain

$$\frac{S_2}{S_1} = \frac{AI_2}{AI_1} \tag{6}$$

Because both response spectra have the same damping factor, their ratio is approximately equal to the ration of the Fourier spectra. We shall use the same symbols S_1 and S_2 for response spectra in the following analysis.

5.3 Statistical Estimates of AI and CAV

First, let us find the averages for both AI and CAV. We assume that the observed acceleration x is a random variable with 0-σ normal distribution. The zero average is assumed since we usually have the mean value removed in seismic data processing. The standard deviation is denoted by σ. Its distribution function is given by

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{x^2}{2\sigma^2}\right) \tag{7}$$

x^2 is then a function of the random variable x. Thus the average of x^2 is (Kaplan, 1981)

$$\overline{x^2} = \int_{-\infty}^{\infty} x^2 p(x) dx = \sigma^2 \tag{8}$$

The distribution of $y = x^2$ is a chi-squared distribution with degree of freedom parameter $n = 1$

$$q(y) = \frac{1}{\sqrt{2\pi}\sigma} y^{-\frac{1}{2}} \exp\left(-\frac{y}{2\sigma^2}\right). \tag{9}$$

$|x|$, the integrand in (2), is not a differentiable function of x. We cannot derive its distribution from that of x directly. However, we can define $|x| = \text{sqrt}(y) = \text{sqrt}(x^2)$. We take only the positive square root here, so that it is a single-valued differentiable function of y. The average can be obtained based on the distribution of $y = x^2$.

$$\overline{|x|} = \int_0^{\infty} y^{\frac{1}{2}} q(y) dy = \sqrt{\frac{2}{\pi}}\sigma \tag{10}$$

The values of AI and CAV can easily be obtained from their averages.

$$AI = \frac{\pi}{2g} \int_0^{t_0} a^2(t) dt = \frac{\pi}{2g} \overline{x^2} t_0 = \frac{\pi}{2g} \sigma^2 t_0 \tag{11}$$

$$CAV = \int_0^{t_0} |a(t)| dt = \overline{|x|} t_0 = \sqrt{\frac{2}{\pi}} \sigma t_0 \tag{12}$$

5.4 Prediction of CAV

Let us assume standard deviations σ_1, σ_2 for seismic records at locations 1 and 2. From (11) and (12) we have

$$\frac{AI_2}{AI_1} = \frac{\sigma_2^2}{\sigma_1^2} \tag{13}$$

$$\frac{CAV_2}{CAV_1} = \frac{\sigma_2}{\sigma_1} \tag{14}$$

i.e.

$$\frac{CAV_2}{CAV_1} = \sqrt{\frac{AI_2}{AI_1}} \tag{15}$$

From (6), we obtain

$$\frac{CAV_2}{CAV_1} = \sqrt{\frac{S_2}{S_1}} \tag{16}$$

Now we can predict *CAV* as easily as *AI*.

5.5 Conclusions and Discussions

Our analysis shows that *CAV* can be predicted based on the prediction of response spectra. The steps of making predictions of *CAV* at a power plant site from an observed seismic waveform at a seismograph stations are:

1) Calculate PSA at a station site and predict PSA at a power plant site according to the relationships developed by Atkinson and Boore (1995).
2) Get the approximate spectral integrals S_1 and S_2 following (5).
3) Get the value of CAV_1 following (2).
4) Make the prediction of CAV_2 using (16).

When records are available from more than a single component of the seismic waveform at one station, the *CAV* values obtained from each component may be averaged to make a single estimate of *CAV*. A weighting factor of 1.4 should be applied to the vertical component (Atkinson, 1990). If records are available from more than one station, all the calculated *CAV* values can be shifted to the epicenter following the same procedure of (16). After an averaged value of *CAV* is formed at the epicenter, predictions of *CAV* at the power plant site can be made from it.

The CAV values calculated and predicted using this method follow the traditional definition as (2). The threshold for OBE is 0.30 g-sec in this case. YAEC (1991) made a "standard" definition of *CAV*, whose calculation is performed on one-second intervals of the time history

where PGA exceeds the threshold value of 0.025g. The low value segments would be discarded even if they are in the middle of a waveform. The *CAV* value calculated this way is not a differentiable function of time and distance. The analysis presented herein is not applicable to it mathematically. However, one can still explore pragmatically whether this kind of *CAV* can be predicted approximately, using our method in the practical data processing.

The aforementioned steps have been implemented in a program called *Predspec*. The prediction result for the nuclear power plant at Shoreham, NY using seismograms for an earthquake on 16 June 1995 is shown in Figure 24. CAV_1 is the traditional *CAV*, according to (2). CAV_2 is the "standard *CAV*" of YAEC (1991). Because the amplitudes of the acceleration waveform never exceed 0.025g in this particular case, the value of CAV_2 is 0.0.

5.6 References

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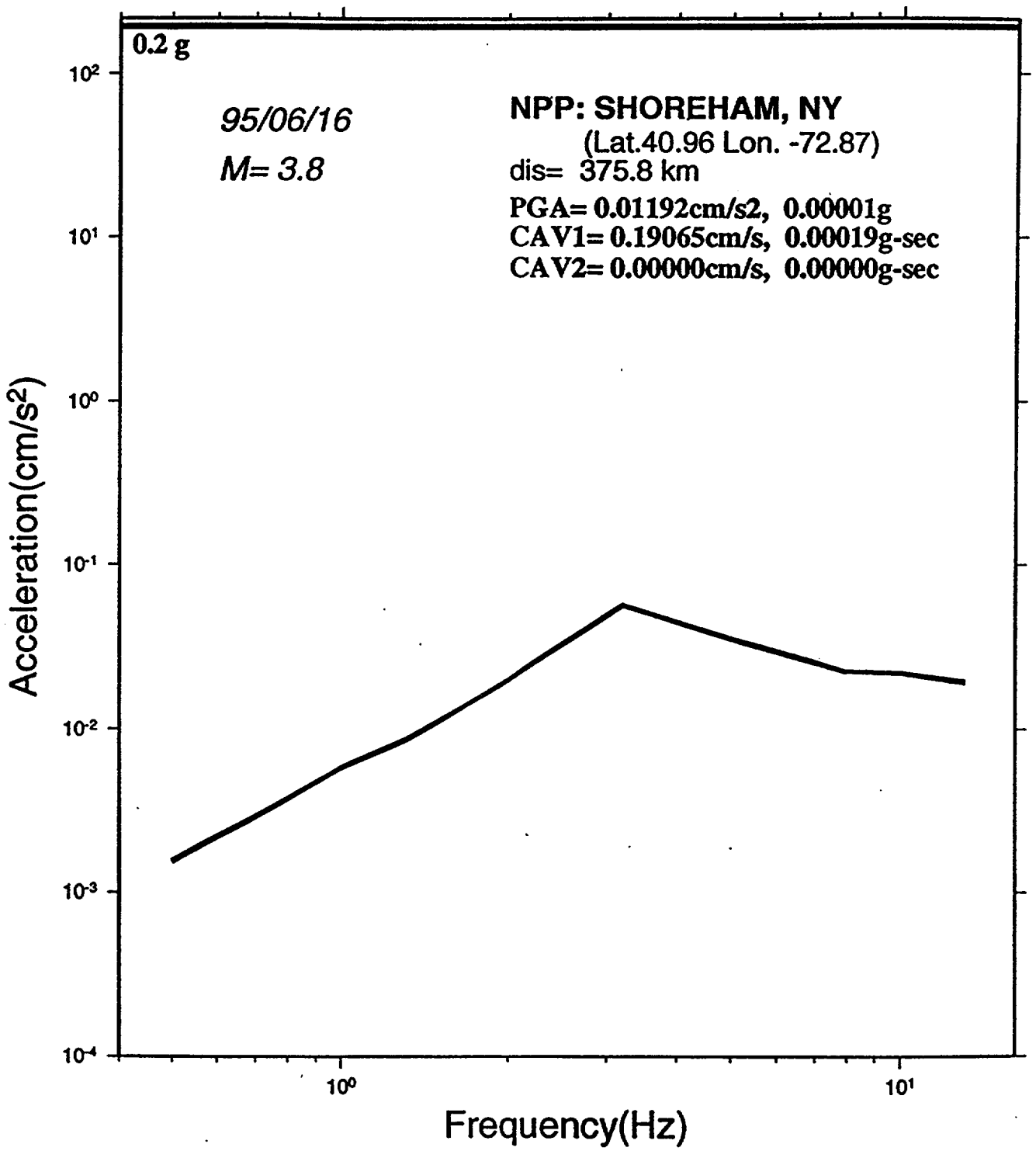

Figure 24. Predicted spectrum at the nuclear power plant in Shoreham, NY, from the earthquake of 16 June 1996. The distance from the epicenter is 375.8 km.

6 User's Manual for the Automated Seismic Event Monitoring System (ASEMS)

6.1 Introduction

This document describes the Automated Seismic Event Monitoring System (ASEMS)*, which is installed at the U.S. Nuclear Regulatory Commission. The main function of the system is to provide early warnings of seismic events whose magnitude and proximity to U.S. nuclear power plants exceed preset limits. The system components responsible for this task are completely automated. Near-real-time seismic data is received at NRC, via satellite, from the National Earthquake Information Center (NEIC). Event locations and magnitudes are computed from single-station three-component signals, and a warning is issued for large events located near a power plant. The data and all derived parameters for confirmed events are archived on NRC computers.

After computing an event location from the single-station data, the system attempts to confirm the location by checking for its appearance in the NEIC near real time Event Bulletin. This bulletin is computed from multiple station data and is periodically updated on the Internet. If the event appears in the bulletin, the NEIC event location and magnitude parameters are archived with the data. Event warnings can optionally be issued only after confirmation of the event has been obtained from the NEIC bulletin.

In addition to the automated components, the system also includes several interactive components for setting system parameters, verifying system operation and reviewing and analyzing archived data. Some of these components are closely integrated with the automated processing, such as a graphical component that displays incoming data and a map component that displays recent event locations, but their operation is not required and they do not interfere with the automated processing.

All warning messages are recorded in log files and emailed to preset addresses. Messages about unconfirmed events, confirmed events and system execution errors are sent to the same or different addresses.

The system code is written in C language and Java language. Two programs that execute continuously handle the automatic processing. The interactive graphical displays are all Java classes and can be executed within a single Java Runtime Executable (JRE). The current hardware platform is a SPARC-5 workstation, but the portable design of the system should allow it to run on other platforms equally well.

The next section details the steps necessary to stop and stop the system and discusses the requirements of the automatic processing. That is followed by a description of the interactive Java classes that are used for visual verification of the system performance and reviewing and analyzing the archived data. A programmer's software documentation reference is provided in a separate volume.

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* This document describes the revised system as of 3/10/1999 and replaces the document "Users Guide for the Real-Time Event Analysis System installed at the Nuclear Regulatory Commission".

6.2 System Operation

This section describes the operation of the system, starting and stopping it and other details of the automated processing. We begin with the directory structure.

6.2.1 Directory Structure

The system has been installed into two directory trees on the computer *res18*. The system code, the executables, the input files and the logs are all under the directory /local1/Loc_Sys. Its subdirectories are:

/local1/Loc_Sys/bin	- system executables and parameter files
/local1/Loc_Sys/com	- system source and Java class files
/local1/Loc_Sys/lib	- run-time shared libraries
/local1/Loc_Sys/jre1.1.6*	- Java Runtime Executable installation
/local1/Loc_Sys/logs	- system log files
/local1/Loc_Sys/world*	- map files

The seismic data files are written to subdirectories under the directory /local1/Events:

/local1/Events/archive*	- event subdirectories organized by year/month/date
/local1/Events/current	- incoming data
/local1/Events/recent	- data for the last week

The subdirectories that do not have asterisks must be located under the same parent directory. The subdirectories with asterisks can be moved to any arbitrary location (to another disk partition) as long as their location is specified in the system parameter file.

The subdirectories under archive must look like:

1998/OCT/907934087/

1998/OCT/908211788/

1998/NOV/910276860/

...

1999/JAN/915965538/

...

The date subdirectory name is the epochal time (seconds since Jan. 1, 1970) of the event. Data in each event directory is stored in SAC format using the station and channel names as the file names, such as DUG.BHZ.

The executables to start, stop and monitor the system are all in the bin subdirectory. The four UNIX scripts shown below are all that are needed for normal system operation.

/local1/Loc_Sys/bin/start_vsat	- start the automated processing
/local1/Loc_Sys/bin/stop_vsat	- stop all automated processing
/local1/Loc_Sys/bin/stop_UsnMonitor	- stop only the UsnMonitor process

/local1/Loc_Sys/bin/event_map - execute the interactive interface

The other two executables in the bin directory are not normally directly executed by the system operator. They are executed by the scripts shown above.

/local1/Loc_Sys/bin/readsat - creates raw VSAT data files

/local1/Loc_Sys/bin/UsnMonitor - automatic event detector

The remaining two files in the bin directory are parameter input files.

/local1/Loc_Sys/bin/system.par - all system parameters

/local1/Loc_Sys/bin/usn.channel - USNSN station/channel codes

6.2.2 Starting the Automated Processing

The automated processing can be started from the command line or from the graphical interface described later. To start the system from the command line, change directories to the directory /local1/Loc_Sys/bin and type the command start_vsat.

```
cd /local1/Loc_Sys/bin
start_vsat
```

The UNIX script start_vsat executes both the program readsat and the program UsnMonitor. It first checks that either or both of the programs are not already running, to avoid executing a second instance of either program. If readsat is already running, but UsnMonitor is not executing, then start_vsat will start only the program UsnMonitor. The script reports its successful operation with a few lines to the terminal. For example:

```
/local1/Loc_Sys/bin> start_vsat
    +Checking if readsat is running.
    +Starting readsat on res18 at Mon Mar 8 10:57:42 EST 1999
    -readsat is now running.
    +Checking if UsnMonitor is running.
    +Starting UsnMonitor on res18 at Mon Mar 8 10:57:45 EST 1999
    -UsnMonitor is now running.
/local1/Loc_Sys/bin>
```

You can use start_vsat to confirm that the automated processes are executing. For example, if they are currently executing, you will receive a report like:

```
/local1/Loc_Sys/bin> start_vsat
    +Checking if readsat is running.
    -readsat is already running.
    +Checking if UsnMonitor is running.
    -UsnMonitor is already running.
/local1/Loc_Sys/bin>
```

The UNIX ps command can also be used to check that the system is executing. For example, if the system had been executed by the user multimax, then the following command would list the executing processes:

```
/local1/Loc_Sys/logs> ps -ef | grep multimax
multimax 23014 1 0 10:57:42 pts/2 0:00 /local1/Loc_Sys/bin/readsat stop_file=/local1/Loc_Sys/bin/readsat.stop
multimax 23038 1 0 10:57:45 pts/2 0:00 /bin/csh -f UsnMonitor /local1/Loc_Sys/bin/system.par
multimax 23048 23038 2 10:57:46 pts/2 2:27 /local1/Loc_Sys/jre1.1.6/bin/../bin/sparc/green_threads/jre -mx128m -cp /local1
multimax 23102 21796 1 11:31:52 pts/2 0:00 grep multimax
multimax 23075 23073 0 11:27:01 pts/1 0:01 -csh
/local1/Loc_Sys/logs>
```

Note that there are actually three process id's associated with the automatic processing. Readsat is a single process (23014 in this example) and UsnMonitor is a script (23038) and an instance of the JRE (23048).

6.2.3 Stopping the Automated Processing

The program readsat and the program UsnMonitor are both stopped with the UNIX script stop_vsat. For example:

```
/local1/Loc_Sys/bin> stop_vsat
  +Waiting for readsat to stop. Could take a minute.
  -readsat has terminated.
  +Waiting for UsnMonitor to stop.
  -UsnMonitor has terminated.
/local1/Loc_Sys/bin>
```

To stop only the program UsnMonitor and allow readsat to continue executing, use the script stop_UsnMonitor. For example:

```
/local1/Loc_Sys/bin> stop_UsnMonitor
  +Waiting for UsnMonitor to stop.
  -UsnMonitor has terminated.
/local1/Loc_Sys/bin>
```

Stopping and restarting UsnMonitor does not cause any loss of information. As discussed later in the section about data flow, UsnMonitor can be stopped in order to change one or more processing parameters and then restarted. It will continue processing the data where it stopped. On the other hand, stopping and restarting readsat can result in a loss of data.

6.2.4 Log Files

Several log files that record information about the automated processing are located in the directory /local1/Loc_Sys/logs. These are:

/local1/Loc_Sys/logs/readsat.log

/local1/Loc_Sys/logs/readsat.status

/local1/Loc_Sys/logs/UsnMonitor.log

/local1/Loc_Sys/logs/UsnMonitor.status

/local1/Loc_Sys/logs/run_log

The ".log" files are always appended to by the system and contain messages from all previous executions of the programs as well as the current execution. The ".status" files are created at the beginning of each execution and thus contain information only about the current or last execution. For example, the file readsat.log might look like

```
Executing readsat(1.01) at Tue Mar 08 08:34:48 EST 1999
user.name=multimax
stop_file found: /local1/Loc_Sys/bin/readsat.stop
readsat terminating Mon Mar 09 13:05:21 EST 1999
-----------------------------------------------------------------
Executing readsat(1.01) at Mon Mar 09 13:41:13 EST 1999
user.name=multimax
```

The file UsnMonitor.log contains similar messages about the execution and termination of UsnMonitor. It will also contain the parameter settings

```
...
mail_unconfirmed_to property not found.  No warnings of
unconfirmed events will be mailed.
Warnings of confirmed events will be mailed to ihenson@multimax.com
Error messages will be mailed to ihenson@multimax.com
max_station_distance=3500.0
warn_distance=300.0
using input save_time: 604800.0
using input snr_threshold: 5.0
snr_filter: type=high_pass order=8 low=1.0 high=0.0
using input snr_noise_length: 20.0
using input snr_signal_length: 5.0
det_filter: none
...
```

and warning messages, such as

```
warning: receiving data from unknown station.
  net_route_id=224 node_id=2 sta_chan_id=63
  All data from this station will be ignored.
```

Add station to /local1/Loc_Sys/bin/usn.channel

...

and messages reporting preliminary locations, such as

```
***************** PRELIMINARY LOCATION *****************
39.47N 79.51W 99/02/27 03:01:57.872
Magnitude: 3.83Mb
Station used: BINY
Nearest plant (150.0 km): Beaver Valley
```

The file run_log will contain fatal execution error messages.

6.2.5 Data Flow

This section describes the flow of data through the two continuously executing programs readsat and UsnMonitor. The raw data are read by the program readsat from UNIX device /dev/vsat, which is a link to a hardware-dependent serial port. This link is created via the UNIX shell command "ln –s /dev/ttya /dev/vsat". (This command requires root access.) The data are transmitted in packets[1]. Each packet contains a header of information including the station, channel, sample rate, start time, etc., followed by compressed data. The transmission of data is "triggered" by an event detector at each station, so data arrives at NRC in multiple-packet segments with an event-dependent duration, commonly ten to fifteen minutes. The program readsat does not attempt to read the header or decompress the data. It writes the raw data to the file /local1/Events/current/vsat.current, until the transmission stops for a preset time period (see the section 3.1 readsat). The file is then closed and renamed vsat.yy.mm.dd.hh.mm.ss, for example vsat.99.03.09.10.29.26. Any data that is transmitted to NRC when readsat is not running will be lost.

The second automated program, UsnMonitor, periodically checks the directory /local1/Events/current for new vsat files. It moves them to the directory /local1/Events/recent and begins the event detection processing. If UsnMonitor is not running, vsat files will accumulate in the current directory. When UsnMonitor is restarted, it will process all accumulated files in the order in which they were created, and then wait for more vsat files to be created.

The vsat files remain in the recent directory for a preset time period (the default is one week), until automatically deleted. As UsnMonitor processes the data, it creates additional files in the recent directory. The file recent.trace contains a one-line record for each data segment decompressed and analyzed. The file recent.detection contains a record for each phase-detection computed. There are also three files that are created for each event detected that exceeds the size and location criteria (see section 6.2.6 System Parameters). These are:

yy.mm.dd.hh.mm.ss.ev	- unconfirmed event file
yy.mm.dd.hh.mm.ss.ts	- three-channel uncompressed event data file
yy.mm.dd.hh.mm.ss.usgs	- event confirmation file

[1] NUREG/CR-6085, United States National Seismographic Network, R. Buland, September, 1993.

If UsnMonitor is stopped with the stop_UsnMonitor script, there might also be a file called unconfirmed.events in the recent directory. This file contains information about unconfirmed events that UsnMonitor will attempt to confirm when it is restarted.

6.2.6 System Parameters

All of the system parameters are specified in the file /local1/Loc_Sys/bin/system.par. The programs in the /local1/Loc_Sys/bin read this file by default when they are executed from that directory. The parameter file can be edited with a text editor or with the program event_map described later in this document. The parameters are described below.

main_path	The directory containing the system. Defaults to /local1/Loc_Sys.
data_path	The directory containing the current and recent subdirectories. Defaults to /local1/Events.
archive_directory	The directory containing the archive. The system creates subdirectories YYYY/MMM/epochal_time for confirmed events. Defaults to /local1/Events/archive.
parameter_file	The file containing these parameters. Defaults to /local1/Loc_Sys/bin/system.par.
map_log	The error log file for the interactive program event_map. Defaults to /local1/Loc_Sys/logs/event_map.log.
map_directory	The directory containing the map files that are read by event_map. Defaults to /local1/Loc_Sys/world.
jre	The Java Runtime Executable. Defaults to /local1/Loc_Sys/jre1.1.6/bin/jre.
log_file	The log file for UsnMonitor. Defaults to /local1/Loc_Sys/logs/UsnMonitor.log.
channel_file	The file containing the identification codes and sample rates for the stations of the US National Seismic Network. Defaults to /local1/Loc_Sys/bin/usn.channel.
save_time	The length of time (seconds) to save the raw vsat files in the recent directory. Defaults to 604800, one week.
mail_unconfirmed_to	The email address to send warnings of unconfirmed events. Warnings are sent for any event that has magnitude greater than **warn_magnitude** and is within **warn_distance** kilometers of a power plant.
mail_confirmed_to	The email address to send warnings of confirmed events. The system attempts to confirm events by retrieving the online NEIC bulletin every five minutes.
mail_errors_to	The email address to send system warnings and execution error messages.

snr_signal_length The length of the data-window (seconds) used for signal amplitude measurement. Defaults to 5.

snr_noise_length The length of the data-window (seconds) used for noise amplitude measurement. Defaults to 20.

snr_threshold The signal to noise threshold at which event location will be attempted. Defaults to 5.0.

snr_filter_type The type of IIR filter that is applied to the data before computation of the signal-to-noise ratio for comparison with **snr_threshold**. Defaults to high_pass.

snr_filter_order The order of the IIR filter that is applied before SNR computation. Defaults to 8.

snr_filter_low The low-cut frequency of the **snr** filter. Defaults to 1.

snr_filter_high The high-cut frequency for the **snr** filter. Defaults to 0.

det_filter_type The type of IIR pre-detection filter that is applied to the data before the phase detector is run. Defaults to none.

det_filter_order The pre-detection filter order.

det_filter_low The pre-detection filter low-cut frequency.

det_filter_high The pre-detection filter high-cut frequency.

max_station_distance The maximum station-event distance (km) for which events are accepted for further processing. Events farther that this distance from the detecting station are ignored. The default is 3500.

warn_distance The distance (kilometers) from a power plant at which event warnings will be sent. Defaults to 300.

warn_magnitude The event magnitude (m_b) at which event warnings will be sent. Defaults to 3.5.

6.2.7 System Files

All of the files used and created by the system are summarized in the tables below:

Program files

file	directory	type	description
start_vsat	/local1/Loc_Sys/bin	csh script	Starts automatic processing
stop_vsat	/local1/Loc_Sys/bin	csh script	Stops automatic processing
stop_UsnMonitor	/local1/Loc_Sys/bin	csh script	Stops UsnMonitor event detector
event_map	/local1/Loc_Sys/bin	csh script	Starts JRE interactive display
UsnMonitor	/local1/Loc_Sys/bin	csh script	JRE executes UsnMonitor class
readsat	/local1/Loc_Sys/bin	Sun executable	Creates vsat files in /local1/Events/current
mmi_native.so	/local1/Loc_Sys/lib	shared library	Used by UsnMonitor and event_map
*.class	/local1/Loc_Sys/com/	Java class file	Used by UsnMonitor and event_map

Input files

file	directory	type	description
system.par	/local1/Loc_Sys/bin	ascii	Parameter file
usn.channel	/local1/Loc_Sys/bin	Formatted ascii	USNSN station parameters
world	/local1/Loc_Sys/world	Binary data	Used by event_map
countries	/local1/Loc_Sys/world	Binary data	Used by event_map
states	/local1/Loc_Sys/world	Binary data	Used by event_map

Output files

file	directory	type	description
recent.trace	/local1/Events/recent	Formatted ascii	Data segment table
recent.detection	/local1/Events/recent	Formatted ascii	Detection table
vsat.current	/local1/Events/current	binary	VSAT incoming raw data
vsat.yy.mm.dd.hh.mm.ss	/local1/Events/current and ./recent	binary	VSAT raw data
yy.mm.dd.hh.mm.ss.ev	/local1/Event/recent	ascii	Unconfirmed event location
yy.mm.dd.hh.mm.ss.ts	/local1/Event/recent	Java objects	3-component event data
yy.mm.dd.hh.mm.ss.usgs	/local1/Event/recent	ascii	Confirmed event location
unconfirmed.events	/local1/Event/recent	Java objects	Read by UsnMonitor on restart
STATION.CHAN	/local1/Events/archive	SAC binary	Confirmed event data
readsat.log	/local1/Loc_Sys/logs	ascii	readsat log file
readsat.status	/local1/Loc_Sys/logs	ascii	readsat status file
UsnMonitor.log	/local1/Loc_Sys/logs	ascii	UsnMonitor log file
UsnMonitor.status	/local1/Loc_Sys/logs	ascii	UsnMonitor status file
event_map.log	/local1/Loc_Sys/logs	ascii	event_map error log file
run_log	/local1/Loc_Sys/logs	ascii	UsnMonitor fatal-error log file

6.2.8 Hardware

The data are received at NRC by a Very Small Aperture Terminal (VSAT) satellite system, implemented by the National Earthquake Information Center. The VSAT is on the upper Penthouse (OWFN). Waveform data travel from the VSAT to the SPARC-5 workstation *res18,* located on the tenth floor of NRC in office T-10 L7, via a solid copper wire connection with a line amplifier and modems at each end. Data from the modem are downloaded to *res18* via a serial connection operated by the software device driver /dev/ttya. The external "black box" serial buffer, which was used in the SDAES hardware configuration to hold data prior to downloading them to the workstation, is no longer required. The SPARC-5 workstation is capable of downloading data directly at the I/O rate of the modem, so an intermediate buffering stage is no longer required.

6.3 Program Descriptions

This section describes in more detail the automated and interactive programs of the system. There is a subsection for each program that describes all program options. The programs include binary executables, UNIX scripts and Java classes.

6.3.1 readsat

Synopsis: readsat [max_size=] [wait_seconds=] [stop_file=]

This is a C program that copies bytes from the UNIX device /dev/vsat to the file vsat.current, until either there is no data available to read for a time interval of wait_seconds, or the file size exceeds max_size bytes. The file vsat.current is then renamed to vsat.yy.mm.dd.hh.mm.ss, using the year, month, day, hour, minute and second of the current system time. The program "syncs" on the two-control-character sequence ESC STX before starting each new file.

Options:

max_size The maximum size allowed for the output file. Defaults to 1 megabyte.

wait_seconds The time period to wait for more data before starting a new file. Defaults to 60 seconds.

stop_file The program terminates if it detects the existence of this file.

No default.

The control-characters ESC and STX begin each USNSN data packet. The 60-second default wait time interval insures that the data for all three channels of a station, each consisting of multiple data packets, are written to the same output file. There can be data for more that one station in the output file. This program does not examine the contents of the data packets. It only looks for the ESC,STX sequence to begin each file. The UNIX script start_vsat executes this program.

6.3.2 start_vsat

Synopsis: start_vsat [parameter_file]

This is a UNIX csh script that executes the C program readsat and the Java class UsnMonitor. The parameters **main_path** and **data_path** are obtained from the parameter_file. The program readsat is executed in the directory **data_path**/current, so that its output file vsat.current will be created there. The UNIX script UsnMonitor is executed in the directory **main_path**/bin and given the same parameter file.

Options:

parameter_file The system parameter file. Defaults to system.par.

Before each program is executed, a UNIX ps command is used to check if the program is already running to avoid executing two instances of the same program. The stop files **main_path**/bin/readsat.stop and **main_path**/bin/UsnMonitor.stop are removed before each program is executed. The standard output and standard error output of the programs is redirected to the files readsat.status and UsnMonitor.status in the directory **main_path**/logs.

6.3.3 UsnMonitor

Synopsis: UsnMonitor [parameter_file]

This is a UNIX csh script that executes the Java Runtime Environment (JRE) with the Java class object com.multimax.mmi.usnsn.UsnMonitor. The parameters **main_path** and **jre** are obtained from the parameter_file. The stop file UsnMonitor.stop in the directory **main_path**/bin/ is removed before **jre** is executed. The environment variable LD_LIBRARY_PATH is set to **main_path**/lib. The standard output and standard error output of the **jre** process are redirected to the file **main_path**/logs/run_log.

Options:

parameter_file The system parameter file. Defaults to system.par.

6.3.4 com.multimax.mmi.usnsn.UsnMonitor

Synopsis: jre com.multimax.mmi.usnsn.UsnMonitor parameter_file [stop_file=]

This is the Java class that performs the automated signal analysis of the seismic data in the vsat files created by the program readsat. As the vsat files are created in the directory **data_path**/current, they are moved to the directory **data_path**/recent and the following procedure is applied to each file.

The seismic records are decompressed from the USNSN format and the header containing the station/channel identification is read. The vsat file can contain data for multiple stations and channels. Normally it will contain three components for each station. If all three components for a station are not present in the file, the data for that station are ignored.

For each station/channel found in the file, a line is appended to the file recent.trace in "tables.Trace" format.

The file specified by the channel_file parameter (**main_path**/bin/usn.channel) is read to obtain the channel name and sample rate corresponding to the channel id. If the id is not found in that file, the data for the station is ignored and a warning is printed in the log file.

If the calibration for the station/channel is not found in the class "usnsn.Calib", the data are ignored.

The signal-to-noise ratio (snr) is computed using all three components and the window lengths specified in the parameter file. If the largest snr is less than the snr_threshold parameter, the data are ignored.

If the pre-detection filter is defined, it is applied to the data. (det_filter_type is not set to "none". Filter types are "high_pass", "low_pass", "band_pass" and "band_reject".)

A recursive detection filter is applied to detect a P phase arrival followed by an S phase arrival. The detection filter uses short-term/long-term filtered data averages to detect the arrivals. The vertical component is used to detect the P phase. The signal azimuth is computed for a data window following the P arrival and another STA/LTA ratio for the transversely projected component is used to find the S arrival. The recursive formula is:

1) $\text{scale} = 1./(1. + c_1)$

2) $y_i = c_1\, y_{i-1} + (x_i - x_{i-1})\ \text{scale}$

3) $dx_i = c_2\, (x_i - x_{i-1})$

4) $e = (1 - c_2)\, y_i^2 + dx_i^2$

5) $STA_i = STA_{i-1} + c_3\, (\, e - STA_{i-1})$

6) $LTA_i = LTA_{i-1} + c_4\, (\, e - LTA_{i-1})$

7) $RATIO_i = STA_i / LTA_i$

An arrival is detected when the value of $RATIO_i$ is greater than c_5. The parameters for the P detection are (see the reference for "com.multimax.mmi.sp.DetectPS.java" in Section A.9 in the separate volume containing the programmer's reference documentation):

$c_1 = .95, c_2 = .9, c_3 = .05, c_4 = .0025, c_5 = 5.0$

The parameters for the S detection are:

$c_1 = .95, c_2 = .2, c_3 = .2, c_4 = .2, c_5 = 5.0$

The distance is computed from the P-S travel time differential (see the reference for "com.multimax.seismic.SmP.java" in Section A.8 of the programmer's reference documentation), and together with the azimuth, a preliminary event location is determined. The quality of this single station solution is dependent on the accuracy of the P and S phase detections, as well as the S-phase azimuth. Under some circumstances, it is possible for highly erroneous locations to be reported. In addition, sometimes station calibration pulses can appear to be earthquakes. Therefore, it is imperative that the P and S phase detections be verified visually.

The event magnitude is computed form the P arrival using the formula

$$mag = \log10(P_amplitude) + alog0 + 4.1$$

where

$$alog0 = -\log10(c * r^{-a}) * \exp(-b * r)$$

$$r = sqrt(distance * distance - 8*8)$$

$$c = 0.49710$$

$$a = 1.2178$$

$$b = 0.00530$$

If the station-to-event distance is less than the parameter max_station_distance, and the distance from the event to the nearest power plant is less than the parameter warn_distance, and the magnitude is greater that the parameter warn_magnitude, a warning messages is logged in the UsnMonitor.log file. The warning is also emailed to the address specified by the parameter email_unconfirmed_to.

All detections are appended to the file **data_path**/current/recent.detections, and the three-component decompressed data for each station are written as a "TimeSeries" object to the file yy.mm.dd.hh.mm.ss.ts. The preliminary event location, the corresponding data, and the detections can all be viewed with the program event_map, discussed in the following section.

The program attempts to confirm the preliminary single station location by retrieving the *NEIC Event Bulletin* that is available on the Internet at the URL "finger quake@ gldfs.cr.usgs.gov". A separate thread executes to retrieve this bulletin every five minutes, when there are unconfirmed events. If an event match is found, the hypocenter is written to a file called yy.mm.dd.hh.mm.ss.usgs in the recent directory. A warning is logged in UsnMonitor.log and also emailed to the address specified by the parameter email_confirmed_to. The data for confirmed events is written to the archive directory YYYY/MM/epochal_time in SAC-formatted files named station.channel. When any bulletin event times are two hours later than the unconfirmed event, the search is discontinued for that particular event.

Once every hour, the program removes files from **data_path**/recent that are older that the time period specified by the parameter save_time, which defaults to one week. The program can be stopped and restarted without causing any data to be lost. If the file **main_path**/bin/UsnMonitor.stop is found (created by stop_UsnMonitor), a list of the unconfirmed events is written to a file named unconfirmed.events (as Java objects). When restarted, the program reads this file in order to continue the confirmation process if necessary.

The data processing in UsnMonitor and the bulletin retrieval are executed as two threads of a parent thread that catches all fatal execution errors. These errors, with code line numbers, are written to the file **main_path**/logs/run_log. The parent thread creates new threads starts them again. If the threads die three times in less than one minute, they are not restarted and the program terminates.

6.3.5 event_map

Synopsis: event_map [parameter_file]

This is a UNIX *csh* script that executes the Java Runtime Environment (JRE) with the Java class object com.multimax.mmi.nrc.EventMap. The parameters **main_path** and **jre** are obtained from the parameter_file. The environment variable

LD_LIBRARY_PATH is set to **main_path**/lib. The standard output and standard error output of the **jre** process are redirected to the file **main_path**/logs/map.log.

Options:

parameter_file The system parameter file. Defaults to system.par.

6.3.6 com.multimax.mmi.nrc.EventMap

Synopsis: jre com.multimax.mmi.nrc.EventMap parameter_file

This class is the main graphical interface to the interactive system monitoring and data analysis classes. It displays a world map initially zoomed on the U.S., with symbols for transmitting USNSN stations and the unconfirmed and confirmed events in the recent directory. As the contents of the recent directory change (raw data is added/removed, events are added/confirmed/removed), the map, the waveform displays and the event table are automatically updated.

Options include:

- Display all recent events or only confirmed recent events on the map
- Display the USNSN stations on the map
- Display the power plant locations on the map
- Display the Recent Event Table
- Display the Archive Event Table
- Display the Most Recent Data in the recent directory
- Display the Most Recent Event in the recent directory
- Display the Data Table of all raw data in the recent directory
- Display the Detection Table
- Display the System Parameters

- Restart the automatic process UsnMonitor (stop_UsnMonitor, start_vsat)
- Stop both the automatic processes readsat and UsnMonitor (stop_vsat)

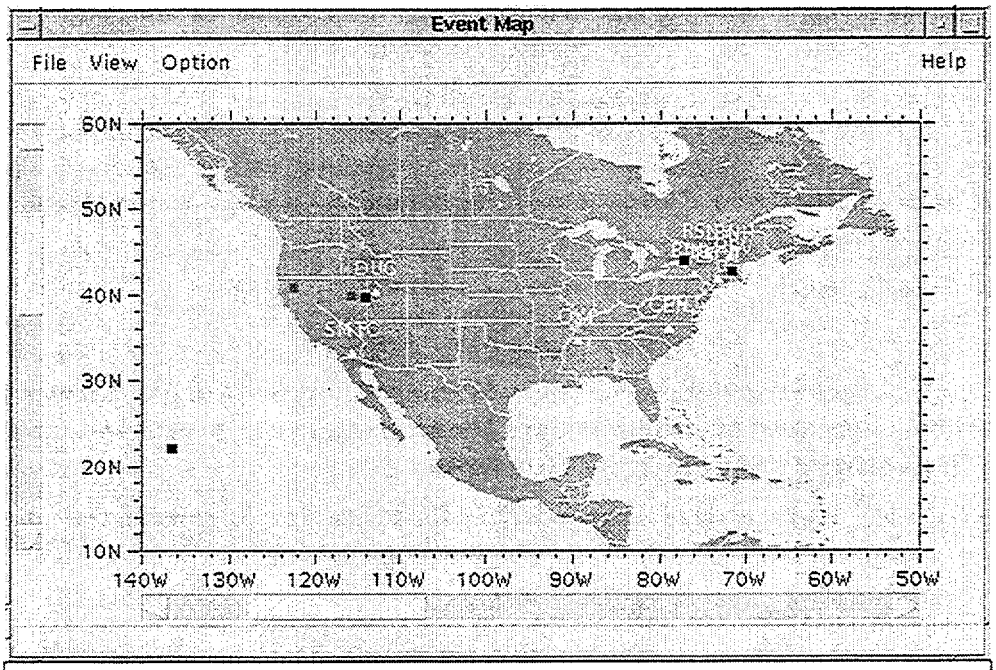

Figure 25. Map showing unconfirmed and confirmed events.

Figure 25 shows the map window. Unconfirmed events will be displayed as blue rectangles. When they are confirmed, their position is updated and the color changed to red. The data for an event can be displayed by clicking near the event with the left mouse button. The map can be zoomed in with a right mouse button drag. The program automatically updates the map display to reflect the contents of the recent directory.

Events

Display Data | Close

station	latitude	longitude	time	magnitude	confirmed_lat	confirmed_lon	confirmed_time	confirmed_mag
DUG	39.56	-114.04	98/11/27 17:28:17.625	2.42	-999.0	-999.0		
DUG	39.05	-114.84	98/11/30 19:32:30.408	2.77	39.79	-115.71	98/11/30 19:32:20.000	9.1245434E8
HRV	42.51	-71.56	98/12/01 15:28:08.152	0.47	-999.0	-999.0		
DUG	35.65	-119.54	98/11/26 22:58:17.176	4.49	40.62	-122.4	98/11/26 22:58:06.000	9.1212108E8
BINY	6.42	-108.63	98/11/27 02:50:40.812	16.35	-999.0	-999.0		
DUG	22.05	-136.48	98/11/27 09:22:35.157	10.58	-999.0	-999.0		
LBNH	43.82	-77.21	98/11/30 03:03:07.881	3.75	-999.0	-999.0		

Figure 26. Recent event table.

The events can also be displayed in a table, as shown in Figure 26. This table also automatically updates by adding new events, adding confirmed locations and removing old events. The data corresponding to the event can be displayed by selecting a row of the table and clicking on the Display Data button.

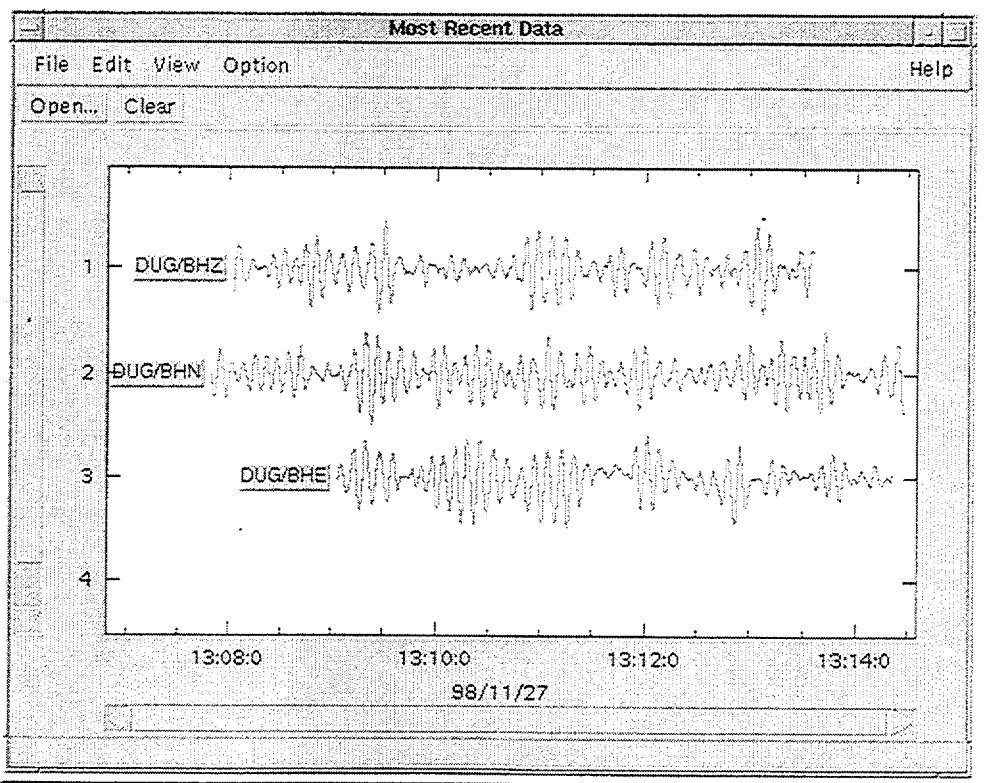

Figure 27. Most recent data display.

The most recent data received by the system can be displayed from the EventMap interface. Figure 27 shows a WaveformViewer object displaying data. The data in this window and the data in the "most recent event" window will automatically be updated as data are received and as events are detected and located. The WaveformViewer (see the reference for "com.multimax.mmi.apps.WaveformViewer.java" in Section A.1 of the programmer's reference documentation) has options to display the amplitude spectra for the data and apply IIR filters to the data. Multiple WaveformViewer windows can be displayed simultaneously and data can be read into them directly from the vsat files, the .ts files and the SAC files. Data can be cut/copied/pasted from one window to another for comparison of events, and collections of traces can be saved to a new file.

The archived data can also be displayed with the "Archive Table" option, as is shown in Figure 28. The archive directory tree will be scanned. All subdirectories of the form YYYY/MON/epochal_time are searched, where YYYY is the year, and MON is the month (JAN, FEB, MAR, etc.), and "epochal_time" is a 9-digit or larger integer representing the elapsed seconds since Jan. 1, 1970. All SAC files found are listed in the table. The format of the SAC file name should be "station.channel". The header of one SAC file in each event directory is read to obtain the event hypocenter. The distance from the event to the recording station and the distance from the event to the nearest power plant are computed and included in the table. A com.multimax.mmi.tables.Record table file, that contains a record for each event, is created in the archive directory. This file is then read by the open routine of the "TableViewer" superclass. The columns of the table are "event time", "event lat", "event lon", "event depth", "station", "channel", "km to station", "nearest plant", "km to plant", "directory", and "file" (see Figure 28). A "Display Data" button is added to the TableViewer interface to display data corresponding to selected table rows using the WaveformViewer class.

/home/henson/src/java/nrc/archive/contents.record

File Edit View

Open... Display Data

event time	event lat	event lon	event depth	station	channel	km to station	nearest plant	km to plant	dir
95/01/16 20:46:00.000	34.700	135.000	33000.000	biny	lhe	10938.644	Monticello	9884.996	19
95/01/18 15:51:39.000	34.774	-97.596	5.000	ALQ	BHE	810.279	Comanche Peak	275.176	19
95/02/03 15:26:00.000	41.600	-109.700	5000.000	biny	bhe	2781.243	Fort Calhoun	1135.711	19
95/02/10 00:14:59.000	42.830	-111.290	-999.000	DUG	BHE	319.182	Fort Calhoun	1264.115	19
95/02/10 20:26:59.000	-19.530	-68.560	-999.000	LSCT	BHE	6788.271	Turkey Point	5130.181	19
95/02/12 16:44:31.000	44.267	-70.250	5.000	BINY	BHE	519.577	Maine Yankee	56.621	19
95/02/12 17:53:51.000	38.000	-118.440	-999.000	DUG	BHE	544.308	Fort Calhoun	1950.527	19
95/02/13 00:55:39.000	38.000	-118.480	-999.000	DUG	BHE	547.403	Fort Calhoun	1953.858	19
95/02/14 18:20:32.000	31.640	-115.730	-999.000	SMTC	BHE	145.134	Comanche Peak	1695.563	19
95/02/15 15:53:57.000	45.900	-75.040	18.000	BINY	BHE	418.324	Fitzpatrick	285.283	19
95/02/17 01:13:16.000	44.173	-70.236	8.000	LBNH	BHE	135.342	Maine Yankee	49.846	19
95/02/18 13:22:44.000	51.100	-171.360	-999.000	CEH	BHE	7156.237	Monticello	5530.074	19
95/02/18 20:17:09.000	38.860	-119.630	-999.000	CEH	BHE	3576.813	Fort Calhoun	2021.540	19
95/02/19 04:03:15.000	40.510	-125.620	-999.000	BINY	BHE	4100.239	Fort Calhoun	2476.385	19
95/02/19 12:57:06.000	39.120	-83.470	10.000	BINY	BHE	719.194	Davis Besse	277.072	19
95/02/19 21:24:15.000	33.960	-118.960	-999.000	DUG	BHE	881.351	Comanche Peak	1980.842	19
95/02/19 22:54:51.000	33.950	-118.980	-999.000	DUG	BHE	883.342	Comanche Peak	1982.701	19
95/02/20 11:35:57.000	63.340	-151.180	-999.000	DUG	BHE	3598.865	Monticello	4053.124	19
95/02/20 20:18:45.000	62.500	-151.400	-999.000	CEH	BHE	5652.979	Monticello	4062.250	19
95/02/23 09:32:13.000	41.870	-80.830	5.000	BINY	BHE	402.869	Perry	27.138	19
95/02/23 20:05:56.000	19.380	146.640	-999.000	SMTC	BHN	9541.932	Monticello	10608.697	19

654 rows, 11 columns

Figure 28. Archive event table.

The rows of the archive table can be sorted by any of the columns and multiple events can be selected and displayed together.

The system parameters are displayed with the "System Parameters" option. The values in the table can be edited, and the automatic process "UsnMonitor" can be restarted with the new system parameters using the "Restart System" option under the "File" menu.

6.4 Operations Summary and Data Flow

Although the preceding detailed description of the separate program elements may seem complex, the actual operation of those program elements is straightforward. Much of the complexity of the SDAES software was eliminated when the ASEMS software system replaced it, since ASEMS does not need the endless loop of data reading and writing routines (VSATSAV and VSATRD) that formed the architecture of SDAES. Now the data flow through the system in a smooth pipeline, as is summarized below.

The operations task has been simplified so that the operator need know only four UNIX scripts to run the system. These are:

1) start_vsat to check whether readsat and UsnMonitor are running and then to start either one or both of those processes, as needed.
2) stop_vsat to stop both readsat (which will cause the system to lose incoming data) and UsnMonitor
3) stop_UsnMonitor to stop UsnMonitor only (which will not cause data to be lost)
4) event_map to operate the graphical user interface shown in Figures 25 – 28 above

The flow of data through the system is straightforward:

1) The data are transferred from the input port /dev/vsat to the program readsat
2) readsat writes waveform data to /local1/events/current
3) The contents of /local1/events/current are periodically examined by UsnMonitor
4) UsnMonitor processes the data and writes its results to /local1/events/recent

Finally, UsnMonitor and the bulletin retrieval thread (which are parts of the same parent application) process the data in a cascading procedure that eliminates the need for looping back through the data flow:

1) Decompress the data in USNSN format, and read the header
2) Read the channel ID; proceed only if this station and channel are recognized
3) Check the calibration file for this channel; proceed only if calibration factors are available
4) Compute the signal-to-noise ratio; proceed only if it exceeds a threshold
5) Apply a pre-detection filter (currently not station-dependent, although it could be tuned for the noise environments of each station under various conditions of earth noise)
6) Apply a recursive detection filter; proceed only if the ratio of the short-term average to the long-term average exceeds a threshold
7) Compute the distance to the event based on the P – S delay time
8) Compute the azimuth of the event based on a weighted average of polarization measurements
9) Compute the (single-station) location based on the distance and azimuth
10) Compute the event magnitude based on the P amplitude and the distance
11) Issue a warning message for strong earthquake near power plant sites
12) Append the detection to a cumulative detection data file
13) Create a new waveform file from the decompressed USNSSN data
14) Query USGS for new epicenters every 5 minutes
15) If USGS confirms the event: (a) write the new hypocenter to a file; (b) issue an event notice; (c) write the waveform in SAC format to the permanent seismogram archive directory
16) Every hour, remove week-old data from the directory of recent events

6.5 Relation to Other Software

The ASEMS software described above runs in an automated fashion (once the operator has initiated the process with the script run_vsat). The overall seismic analysis software package at NRC has several other components, however, which are interactive programs; *i.e.*, they require operation by a scientist or data analyst who will examine the waveforms, select processing operations to perform on them, specify parameters or data tables to be used by those processing operations, and direct the output (in some chosen format) to a data file and/or to another program. Of necessity, these interactive program run separately from the automated analysis. However, the detailed processing that is performed by the scientist or data analyst will of course take as its input the waveforms that are decompressed by the automated processing, at least after the automatic system has found a signal detection that then can be studied intensively using the interactive programs.

The principal programs in use at NRC for interactive seismic data analysis are the Seismic Analysis Code (SAC, known as SAC2000 in its most recent release), *geotool*, and the Programmable Interactive Toolkit for Seismological Analysis (PITSA). Separate user's manuals (Tapley and Tull, 1993; Scherbaum and Johnson, 1993) are available for these highly complex programs that offer a wide variety if options to the user. The preferred choice among these is likely to be SAC, because the waveforms in the permanent data archive are stored in SAC format. However, programs are available at NRC to convert SAC data files to SEED or CSS format, so the same waveforms can also be used by the other programs once they have been re-formatted.

A problem with using the interactive analysis software is that the waveforms are not entered into the permanent data archive, where they can be retrieved by the interactive programs, until they

have first been associated with an event and then had that event's hypocenter verified by USGS. This prevents a scientist or analyst from examining waveforms "on the fly" when they are still being processed by the automated system. It would certainly be useful to be able to do that, since the scientist or analyst may want to verify what the automated system is doing or to apply some special processing techniques to a newly recorded waveform of special interest in near-real time. However, under the SDAES architecture it was not possible even to examine the waveforms visually until the automated processing system had written them out in the SAC archival format. It is thus possible that many "interesting" signals never triggered the detector and hence passed through the system completely unseen by the scientist or analyst. In some cases these noisy waveforms that are never written to the archives should be subjected to special filtering to find signals buried in the noise, since even small earthquakes are useful for calibration purposes and for determining seismicity rates.

As is shown in Figure 27 above, this problem has been addressed by the ASEMS software system. It is now possible to examine not only the most recent signals detected by the automated processing (before they have been associated with an event), but it is now also possible to examine even the most recently downloaded waveforms as they are being decompressed. It is also possible to see detailed results of recent event detections, whether or not they were verified by USGS, as is shown in Figure 26. The waveform display in Figure 27 is only part of the new capabilities offered to the scientist or analyst by ASEMS, however. By using the pull-down menus, it is possible not only to view the waveforms but also to manipulate them, by applying filters, zooming into waveform segments at high resolution, measuring amplitudes, computing spectra, overlaying waveforms, re-scaling separate traces, etc. In short, it is now possible to use the ASEMS software itself to duplicate many of the analysis functions that previously had to be performed using SAC, *geotool*, or PITSA, and now this analysis can be performed on near-real-time data instead of only on archived data. This is an important development, and it will lessen the need to rely on the stand-alone seismic data processing programs. Because ASEMS is an object-oriented software system (as all Java applications are), it is built on an architecture that is designed to allow the incorporation of additional modules in a straightforward manner without requiring modification to the internal operations of the existing modules. This means that ASEMS is easily extensible to incorporate more and more of the functions currently performed only by SAC, *geotool*, and PITSA. Because it is very helpful to have these functions integrated into a single data processing package that can operate on near-real time data, we expect that ASEMS will evolve eventually to replace those other programs for most purposes within the software environment of the *res18* workstation.

Another stand-alone software package that is used on *res18* is of course the *ArcView* Geographic Information System, which was the subject of Chapter 3. *ArcView* has a separate User's Manual (ESRI, 1996), which is certainly required for such a complex program, and individual User's Manuals are available for the *ArcView Spatial Analyst* and *ArcView 3-D Analyst* tools. *ArcView* is intended solely as an interactive program, and it is not part of the automated data processing performed by ASEMS. However, *ArcView* does of course make use of the tables of stations, power plant sites, and epicenters determined by ASEMS or USGS. In Chapter 3 a number of examples were presented that showed the display in *ArcView* of this information. The connection between ASEMS and *ArcView* is thus the sharing of data files. An important data file that is shared is the master seismogram archive file, discussed in Chapter 2, that identifies every event / station / channel combination available in the seismogram database. That master seismogram file can be read by *ArcView* (which is a powerful program for database operations) and displayed as a table that can be queried to find particular data in the same manner as other *ArcView* tables.

It must be admitted that experience is necessary for the effective use of *ArcView*, and it requires some effort on the part of the user to create the data files of newly detected epicenters and import

it into *ArcView*. For this reason, it was found helpful to use a much simpler mapping tool within ASEMS itself for displaying newly calculated event locations. Figure 25 above showed an example of the use of this simplified map software to display both unconfirmed and confirmed event locations for a one-week period. This simple map is a part of ASEMS, so it is completely integrated with the rest of the software system. There is thus no need to create new data files for this map tool, since it has direct access to the data within ASEMS. This map can thus be used as an interface to the database, allowing the user to select events and stations and then retrieve all available seismograms matching that selection.

ArcView remains the preferred map tool for producing sophisticated interactive maps, such as those that were shown in Chapter 3. The power of *ArcView* lies in the ability to overlay data themes at the operator's discretion and display them using a wealth of options, features that are unavailable in the simple mapping tool that is part of ASEMS. We feel that *ArcView* will therefore be used for detailed geologic and geophysical studies, and the ASEMS maps will be used for quick monitoring of event locations and for data retrieval. However, the object-oriented architecture of ASEMS makes it possible to communicate with *ArcView* in a more straightforward manner than SDAES was able to do. Specifically, "hot links" can be embedded in the Views to perform functions such as retrieving data objects from ASEMS. This will allow the event locations to be more easily used as indexes for data retrieval from *ArcView*.

Another important stand-alone code is *Predspec*, a program that performs the CAV calculations described in Chapter 5. In principle, the calculation of CAV can be incorporated within the automated processing system, but the results of such calculations would have to be considered somewhat suspect. *Predspec* allows a scientist or data analyst to choose certain ones (possibly all) of the seismograms recorded at different stations for a given event, and it computes the spectra of the chosen seismograms to estimate the spectrum at the seismic source and the attenuated spectrum at the power plant site. For small events, the spectra (especially at stations more than a few degrees away) are noisy, and it is only within sometimes narrow spectral bandwidths that they can be used in the CAV calculations with any validity. The operator must therefore choose data windows in the time domain to calculate the spectra and then spectral windows in the frequency domain for which the data will be used. Weighted averages of data from different components, and from different stations, are computed to determine the best estimate of the spectrum and hence the CAV. Although an algorithm for making these decisions could be automated, the interaction of the scientist or analyst will certainly be valuable in conducting these calculations. *Predspec* is thus an interactive program that lets the operator choose the waveforms, examine them in the time and frequency domains, and specify exactly which windows will be used (with what weights) in the calculation of the CAV. Currently the CAV values are not archived permanently, although of course the results of *Predspec* could be saved along with a log of the interactions that were performed to create each CAV estimate.

Predspec was written for use with SDAES, and it therefore uses X Windows and Motif widgets in its graphical interface. This approach to user interfaces was dropped when SDAES was replaced by ASEMS, so *Predspec* is now a bit of a bother to use in the same environment as the rest of the system. It would be preferable to have a common user interface for all parts of the seismic analysis, and so it would be better if the algorithms developed in Chapter 6 were ported from *Predspec* to some other program that enables the operator to select, view, and process the waveforms, using the Java interface instead of X Windows. As was discussed above, ASEMS itself now provides those capabilities, using the pull-down menus from the display in Figure 25. Since ASEMS permits the necessary time- and frequency-domain manipulations to be performed on the data, it would be straightforward to implement the CAV calculations directly within ASEMS instead of using the stand-alone *Predspec* program. Moreover, CAV calculations could be performed by the operator in near-real time on data for events that have not yet been archived.

Of course, these same calculations could be performed by the automated system, albeit it less reliably than by the scientist or data analyst. Just as ASEMS has replaced many of the analysis functions of SAC, *geotool*, and PITSA as well as some of the mapping functions of ArcView, we expect that it will also ake over all the CAV calculations from *Predspec*. Then all of the seismic data processing routines will be integrated into a single coherent system that can easily share data among its different subsystems.

6.6 References

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APPENDIX A

Reqdata User's Manual

INTRODUCTION

This document describes ReqData, a package for requesting and receiving seismic waveform data from Internet sites running an autoDRM [1] (automatic Data Request Manager; Kradolfer, 1993). The ReqData package simplifies the task of formatting the email requests for the user's list of events and stations. ReqData automatically parses the email responses from the autoDRM, converts GSE2.0 format to CSS3.0 and installs data in directories as specified by the user. Also included with ReqData is a GUI for managing the progress of the responses. To help manage station files, two programs are included in the ReqData package: one for querying the autoDRM about stations and one to parse the responses into CSS3.0 station files.

Parameters to the waveform request program, `reqdata` are: an approximate time and location of events to request, a list of stations and channels to request and the directory in which to install the data. To limit the size of the individual email responses, requests are formed separately for each station. A status file and a log file are created in the data directory using the data prefix specified by the user. The log file initially contains a copy of the autoDRM-formatted email requests sent to the specified autoDRM site. The status file records the requested times for each channel, the date of the request and the status (`waiting`, `received-data`, `no-data-available`, etc.). As email responses are received from the autoDRM, both the log and status files are updated.

The log and status files are ASCII text and can be viewed by hand. An X-Windows program, `reqstat`, is provided as a convenient tool for viewing these files. With `reqstat`, the user can easily see the status of all event-requests and the status of all individual channel-requests. From `reqstat`, requests can be resubmitted to the same or a different autoDRM site.

The software that automatically parses GSE2.0-formatted responses from an autoDRM consists of three parts: a mail delivery program named `deliver`[2], the shell script that controls `deliver`, named `.deliver`, and the conversion programs `gse2css` and `gse2site`.

After ReqData is installed, a user's incoming email is automatically filtered by the `.deliver` script to catch all GSE2.0 formatted messages. These messages are removed from the user's email and processed by ReqData conversion programs. All

[1]Since no strict standards exist for autoDRM, ReqData may not work equally well at all sites. ReqData was designed and tested primarily with the autoDRM implemented at USGS and uses GSE2.0 autoDRM commands defined in CRP 243.

[2]Chip Salzenberg, ComDev/TC Telemanagement

messages not recognized as GSE2.0 are forwarded to the user's regular mailbox.

At the time of request, each request is logged and given a unique request-id that is returned by the autoDRM as the `REF_ID` in the email response. The `REF_ID` allows the email parsing programs to match incoming data with the request-ids and install the data in the appropriate directory.

The `.deliver` script compares the `REF_ID` of each GSE2.0 message to the request log created by `reqdata`. If the `REF_ID` is valid, a conversion program is executed to process the message. If the `REF_ID` of a GSE2.0 message is not found in the request log, the message is forwarded to the user's regular mailbox. It is an installation option to have all processed GSE2.0 email messages either saved in a file or discarded. When any message fails to be processed for any reason, all processing error messages are logged and the message can be either forwarded to the user's mailbox or saved, depending on installation options.

Each site operating an autoDRM places restrictions on the size of the email response to the user. In order to facilitate email transfer of large responses, some sites employ the CONTINUE command, which is part of the GSE2.0 autoDRM command set. The `.deliver` script can handle autoDRM responses that are continued over two or more separate email messages. Frequently, the individual messages of a continued response will arrive out of order. The `.deliver` script holds continued messages until the first message of the response, which contains the `REF_ID`, is received before processing all the continuations.

The waveform parsing program, `gse2css`, converts GSE2.0 WID2 headers and CM6 compressed waveform data to CSS3.0 format. An origin file is created from the event information input at request time. Individual waveform files are created for each channel following the naming convention of `sta.chan.epochaltime.w`. If a request is repeated, the incoming data will write over the older data if the sta, chan and epochal time are the same.

Another request program, `reqchan`, requests station and channel information from an autoDRM. When the `.deliver` script finds keywords `DATA_TYPE STATION` or `DATA_TYPE CHANNEL` in the autoDRM response, a different conversion program, named `gse2site`, is executed. `Gse2site` creates or updates the system's CSS3.0 site and sitechan tables if new station and/or channel information arrives from an autoDRM.

ReqData supports multiple, simultaneous users. A CSS3.0 lastid table-file is updated with orid, wfid, chanid and msgid records. A central request-file logs request-ids for all users. A Unix file locking mechanism insures that all files being written to by

the message conversion programs, including lastid, origin, wfdisc, status and data files, are updated correctly. This is necessary not only to allow multiple users, but even for a single user, since the processing of sequentially arriving email messages can overlap in time, resulting in the execution of multiple instances of the conversion programs.

INSTALLATION

Getting The Package

The ReqData package can be obtained by anonymous FTP from es2.multimax.com. In the directory `pub/gtdb/reqdata`, you will find compressed tar files containing executables for SunOS-4.1.3, Sun-5.3 (Solaris-2.3), and IRIX-5.3:

```
reqdata1.0.bin.sun4.1.3.Z

reqdata1.0.bin.sun5.3.Z

reqdata1.0.bin.irix5.3.Z
```

These tar files also contain tables of station locations, travel times and autoDRM addresses. This document is included as a PostScript file, and there are Unix "man" pages for the programs. The complete source code is also available as a separate compressed tar file:

```
reqdata1.0.src.Z
```

The directories in the ReqData package (excluding the source) are:

```
reqdata/bin

reqdata/continued

reqdata/doc

reqdata/info

reqdata/logs

reqdata/man/man1
```

```
reqdata/man/man3

reqdata/man/man5

reqdata/save

reqdata/tables/static

reqdata/tables/dynamic
```

Install this directory tree in a location available to all users and make sure that the directories `tables/dynamic`, `logs`, `continued`, and `save` are writable by all users of the package. Add `reqdata/bin` to each user's `PATH` environment variable and add `reqdata/man` to the `MANPATH` environment variable. Each user must also set the environment variable `REQDATA_HOME` to the location of the reqdata directory.

Activating Automatic Email Parsing

There are just a few steps necessary to activate the automatic parsing of GSE-formatted email. First, edit the file `reqdata/.deliver` and change the line `REQDATA_HOME=/path/reqdata` to be the actual location of the `reqdata` directory. Then copy `reqdata/.deliver` to each user's home directory (or make a link to it). Create a file named `.forward` in each user's home directory containing the line:

"`|`*/path*`/reqdata/bin/deliver` *username* `|| exit 75`".

Include the quotes. Substitute for */path*`/reqdata` the actual location of reqdata and substitute for *username* the user's login name. Mail must be deliverable locally to `username`, so it cannot be an address to another machine (No `@`). If the user's mailbox file is not in the directory `/var/spool/mail`, then specify the mailbox directory with a `-m` option. For example, if the user's mailbox file is in the directory `/var/mail`, then create a `.forward` file with:

"`|`*/path*`/reqdata/bin/deliver` *username* `-m /var/mail || exit 75`".

Leave a space between the `-m` and `/var/mail`.

The `.forward` file will instruct the Unix mail receiving program (`sendmail`) to execute the `deliver` program and pass all email to it. The `deliver` program will use the `.deliver` script to detect GSE formatted mail and execute the appropriate

parsing program. If `reqdata/bin/deliver` is unavailable (perhaps because a file server is down or an automounter failed), the "`|| exit 75`" in the `.forward` file instructs `sendmail` to requeue mail for later delivery. Normally, this is a sufficient safeguard against bouncing mail back to an autoDRM. But if the `deliver` program is unavailable for a long time (more than a few hours), `sendmail` will reply to senders that it is having a delivery problem and eventually return messages to senders.

Optional Installation Step

The following optional installation step will prevent mail from being returned to the sender when the `deliver` program is unavailable for a long time. Instead of requeueing messages, we can instruct the `sendmail` program to bypass the `.forward` file and send mail directly to the user's mailbox whenever the `deliver` program is unavailable. First remove the "`|| exit 75`" from the `.forward` file. Edit the `sendmail` aliases file, usually `/etc/aliases`. (You will probably need root permission to edit this file. If it is not in `/etc`, check for its location in the configuration file `/etc/sendmail.cf`.) Look for a line in `/etc/aliases` that begins with *username*:, where *username* is your login name. After that line, add (substituting your login name for *username*):

`owner-`*username*: *username*

If there isn't a line beginning with *username*:, then add the following two lines to the file:

username: *username*

`owner-`*username*: *username*

The "`owner-`*username*:" line in the aliases file will prevent email from being bounced back to the sender, in the event that the `deliver` program is unavailable or fails to execute correctly. If `deliver` fails for any reason, `sendmail` will send the mail along with an error message directly to the user's mailbox.

Testing The Installation

It is a good idea to test the installation "locally" before sending a request to an autoDRM. After you have completed the installation steps of the previous section (installed the `reqdata` directory, edited and installed the `.deliver` and `.forward` files), try the following test:

```
setenv REQDATA_HOME /path/reqdata

cd /path/reqdata

bin/reqdata par=test_parfile
```

The file `test_parfile` contains:

```
stachanlist=AAE/B*

address=user

retaddr=me@mymachine.address

basedir=/tmp/test_reqdata

time=96/06/19 00:18:02

lat=36.11

lon=35.80

depth=10.0
```

This will instruct `reqdata` to form a request and mail it to you. Check your mail for the test request message. If you do not receive it after a few moments, look in `logs/deliver.log` for error messages and check the mail queue to see if the test message could not be delivered. If you do receive the test request message, you can delete it and continue. Check to see if the directory `/tmp/test_reqdata` was created, and if it is there, proceed with:

```
bin/reqstat /tmp/test_reqdata &
```

The `reqstat` main window should display one event in its `Requested Events` list with status "waiting" and prefix "test_reqdata". Select the event with a mouse click and select the **Stations...** button to display the channel listing. There should be three lines for `AAE` and channels `BHE`, `BHN` and `BHZ`.

Continue the test of the mail parsing programs by mailing a GSE-formatted message to yourself:

```
mail username < test_msg
```

After a few seconds, the `reqstat` status fields for channels `BHN` and `BHZ` should change to "response", and the files

```
/tmp/test_reqdata/w/AAE.BHE.835143783.02.w

/tmp/test_reqdata/w/AAE.BHZ.835143783.02.w
```

should be created. If they are there, the installation is good.

SENDING REQUESTS WITH ReqData

Basic Operation

The program `reqdata` requests waveform data from one or more autoDRM's, given an approximate event time and location and a list of stations. This information can be input on the command line, or the user can place arguments in a file and input the filename on the command line with `reqdata par=parfile`. A simple `parfile` for `reqdata` looks like:

```
retaddr=username@myaddress

basedir=/disk1/data/event01

stachanList=AAM/*,ALQ/B*,BLA/BHZ,NORES/*,ESDC/b*

time=96/05/13 04:53:47

lat=7.19N

lon=76.88W

depth=27.0
```

Specify your email address with the `retaddr` argument, and specify the directory where the data will be installed with the `basedir` argument. The `stachanList` argument is a list of station/channel or network/element pairs. The list can contain the '*' wildcard character as the final character of the channel or array element name. When a wildcard character is encountered, the program first searches the affiliation table `$REQDATA_HOME/tables/static/global.affiliation` for a matching network name. In the example above, `NORES/*` will expand to include all the elements of

the NORES array and all the channels of each element. Array expansion can also be limited. In the example above, ESDC/b* expands to include only the broad-band channels at the ESDC array: ESLA/BHZ, ESLA/BHN, ESLA/BHE. The program also searches the sitechan file $REQDATA_HOME/tables/static/global.sitechan for a matching station name, and if found expands the '*' character to include all channels for the matching station. AAM/* expands to include all channels AAM/HLZ, AAM/HLN, AAM/HLE, AAM/BLZ, AAM/BLN, AAM/BLE, AAM/LLZ, AAM/LLN, AAM/LLE, whereas ALQ/B* expands to only the broadband channels ALQ/BHZ, ALQ/BHN, ALQ/BHE. Station and channels names are case insensitive, so for example, you could specify alq/b* instead of ALQ/B*.

Input an approximate event time and location with the arguments time, lat, lon and depth. The format for time is yyyy/mm/dd hh:mm:ss.s, but reqdata also recognizes a two digit year-1900, as shown above, or an epochal time as in CSS3.0 origin tables. Input the latitude and longitude using N, S, E, W for north, south, east or west or input a positive number for north and east and negative number for south and west.

Reqdata searches $REQDATA_HOME/tables/static/global.site for station locations and computes request time windows. The default time window for each station starts one minute before the first P arrival time and ends 30 minutes after the LR arrival. The user can change the default by using the optional arguments begPhase and endPhase. The format for these arguments is phase+/-seconds. Using this format, the default time window looks like:

```
begPhase=P-60.

endPhase=LR+1800.
```

To request a four-minute time window centered on the P arrival time, for example, add the following lines to the parfile:

```
begPhase=P-120.

endPhase=P+120.
```

Other standard phases in the IASPEI table are also recognized for begPhase and endPhase.

Once reqdata has computed time windows for all station/channel pairs, it searches the address file $REQDATA_HOME/tables/static/global.address for the address of

an autoDRM associated with each individual channel. The address file contains free-formatted lines with `sta`, `chan`, `address`, `format` information. For example, the following lines

```
ALQ BHZ autodrm@gldfs.cr.usgs.gov GSE2.0
ALQ BHN autodrm@gldfs.cr.usgs.gov GSE2.0
ALQ BHE autodrm@gldfs.cr.usgs.gov GSE2.0
NRA0 she messages@cdidc.org GSE2.0
NRA0 shn messages@cdidc.org GSE2.0
NRA0 shz messages@cdidc.org GSE2.0
NRA1 shz messages@cdidc.org GSE2.0
NRA1 shz messages@cdidc.org GSE2.0
...
```

instruct `reqdata` to request `ALQ` broadband channels from `autodrm@gldfs.cr.usgs.gov` and request `NORES` channels from `messages@cdidc.org`. If two different addresses are listed in the address file for one station/channel, `reqdata` uses the first line encountered.

Optional Arguments to ReqData

`stachanFile` This optional argument can be used in place of `stachanList` to specify a list of stations and channels to request. Simply list the station/channel and network/element pairs in a file, one pair per line, and input the filename using `stachanFile=filename`. Only the first two columns of this file are used by `reqdata`. Everything on the line after the channel name is ignored. The wildcard character can be used in the file. The '#' character can be used to comment-out lines. This allows one to easily use a channel listing obtained from an autoDRM (see `reqchan` below) as a `stachanFile`, which might look like:

```
#autodrm@gldfs.cr.usgs.gov
#Sta Chan Aux  Latitude   Longitude  Elev   Depth  Hang  Vang
AAE  BHZ IU    9.02917    38.76556   2.442  0.000   0.0   0.0
AAE  BHN IU    9.02917    38.76556   2.442  0.000   0.0  90.0
AAE  BHE IU    9.02917    38.76556   2.442  0.000  90.0  90.0
AAE  LHZ IU    9.02917    38.76556   2.442  0.000   0.0   0.0
AAE  LHN IU    9.02917    38.76556   2.442  0.000   0.0  90.0
AAE  LHE IU    9.02917    38.76556   2.442  0.000  90.0  90.0
```

```
AAM  HLZ US   42.29972  -83.65611   0.249  0.000   0.0   0.0
AAM  HLN US   42.29972  -83.65611   0.249  0.000   0.0  90.0
AAM  HLE US   42.29972  -83.65611   0.249  0.000  90.0  90.0
AAM  BLZ US   42.29972  -83.65611   0.249  0.000   0.0   0.0
AAM  BLN US   42.29972  -83.65611   0.249  0.000   0.0  90.0
AAM  BLE US   42.29972  -83.65611   0.249  0.000  90.0  90.0
...
```

`prefix` When `reqdata` is executed it creates the files `prefix.reqlog` and `prefix.reqstatus` in the directory specified by `basedir`. When `gse2css` processes a response to the data request, it creates `prefix.origin` and `prefix.wfdisc` in the same directory. The default value of `prefix` is the directory name. For example, the `parfile` above would cause the following files to be created.

```
/disk1/data/event01/event01.reqlog
/disk1/data/event01/event01.reqstatus
/disk1/data/event01/event01.origin
/disk1/data/event01/event01.wfdisc
```

`dir` This is the directory where waveform files are installed using the naming convention `sta.chan.epochal_time.w`. It is relative to `basedir`, if it does not begin with '/'. The default for `dir` is `w`. Before it sends any requests, `reqdata` confirms that the data directory exists or can be created.

`mb` This body wave magnitude is recorded in the `prefix.origin` file.

`ms` This surface wave magnitude is recorded in the `prefix.origin` file.

`ml` This local magnitude is recorded in the `prefix.origin` file.

`origin` An alternative method of specifying the event time and location is to input a free-formatted CSS3.0 origin record with the `origin` argument. All the fields of the origin record must be specified (null values may be substituted), and they will be recorded in the `prefix.origin` file. The `origin` argument can also be set to the name of a file containing one or more CSS3.0 origin records. Data requests will be made for each origin in the file.

`maxChan` The maximum number of channels per email request. The default is 3 channels. Three email requests will be sent for a station that has 9 channels.

`address` If this argument is specified, all requests will be sent to the value of `address`, and `$REQDATA_HOME/tables/static/global.address` will not be used.

`ttonly` If this argument is set to 1, the start and end times of each waveform that would be requested are printed, but no requests are sent.

`verbose` Controls information printed during execution. Set to 0, 1 or 2.

`start_time` Overrides `begPhase` for the computation of the requested waveform start times. If specified, this will be the start time of all waveforms requested for all stations.

`end_time` Overrides `endPhase` for the computation of the requested waveform end times. If specified, this will be the end time of all waveforms requested for all stations.

`sendmail` The location of the `sendmail` program can be specified with this argument. The default value is `/usr/lib/sendmail`. (`Sendmail` is a standard Unix mail daemon, responsible for routing mail.)

`sleep` Time in seconds that `reqdata` sleeps between executions of `sendmail`. Defaults to two. A sleep is frequently necessary to prevent mail queues from filling up or prevent exhausting other Unix system resources, such as total number of processes.

`tableDir` This is the directory containing the two subdirectories `static` and `dynamic` with table-files used by `reqdata` and associated programs. If `tableDir` is not specified, the directory `$REQDATA_HOME/tables` will be used. The following files are needed by `reqdata`:

```
static/global.address
static/global.affiliation
static/global.site
static/global.sitechan
static/iasp91.hed
static/iasp91.tbl
```

and the following files will be created by `reqdata` or conversion programs:

```
dynamic/global.lastid
dynamic/global.request
dynamic/global.continued
```

`addressTable` Overrides the default address-table file.

`affiliationTable` Overrides the default affiliation-table file.

`siteTable` Overrides the default site-table file.

`sitechanTable` Overrides the default sitechan-table file.

`iaspeiTable` Overrides the default IASPEI table prefix.

`lastidTable` Overrides the default lastid-table file.

`requestTable` Overrides the default request-table file.

Updating Station Information with reqchan

The ReqData package comes with `global.site`, `global.sitechan`, `global.address` and `global.affiliation` files which contain station and channel information for several autoDRM sites. If the user wishes to request data from stations at a new autoDRM site, the program `reqchan` can be used to update all of these station files, except `global.affiliation`. Another use for the `reqchan` program is to update the station files for any autoDRM site to catch new stations that may have been added to the site's database. A simple `parfile` for `reqchan` looks like:

```
retaddr=username@myaddress

address=autodrm_name@autodrm_address

log=logfile
```

`Reqchan` sends a request for a complete station and channel listing to the specified autoDRM. The response is processed by the program `gse2site`, which creates or updates the `site`, `sitechan` and `address` files. The response is also forwarded to the user's mailbox, so it can be saved for use as `stachanFile` input to `reqdata`.

MANAGING REQUESTS WITH REQSTAT

Basic Operation

When data requests are made by `reqdata`, the files `prefix.reqlog` and `prefix.-reqstatus` are created in the `basedir` directory. For the example `reqdata parfile` shown above, the following two files would be created:

```
/disk1/data/event01/event01.reqlog

/disk1/data/event01/event01.reqstatus
```

The information in these files can be reviewed with the program `reqstat`. You can execute `reqstat` with no command line arguments, with a `.reqstatus` file, or with a directory name. For example, the following are valid execution statements:

```
reqstat

reqstat /disk1/data/event01/event01.reqstatus

reqstat /disk1/data
```

If no files or directories are on the command line, the user has the option to input `.reqstatus` files with the **File/Open** option, discussed below. If `reqstat` is executed with a filename as a command line argument, it reads the contents of that file only. On the other hand, if a directory name is input on the command line, `reqstat` recursively searches for all `.reqstatus` files in the input directory and in all subdirectories beneath the input directory.

Figure 1 shows the main window of `reqstat` displaying a list of requested events. In addition to the status of each event request, other information about the event is displayed including time, location, date requested, and all fields in the origin table-file. The **status** field displays "done" when autoDRM responses have been received for each individual station request associated with the event.

The status of individual stations will be displayed in another window when the user selects an event line and selects the **Stations** option button. Figure 2 shows the `reqstat` station request window for one event. Each station/channel requested for the event is listed. The **status** field displays "**waiting**" or "**response**". The limits for the time window requested and the time window actually received are displayed. If no data has been received for a channel, the **received-tbeg** will display additional status information, such as **NO RESPONSE**, **NOT AVAILABLE** or **REQUEST ERROR**. The address of the autoDRM to which the request was sent is displayed along with the time of the last activity.

The `reqstat` station request window has a **Re-request** option that allows the user to re-request all selected channels, all channels with a **NO RESPONSE** status, or all channels with a **NOT AVAILABLE** status. The **Re-request** option generates a **Confirm Re-request** window that lists all the channels that will be re-requested and allows the user to edit the time window limits and the autoDRM address. Use

File Edit View Option Help

Open... Stations...

Requested Events

status	prefix	time	lat	lon	depth	mb
waiting	event01	96/ 1/18 09:33:50.0	41.66	77.57	33.000	5.50
done	event02	96/ 1/28 08:43:16.0	34.26	46.37	33.000	5.00
done	event03	96/ 2/05 08:28:13.0	35.66	58.20	33.000	5.00
done	event04	96/ 2/21 04:59:51.0	28.75	34.85	10.000	5.30
waiting	event05	95/12/12 23:41:36.5	23.00	-130.00	0.000	-1.0

Figure 1: The main window of reqstat. All requested events are listed.

File Edit View Option Help

Hide Messages...

Stations for event: event05 95/12/12 23:41:37 lat=23.00 lon=-130.00

sta	chan	status	msgid	requested-tbeg	requested-tend	received-tbeg	re
AAM	BLE	waiting	104	95/12/12 23:48:36	95/12/13 00:38:06	NO RESPONSE	
AAM	BLN	waiting	104	95/12/12 23:48:36	95/12/13 00:38:06	NO RESPONSE	
AAM	BLZ	waiting	104	95/12/12 23:48:36	95/12/13 00:38:06	NO RESPONSE	
AAM	HLE	waiting	103	95/12/12 23:48:36	95/12/13 00:38:06	NO RESPONSE	
AAM	HLN	waiting	103	95/12/12 23:48:36	95/12/13 00:38:06	NO RESPONSE	
AAM	HLZ	waiting	103	95/12/12 23:48:36	95/12/13 00:38:06	NO RESPONSE	
AAM	LLE	waiting	105	95/12/12 23:48:36	95/12/13 00:38:06	NO RESPONSE	
AAM	LLN	waiting	105	95/12/12 23:48:36	95/12/13 00:38:06	NO RESPONSE	
AAM	LLZ	waiting	105	95/12/12 23:48:36	95/12/13 00:38:06	NO RESPONSE	
ALQ	BHE	waiting	106	95/12/12 23:45:50	95/12/13 00:26:15	NO RESPONSE	

Figure 2: The reqstat station request window. The status of each station/channel request for one event is displayed.

a right-mouse-button click in any field of the **Confirm Re-request** window to enter edit mode. An autoDRM address can be entered for each channel or one can be selected from a list. After a re-request is confirmed, a new line for each channel re-requested is be added to the station request window.

From the `reqstat` station request window the Messages option can be used to display a copy of the exact autoDRM-formatted request that was sent and detailed information on the response that was received for the selected channel. Figure 3 shows an example of the content in a `reqstat` messages window. The time that `gse2css` was executed to process the autoDRM response is displayed followed by message identification lines and all `DATA_TYPE LOG` lines that were in the message.

Reqstat Options

All options for each `reqstat` window are listed below with a brief explanation of their function.

Main Window

File/Open Displays the standard X11 file selection popup. Select an individual `.reqstatus` file to view, or select a directory (double click on the directory name in the **Directories** list).

File/Warnings Displays a list of all warnings encountered.

View/Attributes This popup allows the user to customize the information displayed for each requested event. Click on an attribute **Name** to add or remove that attribute from the display line. Attributes can be reordered by deselecting all of them and then selecting in the order you want them displayed. Click in the **Format** field to edit the format used to display the attribute.

View/Clear Remove the current event listing from `reqstat`.

View/Sort Select the sort option for the events: sort by **Prefix**, by **Event Time** or by **Request Date**.

View/Stations Display the `reqstat` station request window for the selected event.

Option/Re-request This option will re-request stations for the selected events. There are two types of re-requests: re-request all stations for which no response has been received, or re-request all stations for which a **NO DATA**

```
msg_id=2521 requested Tue Apr 23 09:06:09 1996
/usr/lib/sendmail autodrm@gldfs.cr.usgs.gov
  BEGIN GSE2.0
  MSG_TYPE REQUEST
  MSG_ID 2521 reqdata
  E-MAIL ihenson@multimax.com
  STA_LIST ARU
  CHAN_LIST bhz,bhn,bhe
  TIME 1996/1/28 8:47:25 TO 1996/1/28 9:12:33
  WAVEFORM GSE2.0
  STOP
msg_id=2521 executing gse2css at Tue Apr 23 09:16:38 1996
MSG_TYPE DATA
MSG_ID 96114_125748_multima USA_NDC
REF_ID 2521 reqdata
DATA_TYPE LOG
   :
 This message was generated by the U. S. Geological Survey (USA_NDC)
 Automatic Data Request Manager (AutoDRM).
   Request received at:   Apr 23 06:57:48 1996 (local).
   Processing started at: Apr 23 07:07:21 1996 (local).
 907 waveform channels are currently available.
 Command syntax GSE2.0 selected.
 Time range: 28 JAN 1996 08:47:25.00 to 28 JAN 1996 09:12:33.00 (WAVEFORM).
   Channels selected (WAVEFORM):
 ARU: BHZ, BHN, BHE
   :
ARU/BHZ     1996/01/28 08:47:29.434   1996/01/28 08:57:34.434
ARU/BHZ     1996/01/28 09:12:20.634   1996/01/28 09:12:32.984
ARU/BHN     1996/01/28 08:47:29.434   1996/01/28 08:57:48.834
ARU/BHN     1996/01/28 09:12:20.634   1996/01/28 09:12:32.984
ARU/BHE     1996/01/28 08:47:29.434   1996/01/28 08:56:25.234
ARU/BHE     1996/01/28 09:12:20.634   1996/01/28 09:12:32.984
   :
   :
   :
```

AVAILABLE response was received. Before the re-requests are actually sent, a **Confirm Re-request** window will list the channels that will be re-requested. The requested time limits and the autoDRM addresses can be changed before a **Confirm** option sends the re-requests. A **Cancel** button is also available.

Station Request Window

View/Attributes This popup allows the user to customize the information displayed for each requested station/channel. Click on an attribute **Name** to add or remove that attribute from the display line. The attributes can be reordered by deselecting all of them and then selecting each attribute in the order you want them displayed.

View/Messages Display the exact GSE-formatted request message that was sent to the autoDRM and display any **DATA_TYPE LOG** or **DATA_TYPE ERROR** messages received from the autoDRM. Error messages from `gse2css` are also displayed.

Option/Re-request This option will re-request data for the specified stations or channels. There are three types of re-requests: re-request all selected stations, re-request all stations for which no response has been received, or re-request all stations for which a **NO DATA AVAILABLE** response was received. Before the re-requests are actually sent, a **Confirm Re-request** window will display all the stations and channels that will be re-requested along with **Confirm** and **Cancel** buttons. The requested time limits and the autoDRM addresses can be changed in the **Confirm Re-request** window.

Confirm Re-request Window

This window is generated by a **Re-request** option from either the `reqstat` main window or the stations request window. The time limits of the re-request, **tbeg** and **tend**, and the autoDRM **address** can be changed before confirming the re-request. Enter edit-mode with a right-mouse-button click in any text field. The **Address** option is a tool for changing the autoDRM address for multiple channels in the **Confirm Re-request** window. First select channels in the **Confirm Re-request** window with a left-mouse-button (or ctrl-left-mouse-button) click. Enter an address in the **Enter New Address** text field of the **Address** popup or select one from the list of autoDRM sites. The list of autoDRM addresses is generated from the unique addresses in the `$REQDATA_HOME/tables/static/global.address` file.

HANDLING ERRORS

Error messages from reqdata and reqchan are written directly to the screen (stderr). Most of the errors are caused by missing arguments, missing table files, invalid file permissions or invalid file formats. The fatal errors from the programs reqdata and reqchan and the exit codes generated are listed in the following two tables.

Code	reqdata Errors
1	Missing argument retaddr
2	Missing argument basedir
3	Invalid time argument
4	Missing stachanList or stachanFile argument
5	No stations or channels found in stachanFile
6	No stations or channels found in stachanList
7	Invalid begPhase argument
8	Invalid endPhase argument
9	No iaspeiTable specified
10	No siteTable specified
11	No sitechanTable specified
12	No affiliationTable specified
13	No addressTable specified
14	No lastidTable specified
15	No requestTable specified
16	Cannot open iaspeiTable.hed
17	Cannot open iaspeiTable.tbl
18	Cannot open tmpfile
19	CSS3.0 origin free-format error in origin input string
20	Origin time value missing or null
21	Origin lat value missing or null
22	Origin lon value missing or null
23	Origin depth value missing or null
24	Cannot open origin input file
25	Malloc error.
26	CSS3.0 origin format error in origin input file
27	Cannot stat origin input file
28	No origins specified
29	Both stachanList and stachanFile specified
30	Cannot open stachanFile

Code	reqdata Errors Continued
31	Cannot stat affiliationTable
32	Cannot open affiliationTable
33	CSS3.0 Format error in affiliationTable
34	Cannot stat sitechanTable
35	Cannot open sitechanTable
36	CSS3.0 format error in sitechanTable
37	Cannot open addressTable
38	Cannot stat siteTable
39	Cannot open siteTable
40	CSS3.0 format error in siteTable
41	Requested station not found in siteTable
42	No autoDRM address for requested sta/chan
43	Unknown format field in addressTable
44	Cannot open requestTable
45	No travel time for begPhase at requested station
46	No travel time for endPhase at requested station
47	Cannot open prefix.reqstatus file
48	Cannot open prefix.reqlog file
49	Error computing travel time
50	Error getting nextid
51	Cannot execute sendmail program
52	Sendmail program failed

Code	reqchan Errors
1	Missing argument retaddr
2	Missing argument address
3	No lastidTable specified
4	No requestTable specified
5	Cannot open requestTable
6	Cannot open log file
7	Cannot get nextid
8	Cannot execute sendmail program
9	Sendmail program failed

When an error occurs during the processing of an autoDRM email response, the error is logged and the email response is saved. The message can be saved in a file or forwarded to the user's mailbox. To instruct the `deliver` program to forward all email that fails to be processed to the user's mailbox, set the variable `FORWARD_FAILED_MSG` to 'yes' in the `.deliver` script.

```
FORWARD_FAILED_MSG=yes
```

By default, autoDRM email that is successfully processed is discarded. To save all autoDRM email messages, set the variable `SAVE_ALL_GSE_MESSAGES` to 'yes' in the `.deliver` script.

```
SAVE_ALL_GSE_MESSAGES=yes
```

Each autoDRM message will then be saved in a separate file in the directory `$REQDATA_HOME/save`.

An error in the `.deliver` script which prevents the processing of all messages, causes a description of the error to be mailed to the user. Other less severe errors encountered by the `.deliver` script are logged in the file `$REQDATA_HOME/logs/deliver.log`. Error messages from the message parsing program `gse2css` are logged in the `prefix.reqlog` file in the `basedir` directory. These can be reviewed with the program `reqstat`. Error messages from the autoDRM are also logged in the `prefix.reqlog` file. The fatal errors from the programs `gse2css` and `gse2site` and the exit codes generated are listed in the following two tables.

Code	gse2css Errors
1	Cannot open reqLog
2	Missing argument basedir
3	Missing argument prefix
4	Missing argument dir
5	Length of argument dir > 64
6	Missing argument lastidTable
7	Cannot open input file
8	Cannot open reqstatus file
9	Cannot open tmpfile
10	CSS3.0 origin format error
11	Get nextid failed
12	Cannot open .origin file
13	Write to .origin file failed
14	Cannot open .wfdisc file
15	GSE WID1 format error
16	GSE WID2 format error
17	No GSE WID header found
18	Malloc error
19	GSE CHK2 line not found
20	Unknown compression format
21	Cannot open dfile (.w file)
22	Write to .wfdisc file failed
23	Write to dfile failed

Code	gse2site Errors
1	Missing argument address
2	Missing argument lastidTable
3	Missing argument siteTable
4	Missing argument sitechanTable
5	Missing argument addressTable
6	Cannot open input file
7	Cannot open logFile
8	Cannot open siteTable
9	Malloc error
10	CSS3.0 format error in siteTable
11	Cannot open sitechanTable
12	CSS3.0 format error in sitechanTable
13	Cannot open addressTable
14	Format error in addressTable
15-19	Error parsing DATA_TYPE STATION
20	Write to siteTable failed
21-25	Error parsing DATA_TYPE CHANNEL
26	Write to sitechanTable failed
27	Write to addressTable failed

REFERENCE LIST

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GSE Conference Room Paper 243 Concept for GSE Messages.

APPENDIX B

Predspec User's Manual

Predspec is a program (or more accurately, a collection of programs) that predicts the response spectra, the Peak Ground Acceleration (PGA), and the Cumulative Absolute Velocity (CAV) at nuclear power plants caused by nearby earthquakes. The input data are the waveforms from seismograms recorded at stations in the eastern United States. The user first selects waveforms according to their quality (signal-to-noise, absence of dropouts, etc.), and then he performs a deconvolution of the instrument response, a computation of the response spectrum, and finally a prediction of the ground motion parameters at each power plant site. The predicted spectrum is 5% damped PSA (Pseudo Spectrum of Acceleration), but other spectra like PSRV (Pseudo Spectrum of Relative Velocity) are easily obtained from PSA divided by frequency.

Predspec differs from other codes for calculating ground motion in that it uses whole waveform information to calculate the predicted response spectrum. Previous methods calculate the magnitude first, and then they estimate the response spectrum with a fixed shape which is obtained from the average over many earthquake observations. These methods lose the earthquake-specific information that is included in the individual waveforms. Our method keeps that waveform information, so it should therefore reduce the prediction error.

There are three main codes in *Predspec*:

1. *deconw* - a shell script. It calls SAC to deconvolve the waveforms, *i.e.*, to remove the instrument response.
2. *specalc* - a C program calling a Fortran subroutine. This Fortran subroutine is *rsac1*, which is provided with SAC. This code calculates PSA (Pseudo Spectrum of Acceleration).
3. *Predspec* - a C program that calculates the synthetic source term and then makes a prediction of the response spectra at each nuclear power plant site.

Steps for Running the Codes

(1) ***Data selection.***

Login into the workstation *res18*, then enter the directory /local1/Event/1995/MAR/794909752., for example. There are 14 waveforms in that directory:

BINY.BHE BINY.BHN BINY.BHZ CEH.BHE CEH.BHN CEH.BHZ
HRV.BHN LSCT.BHE LSCT.BHN LSCT.BHZ OXF.BHE OXF.BHN
OXF.BHZ RSNY.SHZ

There are other data in this directory as well. To list only the SAC-format waveforms, run a simple shell code called *formlist*. Type *formlist* at the shell prompt, and a file called *thelist* will be generated containing the names of all the SAC-format waveforms in the current directory, like the list shown above.

Because the quality of the waveforms varies greatly, especially for small-magnitude earthquakes that are poorly detected at seismic stations not close to the epicenter, it is necessary to inspect the seismograms visually before using the data in the ground-motion calculations. We use SAC to view each waveform, canceling those with high-level noise or other problems. This procedure will be improved with a different computer graphics interface later. The Fourier spectrum of each waveform can be viewed with SAC as well.

After visual inspection of the waveforms in the list shown above, only 5 waveforms are selected for use in the ground motion prediction. Their names are listed in a file called *thelist*:

```
$>more thelist
CEH.BHE
```

```
CEH.BHN
CEH.BHZ
OXF.BHN
OXF.BHZ
```

(2) ***Deconvolution with instrument response.***

In the same directory, type *deconw*. This program will read the file called *thelist*, and then it will read in all the listed SAC-format seismograms one by one. After calling the SAC function *transfer*, the programs saves the deconvolved waveforms will as d.* files, *i.e.,* files with names like d.CEH.BHE in the case of the first waveform listed above . At the same time, a few files are generated for later use. These files are *dfile*, *output*, and *parameters*. *dfile* is a list of the deconvolved waveforms:

```
$>more dfile

d.CEH.BHE
d.CEH.BHN
d.CEH.BHZ
d.OXF.BHN
d.OXF.BHZ
```

output contains the file names and 4 parameters: latitude and longitude of the station, peak ground acceleration, and sampling rate. They are used later in *Predspec*.

```
$>more output

d.CEH.BHE
35.891  -79.093  250.5700  20.00000
d.CEH.BHN
35.891  -79.093  306.9200  20.00000
d.CEH.BHZ
35.891  -79.093  121.9300  20.00000
d.OXF.BHN
34.512  -89.409  88.00300  20.00000
d.OXF.BHZ
34.512  -89.409  30.32600  20.00000
```

parameters contains the earthquake source parameters, including the directory name, date, time, location, magnitude, and region. These parameters describing the source are taken from the epicenter listings retrieved from USGS:

```
$>more parameters

794909752. 95/03/11 08:15:52 36.98N 83.16W 5.0 3.8Lg A TENNESSEE
```

(3) ***Spectrum Calculation.***

In the same directory, type *specalc*. This program will read the file *dfile*, then it will read in all the listed deconvolved files one by one. It also reads in a file called *vsat.calib*, which contains the calibration coefficients for each station:

```
$>more vsat.calib

BINY 912.30
CEH 923.94
DUG 979.17
HRV 2966.9
```

LBNH 982.39
LSCT 1039.1
RSNY 1.6134e-3
SMTC 717.3
OXF 920

When the waveforms were saved by the SDAES data-recording system, they were divided by the corresponding calibration coefficients. Here they are multiplied back to recover the proper values. All the calculated 5% damped response spectra are saved in files with the suffix *.sp.

(4) ***Prediction of Response Spectra at NPP sites***

The code *Predspec* reads in all the calculated spectra files *.sp as well as several other files. Of those input files, "output" and "parameters" have been explained in (2) above. *NPP.SITES* contains the names and locations of nuclear power plants in the eastern U.S. It predicts the response spectra for all those sites within 500 km of the earthquake. A map file called *map.npp* is generated showing the location of the earthquake and of all the nuclear power plant sites within 500 km of it. All the predicted spectra and other information are summarized in a text-format file called *RESULT_LIST*. A graphical presentation of the spectral prediction at each nuclear power plant site is written into files with the suffix *.plt. The file *map.npp* and the *.plt" files are all GMT files. They can be transfered to Postscript files by typing *sh <filename>*. An example of these plots of the response spectra is shown as Figure 24 in Chapter 5 of this report.

Sample Output

The following *Predspec* output was obtained for a magnitude 3.9 earthquake that occurred on April 9, 1996, close to the Kentucky-Virginia border. Many seismic stations in the eastern US recorded good-quality waveforms for that event. Of the waveforms in the data archive, the ones that were selected for use on the basis of visual inspection with SAC were:

CBKS.BHE CBKS.BHZ
CEH.BHE CEH.BHN CEH.BHZ
EYMN.BHE EYMN.BHN EYMN.BHZ
GOGA.BHE GOGA.BHN GOGA.BHZ
GWDE.BHE GWDE.BHN GWDE.BHZ
JFWS.BHN JFWS.BHZ
LSCT.BHE LSCT.BHN
MCWV.BHE MCWV.BHN MCWV.BHZ
MIAR.BHZ

It should be noted why the waveform CBKS.BHN was not used. This waveform was of good quality, but it has 32,789 data points. When the SAC function *transfer* operates on this waveform, the execution time is far too long. On the other hand, the waveform CBKS.BHE has 32,541 data points, and the execution time is acceptable. The cut-off for acceptable performance is 32,768 points (2 raised to the power 16), since the Fast Fourier Transform algorithm operates on data with lengths that are powers of 2. Extending the data length to the next highest power of 2 overtaxes the computational power of the computer. The inability to process waveforms as long as the one represented by CBKS.BHN is a serious limitation on the system. What is required is a graphical interface for selecting a particular time window of acceptable length from a longer seismogram, and computing the spectrum of only that selected window. The waveform viewer of the Seismic Event Analysis System in fact offers that capability, and this is another reason why the existing *Predspec* program should be replaced by incorporating its calculations into the waveform viewer software instead of continuing to run as a separate program.

The following listing is the output of *Predspec*, as written into the file *RESULT_LIST*.

```
**EARTHQUAKE  INFORMATION**

 506
Date=  1996110
LAT=  36.981000   LON=  -83.018000
Magnitude=  3.900000


**STATION  INFORMATION**

1 CBKS
  LAT=  38.81   LON=  -99.74   dis= 1474.78 km
2 CEH
  LAT=  35.89   LON= -79.09   dis=  370.62 km
3 EYMN
  LAT=  47.95   LON= -91.50   dis= 1401.11 km
4 GOGA
  LAT=  33.41   LON= -83.47   dis=  400.04 km
5 GWDE
  LAT=  38.83   LON= -75.62   dis=  679.02 km
6 JFWS
  LAT=  42.91   LON= -90.25   dis=  901.53 km
7 LSCT
  LAT=  41.68   LON= -73.22   dis= 988.37 km
8 MCWV
  LAT=  39.66   LON= -78.85   dis= 406.22 km
9 MIAR
  LAT=  34.55   LON= -93.57   dis= 987.22 km


**SOURCE TERMS**
```

FREQ. (Hz)	SPECTRA (cm/s2)	(g)
0.50	0.46196	0.00047
0.80	1.03387	0.00105
1.00	1.40001	0.00143
1.30	1.43554	0.00146
2.00	1.24154	0.00127
3.20	1.51460	0.00155
5.00	1.82132	0.00186
7.90	4.97541	0.00508
10.00	11.25815	0.01149
13.00	28.29636	0.02887
PGA	10.10619	0.01031
CAV1	147.75554	0.15077

PREDICTIONS

BEAVER_VALLEY PA (40.62 -80.44)
dis= 462.41

FREQ.	SPECTRA	
(Hz)	(cm/s2)	(g)
0.50	0.00100	0.00000
0.80	0.00224	0.00000
1.00	0.00303	0.00000
1.30	0.00310	0.00000
2.00	0.00268	0.00000
3.20	0.00293	0.00000
5.00	0.00242	0.00000
7.90	0.00414	0.00000
10.00	0.00671	0.00001
13.00	0.01200	0.00001
PGA	0.00519	0.00001
CAV1	0.07319	0.00007

BELLEFONTE AL (34.71 -85.93)
dis= 364.10

FREQ.	SPECTRA	
(Hz)	(cm/s2)	(g)
0.50	0.00127	0.00000
0.80	0.00284	0.00000
1.00	0.00385	0.00000
1.30	0.00394	0.00000
2.00	0.00341	0.00000
3.20	0.00381	0.00000
5.00	0.00341	0.00000
7.90	0.00644	0.00001
10.00	0.01121	0.00001
13.00	0.02155	0.00002
PGA	0.00895	0.00001
CAV1	0. 12406	0.00013

BROWNS_FERRY AL (34.71 -87.12)
dis= 447.84

FREQ.	SPECTRA	
(Hz)	(cm/s2)	(g)
0.50	0.00103	0.00000
0.80	0.00231	0.00000
1.00	0.00313	0.00000
1.30	0.00321	0.00000
2.00	0.00277	0.00000
3.20	0.00303	0.00000
5.00	0.00254	0.00000
7.90	0.00440	0.00000
10.00	0.00722	0.00001
13.00	0.01304	0.00001
PGA	0.00561	0.00001
CAV1	0.07879	0.00008

CATAWBA SC (35.05 -81.07)
dis= 277.21

FREQ.	SPECTRA	
(Hz)	(cm/s2)	(g)
0.50	0.00167	0.00000
0.80	0.00373	0.00000
1.00	0.00505	0.00001
1.30	0.00518	0.00001
2.00	0.00448	0.00000
3.20	0.00511	0.00001
5.00	0.00491	0.00001
7.90	0.01012	0.00001
10.00	0.01876	0.00002
13.00	0.03844	0.00004
PGA	0.01540	0.00002
CAV1	0.21252	0.00022

HARRIS NC (35.63 -78.96)
dis= 392.61

FREQ.	SPECTRA	
(Hz)	(cm/s2)	(g)
0.50	0.00118	0.00000
0.80	0.00263	0.00000

1.00	0.00357	0.00000
1.30	0.00366	0.00000
2.00	0.00316	0.00000
3.20	0.00351	0.00000
5.00	0.00307	0.00000
7.90	0.00563	0.00001
10.00	0.00960	0.00001
13.00	0.01807	0.00002
PGA	0.00760	0.00001
CAV1	0.10565	0.00011

MCGUIRE NC (35.42 -80.95)
dis= 253.21

FREQ.	SPECTRA	
(Hz)	(cm/s2)	(g)
0.50	0.00182	0.00000
0.80	0.00408	0.00000
1.00	0.00553	0.00001
1.30	0.00567	0.00001
2.00	0.00490	0.00001
3.20	0.00562	0.00001
5.00	0.00551	0.00001
7.90	0.01164	0.00001
10.00	0.02196	0.00002
13.00	0.04580	0.00005
PGA	0.01817	0.00002
CAV1	0.25087	0.00026

Similar results are next listed for the power plants sites North Anna VA (distance 475.12 km), Oconee SC (244.44 km), Robinson SC (386.01 km), Sequoyah TN (269.33 km), Virgil C. Summer SC (335.74 km), Vogtle GA (443.17 km), and Watts Bar TN (220.84 km).

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/CR-6625

2. TITLE AND SUBTITLE

Automated Seismic Event Monitoring System

3. DATE REPORT PUBLISHED

MONTH	YEAR
May	2000

4. FIN OR GRANT NUMBER

W6094

5. AUTHOR(S)

I. Henson, R. Wagner, W. Rivers, Jr.

6. TYPE OF REPORT

Technical

7. PERIOD COVERED *(Inclusive Dates)*

November 1993 - January 2000

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Multimax, Inc.
1441 McCormick Dr.
Largo, MD 20774

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Engineering Technology
Office of Nuclear Regulatory Research
US Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

E. Zurflueh, NRC Project Manager

11. ABSTRACT *(200 words or less)*

A data recording, processing, and archiving system was constructed to enable the U.S. Nuclear Regulatory Commission (NRC) to monitor seismic activity in near-real time. The system detects seismic signals, calculates epicenters and magnitudes, and issues alerts whenever a strong earthquake has occurred near a nuclear power plant. This system takes raw waveforms from the U.S. National Seismographic Network that have been re-broadcast via satellite to the NRC, so the system is able to perform its calculations within minutes of an earthquake. However, as soon as the U.S. Geological Survey calculates improved event locations, they are downloaded via the Internet. Seismograms that were not received at the NRC are also retrieved via the Internet and added to the permanent seismogram archive.

The software permits the seismograms to be studied off-line by means of seismic data analysis packages. The seismograms can also be used to estimate the Cumulative Absolute Velocity at nearby nuclear plant sites. These calculations use tables of frequency-dependent site effects that were computed for power plant sites on the basis of local geologic structures. A Geographic Information System is also available to display epicenters, seismic stations, and power plant sites together with geologic and geophysical data sets.

The software has been re-written in the Java programming language to make it platform-independent. In addition, a graphical interface has been developed that permits information to be displayed in tables, and raw waveforms to be viewed and analyzed.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

National Seismographic Network
Seismic Data Processing
Seismic Data Archiving

13. AVAILABILITY STATEMENT

unlimited

14. SECURITY CLASSIFICATION

(This Page)

unclassified

(This Report)

unclassified

15. NUMBER OF PAGES

16. PRICE

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WASHINGTON, D.C. 20555-0001

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