I. Status and Program Plan: The Global Seismographic Network

Standardized, High Performance, Very Broad Band Stations

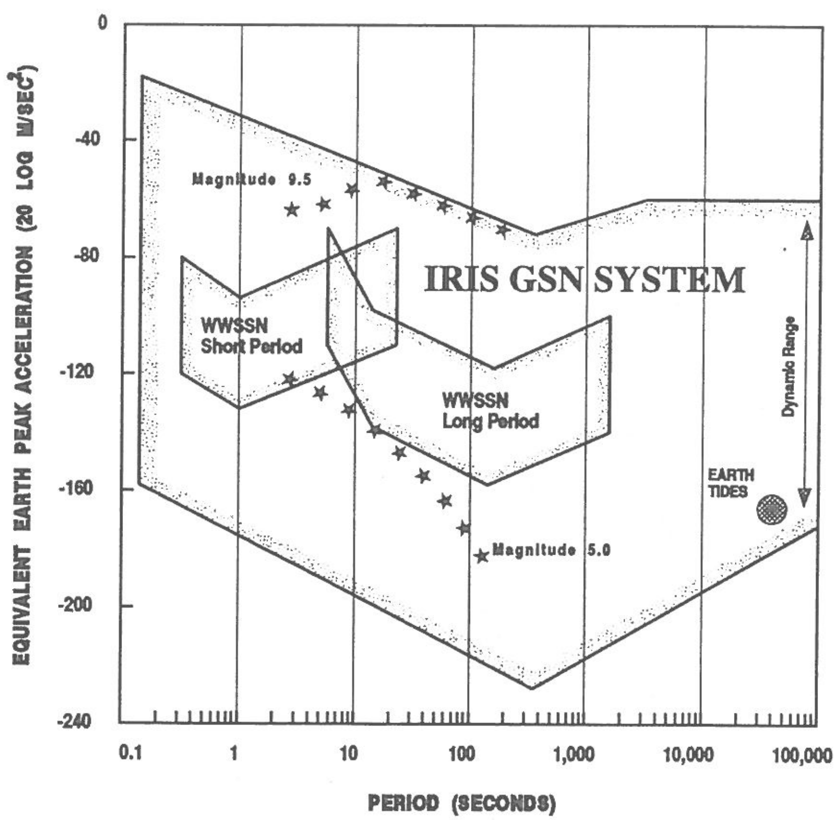
The success of the GSN lies in its ability to serve the scientific community. The community has succinctly defined its needs: seismometers with the broadest frequency response, high-dynamic range digital recording, low-noise seismic stations, ready access to data, and uniform, dense global coverage. In each of these areas the GSN has been a leader.

Each of the needs expressed by the scientific community involve many technical—often highly complex—considerations. To clearly illustrate this, the progress of the GSN is depicted in a series of figures. These may be grouped by the stated scientific needs of the community. Specific figures are referred to as *GSN Figure number*.

- *Seismometers with the broadest frequency response*

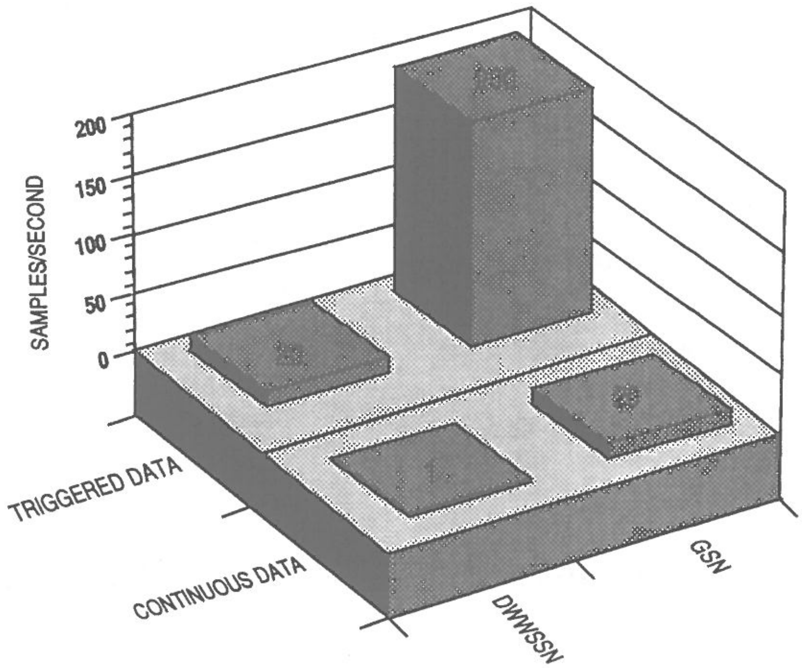
The bandwidth of modern GSN seismometers is extraordinary, compared with the instrumentation used in previous global networks. In *GSN Figure 1* the broad band response of the GSN sensor is compared with the WWSSN Long-Period sensor. The design goals for the Global Seismographic Network call for continuous, three component recording at 20 samples per second at each GSN station. At most locations there is also a need for auxiliary sensors to record high-frequency signals, or strong ground motions in the vicinity of an earthquake. In these cases the systems are augmented with triggered channels capable of recording at 200 samples per second. In *GSN Figure 2* the increased data sample rate capabilities of the GSN system over its predecessor network are illustrated.

Broad Band Response



GSN Figure 1. The new seismic instrumentation for the IRIS Global Seismographic Network has tremendous bandwidth and dynamic range compared to its predecessor, the World Wide Standard Seismographic Network. Using two seismometers, the WWSSN was able to record only a limited period and amplitude range of earthquakes. The H's indicate, over an abridged period range, the approximate acceleration of magnitude (M_s) 5.0 and 9.5 earthquakes recorded at 30° distance from the events. The IRIS GSN System is capable of recording the full range of earthquake motions on scale, and has a long-period response well beyond the Earth tides.

Data Sample Rates



GSN Figure 2. The GSN records continuous three-component broad-band data at 20 samples per second, and has the capability to record additional triggered high-frequency and strong-motion channels at sample rates up to 200 sample/sec. These sample rates are an order of magnitude improvement over the capabilities of the previous global network, the Digital World Wide Standardized Seismograph Network, and significantly improve our ability to resolve seismic signals from earthquakes.

- *High-dynamic range digital recording*

  The design goal for the GSN is 24-bit digitization of the broad band seismometer output. When the GSN began in 1986, only two manufacturers could produce those instruments, and then in only very specific hardware contexts. The IRIS-1 and IRIS-2 data loggers adopted this lineage, and are in active production and usetoday. *GSN Figure 3* compares the dynamic range of these GSN design goal systems with the previous generation network. While developing the design goal systems, the GSN also placed versions of the PASSCAL instrument, termed IRIS-3, at many GSN sites to establish a foundation network. These data loggers obtain the necessary dynamic range through a dual arrangement of overlapping high and low gain 16-bit digitization channels. A 24-bit digitizer for the IRIS-3 data logger has been developed, and all 16-bit systems will be replaced during the next five years.

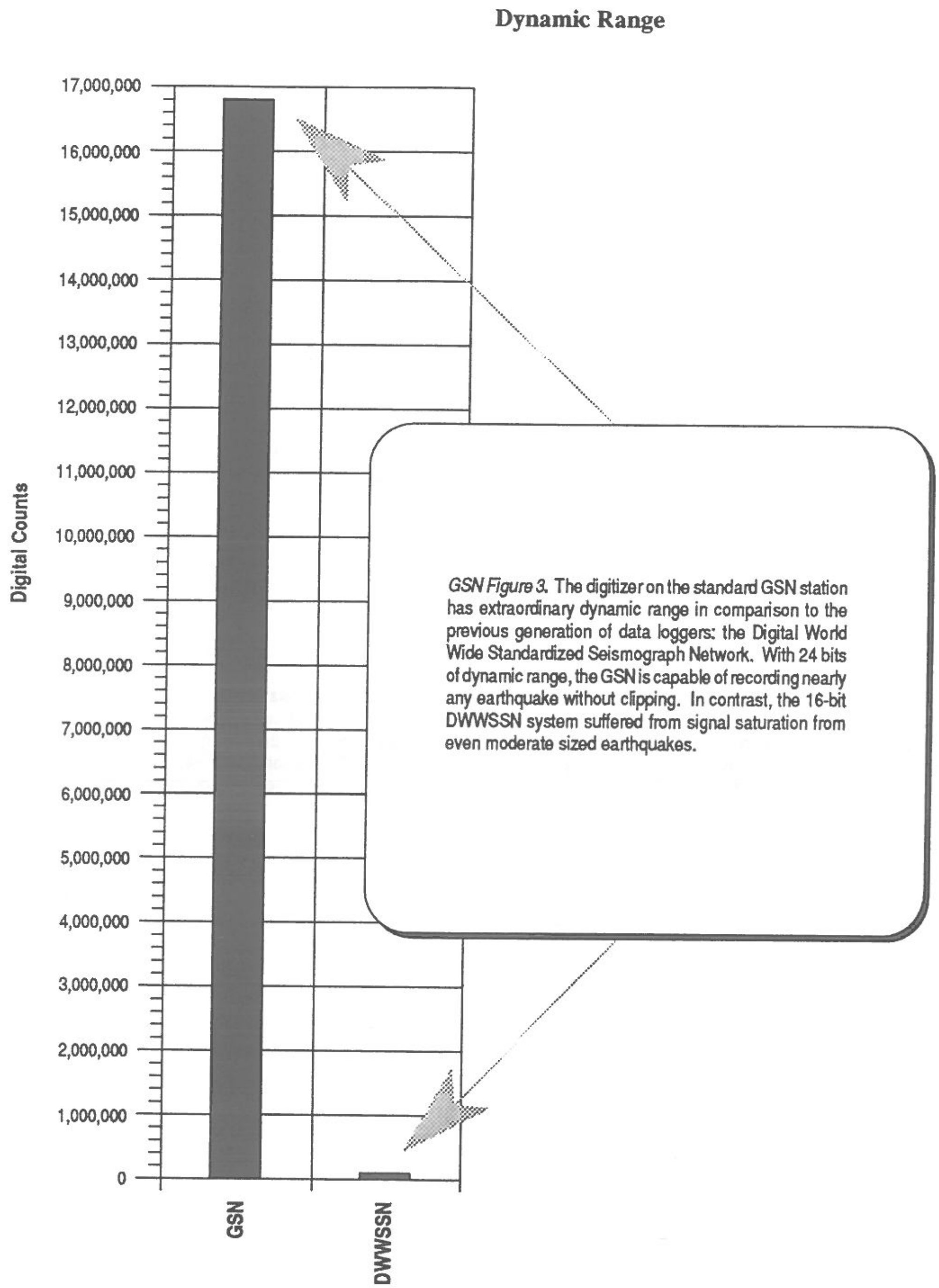
- *Low-noise seismic stations*

  Observations of scientifically interesting signals are made against a background of noise. The noise is increased by the seismometer systems and the seismometer sites. By reducing the system noise in the seismic instrumentation, the measurement of signal by the GSN is limited only by site noise. *GSN Figure 4* illustrates the much lower system noise characteristics of the modern seismometers compared with previous generation sensors. To first order, the site noise at seismic stations is a function of wind speed, thermal variation, and proximity to the ocean. To obtain good (and representative) global coverage the oceans cannot be avoided. The very best sites are deep mines, which are unfortunately rare.

  Substantial noise improvement is obtained by using borehole seismometers at 100 meters depth, in contrast to a seismic vault near the surface, as shown in *GSN Figure 5*. It was for precisely these reasons that the SRO borehole network was installed in the 1970's. As a high priority, IRIS GSN is modifying the current sensor electronics at the existing SRO sites to provide for an improved, broad band response. To achieve the low-noise siting desired by the scientific community, many new borehole sites must to be established.

- *Direct Access to data*

  Two actions by IRIS GSN have made seismological data more available. Many GSN sites can be accessed via telephone dial-up, and waveforms can be displayed and data retrieved directly by the user. After a major earthquake, such as the Loma Prieta Earthquake of October 1989, dial-up access to the data was valuable not just for research interests,



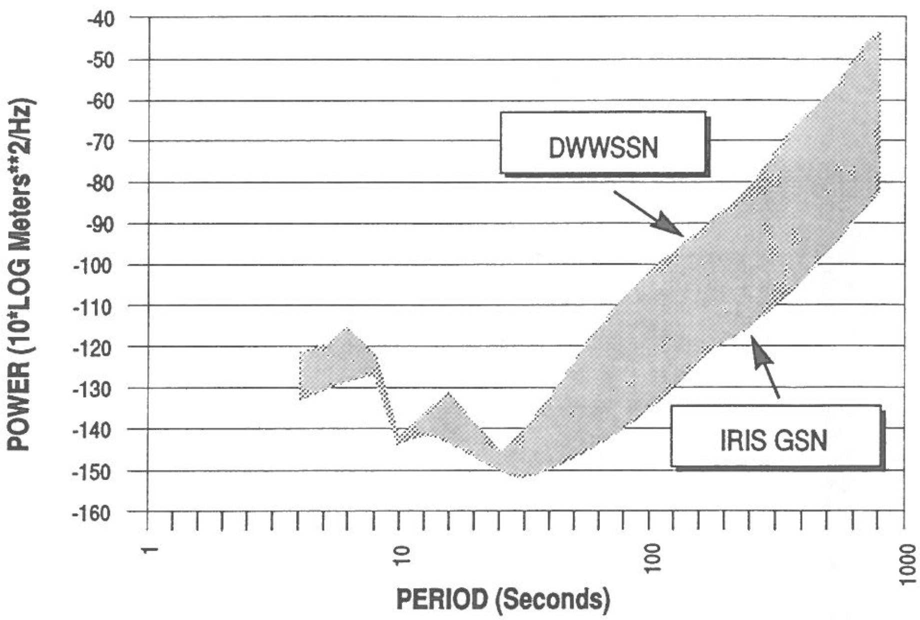
GSN Figure 3. The digitizer on the standard GSN station has extraordinary dynamic range in comparison to the previous generation of data loggers: the Digital World Wide Standardized Seismograph Network. With 24 bits of dynamic range, the GSN is capable of recording nearly any earthquake without clipping. In contrast, the 16-bit DWWSSN system suffered from signal saturation from even moderate sized earthquakes.

but also for rapid response to society's concerns. Dial-up access capability has grown from the basic concept of the NSF-funded Harvard prototype system, adding features to improve the speed and ease of access, as shown in *GSN Figure 6*. A common international format dramatically eases the exchange of data between national and global networks, and benefits the scientific user. The Seed Format (Standard for Exchange of Earthquake Data, presented in *GSN Figure 7*) was drawn both from data exchange considerations, and for use as the native recording format at all GSN sites.

- *Uniform dense global coverage*

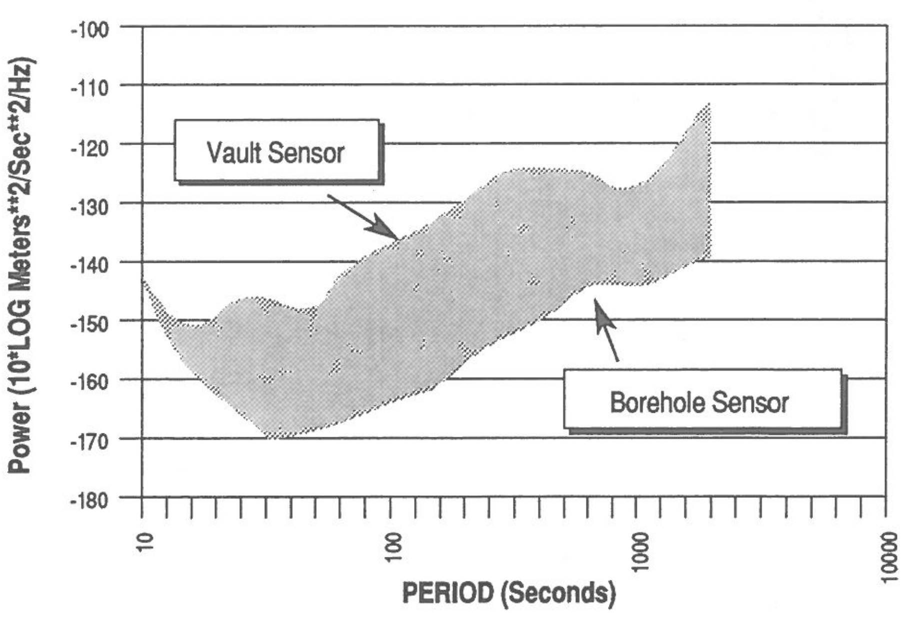
In its first five yearsthe IRIS Global Seismographic Network has upgraded 23 existing seismic stations and established 8 new sites. The growth of the network, shown in *GSN Figure 8*, is one of continuing progress. However, we are far from the long term goal set by the scientific community —

Lowering Instrument Noise



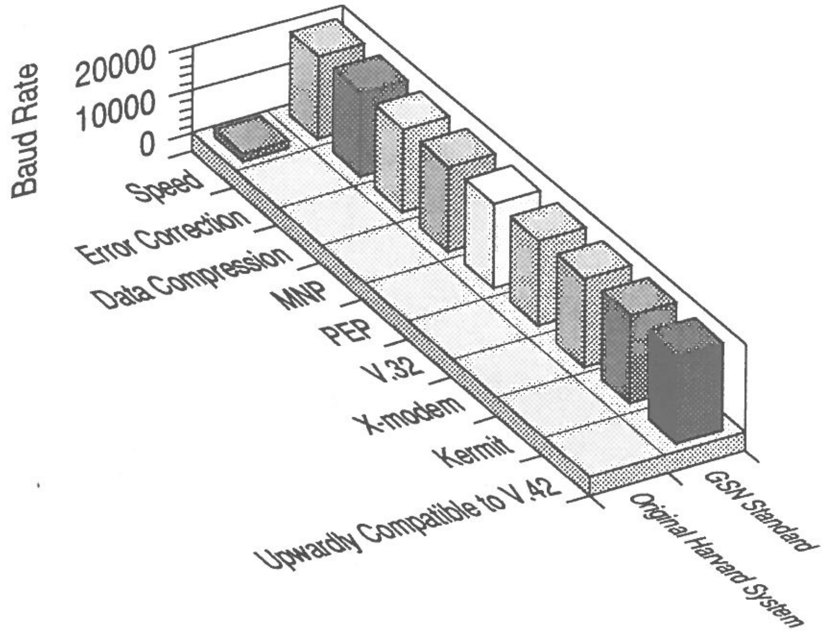
GSN *Figure 4.* The modern Streckeisen seismometers installed by IRIS for the Global Seismographic Network have substantially lower instrument noise than the Sprengnether seismometers of the old Digital World Wide Seismographic Network. A side-by-side comparison of the vertical components of the sensors at the USGS Albuquerque Seismological Laboratory, under quiet Earth noise conditions, is presented in the figure. The upper range is for the Sprengnether seismometer, and the more sensitive lower range is for the Streckeisen seismometer. At 100 seconds period, for example, the IRIS Streckeisen seismometer has better than 30 dB improvement (a factor of over one thousand) in sensitivity–a dramatic enhancement in our ability to resolve surface waves, long-period body waves, and free oscillations of the Earth from earthquakes.

Background Noise



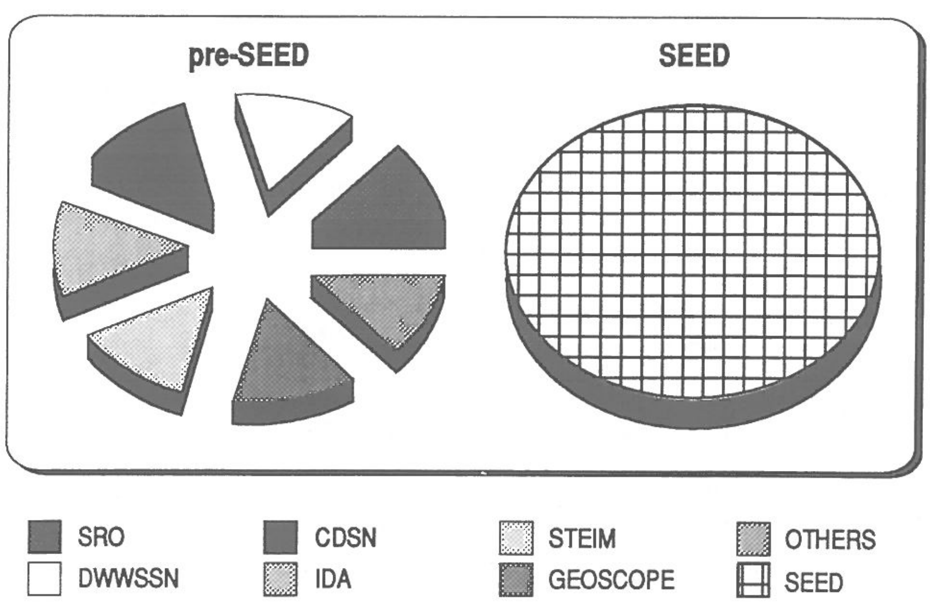
GSN *Figure 5.* At a noisy island or continental site, the use of a borehole seismometer can produce a dramatic reduction in the background noise. On the Island of Guam in the Pacific Ocean, recordings of the seismic background under noisy conditions were made using both horizontal seismometers in a surface vault, and in a 100 meter deep borehole. In the figure it is clear that the borehole sensor registers significantly quieter background noise levels (measured in acceleration power). At a period of 100 seconds, for example, the borehole sensor measures background noise power levels at nearly 30 dB (about a factor of 500) quieter than at the surface. With greatly reduced noise conditions, the borehole seismometer can detect earthquake motions from much smaller events than a surface sensor. On the Earth, quiet surface sites are relatively rare. For an adequate GSN, borehole and deep mine sites are crucial for good, low-noise coverage.

Dial-up Access Capability



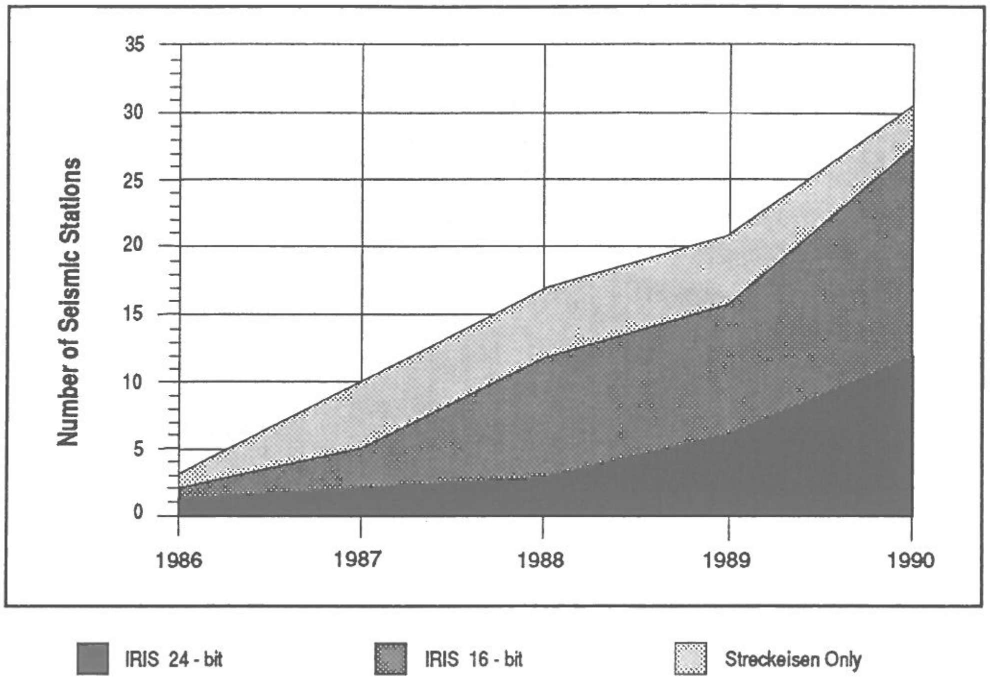
GSN Figure 6. IRIS GSN has been a pioneer in advancing the rapid availability of seismic data through telephone dial-up access to the seismic station processor itself. Improvements have occurred both in the software interface at the station, and through advances in modem technology. Building upon the original Harvard dial-up system concept, IRIS GSN has dramatically increased the speed and capabilities of the system. Error correction and data compression greatly ease data retrieval. The modems "speak" a variety of protocols (MNP, PEP, V.32, Xmodem, Kermit) for users accessing the system with different equipment, and are upwardly compatible with the forthcoming V.42 and V.42bis international protocols.

Seismic Data Formats



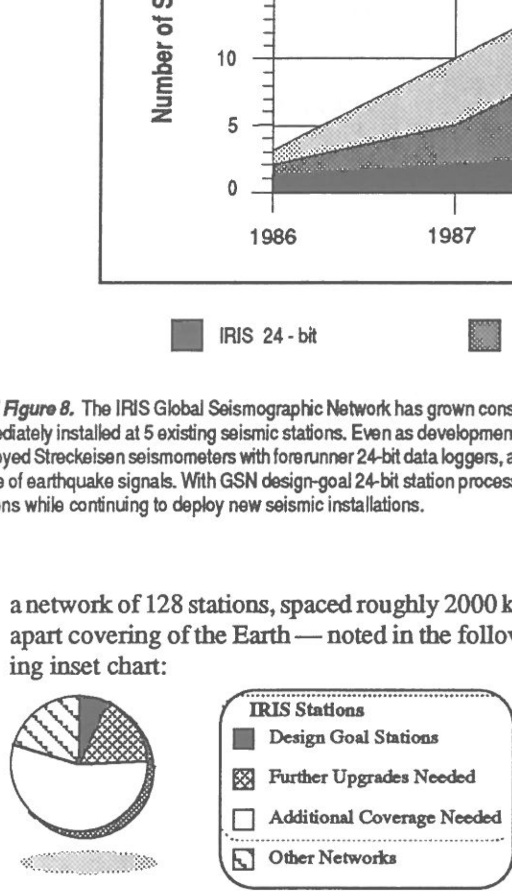
GSN Figure 7. SEED - the Standard for Exchange of Earthquake Data - was developed by the USGS and IRIS as the standard format for the new GSN. Prior to the SEED format, the world of global digital seismic data consisted of a variety of formats, as indicated by the unconnected wedges displayed on the left. SEED is a superset of existing formats, tying the data, header information, and calibration into a common framework. Within the framework of SEED, the seismologist needs only deal with one format. SEED has been reviewed by the international community, and was adopted as *the* format for data exchange among the Federation of Digital Seismographic Networks in 1988. It is currently being implemented by Canadian, French, German, and Japanese networks. Thus, the unification implied by the picture at the right is becoming a reality for the seismological community.

GSN Installations



GSN Figure 8. The IRIS Global Seismographic Network has grown constantly since its inception in 1986. Modern Streckeisen very-broad-band seismometers were immediately installed at 5 existing seismic stations. Even as development of the design-goal 24-bit station processor progressed from 1987 through 1989, IRIS GSN deployed Streckeisen seismometers with forerunner 24-bit data loggers, and with 16-bit data loggers having both high and low gain channels for capturing the dynamic range of earthquake signals. With GSN design-goal 24-bit station processors in production in 1990, IRIS is now poised to rapidly upgrade its existing base of seismic stations while continuing to deploy new seismic installations.

a network of 128 stations, spaced roughly 2000 km apart covering of the Earth — noted in the following inset chart:



Many established sites require upgrades to meet design goal standards. Additionally, IRIS expects about 20% the network to be covered by seismic network programs of other countries, and by other U.S. government efforts, thereby concentrating IRIS's resources on a 100 station network. Most of the work is yet to be done on establishing truly uniform global coverage. Nonetheless, the GSN's accomplishments to date towards this end are substantial, as presented in *GSN Figure 9*.

There is some concentration of GSN sites in North America and central Eurasia. This has naturally occurred in the U.S. through university participation with IRIS member institutions, and in the Soviet Union, through opportunities offered by the Soviet government. Elements of the GSN are outlined in *GSN Figure 10*. All of the GSN sites in the United States will also be stations in the U.S. National Seismic Network, which is being established by the U.S. Geological Survey in the next several years. Globally, some of our current gaps in were dictated by other networks, either in place, or projected. For instance, the U.S. Air Force will be installing a 9 station Global Telemetered Seismic Network (GTSN) meeting IRIS design goals in Africa (4), South America (4), and Antarctica by 1993.

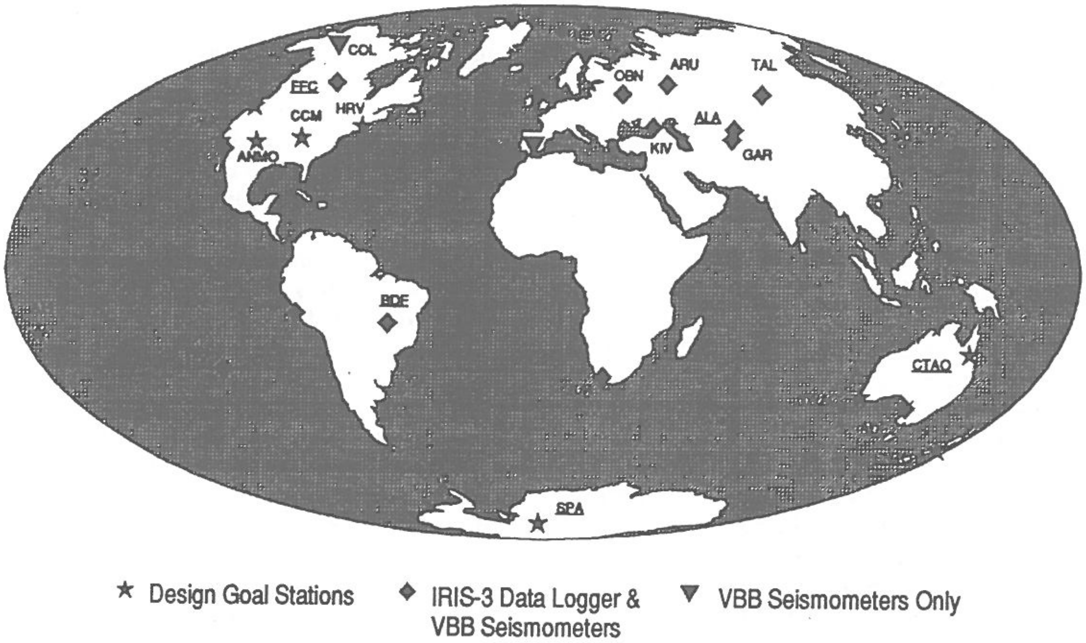
Special Focus

Several areas which have been foci of the GSN during the first five years, deserve particular mention. Each highlights the effectiveness of IRIS GSN as a vehicle for serving the U.S. seismological community's interests in special circumstances.

Stations in the USSR

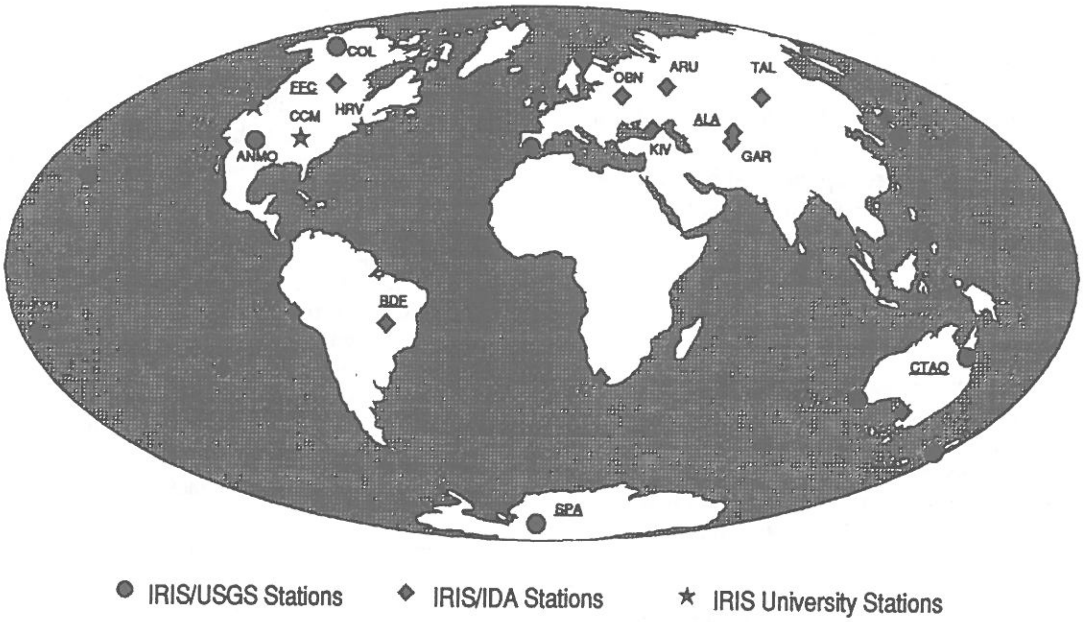
1988 was a special year for the seismological community with the installation of 5 GSN stations in the Soviet Union. Prior to this, the massive central and northern areas of the Eurasian continent were practically voids in terms of global seismic coverage.

IRIS GSN Sites — 1990



GSN *Figure 9.* In its first five years, the IRIS Global Seismographic Network established seismic stations on all of the continents, and on islands of the Pacific Ocean. The design goal stations each have high-dynamic-range 24-bit data loggers, very-broad-band (VBB) seismometers, and telephone dial-up access (except at the South Pole). The 16-bit, high-and-low gain IRIS-3 systems (based on the PASSCAL data logger) are intended to rapidly improve global coverage, and will be upgraded to full GSN design goal standards in the coming years. Three DWWSSN sites which were partially upgraded with VBB seismometers are scheduled for installation with design goal data loggers. Site code names which are underlined indicate installations in the latter half of 1990. The seismic station in Hawaii at KIP, Kipapa, is a cooperative venture between France's Project GEOSCOPE and IRIS.

GSN Elements — 1990



GSN *Figure 10.* The IRIS Global Seismographic Network is comprised of three elements. IRIS and the U.S. Geological Survey cooperate in the installation of the GSN through a Memorandum of Understanding. A component of the GSN is installed and operated by the IDA group at the University of California, San Diego, which receives private funding for equipment through the Cecil and Ida Green Foundation. IRIS University sites arise from the individual efforts of IRIS member Universities. IRIS has provided supplemental funds or other assistance for its Universities to establish and operate design goal GSN stations. France's Project GEOSCOPE and IRIS (through the USGS) cooperatively operate KIP, Kipapa, Hawaii. Underlined seismic station code names indicate installations occurring in the latter half of 1990.

In 1984, overtures to the Soviet Academy of Sciences were made by IRIS toward cooperation in establishing global seismic stations in the Soviet Union — the scarcity of Eurasian seismic coverage being a long-standing concern. When the Soviet administration changed, the American nuclear verification community, led by the National Research Defense Council (a private foundation), got permission to establish temporary seismic stations to prove concepts in treaty monitoring. To achieve this, NRDC turned to the seismic research group at the University of California, San Diego. When the U.S. Congress made funding available for the Soviet Stations, the IRIS organization was sought as the vehicle, and incorporated the operations of its member university, UCSD, within the structure of the Global Seismographic Network. In 1988, IRIS signed a hallmark protocol with the Soviet Academy of Sciences establishing permanent stations in the Soviet Union as a part of the GSN, with reciprocal stations in the U.S. designated for data exchange. In 1989 the Eurasian Seismic Studies Program (ESSP) was added to an existing bilateral protocol and serves as an umbrella for continuing activity between U.S. and Soviet seismologists.

At the end of 1990 there will be at least 6 GSN sites in the Soviet Union (see *GSN Figure 9*). All of these are operated by the IRIS/IDA group of UCSD. The USGS is also important to GSN siting, and has equipment on order for another GSN site in Armenia, to be installed in early 1991. Six additional GSN sites funded by DARPA, IRIS (via NSF), and the USGS, have been agreed upon. The potential density of GSN sites in the Soviet Union exceeds the IRIS global plans, but there is a great scientific return on the opportunity for studying this vast area. When funding cutbacks eventually come, the broad base of stations will allow selection of a supportable subset network, with good distribution and low-noise characteristics. DARPA has promoted the installation of telemetry to speed the flow of data from the Soviet Union. Computer-to-computer circuits on private satellite channels are operational between the IRIS Data Collection Center in Obninsk, USSR, and the IRIS/IDA DCC in La Jolla, California.

South Pole

Continued operation of the ultra-long period LaCoste-Romberg gravimeter at the South Pole has been an important resource to the seismological community. Free oscillation modes are split due to the Earth's rotation, and the South Pole affords a unique vantage to view these modes unaffected by rotational splitting. The South Pole gravimeter operated by UCLA as part of the global Project IDA, had been funded by NSF Polar Programs for over a decade. When this funding was scheduled to be ended in 1987, IRIS assumed its financial support and insured the uninterrupted flow of this seismological data.

Recognizing the importance of this site, IRIS GSN has worked closely with NSF Polar Programs to upgrade this particular seismic facility. Beginning in 1989, the GSN received a five-year, no-cost logistics support grant to establish a new GSN site at the Pole. Plans for a new seismic vault were drawn in 1989, which was constructed during the '89–'90 season. In the following season, modern Streckeisen seismometers and a high-dynamic range IRIS-2 data logger will be installed.

With success imminent for the new GSN site at the Pole, IRIS GSN is now working with NSF Polar Programs to establish a new GSN site at Palmer station on the Antarctic peninsula. Furthermore, because of cooperation with our Soviet colleagues in building GSN sites in the Soviet Union, IRIS is now pursuing joint seismic stations at Soviet sites on the Antarctic continent. Thorough coverage of Antarctica is crucial for coverage of the Southern Hemisphere, which is predominantly ocean.

Data Collection Centers

The USGS Albuquerque Seismological Laboratory has, since the early 1960's, served as the primary Data Collection Center (DCC) in the United States for seismological data. With the advent of the IRIS program, a primary goal of GSN activities was to upgrade the facility well in advance of new GSN data flow.IRIS's timely assessment of the facility was critical to maintaining the flow, even of the existing digital network data — SRO, ASRO, DWWSSN, and China Network. The obsolete computer equipment was near collapse, and any equipment breakdown could have led to weeks of system downtime.

With help from the USGS, a strong effort was made to refurbish the facility. Best use was made of what already existed, while the capability and reliability of the system was expanded. IRIS provided the hardware, and the USGS provided the software effort. IRIS GSN purchased a cluster of DEC microVAXes, tape and disk drives, an optical juke box, and networking software. The USGS rewrote and expanded the existing software used to track, provide quality control, and archive the data into network volumes. The system concept advocated extendibility and modularity, and was conceived as a one which could be cloned and used by other nations. This vision has become reality, as the Italian Mediterranean Network has adopted this same system for its own data collection facility.

Parallel to the effort at Albuquerque, the IRIS/IDA group at the University of California at San Diego expanded its Data Collection Center associated with Project IDA, the international network of ultra-long period gravimeters. Its function was to handle the increased data flow from the growing operations there.

With the dramatic data increase at the onset of the Soviet station operations, the IRIS/IDA DCC was built largely from funds associated with the Eurasian Seismic Studies Program. Expanding the existing software base, their hardware was augmented with compatible SUN system components.

As part of the Eurasian Seismic Studies Program, IRIS has established a Data Collection Center in Obninsk, Russia, 50 km outside of Moscow. Its function is to serve the Soviet GSN stations. This system is based upon exportable PDP-11 and SUN computers. Data are exchanged on magnetic tape via World Data Centers A & B, in Golden, Colorado, and Moscow, respectively.

After some snags in switching over to the new SEED format, all of the GSN Data Collection Centers are operating smoothly, and are capable of managing the ever increasing flow of data from the Global Seismographic Network.

Telemetry

The original goals of the GSN were twofold: uniform coverage of the Earth, and real-time telemetry of data to the IRIS Data Management Center. In the earliest years of IRIS, substantial effort was given to evaluating telemetry systems for GSN needs. Particular consideration was the new "Ku" band, "spread spectrum" satellite technologies which utilize small antenna dishes. Technical evaluations funded by IRIS indicated the "micro Earth station" had promise for domestic use, but would require a large financial investment to realize international system availability for GSN needs. With the difficulties at NSF in 1987 and 1988, it became obvious that global telemetry would not be immediately affordable. Nevertheless, the efforts of the GSN Standing Committee were not in vain, as this same Ku-band satellite technology came to be adopted as the centerpiece of the telemetered U.S. National Seismic Network.

The IRIS/IDA stations in the Soviet Union are being telemetered to the IRIS/IDA DCC as part of the ESSP. This telemetry experiment is providing valuable experience in handling high-volume seismic data sets, and the experiment will be continued for several years with DARPA funding.

IRIS GSN initiated with NASA a telemetry facility on the Earth Observing System (EOS) satellites scheduled to fly at the end of the decade.This facility, the Wide Band Data Collection System, will be discussed further under the section on new initiatives of the GSN program.

In the nearer term, there are several telemetry options available. The GOES satellites over the Americas and the Pacific have limited data rates, but can send continuous very-long period data (0.1 sample/sec) on an hourly basis. IRIS GSN has obtained NOAA permission and FCC licenses for using the GOES system. When testing from HRV, Harvard Massachusetts, is completed, a prototype deployment is planned for Hawaii, Alaska, Easter Island, and California. For polar regional coverage, NSF operates an ATS satellite abandoned by NASA due to a skewed geosynchronous orbit. Its contribution is largely telemetry from the South Pole base and oceanographic ships. IRIS GSN has funded the UCLA group to integrate the flow of seismic data within the present, limited, telemetry capabilities from the Pole. In the same vein, IRIS GSN has initiated discussions with NSF and the Geological Survey of Canada so that some of the capacity of the ATS satellite in the northern polar region can be used for GSN station ALE, Alert, in northernmost Canada.

Finally, a principal advantage in having telemetry capability is the state-of-health information received. Often at remote sites, problems are only noted when a scheduled shipment of magnetic tapes *does not* arrive. With simple state-of-health telemetry, a problemcan be quickly identified, and personnel dispatched. IRIS GSN has been evaluating two possible systems for providing state-of-health information for the GSN: the French ARGOS system, and Comsat's Standard C service.

Federation of Digital Seismographic Networks

The GSN project is inherently international. Planning for IRIS GSN coincided with the growth of the Geoscope network by the French, and plans in other countries to set up, or improve, their national broadband networks. Wide dissemination of Science Plans by IRIS, Geoscope and ORFEUS (an organization of 15 western European countries) further stimulated the interest of the international community. With the encouragement of the International Commission on the Lithosphere and IASPEI (International Association of Seismology and Physics of the Earth's Interior) a meeting for representatives of several countries was organized in early 1986. Its purpose was to determine whether the establishment of an international federation of networks operating broad-band digital seismograph systems is desirable and feasible — and the response was unanimously favorable. The founding meeting of the Federation of Broad Band Digital Seismographic Networks (FDSN) took place in Germany in August 1986. The initial founding members of the Federation included: Australia, Canada, China, France, Germany, Japan, ORFEUS, the U.S. Geological Survey, and IRIS. Great Britain, Italy, and the Soviet Union have since joined the Federation.

The principal objectives of the Federation are:

- Establishment of common instrumentation standards.
- Timely exchange of data recorded by the member networks.
- Coordination of siting plans.

The Federation has proved to be a useful forum for discussions among member networks. Under the auspices of Federation cooperation, Geoscope and IRIS jointly operate a seismic station in Hawaii — KIP, Kipapa — where French Streckeisen seismometers operating in a U.S. vault are mutually recorded by Geoscope and IRIS data loggers. IRIS and the Geological Survey of Canada negotiated the establishment of the GSN station at ALE, Alert, Canada, in the spirit of Federation cooperation. Discussion between IRIS and Japan's Pacific Orient Seismic Digital Observation Network (POSEIDON) regarding mutual siting plans and possible cooperation on sites is carried on from the vantage of Federation membership. Perhaps the Federation's greatest success lies in the adoption of a common format for data exchange — the SEED format, noted previously and discussed more extensively in the section on the IRIS Data Management System.

Participation by the Seismological Community

The IRIS Global Seismographic Network works closely with the U.S. scientific community in serving its goals and vision for the seismological study of the Earth. The efforts of the GSN program are guided by the ten-member Standing Committee for the Global Seismographic Network. Members for the committee are selected for rotating three year terms by the IRIS Executive Committee. Reflecting the close working relationship with the U.S. Geological Survey, the USGS Branch Chief for Global Seismology and Geomagnetism is a permanent member, and the Chief of the USGS Albuquerque Seismological Laboratory is an invited observer.

The committee membership has broadly represented the scope and breadth of interest in global seismology during these first five years. The current and past committee membership includes:

J. Berger, University of California, San Diego

R. Butler, University of Hawaii

F.A. Dahlen, Princeton University

A. M. Dziewonski*, Harvard University

D. W. Forsyth, Brown University

K. Fujita, Michigan State University

S. P. Grand, University of Texas at Austin

D. V. Helmberger, Caltech

E. T. Herrin, Southern Methodist University

H. Kanamori, Caltech

C. A. Langston, Penn State University

T. Lay, University of Michigan

A. Lerner-Lam, Columbia University

R. P. Massé, U.S. Geological Survey

T. V. McEvilly, University of California, Berkeley

B. J. Mitchell, St. Louis University

E. A. Okal, Northwestern University

S. C.Solomon*, MIT

T. L.Teng, University of Southern California

T. C. Wallace, University of Arizona

*Chairman

The Committee has guided the GSN in site selection, station processor and seismometer specifications, telemetry evaluation, data logger development, and a host of technical issues. The Committee has taken the lead in developing the GSN in liaison with the academic community and the U.S. Geological Survey. The Committee can affect change in the GSN program to meet perceived needs. This responsiveness is important for keeping the program on track. For example, the seismological community expressed the need for improved coverage outside of the U.S. immediately after an earthquake. In response, the Committee moved to accelerate the deployment of an IRIS station processor with dial-up capability at MAJO, Matsushiro, Japan.

Responsiveness has led the GSN program into creative solutions for problems. Oregon State University had applied to IRIS for a data logger for its seismic station COR, Corvallis, as part of the University matching fund program, but sufficient funds were not available; the GSN budget could not provide a purchased system. Nonetheless, a lease arrangement was set up with the manufacturer, Quanterra Inc., and a new GSN site was established a year or two sooner than would have been otherwise possible.

The GSN has worked closely with the IRIS Data Management group to improve access time to GSN data. In the past, data collection procedures dictated long delays between the time of an earthquake, and data availability to the user. One solution has been to implement telephone dial-up. Equally important has been to reduce the time lag between the data quality control process at the Data Collection Center, and eventual distribution. IRIS GSN has endeavored to cut this to a minimum, so that data are available to the user in the IRIS Data Management Center, as soon as possible after quality control.

As the GSN has worked on promplty building a foundation network of seismic stations, it has kept an eye on the future and the problems ahead. Two major long-range concerns are oceanic coverage and global telemetry. Parallel to IRIS's programmatic focus on oceanic coverage, the scientific community takes an active and independent role in oceanic science. Two interrelated program elements with the GSN have come from a long term need for seismic stations on or beneath the seafloor. These are the Trans-Pacific Cable Initiative and the Ocean Seismic Network. Complementary to geoscientific observations deep in the Earth's oceans, NASA has a long range program of remote sensing observations of the Earth from orbit. Two components of NASA's plan are congruent to IRIS's — the Earth Observing System satellites, and a global geodetic network.

Ocean Initiatives

A scientific workshop on Broad-Band Downhole Seismometers in the Deep Ocean was convened by Drs. G. M. Purdy and A. M. Dziewonski at Woods Hole Oceanographic Institution in 1988.It concentrated the interest of the Earth and marine seismic communities on a set of benchmark goals for establishing permanent seismic observatories on the seafloor. The recognition that seafloor seismic stations can't use off-the-shelf hardware, available for even difficult land sites, is essential; hardware must be developed. Also, the optimal siting conditions for underwater deploymentsmust be defined. Toward this end, a Steering Committee for an Ocean Seismic Network, was established in 1989, co-sponsored by the Joint Oceanographic Institutions (JOI) and IRIS . Its function is to direct scientific efforts and to raise funding. The membership of the Steering Committee is:

A. M.Dziewonski*, Harvard University

G. M. Purdy*, Woods Hole Oceanographic Institution

H. Kanamori, Caltech

F. K.Duennebier, University of Hawaii

J. A. Orcutt, University of California, San Diego

*Co-Chairmen

The Steering Committee has effectively presented the case for permanent undersea seismic observatories to the funding agencies. In 1990 it successfully applied for an oceanic borehole to be drilled in March 1991 near Oahu, Hawaii. This borehole will be used in research and for testing of prototype undersea seismic deployments. IRIS GSN will be closely involved with research efforts, providing comparison data from the nearby IRIS site KIP, Kipapa, Oahu.

Reference: *Proceedings of a Workshop on Broad-Band Downhole Seismometers in the Deep Ocean*, Conveners G. M. Purdy and A. M. Dziewonski, Woods Hole Oceanographic Institution (1989).

On a separate front, IRIS was approached by the Japanese seismological community in 1987. This was in regard to an attempt to refurbish the Trans-Pacific Cable-1 telephone cable for re-use by the international geoscientific community. The Japanese, led by the Earthquake Research Institute (ERI) of the University of Tokyo, initiated a $10M funding effort for three permanent geoscience observatories on the seafloor between Guam and Japan. In acquiring the TPC-1 — which runs from Oahu to Midway, Wake and Guam, and then to Japan — an American scientific counterpart was needed for discussions with the telecommunications companies AT&T and Japanese KDD. IRIS undertook this effort on behalf of the U..S. scientific community, and kept the Joint Oceanographic Institutions fully apprised of its progress. A series of fruitful discussions with AT&T and KDD followed in 1988 and 1989. Encouragement was given to the proposed scientific efforts, as well as support in smoothly transferring the facility's ownership to the joint Japanese-U.S. scientific community. The government agencies were briefed in 1989, with discussions of ownership models for the cable after transfer from AT&T and KDD. Co-ownership of the transferred cable by ERI and IRIS was proposed as the most favored model.

In early 1990, IRIS and JOI convened a workshop on Scientific Uses of Undersea Cables — funded by NSF, ONR, USGS, and NOAA. It was attended by Japanese and American geoscientists and representatives from KDD, AT&T, and the funding agencies. The workshop's report will recommend that the U.S. provide assistance in Guam for Japanese efforts to fund re-use of the Guam-Japan section of TPC-1, and for a careful study of costs for proposed scientific cable facilities. These would be applied to a number of the retired and soon-to-be-retired cables laid across the world's oceans. To lead these efforts, a Steering Committee was established with liaison to IRIS and JOI. The membership of the Steering Committee is:

A. D. Chave *, AT&T Bell Laboratories

G. M. Purdy, Woods Hole Oceanographic Institution

C. E. Helsley, University of Hawaii

J. A. Hildebrand, University of California, San Diego

A. Schultz, University of Washington

C. S. Cox, University of California, San Diego

*Chairman

To assist the Japanese initiative, the IRIS Executive Committee authorized $50K as seed money to support the organization, while the Steering Committee would raise its own funding. At this time, IRIS and ERI have jointly written to KDD and AT&T, formally requesting transfer of the Guam-Japan segment of TPC-1. Data from all Japanese-intalled seafloor instrumentation on the TPC-1 system will be available both to the U.S. and Japanese scientific communities. In particular, the seismometer sites will become part of both IRIS GSN and Japanese POSEIDON. To provide flexibility in the IRIS five-year authorization by the National Science Board, the IRIS budget slated $250K for TPC-1 Guam cable facilities as a vehicle for spending funds raised by the Steering Committee.

Reference: *Proceedings of a Workshop on Scientific Uses of Undersea Cables*, Conveners R. Butler and T. E. Pyle, Joint Oceanographic Institutions (in preparation, 1990).

Space Initiatives

IRIS GSN, with NASA personnel at Goddard Space Flight Center, has worked since 1987 to develope a telemetry uplink facility on the EOS satellites. These would be a series of instrumented orbital platforms for remotely sensing the Earth, the first of which is scheduled for launch in 1998. IRIS GSN promoted the needs of the seismological community for rapid access to seismic data, and argued that that uplink telemetry capabilities would be invaluable for various *in situ* measurements that NASA required. In doing so, it was able to establish a position on the spacecraft for a Wide Band Data Collection System (WBDCS). Subsequent to IRIS's actions, the NSF Polar Programs group has become involved with WBDCS for use in providing telemetry from its Antarctic facilities.

The system, as currently planned, will be able to send 32 Mbytes of data per day from 128 globally distributed sites. As the EOS platforms are in polar orbit, the ground stations will require small (1 m) tracking antennas. The data will be telemetered from EOS to a transfer geosynchronous satellite. It will then be sent to the EOS Data Information Service at Goddard in Maryland for data error correction and validation, and transferred directly to the IRIS Data Management Center. Although WBDCS has overcome all program hurdles at the time of writing this proposal, final acceptance of the system by NASA will be determined by October 1990. If plans go as proposed, NASA will design and develop the ground station and satellite functionality, handle the telemetry segments, and provide validated data to the IRIS DMC. IRIS and the National Science Foundation would be expected to build and deploy the ground stations.

A second area of IRIS cooperation with NASA is through a global geodetic network — *FLINN* (Fiducial Laboratories of Instrumentation for Natural sciences Network) — proposed by their Crustal Dynamics group. FLINN will consist of 200 globally distributed reference geodetic sites. The network will expand upon the current Very Long Baseline Interferometry and Satellite Laser Ranging sites, with more easily deployed Global Positioning Satellite instrumentation. IRIS GSN and NASA Crustal Dynamics representatives have met on several occasions to discuss the programs. Working together to co-locate many of the facilities is clearly beneficial, and a number of prospective sites have been identified. IRIS GSN has even suggested that the IRIS GSN program could deploy and maintain many of the new FLINN sites for NASA through its current global operations teams in Albuquerque and San Diego. Though no firm plans are yet in place, some area of cooperation will be established.

Five Year Plan — The Goal: An Installed 100 Station IRIS Network
(Reprise from the Opening of the Proposal)

A Global Seismographic Network is a major facility, like a telescope or a ship. The capital and installation costs are substantial, but when completed the operation and maintenance costs are much less. A Global Seismographic Network serves the broad scientific community — it is an international resource for seismologists of all nations. It is a facility which serves large and small Universities alike.

IRIS is committed to a global network of 128 design goal seismic stations that are uniformly located at about a 2000 km spacing. The U.S. scientific community cannot accomplish this alone, given the scarcity of resources for Earth science. To make thsese stretch while strengthening international ties, IRIS has coordinated its plans with those of other nations—in particular, France, China, Canada, Japan, and Germany — and with the U.S. Air Force GTSN program. Of 128 potential sites, about 20% can be covered by other networks, leaving about 100 to be covered by IRIS. A globally distributed, 128 network plan of continental and island sites was shown in *GSN Figure A*, which included siting by other national and international programs. The final network configuration will depend upon international negotiations and site surveys yet to be concluded, and upon attaining permanent ocean bottom stations, which may substitute for certain island coverage.

Withits planned 100 station coverage in mind, IRIS has tried to extend the scarce available resources through several means. IRIS has encouraged the financial participation of its member universities in establishing design goal GSN sites operated by the member institution. Supplementing the private Cecil and Ida Green Foundation instrumentation funds available to the UCSD IDA group, IRIS has striven for international GSN sites operated by UCSD as IRIS/IDA stations. Working with other national networks, IRIS has shared equipment and sites — an example being the Geoscope/IRIS site at KIP, Kipapa, Oahu.

IRIS has developed a detailed *Technical Plan for a New Global Seismographic Network* with the U.S. Geological Survey, which specifically formulates how the GSN will proceed This *Technical Plan* is attached as an Appendix. The implementation of the Technical Plan depends upon funding. With modest funding, IRIS will continue to make modest increments each year to the GSN. However, a rapid science return on the Network investment is ensured when the full 100 station network is deployed within five years. This is sought in this five-year authorization, since an accelerated program not only benefits the science; it is less expensive. By accelerating deployment, the GSN can take advantage of lower cost, bulk procurements, leading to greater standardization of the Network's hardware, with correspondingly lower long-term maintenance costs. Further efficiencies can be achieved by using site preparation and installation teams full-time without slack periods.

Network maintenance facilities for the GSN, co-located with the IRIS/USGS and IRIS/IDA Data Collection Centers in Albuquerque, New Mexico and La Jolla, California, respectively, are fully operational at this time, and are capable of growing to meet the needs of the Network. Maintenance is the key for the network's long-term viability. Providing for proper maintenance of the seismic stations after they are installed is as important as their deployment. The attached *Technical Plan* discusses maintenance issues in detail.

Expediency, and the need for better global coverage determines the schedule for station installation. In establishing the foundation network shown in *GSN Figure 9* during the past five years, IRIS has emphasized occupying and improving existing sites. During the development phase of its design goal station processor, IRIS elected to deploy state-of-the-art broad-band seismometers with available good data loggers, rather than waiting to deploy full design goal systems. The consequences of these actions — though good decisions — are twofold. As many of the "easier" sites have already been established, the cost per station for site preparation and installation will rise as more difficult, remote seismic stations are established. Among the existing stations of the foundation network, nearly two-thirds require additional data logger upgrades to bring them into design specifications. Furthermore, most sites do not yet have seismometers to record in a triggered mode either high-frequency seismic energy outside of the bandwidth of the Streckeisen seismometer, or strong-ground motion sensors in active earthquake areas.

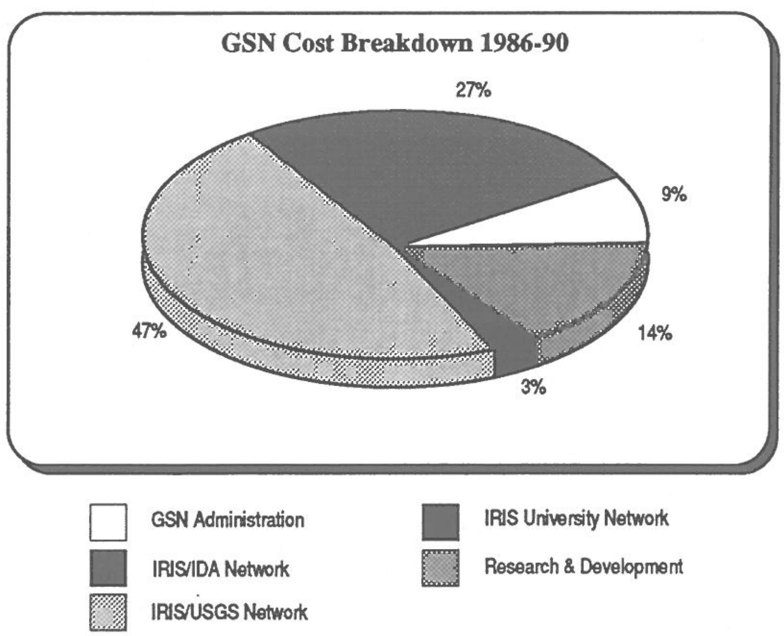
Succinctly stated, there is no reason, except funding, that restrains the U.S. Earth Science Community from having an installed, operational 100-station Global Seismographic Network within 5 years time. Starting nearly from scratch, the 150- station World Wide Standard Seismograph Network was installed over a similar time frame in the early 1960's. The science section of this proposal has made a strong plea for the kind of data that truly global, uniform coverage can provide. IRIS GSN has spent five years using modest funding to lay the best possible foundation for a bold and rapid network deployment. Design goal instrumentation has been developed, network deployment teams are trained and experienced, data collection facilities are in place, and network operation and maintenance centers are operational. The stage is set.

Cost Overview

GSN Budget Figure 1 shows the breakdown of GSN costs among the elements of its program from 1986 through 1990. Expenses for the IRIS/USGS element include seismometers and data logger equipment costs, site preparation and installation, and hardware for the Data Collection Center in Albuquerque—the USGS pays the salary of its permanent personnel. Costs for the IRIS/IDA element include site preparation and installation, personnel salaries, and Data Collection Center equipment—seismometers and data loggers are donated to the IDA group through the Cecil and Ida Green Foundation for the Earth Sciences. The IRIS/IDA element also includes the continuing support of the Project IDA (International Deployment of Accelerometers) Network of long-period gravimeters. IRIS University Network costs include supplemental funds to support GSN sites operated by IRIS member Universities, as well as support for the UCLA gravimeter station at the South Pole which is part of Project IDA. Research and Development includes the costs associated with the development of the GSN design goal station processor, development with PASSCAL of a 24-bit digitizer for the IRIS-3 data logger, a study conducted to determine the cost of drilling island boreholes, and a GOES satellite telemetry study. GSN administration costs include a full time GSN Manager — travel, shipping, communications, computer expenses — and travel support for the GSN Standing Committee. Integrating over *all* of the GSN costs during the first five years, the averaged gross cost per station over the installed base of 31 GSN stations (shown in *GSN Figure 9*) is approximately $250,000.

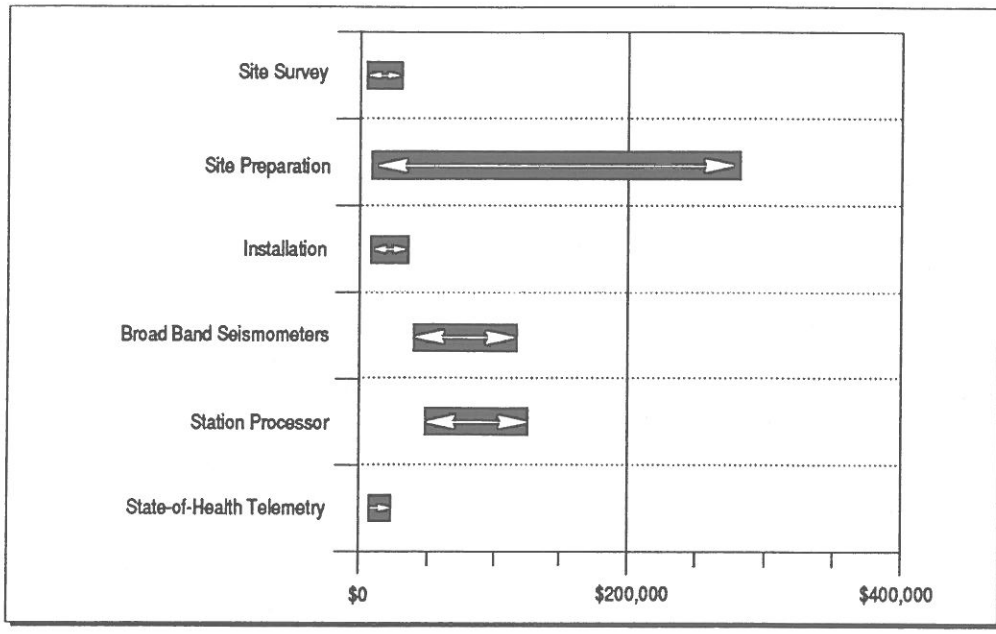
In establishing a seismic station, there are a variety of aspects — each with a range of costs depending upon the circumstances of the site. *GSN Budget Figure 2* illustrates these considerations, broken down by category. The relative costs for seismometers used in the GSN program are shown *GSN Budget Figure 3*, which also lists the number and type of sensors installed through 1990.

- Site surveys range from visiting an existing site to coordinate with the local host organizations prior to facility upgrade, to a full noise survey for determining the optimal locations for new installations.
- Site preparations include improving facilities at an existing borehole or vault, drilling a new borehole or building a seismic vault, necessary telemetry equipment at separated sites (radio frequency, optical fiber or land line, plus modems), and costs for acceptance testing data loggers and seismometers. Borehole drilling costs at remote sites can range from $125K to $250K, based upon (1) a study of drilling costs conducted for IRIS by New Zealand's Division of Science and Industrial Research (who



GSN Budget Figure 1. During the first five years of the IRIS Global Seismographic Network, nearly 80% of the available funds have been spent on seismic stations, and building the infrastructure of network maintenance and data collection centers. Operations of the GSN are directed through three programs: the partnership with the U.S. Geological Survey; the IRIS/IDA group at the University of California at San Diego; and the University Network within the United States. R & D funds have been principally used in developing the design goal IRIS station processor. GSN administration costs include supporting travel expenses of the GSN Standing Committee, as well as those of the full time GSN Program Manager.

GSN Station Costs



GSN Budget Figure 2. Each aspect in establishing of a seismic station involves a range of costs. Initial costs depend upon whether a new station is being sited, or if an existing site is being upgraded. For new sites, the costs depend mainly on the remoteness of the location, and the need for drilling a borehole.Borehole seismometers are crucial for at relatively noisy sites, but can cost nearly a factor of three greater than comparable vault sensors. Deep inactive mine locations are preferable to borehole sites, if the mine is dry. Initial station processor costs, high during development, will decrease with continuing production.

have conducted drilling for seismology on islands and in Antarctica), (2) the costs for the new borehole sites in the Air Force GTSN program.

- Installation includes the travel and personnel costs of the installation team, as well as shipping and station supplies.
- Broad band seismometers are needed at every site — either a vault or a borehole sensor. Some existing borehole sensors can be upgraded to a broadband response.
- Station Processors include the cost of a design goal data logger, or the costs of upgrading existing equipment to design goal standards.
- State-of-health telemetry is needed at sites without dial-up access capabilities.
- Other costs not noted in the *GSN Budget Figure 2* include satellite clocks based upon GPS technology (Global Positioning Satellites), which is replacing the current network of Omega clocks. To augment the continuously recorded broad band sensor, most sites record additional high-frequency or strong-ground-motion sensors on triggered channels.

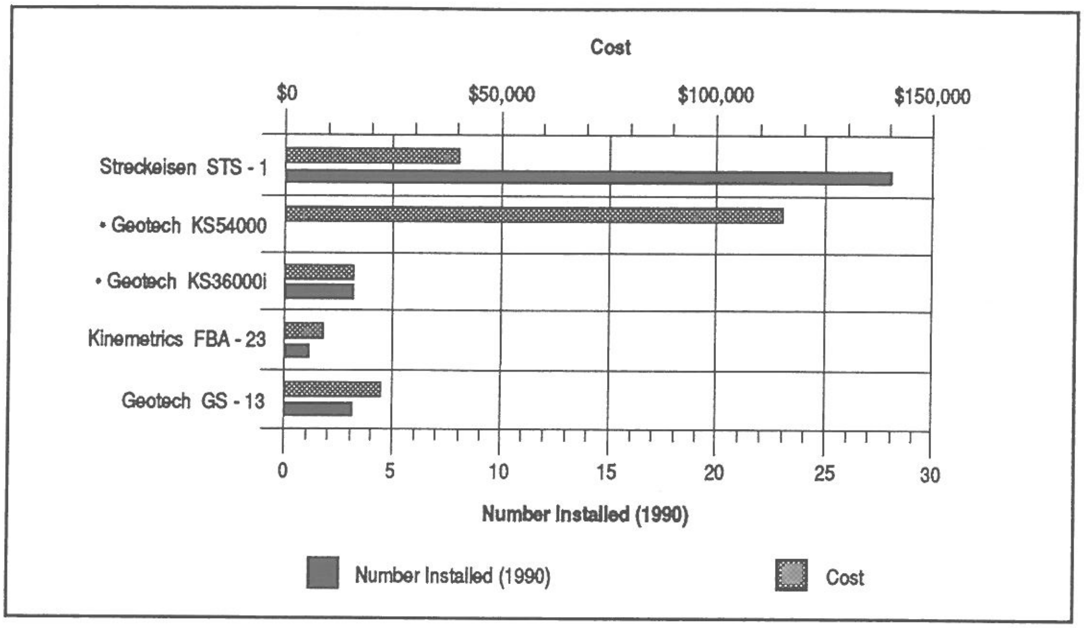
Cost Detail — Budget for a 100 Station GSN

GSN Budget Table 1 outlines the costs for completing a 100 station GSN in five years. The expenditures include: (1) the costs for upgrading the existing base of 31 stations to full design goal standards; (2) the costs for establishing 45 additional sites selected in the Technical Plan based on good coverage and logistics; (3) 24 undesignated new vault and borehole sites which require additional site survey work before they can be specified with certainty. These twenty-four additional sites will all be in remote, difficult locations so that gaps in the global coverage can be filled. They will be specified by site survey crews by the middle of the second year. The costs for the 24 undesignated sites are extrapolated on the basis of logistics experience, assuming a mix of one-third new vaults and two-thirds new boreholes. *GSN Budget Figure 4* plots these integrated costs by category.

GSN Budget Table 2 presents the detailed equipment and logistics requirements for the 100 station GSN costed in *GSN Budget Table 1.* The attached *Legend* annotates the specific entries in *GSN Budget Table 2.*

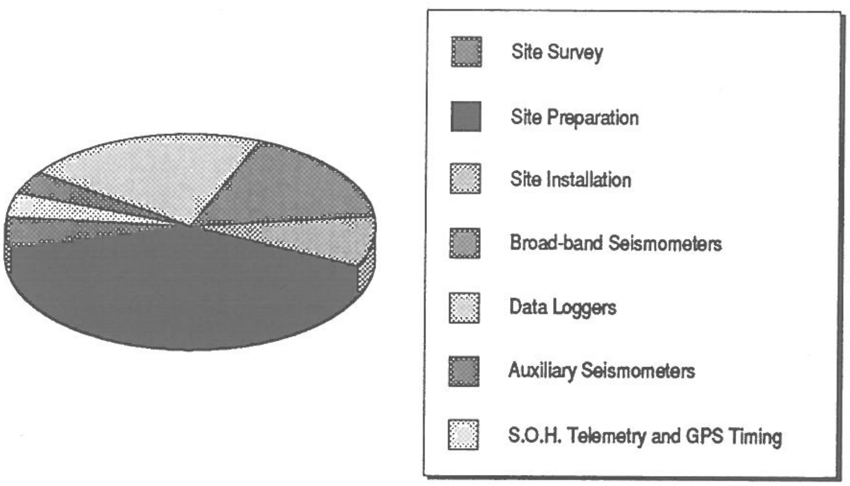
The budget rationale for the GSN's operations and maintenance is given detailed discussion in the *Technical Plan for a New Global Seismographic Network*, and is based upon over twenty-years experience in operating seismic networks by the USGS and the academic community. Costs are twofold, and are presented in *GSN Budget Table 3.* A spare parts inventory must be developed by equipping the Network Maintenance facilities while the stations are being installed. Experience has shown that the inventory needed is about 10% of the capital equipment costs. Yearly maintenance costs are illustrated by the requirements for a 60 station network. For smaller networks, there is some overlap in the key personnel's responsibilities.

Seismometers



GSN Budget Figure 3. The IRIS Global Seismographic Network has set up a substantial base of modern seismic instrumentation since 1986. The Streckeisen STS-1 is the state-of-the-art seismometer of choice for all installations in vaults. Borehole sensors (•) are necessary at noisy locations where there is no recourse to a deep mine vault. To date, IRIS has emphasized modifying the sensors at existing SRO sites (modification costs are noted for the KS36000i, which is no longer manufactured) to a response close to the KS54000, which is the current broad-band standard in this arena. No KS54000 sensors, currently used in the Air Force GTSN program, have yet been purchased by IRIS. The FBA-23 is a strong ground motion instrument in operation at the Pasadena, California site. GS-13 seismometers are used at three sites to extend the seismic frequency band beyond the high-frequency capabilities of the STS-1.

Completion Costs for 100 Station Network



GSN Budget Figure 4. Summary chart of information from GSN Budget Table 1. Wedges reflect relative total costs in each category for completion of a 100 station Global Seismographic Network starting in 1991. Costs do not include operations and maintenance after installation.

Other GSN costs include management, and programmatic research and development. *GSN Budget Table 4* presents the cost breakdown for the GSN's management by IRIS. Travel costs for both the staff and the GSN Standing Committee are included. R&D costs are budgeted at $100K/year in 1991 dollars. These funds are crucial for advancing critical technology for the GSN. Uses will include improvements in seismometer design and borehole technology, telemetry studies and experimentation, site noise reduction studies, and data logger improvements.

Summary Budget

The summary budget presents the costs for establishing a 100 station GSN within five years. The budget assumes that new GSN stations will be installed at a uniform rate — with a mix of existing and new sites — while at the same time revisiting and upgrading the foundation network to design goals. In calculating the five-year budget, a 4% rate of inflation is assumed for the second through fifth years.

GSN Budget Table 1 — Cost Detail for 100 station GSN (in $K)

	Seismic Station	Site Survey	Site Preparation	Site Installation	Broad-band Seismometers	Data Logger	Auxiliary Seismometers	S.O.H. Telemetry and GPS Timing	Total
1	Adak, Alaska	25	151	35	115	95	15	20	456
2	Adelaide, Australia			7		15	15	5	42
3	Afiamalu, W. Samoa			7			20	20	47
4	Akureyri, Iceland	25	151	35	115	95	15	5	441
5	Albuquerque, NM								
6	Alert, Canada			7		15	15	20	57
7	Ankara, Turkey	5	26	35	15		15	5	101
8	Arti, USSR			7		15		20	42
9	Ascension Island	25	276	35	115	50	15	20	536
10	Bermuda	25	151	35	115	95	20	5	446
11	Bogota, Columbia	5	26	35	15	95	15	20	211
12	Brasilia, Brazil			7		15	15	5	42
13	Caico, Brazil	25	276	35	115	95	20	20	586
14	Canary Islands, Spain	25	101	35	42	95	20	20	338
15	Caracas, Venezuela	5	46	35	42	95	20	5	248
16	Cathedral Caves, Missouri			7		95			102
17	Charters Towers, Australia			7			20	5	32
18	Chiangmai, Thailand	5	26	35	15	95	20	20	216
19	Christmas Island	25	276	35	115	95	20	20	586
20	College, Alaska			7			20	5	32
21	Corvallis, Oregon			7		95	15		117
22	Diego Garcia, Indian Ocean	25	151	35	115	50	15	20	411
23	Durango, Mexico	25	101	35	42	50	10	20	283
24	Easter Island, Chile			7		15	15	20	57
25	Erimo, Japan			7		15	10	5	37
26	Eskdalemuir, Scotland			7		15	15	5	42
27	Falkland Islands	25	151	35	115	50	15	20	411
28	Fiji	25	101	35	42	50	10	5	268
29	Flin Flon, Canada			7		15	15	5	42
30	Frunze, USSR			7		15		20	42
31	Galapagos Island, Ecuador	25	276	35	115	95	20	20	586
32	Garm, USSR			7		15		20	42
33	Garni, USSR							20	20
34	Godhavn, Greenland	5	46	35	42	95	20	20	263

GSN Budget Table 1 — Cost Detail for 100 station GSN (in $K)

35	Guam, Marianas Islands		5	26	35	15	95	15	5	196
36	Harvard, MA									
37	Hawaii Island		25	101	35	42	50	10	5	268
38	Honiara, Solomon Islands		25	276	35	115	95	15	20	581
39	Irkutsk, USSR				7		15		20	42
40	Kevo, Finland			46	35		95	20	5	201
41	Khartoum, Sudan		25	276	35	115	95	20	20	586
42	Kingsbay, Spitzbergen Is.		25	101	35	42	95	20	20	338
43	Kipapa, Hawaii				7				5	12
44	Kislovodsk, USSR				7		15		20	42
45	Kodaikanal, India		5	46	35	42	95	20	20	263
46	Kodiak Island		25	276	35	115	50	10	20	531
47	Kongsberg, Norway		5	21	35			20	5	86
48	Kwajalein Island		25	276	35	115	50	15	20	536
49	Lembang, Indonesia		5	46	35	42	95	15	20	258
50	Marquesas		25	276	35	115	50	15	20	536
51	Matsushiro, Japan				7		95	15	5	122
52	Mawson, Antarctica		25	101	35	42	50	15	20	288
53	Middle East		25	151	35	115	95	20	20	461
54	Midway Island		25	276	35	115	50	15	5	521
55	Nairobi, Kenya		25	276	35	115	95	15	20	581
56	Naña, Peru				7		15	10	20	52
57	Narrogin, Australia				7			20	5	32
58	New Delhi, India		25	151	35	115	95	15	20	456
59	New Site, Australia		25	151	35	115	95	20	5	446
60	Obninsk, USSR				7		15		20	42
61	Palmer Station, Antarctica		5	21	35	42	95	20	20	238
62	Pasadena, California									
63	Peldehue, Chile		5	21	35		95	15	20	191
64	Philippines		5	46	35	42	95	15	20	258
65	Piñon Flat, California						15			15
66	Ponta Delgada, Azores		25	151	35	115	95	15	20	456
67	Quetta, Pakistan		5	46	35	42	95	15	20	258
68	Rarotonga, Cook Islands		25	276	35	115	95	20	20	586
69	San Juan, Puerto Rico			46	35	42	95	15	5	238
70	Seychelles		25	276	35	115	50	15	20	536

GSN Budget Table 1 — Cost Detail for 100 station GSN (in $K)

71	South Karori, New Zealand			7			15	5	27
72	South Pole, Antarctica			7			20	20	47
73	Sutherland, South Africa			7		15	15	20	57
74	Taipei, Taiwan	5	26	35	15	95	15	5	196
75	Toledo, Spain	5	46	35		95	20	5	206
76	Wake Island	25	276	35	115	50	15	5	521
77-92	16 Undesignated Borehole Sites	25	276	35	115	95	20	20	586
93-10	8 Undesignated Vault Sites	25	101	35	42	95	20	20	338
	100 Station Totals ($K)	$1,400	$11,660	$2,625	$5,484	$6,400	$1,510	$1,490	$30,569

GSN Budget Table 2.
Site Requirements for 1991+

	Seismic Station	Site Survey	Site Preparation	Site Installation	Broad-band Seismometers	Data Logger	Auxiliary Seismometers	S.O.H. Telemetry and GPS Timing
1	Adak, Alaska	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	StdC+GPS
2	Adelaide, Australia			Reinstall		IRIS3mod	HFseismo	GPS
3	Afiamalu, W. Samoa			Reinstall			LRDCU+HFseismo	StdC+GPS
4	Akureyri, Iceland	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	GPS
5	Albuquerque, NM							
6	Alert, Canada			Reinstall		IRIS3mod	HFseismo	StdC+GPS
7	Ankara, Turkey	Visit •	SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	SROmod		LRDCU+LGseismo	GPS
8	Arti, USSR			Reinstall		IRIS3mod		StdC+GPS
9	Ascension Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
10	Bermuda	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	GPS
11	Bogota, Columbia	Visit	SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	SROmod	IRIS2	LRDCU+LGseismo	StdC+GPS
12	Brasilia, Brazil			Reinstall		IRIS3mod	HFseismo	GPS
13	Caico, Brazil	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
14	Canary Islands, Spain	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
15	Caracas, Venezuela	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	GPS
16	Cathedral Caves, Missouri				Reinstall	IRIS2		
17	Charters Towers, Australia				Reinstall		LRDCU+HFseismo	GPS
18	Chiangmai, Thailand	Visit	SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	SROmod	IRIS2	LRDCU+HFseismo	StdC+GPS
19	Christmas Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
20	College, Alaska			Reinstall			LRDCU+HFseismo	GPS
21	Corvallis, Oregon			Reinstall		IRIS2	LRDCU+LGseismo	
22	Diego Garcia, Indian Ocean	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
23	Durango, Mexico	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS3	LGseismo	StdC+GPS
24	Easter Island, Chile			Reinstall		IRIS3mod	HFseismo	StdC+GPS
25	Erimo, Japan			Reinstall		IRIS3mod	LGseismo	GPS
26	Eskdalemuir, Scotland			Reinstall		IRIS3mod	HFseismo	GPS
27	Falkland Islands	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
28	Fiji	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS3	LGseismo	GPS
29	Flin Flon, Canada			Reinstall		IRIS3mod	HFseismo	GPS
30	Frunze, USSR			Reinstall		IRIS3mod		StdC+GPS
31	Galapagos Island, Ecuador	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
32	Garm, USSR			Reinstall		IRIS3mod		StdC+GPS
33	Garni, USSR							StdC+GPS
34	Godhavn, Greenland	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
35	Guam, Marianas Islands	Visit	SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	SROmod	IRIS2	LRDCU+LGseismo	GPS
36	Harvard, MA							
37	Hawaii Island	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS3	LGseismo	GPS
38	Honiara, Solomon Islands	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	StdC+GPS
39	Irkutsk, USSR			Reinstall		IRIS3mod		StdC+GPS
40	Kevo, Finland		ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies		IRIS2	LRDCU+HFseismo	GPS
41	Khartoum, Sudan	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
42	Kingsbay, Spitzbergen Is.	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
43	Kipapa, Hawaii			Reinstall				GPS
44	Kislovodsk, USSR			Reinstall		IRIS3mod		StdC+GPS
45	Kodaikanal, India	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
46	Kodiak Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	LGseismo	StdC+GPS
47	Kongsberg, Norway	Visit	SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies			LRDCU+HFseismo	GPS
48	Kwajalein Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
49	Lembang, Indonesia	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+LGseismo	StdC+GPS
50	Marquesas	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
51	Matsushiro, Japan			Reinstall		IRIS2	LRDCU+LGseismo	GPS
52	Mawson, Antarctica	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS3	HFseismo	StdC+GPS
53	Middle East	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
54	Midway Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	GPS

GSN Budget Table 2 (cont.).

55	Nairobi, Kenya	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	StdC+GPS
56	Naña, Peru			Reinstall		IRIS3mod	LGseismo	StdC+GPS
57	Narrogin, Australia			Reinstall			LRDCU+HFseismo	GPS
58	New Delhi, India	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	StdC+GPS
59	New Site, Australia	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	GPS
60	Obninsk, USSR			Reinstall		IRIS3mod		StdC+GPS
61	Palmer Station, Antarctica	Visit	SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
62	Pasadena, California							
63	Peldehue, Chile	Visit	SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies		IRIS2	LRDCU+LGseismo	StdC+GPS
64	Philippines	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+LGseismo	StdC+GPS
65	Piñon Flat, California					IRIS3mod		
66	Ponta Delgada, Azores	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	StdC+GPS
67	Quetta, Pakistan	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+LGseismo	StdC+GPS
68	Rarotonga, Cook Islands	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
69	San Juan, Puerto Rico		ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+LGseismo	GPS
70	Seychelles	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
71	South Karori, New Zealand			Reinstall			LRDCU+LGseismo	GPS
72	South Pole, Antarctica			Reinstall			LRDCU+HFseismo	StdC+GPS
73	Sutherland, South Africa			Reinstall		IRIS3mod	HFseismo	StdC+GPS
74	Taipei, Taiwan	Visit	SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	SROmod	IRIS2	LRDCU+LGseismo	GPS
75	Toledo, Spain	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies		IRIS2	LRDCU+HFseismo	GPS
76	Wake Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	GPS
77	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
78	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
79	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
80	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
81	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
82	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
83	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
84	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
85	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
86	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
87	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
88	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
89	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
90	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
91	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
92	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
93	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
94	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
95	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
96	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
97	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
98	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
99	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
100	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS

GSN Budget Table 2

Legend

Catagory	Entry	Cost ($K)	Note
Site Survey			
	NewSurvey	25	New site survey
	Visit	5	Site visit
Site Preparation			
	NewBorehole1	125	New borehole at site with services
	NewBorehole2	250	New borehole at difficult site
	ExistBorehole	3	Re-use of existing borehole
	NewVault	80	Prepare new seismic vault
	ExistVault	25	Refurbish existing seismic vault
	SiteTelemetry	16	Site telemetry between seismometers recording facility
	LoggerTest	5	Acceptance test for data logger
	SeismoTest	5	Acceptance test for seismometer
Site Installation			
	NewInstall	25	New equipment installation
	ReInstall	7	Revisit site to install additional equipment
	StaSupplies	5	Station supplies
	Shipping	5	Shipping costs
Broad-band Seismometers			
	STS1Seismo	42	Streckeisen STS-1
	BoreholeSeismo	115	Geotech KS54000
	SROmod	15	Broadband modification cost for existing KS36000
Data Logger			
	IRIS2	95	IRIS-2 station processor
	IRIS3	50	IRIS-3 station processor
	IRIS3mod	15	Upgrade existing IRIS-3 with 24 bit digitizer
Auxiliary Seismometers			
	LRDCU	5	Additional 16-bit digitizer/calibrator channels
	HFseismo	15	High-frequency seismometers
	LGseismo	10	Low-gain seismometers for strong ground motion
State-of-Health Telemetry and GPS Timing			
	StdC	15	Comsat Standard C system or equivalent
	PolarTelem	15	Polar telemetry via ATS satellite
	GPS	5	Global Positioning System clock

GSN Budget Table 3

Network Maintenance

Spare Parts Depot Inventory: 10% of Installed Hardware Cost		
Yearly Recurring Costs for 60 Station Network	$K/year	$K/year/station
Network Maintenance Team Leader	63	1.0
Field Engineers (6)	315	5.3
Bench Technicians (5)	250	4.2
Engineering (shop) Technician (1)	50	0.8
Supply/Shipping Clerk (1)	35	0.6
Clerk/Typist (1)	30	0.5
Supplies & Parts	90	1.5
Factory Repair	60	1.0
Travel Expenses	420	7.0
Communications	60	1.0
Shipping	60	1.0
Component Replacement	180	3.0
Yearly Totals	$1,613	$27 K/Station

GSN Budget Table 4

GSN Management

Salaries	78
Fringe Benefits	20
Domestic Travel	30
Foreign Travel	15
Materials and services	10
Publications	5
Consultant Services	5
Computer & Communications	13
Total Management ($K)	$175

GSN Budget Table 5

GSN Five-Year (1991-95) Costs for 100 Station Network Installation

Costs in $K	1991	1992	1993	1994	1995	1996
GSN Management	175.0	182.0	189.3	196.9	204.7	212.9
Programmatic R&D	100.0	104.0	108.2	112.5	117.0	121.7
Spare Parts Depot Inventory	302.0	314.1	326.6	339.7	328.1	0.0
Operation and Maintenance	1021.3	1453.4	1918.5	2418.5	2939.6	3269.8
Site Works & Installation	3182.5	3309.8	3442.2	3579.8	3457.1	0.0
Seismometers & Data Loggers	3019.9	3140.7	3266.4	3397.0	3280.6	0.0
Yearly Totals ($K)	7800.7	8504.0	9251.1	10044.4	10327.1	3604.3

Five Year Total — $45,927K

II. Status and Program Plan: The Program for Array Studies (PASSCAL)

Overview

The PASSCAL Program started operation in late 1985. The Program Plan for the first five years consisted of three major elements:

1. The development of a new type of portable recording instrument, and the selection of sensors, support equipment, and field computers.
2. The transition to operational status for PASSCAL. The initial purchase of large numbers of the new instruments, and the establishment of facilities for maintenance and field support.
3. Project support for "interim" large scale field experiments, aimed at developing field experience in array techniques during the period of instrument development.

The instrumentation schedule drawn in the Spring of 1986 called for the development program to take place in 1986 and 1987 with prototype instruments delivered in early 1988. The prototype instruments were to be tested and the first production instruments were to be delivered in 1989. Even though our funding levels have not been as high as anticipated at that time, we have met all of these goals. The first full-scale experiments utilizing PASSCAL Instruments were successfully completed in the late Summer and Fall of 1989.

Between August 1989 and June 1990, the first 90 production models of the RefTek 6-channel data logger were delivered. The first Instrument Center, established at Lamont-Doherty Geological Observatory, is now in active operational support of field experiments.

PASSCAL supported six major scientific experiments during the period from 1986-1990. Twenty-six IRIS member institutions participated in one or more of these experiments. These experiments have added significantly to the knowledge of the Earth's crust and upper mantle in several areas of the U S. They included a broad spectrum of different experimental designs, thus developing a base of experience about the practical aspects of the new generation of portable array studies. The 1986 experiments in the Ouachita Mountains and in the Basin and Range used available older equipment, while the 1988-90 experiments have made use of prototypes and early production models of the new PASSCAL instrument.

A 1988 funding reorganization at the National Science Foundation placed responsibility for selecting and funding large field experiments with the Continental Lithosphere (now Continental Dynamics) Program at NSF. This step clarified the IRIS mission as one of facility development and support.

Instrumentation

The PASSCAL program plan as outlined in the 1984 proposal called for the acquisition of a 1000 element portable seismic array. This array would permit the nearly continuous spatial sampling of seismic wavefields on a geologically useful scale. At the time we started in 1985 no available instrumentation could meet the need for flexible, large, mobile arrays. Therefore, it was necessary for PASSCAL to participate in the development of a new generation of portable seismic recording equipment.

Development of the PASSCAL Data Logger: Early leadership on the need for a new generation of data logger was provided through a series of community-wide workshops and meetings in 1983 and 1984 (see references to Section 1). Upon the organization of IRIS, a PASSCAL Instrumentation Committee, led by Selwyn Sacks, Bob Meyer, and Bill Prothero, held a number of meetings to develop the specifications for the new instruments.

The PBI Program: NSF provided initial funding to the Carnegie Institution in 1985 to start the PASSCAL program. In response to an unsolicited proposal from the instrumentation group at UCLA, support was provided for the development of a low power communication bus design which would meet the requirements that the new instrument be nonproprietary and flexibly configured and programmed.

This bus structure would allow for a modular instrument which could be easily modified and upgraded. This would greatly extend the life of the instrument and would make it possible to adapt the instrument to experiments which could not be envisioned at the time the instrument was developed. The development of the PASSCAL Bus began in late 1985. A demonstration of a simulated seismic instrument utilizing the bus was conducted at UCLA in early September, 1986. During this demonstration the bus operated at about 30% capacity while handling three data channels sampled at an aggregate rate of 1920 samples/second. The power level even in the demonstration hardware was well below one watt and the power drawn by the bus was proportional to the bus utilization.

Most of the run-time capabilities of the bus were implemented in the demonstration. The bus demonstration showed that the bus could function in a seismic instrument, and would meet all of the goals of the development program. It was concluded, however, that the long lead time required to turn this concept into a product might easily become unacceptable, and that the Request for Proposal should not mandate the PBI technology.

The PASSCAL Instrument: A Request for Proposals for the development of the PASSCAL Instrument was issued on October 10, 1986. The manufacturers were encouraged to examine the work which was done on the PASSCAL Bus and to design the most cost effective instrument which would meet the goals of the program. Upon the recommendation of the evaluation panel, a contract was issued in March 1987, to Refraction Technology, Inc. of Dallas for the delivery of 5 prototype instruments in the spring of 1988.

The PASSCAL Instrument as delivered by Ref Tek represents a significant improvement in portable seismic instrument technology. While the instrument does not utilize the PASSCAL Bus, it utilizes a similar architecture and incorporates many of the ideas of modularity first examined during the PASSCAL Bus Program. The PASSCAL instrument is extremely versatile; it can record every thing from conventional seismic reflection profiles to long-term broadband deployments in support of the Global Seismic Network. The instrument, the auxiliary recording system and the field computer were designed to enable a small group of researchers to support a large number of instruments in the field at one time.

The PASSCAL Instrument consists of four major subsystems (Figure 1, Table 1).

The *Data Acquisition Subsystem* (DAS) is the basic recording unit. It takes the signals from up to six sensors and digitizes the signal, performs event detection when necessary and stores the data in an internal 4 Mbyte memory or to an attached SCSI disk system which can retain up to 190 MBytes of data.

The *Time Keeping Subsystem* provides an external clock signal which synchronizes data samples to a common time base. The specifications for the timing system call for an array of recorders to be synchronized relative to one another to within 1 ms. The absolute time accuracy is to be within 10 ms of Universal Time. A GOES receiver and two types of Omega receivers have been tested and the production units currently utilize an Omega timing system which is housed inside the Data Acquisition System. Problems have arisen with the ability of the Omega system to perform at the level of reliability required (due to problems with signal acquistion), and it is likely that a switch to GPS technology will take place.

The *Tape Recorder Subsystem* (TRS) is currently a portable tape unit which is carried to the field to collect data from multiple DAS units, thus permitting them to remain installed in the field. The TRS utilizes a helical scan tape unit which can store 2000 Mbytes of data on

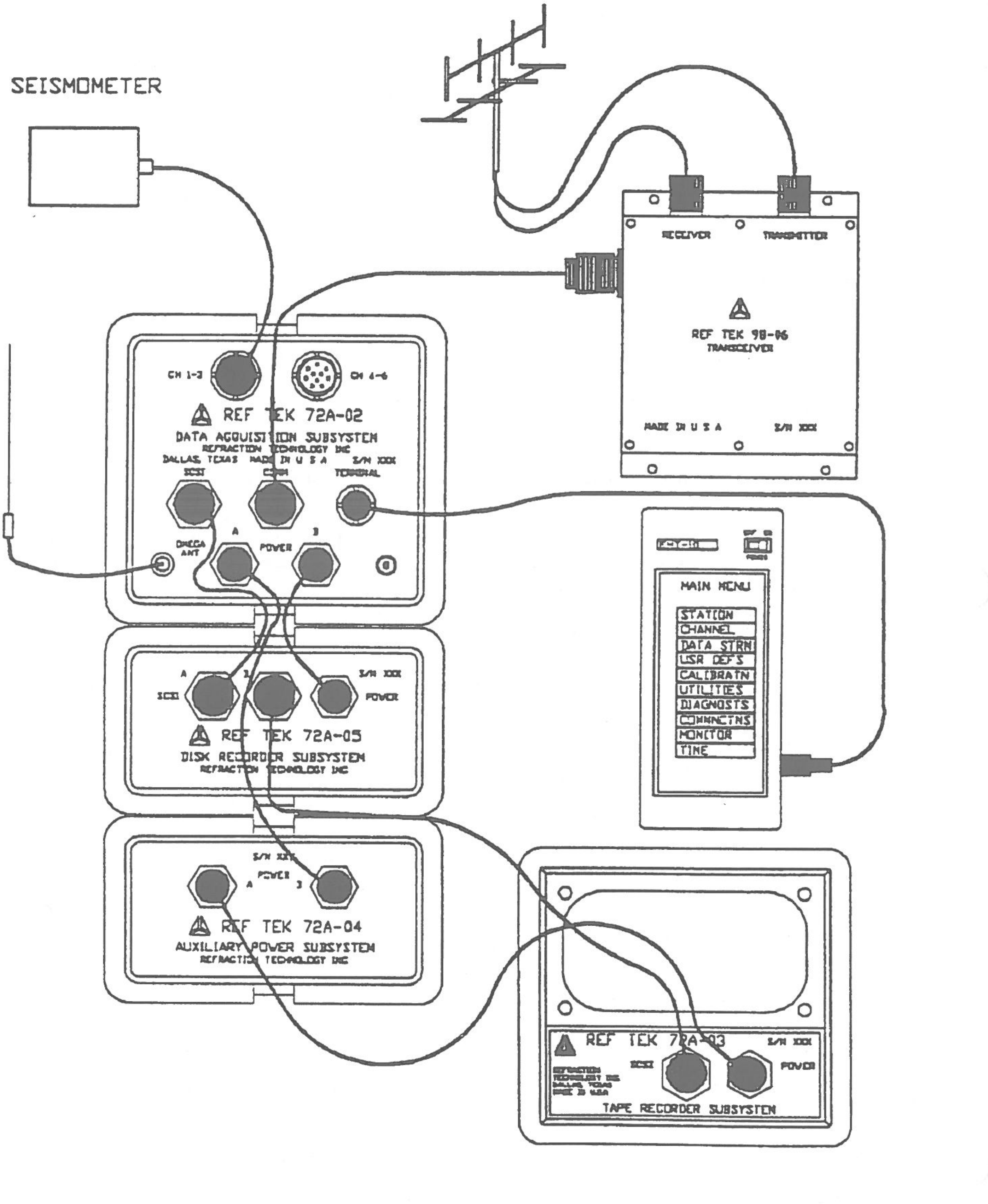


Figure 1 Block Diagram (1:4) of major Passcal system components

Table 1 **PASSCAL Instrument Specifications**

Physical:		
	Size:	12 3/4" D X 8 1/4" W X 7 3/4" H
	Weight:	14 1/2 lbs for logger - 39 lbs total including disk and battery
	Temperature Range:	-40 to +60 degrees C
Power Analog:		2 watts at 10 -15 volts DC
	Number of Channels:	6
	Input Impedance:	2 MOhms with 0.2 microfarad capacitance
	Common Mode Rejection:	Greater than 60 dB
	Alias Filter:	250 Hz 36 dB/octave Butterworth response
	Preamp Gain Ranges:	0 dB to 78 dB in seven steps
	Full Scale Input:	7.5 volts peak to peak
Digital:		
	ADC Type:	16 bit Crystal Semiconductor CS5016BD
	Sample Rate:	1000 samples per second
	Digital Signal Processor:	Analog Devices ADSP 2100 used to obtain sample rates from 1 to 500 samples per second.
	Output Bandwidth:	All sample rates below 1000 sps have band width of 80% Nyquist.
Communications:		
	Serial Ports:	Three RS-232 serial ports for timing, data and command communications
	Parallel Port:	SCSI port ANSI standard 3T9.2 for data upload
Storage:		
	Memory:	2.5 Mbytes memory expandable to 4.5 Mbytes
	Disk:	WREN V
	Disk:	WREN V disk with 190 Mbytes of storage
Timing:		Kinemetrics/Truetime OM-PCB 254 Omega timing receiver is standard

a tape. By utilizing the SCSI port available in the TRS, it is possible to change to new mass storage units as technology improves.

A *Disk Recording Subsystem* provides the capability to record large amounts of data in the field. This system is a SCSI disk which can hold up to 190 MBytes of data. The data are dumped to the tape unit during the servicing of the instrument.

The *Auxiliary Power Subsystem* is the battery which provides for several days operation in the field. This system can be supplemented by additional batteries or solar cells for longer term operation

The final part of the system is the *Field Set-Up Terminal*. This is a small hand-held terminal which is carried to the field and used by the operator to communicate with both the DAS and the TRS. The operator can down-load all of the set-up parameters, run self-checks and calibrations, and modify instrument performance through this unit. It can be used to display data, check geophone installation, and check general system performance. Two different types of terminals are available, the Epson Terminal, a small, light weight unit which can easily be used in rugged terrain, and a laptop PC.

The DAS has six input channels. If channels 4-6 are not being used, the supply voltage to the analog section of these channels is turned off to save power. Each of the six channels is sampled with 16 bit resolution at a rate of 1000 samples per second. The signals are then passed to the Digital Signal Processor where they are filtered and decimated to the final output sample rates for the various data streams. The Digital Signal Processor operates with 32 bits of resolution; by filtering and decimating it is possible to have more than 16 bits of resolution at the lower sample rates.

The concept of the *Data Stream* is unique to this instrument. The instrument can handle up to eight data streams. Each data stream consists of from one to six input channels sampled at a given sample rate and activated by a specified trigger. As an example, Data Stream 1 could consist of channels 1-3 sampled at 200 samples per second with an event trigger designed for local events. Data Stream 2 could consist of channels 1-3 sampled at 20 samples per second with an event trigger designed for teleseismic events. Data Stream 3 could be channel 1 recorded continuously at one sample per second. There is no restriction on which input channels can be connected to a given data stream. All channels in the stream will have a common sample rate in that data stream. There are several different triggers which can be used to activate a data stream. These are:

- Event trigger,
- Radio or External trigger,
- Timed trigger,
- Continuous trigger, and
- Cross trigger.

The cross trigger allows one data stream to be triggered by the activation of a trigger on another stream. With this concept, each data stream is like a separate instrument in the field. It is possible to conduct multiple experiments within a single instrument. Another feature of this unit is in the fact that sampling may be synchronized to an external clock. In the past, when an external clock was present it was recorded on an auxiliary data channel, and any timing corrections were made during post-processing. Because this correction is a labor intensive task, it was not always done. The PASSCAL instrument is synchronized to the clock. Each sample is time tagged with the correct time as it is taken. Thus all of the data have the correct time as they are read into the field computer. This type of system is a necessity if many instruments are to be deployed at a single time.

The PASSCAL Instrument is designed with a Small Computer System Interface (SCSI) port as standard feature. This port gives the instrument the capability to be used in many different types of environments. The port acts as the standard upload port for data to be transferred from memory to the ARS. The speed of this transfer is extremely fast: a typical upload of 4.5 Mbytes to the tape recorder takes about 2 minutes. The port also allows auxiliary SCSI recording devices to be installed with the data acquisition system. The standard disk system gives the unit about 190 Mbytes of storage. This allows service intervals as long as two to four weeks. The disk is powered only when it is being written to, so that the overall increase in power necessary to operate is minimal. The data can be uploaded to the tape unit by execution of a SCSI copy command. This can take place quickly without the need of CPU intervention of the recording system.

The SCSI port allows the PASSCAL instrument to utilize any mass storage system that has a SCSI port. Currently this includes magnetic and optical disks as well as several different tape units. The major market for this technology is the PC industry so that developments are rapid and we can take advantage of the cheaper pricing of this market. The PASSCAL instrument is not tied to any one kind of mass storage medium. Currently none of the mass storage units are specified to operate below freezing; therefore, if the units are to be deployed in freezing conditions it is necessary to use the solid state memory as the recording medium.

Two additional features of the system are important. First, all non-data related happenings including operator communications are logged in a State of Health channel with the data. This State of Health channel is uploaded with the data and provides a record of what went on in the instrument. Second, all communications between the Field Set-Up Terminal, including uploading of the data, can be accomplished without stopping data acquisition. This allows the operator to check instruments and look at event directories without interfering with the data gathering activities of the instrument.

The first five prototype instruments were delivered in Spring of 1988. Five additional units were delivered in August of 1988. These units were first field tested by the University of California at Santa Barbara at sites near Parkfield, California. The initial plans called for testing these instruments for about a year before they were to be used in actual field experiments. However, the problems encountered during the initial stages of the Nevada Teleseismic experiment made it necessary to commit the prototype instruments to that experiment. Testing and development of the various parts of the system continued throughout the deployment in Nevada.

An order for the first production run of 35 instruments was placed in December, 1988. The production instruments differed from the prototype instruments in that a new multi-wire circuit board was used which allowed the instruments to be 30% smaller than the originals, and plastic cases reduced the weight from 45 lbs to 25 lbs. The production units were delivered in August 1989, and were immediately utilized in the Greenland experiment and then the Loma Prieta aftershock experiment. 45 additional instruments have been delivered in 1990.

The PASSCAL Simple Instrument: Very early in the PASSCAL Program, it was realized that the PASSCAL Instrument would be a relatively expensive instrument. Even though it is extremely versatile and capable, there are certain types of experiments where it is more important to have large numbers of sensors on the ground than it is to have maximum flexibility. For example, these experiments would probably involve the use of explosive sources with instruments located up to a couple of hundred kilometers from the source. Instrument spacing would be anywhere from a hundred meters to several kilometers.

We have sought an available cheaper instrument which could satisfy this need. A special committee met in December, 1989 to agree on specifications and to examine the existing instrumentation to see if any met our needs. The committee agreed that there was currently no such instrument, although several existing instruments could probably be modified to come close to our needs. In order to try to get bids from interested manufacturers, PASSCAL issued an RFP for five prototype simple instruments which would meet the specifications given below:

- Three channels of analog input capable of accepting standard exploration seismometers with resonant frequencies ranging from 2 to 20 Hz
- Twelve or sixteen bit gain ranged A/D converter with at least 60 dB and preferably 90 dB of gain ranging
- Optional preamplifiers which are operator selectable with ranges which bring the overall system gain to 120 dB
- Sample rates and alias filters for sample rates ranging from 2 to 16 ms per channel: (A sample interval of 1ms is desirable but not necessary)
- Timing system which can easily be corrected to better than 10 msec during post processing
- Minimum of one MByte of storage capability expandable to at least 4 Mbytes;
- Capable of multiple timed turn-ons or external triggering
- Capable of accepting record lengths ranging from a few seconds to more than 60 seconds
- Capable of having all data dumped in less than a minute via a standard interface
- Capable of being deployed for at least three days on internal batteries
- A unit cost of about $4,500 in quantity of 50.

The panel considered several bids from vendors, and selected Ref Tek, to provide a simple instrument which is a simplified version of the 6-channel PASSCAL instrument. Five prototypes are scheduled for delivery in late 1990. It is planned to purchase 60 to 80 of the simple instruments in 1991.

The Field Computer: The PASSCAL field computer was configured to make it possible to get the data from the field instrument into a format which can be examined and processed as quickly as possible. The system has been designed around Sun Microsystem workstations both because of their technical performance and their popularity in the IRIS community.

Engineering of the field computers has been done principally by Data Management System personnel, including the selection and purchase of hardware and the development of the software. This role will devolve upon the Instrument Centers in the coming years.

The first deployment of a prototype field system took place during the first week of June, 1988. The system was installed at the University of California, Santa Barbara where the field testing of the various PASSCAL field instruments was being performed. The instruments tested included the following data recorders:

- EDA PRS-4,
- Sprengnether DR2000,
- Teledyne Geotech PDAS-100,
- Kinemetrics SSR-1, and the
- REFTEK Model 72 (the IRIS/PASSCAL instrument)

Software that translates the data formats recorded by the five instruments into a SEGY format has been written for the PASSCAL field computer. The SEGY format has been modified to store non-reflection trace header values in the unassigned entries of the SEGY header. For instance, the SEGY format used by industry does not allow for storage of the time to the nearest millisecond for the first sample in the trace; one of the PASSCAL modifications allows for storage of this time index. Effort was made to insure compatibility of the PASSCAL/SEGY format with standard industry processing packages.

Since PASSCAL field computers will be used by a wide variety of university users, effort was made to provide interfaces with tools presently in use in the university community. Programs have been written that provide conversion of the SEGY formatted traces into both SAC and AH data formats. This allows users wishing to further analyze trace data to use the tool they are presently familiar with. Although only SAC and AH are supported at the present time, we feel that this provides support for the vast majority of IRIS users.

In addition to SAC and AH, some of the field computers are equipped with the SierraSEIS processing package. This is a standard seismic reflection processing package with modifications to accommodate refraction and passive source data.

At the present time, hardcopy is provided by doing screendumps to either a BENSON B-90 plotter or a GULTON Wellogger ST-250 plotter. Both of these plotters are Versatec V-80 compatible plotters and produce hardcopy by a thermal process. Future PASSCAL field computers will be equipped with the Gulton ST-250 plotters since they are less expensive, faster and easier to load with paper than the B-90. It is worth noting that the field computers can drive other Versatec plotters including the V-80 and 24" Versatecs with no modifications to the software.

During the development of the PASSCAL field computer, specific processing requirements have been more clearly identified and three separate hardware configurations have been determined. The first system is designed to support up to 100 PASSCAL instruments and is presently designed around a SUN 3/180, a second system will support up to 25 PASSCAL instruments and is designed around a SUN 3/60, and a third system could be used to support about 12 instruments and is designed around a SUN 3/50. At the present time two of the large systems are fully operational. Additionally two SUN 3/50 system and one SUN 3/60 system exist to cover the low end of the field computer requirements but do not yet have appropriate hardcopy support. In addition to the systems described above, we have just obtained two systems based upon the SUN SparcStation. These systems will replace the older and heavier SUN 3/180 systems in the field environment. They should be fully operational by Summer 1990.

The field computer provides adequate field processing power to allow field personnel to monitor the quality of data as it is being recorded. The SierraSeis reflection package with IRIS enhancements provides the capability to perform initial data analysis while in the field. The field computer with the IRIS supported software is indistinguishable from a SUN workstation used at a university for research. All development and support of the field computers, then, is immediately available elsewhere for use on workstations.

Sensors: The development of the PASSCAL Instrument has enabled us to record extremely high quality data with portable instruments. The capability of the instrument to record earthquakes with a wide dynamic range and bandwidth is currently limited by the traditional moving-coil seismometer designs. This has produced a need for high quality portable broad-band sensors with high dynamic range in the 20 sec - 20 hz band. Several new sensors with relatively low power electronic feedback systems have come on the market during the last few years. We are now in the process of evaluating these sensors in both semi-permanent installations and in portable installations. Acquisition of 90 portable broad band 3-component sensors to go with the existing 90 PASSCAL instruments is now a high priority for the immediate future.

Operational Support

The Instrument Center: The PASSCAL program acquired its first complement of production instruments during the summer of 1989. In anticipation of this, we established the PASSCAL Instrument Center at Lamont-Doherty Geological Observatory in May, 1989. The Instrument Center provides all of the support functions necessary to operate and maintain the instruments in the field. This support includes the first line maintenance of the instruments, training of users, instrument and sensor testing, and field support for investigators using PASSCAL Instruments. The Instrument Center currently has a staff of four full-time and part-time support for another full-time equivalent. These personnel are employees at Lamont who work under contract to IRIS. The Instrument Center operates under the direction of the Chief Engineer of PASSCAL.

Training: Any Investigator who wants to borrow PASSCAL Instruments must send personnel to the Instrument Center for training in the use of the instrument and the associated field computers. This training is important since the investigators are usually not familiar with the equipment. Personnel from nine institutions have been through the training conducted by the Instrument Center.

Field Support: The Instrument Center provides support for experiments in the field. For larger experiments this usually entails sending personnel to the field to provide further training and to insure that all of the equipment is operational. For small experiments the support consists of providing the equipment, spare parts and "Hot Line" support. During its first year of existence the Instrument Center provided support for the following experiments:

Table 1

Archean-Proterozoic Transition	University of Wisconsin Carnegie Institution
West Greenland Onshore-Offshore	University of Wyoming
Loma Prieta Aftershocks	Columbia University U.C. Santa Cruz U.C. Santa Barbara
Yellowstone Local Earthquakes	University of Utah
Kenya Rift Teleseismic Profiling	University of Wisconsin UCLA
Beaufort Sea Noise Study	University of Washington
Rio Grande Rift	New Mexico Tech New Mexico State
New Haven Engineering Site Study	Yale University
Pinon Flat Prototype Tight Array for the ESSP	U.C. San Diego Indiana University University of S. Carolina
Southern California Borderland Onshore-Offshore Source Test	U. C. Berkeley UCLA University of S. California

In addition, the Instrument Center is scheduled to support the following experiments during the last half of 1990.

Table 2

Brooks Range Reflection/Refraction	Rice University
Iceland Refraction	Columbia University
Eastern Minnesota Refraction	University of Wyoming
Antarctic Refraction	University of Wisconsin
South Carolina Microseismic Noise Study	Oregon State University
East Coast EDGE profiling: Onshore-Offshore	The EDGE consortium

Engineering Support: The development of the PASSCAL Instrument has been a major undertaking. As in any development program of this size there have been bugs in the equipment. The Instrument Center has been called upon to help identify the problem areas and work with the investigators to create short-term solutions to allow the experiments to proceed and to work with the manufacturer to achieve long-term solutions to the problems.

The engineering support function also extends to testing and calibrating sensors, developing the necessary interface circuits for the sensors, testing alternative technologies for such things as clocks etc., and finally developing comprehensive test procedures for all of the standard equipment so that we can quickly service and return equipment to the field.

Software Development: The continued development of software for the field computers will be a long-term need. The initial field computer software consisted of several "off-the-shelf" processing systems with some additional software written to get the data from the PASSCAL Instrument into the necessary processing formats. This solved the immediate problems of being able to look at the data and do initial processing. However, it did not solve all of the problems.

The field computers have three main processing functions. These are:

- Quality control of recorded data
- Preliminary processing of data
- Production of output volumes for the Data Management Center and the Investigators

The initial software allows preliminary processing of the data and production of output volumes for the investigators. However, it has not yet been augmented to provide quality control and does not produce all of the formats necessary for the Data Management Center. The continued evolution of the field computer software has been a task which the Instrument Center has assumed and will continue in the future.

Table 3 shows the equipment currently available for field use. The equipment is staged from the Instrument Center at Lamont-Doherty Geological Observatory. The center is now acting as a repair and maintenance facility for the instruments, it furnishes personnel and instrument support for field programs and also provides engineering support for the continued development of the instrumentation.

Table 3 — PASSCAL Instrumentation: June 1990

Recording Equipment	Data Loggers	90
	Disk Units	90
	Exabyte Recorders	14
Sensors	L-22 2 Hz Sensor Sets	100
	L-4 1 Hz Sensor Sets	5
	S-13 1 Hz Sensor Sets	10
	Broadband Sensor Sets	3
Field Computers	SUN 3/180	2
	SUN 3/50	2
	SUN SparcStation	2
Misc	3-Channel Cables	100
	Trimble Pathfinder GPS Receivers	2
	Kinemetrics Portable GOES Receiver	1
	Nanometrics Portable Clocks	3

By the end of 1990 we will have supported an additional fifteen experiments conducted by eighteen different member institutions. In 1989 the instruments were in the field for a total of 175 instrument months out of a possible total of 225. In 1990 the expected usage will be 552 instrument months out of a possible 885. All of the unscheduled capacity in 1990 has been needed to take the Instrument Center through its own development and standardization program. Normally, over 80% of capacity should be realizable in the field.

A formal policy for requesting the use of PASSCAL Instruments was established in 1988. PASSCAL furnishes all of the equipment necessary to record and perform initial processing on the data. We provide field support on the instruments and provide training for the investigators and their field team. The principal requirements for use of the equipment are:

- The equipment must be used for non-commercial purposes;
- The data must be made available to the IRIS Data Management Center within six months after the completion of the field experiment;
- The experiment must pay all shipping costs for the instruments;
- The experiment must pay for travel costs associated with technical support of the experiment in the field; and
- The investigator must send personnel to the Instrument center to receive training in the care and use of the instruments.

The SGR Facility: PASSCAL has participated as a co-sponsor of the SGR Facility at Stanford for the past two years. This facility consists of 200 Seismic Group Recorders (SGRs) donated to Stanford by AMOCO. These instruments are single channel recorders with a radio turn-on capability.

The instruments were received by Stanford in late 1988. They have been modified to allow for long records and for timed turn-on, for use in large explosion refraction experiments. For the last two years the operation of the facility has been supported by Stanford, the US Geological Survey and PASSCAL. The operational costs associated with using the instruments are paid by the investigators. PASSCAL support for this fa-

Table 4 — 1990 PASSCAL Instrument Scheduling

	Month											
Experiment	1	2	3	4	5	6	7	8	9	10	11	12
Kenya Teleseismic: Wisconsin, UCLA	6	6	6	6								
Yellowstone Local Earthquake: Utah	4	4	4	4	4							
Rio Grande Rift: NMSU, NMIT	4	4	4	4	4	4	4	4	4	4	4	4
Beaufort Sea: University of Washington			4	4								
Pinon Flat Array: Soviet Kirghizia Team				20	20							
EDGE Test Offshore S. Cal: USC, UCB					5							
EDGE profile: WHOI, Wyoming									10			
Brooks Range: Rice				1	1	1	40					
Iceland: Lamont							10	10				
Hawaii: Wisconsin, UCSB							18	18	12	12	12	12
Minnesota: Wyoming								40	40			
Long Valley Student Camp Princeton										5		
Microseism Study: Oregon State										35	35	35
Antarctic Refraction: Wisconsin											30	30
Total Scheduled	14	14	18	39	34	5	72	72	66	56	81	81
Total Available	45	45	45	60	60	90	90	90	90	90	90	90

cility is viewed as being short term. The SGR Facility provides a significant number of instruments which can be used in reflection and refraction profiles which are not currently available through other means. However, the 3-channel simple instruments being acquired by PASSCAL should take over the functions now provided by the SGRs.

The SierraSeis Maintenance Center: The PASSCAL Program in conjunction with the Data Management Center provide a small amount of support for a SierraSEIS Maintenance Center at Lawerence Berkeley Laboratory. The purpose of this facility is to act as a focal point for IRIS members who use the SierraSEIS processing package. The Center will operate a User's Group to facilitate the exchange of university developed modules and provide some experience to users who are trying to utilize the package in "non-standard" ways.

Field Experiments

The interim field experiments funded by PASSCAL were selected by a review panel which considered proposals written in response to an RFP. Two experiments were funded for the 1986 season and two were funded for 1988. Funding for 1987 was limited due to our commitment to instrument development, and was restricted to data analysis support for the 1986 investigators. Criteria for selection were heavily weighted toward investigators who could experiment with the techniques of full waveform recording and processing which form a key part of the rationale for the PASSCAL arrays.

By 1989, the responsibility for funding field experiments had been handed back to the NSF. Consequently, the last two experiments were special cases which illustrate the sort of situation which would justify IRIS support for field work.

Table 5

Year	Institutions	Location	Remarks
1986	Purdue University U. Texas El Paso U. Texas, Dallas	Ouachita Mts	200 km long wide angle imaging commercial SGR crew dynamite sources
1986	Stanford University U.S. Geol. Survey and 15 other organizations	Basin and Range	Cross-geometry wide and narrow angle imaging. USGS instruments, with university reflection trucks, dynamite
1988	Univ. of Missouri Univ. of Nevada Lawrence Livermore	Basin and Range same as 1986 expt.	Passive teleseismic 3-component arrays for receiver functions. First test of Passcal prototypes.
1988-90	Rice University	Brooks Range	Wide/narrow angle reflection SGR's,USGS units, Passcal units.
1989	Univ. of Wisconsin Carnegie Institution	Archean-Proterozoic Transition	1500 km array of 3-component seismometers for mantle imaging, including anisotropy of S waves. IRIS support for Passcal instrument beta testing.
1989	Lamont-Doherty U. C. Santa Cruz U. C. Santa Barbara NCEER	Loma Prieta after- shock recording and engineering site meas.	Unplanned rapid response initiative by IRIS. Subsequently funded out of special earthquake research funding.

It should be recognized that until the first PASSCAL prototypes appeared in 1988, it was difficult to record teleseisms with a portable array.

In retrospect, the IRIS role in providing funding for these experiments was needed to provide the means for the scientific community to begin pushing the state of the art forward. Now that the PASSCAL instruments are available, the efforts of these groups have demonstrated concretely a number of the propositions upon which PASSCAL was justified: the importance of multiple techniques on the same site; the importance of 3-component recording; the need for dynamic range; the extension of conventional reflection and refraction methods to a single unified crustal imaging technique.

The 1986 PASSCAL Ouachita Experiment: The first large-scale PASSCAL experiment was conducted in the Ouachita Mountains area of southwestern Arkansas and northeastern Louisiana during May of 1986. The layout included an exact overlap of the southern 1/3 of the COCORP Ouachita profile. The 200 km long profile extended from the Benton Uplift on the north well into the Gulf Coast region. From the standpoint of PASSCAL objectives, the design of this experiment entailed several key factors including: close station spacing, simultaneous recording at near vertical and wide angles of incidence, broad-band recording, wide dynamic range recording, and coverage aimed at a combined reflection/refraction interpretation. Key tectonic questions addressed included the location and nature of the Paleozoic and Mesozic continental margins in the area, the deep structure and origin of the Ouachita orogenic belt, and the effects of Mesozoic rifting on lithospheric structure. The major portion of the experiment consisted of two deployments of 400 Seismic Group Recorders (SGR) at a spacing of ~0.25 km. These radio-controlled instruments were on loan from the AMOCO Production Company and recorded on digital cassettes. Strings of 6, standard 8 Hz vertical geophones were used. The 29 shots included multiple large (up to 2000 kg) shots along with smaller (~200 kg) shots at intervals of 10 km. Data recovery and shot efficiency were generally good with approximately 7000 seismograms being recorded. Each of the seismograms was 40 sec long, with a sampling rate of 500 samples per second.

In conjunction with the main experiment, several auxiliary seismic experiments were conducted. First a three-component seismic study was conducted using receiver locations common to the seismic group recorders (SGR) to provide a comparison between vertical component seismic recording and three-component seismic recording. The recorders at these common sites were triggered by the SGR. Twenty digital, three-component recorders were placed at 500 m intervals over a distance of 10 km in the central part of the SGR line. Shots were fired at both ends and at various distances off both ends of the three-component segment of the line producing coverage to a distance of 40 km. Also a variety of three-component geophones and seismometers were used for comparison with the 8 Hz geophones used with the SGRs.

The data set realized the goal of unaliased wavefield recording out to long offsets. The science team has combined a number of different techniques to develop both a coherent 2-d velocity structure, and to track major crustal discontinuities using reflections. Examples appear in Section 2 of this Proposal, II.14-15.

The 1986 Active Source Basin and Range Experiment: The field area, in western Nevada, coincided with the COCORP Nevada line. The experiment involved 17 University and government organizations, operating out of Lovelock, Nevada. The experiment focused on:

1. the lithospheric structure of this active region of extension,
2. anomalous upper-mantle velocity structure,
3. resolving conflicts between previous refraction and reflection interpretations of lower crust and upper mantle structure, and
4. recording of on-line earthquake sources.

The experiment consisted of controlled-source and earthquake recording in three deployments (two EW deployments providing a 280 km main line and a 200 km NS cross line). Instrumentation consisted of 120 USGS portable vertical-component packages, 60 GEOS and MEQ three-component digital packages, four standard reflection spreads (total of 396 channels), and two Vibroseis units from the University of Wyoming. All lines were reversed with multiple shots from 2000 to 6000 lbs at 50 km spacings and smaller 500 lb shots for detail across the reflection spreads. Drilling and shooting was done by the USGS. A total of 28 shots was detonated.

The north-south refraction cross-line extended 200 km at 1.5 km spacing with the reflection spreads deployed at the center of the array for 25+ km. Sixty three-component digital stations were deployed along the line at 1.5 to 3.0 km spacings. Seven shots were fired into the entire refraction/reflection spread with shot spacings of 50 km including large multiple shots at the end of the spreads. Vibroseis recordings were also made on the reflection spreads. In addition, a large shot to the west of the array provided 90 degree fan coverage on the NS line at approximately 140 km distance.

While the N-S line was deployed, on 21 July, a M6.1 earthquake occurred near Bishop, California, that produced several large aftershocks that were recorded on the triggered GEOS and MEQ recorders. The epicenters of these events were approximately 220 km from the south end of the line and were recorded over 100 km along the NS line, which was within 10 degrees of the azimuth from the sources. These data provided upper-mantle ray-paths with excellent shear waves.

The second deployment was concentrated along the western 140 km of the main EW line. The refraction recorders were deployed at 0.9 km to 1.4 km spacing. The reflection spread was along the line west of the center of the spread. Ten shots were successfully recorded, including one 1500 lb fan-shot at 100 km from the spread. Vibroseis signals were recorded on the reflection spreads. Some of the three-component digital stations remained on the NS cross-line and recorded the EW on-line shots, providing additional detailed fans at distances from 40 to 140 km from the shots.

The final deployment was concentrated on the eastern 140 km portion of the line, from the center to near Eureka, Nevada, and this completed the 280 km EW profile. All refraction, reflection and digital recorders were deployed in-line to record 10 shots. One off-line 1500 lb shot was fired onto the EW line for the completion of the large EW 160 degree fan. Vibroseis was recorded on the reflection spreads.

The 1988 Nevada Teleseismic Experiment: Small arrays of three-component instruments were deployed in western Nevada near the center of the 1986 Active Source Experiment. The project was designed to resolve the shear velocity structure of the region using teleseismic receiver function analysis and to use a small array to begin to evaluate the effects of lateral variations on teleseismic waveforms. The experiment location allows the comparison of the results from teleseimic sources to those obtained with the active sources in 1986. In addition this study will help provide data for the design of future large, dense arrays for the study of lithospheric structure using passive arrays.

The experiment consisted of two deployments. The first consisted of 8 broad-band digital seismograph stations with a station spacing of 8-10 km operating in trigger-detection mode at a sampling rate of 20 samples/sec. The second deployment consisted of 13 digital recorders equipped with 1 Hz seismometers. These sites were recorded continuously at 100 samples/sec at a central recording site. The equipment of the 13-station array was part of the "Local Seismic Network" (LSN) developed at Lawerence Livermore National Laboratory.

The LSN array recorded for three months while the broad-band array recorded for a period of 10 months. The broad-band array utilized the prototype PASSCAL recording equipment developed by Ref Tek. These prototypes were not scheduled for use in this experiment, but were brought in when the originally scheduled instruments did not perform correctly at low frequencies.

This experiment yielded very interesting information about the use of an array in exploiting P-SV conversions for crustal imaging. A example appears in Section 2, II.18.

The Brooks Range Pilot Experiment consisted of a wide-angle seismic experiment and a series of seismic reflection wave tests in the Brooks Range, Alaska during the summer of 1988. The objectives of the survey were 1) to determine the upper crustal structure in the Endicott Allochthon from the range front in the north to the Doonerak window area in the center of the range, 2) to acquire wave test data for the design of a future vertical-incidence reflection experiment, and 3) to assess the logistical difficulties of operating a seismic crew along the Alaska Pipeline Haul Road in a remote mountain belt north of the Arctic Circle in anticipation of a larger future experiment.

Eighty-five Seismic Group Recorders (SGR III) were borrowed from AMOCO Production Company for the field work. The instruments were used in four wide-angle deployments and three wave tests. Chemical explosive charges varying in size from 10 to 500 lbs were used as energy sources in drillholes 10 to 70 feet deep at three shotpoints. The SGRs recorded signals from single 8 Hz industry geophones in all of the deployments. The wide-angle deployments produced a 39 km reversed refraction profile and a 14 km unreversed profile, with stations at 150 m and 300 m spacing.

The wave tests were designed to assess near surface noise problems to determine acquisition parameters for a proposed dynamite reflection survey. The SGRs were deployed in short linear arrays at each shotpoint. The stations were spaced at 5 to 10 meters with spread lengths having maximum offsets of 0.7 to 1.3 km. Shots from 7 to 35 lbs were fired at depths of 10 to 60 feet.

The data from this experiment were used to design the array and shot parameters for the 1990 Brooks Range Experiment, to be conducted in July-August 1990. This experiment is the full scale reflection/refraction profile that was anticipated by the pilot study in 1988. A seismic line approximately 300 km long will be shot starting in the center of the Brooks Range and extending north. Recording instruments will be operated by personnel from IRIS member universities, the US Geological Survey and the Geologic Survey of Canada.

The Archean-Proterozoic Transition Experiment recorded teleseismic signals over a four month period (15 June to 15 October, 1989) to characterize the variations in crust and upper mantle structure along a 2000 km traverse in central North America. This traverse spans two major geologic transitions: from the Archean Western Superior Province of the Canadian Shield to the Proterozoic Trans-Hudson, and then to the Archean Wyoming Craton. Twenty-two portable three-component seismic stations were deployed in a line from western Ontario to Wyoming with spacing ranging from 50 to 100 km. The array passed through two permanent RSTN stations, RSON and RSSD, which were recording long and intermediate period channels through much of the experiment. Twelve of the instruments were University of Wisconsin data loggers with three-component 1 Hz sensors operating in a triggered mode, while the other ten stations were the PASSCAL prototype instruments with intermediate period seismometers (Kinemetrics 5s and Guralp CMG3) recording continuously at 10 samples per second.

Of the large suite of teleseismic events that were recorded, more than 30 had well recorded S waves. In addition, two NTS blasts were recorded by many of the instruments, providing an excellent profile over the distance range 10-25 degrees. Three types of studies are being undertaken with this data set. 1) Variations in mantle anisotropy as determined by shear-wave splitting in S, ScS and SKS, 2) variations in the properties of crustal reflectors, the Moho, and upper mantle discontinuities using boundary interaction phases, and 3) variations in travel times in all major phases to gain high resolution information on lateral variations in P and S velocity.

In the preliminary results, a pronounced shear wave birefringence and a correlative travel time anomaly are associated with the Superior Province; an example is given in Section 2: II.9.

The Loma Prieta Aftershock Deployment: At 8:04 pm on October 17, 1989, the magnitude 7.1 Loma Prieta earthquake hit the San Francisco Bay region. The PASSCAL instrumentation had just been received at Instrument Center from the Greenland experiment only four hours earlier. A major element of IRIS future planning for these instruments is their availability and readiness for rapid-response to a major earthquake. Consequently, IRIS asked a team from Lamont and the Instrument Center to lead the initial response. Both the PASSCAL instruments and additional equipment from the National Center for Earthquake Engineering Research were utilized. After this initial deployment, personnel from the University of California, Santa Cruz and the University of California, Santa Barbara were trained and continued the deployment for several weeks. The deployment at Loma Prieta would not have been possible without the generous logistical and communications support provided by the U. S. Geological Survey in Menlo Park during the critical early phases of the work.

The instruments used were the first 24 production dataloggers delivered by the manufacturer in August. These instruments spent the entire period before Loma Prieta in Greenland. Both experiments gave over 75% data recovery, and constituted a successful shakedown cruise for the new equipment. [The bug responsible for most of that loss has been caught].

The Loma Prieta event will have one of the best instrumented aftershock sequences in the history of seismic observation. The large dynamic range and the 3-component recording permits detailed study of both compressional and shear phases from a wide range of event magnitudes. Initial mapping of the rupture zone by aftershock distributions and observations of aftershock waveforms indicate that these data should provide constraints on a number of critical issues regarding the structure of the San Andreas Fault Zone with depth, spatial distribution of moment release and the relation to fault zone geometry and geology, and the capricious patterns of damage observed in the Santa Cruz Mountains and the populated areas to the North. The IRIS data will constitute a significant seismological component of the Loma Prieta data set. These data should be of great interest to a broad constituency in the IRIS community.

As suspected in the writing of the 1984 Program Plan, an aftershock recording campaign puts some of the most severe demands on the performance of these instruments. The dynamic range required, the large number of events, the high sampling rate, the unplanned nature of the exercise, and the problem of data association make this a prototype for the future study of aftershocks. The "high-end" 6-channel instruments will be required.

The instrument deployments can be broken down into five general areas:

- A study of the response of the sediments and bay fill in West Oakland, in cooperation with NCEER, near the collapse of the Cypress structure on the Nimitz Freeway (I-880). Five instruments for one week. *Lamont, National Center for Earthquake Engineering Research.*
- A tight directional array (200 m spacing) in Sunnyvale to study excitation of surface waves at the boundaries of alluvial basins. Four instruments with 5-sec seismometers for five days. *Lamont, NCEER.*
- A detailed study of the aftershock zone, concentrating on the northern half. Ten instruments for the first week, expanded southward to include 20 instruments in the second week. 2-Hz three-component L22 sensors were used in this recording. *Lamont, U.C. Santa Cruz.*
- Small tripartite arrays in the aftershock zone, starting around November 5th and located on some of the sites used during the first two weeks. *U. C. Santa Cruz.*
- Short linear arrays in the southern part of the aftershock zone,, using six instruments, starting November 5. *U. C. Santa Barbara.*

Many thousands of events were recorded during the period from 19 October to 21 November 1990. Many weeks' worth of work have been spent trying to complete the association (including locating events not detected by Calnet). It is clear that we are dealing with volumes of data more in line with multichannel seismic exploration systems than with teleseismic studies. The entire data set collected in this experiment is being preprocessed by a team from Lamont, and will be available for distribution to the IRIS community by the end of the Summer 1990.

PASSCAL is geared entirely to instrumentation services to member universities, as well as to the seismological research community nationally and worldwide.

Program oversight is under the Standing Committee for PASSCAL, whose members serve for two years rotation. The Standing Committee makes all major strategic decisions for PASSCAL. Examples of this: (1) Budget strategy for each year, including which instruments and sensors are purchased in what quantities; (2) Approving specifications for new developments; (3) Determining the instrument use policy. The following members of the scientific community have served on the Standing Committee.

Table 6

Current Members			
Larry Braile (chairman)	Purdue	Anne Trehu	Oregon State Univ.
David Simpson	Columbia	Walter Mooney	U.S. Geological Survey
Robert Smith	Utah	Tom Owens	South Carolina
David Okaya	Lawrence Berkeley Lab	Paul Silver	Carnegie Institution
Past Members			
Kei Aki	U. Southern California	Gilbert Bollinger	Virginia Tech
William Ellsworth	U. S. Geological Survey	David James	Carnegie Institution
Ken Larner	Colorado Sch. of Mines	Peter Malin	U. C. Santa Barbara
George McMechan	U. Texas at Dallas	Gregory Davis	U. Southern California
William Menke	Columbia University	Robert Meyer	University of Wisconsin
Robert Phinney	Princeton University	Selwyn Sacks	Carnegie Institution

Services to the community are described elsewhere in this Program Plan. They have included funding of interim field experiments, funding of special technical tasks, the loan of array facilities for field programs, the provision of software, documentation and training.

Collaboration with the U.S. Geological Survey: Since its inception, PASSCAL has had a close working relationship with scientists from the U.S. Geological Survey in Menlo Park engaged in studies in crustal structure and earthquake seismology. Individual members of the university community with a desire to conduct field studies have found concrete assistance in many forms from colleagues at the USGS. These have taken some of the following forms:

1. The contribution by the USGS of recording equipment, personnel, and explosive shots to the 1986 Basin and Range Experiment turned this early PASSCAL effort from a small pilot program into a full experiment.
2. The Trans-Alaska Crustal Transect (TACT), a multiyear program involving many different investigators applying a variety of techniques, was funded and operated as a USGS initiative. The organizers of TACT, however, have repeatedly engaged members of the university community as co-investigators, and brought them into the joint planning of some very interesting work. The Brooks Range studies by Rice in 1988 and 1990 are a part of a joint effort with the USGS.
3. The PASSCAL deployment of instruments in the Santa Cruz mountains to record aftershocks from the Loma Prieta earthquake of 17 October 1989 received generous support from the office in Menlo Park. This included a site for operation of the field computers, internet and telephone hookups, access to permits, and vehicular support. IRIS is extremely grateful for this assistance.

Table 7

Universities which have participated in Passcal supported field programs	
University of Alaska at Fairbanks	University of New York-Binghampton
Boston College	Princeton University
University of California-Santa Barbara	Purdue University
University of California Santa Cruz	Rice University
University of California Los Angeles	University of South Carolina
Carnegie Institution	Stanford University
Lamont-Doherty Geological Observatory	Texas A&M University
Lousiana State University	University of Texas at Dallas
Massachusetts Institute of Technology	University of Texas at El Paso
Memphis State University	University of Utah
University of Missouri-Columbia	University of Wisconsin-Madison
University of Nevada-Reno	University of Wisconsin-Oshkosh
New Mexico Technological Institute	University of Wyoming

Universities borrowing equipment in externally sponsored experiments 1989-1990	
University of California Berkeley	Rice University
University of California Los Angeles	Stanford University
University of California San Diego	University of South Carolina
University of California Santa Barbara	University of Southern California
University of Hawaii Hilo	University of Utah
Indiana University	University of Washington
Lamont-Doherty Geological Observatory	University of Wisconsin-Madison
New Mexico Institute of Technology	University of Wyoming
New Mexico State University	Yale University
Oregon State University	

The PASSCAL program has passed through a development and testing phase. An instrument exists that achieves the design goals outlined in the original 1984 IRIS proposal. The PASSCAL instrument is a reality, and funding is the only remaining technical factor in acquiring this essential geophysical facility.

Equipment Acquisition

Data Loggers: There are presently two versions of the PASSCAL instrument: a six channel and three channel recorder. Both are made by the same manufacturer. The cost per channel for the two different versions is comparable, but there are tradeoffs in flexibility and performance versus modularity. The basic functional distinction is that the 3-channel recorders would see greatest use in refraction and reflection experiments where modularity, portability, and price are more critical than maximum flexibility and dynamic range. Conversely, the 6-channel recorders could see greater use in earthquake studies where flexibility and broader dynamic range is more critical. Present plans are to acquire approximately equal numbers of total channels of both versions of the instrument, as follows:

Table 8

Instrument	Number	Channels
6-channel dataloggers	450	2700
3-channel dataloggers	1100	3300

Sensors: A flexible facility demands several different sensor models. Portable sensors fall into three general categories:

- Exploration geophones, with f_0 ranging from 4.5hz to 50hz, usually cabled in linear arrays.
- Short-period seismometers, with f_0 around 1 or 2 hz.
- Broadband, or intermediate-period seismometers, with response between 20 sec and 20 hz.

For many applications, 3-component strings of exploration geophones and 3-component, 2hz seismometers are most suitable, relatively inexpensive, and easy to deploy. Enough of these will be acquired to serve each instrument, along with extender cables, as needed.

Broadband force-balance instruments are now the preferred technology for high dynamic range recording of signals in the longer period range. They function on the same principles as the Streckeisen STS-1 VBB instruments used by the GSN to cover the frequency range from the Earth's normal modes to 10 hz. To achieve price and portability, performance in the normal mode range from 1 to 10 mhz is sacrificed. They are in high demand for several reasons:

(1) Broadband sensors can produce the better-quality data needed for undistorted waveforms in crustal imaging experiments.

(2) Large numbers are needed for the arrays which will image mantle structure at the resolution needed for geological significance.

(3) Broadband sensors are a powerful tool for looking at local and regional earthquakes and determining their rupture mechanisms.

(4) Broadband sensors are likely to be deployed in arrays that run for many months at a time. This will lead inevitably to scheduling demands that require enough sensors to support multiple deployments.

In the presently available technology, they are still too expensive to afford in quantities of 1000's, and they are not portable in the same sense that a geophone is portable. Each site must receive a fraction of a day's effort of preparation.

We propose a compromise target for the PASSCAL facilities of 720 (3-component) broadband sensors. This would allow multiple experiments of a reasonable scale to be running at any given time, while working within fiscal bounds that are practical relative to the rest of the IRIS program. It is planned to acquire the first lot as early in the five year period as possible, in order that the critical teleseismic array experiments can be fielded soon.

Field Computers: The 1984 IRIS proposal projected a need for field computers to do quality control and initial data processing in support of field programs with PASSCAL instruments. At that time it was projected that one field computer could support from 50 to 100 instruments, depending on the nature of the experiment. That projection has turned out to be remarkably accurate and remains the working figure used in our budget estimates. An important development for the future of the program, however, is that the cost of required computer hardware has fallen dramatically in the past 5 years, and the net cost of this portion of the facility has been reduced drastically.

It is now widely recognized that software development is more costly and difficult than finding hardware. IRIS will continue to support efforts to upgrade the field computer software and to add the high performance functionality required to deal with large gathers of data.

Operational Support

The continued expansion of the instrument facilities and the increase in the number and types of instruments serviced within the PASSCAL Program mean that service capabilities of the program must also expand.

New Instrument Centers: The current facility at Lamont has almost 100 instruments and employs the equivalent of five full-time personnel. With the purchase of 90 Simple Instruments in early 1991, it will be necessary to open a second Instrument Center. Current plans call for the issuance of a Request for Proposals from interested institutions in the Fall of 1990, with the goal of establishing a new facility in the Spring of 1991.

Training: The training function as handled at the Instrument Center at Lamont will continue. During the next year a major effort will be mounted to generate training materials and instruction manuals so that the efforts can be conducted at the new instrument centers as they are opened. This will also enable experiment personnel who have received the training to return home and train others before the experiments are conducted in the field.

Software Support: Continued software development will have a high priority with the PASSCAL Program. The field computer must handle all of the quality control and prepare the data for distribution. A single PASSCAL Instrument will generate between 10 MBytes and 50 MBytes of data per day. Large experiments can have between 50 and 500 instruments operating at any given instant. This represents a sizeable data processing problem. Consequently, large experiments will require dedicated personnel primarily responsible for the data processing and quality control. The software must be developed to automate the quality control processing as much as possible.

In addition to handling quality control, the field computer also serves as the point where ancillary information such as station locations, and source locations are entered into the data. The field computer also acts as the interface with the Data Management Center and with the Investigators own processing system. Therefore, the field computer must be able to output the data in formats compatible with the DMC and to the maximum extent possible with other major processing systems.

The field computer will continue to rely on "standard" processing packages such as SierraSEIS, the Seismic Analysis Code (SAC) from Lawrence Livermore National Laboratory and the AH code from Lamont to do the scientific processing of the data. The development efforts for our software will be in the development of robust, automated software to accomplish the quality control and data output.

Initial efforts on a fast viewing program which lets the user quickly look at the data have been started. The prototype programs will be tested this summer. The basis for the quality control and output modules will be a database system designed to use as much of the techniques and code developed within the Data Management Center as possible.

New Technical Development

The PASSCAL Program has made significant progress in the last five years. We have completed major development efforts and are in a mode where most of our money is going to the purchase of equipment for the instrument pool. However, we can not afford to stop equipment development altogether. Things are changing very rapidly today in the areas of technology that impact PASSCAL. The electronic technology which will be available in the future makes it desirable to keep working to upgrade the equipment so that the equipment we buy five years from now will be significantly better that what we can buy today. This will not only upgrade the capabilities of the array, but also assure that it will have the longest possible lifetime. We expect this will also have a positive feedback on the science. The changes in the equipment should lead to new types of experiments which should be done five years from now are probably significantly different from those which are being done today.

Several areas of work can be identified at the present time.

Sensors: The current state-of-the-art in portable broad-band sensors is represented by passive five second seismometers. These sensors have been proven in the field and methods for the deployment of the sensors have been developed which allow for recording signals in the 5 to 20 second range.

The availability of new transportable broad-band sensors based on force-balance design opens new scientific possibilities for portable instrumentation. These sensors offer frequency response from 40 to 50 Hz down to 100 seconds and fit in the volume of a cube of approximately 30 cm on a side. However, before these instruments can be effectively used in large scale experiments, several operational problems must be addressed. Power levels must be reduced, ideally to less than 1/2 watt. The instruments must be tested to see if they can withstand the shock and abuse associated with portable deployments. Finally, deployment methods must be devised to allow stable operation of the sensors at long periods.

A new requirement is emerging in the field of local and regional earthquake seismology. The distinction between strong-motion accelerometers and short-period seismometers exists largely because traditional instruments and dataloggers lacked the ability to record the full dynamic range of accelerations between least background noise and 0.5g. It would greatly simplify a number of tasks in local earthquake seismology if arrays of sensors were available which could serve both for engineering strong motion and small-amplitude seismic signals. The PASSCAL Standing Committee has begun conversations with representatives from NCEER to determine whether an initiative in this direction would be timely.

Timing: The original goal of the PASSCAL development program was to have a portable array in which all of the units were synchronized to within one millisecond of each other. This type of timing accuracy is obtainable with today's technology. The current PASSCAL Instruments have OMEGA receivers which keep the units synchronized to within the desired specification. However, these timing receivers have had reliability problems associated with the variations of the strength of the OMEGA signal. These problems have meant that the receivers do not always lock onto the signal and produce reliable timing information. While the reliability rates have generally been about 80% and methods have been developed to manually determine instrument drift, these problems add significantly to the field labor and post-processing load. Several options are under consideration for eliminating this problem, the most promising being a conversion to Global Positioning System (GPS) units.

During the last half of 1990, we will look at alternative OMEGA clocks, examine possible changes to the current clock and look at the possibility of incorporating Global Positioning Satellite clocks into the instruments. All of these options will be studied and the option which offers the best long term solution will be chosen. This new clock will be incorporated in future instruments.

Instrument Maintenance: The engineering support associated with the current PASSCAL Instrument is directed principally at detecting and fixing problems as they occur. With the large number of instruments, this will require the development of maintenance procedures and the development of semi-automated check out methods which can quickly identify problems with instruments as they come through the center between field programs.

New Field Methods: With the development of the PASSCAL instrumentation it is now possible to collect data in ways not envisioned in the past. Part of the engineering support effort within the PASSCAL Program will be the demonstration of new ways to acquire seismic data. These demonstrations usually will not be special experiments. They will generally involve the use of a small number of instruments within one of the regularly scheduled experiments.

Simple Instrument: The five prototype simple instruments will be delivered in late 1990, for testing and evaluation. Possible changes for the production units must also be examined. We currently plan to be able to place a purchase order for the first group of production units in early 1991, so that we can get delivery by Summer 1991.

Telemetry: The PASSCAL System as it has been configured to date consists of individual stations, each with its own recording capability. The use of telemetry for portable instruments in the past has been very difficult. The availability of radio frequencies has been limited, and the restriction of having line-of-sight makes the problem more difficult. However, we continue to examine the technology and look for new ways to increase the effectiveness of our deployments. A local telemetry system for small arrays has been tested for the ESSP array in the Soviet Union, and may be useful for certain experiments.

New technology in satellite communications may make it possible to receive low data-rate state-of-health information from a widely spaced array. This will enable the investigator to more effectively schedule field visits in long-term deployments.

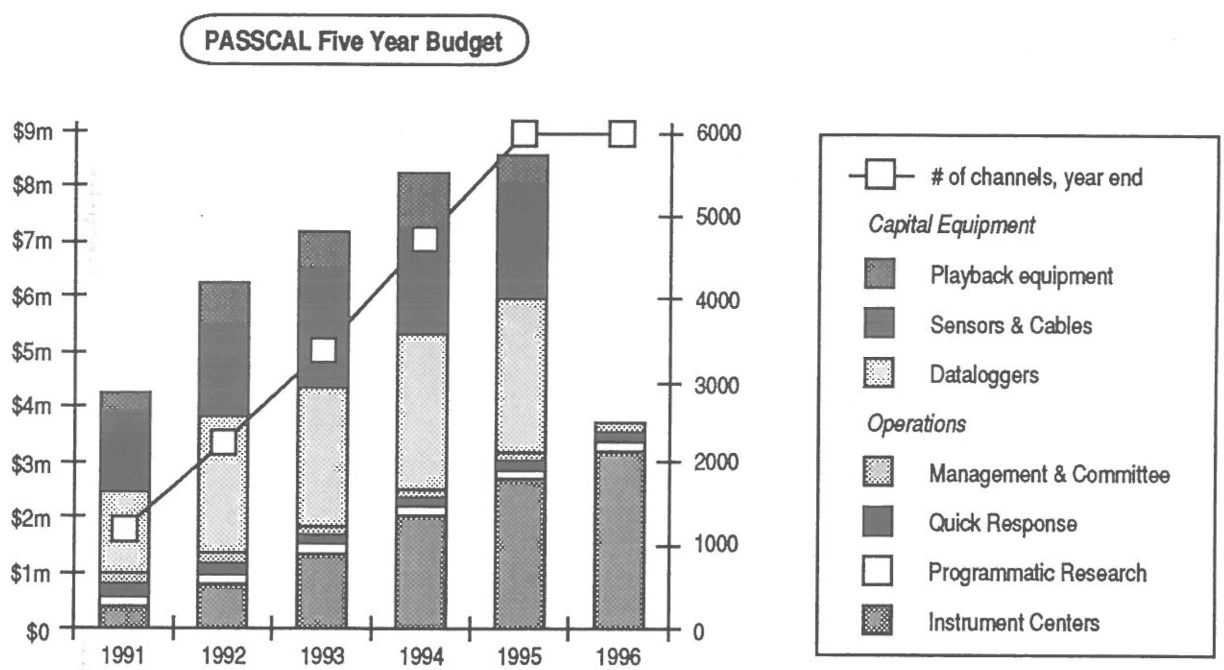
New software for the PASSCAL Instrument now makes it possible to connect to a modem. For long term deployements which can obtain telephone lines, this will allow the instrument to not only communicate state-of-health information, but to also upload limited amounts of data to the scientist in his laboratory.

Twenty-four Bit A/D Converters: One of the developments which should have an impact on the PASSCAL Program in the next few years is that of the 24 bit converter. The current versions are not suited for portable equipment because of their power consumption. However, there are several possible units which can be adapted to the portable environment. PASSCAL will continue to monitor the availability of 24 bit A/Ds and probably provide minor amounts of support to adapt promising units to the PASSCAL Recorder for testing and evaluation. Depending upon the cost, we would expect to equip as many of the PASSCAL units as possible with 24 bit encoders. Applications requiring this dynamic range include both earthquake recording experiments and artificial source reflection programs where some source points are close to the sensors.

The budget plan follows from the program plan. The major costs are formula-based. The annual capital investment cost depends on the number of channels to be acquired, and the annual maintenance cost is proportional to the total installed base.

The recommended PASSCAL budget is based on the assumption that 6000 channels of datalogger capacity are acquired by the end of 1995. This will involve acquiring about 1200 channels per year, in a combination of 6-channel and 3-channel dataloggers. Costs for the capital equipment are currently established purchase prices.

Management includes (1) salary, benefits, and travel of the Program Manager, who also serves as IRIS Chief Engineer on behalf of the other Programs, (2) travel and incidental expenses of the Standing Committee, (3) other incidental costs, and (4) the salary, benefits and travel, beginning in 1992, of a Manager for Instrument Centers.



The principal operating cost, for Instrument Centers, is based on the assumption that a new center will be required for each 600 channels. It is based on the current experience with the first Instrument Center at Lamont. Costs include about 2 FTE personnel, travel, overhead, supplies, test equipment, service and training equipment. The Lamont Instrument Center will serves as a national focal point for engineering and software development, quality control and standards, and carries about 4 FTE.

Quick Response is a reserve to support the rapid deployment of portable instruments in the event of a significant earthquake in this country. It is based on the cost of the Loma Prieta deployment, but does not include extended operation of the stations or preparation of the data for distribution.

The items discussed under "New Technical Development" appear within several different budget lines. Sensors, timing, simple instruments, and 24 bit converters involve simple purchase of available hardware, and would occur as options or alternatives within the outlined plan for purchase of capital equipment. Instrument maintenance enhancements are covered under the overall envelope for support of the Instrument Centers. Support for Field Methods appears as "R&D/Methodology". Due to the immaturity of the desired technology and the uncertainty about its importance to experimenters, telemetry is being treated as a low-level exploratory development, within the envelope of the Instrument Center efforts and the stated capital budget.

The dependence of the PASSCAL facility strength on funding levels may be judged from this table, which estimates the number of channels after five years, as well as the number of years of continuous capitalization required to build to 6000 channels, for three funding levels.

5 yr IRIS Funding	5 yr PASSCAL Funding	Number of Channels in 5 Years	Number of Years for 6000 ch
$86131k	$30898k	6000	5
$60695k	$19796k	3450	8
$38172k	$13686k	2235	17

At the lowest level, fixed costs become more important, and drive up the number of years. In practice, the number of channels could never grow beyond about 3000, at that funding level.

PASSCAL Five Year Budget Plan	Recommended	1991 Qty	1991	1992 Qty	1992	1993 Qty	1993	1994 Qty	1994	1995 Qty	1995	1996
		All Amounts in thousands of dollars										
Operations	Salaries & benefits		105k		175k		175k		175k		175k	175k
	Staff Travel		35k		40k		45k		45k		50k	50k
	Committee Travel		35k		35k		35k		35k		35k	35k
Total Operations			**175k**		**250k**		**255k**		**255k**		**260k**	**260k**
Subcontracts	Instrument Centers (*)		650k		944k		1,367k		1,827k		2,306k	2,785k
	Insurance		40k		69k		112k		158k		206k	253k
	R&D/Methodology		100k		100k		100k		100k		100k	100k
	SierraSEIS Support		50k		75k		75k		75k		75k	75k
	Software Development		75k		100k		100k		150k		150k	100k
	Quick Response		100k		100k		100k		100k		100k	100k
Total Subcontracts			**1,015k**		**1,388k**		**1,853k**		**2,410k**		**2,937k**	**3,413k**
Total Operations & Subcontracts			**1,190k**		**1,638k**		**2,108k**		**2,665k**		**3,197k**	**3,673k**
		Qty		Qty		Qty		Qty		Qty		
Capital Equipment	PASSCAL Instruments	*60*	960k	*75*	1,200k	*75*	1,200k	*75*	1,200k	*75*	1,200k	
	Simple Instruments	*100*	600k	*200*	1,200k	*250*	1,500k	*275*	1,650k	*275*	1,650k	
	Aux Recorders	*23*	115k	*39*	195k	*46*	230k	*50*	250k	*50*	250k	
	Field Computers	*5*	125k	*7*	175k	*8*	200k	*8*	200k	*8*	200k	
	2 Hz Sensors	*100*	11k	*200*	15k	*250*	17k	*275*	17k	*275*	17k	
	1 Hz Sensors	*60*	270k	*75*	338k	*75*	338k	*75*	338k	*75*	338k	
	Broadband Sensors	*45*	675k	*56*	844k	*56*	844k	*56*	844k	*56*	844k	
	Cables	*120*	120k	*150*	150k	*150*	150k	*150*	150k	*150*	150k	
	Shipping cases,etc	*160*	64k	*275*	110k	*325*	130k	*350*	140k	*350*	140k	
Total Capital Equipment			**2,940k**		4,226k		4,608k		4,788k		4,788k	
Total PASSCAL (Annual)			4,130k		5,864k		6,716k		7,453k		7,985k	3673k
Cumulative Total Capital Equipment			2,940k		7,165k		11,774k		16,562k		21,350k	
Cumulative Total PASSCAL			4,130k		9,994k		16,710k		24,163k		32,148k	
Total Equipment Available	PASSCAL 6-ch Instruments	*150*		*225*		*300*		*375*		*450*		
	Simple 3-ch Instruments	*100*		*300*		*550*		*825*		*1100*		
	Total Channels	*1200*		*2250*		*3450*		*4725*		*6000*		

PASSCAL budget plan for 1991-95. Designed to build to 6000 channels in 5 years.
Figures for 1996 show operational cost for 6000 channels.

III. Status and Program Plan: The Data Management System

Digital seismology has been around conceptually since at least 1958, and was vigorously taken up by industry in the late 1960's. In the research community, however, the lack of funding for serious academic facilities and the applied perspectives of agency programs have resulted in overall fragmentation of R&D efforts in digital seismology for many years. It has been commonplace for investigators to spend months or years converting data from different sources into a form usable for research.

The increasing importance of large datasets, consisting of hundreds or thousands of seismic traces, mandates that modern digital seismology be engineered so that the data finally delivered by the system is in a form convenient for research, with minimum time delay.

The complete obsolescence of the analog World Wide Standard Seismographic Network (WWSSN) led the research community to organize the IRIS/GSN Program. This became an opportunity to put into operation the kind of data management needed if the new digital data acquisition technology were to be of any use.

IRIS has addressed this issue by organizing a Data Management System (DMS) as an equal partner with the GSN and PASSCAL programs. Standardization and compatibility of all three programs has been a basic principle of the IRIS effort over the past five years. The DMS has taken shape as a more functional, less expensive and complicated system than could have been anticipated even five years ago. This has been possible only because of the unprecedented growth of the high technology needed to handle the IRIS data. As a consumer, not a developer of this technology, IRIS has been building the DMS right at the edge of what is available and affordable.

The Data Management System (DMS) stands as the principal point of contact between IRIS members and the two data generating facilities of IRIS, GSN and PASSCAL. The effort during the period 1986-90 has been directed to putting a fully functioning prototype DMS into operation in time to archive data from the first GSN installations. This has involved the community, through two Workshops and the efforts of the Standing Committee, in the process of defining the functionality required and determining the technical means of accomplishing these goals. With the decision to locate the prototype Data Management Center at the University of Texas, Austin, in 1988, the focus of effort moved over to the engineering development work itself. Data was first entered into the new archive in mid-1989. By late 1989, users could access the data through interim software. At the time of this Proposal, July 1990, the prototype DBMS is in full beta test, and the seismological community is actively making use of the DMS services.

The principal responsibilities of the IRIS DMS are as follows:

- Oversee data flow through the entire IRIS system, from the Data Collection Centers (DCC) to the Data Management Center archive, and from the archive to the users. .
- Oversee operations and quality control at the DCCs.
- Data standardization. DMS has key responsibilities in the development and support of the Standard for Exchange of Earthquake Data (SEED) format that has been officially adopted by the Federation of Digital Broadband Seismographic Networks (FDSN).
- Archive all IRIS-generated data. Archive all continuous data sent by other network operators with stations meeting the GSN design standard. Archive both continuous and triggered data in a timely manner and support the integrity of the archive for an indefinite lifetime.
- Data management: maintain and update the information in the data base as corrections are needed.
- Develop data access methods to the archive that make it easy for a researcher to obtain needed data.
- Preassemble data volumes for significant events such as the Loma Prieta earthquake or the Joint Verification Experiment.
- Develop flexible data distribution methods.
- Distribute utility software for seismic data processing and management.
- Provide services for user communications such as the electronic bulletin board that provides IRIS users with information about the current status of IRIS and IRIS DMS systems.

The Continuous Archive: a unique capability: The IRIS DMS has adopted the goal of archiving and distributing continuous 20sps data from global broadband seismographic stations. The need for continuous data was enunciated in the 1984 GSN Program Plan, and has been reiterated regularly by the Standing Committees. This complements data archives supported by the USGS and foreign networks. The event CDROMs distributed by the USGS capture events listed over M5.5, and are a convenient tool for researchers on a worldwide basis.

The continuous archive is not only unique in the world, but serves data needs which cannot be met by compiled event-oriented products.

1. The archive is dynamically growing, thus providing rapid access to events of importance. As GSN network communications continue to be upgraded, much of this access will become near-real time.
2. Broadband, high dynamic range data is now demonstrated to be a powerful tool for studying earthquakes at regional and local distances from GSN stations in tectonic regions as well as in stable cratons. Many of the events of importance are not included in a global catalog of larger events.
3. Large or unusual events excite free oscillations which can last for days or which are not associated with the cataloged events. The newly discovered slow earthquakes associated with oceanic transforms can only be studied by access to a continuous archive. The M7.7 earthquake in Iran on 20 June 1990 and its aftershocks form a unique record of plate collision, which is manifested in both the body waves and the free oscillations. Continuous data for several weeks at regional and teleseismic distances is mandatory.
4. The technology available in 1990 makes it just as simple to maintain a continuous archive and to manage its input and output on a near-real-time basis as it would be to save only specified events. Requests for particular gathers of data from the DMS can relieve the researcher of a possibly time-consuming job of compiling the gathers from a general distribution medium.

The continuous archive thus complements the data products available elsewhere, and provides the broadest flexibility to the researcher, when needed. It has become attractive to operators of networks in the FDSN to deposit their continuous data in the IRIS DMS, thus relieving them of a major chore. The result is that the IRIS DMS archive provides a single access point for data in a truly global sense. This role places a responsibility on IRIS to be sure that the data is readily available on a global basis, a task which will become increasingly important in the coming five years.

Full Operational Status: (1991).

The currently operating facility at the University of Texas Institute of Geophysics has the status of a *functioning prototype*. In late 1990, an assessment of the lessons learned from this system will be conducted by the Standing Committee (with additional participants), and recommendations will be made for the implementation of the permanent operational database management system. The Prototype system in place now is designed to be largely independent of hardware: indeed, it could readily be adapted for management of a regional network. The two principal decisions which will have to be made are: (1) choice of a mass storage technology to be used for the next five years; (2) selection of a host institution. Other issues, of less strategic import, will involve the growth of the service role of the DMS beyond the management of the archive and the eventual movement to satellite or fiber optic transmission of data.

The program review will be followed by a Request for Proposal to IRIS member institutions who may wish to be selected as host institution for the operational DMS. While there are many strong reasons for remaining at UTIG, it is Executive Committee policy that other institutions should also have an equal opportunity to compete. The scope of the RFP and the criteria for selection are to be drawn up as a result of the program review.

At the present time the IRIS Data Management Center is a functioning prototype. Data from both Data Collection Centers are received on a weekly basis and archived. Major capabilities that are presently in place include;

- routine archiving of GSN, PASSCAL and GDSN data
- nearly real time access to significant earthquake data
- an electronic bulletin board
- an interactive data retrieval system available through Internet
- a distribution mechanism promoting the reuse of existing software
- an interactive method to determine data availability
- a method whereby data problems can be reported, tracked and resolved
- distribution of a program to translate SEED formatted data into common data analysis formats

Inquiries about data availability are common, and requests for data are now being serviced at a rate of about 2-3 per day, a number already in excess of the estimates made in the original design study. Small requests are served by electronic transfer over Internet, and larger ones by express delivery of 8mm helical scan tape or half inch tape. The archive now available consists of GSN, GDSN, SRO, ASRO, and CDSN data beginning January 1988, up to the most recent data, which reaches the archive normally within 60 days.

Design Studies

The GSN and PASSCAL programs will generate one Terabyte (10^{12} bytes) of seismic data per year when those systems are at their final projected sizes. An archive of that scale, with access services of the sort needed by seismologists, did not exist in 1986. Consequently, two design studies were conducted to allow IRIS to better determine the requirements of the Data Management System, and to develop a more concrete idea of the practical issues and the strategy for developing an archive. The initial report was prepared by Science Horizons, Inc. in 1986. This report presented a comprehensive summary of the anticipated data flow into the DMC, the functions that needed to be implemented within the DMS, and generally serves as an excellent background study. Many of the recommendations presented in the report have been implemented at this time. A second major design study was conducted by The Analytical Sciences Corporation (TASC). This gave more specific detail about the implementation of the DMS. Unfortunately funding levels for the IRIS program were smaller than anticipated and the TASC report could not be implemented in detail. Nonetheless, key elements of the implementation strategy were provided and justified by the report. These include the requirement that data be archived in two major sort orders as well as the importance of a network rather than a relational database management system. These recommendations shaped the design of the present DMS.

Structure of the Data Management System

The DMS encompasses data flow from the point that data is received from the network stations at a Data Collection Center to the archive to the user. The design is summarized in Figure 1 and Table 1.

1. Data are received at the Data Collection Centers (DCC) from network stations. This can be in the form of nine track tape, 8mm tape cartridge, or data telemetered over satellite link or common carrier (capability planned for Soviet stations, late 1990).

Table 1: Acronyms in the Data Management System

DCC	A network Data Collection Center: one at UCSD and one at USGS, Albuquerque.
DMS	The IRIS Data Management System: includes all networked elements from the DCC's to the archive to the user terminal.
DMC	The Data Management Center: the IRIS facility in Austin, TX, which houses the archive.
UTIG	The University of Texas Institute of Geophysics
CHPC	The Center for High Performance Computing, University of Texas, Austin
DBMS	The Database Management software resident on the IRIS SUN node at CHPC. May be the "prototype" or the "interim" package.
archive	The mass store at CHPC on which the data resides. Also refers to the data itself.
SEED	The new standard format for data recorded at seismic stations, adopted by the FDSN
FDSN	The Federation of Digital Seismographic Networks

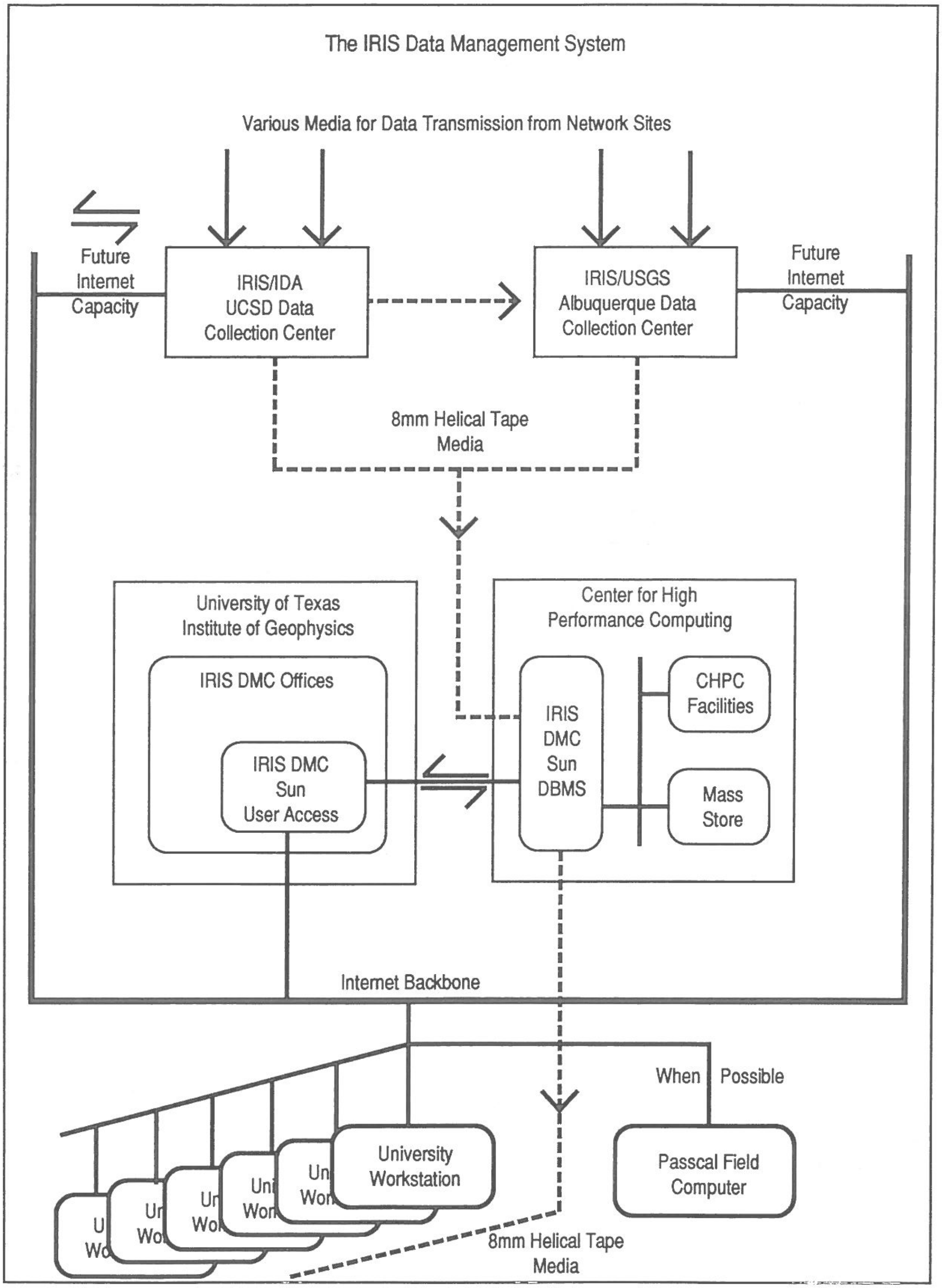


Figure 1 The IRIS Data Management System

2. The DCCs log the data stream, monitor station performance, and conduct a quality control screening of the data. Data are sent to the IRIS DMC by 8mm cartridge tape, and data from San Diego are also sent to Albuquerque where network data is staged for inclusion in the USGS CDROM product.

3. Data received at the DMC are read into the IRIS DBMS machine in the Center for High Perfor-

IRIS Data Management Center

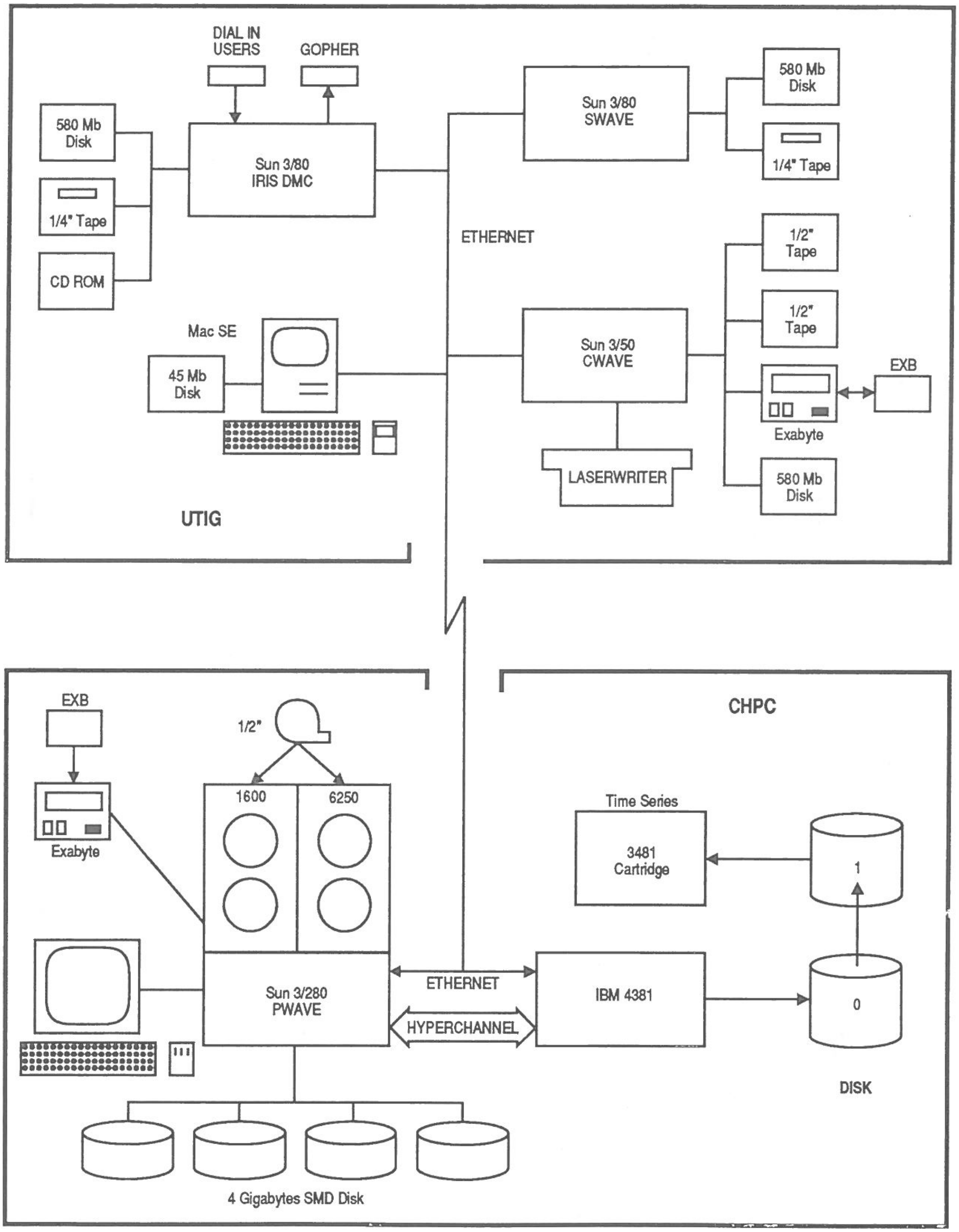


 Figure 2 IRIS Data Management Center

mance Computing and maintained physically on the mass store of the CHPC, via a hyperchannel link.

4. Users inquire about data and services through the bulletin board at Internet node *irisdmc* located on the Sun in the UTIG building. Requests for data are mailed to the DBMS machine, which services the request and builds the files for copying to the output medium. Large volume requests are sent on 8mm cartridge media, and smaller requests are directly transmitted over Internet.
5. Near-real time data in the GOPHER special archive are obtained through the IRIS DMC bulletin board over Internet.

The Facilities of the Data Management Center

Hardware Design

The architecture and design choices for the DMS facilities at the Data Management Center were dictated by the decision to utilize the mass storage system available in the Center for High Performance Computing. The system is an integrated IBM product based on a 4381 mainframe, a number of disk drives, and a group of 3481 tape cartridge drives. The 3481 cartridges hold about 750 mb of data in a robust auto-load cartridge design. The 4381 receives service requests for storage or retrieval of files from devices on the hyperchannel, such as the CHPC Cray, and transparently manages the storage of the files on the two memory systems. Files which are not accessed frequently are automatically staged out to the operator-mounted cartridges. A few thousand cartridges in a small storage room near the cartridge drives has a few-terabyte capacity. The system is optimized for service to a large computing facility. It has provided IRIS with a means of building a prototype data archive without making a final decision about the technology of the data storage medium.

The seismic waveform archive consists of station-day binary files maintained in the mass storage system. The DMS database residing on the Sun 3/280 contains the parameter information for the waveform files, pointers to the files in the mass store, and (1990) an event database obtained from the NEIC and the ISC. The db-Vista network DBMS on the Sun 3/280 manages this information. Its principal functions are:

(1) Receipt of new data volumes from the network. Stripping of the SEED header information into the database, and archiving of the waveform files on the mass store. Header validation and quality control.

(2) Receipt of and response to inquiries about the contents of the database.

(3) Receipt of and response to requests for data.

The principal exchange media for data into the archive are 9 track, half inch tape, 8mm Exabyte cartridges, and Internet. Direct satellite or fiber optic connection to the DCC's will be installed eventually, as the real-time element of the GSN evolves.

The DMC facilities at the University of Texas Institute of Geophysics consist of three Sun platforms:

(1) IRIS DMC: The user interface. The bulletin board, the GOPHER software and archive, and all other facilities which talk to the outside world operate on IRIS DMC. Requests for service from the DBMS or the archive are interpreted and transmitted to the database machine at CHPC. System and Center administration is handled from IRIS DMC.

(2) and (3): SWAVE and CWAVE are used by the Program Manager and the Senior Database Programmer for software development and maintenance.

During the startup period of IRIS, the responsibility for engineering the PASSCAL field computers fell to the DMS program. The hardware budget for DMS for 1986-90, then, includes the purchase of the six field computer systems currently in the PASSCAL Instrument Center.

Status of the DMS Archive:

The present archive principally represents data generated since January 1989.

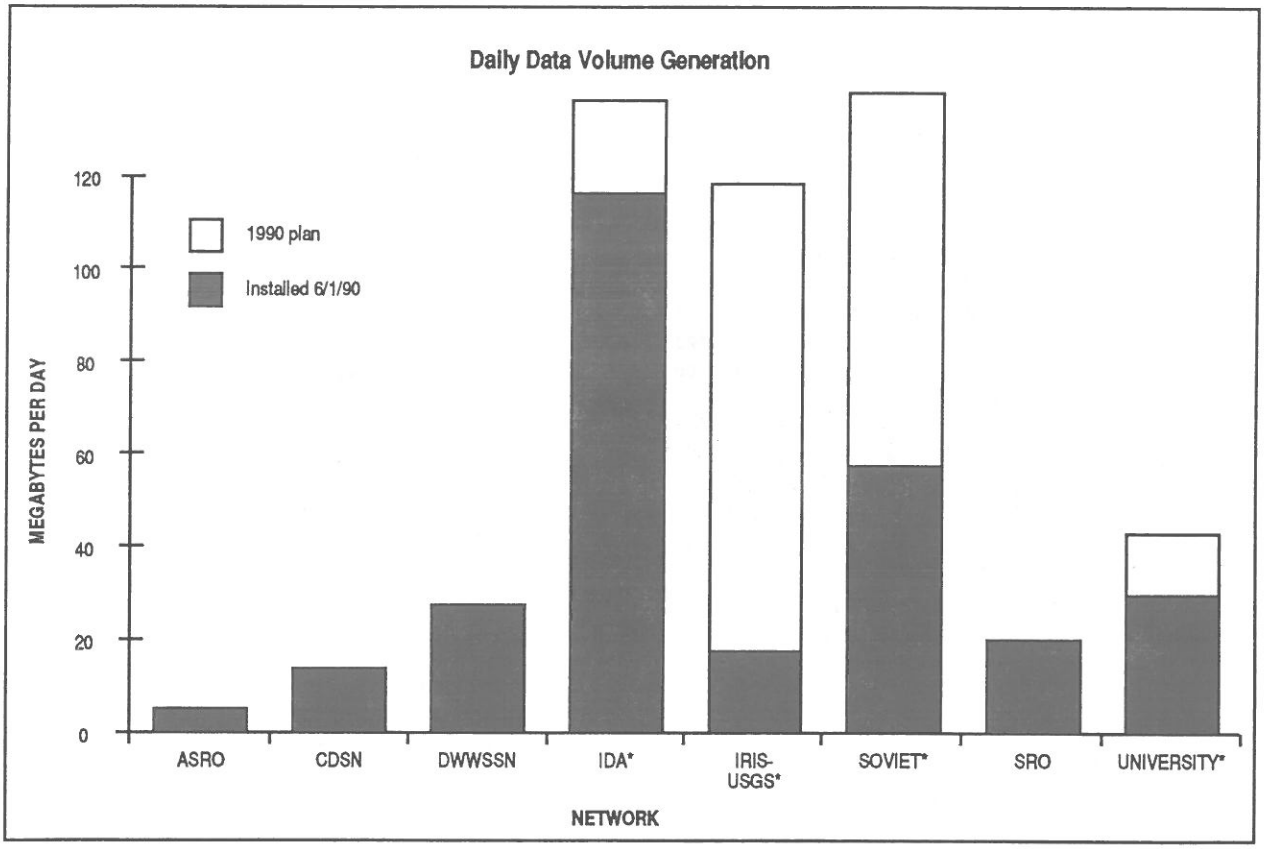
Volume	31 Gigabytes
Stations	49
Station-Days	15000

In addition to the complete archive of GSN data, the IRIS DMS maintains an online archive of 40 Megabytes of data from more than 150 earthquakes, retrieved from the IRIS open stations through dialup telephone access. Events are flagged for dialup on the basis of USGS NEIC bulletins, and are typically available within 3 hours of a significant event. For instance, within 2 hours after the Loma Prieta earthquake, IRIS members were able to access data from the IRIS DMC, view the data, and if desired transfer the data back to their home institutions. During the 24 hours following the Loma Prieta earthquake more than 100 accesses of the quasi real time system were made. Preliminary source mechanisms were calculated using these data. This real time data access system partially addresses the need to have the ability to quickly look at earthquake data soon after the event.

PASSCAL data sets are deposited in the archive in SEGY format. Data Collection Center functions, such as quality control, editing, and documentation are performed by the Principal Investigator using the Field Computer. Data is normally required in the DMS six months after the completion of data acquisition. Data is distributed as complete datasets, on 8mm cartridges or 9 track tape. Over 40 copies of PASSCAL datasets have been distributed in the past year. PASSCAL experimenters have been cooperative in meeting their obligation to produce a documented archival copy of their data, within 6 months of the end of acquisition, if possible.

Presently the IRIS DMC is routinely receiving data from 14 IRIS stations. These include 4 stations in the Soviet Union (ARU, GAR, KIV, OBN), 4 IRIS/IDA stations (ESK, NNA, PFO, RPN), and 6 stations handled by the USGS ASL DCC (ANMO, CCM, COR, HRV, KIP, PAS). These stations dominate the daily data flow into the IRIS DMC. Additionally the DMC receives data from 35 stations from established networks. These include 13 DWWSSN stations (AFI, BDF, CMB, COL, GDH, HON, KEV, LEM, LON, SCP, SLR, TAU, TOL), 13 SRO or ASRO stations (ANTO, BCAO, BGIO, CHTO, CTAO, GRFO, GUMO, KONO, MAJO, NWAO, SNZO, TATO, ZOBO) and 8 CDSN stations (BJI, ENH, HIA, KMI, LZH, MDJ, SSE, WMQ) and 1 station from the GSC (GAC).

New installations committed for the end of 1990 or early in 1991 will double the data flow into the archive (Figure 3).



Data Distribution Services

The primary role of the IRIS DMC is to distribute seismic data to the research community. Requests are serviced either by the DMC staff or may be directly entered into the DBMS user interface through Internet.

Three principal archives are available:

1. The continuous global seismic station data, consisting of IRIS GSN 20 sps data, supplemented by data from the older networks, archived in SEED format on the CHPC mass storage system.
2. PASSCAL data sets, archived in SEGY format on the CHPC mass storage system.
3. The online archive of data from major events, downloaded from the field by dial-up on a near-real-time basis.
4. Special customized data products, which are prepackaged for distribution. Normally these are global data sets from unusual or particularly important earthquakes or other sources.

The Bulletin Board: Information and Access to IRIS DMS

Information and access to the IRIS DMS is provided through the online Bulletin Board maintained at *IRIS DMC*. In addition to the computerized services listed on the Bulletin Board, phone calls or email communica-

Figure 4 Electronic Bulletin Board

ELECTRONIC BULLETIN BOARD

[telnet 128.83.149.25, login bulletin, password board]

Main Menu

Enter	a	ASSEMBLED data products
	b	BULLETINS of special interest
	c	CURRENT data holdings
	g	GENERAL INFORMATION
	h	HELP
	i	INFORMATION about IRIS contacts
	m	on-line MANUALS
	n	send NOTES to DMC staff
	p	PROGRAMS available
	ret	RETRIEVE data from Archive
	s	STATIONS and channels available
	u	USER comments, problem reporting
	q	QUIT

tions to Tim Ahern, the DMS Program Manager, and Becky Wofford, the System Manager are welcome.

Access via Database Management System (DBMS).

The principal database management development of the DMS has been the creation of a customized DBMS and interface for the archiving of continuous global data. A network database design has been built on top of the Unix database product *db-Vista*, from the Raima Corporation. The DBMS resides on the IRIS Sun which serves as the gateway to the CHPC mass storage system. The DBMS contains parameter information for all data files, along with links to the files in the mass storage system.

Its purposes are: (1) to permit users to generate on-line custom requests for data and (2) as a tool for the dynamic maintenance of the database by the DMS staff. This system has been under development at DMC by Senior Database Programmer Sue Schoch, and a prototype is now in active beta test. This "Prototype System" is organized internally to establish index relations between information in the database which is logically related in terms of the structure of the data. A network-design database, it is particularly fast in executing a search, in comparison with a comparable relational database. Users will be able to make very general queries of the database.

For the past year, a user application called the *Interim* system has provided elementary database services to users requesting data. In the past months, a user interface called *Retrieve* has provided a friendly interactive means of utilizing the Interim system. The *Interim* and *Retrieve* software were written for IRIS at UTIG and Lamont, respectively. While the *Interim* system has served the needs of the community for the past year; it will not be capable of handling a much larger archive, and is not a true DBMS.

The Prototype system manages the input of data into the archive, as well as servicing requests for data. It accepts input data tapes from various sources. Information describing the stations and channels is extracted from the input volumes, the network database is updated as necessary and the seismograms are transferred over a hyperchannel interface into the IBM mass storage system.

The Prototype system is now available for testing by users. Its natural interface is a standard Structured Query Language (SQL) input. The user's request can be used to generate a SEED output volume and the data sent to the user's home institution through a variety of transfer methods. Later this year, the prototype DBMS will be enhanced to include earthquake information generated by the National Earthquake Information Center (NEIC) and the International Seismological Centre (ISC).

A user-friendly graphic interface for local or Internet users now under contract should be available later in the year.

Utilization of the archive by the community

The DMS opened its doors for data requests in October 1989, using the *Interim* system. Initially all requests from users were routed through DMC staff, who generated the actual requests. With the completion of the *Retrieve* interface in spring of 1990, interactive access to the archive has been available.

Although this capability is quite new, it is being used frequently by IRIS membership. For a ten week period in early 1990, 31 requests for customized data sets were generated by the seismological community. The average size of the request was greater than 100 Megabytes. In just a two and one half month period, the IRIS DMS has placed more than 3 Gigabytes of seismic data in the hands of the seismological community.

In anticipation of certain data sets having broad appeal, the IRIS DMS routinely produces data products for events of special significance. At the present time, data products have been produced for the Joint Verification Experiment, the Armenian earthquake of December, 1988, the MacQuarie Islands earthquake of May, 1989 and the Loma Prieta Earthquake of October, 1989. A total of 252 copies of special data sets were distributed during the period from November, 1989 through March, 1990.

The TASC Design Study predicted approximately three requests for data per day. For the period of time from November 1989 through March 1990, the IRIS DMS was delivering data sets to our users at a rate of more than two volumes per day, even though the archive contains data for less than 2 years and is still in testing. It is estimated that a comparable number of additional users will be using the DMS when more historical data is installed and as the current data flow increases. Requests for data should grow by a factor of about four as the archive and its services mature in the next couple of years... a load of perhaps 8 data sets per day.

Data Retrieval in near real-time: the GOPHER system:

The ability for users to obtain data quickly from major earthquakes has been one of the top development priorities for IRIS, and was clearly identified in the Design Studies. A package was developed for IRIS by Steve Malone of the University of Washington based on the "open system" design of the standard GSN stations. Every open station maintains a dial-up port and a user interface to a local on-line archive in which large events are filed as they come in. The GOPHER system is notified of important events through the Alert Bulletins from NEIC. It then automatically dials up all suitably equipped stations and downloads the data into an online directory in the DMC.

Users may access the GOPHER archive via Internet. The services include viewing the list of available data, screen display [across the network, on the user workstation], and *ftp* retrieval of the waveform data.

The GOPHER archive begins with March 1989 and contains 165 events of M5.5 or greater. Data is obtained from 6 US stations and is archived in two forms: a 60 minute window of simulated long period data and a 3.5 minute window of unfiltered very broad band (VBB) data.

Ten new IRIS-2 GSN dataloggers are now in delivery from Martin-Marietta, for installation over the next 10 months by the US Geological Survey at sites designated in the GSN technical plan. All are equipped with the dialup capability, and nearly all will be accessible by telephone. The first is going into Matsushiro, Japan in fall of 1990. The IRIS/IDA dataloggers are scheduled for retrofitting with dialup capability, and many will be accessible to GOPHER.

This planned growth in the dialup program will require a more efficient access method than simply having the IRIS DMC serially dial up each station. It is planned to install more outgoing lines at the DMC and to install GOPHER at remote nodes where several stations can be concentrated into one file for retransmission to the DMC. Within the near future, the availability of affordable high data rate common carrier services should greatly simplify this entire process.

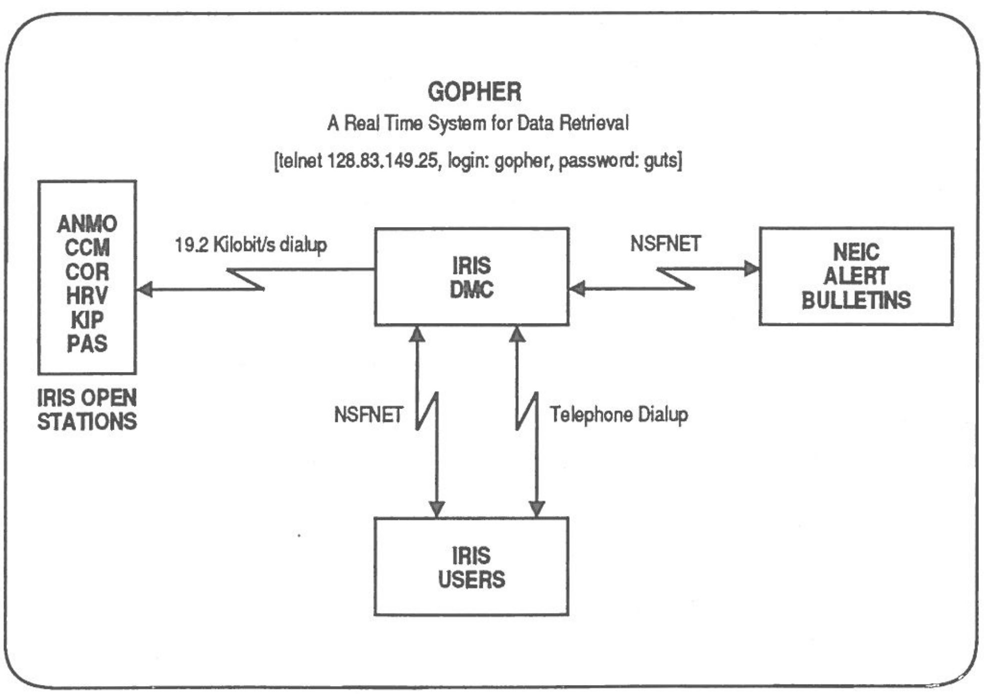


 Figure 5 GOPHER

PASSCAL Data Management:

PASSCAL data have traditionally been collected in some variant of the reflection/refraction experiment. As such, the data are naturally collected in common source gathers with a common time base, and fit naturally into the data formatting and processing methods used in the exploration industry. The basic path for PASSCAL data thus involves the following steps:

1. Data downloaded from field instruments is entered into the Field Computer at the local headquarters. It is screened for errors, plotted, filed onto disk, and reorganized into shot gathers. Experimental parameters are logged into machine-readable files.
2. The members of the scientific team take copies of the gathers back to their home institutions and go through a second stage of preprocessing and the initial stages of analysis, in order to establish to first order the value of the data and the most profitable path for analysis in depth.
3. At this point, several months after the end of field work, the data set is sent to the IRIS DMS in the form of a SEGY formatted 8mm or half-inch tape, along with documentation, usually as an ascii file.
4. IRIS DMS distributes data to those requesting it by merely sending a copy of the SEGY dataset and the documentation. At this point, the requester must deal with the original experimenters for further assistance.

Data from the 1986 PASSCAL Ouachita and Basin and Range Experiments have been transmitted to the DMS.

The earthquake data sets collected by the Archean-Proterozoic experiment and the Loma Prieta aftershock experiment present a very different set of problems. Development of software to deal with the flow of this kind of data is a top priority for IRIS planning for the next couple of years.

Software Services

The IRIS DMS develops, supports, and distributes a variety of utility software needed to simplify and standardize the task of the researcher working with digital data. This includes software which has been developed by members of the community and software whose development and documentation DMS has directly supported. The evolution of these services has been dependent on input from the research community, which, through the Standing Committee, provides guidance to the DMS staff. Nonproprietary products are distributed as C source code, for implementation on Sun workstations. In response to requests, this support will be extended to microVax workstations. Currently, DMS provides support for the following:

Table 2:

Electronic Bulletin Board	Entry point to DMS for most information and service needs	Developed and managed by DMS.
GOPHER	Automated dialup and retrieval of event data from GSN stations	Developed at University of Washington. May be installed at remote sites as a concentration point for data retrieval.
RDSEED	Reads FDSN standard SEED data volumes. Outputs SAC, AH, or unformatted data.	Developed, documented, supported by IRIS, with USGS. Now widely ported to national and international users.
SEED Toolbox	Source language tools for building SEED applications	Developed & Supported by IRIS
SAC: Seismic Analysis Code	Developed by Lawrence Livermore for manipulation and analysis of 3-component network data on a workstation.	LLNL maintains the code, IRIS distributes it.
Format conversion utilities	SEED, SAC, AH, CSS, SEGY	IRIS supported
Retrieve	User interface for access to the DMS Interim database system.	Written at Lamont-Doherty. Supported by DMS.
ZPLOT	Package for display and hardcopy of trace gathers on Sun workstation.	Developed by the University of Utah. Distributed and maintained by IRIS under agreement.
SierraSEIS	Seismic reflection processing . package	Sold and supported by Sierra Geophysics under agreement with IRIS.

Table 2 (cont)

Sierra Modeling Programs	Synthetic seismogram and ray tracing programs.	Sold and supported by Sierra Geophysics under agreement with IRIS.
Field Computer Software	Utility package for Passcal field experiments	Developed by DMS. Requires continued multi-year effort to upgrade.

The Standard for Exchange of Earthquake Data (SEED) format was adopted as an international standard by the Federation of Digital Broadband Seismographic Networks. In order to speed up the difficult process of conversion from many different formats to SEED, IRIS DMS wrote a portable program which reads SEED data volumes and translates the data into conventional internal trace formats. Source code for RDSEED has been distributed to nearly 100 users in several countries who use it routinely. IRIS has agreed to continue to maintain this software and be responsible for documentation. In addition to the SEED reader, IRIS DMS has issued a "SEED toolbox", a documented package of utilities and code modules to assist network operators to build systems which manage SEED format data.

The DMS serves as a distribution point for utility and applications software developed in the research community. Beyond the basic functions of the data archive, it is preferable that software standards evolve out of the initiative and coordination among people active in writing and using software. Thus, the IRIS distribution service serves mainly as a supermarket where it is simple to obtain information and software. IRIS will distribute a particular piece of software only if it is adequately tested and documented, and, in some cases has made a small investment into generating documentation and "bulletproofing". Currently available software is listed in Table 2.

The SierraSEIS reflection package is offered for purchase by IRIS members under the terms of an agreement with the vendor, Sierra Geophysics. IRIS has adopted this software as a current standard for use on the Field Computers and for other utility work requiring the management of multitrace gathers of the sort used in reflection seismology.

The IRIS DMS is cooperating with the PASSCAL program in setting up a SierraSeis Service Center at Lawrence Berkeley Labs to coordinate SierraSeis activity within the IRIS community. The SSSC has written an extensive set of supplements to SierraSeis, called IRISSeis, which adopt the package to the kinds of data acquired in PASSCAL field experiments. The SSSC also coordinates a SierraSeis users group, which speeds up the process of putting new modules and capabilities into the community. We expect the DMS role in this area to increase significantly in the future.

A "version 1" field computer package was written by Tim Ahern, the DMS program manager, for the first PASSCAL field computer, for use in the 1988 Basin and Range experiment. It translates the format of the data packets from the PASSCAL instrument into standard trace sequential form, and allows rapid display and analysis of the data. The choice of a Sun for the hardware was based largely on the ease with which utilities and filters could be written for the field computer in the spirit of the Unix toolbox. Continued evolution of this software is taking place under the coordinated efforts of the DMS and the PASSCAL Instrument Center.

Documentation

The DMS is naturally required to serve as a documentation center for users of digital seismic data. Since IRIS cannot put major resources into a formal documentation effort, much of the documentation of software and DMS services is maintained online or through self-documentation of software. SierraSeis has its own support center at Lawrence Berkeley, with its own documentation and manual pages.

The importance of the SEED format as an international standard has required IRIS to produce a professional level of documentation which can be widely distributed. Working in close cooperation with the USGS and the FDSN, the IRIS DMS generated a comprehensive SEED reference manual. This reference manual has been distributed to approximately 300 seismologists worldwide.

A SEED Programmers Manual is being prepared, to support the utilities needed by network operators and data managers for reading, writing, and translating SEED format.

Community Participation

Program oversight is under the Standing Committee for the DMS, whose members serve in two year rotation. The Standing Committee makes all major strategic decisions for the DMS. In particular, the Committee determines the particular services and capabilities which are most important to the community. The following members of the scientific community have served on the Standing Committee.

Current Members

Dr. E.R. Engdahl (Chairman)	USGS	Dr. J. Nabelik	Oregon State University
Dr. S. Alexander	Pennsylvania State University	Dr. B. Minster	U. C. San Diego
Dr. K. Nakanishi	Lawrence Livermore National Lab	Dr. C. Frohlich	University of Texas, Austin
Dr. W. Menke	Columbia University	Dr. T. Tanimoto	Caltech
		Dr. S. Malone	University of Washington

Past Members

Dr. L Johnson	U. C Berkeley	Dr. L. Ruff	University of Michigan
Dr. R. Crosson	University of Washington	Ms. A. Kerr	CSS- DARPA
Dr. F. Tajima	University of Texas, Austin	Dr. D. Simpson	Columbia University
Dr. A. Levander	Rice University	Dr. J. Woodhouse	Harvard University
Dr. G. Pavlis	Indiana University	Dr. M. Backus	University of Texas, Austin
Dr. J. Orcutt	U. C San Diego		

Liaison with Other Networks

The IRIS DMS acts as the interface between IRIS and other data generating broadband stations around the world. The goal of having some of the GSN siting targets filled by other networks in the FDSN is only possible if the DMS archive receives and distributes data from such sites in a seamless manner.

Within the US context, digital data from several older networks and from newer non-NSF programs is handled by the DMS, including the China Digital Seismographic Network (CDSN), the Advanced Seismic Research Observatories (ASRO), the Seismic Research Observatories (SRO), and the Digital World Wide Seismological Station Network (DWWSSN).

Growing interest in rebuilding US local and regional networks will probably result in a significant increase in the quantity of broadband digital data being produced in this country. This growth is at a particularly early stage now. The new U.S. National Seismic Network has completed its development efforts and is beginning a program of station installation. The southern California TERRASCOPE network of VBB stations is being expanded about the IRIS/Caltech station at PAS and the UCSD PFO station. Integration of these efforts with the IRIS DMS will be a major organizational task for the near future.

Internationally, IRIS has offered to act as the archive for all continuous data recorded by the FDSN. Agreement has been reached for data to be sent to the DMS by the GEOSCOPE network, the ORFEUS array, and stations of the the Geological Survey of Canada (GSC). The IRIS DMS is cooperating with the Japanese operators of broadband stations, the scientists at the Grafenberg Array in Erlangen, West Germany and several other non-US operators of broadband stations. These arrangements not only provide US scientists with access to a major resource of non-US data, but provide non-US scientists with a central point of access to global data.

Data is regularly distributed on request to seismologists outside of the IRIS member institutions. In the U.S., DMS data have been utilized by the U.S. Geological Survey, Lawrence Livermore National Laboratory, and the Air Force Geophysical Laboratory. Data have been distributed to foreign colleagues in France, Germany, the USSR, Great Britain, Japan, Taiwan, and the Netherlands.

The goal of the IRIS DMS is to simulate as closely as possible the scientist's ideal data source: one which is rapid to respond to any inquiry or need, one which delivers information or data in exactly the form desired, one which anticipates all needs and inspirations. Like the engine with 100% efficiency, this ideal can not be achieved. However, it is kept as a goal.

We are adopting the following goals for the next five years, as the DMS goes into full operational status.

- Grow in capacity as networks and arrays grow
- Maximize service, convenience, and responsiveness
- Archive worldwide continuous VBB data
- Achieve a high level of quality control
- Develop the means to manage earthquake data from portable arrays

The transition to full operational status will require a formal program review, followed by issuance of an RFP and selection of a host institution. The past five years has been a period of definition, development, and prototyping. The development of a modest interim capability has led to an improved understanding of the kind of functionality and service which the scientific community needs from the DMS. The DBMS and the operating architecture which are now in prototype will be the core of the operational system, but many technical choices remain, particularly the choice of mass storage technology.

A High Capacity Operational DMS

The growth in the data load at the DMS may be estimated, based on the five year plan for building the GSN and PASSCAL facilities. The increase in data from the GSN will come in an orderly, planned fashion, as about 15 stations go in each year. The potential data load from PASSCAL arrays deployed for earthquake recording exceeds the data from the GSN by a substantial margin.

The feasibility of handling this kind of growth is based on the rate at which new data handling technologies are transforming performance limits. In the very near future, it will be possible to store the entire annual output from the 100 station GSN on 5 video cartridges. Satellite-based cellular communications capabilities will open up data transmission possibilities. On the other hand, the growing data flow in Figure 6 will come to a steady state, as the capacity of the community to deploy instruments and analyze data is going to be manpower limited at some point.

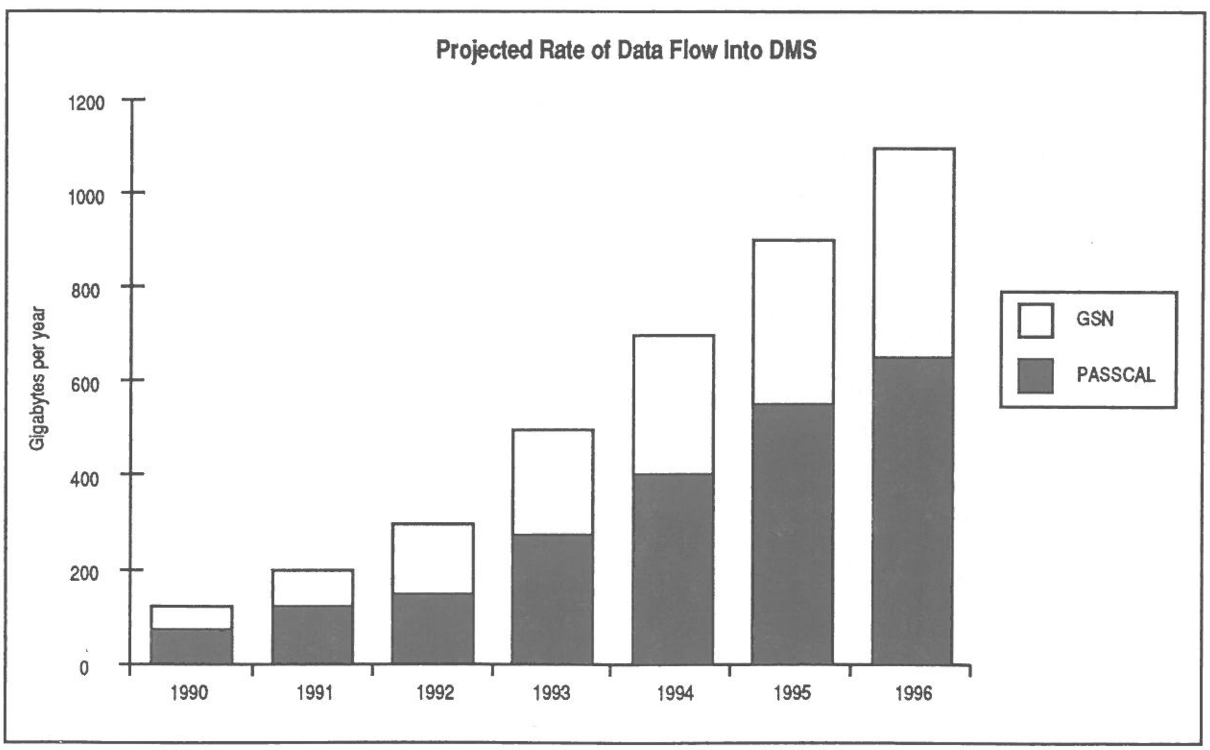


 Figure 6 Projected Rate of Data Flow into DMS

PASSCAL data sets are more variable in size but it is clear that they can easily exceed the data volume generated by the GSN. An example to illustrate this point can be given from IRIS' experience after the Loma Prieta Earthquake. Starting on October 18, 1989, 22 PASSCAL instruments were deployed for a ten day period after the Loma Prieta earthquake. These instruments recorded approximately 100 aftershocks per day during this period. Trigger windows were set to 90 seconds and sampled at 200 samples/s. Each PASSCAL instrument was recording 6 channels. Therefore each instrument recorded 21.6 Megabytes of data per day. If there had been a full Passcal deployment of perhaps 100 instruments then more than 21 Gigabytes of data would have been collected in the ten day period. Since it is anticipated that there will be 1000 PASSCAL instruments within five years this translates into several hundred Gigabytes of data generation per year. In principle there is no difference between aftershock PASSCAL deployments and GSN data sets. The growth of the archive can be drastically impacted by PASSCAL data in a manner that is not yet completely understood.

The GOPHER system places a relatively small demand on the storage systems at the IRIS DMC. In fact all earthquake data that has been retrieved by telephone is still stored on a single disk on the main user computer at the DMC. At present only six IRIS stations that have dialup capability are presently installed. In the future it is possible that this number would increase to around 50. At that time a more sophisticated system of retrieving these data from the field would be required, but the archive would still be small.

The more difficult issues with growth have little to do with the size of the archive, but lie with application software. Our community is not large enough to attract commercial software, yet the tasks are often too complex for the single scientist-programmer. Here, a focused effort by IRIS, bringing some resources to bear in critical areas, can make a difference.

We consider the principal hardware issues.

Mass Storage systems

One of the major reasons the prototype DMS facility was housed at an IRIS institution with an mass storage system was to defer making any irreversible choices in mass storage technology at a time when this technology was changing rapidly. Not only are there now interesting mass storage options that did not exist two years ago, but the type of integrated mass store we have been using is now clearly seen to be inappropriate. It is necessary to maintain two copies of the data in predetermined sort orders. Control of sort order of individual files is not permitted on existing mass storage systems as implemented in the supercomputer environment. Moroever the bandwidth between the DMC database computer and the mass store system is inadequate for reasonable data retrieval speeds.

To meet the needs of our users it is clear that the IRIS DMC must acquire a mass storage system that directly connects to the DMS database machine. At the present time affordable alternatives exist that can archive over five Terabytes of data. These systems possess both higher bandwidth to the DMS computers and permit complete control of the sort order of the data files. Present options including D1 video cartridge technology or helical scan DAT data recorders can provide an affordable mass storage system with performance that can satisfy the needs for throughput and speed.

Enhanced Capacity and Response of Communication Links

Since the IRIS DMS has adopted a non-centralized data management system, it is far more important for the DMS to place an emphasis on communication. In the future it is anticipated that the IRIS DMS will install satellite transmission links between the most significant nodes in the DMS system. These will consist of the DCCs in San Diego and Albuquerque, the DMC in Austin, TX, IRIS headquarters and the US National Seismographic Network at the NEIC in Golden, Colorado.

At the present time, most data distribution takes place by physical media. The largest delay in actually providing data to a user is the time it takes to physically transport the physical media from the archive to the user's home institution. For certain small datasets, the DMC has already transferred SEED distribution volumes over the Internet. In the future it is anticipated that electronic transfer will become more widely used. For this reason it will be important for the DMC to coordinate its activities with those of the developers of the computer networks in the country. This approach has been coined IRISNET and it is likely that significant resources of the DMS program will be directed towards improving the communication links between the major nodes of the DMS and IRIS members.

New Services

The principal service goal of the DMS is to see that the basic data access is as convenient as possible. Additional services can be provided, under the priorities given by the Standing Committee. Enhancement of near-real time access to data and partial browse capability are the most obvious possibilities.

Near-real time data

The detailed information about earthquake source dynamics which can be obtained from digital VBB instruments now puts some real urgency into making this data available within minutes after a major earthquake. The GOPHER system provides a demonstration of this capability, which will be expanded as other dial-up stations are installed in the GSN. Substantial upgrading in the way this information is downloaded will be required as the number of open stations increases substantially. At the present time the IRIS DMS has supplied this software to the TERRASCOPE group at Caltech and to the ORFEUS Data Center in the Netherlands. These organizations will act as data concentration centers for stations equipped with remote access in their vicinity.

Expansion of rapid access to data beyond dial-up will depend on the feasibility of adding satellite communication to the GSN. Satellite telemetry throughout the GSN-DCC-DMS system has been a long-term goal for IRIS since the 1984 Program Plans were developed. It is planned to adopt satellite telemetry as particular opportunities make it practical and affordable to do so. The Soviet program, for example, is funded to put in telemetry from the GSN sites to the Obninsk DCC, while the Obninsk-San Diego link is already in place. The immediate practicality of doing this for the bulk of non-US sites is still unclear, however. Within the US, the KU band satellite telemetry being used for the US National Network might augmented to provide domestic services which assist the IRIS goals. Satellite based cellular telephone service and greatly enhanced availability of fiber optic capacity are just around the corner.

Data Browsing

Due to the large volume of data archived at the IRIS DMC it is impossible to browse the entire archive on a random basis. Often researchers are not certain exactly which stations may have recorded the type of information they are searching for. These users require an ability to "browse" through a series of waveforms and selectively pick seismograms.

Because the waveforms must be stored in a mass storage system, it does not appear that an immediate browse capability will be developed during the next five years. However the concept of having a "Delayed Browse" is very possible. The delayed browse would work as follows. An IRIS user would specify an initial subset of the archive believed to contain the information being sought. This request would be specified using normal procedures for making data requests with the exception that the distribution medium would be designated as "browse". The DMC would not transfer the data to the user after it had been assembled. Instead the browse dataset would be assembled and placed on disk. The user would then remotely activate a program that would present the preassembled traces in a variety of sorted orders. A point and click interface would permit selectively accepting or removing traces for a subsequent data request. The browsing process would result in a smaller subset of data being delivered to the user either electronically or by physical media. Technically the delayed browse capability is possible now.

Path Search Capability

The prototype database management system that will be released during 1990 has the ability to request data either by station-channel-time windows or by seismic event. The prototype system has a limited ability to access data whose ray paths traveled through a specific portion of the Earth at their midpoint. The retrieval of seismograms that have passed through a particular volume of the Earth is a much more complicated problem. The number of possible ray paths is too numerous ever to include the necessary information in any type of database. For this reason a considerable amount of effort must be directed toward solving the general ray path problem. This may be solved by a dedicated high performance computational node. The output of the path program would result in a request for data by standard station-channel time windows.

Although this functionality was requested by many members of the community in 1986 during the Design Study, it is not yet clear precisely how people are going to organize their access and inquiry of a very large database. Some additional effort will be required by the Standing Committee to decide what the community actually needs, based on the early experience with the DMS archive.

Reusable Software

In the past, a considerable amount of effort at each university has been directed toward the development of software to solve problems that have already been solved elsewhere. It is no longer reasonable to expect every researcher to write software from scratch. The IRIS DMS has already taken steps to distribute certain types of software that are generally applicable. These include data analysis packages such as Seismic Analysis Code (SAC) produced by Lawrence Livermore National Laboratory, SierraSEIS produced by Sierra Geophysics, Inc and AH, a time series analysis tool distributed by Lamont Doherty. The IRIS DMS internally developed a method by which SEED formatted data exchange volumes can be easily converted into other formats.

In the future it will be part of the DMS task to determine what types of data analysis tools, plotting capabilities, and user interfaces are of general use in the community. The DMS will either develop these tools internally or issue contracts to either universities or other organizations to see that these tools are developed.

With some coordination by the DMS, a good deal of duplicated effort can be avoided.. Seismologists can spend more time doing science and less time writing software. By adhering to programming standards and making use of computer standards such as X-Windows the DMS should be able to produce tools that are portable from one system to another and thereby support the vast majority of university computer systems.

User Training

The IRIS DMS will devote considerable effort to making the systems that it develops easy to use and yet flexible enough to solve even the most demanding problems. The key to successful use of sophisticated systems is the ability to allow university users to have a good understanding of how the entire DMS system is designed and how it can be used to meet both data and scientific needs.

For this reason, it is the intent of the IRIS DMS to develop comprehensive documentation and training courses. Facilities will exist at the DMC that will allow an interested user to gain a usable understanding of the DMS system as it applies to their particular problem.

Many other possibilities for DMS service exist. For example: the promotion of station processing software as promoted by ISOP, the digitization and archiving of historical seismograms, the development of methods to characterize waveforms and their inclusion in the database management system.

Worldwide Coverage

Data from other networks

The increasing likelihood that other network operators may want to adopt the IRIS DMS for the archiving of continuous VBB data provides an excellent opportunity to achieve integration of global seismology *from the viewpoint of the user*. The extension of the scope of the DMS beyond the GSN to the VBB stations of every country is perhaps the single greatest change in scope of the DMS in this second five year program. It raises the requirement that IRIS be prepared to provide reciprocal access by seismologists from all countries to the DMS archive.

This year marks the start of the effort to merge data from existing VBB networks with the archived data from the GSN and PASSCAL programs. Most of the other networks support the SEED format, which will make the task of merging the data much simpler. These networks include those of France (GEOSCOPE), Canada (CNSN), Italy (MEDNET), Japan (POSEIDON), US National Net (USNSN), Europe (ORFEUS). In most cases it is anticipated that the data will actually be archived at the IRIS DMC.

In some instances the volume of data would be too large to consider storing at the DMC. In this later case software will be developed that will allow the access to these data in a simplified manner from the perspective of the researcher. Perhaps the most significant example of this will be the interface between the Center for Seismic Studies (CSS) database and the IRIS Data Management Systems database. Since both systems use the Structured Query Language as the database access method, it is anticipated that problems in this area will be minimized.

It is the goal of the IRIS DMS to have all IRIS users look to the DMS for all of their data requirements. If the data do not actually reside within the DMC archive, the interface procedures will be clearly established that will make accessing the data from the other archive simple. It is important that the researcher making the request does not have multiple data formats complicating his task. For this reason it will also be necessary to produce format conversion software that will translate data formats such as CSS format into SEED format. In principle this method of accessing seismic data from other sources applies to data from any other network, including regional networks, foreign networks, and even PASSCAL natural source data. Remote databases must be seamlessly integrated with the DMS system.

Quality Control

The Data Management program has been assigned overall responsibility for quality control of data throughout the IRIS program. For this reason, the operations of the Data Collection Centers have come under DMS oversight. The importance of uniform quality control can be seen by reading the Bulletin Board: "*... the data is wonderful, but the leads were reversed at station XXX for 18 months*". A recent field report from the ESSP array experiment at Pinon Flat followed two pages of raves about the revolutionary new data with 8 single spaced pages detailing bugs in the flow of data.

Project GEOSCOPE, which has been operating for eight years, has an impressive protocol for quality control. Quality control is the hallmark of a mature operation.

The implementation of an effective quality control program is as much a matter of organizing the way in which different people work together for this purpose as it is a matter of putting in quality control software in the DCC's and the DMC. The process will begin in fall of this year with a meeting of the network operating personnel and representatives from the Standing Committees.

Support of Standards

The distributed nature of the DMS, with its Internet skeleton, imposes a need for strongly compatible data handling software. It is planned that the DMS will start providing a full implementation of standards such as X-Window interfaces which allow software running on DMC computers to generate the appropriate displays on systems at IRIS members home institutions. This approach will also limit the amount of hardware dependence in the systems being developed.

The DMS will continue to be a strong advocate of the SEED data exchange format adopted by the FDSN. By providing data in a common format the DMS has already simplified the data handling problems at a users home institution. Although all data shipped by the DMS will continue to be in SEED format, the IRIS DMS will expand the number of data formats that the SEED data can be transcribed to. This may be done within the SEED reading program already being distributed by the DMS or it may be through standalone data translators. The complete list of formats that will be supported has not yet been determined but will certainly include the Center for Seismic Studies (CSS) format, SAC format, AH format and probably RETRIEVE files supported by the USGS NEIC. The IRIS DMS will continue to produce the documentation for the SEED format and make it available to members of the FDSN.

Management of data from portable arrays

Initially it was planned that PASSCAL data would be distributed as a simple dataset based on the SEGY format. The IRIS DMS presently distributes PASSCAL data in this manner. However, the recent Loma Prieta Earthquake and the Archean-Proterozoic Experiment have made it clear that earthquake data acquired by portable arrays needs to be managed just like earthquake data recorded by the GSN or any other fixed network.

It is the goal of the DMS to develop field computer software that will allow PASSCAL natural source data to be quality controlled and then output as SEED volumes. In so doing the PASSCAL data could be merged into the DMC archive. We anticipate that much of the needed functionality can be obtained by cloning the prototype DBMS to the PASSCAL field computer. The development of quality control procedures for the PASSCAL field computer will continue to be a responsibility of the DMS program. The implementation of the necessary hardware and software will be shared by the PASSCAL and DMS programs.

The software for the PASSCAL field computers represents one of the most difficult development challenges faced by IRIS. The basic requirement is for a rapid, bulletproof, powerful package of tools for preprocessing data which is read in from the field units. It ought to have a user-friendly database and window interface, permit the flexible display of large, complex data sets, have tools for earthquake event identification and sorting of gathers. In short, a powerful, state-of-the-art applications package which would cost a million dollars if written by a commercial software firm. This is a nice illustration of the rule of thumb that software is now much more painful and difficult to obtain than the hardware. The desirability of such software is the greater since it would also meet a major need on the university workstation.

Portable arrays recording earthquakes will function like regional or local networks. It will be necessary to port or develop network utility software for the field computers to manage the problems of event association and location.

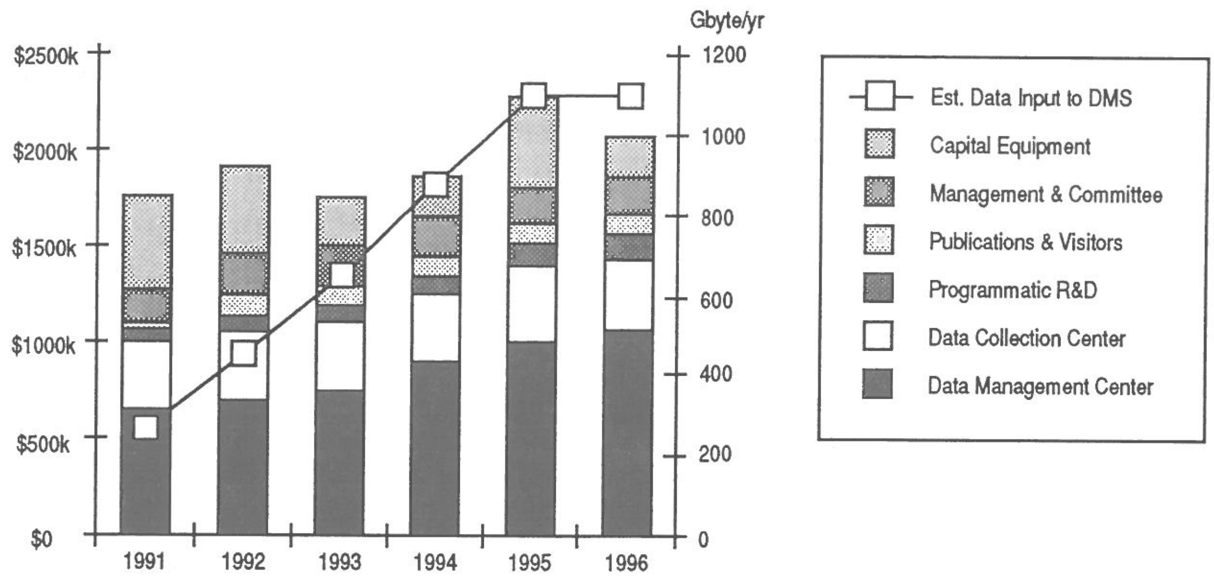
Controlled source PASSCAL reflection and refraction experiments will be continued to be distributed as complete datasets. Reporting standards for documentation and data presentation will be distributed, under the sponsorship of the Instrument Center and the DMS.

The cost structure for the Data Management System is unlike that of the other Programs. It consists of:

- A fixed salary and facility cost, required for maintenance of the DMC, including reinvestment in hardware.
- Incremental cost of salary, supplies, and incidentals, dependent on the service load to the community.
- Incremental cost of mass storage.
- Continued R&D costs
- Cost of operation of the San Diego DCC

It is assumed that continuing increases in the density and decreases in the cost of mass storage, as well as similar improvements in the capacity of networks, will largely offset the increase in input and output to the DMC associated with the growth of GSN and PASSCAL. The overall fractional growth of DMS cost is thus much less than the other programs. By the same token, relatively little is saved by setting a much lower rate of growth for GSN and PASSCAL

DMS Five Year Budget



Programmatic R&D represents the cost of essential software development to facilitate the user access to and interface with data from the IRIS facilities. It is probably a factor of five or ten less than the cost of producing professional quality software for seismic data manipulation in a modern workstation environment, and represents a minimum allowance for basic functionality.

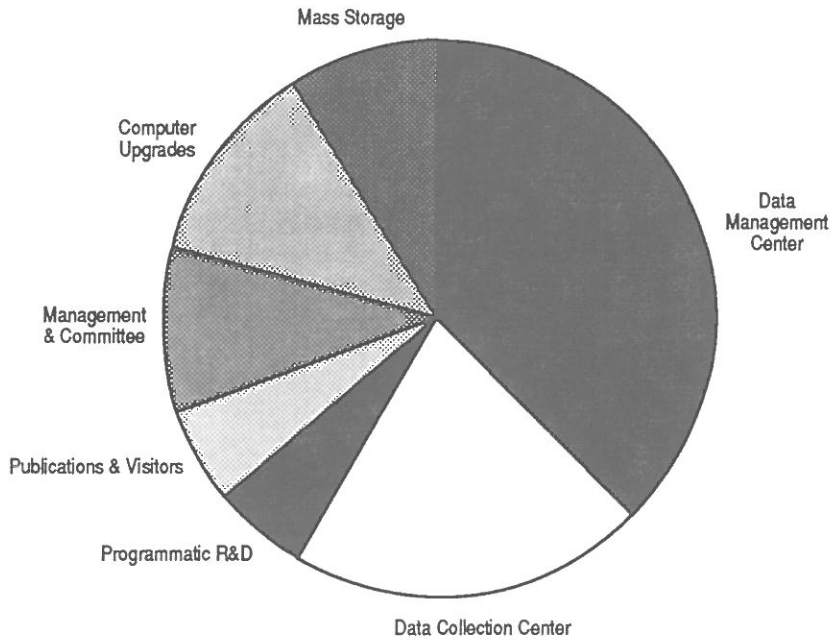
Some capital reinvestment is shown to maintain the hardware capability of the DMC equipment at the state of the art, and in response to the increased load.

The detailed budget breakdown for DMC costs shows a mixture of IRIS direct costs with the subcontract to the host institution for space and other support. This reflects the current arrangement with the University of Texas Institute for Geophysics. A competitive selection will be conducted in early 1991 to determine the host institution and program management plans for the next five years. The line-by-line breakdown from that point on would reflect the arrangement with the newly selected host. In particular, much of the direct salary charge to IRIS could move to the host institution subcontract.

Management includes the salary, benefits, and travel of the Program Manager, travel and incidental expenses of the Standing Committee, and other incidental costs.

The Data Collection Center at the University of California, San Diego is now administered under the IRIS DMS. The budget shows a prorated fraction of the full expense of operating this DCC, based on the IRIS/IDA stations not covered by the Eurasian Seismic Studies Program. Although under DMS oversight, the DCC operations at Albuquerque are funded by the USGS under the language of the Memorandum of Understanding.

DMS Projected Use of Funds 1991-95



DMS Recommended Five Year Budget Plan	1991	1992	1993	1994	1995	1996
	All Amounts in thousands of dollars					
end of year statistics						
Number of GSN	*45*	*59*	*73*	*87*	*100*	*100*
# of Passcal channels	*1200*	*2250*	*3450*	*4725*	*6000*	*6000*
Data Volume (Gbyte/yr)	*274*	*475*	*675*	*876*	*1077*	*1077*
Number of staff	*5*	*6*	*6*	*7*	*8*	*8*
Operations						
Salary: Base	250.0	300.0	300.0	350.0	400.0	400.0
Benefits	62.5	75.0	75.0	87.5	100.0	100.0
Travel Staff	40.0	50.0	50.0	50.0	50.0	50.0
Committee	32.0	32.0	32.0	32.0	32.0	32.0
Supplies & Services	95.0	109.3	125.6	144.5	166.2	191.1
Publications	40.0	40.0	40.0	40.0	40.0	40.0
Visitor support	0.0	50.0	55.0	60.5	66.6	73.2
Total Operations	**519.5**	**656.3**	**677.6**	**764.5**	**854.7**	**886.3**
Subcontracts						
IDA/UCSD DCC	350.0	367.5	385.9	405.2	425.4	425.4
DMC host inst. support	190.0	190.0	190.0	190.0	190.0	190.0
Hardware Maintenance	50.0	55.0	60.5	66.6	73.2	80.5
Software maintenance	100.0	110.0	121.0	133.1	146.4	161.1
Software development	75.0	82.5	90.8	99.8	109.8	120.8
Total Subcontracts	**765.0**	**805.0**	**848.1**	**894.6**	**944.8**	**977.8**
Total Operating costs	**1284.5**	**1461.3**	**1525.8**	**1659.1**	**1799.6**	**1864.1**
Capital equipment						
Maintenance of facility	200.0	200.0	200.0	200.0	200.0	200.0
Mass Storage	250.0	250.0	0.0	0.0	250.0	0.0
Total Capital Equipment	**450.0**	**450.0**	**200.0**	**200.0**	**450.0**	**200.0**
Total	**1734.5**	**1911.3**	**1725.8**	**1859.1**	**2249.6**	**2064.1**

Data Management System budget plan for 1991-95
Designed for recommended GSN and PASSCAL strength

IV. Technical Plan for a New Global Seismographic Network

INCORPORATED RESEARCH INSTITUTIONS FOR SEISMOLOGY

AND THE

UNITED STATES GEOLOGICAL SURVEY

CONCURRENCE

This Technical Plan for a New Global Seismographic Network represents the coordinated position of the organizations responsible for implementation and operation of the Global Seismograph Network. The Plan will be amended or modified periodically with the concurrence of the responsible organizations.

National Science Foundation

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United States Geological Survey

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Incorporated Research Institutions for Seismology

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1. INTRODUCTION

A major initiative is underway to modernize the global seismograph network by deploying a new generation of broadband seismograph systems, and improving data collection and data management facilities. The deployment of the Global Seismograph Network (GSN) is being funded by the National Science Foundation (NSF) and led by the Incorporated Research Institutions for Seismology (IRIS) in cooperation with the U.S. Geological Survey (USGS). Once in place, the management, maintenance, and upgrading of the GSN will be funded by the USGS and NSF.

IRIS is a non-profit consortium of 61 universities in the United States, which includes virtually every university with a research program in seismology. IRIS was established in 1984 for the purpose of creating and managing new research facilities in seismology. IRIS acts as the agent for the National Science Foundation for the development of national research facilities in seismology.

The goals and objectives of the IRIS program to upgrade the global seismograph network are documented in a report published in 1984, entitled *Science Plan for a New Global Seismographic Network.* It states: "the goal of a new generation global seismograph network is to produce broadband, wide dynamic-range digital data from a global network of at least 100 stations and provide for the timely collection and distribution of these data to a wide variety of users." The authors of the Science Plan also used the term 'evolutionary' to characterize the new network, in the sense that it must be upgradable and supportable well into the twenty-first century.

IRIS and the USGS share a common purpose in developing the new GSN in supporting seismological research. In 1984 a cooperative agreement was adopted by IRIS and the USGS to coordinate joint activities and contributions in developing and managing the new GSN (see Appendix 7). The agreement was later appended to an Interagency Accord on Implementation of the Committee on Science Engineering and Public Policy Recommendations for Research Initiatives in Seismology. It was signed by the Defense Advanced Research Projects Agency (DARPA), the USGS, and NSF. Within this framework, IRIS will provide scientific leadership for the program, establish a data management center, and support a university component of the GSN; the USGS will be the primary organization with responsibility for deployment and operation of the new GSN. NSF will provide funding through IRIS and the USGS for development, deployment, and upgrading, and the USGS will provide long-term support for stations and facilities deployed and operated by the USGS.

This Technical Plan addresses those issues of planning that affect coordination between IRIS and the USGS. It defines the organizational responsibilities and support of a university component of the GSN — the IRIS/IDA Network operated by the University of California at San Diego, individual university seismic stations, and future university subnetworks not yet in existence.

The Global Seismographic Network is composed of those global networks that produce and freely exchange high-resolution broadband data. Indeed, other networks, such as the French GEOSCOPE network, were considered during development of an IRIS siting plan. Within the context of this document, however, the term GSN refers only to the IRIS contribution to the Global Seismographic Network.

A great deal of work has been accomplished by IRIS and its standing committees, the USGS, and other active participants in the program. Design goals and specifications for the instruments have been developed, sites have been selected, a prototype GSN data system (IRIS-2) has been delivered for testing, and an initial version (IRIS-1) has been established. The IRIS PASSCAL portable data logger (IRIS-3) has been deployed at GSN sites in the Soviet Unionalong with very broadband seismometers. They have created a standardized data format and developed international organizational contacts. Substantial progress has been made in improving and establishing data collection centers and the IRIS data management center. At the same time, it is clear that some program goals must be recast in the light of diminishing budget expectations. While these constraints will adversely affect the program schedule, they need not compromise basic system design goals or the quality of the collected data.

The establishment of a global network of standardized seismographs is a complex, multi-faceted program. It involves system development and testing, the selection, negotiation, and preparation of suitable sites, training, the installation of instruments under a variety of unusual conditions, and the development of data collection and network support facilities. Fortunately, the foundation for the new GSN already exists because there are global networks in place — the World-Wide Standardized Seismograph Network (WWSSN) and the Global Digital Seismograph Network (GDSN), operated by the USGS, and the International Deployment of Accelerometers (IDA) network, operated by the University of California at San Diego (UCSD). Most of the GSN systems will be installed at existing stations because of the availability of facilities and experienced personnel, and new stations will be installed to improve the global coverage. To enhance the noise characteristics of the network, surface vaults at many existing stations may need to be replaced by underground vaults or borehole facilities, and at new locations low-noise siting will be emphasized. In addition to the networks of existing stations, there are maintenance and data collection facilities that need not be duplicated. Past experience in network management and operations is another valuable asset in accurately anticipating requirements.

The deployment of the new GSN is the first phase of a program that is intended to provide the scientific community with high-quality seismological data well into the twenty-first century. However, the second phase of the program, which is to operate the network, to upgrade it network with new technology when warranted, and to provide for continued improvement of seismometer siting in minimizing noise, is even more challenging. Experience has clearly shown the difficulty in supporting a global seismograph network after it has been installed, much less of obtaining funds for improvements. The reason for this is also clear. The existing networks were deployed by a sponsoring agency without any plan for long-term support. The new GSN will fare no better unless long-term support with well-defined organizational responsibilities is part of current planning.

Among the requirements set forth in the IRIS/USGS cooperative agreement is the preparation of a Technical Plan for the New Global Seismographic Network. Its purpose is to translate the scientific goals and objectives of the GSN program into plans for instrumentation, station siting, deployment, operation and maintenance, data collection, data management and distribution, budget and schedule, and organizational responsibilities. Since there will be several organizations involved in the deployment and operation of the GSN, this document will try to establish common procedures and standards to be used during the deployment, testing, and operation of the GSN data systems. Uncertainties about funding for the program require flexibility in planning the network. Elements of this Plan will require periodic updating by IRIS and the USGS. Amendments to the Plan will be adopted by agreement of both IRIS and the USGS.

2. NETWORK CONCEPT

The new GSN, like its predecessors, will be a global infrastructure composed of the station instrumentation, data collection facilities, data management and distribution facilities, and maintenance support. All of these elements, shown schematically in Figure 2.1, are vital to the network's operation, and the support facilities must be in place as the first stations are installed.

Many of the GSN data acquisition systems will be installed at existing manned observatories where they will be operated by host organizations. The host organization is a key participant in the network, not only in providing operating facilities and personnel, but in sponsoring the cooperative program in foreign countries. Often the host organization is also a data user, and depends upon the station to provide data for local earthquake studies. Some of the GSN data systems will be installed at remote unmanned sites from which the data must be retrieved by satellite telemetry, and some will be installed at manned sites where there is no interest in the local utilization of the data. The configuration of the GSN data system will be tailored to specific site requirements.

Real-time satellite telemetry between the GSN stations and the data collection center continues to be an important program goal, although it is now clear that the implementation of satellite telemetry will be delayed except in special cases. IRIS is working to complete an agreement with NASA in which GSN telemetry requirements will be included in NASA baseline plans for their Earth Observing System (EOS), to be launched in the mid-1990s.

Data from some stations will be accessible via telephone dial-up. At these sites the IRIS Data Management Center and seismologists will be able to view and retrieve segments of recent seismic data from a buffer memory. Transmission of messages, computer commands and files between the stations, and the data collection center will ease the maintenance of the network.

Data will be recorded at the stations on high-density tape cartridges. They will be mailed about every two weeks to a data collection center where the station data will be loaded into a computer, and reviewed for quality and accuracy. Data Collection Centers have been upgraded at the USGS Albuquerque Seismological Laboratory (IRIS/USGS DCC) in New Mexico and at the University of California at San Diego (IRIS/IDA DCC). Validated data are then staged to a buffer for prompt transmission to the IRIS Data Management Center. All IRIS data are routinely provided to the IRIS/USGS DCC, where they are merged with other GSN data and data from other networks in a mass store facility. The data collection centers are part of the network data acquisition system in that validating data accuracy, calibration, timing and similar functions, are extensions of quality-control processes beginning at the stations. For the same reasons, it is important that the data collection and network maintenance centers be co-located so that there is close and effective communication between them. After the network data are processed, they are formatted and ready for bulk distribution to other data centers.

A network maintenance center fills the basic support functions for the network by providing supplies, training, replacement components and parts, and on-site technical assistance when needed. The center will be in frequent communication with the stations, and will respond quickly to requests for assistance.

Data management centers (DMCs) will provide an important interface between the network and the data users. Most data users are selective in their requirements and need data management support to retrieve signals of interest from the rapidly expanding global data base. Rapid access to data after quality control and assurance procedures are completed is another DMC concern. An important function of the data management centers will be to provide researchers with selected data via a convenient format and medium; for example, event data on compact disks, or customized data sets via electronic transfer. Efficient data management and distribution is a challenging task considering that the data base may be growing by as much as a gigabyte per day when the GSN is fully operational. Fortunately, much of the preparatory work has been accomplished by IRIS and the USGS. For example, IRIS has established a DMC in Austin, Texas at the University of Texas, and the USGS has established a DMC in Golden, Colorado at the National Earthquake Information Center (NEIC). The IRIS DMC will archive all continuous and triggered GSN data immediately following quality control and assurance at the Data Collection Centers, and will provide for rapid access to the GSN database for all users. The USGS DMC at NEIC will continue to produce sets of seismic data on CD-ROM media from all seismic events larger than a certain threshold, collected from the GSN and other networks, within a year following the events.

3. STATION INSTRUMENTATION PLAN

3.1 *DESIGN GOALS AND CONSIDERATIONS*

The selection of station instrumentation is the most important decision that will be made in the GSN program. The Science Plan described the GSN data requirements in terms of resolution, bandwidth, and dynamic range, and these were the most important system attributes considered by the IRIS Standing Committee for the GSN (SCGSN). One of the important early tasks of the SCGSN was to translate the general scientific goals for the GSN into design goals for the GSN data acquisition and collection systems. This work was published in draft form as "The Design Goals for a New Global Seismographic Network" and distributed widely for comment and suggestions. The design goals were then used as the basis for preparing specifications for a GSN data system. These were issued as part of a request for proposals by IRIS, and, after competitive evaluation of the responses, a contract was awarded in April 1987 to Gould, Inc. (acquired in 1988 by Martin Marietta, Inc.) for development of a GSN prototype data system (less seismometers). The prototype system was delivered to the Albuquerque Seismological Laboratory in November 1988 for test and evaluation. The first production units (IRIS-2 systems) became available for deployment in mid-1990. Concurrent with the development of the GSN prototype, Quanterra Inc. has produced a compatible, abridged version of the system which has been successfully operated (IRIS-1).

In a separate development through the IRIS portable array program, PASSCAL, specifications were drawn in 1986 by a joint IRIS and USGS committee for a portable seismic data logger to be used in large scale portable array experiments (up to 1000 elements) to image the Earth. After a competitive evaluation, a contract was awarded to Refraction Technology Inc. (RefTek) in 1987. Delivered and tested in 1988, this version of the PASSCAL data logger, called the IRIS-3, immediately was put to use as a GSN data logger at five sites in the Soviet Union. Although not presently meeting the full design goals of the original GSN specification, the IRIS-3 instrument is systematically evolving to this end. The SCGSN adopted the IRIS-3 as a data logger for the IRIS/IDA Network in 1989.

The process of developing GSN system design goals and specifications, drew upon a broad range of scientific and engineering expertise that the latest applicable technology is used to create a digital broadband seismograph system. Will produce much higher quality data than are now available and be supportable and upgradable well into the twenty-first century. The key requirements for the new network station instrumentation were listed in the design study:

- Bandwidth sufficient to record the entire spectrum of teleseismic signals;
- Dynamic range sufficient to resolve ground noise and to record the largest teleseismic signals;
- Digital data acquisition with real-time or near real-time data telemetry;
- Low noise instrumentation and environment;
- Linearity;
- Standardization of system modules.

From a data user standpoint, the most important of these are likely to be bandwidth and dynamic range. The recently-developed very broadband (VBB) seismometers coupled with the new high resolution 24-bit digital encoders make it possible for the first time to record signals from a teleseismic event in a single data stream. At locations where additional bandwidth or dynamic range is appropriate, very-short-period (VSP) and low-gain (LG) seismometers will be included with the data system. Seismometers consistent with GSN design goals are selected by SCGSN for deployment after testing and evaluation at the USGS Albuquerque Seismological Laboratory with recommendation to SCGSN.

The resolution of small signals for detection purposes has been an objective spurring sensor technology improvement. It is important in the context of broadband data as detailed source mechanism studies are applied to events of small magnitude. The amplitude of self noise will be one of the important criteria used in the evaluation and selection of sensor systems for the GSN. The choice of low-noise recording sites is a goal that must often be compromised because of the need for stations at critical geographic locations (e.g., islands and coastal regions). Using borehole seismometers should reduce the levels of recorded noise on islands and at other sites, and the separated version of GSN data systems (with local telemetry between the sensors and recording station) will be used where appropriate to avoid cultural noise.

Signals recorded on GSN systems would ideally be linear through the full 140 dB amplitude range specified for the system, but this is not presently achievable. As specified in the Design Goals, signals near the ground noise minimum can be resolved in the presence of ground noise at other frequencies near the expected ground noise maximum; that is, distortion levels below -80 dB. Most of the broadband seismometers have measured distortion levels between -80 and -90 dB. This is one area of sensor technology that would bear improvement, so that full advantage can be taken of the high resolution digital encoders.

Standardization of station hardware and software was considered a key requirement during the design study in reducing maintenance complication and cost. As stated in the Design Goals: "Past experience with operating seismic networks, regional or global, has graphically demonstrated the disadvantages of constructing a network from a diversity of individual stations with differing characteristics."

The standardization of data format has already been accomplished. At the urging of the IRIS SCGSN, a standard data format, called the Standard for the Exchange of Earthquake Data (SEED), has been developed by the USGS with input from IRIS and the international scientific community. Widely reviewed, the SEED format has been adopted for use by the Federation of Digital Broadband Seismograph Networks. The SEED format for recording data at the GSN stations will also be used in the distribution of GSN data by the Data Management Centers, as well as in the exchange of the data among Federation data centers.

Several other design considerations were important in developing design goals and specifications for the GSN system. Modular system design is important for providing flexibility configuring data systems for particular locations. At some GSN locations local telemetry links between the sensor system and recording system will be required, whereas at others the systems will be collocated. Many sites are at active seismological observatories with an interest in using the broadband seismic data for local analysis, whereas other sites may be remote and essentially unmanned with little or no local interest in the data. The configuration of a GSN data system will be tailored to meet the site requirements. System design will permit separation of the sensors and the recording system using wire, fiber optic links, telephone circuits, or radio links, so that the sensors can be positioned away from sources of cultural noise.

Modularity, the fullest possible use of off-the-shelf components, and a standard bus will make the IRIS-1 and -2 systems easy to support and upgrade in the future. Ideally, the entire data system can be replaced over the years piece by piece, as the need arises. The use of off-the-shelf, commercially available modules reduces a potentially costly dependence on the system manufacturer when future design modifications are needed. On the other hand, the IRIS-3 system developed by RefTek as the chosen IRIS PASSCAL instrument, is part of an evolving product line of the company. Using more proprietary components than the IRIS-2 system, the IRIS-3 system nonetheless uses industry standard I/O interfaces. However, with the broader customer base, the RefTek line will continue to stay at the leading technological edge without relying solely on IRIS for development funds.

Reliability and maintainability are clearly important design considerations. The reliability of a data acquisition system depends on many factors, including equipment design, local interest in the data, adequacy of spare components at the station, turnaround repair time, training, stability of local line power, and environmental conditions. The methods used in this program to deal with factors affecting station reliability include using of proven equipment, built-in diagnostics, operator training, robust backup power systems, and use of fiber optic cables where lightning is a problem. A data availability of 90% is the minimum acceptable goal for the GSN.

Local utilization of the GSN data can have a very dramatic impact on network operations. Past experience in operating the WWSSN and GDSN networks clearly shows that the reliability and survivability of stations are much higher when the data are accessible and useful to the host organization. This is the most important reason for the durability of the WWSSN. In contrast, the GDSN stations are much more difficult and expensive to support, because at most of them the digital data are not generally available for local use causing little incentive to keep the systems operating. The GSN data systems are designed to provide local access to the digital data. All of the data stored in the buffer memory will be accessible for display and analysis on the system monitor, and a plotter will be provided to make hard copies. All of the data in near-real time will be accessible at the station through a data access port for processing or recording on station-furnished equipment, and host organizations located at some distance from the station may retrieve data from the buffer memory via the dial-up circuit. The GSN data processor will have analog outputs (where needed) to simulate the WWSSN short- and long-period signals. The output signals may be recorded on the existing WWSSN thermal recorders.

3.2 *BASIC GSN DATA SYSTEMS*

3.2.1 *General*

Many concepts used in developing and configuring hardware and software for the GSN data system evolved from VBB seismograph systems developed at Harvard University by J. Steim (1986) and the IDA group at UCSD. The basic GSN data system being manufactured by Martin Marietta is often referred to as the IRIS-2 system. IRIS-1 systems are essentially updated copies of the original Harvard system with some modifications. IRIS-1 systems, previously available through Gould Inc., are now available through Quanterra Incorporated. The IRIS-2 systems can be operated in several different configurations and with several hardware options. Fully configured, the IRIS-2 data acquisition system can replace virtually all of the instrumentation currently operated at a typical seismological observatory. The IRIS-3 system is based upon the IRIS PASSCAL seismic data logger and is manufactured by RefTek with most of the software development done by the IDA group at UCSD.

Block diagrams of the basic GSN data systems are shown in Figure 3.1 and 3.2 for the IRIS-2 and IRIS-3 systems, respectively. Using separate data acquisition and processing modules permits installation of sensor systems at remote sites when necessary, with recording at station facilities that are often located in noisy environments. It is expected that approximately one-third of the GSN stations will be operated with a local telemetry link. The link may be a few kilometers of fiber optic cable or thousands of kilometers over a satellite circuit.

The data acquisition (DA) module includes the sensor subsystems, digitizer/calibrators, a timing subsystem, and a microprocessor for data acquisition control and data formatting. Time critical operations will all take place in the DA module so that intermodule transmission delays will not be of concern. Data will be formatted into packets, time tagged, then forwarded to the data processing (DP) module. The DP module will contain a second microprocessor, buffer memory, digital recorders, data access ports, a single-channel analog recorder, CRT terminal, printer, optional plotter, and optional analog recorders. A full duplex 2400-baud serial circuit will be adequate for transmission of continuous broadband data between the DA and DP modules; higher capacity circuits (up to 19.2K baud) will be needed to handle optional VSP and LG data.

3.2.2 *Sensor Subsystems*

All of the GSN data systems will be equipped with a triaxial VBB sensor subsystem having a flat velocity response from at least 0.25 to 360 seconds period and a dynamic range at 20 seconds of at least 140 dB. The type of VBB sensors used (borehole or vault type) will be site dependent. Streckeisen STS-1 VBB sensor subsystems have already been in place at several stations. Other candidate VBB sensors that may be used in vaults include the Güralp CMG-3 and the Streckeisen STS-2 sensors now under development. The choice will depend on an evaluation of dynamic range, linearity, and other technical factors. Borehole seismometers will be used at Seismic Research Observatories (SRO) stations where boreholes already exist, and at island sites and other sites where the drilling costs are not prohibitive. The Teledyne-Geotech KS 36000 borehole seismometers now at the SRO stations will be modified to produce broadband (0.25 to 360 sec) signals. Candidate seismometers for use at new borehole sites include the Güralp CMG-3 and STS-2 packaged for borehole operation, and the Teledyne-Geotech KS 54000 developed for use in the Global Telemetered Seismograph Network (GTSN). VBB signals will be digitized at a rate of 20 samples per second (sps), compressed in the DA processor, then recorded or transmitted in a continuous data stream.

Some stations will be equipped with triaxial very-short-period (VSP) sensor subsystems. Geotech GS-13 sensors are used at several IRIS-1 sites, and Geotech 54100 borehole sensors are in place at some IRIS-3 sites in the Soviet Union. Other VSP sensors are under consideration. Desirable characteristics are a response flat to velocity from 1 to at least 40 Hz, and a sensitivity adjustable to accommodate differences in background noise levels. The digitization rate will be at least 100 sps, and may be set as high as 200 sps depending on station configuration. An automatic signal detector will be used to detect events in the VSP signals, and only detected events will be stored in buffer memory, recorded on site, or transmitted. Some stations will also be equipped with triaxial low-gain (LG) sensor subsystems that record ground motion from major earthquakes which overdrive the VBB sensors. Kinemetrics FBA-23 accelerometers have been installed at the seismic station PASI in Pasadena California, and other sensors are under consideration. The digitization rate of the LG signals will be at least 50 sps and only detected events will be stored in the buffer memory, recorded on site, or transmitted.

The GSN data system will also accommodate other types of sensor signals, such as wind velocity and direction, barometric pressure, and magnetic and gravity field. However, there are no plans to install these types of additional sensors during the initial deployment of the network. Data from IDA gravimeters will be recorded from current IDA sites occupied and upgraded as part of the GSN.

3.2.3 *Digitizer Units*

Each data system will have digital encoders that convert analog outputs of the sensor subsystems to digitally encoded signals. Digitizers will be located close to the sensor subsystems, and cabled to the DA processor through up to 100 meters of wire or fiber optic cables.

A Martin Marietta EDME (enhanced delta modulation encoder) four-channel high-resolution digitizer/calibrator (HRDCU) will encode the VBB signals in the IRIS-2 system. The EDME has a dynamic range of 140 dB and 24-bit resolution. It samples at a high rate, digitally filters the signal with a corner at 8 8.2 Hz, and provides an output rate of 20 sps. In addition, the HRDCU generates calibration signals that can be applied to the sensors on command, and encodes the calibration signal on the fourth EDME channel. The Quanterra quantagrator, which also meets GSN design performance goals, is part of several IRIS-1 systems and may be optionally used in the IRIS-2 systems. A Hewlett-Packard 24-bit digitizer is being integrated into the IRIS-3 system by RefTek, and can serve also as an optional digitizer for the IRIS-1 and -2 systems.

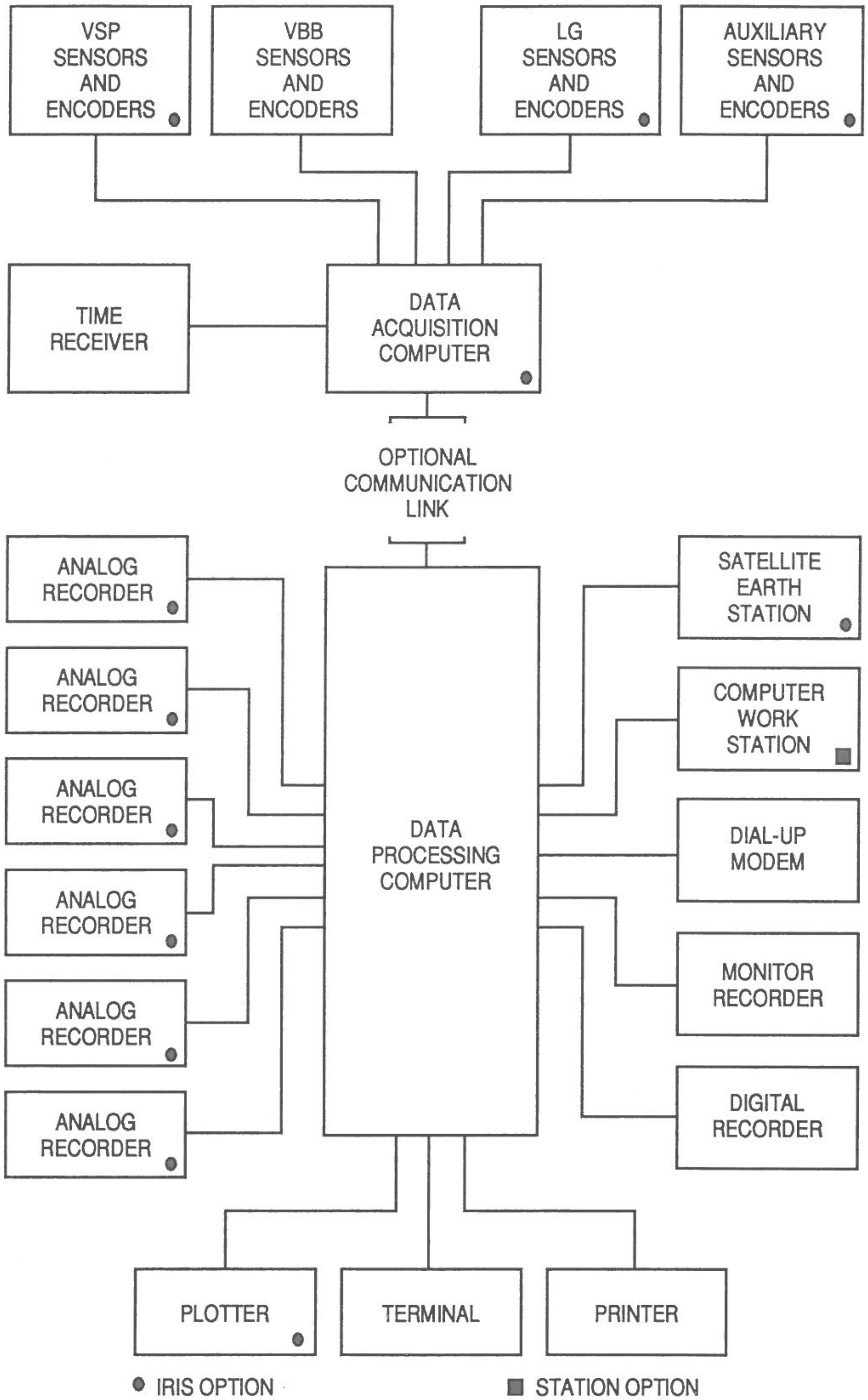

Figure 3.1 Block diagram of IRIS-2 system with separated data acquisition (DA) and data processing (DP) modules.

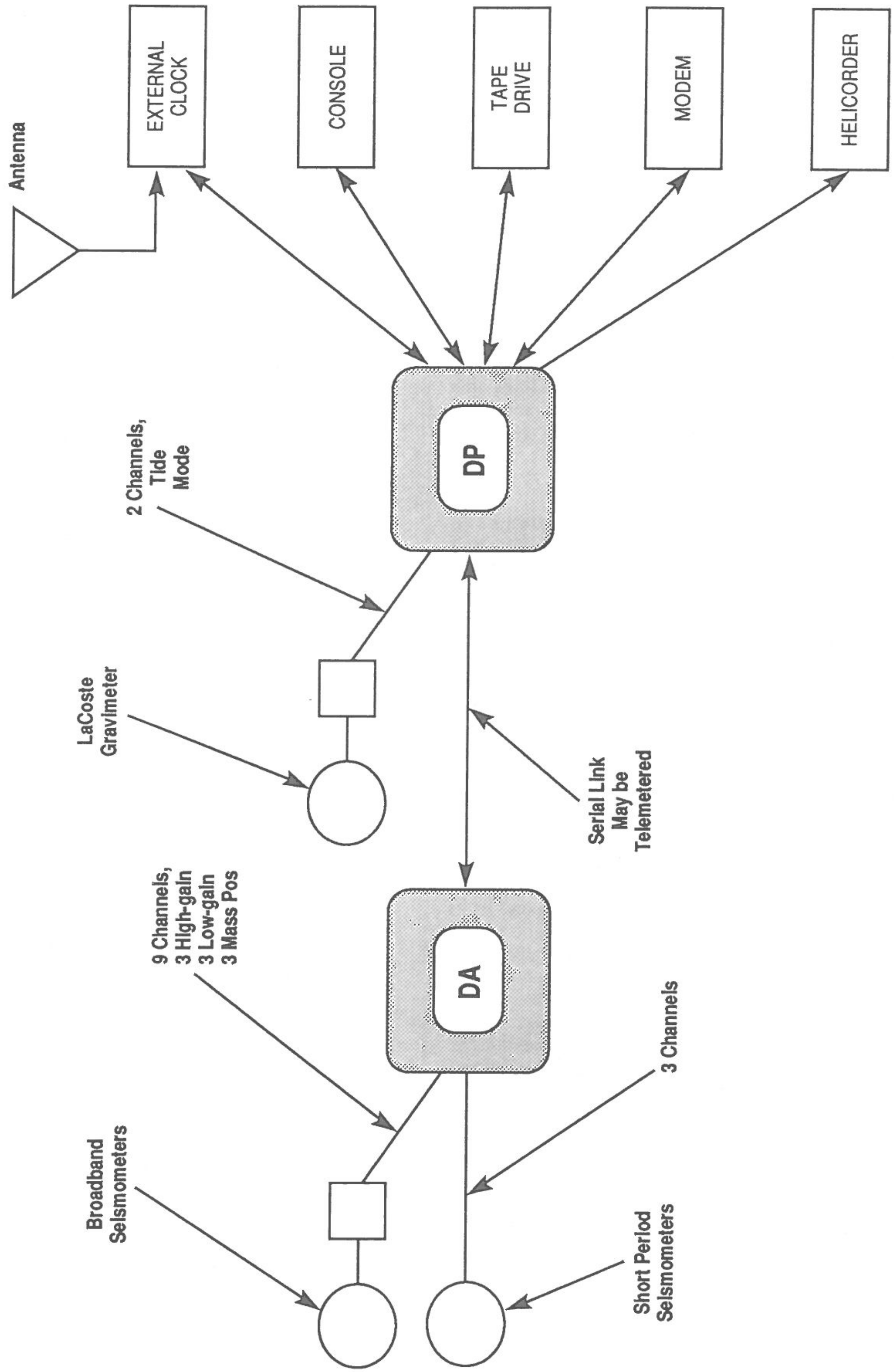

Figure 3.2 Block diagram of IRIS-3 system with separated data acquisition (DA) and data processing (DP) modules.

An optional 6-channel digitizer/calibrator (LRDCU) will be furnished with IRIS-2 systems that include optional VSP or LG sensors. Sampling rate will be selectable at 50, 100, or 200 sps, with maximum throughput of 600 sps. The LRDCU will have a dynamic range of at least 96 dB and 16-bit resolution. The LRDCU will also include a calibrator, and records the input calibration signal on a seventh channel. The Streckeisen 16-bit digitizer is now used at several IRIS-1 sites to record VSP and LG channels. The PASSCAL/IRIS-3 digitizer samples with 16-bit resolution at 1000 sps per channel. It uses a digital signal processing (DSP) chip to digitally filter the data to both a lower desired sample rate and increased resolution. The IRIS-3 system also contains a calibrator.

Each data system can be equipped with an auxiliary 16-bit digitizer unit (AUXDU), which would sample mass position outputs of the VBB sensors and other low-rate data channels that may be added in the future.

3.2.4 *Data Acquisition Processor*

The DA processor in the IRIS-2 system uses a 32-bit Motorola 68030 central processing unit (CPU) and other hardware modules attached to a standard VME bus. The Microware OS-9 operating system is designed for real-time applications. Application software is written in a high-level language (PASSCAL) to simplify future modifications and enhancements that are certain to be made. In the IRIS-3 system, a Motorola CMOS 68000 CPU is used with an Analog Devices ADSP2100 digital signal processing chip within a custom real-time operating system. Application software is written in the high-level C language. The principal functions of the DA processor are to: control timing, collect digitized data from the digitizers, time tag data blocks, compress VBB signals, perform automatic event detection, and transmit data to the data processing module. Software will be stored in programmable read-only memories. The DA module may be operated in a remote, unattended site and will be capable of automatic reboot when power comes up after a lengthy failure that exceeds the capacity of the remote backup power subsystem. In sites where the separation of data acquisition and data processing functions by a telemetry link are not required, these functions may be collocated to minimize hardware. In these cases the DP functions are performed by a DA/DP system using DA hardware. The IRIS-1 systems are essentially collocated IRIS-2 systems, whereas the IRIS-3 systems may be configured in either manner.

3.2.5 *Timing Subsystem*

The timing subsystem is synchronized to signals transmitted by the Omega navigational system. Timing is within 10 milliseconds of Universal Time. Backup timing signals are provided by an internal oscillator if the Omega signals fade. GOES clocks may also be used but are limited to the western hemisphere. The timing subsystem is self synchronizing and does not require any operator intervention; thus, it may be used at unattended sites. The Omega clocks are much less expensive than clocks synchronized by the Global Positioning Satellite (GPS), and will be used in the network for several years. However, they will have to be replaced when the Omega navigational system is replaced by the GPS positioning system.

3.2.6 *Data Processing Processor*

The DP processor hardware is similar to the DA processor hardware. The DP processor's major functions are data manipulation, system diagnostics, calibration, and data processing. The DP processor receives data packets from the DA processor. It performs decompression, filtration, and decimation of the VBB data to produce long-period (LP) and very-long-period (VLP) digital signals that are stored and recorded together with the VBB signals. It generates and time tags the analog signals recorded on the monitor recorder and the optional WWSSN recorders and formats event detection parameters for storage and printout. It also monitors state-of-health (SOH) information and reports errors to the operator distributes the data packets to various storage, recording, and transmission functions and provides for operator monitoring and control. The DP processor has excess capacity that is available for additional tasks in the future.

3.2.7 *Communications Link in Separated Systems*

Both the IRIS-2 and IRIS-3 systems may be configured as separated systems with Data Acquisition and Data Processing modules communicating over a telemetry link. This permits the seismometers to be located at quieter sites more isolated from cultural noise, while at the same time permitting the host organization easy access for recording the data. The telemetry link can be wire or fiber optic cable, a dedicated telephone circuit, a radio frequency channel, or a satellite channel. The data are packaged and time tagged at the remote site. Using a 9600-baud modem, a voice-grade circuit will support telemetry of continuous VBB and VSP data. A buffer memory in the DA is used to store VBB, LP, and VLP continuous and event data, as well as VSP and LG event data (if available). The standard buffer memory will typically store at least 10 minutes of data when all channels are operational, and up to two hours continuous data when optional VSP and LG channels are not used. To extend these limits, more memory may be added to the systems. Transmission errors caused by noise bursts and outages are typically ten minutes or less. The data packets are verified error-free on receipt or re-transmission is requested. If a circuit outage persists and the buffer fills, data will be lost. In the IRIS-2 system data streams are prioritized and on a buffer-full condition the packets may be systematically discarded, based upon priority to minimize total loss of data. For example, up to 24 hours of continuous LP and VLP data and VBB event data in the IRIS-2 system can be saved in the standard buffer for automatic retransmission when the circuit is reestablished.

3.2.8 *Buffer Memory*

A hard disk with at least a 40-megabyte capacity is furnished with each IRIS-1 or -2 data system for on-line storage of digital data and information. The IRIS-3 may be optionally configured with a hard disk. The buffer memory will store 24 hours of VBB data, LP data, VSP event data, and LG event data, event parameters, SOH and other information, and up to 30 days of VLP data. It has two purposes: to provide access to current data by station personnel and data centers (via the dial-up port), and to serve as a buffer when large earthquakes increase the data rate above the capacity of a real-time telemetry link. Normally, a station is expected to generate about 6 - 7 megabytes of compressed data per day.

3.2.9 *Digital Recording Subsystem*

Digital data are currently recorded on magnetic media, but optical media can potentially be used. The IRIS-1 and -2 systems use high-density (150-Mbyte) tape cartridges. Each cartridge will store over two weeks of data, and two cartridge drives are provided so that cartridges may be changed without loss of data. Automatic switch over will occur if the on-line cartridge fills with data or fails. The IRIS-3 system uses the high-density helical-scan Exabyte cassettes, except where export restrictions force the use of 9-track tape (i.e., in the Soviet Union). A single recorder currently records two weeks of data (one week at 9-track tape sites), and data are buffered in memory when the medium is being changed. At all sites, SOH and diagnostic information, message text, and all operator commands and logs will be recorded with the data. No paper logs will need to accompany the tapes to the DCC. The SEED format is used to construct the data records. Higher density media may be adopted in the future, but to assure timeliness, the data will always be sent to the DCC at intervals no greater than two weeks.

3.2.10 *Real-Time Data Access*

Each data system is designed so that real-time transmission of all data, information, and message text can be implemented in the future. Message text will be received at the station on a return link.

3.2.11 *Dial-Up Data Access*

Each IRIS-1 and -2 data system has a dial-up port and 9600-baud modem designed for full duplex operation through a commercial telephone circuit. The dial-up link will be used by the host organization or data centers to request data segments stored in the buffer memory, or to exchange message text with the station operator. Access will be controlled by using a password. Dial-up access for the IRIS-3 system is being developed.

3.2.12 *Local Data Access*

All of the data and information generated by the IRIS-2 GSN system is available through a 9600-baud serial port in real time. Station personnel may connect the GSN system directly to work stations or other on-site computer facilities. The IRIS-3 system uses a standard SCSI interface.

3.2.13 *Operator Terminal and Control*

The GSN systems have a terminal and printer for operator control. The terminal may be used to check or set the time; view event, error, or status logs; set, change, or display event detection parameters; re-center the VBB seismometers; exchange message text over the real-time or dial-up ports; initiate calibration and run a calibration analysis; select channels for the monitor recorder; select simulated responses (WWSSN, SRO, and other) for analog recording; and view a continuously updated display showing a snapshot of all data channels, UTC time, space remaining on the on-line tape cartridge, status of event detectors, tape error rates, messages, status and error messages, and seismometer mass position. The IRIS-1 and -2 systems can display and plot selected waveforms stored in the buffer memory on the console graphics screen. The IRIS-2 system can also display selected channels in quasi-real time on the graphics screen. However, normal operation of the GSN system does not require operator intervention, except to replace tapes at biweekly intervals or service any analog recorders used at the station. Hand-held terminals are used to provide to access at remote DA sites.

3.2.14 *Monitor Recorder*

Each GSN system provides so that any of the active channels (VBB, LP, VLP, or VSP) can be selected for recording by the operator. The monitor recorder records tests and sensitivity adjustments. It evaluates signal detection parameters, and provides a continuous analog record of any channel at the discretion of the operator.

3.2.15 *Analog Recording Subsystem*

Up to six analog output channels are available from the DP processor for local recording on conventional seismograph recorders provided by the station. WWSSN and Seismic Research Observatory (SRO) stations have four to six analog recorders for this purpose. Software simulations of WWSSN and SRO SP and LP responses derived from the VBB signals are currently available at IRIS-1 and -2 sites for recording. Signals with other response characteristics can be implemented in the future at all GSN sites.

3.2.16 *Digital Plotter*

A digital plotter will be furnished at stations that require data for local analysis. The plotter will record signals, such as local events of interest from the buffer memory, or data from processed signals, and may be used at some stations to produce 24-hour seismograms.

3.2.17 *Station Power Subsystems*

An uninterruptible power subsystem (UPS) will be in place at each station. The UPS will condition the local power, and provide four hours of battery backup in event of a power failure. The power required for a fully-configured IRIS-2 GSN system is about 750 watts during normal operation (including six analog recorders). A separate smaller UPS will come with the DA module when it is located at a separate site. Power required at a remote sensor site is from 10 to 275 watts depending on the configuration of the IRIS-2 system, and 1.5 to 5 watts the IRIS-3 system. All system equipment should operate from local power, so that a failure in the power subsystem will not cause a complete data system failure.

3.2.18 *Lightning Protection*

Lightning has been one of the principal causes of catastrophic system failures at seismograph stations. In the GSN system, all data lines are protected with Zener diodes, and DC power lines are protected with a combination of Zener diodes and gas arresters. The use of fiber optic cable for signals lines will further reduce susceptibility to lightning-induced failures.

3.2.19 *Mechanical Configuration*

Station recording equipment, including the monitor recorder for the IRIS-2 system, is housed in a single 6-foot cabinet. A table is provided for the terminal and printer. Analog recorders, if used, will be mounted in separate racks. The UPS charger, inverter, and controls are mounted in an 18-inch cabinet with batteries in a separate rack. Normally, the UPS is located in a separate, well-ventilated room or shed. The digitizers, which will be near the seismometers, are mounted in a sealed box. Similar configurations are used for IRIS-1 and -3 systems. At separated seismometer sites, or in difficult environments, the DA or DA/DP module will also be housed in a sealed enclosure.

3.2.20 *Calibration*

Calibration signals applied to the VBB seismometers are generated in the IRIS-2 system in the HRDCU, and recorded on a fourth EDME encoder (which also serves as a spare). Calibration input signals for the optional VSP and LG sensors are provided by the LRDCUs, and separate channels can separately record the input signals. Step functions, random binary signals, and sine waves at discrete frequencies are all available as inputs to the sensor calibration circuits in both the IRIS-2 and -3 systems. Since both the sensor input and output signals are measured and recorded, sensor transfer functions can be automated in the data system using techniques developed and used by E. Wielandt (1986a, 1986b). Here the input signal, convolved with a trial transfer function is matched to the sensor output signal using least-squares fitting. Quantization error, noise, instrument drift, and non-linear behavior can also be identified using this method. Calibration will be performed at periodic intervals. Sine-wave calibration is also used to adjust magnification of analog recording. The IRIS-1 systems currently have limited calibration capabilities.

3.2.21 *Exportability*

To meet export restrictions to certain countries, some modules on the GSN systems will need to be modified. In these cases the system's modularity will permit replacing of key components with exportable components. The high density tape cartridge drives may be replaced by lower density reel tapes; or a high-speed microprocessor chip. For example, the IRIS-3 system has been installed in the Soviet Union using 9-track magnetic tape for recording. By maintaining an up-to-date awareness of current exportability requirements, systems can be deployed and upgraded so that state-of-the-art standards can be maintained.

3.3 *REMOTE GSN DATA SYSTEMS*

Several of the proposed locations for GSN systems are remote sites that may be unattended or minimally attended by local personnel whose sole responsibility is to change tape cartridges biweekly. In these cases power drain may be an important consideration, and it will not be necessary to provide local access to either digital or analog data except for maintenance purposes. The IRIS-3 systems is designed for these circumstances. A remote IRIS-2 data system is also ideal. In either case a remote GSN data system is expected to have most of the following salient features.

- VBB sensors and optional VSP and LG sensors
- VBB dynamic range of 140 dB at 20 seconds
- VSP and LG dynamic range of at least 96 dB
- Low power (< 100 watts); DC powered
- RAM-based buffer memory of at least 10 MBytes
- Both real-time and dial-up ports
- Optional cartridge or disk recording
- SEED data format
- Calibration procedures same as basic GSN system
- Port for portable terminal
- Switchable DAC for monitoring signals.
- Automatic mass positioning
- Backup power
- Lightning protection
- Sealed, weather-proof enclosures.

If a remote station is not connected to the DCC via a satellite telemetry link, a dial-up communication link will be not only to retrieve data segments, but to run diagnostics and perhaps to download software, and change station operating parameters. Ideally, the remote GSN system hardware and software will be similar to that used in the basic GSN system to simplify long-term maintenance.

4. STATION SITING PLAN

4.1 *SITE SELECTION*

The task of developing a station siting plan for the new GSN stations was assigned to an IRIS SCGSN Site Selection Subcommittee, and the results were reported in 1986 as the 5-Year Siting Plan IRIS Contribution to the Global Digital Seismographic Network. In early 1989, IRIS SCGSN updated and modified the current siting plan. The principal criterion was a uniform global distribution of stations. The surface of the Earth was divided into 128 equal areas approximately 18° by 18° at the equator. Ninety of the blocks contained seismograph stations regularly reporting arrival times to the International Seismological Centre (ISC), and an additional 25 blocks contained oceanic islands on which remote seismograph stations could be placed. Thus, uniform global coverage is a feasible goal with at least 115 land based stations.

Blocks were not considered if they contained existing or planned stations expected to produce broadband digital data. These were stations of the China Digital Seismograph Network (CDSN), the Global Telemetered Seismograph Network (GTSN), the GEOSCOPE network, and the Canadian network. Prospective sites were identified in many, but not all, of the remaining blocks. A complete listing of the prospective sites was published with the Minutes of the SCGSN, March 1986. Primary consideration was given to any station within the region that has participated in the WWSSN, GDSN, or IDA networks, since these stations have trained personnel and established facilities. Preference for these stations has resulted in duplication within some blocks, but only where this was judged to be appropriate.

Fifty-one proposed sites for the new GSN equipment were selected in the 1986 5-year siting plan, and the Subcommittee recommended that nine additional sites be selected later from within the conterminous United States. Several modifications, principally additions, have been made since the Subcommittee submitted its initial recommendations. As the result of an agreement between IRIS and the USSR Academy of Sciences, five broadband stations were installed in the Soviet Union in 1988. Also, several stations have been added to the list where host organizations have contributed to the purchase of equipment, including university operated stations. The current distribution of proposed IRIS GSN stations is shown in Figure 4.1 together with planned GTSN stations. Only a few of the host organizations have been officially contacted establishing a GSN station, and some modifications in the siting plan may be expected pending the outcome of these queries.

The working plans shown in Figure 4.1 represent the first major installment in the long term goal of uniform global coverage. With a minimum of 115 stations, this can be achieved, excluding only those areas which will require ocean-bottom deployments. There is a great interest in providing coverage even in these difficult oceanic environments, but such discussion is beyond the scope of this Technical Plan. Beyond a minimum 115 stations for uniform coverage, there will be areas of greater station density, such as in the United States. Other networks — for example, GEOSCOPE and the Canadian Network — will provide coverage in many areas of the globe, and such efforts are welcomed and encouraged.

4.2 *SITE REQUIREMENTS*

4.2.1 *General*

Apart from geographic considerations, an ideal station site for a GSN VBB station would have a deep subsurface vault, isolation from cultural noise, stable and reliable power, and a trained, highly motivated technical staff. Few of the proposed sites have all of these attributes. The need for uniform coverage often outweighs specific factors affecting the quality and reliability of the data.

4.2.2 *Seismometer Vault*

Seismometer emplacement is one of the key factors affecting data quality, especially in the long-period band. It cannot be emphasized too strongly that the quality of data recorded from a particular station will depend primarily upon the quality of the seismometer placement. Surface deformation caused by wind and solar heating can contaminate horizontal-component LP signals to the point of uselessness. Long-period data from the GDSN and CDSN networks clearly demonstrate an order of preference for seismometer emplacement: (1) subsurface vault greater than 100 m in depth; (2) borehole of at least 100 m in depth; (3) subsurface vault greater than 10 m in depth; (4) surface vault. Surface vaults are usually unsatisfactory — the resulting data will likely be excessively noisy. Geologic factors are also important, since surface deformation is a function of the rigidity of the rock. A broadband sensor installed in a surface or shallow subsurface vault on unconsolidated sediment has very limited usefulness. Deep subsurface vaults are in active or inactive mines. Development of new subsurface vaults is prohibitively expensive, but efforts should be made to locate potential subsurface vaults in the vicinity of the proposed station sites where improved facilities are needed. Experimentation with "posthole" or other shallow burial techniques may provide alternatives for sites where deep boreholes or adequate vaults are not practical.

There are boreholes at all of the SRO stations, and they will continue in use with the new instrumentation. The cost of drilling and casing a borehole varies widely ($8,000 - $250,000) mostly depending on the availability of a drill. The worst case would be a remote island site where the drill must be barged in. Despite the cost, borehole construction at new station sites lacking vaults, or at existing sites that have poor vault facilities is highly desirable. Even shallow boreholes or postholes drilled into bedrock would be preferable to surface vaults resting on unconsolidated sediments.

4.2.3 *Seismic Noise*

Natural microseisms are unavoidable at stations operated near coasts and on islands. Broadband recording at such locations was not practical until sensors and

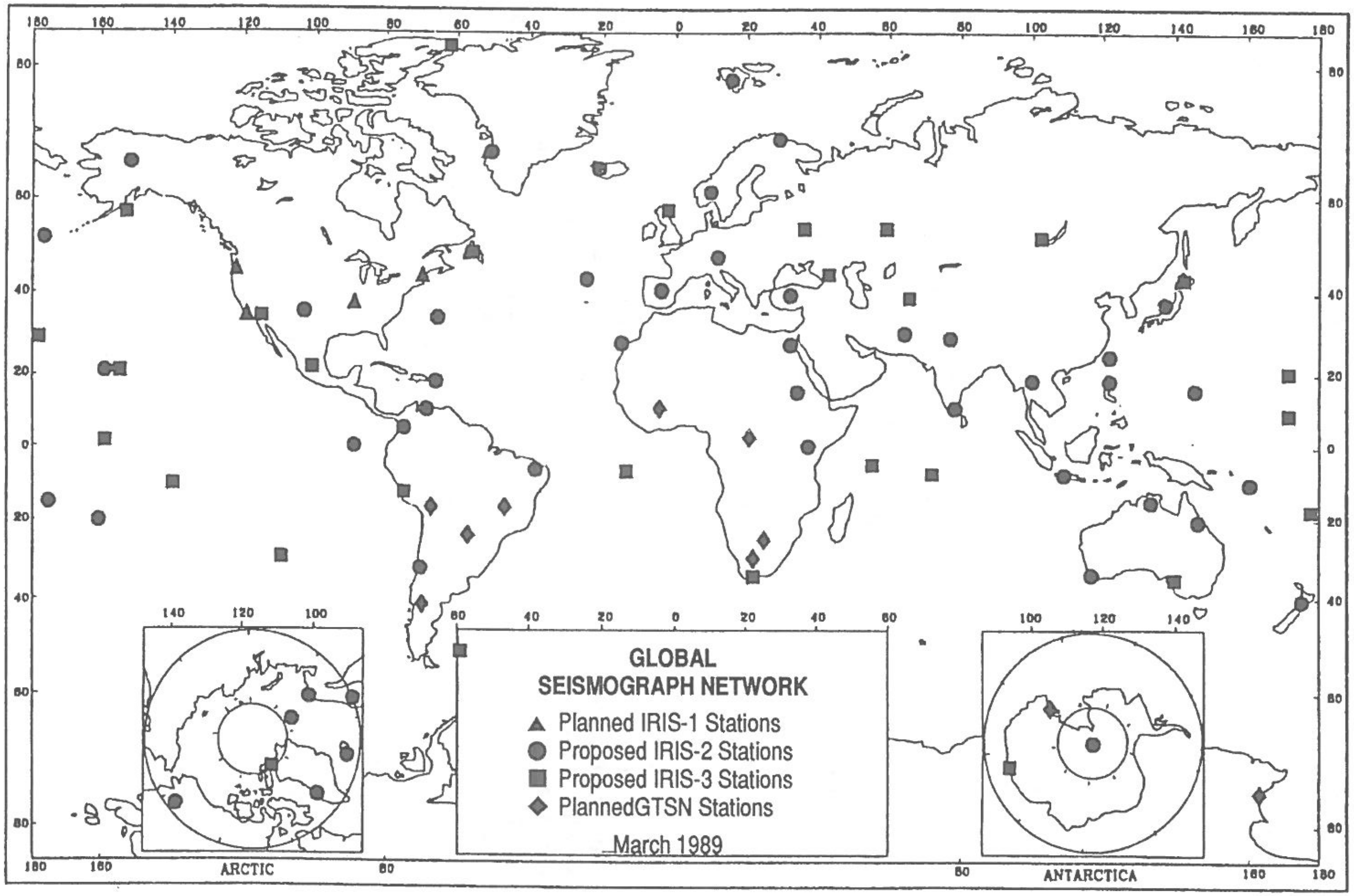

Figure 4.1 Map showing locations of planned IRIS GSN stations. IRIS-1 systems are installed at several IRIS member Universities. The USGS is responsible for deployment and support of the IRIS-2 systems. The IRIS/IDA group at the Unitversity of California at San Diego is responsible for deployment of the IRIS-3 systems. In addition, planned locations for GTSN stations are shown.

encoders with dynamic range and linearity were introduced which could accommodate the high signal levels in the microseismic bands without affecting resolution in other bands. The GSN system has these characteristics, so it is unnecessary to suppress microseismic noise using band-limited recording.

Cultural noise can be avoided to some extent, although circumstances often dictate compromise. Many stations worldwide were constructed over 25 years ago during the early years of the WWSSN program, and in most cases the locations were relatively isolated from cultural activities. Since then, few have escaped encroachment, and almost none have been relocated to quieter sites. The best solution for a noisy station is to locate the sensors in an isolated vault or borehole and telemeter the signals back to the recording station. The GSN system has been specifically designed for this mode of operation. Stations where local telemetry is currently employed or recommended are noted in Table 4.1. Experience has shown that line-of-sight radio-frequency (RF) telemetry links are much more reliable than telephone circuits. However, some of the links are expected to be thousands of kilometers in distance, and both satellite and microwave circuits will be used. Site testing is appropriate where new sensor sites are to be selected.

4.2.4 *Station Facilities*

The participating station will provide a vault or borehole for the sensor systems, a communication circuit if local telemetry is employed, facilities for the recording system and UPS equipment, and power to operate the data system. Some stations will require financial support for site preparation work.

Boreholes used for broadband seismometers are generally drilled to a depth of 100 m, cased with 7-in steel casing, cemented, and sealed. Vertical offset must be less than 4° for use with the SRO-type seismometer. The borehole must be watertight, and it is preferable that it be airtight. Detailed specifications for the drilling and finishing of a borehole are available at ASL.

Installed in a vault, the sensor systems need less than three square meters of floor or pier space. The vault should be thermally isolated from daily temperature fluctuations, and it should be dry. The VBB vertical-component sensors are sealed and therefore unaffected by pressure changes in the vault. More detailed vault specifications will be available at ASL.

The recording equipment should be located in an enclosed dust-free room or instrument rack that is maintained at a temperature between 20 and 25°C year round. Air conditioning is essential in most regions of the world. The amount of space required depends on the use of analog recorders. For safety reasons, the UPS batteries should be located in a separate, well-ventilated room or shed. The UPS rack is often placed in the battery room as well because of the inverter noise.

Power required for the IRIS-2 system with 6-channel analog recording will vary from about 750 watts when the batteries are on trickle charge, to about 1000 watts when the batteries are on full charge following an outage. Much of the power is consumed in the UPS system. Power required at a remote sensor site is 10-275 watts, depending upon configuration. Power failure is the most common cause of station downtime in the global networks. The UPS systems are designed to provide 4-hours of battery backup when line power fails, at both the recording station and at the remote sensor site.

5. NETWORK DEPLOYMENT PLAN

5.1 *INTRODUCTION*

Establishing the network involves more than the shipment and installation of the data systems. It begins with the development or modification of station agreements. It involves site preparation, preparation and shipment of the data systems, preparation of field teams, training, system installation, and ends when the network is fully operational. The deployment of the GSN is a major operation that requires intensive planning and effective management. Delays caused by poor planning can be very costly.

5.2 *STATION AGREEMENTS*

Agreements between the Network Manager and the host organization form the basis of cooperation. The model for these agreements is represented by USGS practice, which is discussed herein. Initial contact with a station is a letter to the host organization requesting their participation in the program. The letter includes a statement of the scientific objectives, a description of the instrumentation, an outline of site requirements, operational requirements, and proposed support for the station. It provides a summary of benefits that the host organization will receive by participating in the program. Informal letter agreements or amendments to existing agreements are preferred, although more formal agreements are required in certain cases. It is also necessary in some cases to follow up the initial letter with a visit to negotiate specifics. Agreements that require ministerial approval, which are often the case when stations are operated by government organizations, may take as long as a year to conclude, so the process must begin at least a year before scheduled deployment.

A typical station agreement will define USGS and host organization responsibilities as follows:

USGS Responsibilities:

- Site preparation (in some cases)
- Delivery of equipment to the site

- Installation of equipment
- Training of station personnel
- Provision of supplies and parts
- Technical assistance and periodic maintenance visits
- Return of original data, if desired.

Host Responsibilities:

- Site preparation (in some cases)
- Furnish vault and recording facilities and power to operate the equipment
- Assist with importation of equipment
- Assist with installation of equipment
- Operate equipment and notify the network maintenance center of any problems
- Mail data and logs promptly to the DCC.

The disposition of the equipment is also addressed in the station agreement. Title to the WWSSN and GDSN equipment has been retained by the USGS in the case of domestic stations, and given to the host organization in the case of foreign stations. In most cases the IRIS/IDA Network maintains title to equipment at foreign sites.

5.3 *SITE PREPARATION*

A detailed site plan will be developed for each station in cooperation with the host organization. Important considerations are the vault type, the system configuration (separated or local), type of telemetry (if used), analog recording requirements, and commercial power specifications. The site plan will include layouts showing the location of sensor systems, recording equipment, power equipment, and the power and signal cables. It will list any special requirements for extra length cables, fiber optic cables, new conduit, air conditioning, building modifications, and so forth. Most stations that have not been upgraded for the past 25 years require some preparation usually new power lines, power line transformers, and air conditioning.

Major site preparation work at new sites and at a few of the existing stations may include construction of a borehole or vault, major modification or construction of recording facilities, and the construction of roads and power lines. In most cases, this work will have to be funded by IRIS. In the past, for example, the USGS has contracted locally for construction work with the help of the host organization. Alternately, the USGS has provided funds for site preparation to the host organization through the Embassy in the form of a grant. In either case, intensive monitoring is required to see that the work is completed satisfactorily and on schedule. Acceptance tests on boreholes are especially important, and must be performed by a Network representative using proper test equipment.

5.4 *PREPARATIONS FOR INSTALLATION*

The GSN station equipment will be installed by a two-man installation team with assistance from local station personnel. Training in the data system and in the variety of sensor systems that will be employed by the GSN will be provided by ASL or IRIS/IDA support personnel, with input by the system manufacturer.

Each team will be provided with an installation kit containing tools, test equipment, report forms and other items needed for installation. The kit will also contain a supply of critical spare parts and boards. The first IRIS-2 production system will be installed at the Albuquerque Seismological Laboratory as station ANMO. This will provide additional training for the installation teams, and an opportunity to evaluate installation procedures, tests, and reports. An IRIS-3 system is similarly deployed at the Pinon Flat Geophysical Observatory.

Each IRIS-1 and -2 production system will be configured at the factory for a specific station location, fully assembled and tested, then packed for export shipment. Packing methods and materials have been designed so that the shipment can be stored outside without damage. Any damage sustained during shipment as a result of improper packing or defective mechanical design is the responsibility of the manufacturer. IRIS-3 systems are configured at the IRIS/IDA Network Maintenance Center in La Jolla, CA, then tested and shipped to the site. Shipping damage is doubly expensive because it often prolongs the field installation.

5.5 *SYSTEM INSTALLATION*

The time required to install a GSN data system is expected to be three or four weeks, depending on the complexity of the station and the type of sensor systems specified for the site. The first week is typically used to complete minor site preparation work, install and test the sensor systems, and assemble the data recording equipment; the second week to perform the component and system tests, and complete the installation report; and the third week to monitor system performance and train local personnel in daily operation and maintenance: board replacement, log keeping, communication with the network maintenance center and DCC, data shipping, and other important activities. The training at IRIS-1 and -2 sites includes software as well as hardware, and covers procedures used to retrieve, display, plot, and process the data.

5.6 *FIELD REPORTS*

Because of the importance of information concerning the station, installation test results, and test records, a special Installation Report form will be developed specifically for the GSN network by the USGS and IRIS/IDA. Following formats used with the WWSSN, GDSN, and CDSN networks, the report will contain: a brief history of the station, a description of the vault and recording facilities, coordinates and elevation of the sensor systems, local geologic setting, local topographic setting, a description of nearby cultural or natural sources of seismic noise, an assessment of power reliability, a list of all equipment with serial numbers and sensitivity constants (where appropriate), calibration and test instructions in cookbook form, and test results. Maps, photographs, test records, and test tapes will be submitted and filed with the report. A recommended installation report form will be developed prior to deployment of the IRIS-2 systems. The IRIS Data Management Center will maintain an up-to-date catalog of the information contained in these reports for all GSN stations.

5.7 *U.S. TRAINING FOR STATION PERSONNEL*

During the deployment of the GDSN network, operators from each of SRO and ASRO stations were brought to ASL for six weeks of intensive training in the operation and maintenance of the data systems. The training was effective in some cases, but not in others because of language barriers, and because of the great diversity of technical capability on the part of the station personnel. Nevertheless, the program was highly beneficial because close working relationships were established between the station operators and ASL support personnel. The operators became familiar with station support and data collection operations at ASL, and realized the importance of logs and the necessity of sending data promptly. They became more aware of the importance of their role in the program.

Budget permitting, a similar training program will be conducted at ASL or IRIS/IDA for GSN station personnel. In this case, more emphasis will be placed on software and data handling. In fact, because of capability of the GSN system for off-line computer processing and the potential for local data analysis, scientific personnel are likely to take much more interest in the station operation and may want to participate in the training.

6. NETWORK OPERATION AND MAINTENANCE PLAN

6.1 *INTRODUCTION*

Establishing a new network is a milestone, not the final objective. A network will not survive long without adequate operational support after the stations are installed. Subsistence-level support includes resupply, replacement of defective parts and components, and limited on-site technical assistance. Past experience clearly demonstrates that subsistence-level support is not adequate; it promises a steady deterioration of data quality and availability, and premature obsolescence. If the GSN is to be the dynamic scientific resource envisioned during its conception, there must be more than this. The agency responsible for the network must continue developmental engineering, provide the funds needed to make improvements, continue training, and manage the network as an integrated scientific facility rather than an odd collection of independent stations. The GSN will be equipped with the most versatile seismograph system ever deployed in a global network. It was intentionally designed to evolve with advances in technology. The GSN will remain a state-of-the-art network as long as it is adequately supported.

Two Network Maintenance Centers have been established. The USGS Network Maintenance Center established many years ago at the Albuquerque Seismological Laboratory will serve as the maintenance center for the IRIS GSN component operated by the USGS. ASL will also serve as maintenance center for GSN stations in the university subnet which operate IRIS-1 or IRIS-2 systems. The IRIS/IDA Network operates a maintenance center at the University of California at San Diego. IRIS/IDA will also serve as maintenance center for GSN stations in the university subnet which operate IRIS-3 systems. The IRIS/IDA Network Maintenance Center is an element of the IRIS's PASSCAL instrument maintenance network, which also includes the PASSCAL Maintenance Center at Lamont-Doherty Geological Observatory in Palisades, New York.

6.2 *STATION OPERATION*

The GSN data systems have been designed to function with minimum operator intervention. Timing, calibration, mass positioning, and log keeping are all automated, as are all of the other routine functions with the exception of analog record changing where necessary, and biweekly replacement of the tape cartridges. The primary daily activity of the operator will be to monitor the status of the system. Buffered event data will probably be used in place of seismograms for local analysis as application software becomes available. This will be encouraged to guarantee active participation by station personnel in the operation of the GSN system.

The station operator becomes especially important and cost effective when a problem occurs at the station, and of course these events are inevitable. The operator will be trained to isolate a failure to board level, and to replace defective modules and boards. If a replacement unit is available at the station, downtime is minimized; if not, the operator will immediately request a replacement by express mail from the network maintenance center.

The level of replacement parts initially assigned to a station represents an important tradeoff between deployment costs and network reliability. A high level of station spares is expensive at the outset, but it significantly reduces the amount of data lost when there is a failure. Unfortunately, it is not easy to predict which components are most likely to fail, and some experience is valuable before a large investment is made in spare boards and modules. With digital systems, most board failures have been associated with line power problems, either transients that penetrate the power conditioning equipment or stray currents caused by poor grounding. The manufacturer of GSN data systems will provide a list of recommended station spares, and discretion will be used in making an initial selection.

6.3 *FUNCTIONS OF A NETWORK MAINTENANCE CENTER*

6.3.1 *Introduction*

A network maintenance center (NMC) is the operational headquarters of a network. It communicates frequently with the stations and provides all of the support and assistance needed to keep the stations in operation. It also provides close support to field teams that may be installing or servicing stations. The NMC operates in partnership with the data collection center, on which it relies for detection of problems in data quality and calibration.

6.3.2 *Station Resupply*

The NMC keeps inventories of supplies and spare parts for each station in the network as well as an inventory of depot supplies. Supplies are purchased in bulk quantities, then parceled out in shipments to the stations well before they are needed. This is a substantial effort considering the amount of purchasing involved, and the diverse shipping procedures that must be used to avoid delays in customs. Often, different shipping procedures are used for routine supplies and emergency replacement parts.

6.3.3 *Equipment Repair*

Equipment repair and reconditioning is one of the vital functions of the NMC. Some defective equipment must be returned to the supplier for repair, but most of the GSN equipment will be repaired in the electronics shop of the NMC, saving considerable time and expense and reducing the number of spares required. Virtually any digital board can be repaired in the ASL electronics shop or PASSCAL Maintenance Center if circuit and function diagrams are available, and special facilities are available for testing seismometers. A GSN data system will be used in the shop as a test bed for diagnosing problems and checking boards and modules after they have been repaired. Skilled technical personnel and the test system must be available early in the deployment phase. Normally, there will be a relatively high board failure rate initially that will subside after a burn-in time of several months.

6.3.4 *Documentation*

The NMC staff maintains the station files. These include installation reports, maintenance reports, correspondence and messages, shipping documents, export licenses, and any other material related to station operation. The NMC staff also maintains the manuals, source code, drawings, schematics, and other documentation describing the data systems, maintains detailed records of system modifications on a station-by-station basis, and maintains statistics on component failures.

6.3.5 *Training*

The NMC staff prepares and conducts training classes for new support personnel and for station personnel at the station or at the NMC. Many possibilities exist for distributing training courses, special instructions, and menu-driven diagnostics to the stations on floppy disks. There is a recurring need for operator training because of turnover at the stations.

6.3.6 *Engineering Support*

The first modification performed on a new data system inevitably precedes the first station installation, and modifications are a continuing practice thereafter. Engineering support for the network is needed to monitor system performance, to identify design problems, and to design, test, and evaluate hardware and software changes that will improve data quality and reliability.

This activity increases in importance as the equipment ages and becomes more difficult to support. Typically, there is heavy dependence on the system supplier for engineering support during the early stages of deployment, but this dependence must not continue indefinitely. The IRIS-1 and -2 GSN data systems have been specifically designed to reduce dependence on the primary supplier. The use of off-the-shelf modules, application software written in a high-level language, and a standard bus contributes significantly to effective network support, and makes it much easier to introduce subsequent enhancements made possible by new technology. The IRIS-3 system will depend upon the broad support base in the network of PASSCAL instrumentation maintenance centers for the 1000 digital recorders in the PASSCAL program.

6.3.7 *Field Maintenance*

On-site maintenance by a skilled technician is a vital component of network support. Despite the best design, diagnostic support, spare boards, and training, stations will develop problems that cannot be corrected by station personnel. Direct lightning strikes, power system failures, and problems with borehole seismometers usually require expert assistance. At some stations the skill level of the operator is not adequate to deal with more common problems. Ideally, field technicians will be within one or two days travel of all but the most remote stations. When not engaged in emergency visits, they will routinely visit stations to update hardware and software modifications and train new station operators. Field support is expensive, but it is a key element in maintaining an acceptable level of data availability. It is the only way of supporting remote, unattended stations.

6.3.8 *Communications*

Good communications between the NMC and the supported stations are essential. Telex is the most common form of communication used at present. Where dial-up circuits can be established, the NMC will be able to communicate directly with a GSN data system to exchange message text with the operator, monitor system operation, run diagnostics, download software, and check data quality. Dial-up circuits will be especially important for communicating with stations that are serviced only biweekly by an unskilled attendant.

7. DATA COLLECTION PLAN

7.1 *INTRODUCTION*

The basic functions of a data collection center were institutionalized with the establishment of the WWSSN. Seismograms were collected from the stations, reviewed for correct labeling, calibration, and quality, then microfilmed, archived, and organized for efficient retrieval, and distributed to data users on request. The original seismograms were returned to the stations, and the stations were advised of any defects or problems noted during the data review. These functions changed little with the advent of digital recording in the early 1970's. Since then, both the volume of digital data and the complexity of the operations have increased substantially, but the only functional change has been that the DCC now does not normally distribute data directly to the end users. Data management centers, developed to merge data from several networks, organize the database and permit more rapid and efficient access by the end user.

Necessity dictates that network management, maintenance, and data collection be linked organizationally. Data collection centers are integral parts of network operation because of the importance of data review in monitoring and maintaining station performance. Each organization responsible for network maintenance must also collect and review the data; thus, there are separate DCC's for IRIS stations supported by the USGS, and IRIS stations supported through the IRIS/IDA operation at the University of California at San Diego. A DCC has been operated at the Albuquerque Seismological Laboratory since the earliest deployment of digital stations. The ASL DCC serves as the data collection center for all IRIS-1 and -2 sites in the GSN, including USGS deployments and university subnetwork sites. The IRIS/IDA DCC was established with the onset of IRIS/IDA operations in 1987, and is the data collection center for all IRIS-3 sites in the GSN, including IRIS/IDA deployments and other university subnetwork sites.

A need for a new data collection system at ASL to process data from the GSN stations was dictated by the extraordinary increase in data volume projected for the next few years. At the present, the ASL DCC processes approximately 30 megabytes of data each day, collected mostly from the GDSN and CDSN networks. If in a few years the USGS processes data from 50 GSN stations, the GTSN network, and the CDSN network, the volume of data will approach 400 megabytes per day. Similarly, with the IDA Network of long-period gravimeters expansion into a network of broadband, three component seismometers, a six-hundred-fold data increase is impending. New concepts, new hardware, new software, additional personnel, and automation are all needed to cope with the expanding volume of network data.

The concepts used for planning the new DCCs are described in The Design Goals for a New Seismographic Network. Based on well-established functional requirements and the need for a versatile system that can be easily expanded as data volume increases. Since there must be a capacity to process network data before the network is deployed, developing a new IRIS/USGS data collection center was a high priority. New hardware has been purchased by IRIS, used hardware has been scavenged from the former DCC, and application software has been developed at ASL. An optical mass store purchased by IRIS has been installed to serve as the primary archive in building the network volumes, and a SUN computer has been installed on the DCC computer network for communications (data and electronic mail) with the IRIS DMC and IRIS/IDA DCC. As a result, the new IRIS/USGS DCC is already in operation. Still to be installed are the hardware and software needed to receive and process real-time data, a lower priority because of plans to defer the implementation of satellite telemetry. The IRIS/USGS DCC was not intended to be a unique facility; it may be duplicated by other organizations operating networks, with storage and throughput capacity scaled according to need. New hardware — SUN and microVAX computers, tapes and disk systems — has also been purchased from both IRIS and private UCSD funds for the IRIS/IDA DCC, which is also presently operational.

7.2 *FUNCTIONS OF A DATA COLLECTION CENTER*

7.2.1 *Introduction*

The IRIS data collection centers have been designed to perform the following tasks:

- data acquisition
- time and format validation and correction
- data quality validation
- distribution of validated data to the IRIS DMC
- communicating problems
- backup archiving
- returning original data to the stations
- data format conversion
- status reports and database maintenance.

The IRIS/USGS Data Collection Center at ASL has also been designed to perform the following additional tasks:

- network volume assembly and quality assurance
- final archiving
- distribution of network volumes.

These tasks are summarized briefly below.

7.2.1 *Data Acquisition*

The data stream from the new GSN stations will consist of continuous compressed VBB, LP, and VLP signals, optional compressed VSP and LG event data, logs, and message text. Initially, all data will arrive on high-density cartridges, helical scan Exabyte cassettes, or — in the case of Soviet data — 9-track tape reels. The tapes will normally contain up to two weeks of data and, except in unusual circumstances, should arrive at the DCC within 60 days of the recording date. Data from a few remote stations, such as those in Antarctica, will arrive late, and procedures will be established for processing and archiving late data. The ASL DCC will continue to receive data from other networks, usually on magnetic tape, but often written in different formats.

When satellite telemetry is implemented, real-time data may be received simultaneously at a DCC and the IRIS Data Management Center, and monitored at the DCC to verify system performance. Quasi-real time telemetry may be implemented using a file-transfer protocol between the Soviet Data Center in Obninsk and the IRIS/IDA DCC. Except at remote, unattended sites, there will be redundant site recording of the telemetered signals until the reliability of the communication circuits have been substantiated. The telemetered and site recorded data will be merged into a single data stream at the IRIS DMC, and as the network volumes are assembled at the ASL DCC.

Data collected at the IRIS/IDA DCC will be shipped weekly to the IRIS/USGS DCC at ASL for inclusion in regular and late network volumes — this transfer may occur via the IRIS DMC, if such action provides more timely data to the seismological community. When direct satellite telemetry is established among the DCCs and IRIS DMC, electronic transfer will occur shortly following data quality control and assurance.

7.2.2 *Time and Format Validation and Correction*

Data tapes and cartridges from the seismic station are read and loaded into a disk staging area at the DCC. During this process, the data records are checked for continuity, correct format, correct timing, correct record lengths, hard read errors, and correct header information. State-of-health and parametric values are monitored. A subsidiary index is created, providing a standard interface to the data and headers. It can also utilize quick random disk access techniques. All corrections are made in the subsidiary index, not in the main data file. This increases system throughput and provides audit control and error recovery.

Except for time errors, all corrections and salvaging operations are performed automatically as the data are loaded onto disk. After the data records are on the disk, a time edit list is produced that lists any time errors and provides a summary of data record quantities. Timing errors are the most common form of errors in the GDSN data, usually caused by transients that affect the clock, operator error in setting time, or gaps in the data. Corrections can be made using either an automatic editor that contains a library of programs to repair common errors, or a manual screen-oriented editor which refines automatic corrections or repair errors that cannot be handled by the automatic editor.

7.2.3 *Data Quality Validation*

After corrections have been made to the record headers, data quality is evaluated. In its simplest form, currently implemented, a series of waveform plots are made automatically that display a sampling of data for evaluation, and calibration signals are automatically plotted and checked for stability. The original seismic data are not modified in any way. When needed, comments are placed in the data logs to alert data users to data or calibration anomalies. Occasionally data are considered unusable, and marked for exclusion from the network volume. In some instances, excessive amounts of data are recorded on a triggered channel as a result of defective field detector parameters, special tests, or microseismic storms. These signals are re-detected for reduction of data on the network volume, although the complete original data stream is stored in the station backup archive.

Data qualification procedures will be refined following the completion of DCC system development. RMS values will be sampled to detect changes in noise levels, and spike detectors will be used to alert the operator to anomalous data. Comparison of recorded and synthetic waveforms will reveal polarity reversals and gross time errors. These have been surprisingly difficult to detect in the past.

7.2.4 *Distribution of validated data to the DMCs*

After data from a seismic station have been validated by the DCCs, they are staged over the local computer network to a disk buffer, where they are collected for transmission to the IRIS Data Management Center. The data are transferred to high-density helical scan magnetic cassettes (e.g., Exabyte media) and shipped by overnight mail to the DMC. After the data have been successfully entered into the DMC archive, the DMC acknowledges to the DCC, and the transmitted data are deleted from the staging buffer. Data transfers from DCC to the IRIS DMC occur weekly, and more frequent transmittals may eventually be requested. When direct satellite telemetry links are in place, the data will be transmitted nearly immediately following validation. Data transmission to the USGS DMC will generally originate from the DCC at ASL and will be by real-time linksor or by the physical transfer of high-density media.

7.2.5 *Communicating Problems*

Problems and defects found during initial review and edit, or during quality control, are reported promptly to the maintenance center so that any operational difficulties at the stations can be rectified. The DCC is also the communications interface between the network operators and the data centers and users. The data users are the final evaluators of network performance, and their feedback to the DCC is needed to maintain data quality. As focus for many user inquiries regarding the seismic data, the IRIS Data Management Center will log all inquiries received, and will forward the same to the appropriate Data Collection Center for response.

7.2.6 *Backup Archive*

After processing data from a station tape is complete, each station file in its original format: its indexes, statistics, and status reports are backed up. Since the original data and the index are both backed up, the data archive is complete.

7.2.7 *Return of Original Data*

Some host organizations request that recorded data be returned to the station. Either the original, or a corrected version of the data will be compiled from the backup archive, and returned to those stations requesting it.

7.2.8 *Data Format Conversion*

Although a standard format has been adopted for the GSN and other broadband stations, much of the station data entering the DCCs during the next several years will be in non-standard format. All data will be converted to the SEED format prior to transmittal to the IRIS DMC, the network volume assembly, and final archiving at ASL. Further, all data from new GSN sites (IRIS-1, -2, and -3 systems) will be converted at the originating DCC to SEED format using Steim data compression until this standard format is completely implemented.

7.2.9 *Status Reports and Database Maintenance*

Long-term statistical reports are produced in numeric or graphic form which present an overall history of the network or stations. Traffic analysis and inventory reports are produced indicating recent performance of the network, including uptime and data promptness. Programs running during production evaluate event detectors and field equipment operation and manage network volume production. A disk pool manager operates in the background manipulating the station data staging areas and network file storage, so that intervention is not necessary. Several databases are kept which contain key information for the assembly of the network volume. Other databases track the progress or location of data in the system.

7.2.10 *Assembly of Network Volumes (ASL)*

All data are demultiplexed and repacked into a network volume format, in which the data from all stations in the network are combined into time span units, normally days. The network volume is written entirely in the SEED format. At this stage the corrected information in the subsidiary indices are combined with the original seismic data. Also at this stage, telemetered data, stored in disk, and site-recorded data, will be merged into the single data stream that will be retained. It will be decided which of the redundant data streams is most suitable for permanent archive.

7.2.11 *Final Archiving (ASL)*

After the data are assembled into the network volume format, they will be written on the optical mass store. This will have been segmented into a number of consecutive days for storage. Initially, each optical disk in the mass store will hold up to 20 days of network data, but fewer than 5 days of data when the network is fully deployed. The mass store will hold 50 optical disks, so a large amount of data may be stored on line. The optical disks will be the final archive media. The entire tape archive at ASL, which dates back to 1971, will be transferred to optical disks.

7.2.12 *Distribution of Network Volumes (ASL)*

Network volumes are principally written for transmission of data to the USGS DMC in Golden, Colorado, to produce event oriented CD-ROM media. Currently, network volumes containing one to three days of data written on 6250 bpi tapes are compiled and distributed to the USGS DMC and other data centers. With the increasing volume of data from the GSN and other networks, higher density magnetic or optical media will be needed for the transfer in the future. Network volumes are usually sent to the USGS DMC at sixty days after real time. Data arriving after this are for late network volumes. These late volumes will be made up to 150 days after real time (or later in unusual circumstances). All data on the regular and late network volumes will be used by the USGS DMC at NEIC in the production of the Event CD-ROMs, or other data distribution.

7.3 *GSN DATA FLOW*

7.3.1 *INTRODUCTION*

This section describes the dataflow from the seismic stations to the Data Collection Centers and then to the Data Management Centers.

7.3.2 *IRIS/USGS SITES*

Data will be recorded on magnetic tape cartridges, with approximately two weeks of data on each. Tapes are to be promptly shipped to the IRIS/USGS Data Collection Center. The station field tapes are currently written in a variety of formats which depend upon the data logger—DWWSSN, SRO, ASRO, CDSN, IRIS-1. All data received at the IRIS/USGS DCC are converted to SEED format after quality control and assurance — a process currently taking about four days. All field tapes will be written in the standard GSN format as soon as possible. All new IRIS-1 and IRIS-2 stations will be installed with GSN format, and existing IRIS-1 stations will be retrofitted to write GSN format. DWWSSN, SRO, ASRO, and CDSN data formats will remain in the SEED data format.

The GSN format is a subset of SEED — defined by the SEED working group implementors from ASL, IDA, NEIC, IRIS and UTIG — using a record size of 4096 bytes with Steim data compression, and with logical records flushed daily to initiate a new logical record at zero hours UTC.

7.3.3 *IRIS/IDA Sites*

Non-Soviet Data will be recorded on magnetic tape cartridges, with approximately two weeks of data per cartridge. Tapes are to be promptly shipped to the IRIS/IDA Data Collection Center. Soviet data are recorded on a magnetic medium of the highest density exportable. Data shipments from the Soviet Union to IDA are covered under the protocol between the USSR Academy of Sciences and IRIS. The station field tapes at Soviet and non-Soviet IRIS/IDA sites are currently written in an IDA format. After quality control and assurance at the IRIS/IDA DCC — a process currently taking one to two weeks — all IRIS/IDA data are promptly shipped to the IRIS/USGS Data Collection Center in GSN format. IRIS will implement the GSN format on the IRIS-3 data logger used by IDA. As soon as possible after proper testing and verification of the GSN format software, it will be installed by the IRIS/IDA group on all IRIS-3 data loggers.

IDA gravimeter data recorded at IDA sites will continue to be processed by the IDA data collection center using existing operational procedures. All IDA gravimeter data will be promptly sent to both the IRIS and USGS Data Management Centers after quality control and assurance. At IRIS/IDA sites using the IRIS-3 data logger with GSN format, the IDA gravimeter will be recorded as an additional channel which will be forwarded with the other data channels to the IRIS/USGS DCC.

The data flow from IRIS/IDA DCC to IRIS/USGS DCC will take place in weekly transfers of magnetic tape, preferably Exabyte cassettes. The current IDA station tape will be converted to a network SEED volume in which the network consists of the single station. Each weekly tape will contain a number of network SEED volumes, corresponding to all of the data which has undergone quality assurance since the previous weekly transfer.

7.3.4 *Other IRIS University Sites*

At university sites which use a data logger based on the IRIS-1 or -2 systems, station tapes will be shipped to and processed by the IRIS/USGS DCC. For universities which use a data logger based upon the IRIS-3 system, the station tapes will be shipped to the IRIS/IDA DCC and processed as with other IRIS/IDA data.

7.3.5 *IRIS/USGS Data Collection Center*

After data quality control and assurance procedures plus reformatting to SEED, all data originally processed at the IRIS/USGS DCC are staged to a buffer for transmittal to the IRIS DMC. They are also written to a local optical mass store. For data originally processed at the IRIS/IDA DCC and sent to the IRIS/USGS DCC, no additional quality control and assurance procedures will be done. The IRIS/IDA data are staged to a buffer for transmittal to the IRIS DMC and also written to the local optical mass store. Data transfers to the IRIS DMC will occur weekly, though more frequent transmittal may be requested. Data transfer will take place via magnetic tape, preferably Exabyte cassettes.

At sixty days after real time, network volumes spanning a day (or some shorter time unit) will be produced by the DCC from the accumulated station data on the optical mass store. Data which arrive too late to make this sixty day cut-off will be saved for production of late network volumes. These late volumes will be produced as needed for up to 150 days after real time (or greater in unusual circumstances). All regular and late network volumes are sent to the USGS DMC at the National Earthquake Information Center in Golden, Colorado, for production of event-oriented data distributions, such as the Event CD-ROMs.

7.3.6 *IRIS Data Management Center*

All data received from the IRIS/USGS and IRIS/IDA Data Collection Centers are logged by the database management software and archived in the local mass store. Rapid access to all IRIS data which have passed quality control and assurance procedures, is very important to the IRIS community. IRIS DMC will work to provide timely access by improving system throughput. When system performance allows, IRIS DMC may request more frequent transfer of data than the current weekly transfer arrangements. IRIS DMC may elect to receive all data directly from the IRIS/IDA DCC, and then forward the data in a timely manner to IRIS/USGS DCC for production of network time volumes. IRIS may install satellite telemetry to immediately enable electronic transfer of data, after quality control and assurance.

8. DATA MANAGEMENT PLAN

8.1 *INTRODUCTION*

The ultimate success of the GSN will depend on the extent that seismic data produced by the GSN are used to discover new information about earthquakes and the Earth's interior. It is important, therefore, that seismic data from the GSN be available to the scientific community in a form that is easily and quickly accessible. The primary purpose of the data management system is to provide this easy access to GSN data. The goal is for a researcher to concentrate primarily on the analysis and interpretation of data rather than the assembly of usable data sets.

The scientific community's demands for GSN data can be divided into three categories. The first consists of those that can be met by standard event-based collections of data routinely produced and distributed on media such as CD-ROM approximately five months after real time. The assembly and distribution of standard GSN event data sets will be the responsibility of the USGS Data Management Center.

The second category of data requests are those which require the assembly of special sets of data from an archive of all continuous and triggered GSN data. Examples of these include earthquake source and receiver studies, studies of events in particular regions, seismic phases with particular propagation paths, and Earth structure studies in certain distance ranges. Many of these custom data requests are too estoric to justify routine production. Users need to be able to generate custom data requests using a data base management system. Special request data sets will be the responsibility of the IRIS Data Management Center.

The third category of data requests concerns timely access and availability of the data. Following an earthquake or other seismic event of interest, many users wish to have access to data as soon as possible. Providing rapid access to seismic data following validation and quality control procedures, will be the responsibility of the IRIS Data Management Center.

8.2 *IRIS DATA MANAGEMENT CENTER*

8.2.1 *Functions of the IRIS Data Management Center*

The functions of the IRIS DMC relative to GSN data are twofold: first, to assure that all special data requests are promptly satisfied with easily accessible data; and second, to provide rapid access to the validated data from the Data Collection Centers. The IRIS DMC will handle and distribute digital data that range from fixed network recordings (GSN and sub-sets from other U.S. and foreign networks) to controlled-source portable array recordings generated by PASSCAL experiments, and selected data from other U.S. or foreign experiments. To satisfy requests for special sets of GSN data, the IRIS DMC must archive all continuous and triggered data from the GSN. The IRIS DMC will also serve as the continuous data archive for the Federation of Digital Broad Band Seismograph Networks (FDSN).

8.2.2 *Parameter Data Base*

The bulk of the data held by the IRIS DMC will be digitized waveforms, although a smaller data set must exist to make the waveform data usable. This "parameter data base" must maintain a comprehensive data directory that provides an index to data holdings at the center. The system must provide rapid and easy access to bulletin hypocenters and associated phase data, and to other derived data such as focal mechanisms and moment tensor solutions.

The parameter data base will also have detailed seismic station information obtained from current Installation Reports from the ASL and IRIS/IDA Network Maintenance Centers, as well as from updated information from other university participants in the GSN, and FDSN contributing sites. The data base will contain information regarding the host organization for the station (including address, telephone, E-mail, fax or telex numbers), and a brief history of the station. There will be a description of the vault and recording facilities, coordinates and elevation of the sensor systems, local geologic setting, local topographic setting, a description of nearby cultural or natural sources of seismic noise, and an assessment of power reliability. Also included will be a list of all equipment with serial numbers and sensitivity constants, calibration and test results, and a listing of test records and test tapes available at the NMC. Maps and photographs of the site should also be available to the user.

The management system should allow both casual and detailed inquiries into the location and nature of Passcal experiments. The parameters should include: geographic location, source/receiver heights, source types (including earthquakes, explosives, vibroseis, and airgun), receiver types and sensors used. Data base relations for passive earthquake experiments should be capable of cross-referencing global catalogs.

8.2.3 *Waveform Data Base*

The digitized waveform data will form a large and rapidly growing data set that must be properly treated to remain accessible and usable. The IRIS DMC must provide large on-line random-access storage and off-line mass storage capability for digital waveform data from GSN and PASSCAL stations and arrays worldwide.

8.2.4 *Data Base Management System*

The IRIS DMC will develop and maintain an effective data base management system (DBMS) to quickly retrieve parameter and waveform data in an integrated form, independent of its storage location. The system must provide versatility in meeting a variety of types and combinations of features specified by data users in the form of "seismological queries." In addition to this, the DBMS should allow the general user to construct subsidiary data bases for specific research projects. The IRIS DMC should provide rapid archiving of data with a retrieval architecture structured to accommodate specific user needs and frequency of use.

8.2.5 *Data Distribution*

The IRIS DMC will provide a system for preprocessing of data that includes filtering, spectral estimation, sorting, and hardcopy display. This will be provided through utilities such as SAC, AH, and SierraSeis, and will be used by individual researchers. Data will be distributed from the IRIS DMC in SEED format. A SEED conversion utility will also be distributed as needed to convert the SEED format into selected other formats such as SAC. Data will be distributed on a variety of physical media including 9-track tape, helical scan tape, 1/4" tape cartridges, or when applicable, electronically.

8.3 *USGS DATA MANAGEMENT CENTER*

8.3.1 *Function of the USGS Data Management Center*

The function of the USGS DMC, relative to GSN data, is to assure that all standard event-based collections of data are routinely produced and distributed to the scientific community. Event data window size will be a predetermined function of the magnitude of the event and frequency content, or the sampling rate of the data. The USGS DMC will also be required to process event data from foreign networks. In particular, data from stations of the Federation of Digital Broad Band Seismic Networks (FDSN) will be collected and distributed, since the USGS DMC is the DMC for event data from the FDSN. The USGS DMC will therefore archive event data from all FDSN stations (including the GSN stations).

8.3.2 *Parameter Data Base*

The USGS DMC now has an extensive parameter data base. Since the USGS DMC is part of the National Earthquake Information Center (NEIC), it has ready access to the daily determination of hypocenters made for earthquakes occurring around the world. A large amount of parameter information is received each day at the NEIC from hundreds of globally distributed seismograph stations.

8.3.3 *Waveform Data Base*

The even waveform data base will be archived on a large mass storage system at the USGS DMC. This data base will be accessed to produce the standard event-based collections of data.

8.3.4 *Data Distribution*

The primary form of distribution of event-based waveform data will be on media such as the CD-ROM.

8.4 *IRIS/USGS DATA EXCHANGE*

The USGS will, on a timely basis, provide the IRIS DMC with all continuous and triggered data received by ASL from the GDSN, CDSN and GTSN networks; likewise, IRIS will provide continuous and triggered data from the university GSN network to the USGS . Continuous and triggered data from the university network will be archived at the IRIS/USGS DCC with data from the USGS network.

8.5 *COOPERATION BETWEEN DATA MANAGEMENT CENTERS*

Close cooperation between the IRIS DMC and the USGS DMC will be essential for full advantage to be made of the capabilities and resources of both DMC. Only in this way can the scientific community receive the complete benefits of easy access to global digital seismic data.

9. REFERENCES

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APPENDIX 1.

ORGANIZATIONAL RESPONSIBILITIES

1. *Introduction*

The importance of the new GSN demands that its deployment and long-term support be carefully planned by research and operations personnel and adequately funded by the Federal agencies committed to the program. In order to make this possible, the operational roles of these agencies and institutions must be defined at the outset. In this way the necessary steps can be taken to plan facilities, program future funding, and conserve current resources.

The NSF and the USGS are the two primary funding agencies committed to the deployment and long-term support of the GSN.

The responsibility for the development of the new GSN has been primarily the NSF's. The 1983 research briefings for departments and agencies of the Federal government by the Committee on Science, Engineering, and Public Policy (COSEPUP) recommended that "...the National Science Foundation act as overall coordination and lead agency for funding such an array and that the operation be overseen by a university consortium." The consortium became IRIS, which represents the research community in setting scientific goals and represents NSF in specifying and purchasing the equipment. Because of the broad university membership in IRIS, GSN can promise to provide seismological data for research requirements through the next decade and into the twenty-first century.

The USGS had installed several global networks that it currently supports and maintains. The USGS has continued to do so because it recognizes that these data are vital to basic seismological research, and finds such support consistent with its overall charter. The USGS maintains the Albuquerque Seismological Laboratory to support the development, installation, and maintenance of the global and national seismograph networks.

2. *Operational Responsibilities*

The responsibility for deployment, operation and maintenance of the GSN is shared by the USGS and IRIS. The GSN will be deployed, managed and supported by the USGS, by the IRIS/IDA Network, and by universities designated by the IRIS Standing Committee for the Global Seismographic Network. Of the currently proposed GSN stations, the two networks (IRIS/USGS and IRIS/IDA) will make up those stations listed in Table A1.1. The list is tentative; final siting decisions will weigh deployment, operation and maintenance costs. The USGS will operate a network maintenance center and a data collection center at the Albuquerque Seismological Laboratory. It will support the IRIS/USGS network which includes affiliated universities operating IRIS-1 and -2 GSN systems. IRIS will operate a network maintenance center and a data collection center through IRIS/IDA at U.C. San Diego to support the IRIS/IDA network and affiliated universities operating IRIS-3 GSN systems. The IRIS/IDA network maintenance center will be a part of the PASSCAL instrumentation maintenance network of IRIS. The USGS will operate a data management center at NEIC in Golden, Colorado, and IRIS will operate a data management center at the University of Texas, Austin. Methods of exchanging data between the USGS and IRIS data centers have been described in Section 8 of the Technical Plan.

3. *Funding Responsibilities*

The primary funding agencies for the GSN are the NSF and the USGS. Other Federal agencies may provide funds for station deployment but are not likely to be involved in the network's long-term support.

NSF will provide funds through IRIS and the USGS for the development and deployment of the GSN stations and support facilities. This includes the cost of instrumentation, site preparation, training, engineering, installation, shipping and any other costs associated with network deployment; the cost of equipping the network maintenance center; and the cost of developing and equipping the data collection center. NSF will also finance through IRIS the long-term support of the university subnetwork. NSF will fund major improvements to the GSN network through the USGS and IRIS, following initial deployment.

The USGS will underwrite the operation and maintenance of the stations in the IRIS/USGS subnetwork, which includes affiliated universities operating IRIS-1 and -2 GSN systems, plus operation of the network maintenance center and data collection center located at Albuquerque, and operation of the data management center in Golden.

In general, the responsibilities of NSF and the USGS are as given in Article 1 of the Interagency Accord (see Appendix 8). Costs for three year's implementation of this Technical Plan are given in Table A2. These costs will be reviewed annually by GSN Program Managers in IRIS and USGS, and reviewed by IRIS, NSF, and USGS officials during June of each year. Responsible officials at NSF and USGS will meet at least annually to establish agency commitments in covering these costs.

Table A1.

IRIS/USGS SITES	*IRIS/IDA SITES*
Adak, Alaska	Alert, NMT, Canada
Afiamalu, W. Samoa	Ascension Island
Akureyri, Iceland	Adelaide/Tasmania, Australia
Albuquerque, NM	Antarctica site
Ankara, Turkey	Arti, USSR
Baguio, Philippines	Diego Garcia, Indian Ocean
Bermuda	Durango, Mexico
Bogota, Columbia	Easter Island, Chile
Caico, Brazil	Erimo, Japan
Canary Islands, Spain	Eskdalemuir, Scotland
Caracas, Venezuela	Falkland Islands
Cathedral Caves, Missouri	Fiji
Charters Towers, Australia	Frunze, USSR
Chiangmai, Thailand	Garm, USSR
Christmas Island	Hawaii Island
College, Alaska	Irkutsk, USSR
Corvallis, Oregon	Kislovodsk, USSR
Galapagos Island, Ecuador	Kodiak Island
Garni, USSR	Kwajalein Island
Godhavn, Greenland	Marquesas
Grafenburg, W. Germany	Midway Island
Guam, Marianas Islands	Naña, Peru
Harvard, MA	Newfoundland, Canada
Honiara, Solomon Islands	Obninsk, USSR
Kevo, Finland	Piñon Flat, California
Khartoum, Sudan	Seychelles
Kingsbay, Spitzbergen Island	Sutherland, South Africa
Kipapa, Hawaii	Wake Island
Kodaikanal, India	
Kongsberg, Norway	
Lembang, Indonesia	
Matsushiro, Japan	
Middle East	
Nairobi, Kenya	
Narrogin, Australia	
New Delhi, India	
New Site, Australia	
Pasadena, California	
Peldelhue, Chile	
Ponta Delgada, Azores	
Quetta, Pakistan	
Rarotonga, Cook Islands	
San Juan, Puerto Rico	
South Karori, New Zealand	
South Pole, Antarctica	
Taipei, Taiwan	
Toledo, Spain	
US Stations (5)	
USSR Stations (4)	

Table A2.

GSN Five-Year (1991-95) Costs for 100 Station Network Installation*

Costs in $K	1991	1992	1993	1994	1995	1996
Spare Parts Depot Inventory	302.0	314.1	326.6	339.7	328.1	0.0
Operation and Maintenance	1021.3	1453.4	1918.5	2418.5	2939.6	3269.8
Site Works & Installation	3182.5	3309.8	3442.2	3579.8	3457.1	0.0
Seismometers & Data Loggers	3019.9	3140.7	3266.4	3397.0	3280.6	0.0
Yearly Totals ($K)	7525.7	8218.0	8953.7	9735.0	10005.4	3269.8
Five Year Total — $44,437.8K						

*see Appendix 2 for detail

APPENDIX 2.

GSN BUDGET ESTIMATES

1. *Cost Detail — Budget for a 100 Station GSN*

GSN Budget Table 1 presents the detailed costs for completing a 100 station GSN in five years. The expenditures include: (1) the costs for upgrading the existing base of 31 stations to full design goal standards; (2) the costs for establishing 45 additional sites selected in the Technical Plan on the basis of good coverage and logistics; (3) 24 undesignated new vault and borehole sites which require additional site survey work before they can be specified with certainty. These twenty-four additional sites will all be in remote, difficult locations in order to fill in gaps in the global coverage The costs for the 24 undesignated sites are extrapolated on the basis of logistics experience, assuming a mix of one-third new vaults and two-thirds new boreholes, and assuming the use of IRIS-2 data loggers.

GSN Budget Table 2 details equipment and logistics requirements for the 100 station GSN costed in *GSN Budget Table 1*. The attached *Legend* annotates the specific entries in *GSN Budget Table 2*.

The budget rationale for operations and maintenance of the GSN is discussed in detail in the Appendices 3 and 4 of the Technical Plan, and is based upon over twenty years experience in operating seismic networks by the USGS and the academic community. Costs are twofold and are presented in *GSN Budget Table 3*. A spare parts inventory must be developed by equipping the Network Maintenance facilities while the stations are being installed. Experience has shown that the inventory needed is about 10% of the capital equipment costs. Yearly maintenance costs are illustrated by the requirements for a 60 station network. Yearly operations and maintenance costs are extrapolated from the average cost per station and the installed base of stations each year.

2. *Summary Budget*

The summary budget presents the costs for establishing a 100 station GSN within five years. In calculating the five-year budget, a 4% rate of inflation is assumed for the second through the fifth years (see *GSN Budget Table 4*).

Appendix 2 Budget Table 1 — Cost Detail for 100 station GSN (in $K)

	Seismic Station	Site Survey	Site Preparation	Site Installation	Broad-band Seismometers	Data Logger	Auxiliary Seismometers	S.O.H. Telemetry and GPS Timing	Total
1	Adak, Alaska	25	151	35	115	95	15	20	456
2	Adelaide, Australia			7		15	15	5	42
3	Afiamalu, W. Samoa			7			20	20	47
4	Akureyri, Iceland	25	151	35	115	95	15	5	441
5	Albuquerque, NM								
6	Alert, Canada			7		15	15	20	57
7	Ankara, Turkey	5	26	35	15		15	5	101
8	Arti, USSR			7		15		20	42
9	Ascension Island	25	276	35	115	50	15	20	536
10	Bermuda	25	151	35	115	95	20	5	446
11	Bogota, Columbia	5	26	35	15	95	15	20	211
12	Braslilia, Brazil			7		15	15	5	42
13	Caico, Brazil	25	276	35	115	95	20	20	586
14	Canary Islands, Spain	25	101	35	42	95	20	20	338
15	Caracas, Venezuela	5	46	35	42	95	20	5	248
16	Cathedral Caves, Missouri			7		95			102
17	Charters Towers, Australia			7			20	5	32
18	Chiangmai, Thailand	5	26	35	15	95	20	20	216
19	Christmas Island	25	276	35	115	95	20	20	586
20	College, Alaska			7			20	5	32
21	Corvallis, Oregon			7		95	15		117
22	Diego Garcia, Indian Ocean	25	151	35	115	50	15	20	411
23	Durango, Mexico	25	101	35	42	50	10	20	283
24	Easter Island, Chile			7		15	15	20	57
25	Erimo, Japan			7		15	10	5	37
26	Eskdalemuir, Scotland			7		15	15	5	42
27	Falkland Islands	25	151	35	115	50	15	20	411
28	Fiji	25	101	35	42	50	10	5	268
29	Flin Flon, Canada			7		15	15	5	42
30	Frunze, USSR			7		15		20	42
31	Galapagos Island, Ecuador	25	276	35	115	95	20	20	586
32	Garm, USSR			7		15		20	42
33	Garni, USSR							20	20
34	Godhavn, Greenland	5	46	35	42	95	20	20	263

Appendix 2 Budget Table 1 — Cost Detail for 100 station GSN (in $K)

35	Guam, Marianas Islands	5	26	35	15	95	15	5	196
36	Harvard, MA								
37	Hawaii Island	25	101	35	42	50	10	5	268
38	Honiara, Solomon Islands	25	276	35	115	95	15	20	581
39	Irkutsk, USSR			7		15		20	42
40	Kevo, Finland		46	35		95	20	5	201
41	Khartoum, Sudan	25	276	35	115	95	20	20	586
42	Kingsbay, Spitzbergen Is.	25	101	35	42	95	20	20	338
43	Kipapa, Hawaii			7				5	12
44	Kislovodsk, USSR			7		15		20	42
45	Kodaikanal, India	5	46	35	42	95	20	20	263
46	Kodiak Island	25	276	35	115	50	10	20	531
47	Kongsberg, Norway	5	21	35			20	5	86
48	Kwajalein Island	25	276	35	115	50	15	20	536
49	Lembang, Indonesia	5	46	35	42	95	15	20	258
50	Marquesas	25	276	35	115	50	15	20	536
51	Matsushiro, Japan			7		95	15	5	122
52	Mawson, Antarctica	25	101	35	42	50	15	20	288
53	Middle East	25	151	35	115	95	20	20	461
54	Midway Island	25	276	35	115	50	15	5	521
55	Nairobi, Kenya	25	276	35	115	95	15	20	581
56	Naña, Peru			7		15	10	20	52
57	Narrogin, Australia			7			20	5	32
58	New Delhi, India	25	151	35	115	95	15	20	456
59	New Site, Australia	25	151	35	115	95	20	5	446
60	Obninsk, USSR			7		15		20	42
61	Palmer Station, Antarctica	5	21	35	42	95	20	20	238
62	Pasadena, California								
63	Peldehue, Chile	5	21	35		95	15	20	191
64	Philippines	5	46	35	42	95	15	20	258
65	Piñon Flat, California					15			15
66	Ponta Delgada, Azores	25	151	35	115	95	15	20	456
67	Quetta, Pakistan	5	46	35	42	95	15	20	258
68	Rarotonga, Cook Islands	25	276	35	115	95	20	20	586
69	San Juan, Puerto Rico		46	35	42	95	15	5	238
70	Seychelles	25	276	35	115	50	15	20	536

Appendix 2 Budget Table 1 — Cost Detail for 100 station GSN (in $K)

71	South Karori, New Zealand			7			15	5	27
72	South Pole, Antarctica			7			20	20	47
73	Sutherland, South Africa			7		15	15	20	57
74	Taipei, Taiwan	5	26	35	15	95	15	5	196
75	Toledo, Spain	5	46	35		95	20	5	206
76	Wake Island	25	276	35	115	50	15	5	521
77-92	16 Undesignated Borehole Sites	25	276	35	115	95	20	20	586
93-10	8 Undesignated Vault Sites	25	101	35	42	95	20	20	338
	100 Station Totals ($K)	$1,400	$11,660	$2,625	$5,484	$6,400	$1,510	$1,490	$30,569

Appendix 2 Budget Table 2.
Site Requirements for 1991+

	Seismic Station	Site Survey	Site Preparation	Site Installation	Broad-band Seismometers	Data Logger	Auxiliary Seismometers	S.O.H. Telemetry and GPS Timing
1	Adak, Alaska	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	StdC+GPS
2	Adelaide, Australia			ReInstall		IRIS3mod	HFseismo	GPS
3	Afiamalu, W. Samoa			ReInstall			LRDCU+HFseismo	StdC+GPS
4	Akureyri, Iceland	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	GPS
5	Albuquerque, NM							
6	Alert, Canada			ReInstall		IRIS3mod	HFseismo	StdC+GPS
7	Ankara, Turkey	Visit	SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	SROmod		LRDCU+LGseismo	GPS
8	Arti, USSR			ReInstall		IRIS3mod		StdC+GPS
9	Ascension Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
10	Bermuda	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	GPS
11	Bogota, Columbia	Visit	SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	SROmod	IRIS2	LRDCU+LGseismo	StdC+GPS
12	Brasilia, Brazil			ReInstall		IRIS3mod	HFseismo	GPS
13	Caico, Brazil	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
14	Canary Islands, Spain	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
15	Caracas, Venezuela	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	GPS
16	Cathedral Caves, Missouri				ReInstall	IRIS2		
17	Charters Towers, Australia				ReInstall		LRDCU+HFseismo	GPS
18	Chiangmai, Thailand	Visit	SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	SROmod	IRIS2	LRDCU+HFseismo	StdC+GPS
19	Christmas Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
20	College, Alaska			ReInstall			LRDCU+HFseismo	GPS
21	Corvallis, Oregon			ReInstall		IRIS2	LRDCU+LGseismo	
22	Diego Garcia, Indian Ocean	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
23	Durango, Mexico	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS3	LGseismo	StdC+GPS
24	Easter Island, Chile			ReInstall		IRIS3mod	HFseismo	StdC+GPS
25	Erimo, Japan			ReInstall		IRIS3mod	LGseismo	GPS
26	Eskdalemuir, Scotland			ReInstall		IRIS3mod	HFseismo	GPS
27	Falkland Islands	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
28	Fiji	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS3	LGseismo	GPS
29	Flin Flon, Canada			ReInstall		IRIS3mod	HFseismo	GPS
30	Frunze, USSR			ReInstall		IRIS3mod		StdC+GPS
31	Galapagos Island, Ecuador	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
32	Garm, USSR			ReInstall		IRIS3mod		StdC+GPS
33	Garni, USSR							StdC+GPS
34	Godhavn, Greenland	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
35	Guam, Marianas Islands	Visit	SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	SROmod	IRIS2	LRDCU+LGseismo	GPS
36	Harvard, MA							
37	Hawaii Island	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS3	LGseismo	GPS
38	Honiara, Solomon Islands	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	StdC+GPS
39	Irkutsk, USSR			ReInstall		IRIS3mod		StdC+GPS
40	Kevo, Finland		ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies		IRIS2	LRDCU+HFseismo	GPS
41	Khartoum, Sudan	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
42	Kingsbay, Spitzbergen Is.	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
43	Kipapa, Hawaii			ReInstall				GPS
44	Kislovodsk, USSR			ReInstall		IRIS3mod		StdC+GPS
45	Kodaikanal, India	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
46	Kodiak Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	LGseismo	StdC+GPS
47	Kongsberg, Norway	Visit	SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies			LRDCU+HFseismo	GPS
48	Kwajalein Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
49	Lembang, Indonesia	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+LGseismo	StdC+GPS
50	Marquesas	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
51	Matsushiro, Japan			ReInstall		IRIS2	LRDCU+LGseismo	GPS
52	Mawson, Antarctica	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS3	HFseismo	StdC+GPS
53	Middle East	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
54	Midway Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	GPS

Appendix 2 Budget Table 2 (cont.).

55	Nairobi, Kenya	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	StdC+GPS
56	Naña, Peru			ReInstall		IRIS3mod	LGseismo	StdC+GPS
57	Narrogin, Australia			ReInstall			LRDCU+HFseismo	GPS
58	New Delhi, India	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	StdC+GPS
59	New Site, Australia	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	GPS
60	Obninsk, USSR			ReInstall		IRIS3mod		StdC+GPS
61	Palmer Station, Antarctica	Visit	SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
62	Pasadena, California							
63	Peldehue, Chile	Visit	SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies		IRIS2	LRDCU+LGseismo	StdC+GPS
64	Philippines	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+LGseismo	StdC+GPS
65	Piñon Flat, California					IRIS3mod		
66	Ponta Delgada, Azores	NewSurvey	NewBorehole1+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+LGseismo	StdC+GPS
67	Quetta, Pakistan	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+LGseismo	StdC+GPS
68	Rarotonga, Cook Islands	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
69	San Juan, Puerto Rico		ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+LGseismo	GPS
70	Seychelles	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	StdC+GPS
71	South Karori, New Zealand			ReInstall			LRDCU+LGseismo	GPS
72	South Pole, Antarctica			ReInstall			LRDCU+HFseismo	StdC+GPS
73	Sutherland, South Africa			ReInstall		IRIS3mod	HFseismo	StdC+GPS
74	Taipei, Taiwan	Visit	SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	SROmod	IRIS2	LRDCU+LGseismo	GPS
75	Toledo, Spain	Visit	ExistVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies		IRIS2	LRDCU+HFseismo	GPS
76	Wake Island	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS3	HFseismo	GPS
77	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
78	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
79	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
80	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
81	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
82	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
83	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
84	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
85	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
86	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
87	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
88	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
89	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
90	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
91	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
92	Undesignated Site, Borehole	NewSurvey	NewBorehole2+SiteTelemetry+LoggerTest+SeismoTest	NewInstall+Shipping+StaSupplies	BoreholeSeismo	IRIS2	LRDCU+HFseismo	StdC+GPS
93	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
94	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
95	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
96	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
97	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
98	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
99	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS
100	Undesignated Site, Vault	NewSurvey	NewVault+SiteTelemetry+LoggerTest	NewInstall+Shipping+StaSupplies	STS1Seismo	IRIS2	LRDCU+HFseismo	StdC+GPS

GSN Budget Table 2

Legend

Catagory	Entry	Cost ($K)	Note
Site Survey			
	NewSurvey	25	New site survey
	Visit	5	Site visit
Site Preparation			
	NewBorehole1	125	New borehole at site with services
	NewBorehole2	250	New borehole at difficult site
	ExistBorehole	3	Re-use of existing borehole
	NewVault	80	Prepare new seismic vault
	ExistVault	25	Refurbish existing seismic vault
	SiteTelemetry	16	Site telemetry between seismometers recording facility
	LoggerTest	5	Acceptance test for data logger
	SeismoTest	5	Acceptance test for seismometer
Site Installation			
	NewInstall	25	New equipment installation
	ReInstall	7	Revisit site to install additional equipment
	StaSupplies	5	Station supplies
	Shipping	5	Shipping costs
Broad-band Seismometers			
	STS1Seismo	42	Streckeisen STS-1
	BoreholeSeismo	115	Geotech KS54000
	SROmod	15	Broadband modification cost for existing KS36000
Data Logger			
	IRIS2	95	IRIS-2 station processor
	IRIS3	50	IRIS-3 station processor
	IRIS3mod	15	Upgrade existing IRIS-3 with 24 bit digitizer
Auxiliary Seismometers			
	LRDCU	5	Additional 16-bit digitizer/calibrator channels
	HFseismo	15	High-frequency seismometers
	LGseismo	10	Low-gain seismometers for strong ground motion
State-of-Health Telemetry and GPS Timing			
	StdC	15	Comsat Standard C system or equivalent
	PolarTelem	15	Polar telemetry via ATS satellite
	GPS	5	Global Positioning System clock

GSN Budget Table 3

Network Maintenance

Spare Parts Depot Inventory: 10% of Installed Hardware Cost		
Yearly Recurring Costs for 60 Station Network	$K/year	$K/year/station
Network Maintenance Team	63	1.0
Leader		
Field Engineers (6)	315	5.3
Bench Technicians (5)	250	4.2
Engineering (shop) Technician (1)	50	0.8
Supply/Shipping Clerk (1)	35	0.6
Clerk/Typist (1)	30	0.5
Supplies & Parts	90	1.5
Factory Repair	60	1.0
Travel Expenses	420	7.0
Communications	60	1.0
Shipping	60	1.0
Component Replacement	180	3.0
Yearly Totals	$1,613	$27 K/Station

GSN Budget Table 4

GSN Five-Year (1991-95) Costs for 100 Station Network Installation

Costs in $K	1991	1992	1993	1994	1995	1996
Spare Parts Depot Inventory	302.0	314.1	326.6	339.7	328.1	0.0
Operation and Maintenance	1021.3	1453.4	1918.5	2418.5	2939.6	3269.8
Site Works & Installation	3182.5	3309.8	3442.2	3579.8	3457.1	0.0
Seismometers & Data Loggers	3019.9	3140.7	3266.4	3397.0	3280.6	0.0
Yearly Totals ($K)	7525.7	8218.0	8953.7	9735.0	10005.4	3269.8
Five Year Total — $44,437.8K						

APPENDIX 3

REQUIREMENTS FOR THE IRIS/USGS NETWORK MAINTENANCE CENTER AT ASL

1. *Introduction*

A network maintenance center has been operated at ASL since the WWSSN was set up more than 25 years ago. It will continue to support other networks as well as the new GSN. The requirements of an NMC based on past experience are summarized below. Most of the personnel and facilities needed to operate the GSN NMC are already in place, and will be used to support the GSN as GSN equipment replaces GDSN equipment at the stations. The only new requirements are specific to the GSN data system.

2. *Personnel*

The following personnel are required to support a network of 60 operational stations:

- NMC Manager
- Engineer/Programmer
- Maintenance Team Leader
- Field Technicians (6)
- Bench Technicians (5)
- Engineering (shop) Technician
- Supply/Shipping Clerk
- Clerk/Typist

The field and bench technicians are the only categories in which the level of staffing is a linear function of the number of supported stations. Additional engineering and programming support is needed during deployment, or when major system modifications or new instruments are being developed and tested.

3. *Test Equipment and Facilities*

Two GSN data systems are needed for network support. One of these systems, without seismometers, will be installed in the electronics shop. It will be used as a test bed for fault diagnosis of defective components, for testing boards and modules that have been repaired, and for developing diagnostic procedures that can be used in the shop or at the stations. The second data system, in this case the prototype, is needed for evaluating system performance, the training of field teams and operators, development and evaluation of system modifications, and development of programs for station use in local processing of the data. This will be a complete system with seismometers, but only operated intermittently; that is, it cannot be considered an operational station. It will be used most during the training and evaluation stages of the program .

The major facilities required by the NMC are an electronics shop, an instrument shop, a good vault, and a pair of boreholes for testing. The electronics shop must be well equipped with general purpose test instruments and digital test equipment, including the special equipment used to isolate defective components on a board. Some test equipment is developed or programmed specifically for the supported systems. The instrument shop is needed for fabricating and assembling mechanical equipment, including plugs and seals for boreholes, calibration devices, and equipment racks; and for repairing mechanical equipment. The vault and boreholes are for testing seismometers and for evaluating new sensor systems. All of these facilities are currently available at ASL, except for any special test equipment needed specifically for the GSN data recording system and seismometers.

4. *Depot Spares*

The depot inventory is an essential resource that keeps the network operating. It consists of operating supplies, consumable small parts, and a floating stock of major boards and modules that are continuously cycled to the stations as replacements, returned, repaired, and placed back on the shelf. The spare parts needed to support field installation must be in place at the outset to keep production systems from being cannibalized. Spare parts and modules for the first 10 systems will be stocked on recommendations of the System Manager (for the data recording system) and on parts for other equipment needed at the minimum functioning level. An estimate of the initial parts and modules needed is as follows:

Data recording system components and boards	$ 72.2K
STS VBB sensor subsystem	39.0K
STS sensor subsystem component parts	15.0K
Modified KS 36000 electronics (2)	30.0K
VSP sensor subsystem and parts	23.0K
LG sensor subsystem	10.0K
Miscellaneous electronic parts	15.0K
Station supplies	15.0K

Subsequent stocking of depot spares should be budgeted at the rate of $80.0K for each 10 additional stations installed. This sparing level is somewhat less than 10% of total hardware cost (10% to 20% is common), but failure experience develops rapidly, and, after initial stocking, purchases of spare modules and boards, which are the most expensive items, can be more selective.

5. *Recurring Support Requirements*

Apart from personnel costs, other major expenses are for replenishment of supplies and parts, factory repair, travel of field technicians, communications, and shipping. These costs are estimated to be as follows.

Supplies & parts 1.5K/station/year
Factory repair 1.0K/station/year
Travel Expenses .... 70.0K/field technician/year
Communications 1.0K/station/year
Shipping 1.0K/station/year

In addition, it is important to program funds for component replacement beginning four or five years after initial deployment. A funding rate of 2.5K/station/year is sufficient for components that become obsolete or difficult to support; it is not sufficient for wholesale replacement of major subsystems, such as seismometers or digital encoders.

6. *Administrative Support*

Management and operation of a seismograph network requires more than technical facilities and expertise. There is a substantial administrative burden in supporting a global array of stations, especially when there is the diversity of instrumentation that presently exists in the global networks. There is a current active inventory of more than 4,000 line items of parts, components, and supplies at ASL needed to support the WWSSN and GDSN networks. This is a total number of individual items in the tens of thousands. The stock must be expediently maintained at minimum levels; It must be controlled effectively, stored or warehoused, packed and crated, and finally shipped using a variety of methods depending on cost and urgency. ASL makes an average of 1,000 shipments each year varying in size from a single recorder pen to a complete seismograph system. These and related administrative tasks are not trivial in either the volume of personnel, or cost. Clearly, the management and support of a global network requires a balanced organization that can handle both technical and administrative tasks.

APPENDIX 4.

IRIS/IDA Network Maintenance and Data Collection Center

1. *Introduction*

The IRIS/IDA network will be operated and maintained by personnel of the Network Maintenance and Data Collection Center (NM&DCC) located at the Institute of Geophysics and Planetary Physics in La Jolla, CA. This center has evolved over the past 14 years since the inception of Project IDA in 1975. As the IRIS/IDA component of the GSN is implemented in the next five years, some expansion of these facilities are planned.

2. *Personnel*

The personnel of the NM&DCC are listed below. This represents staffing for about a 20 station IRIS/IDA component of the GSN planned over the next five years.

Personnel	% Effort
Principal Investigator	50
DCC Director/Programmer	100
Project Chief	100
IDA Engineer	50
Technician #1	100
Technician #2	100
Computer Operator	100
Research Assistant	100/50
Administrative Assistant	30

3. *Equipment and Facilities*

Facilities for the NM&DCC are currently in the IGPP building at Scripps Institution of Oceanography. During the next five years, a new building is planned to provide expanded facilities for these activities.

3.1 *Network Maintenance*

The IRIS/IDA stations are maintained by a technical staff under the direction of the IRIS/IDA Project Chief. On average, each technician should maintain about 10 stations, visiting each about every second year. However, varying degrees of effort are required to keep each station at the point of optimum function. Upgrades to existing stations and the installation of new stations will require additional technical assistance.

The principal equipment items that will be maintained at the NMC are:

Lab Test Equipment
Field Maintenance Kits (3)
Spare Seismometers (2 sets)
Spare IRIS-3 Data Loggers (2)
Spare IRIS-3 boards (3 each variety)
Spare Tape decks (2 Exabyte, 2 9-track)
Spare Omega clocks (2)

3.2 *Data Collection*

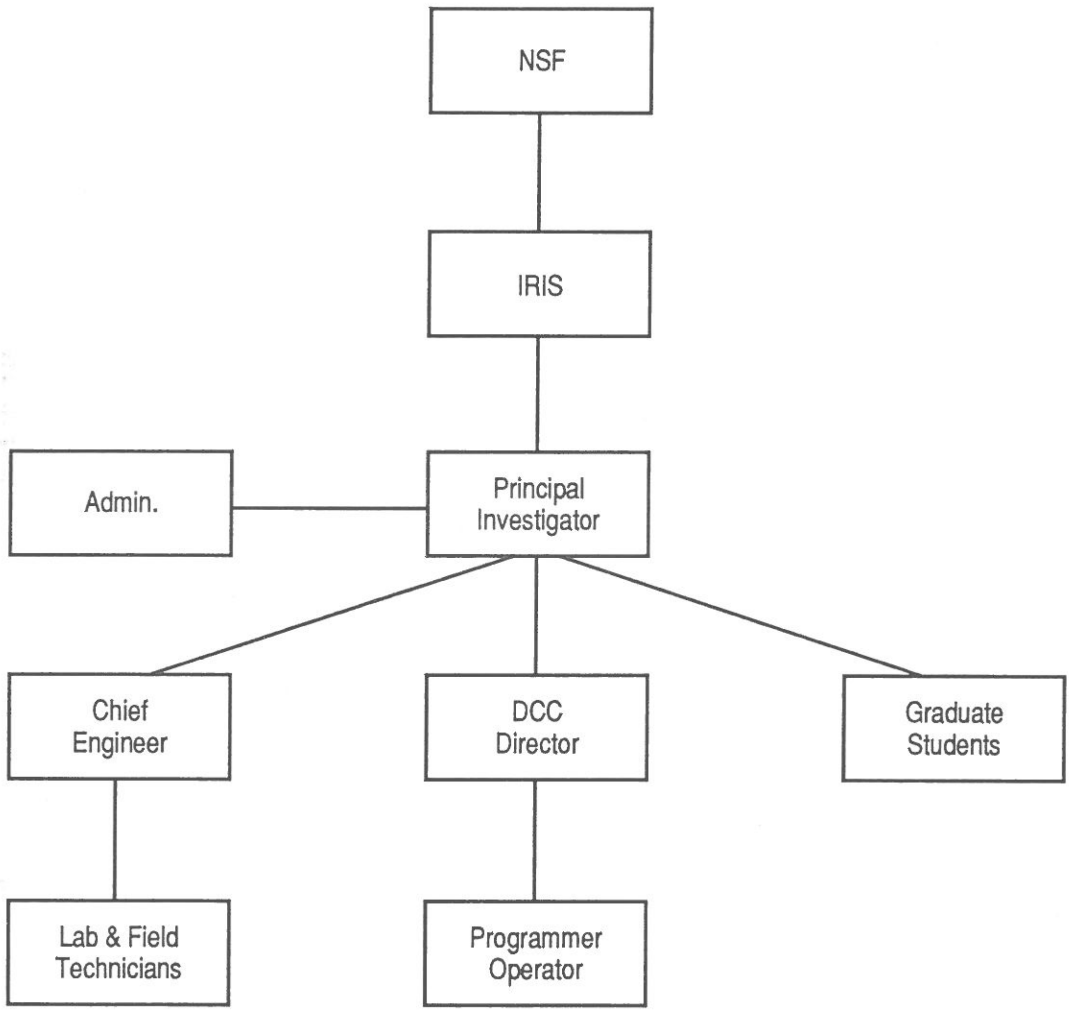
The IRIS/IDA Data Collection will be operated by the DCC Director and his (her) staff of programmer and computer operator support. The DCC is designed to handle the anticipated ~250MB of data collected daily from the IRIS/IDA component of the GSN (see box). Data is recorded at the stations on a variety of magnetic media which include 9-track tapes, 8mm video tape, and cartridge tape. Data is processed by a network of SUN3, SUN4, and microVAX computers and their associated peripherals. During the course of the next five years, it is anticipated that some stations will telemeter their data to the DCC in near real-time.

All raw data from the stations undergoes standard quality control processing to assure data integrity, and provide early indications of equipment malfunctions or other problems. On line channel calibrations and station maintenance histories are maintained as part of the overall data set.

The DCC will produce network volumes in the standard SEED format that will be distributed to the IRIS Data Management System for archiving and distribution.

4. *Management*

The IRIS/IDA component of the GSN is organized as illustrated in the following figure. It is managed under the Principal Investigator(s) by the Project Chief and the DCC Director. They are aided by an administrative staff, working with the normal University administrative infrastructure (accounting, purchasing, contracts & grants, etc.). In addition, shared laboratory facilities are provided by multi-project group within IGPP.



IRIS/IDA Organization

APPENDIX 5.

REQUIREMENTS FOR THE IRIS/USGS DATA COLLECTION CENTER AT ASL

1. *Data Collection System*

Although many desirable features have been included in the design of the new DCC data collection system, the major attributes sought were expandability, reliability, and automation. A flexible, expandable system would enable that capacity, investment, and technology to be tailored to current requirements, making it less costly and less susceptible to rapid technological obsolescence. A flexible system design also makes it possible for others to duplicate the data collection system for their own use.

Reliability is an essential attribute of the data collection system. The flow of data from the network is relentless; a prolonged failure can mean weeks or months of overtime catch-up work. Expandability and reliability are both enhanced by splitting the computational load between several high-performance microprocessors. Operated in a cluster, the processors appear to the user as a single large computer, but a failure or maintenance of one microprocessor will not seriously affect system operations. It is, of course, essential that the system always have 25% to 50% excess data handling capacity.

Increased automation is achieved through development of software that will require less operator intervention as the data are processed. The most important step toward automation from a hardware standpoint is in reducing tape handling to the minimum. Ideally, the only tapes handled are the station tapes, mounted once. The optical mass store is the key piece of equipment needed here. It provides the space needed to permanently store processed data in its final format while waiting for all of the station data to arrive.

A block diagram illustrating the IRIS/USGS DCC hardware configuration is shown in Figure 1. Currently, the DCC consists of three Digital Equipment Corporation (DEC) Microvax II's attached to a local network interconnect (DELNI). The DELNI is a concentrator that allows up to eight Ethernet compatible devices to be grouped together. Each Microvax contains an Ethernet to Q-bus high performance communications controller called a DEQNA that connects the processor to the Ethernet Local Area Network through the DELNI. With Ethernet as a high speed communications system, and with DEC cluster software which allows any peripheral to be used with any processor, the three Microvaxes appear to the user as one large processor. Each processor has several disk drives attached providing a total of 3.5 gigabytes of working disk storage for the system. There are also four tri-density tape drives, two 3M tape cartridge drives, and two Archive cartridge drives for reading station data, and three DEC TK50 tape drives. The mass store, a Sony "jukebox" style optical disk drive, serves both as an archive and as an on-line storage system for a minimum of six months of network data.

The Microvax 2000 workstation functions primarily as a network analysis system for data quality evaluation, and is connected through the DELNI to function as a system processor if needed. The Sun 3/160 workstation operates as a telemetry processor, electronic mail terminal, and programmer's workbench. Other buildings at ASL are connected to the DCC system on an Ethernet link through fiber-optic cables. An additional function of the DCC is to provide general-purpose computer support to the laboratory. Clustered VAX/VMS is used as the operating system. All application software is written in the C language. The Sun system provides a UNIX environment that can be used to modify application software for UNIX-based systems. A backup power system has been employed at ASL for several years. It provides 10-15 minutes of uninterrupted battery power for the computers when line power fails, enough to allow an orderly shutdown during working hours.

With the installation of the optical mass store and the satellite terminal for transmitting data to the DMC, the initial assembly of DCC hardware will be very nearly complete. One important item that must yet be installed is a non-destructive fire suppressant system to protect both the data collection system and the archived data. In addition, a few items of hardware needed include a plotter, memory for the workstation, replacement UPS batteries, and optical disks for the mass store. Some software needed for the satellite communications with the DMC will optimizing disk operations. If data volume increases as planned, in two years it will be necessary to supplement the DCC with a fourth Microvax processor.

Current development of the DCC does not include capability for acquisition of real-time data from the IRIS stations. The basic hardware requirements for reception and processing of real-time data will include receiving equipment, a dedicated Microvax III, additional working disk, high-density tape drives or some other media for data storage in event of a disk or DCC failure, and a diesel generator for backup power.

2. *Personnel Requirements*

The types and numbers of personnel needed to operate the DCC when the data input level reaches 300 megabytes per day are as follows:

DCC Manager
Data Analyst
Programmer
Computer Technician
Senior Computer Operator
Computer Operator (3)
Clerk

Six of these slots are currently filled at ASL; the others will be filled when warranted by the workload.

Two shifts each day may be necessary to utilize the hardware more efficiently, although the computer hardware will function with automated programs around the clock.

3. *Recurring Support Requirements*

The major annually recurring non-personnel costs of DCC operations for supporting an IRIS network of 60 stations, are expected to be as follows:

Hardware and software maintenance .... $ 50.0K

Supplies 40.0K

Communications 30.0K

Equipment Replacement 75.0K

A planned and adequately funded program of equipment replacement is essential. The amount of data that must be processed each day by the DCC allows very little margin for equipment failures or maintenance downtime, and future technological developments that increase operational reliability and efficiency should be exploited.

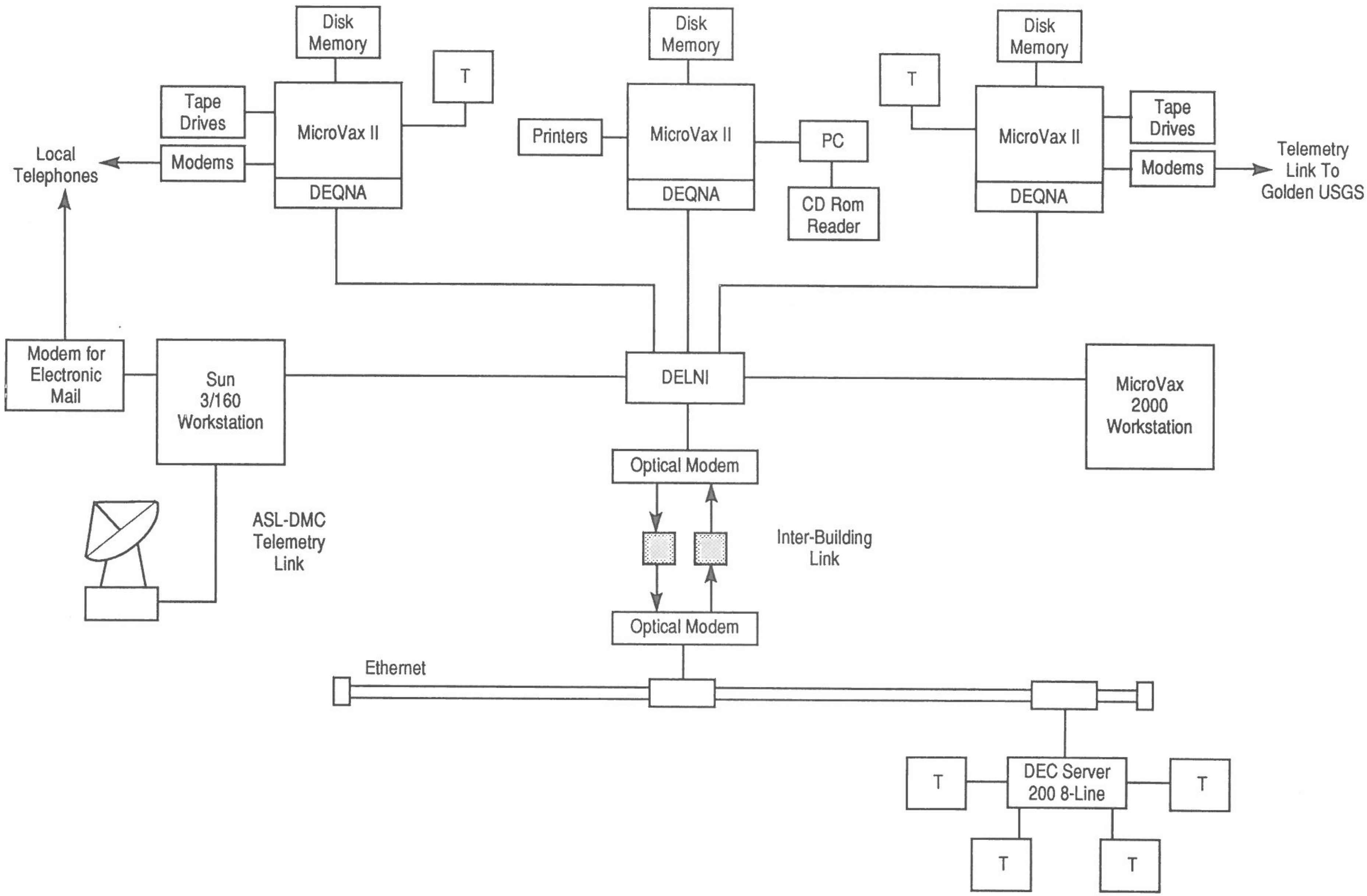


Figure 1. Block diagram showing major components of the IRIS/USGS Data Collection Center.

APPENDIX 6.

IRIS/IDA MEMORANDUM OF UNDERSTANDING

1. *Introduction*

This cooperative agreement establishes a coordinated position between the Incorporated Research Institutions for Seismology (IRIS) and the Institute of Geophysics and Planetary Physics, University of California San Diego (IGPP/UCSD) concerning joint activities relating to the establishment and operation of a new Global Seismographic Network (GSN) sponsored primarily by the National Science Foundation (NSF).

IRIS is a consortium of non-profit research institutions that has been organized for the purpose of promoting and guiding major initiatives to improve facilities for seismological observations and research. UCSD is a member university of IRIS, and faculty and staff of IGPP constitute the interested parties of UCSD.

This agreement pertains principally to the specific IRIS goals of:

- The establishment of a new Global Seismographic Network of 100 modern broadband seismograph systems with satellite communication links for telemetry of the data in real time to data centers.
- The support of an ongoing research and development program directed towards the creation and continued evolution of the IRIS Global Seismographic Network.

The purpose of this agreement is to establish guidelines that will govern program coordination and the division of IRIS and IGPP/UCSD responsibilities. This agreement is not intended to limit IRIS or IGPP/UCSD in any research activities or in developing other joint activities that may be mutually beneficial.

2. *Background*

For the past two decades, IGPP/UCSD has had an active program for the development of seismographic instrumentation and global seismographic network operations. In the mid 1970's, with private and NSF support, it began Project IDA, the deployment of a worldwide digital seismographic network designed specifically to provide data for studying the Earth's normal modes. Since then, data from this network has been used for a wide variety of studies ranging from the Earth's deep structure, to the physics of earthquakes.

Currently the IDA network consists of 23 stations operating in 16 countries. It is one of the three existing global digital seismographic networks, comparable in size and longevity to the USGS Global Digital Seismographic Network. It is also designed specifically to support academic research and as such, its operators have a long-standing interest in supporting the objectives stated in the IRIS report entitled *Science Plan for a New Global Seismographic Network.* The contribution of IDA network resources, through the active involvement of Project IDA in development of the GSN network, will substantially reduce program costs, and help to insure the success of the IRIS initiative. This agreement is meant to govern the activities of IGPP/UCSD in the integration of Project IDA as the IRIS/IDA component of the GSN. In what follows, the IRIS/IDA component of the GSN and IGPP/UCSD will be referred to simply as IDA.

3. *Responsibilities*

3.1 *Technical Plan*

IRIS and IDA, with the participation of the USGS will develop a *Technical Plan for a New Global Seismographic Network*, which will serve as a master planning document for the implementation of the GSN. It will include details of the instrumentation and station deployments, as well as data flow. This document will include plans for the first five year's activities through 1993, but will be reviewed periodically and amended as required.

3.2 *Program Coordination*

Advise on and oversight of the IRIS GSN program will be undertaken by the Standing Committee on the Global Seismographic Network (SCGSN). A member of the IRIS/IDA team will be an ex-official member of the SCGSN.

IRIS/IDA activities within the overall IRIS program will be coordinated by the IRIS headquarters staff, through the Manager of the GSN program and the Principal Investigator(s) of the IGPP/UCSD program.

3.2 *Funding*

IRIS and IGPP/UCSD will jointly develop yearly budgets for the operations and maintenance of the IRIS/IDA network and its related facilities. IRIS will include the costs of these activities as part of its requests for funds from the National Science Foundation for overall IRIS activities. IGPP/UCSD activities will be conducted under an IRIS sub-award, which will constitute the contract between these two parties.

APPENDIX 7.

IRIS/USGS COOPERATIVE AGREEMENT

Introduction

This cooperative agreement establishes a coordinated position between the U.S. Geological Survey (USGS) and the Incorporated Research Institutions for Seismology (IRIS) concerning joint activities that will be undertaken to develop and manage a new global seismographic network sponsored primarily by the National Science Foundation (NSF).

IRIS is a consortium of non-profit research institutions that has been organized for the purpose of promoting and guiding a major initiative to improve facilities for seismological observations and research. Major goals that pertain to this agreement are: (1) to establish a permanent global network of 100 modern broadband seismograph systems with satellite communication links for telemetry of the data in real time to data centers; (2) to establish the data collection facilities needed to organize and distribute the data to research institutions throughout the world; and (3) to establish a scientific data processing center to serve as a nucleus for processing and analyzing the large volume of data that will be created. The technical program will involve both the upgrading of existing networks and data management facilities and the installation of new stations and facilities. The objectives and benefits of the new seismograph network are described in an IRIS report entitled *Science Plan for a New Global Seismographic Network.*

One of the important roles of the USGS is to provide earthquake information and data services to the public. The USGS Albuquerque Seismological Laboratory has a 23-year history in the development, installation, and management of global seismograph networks, including the World-Wide Standardized Seismograph Network (WWSSN) and the Global Digital Seismograph Network (GDSN), together with the data processing facilities needed to collect, merge, and distribute the data to research scientists. The existing networks, and the cooperative agreements under which the stations are operated in more than 60 countries, constitute a valuable infrastructure from which a modern telemetered network can evolve. The past work at the Albuquerque Laboratory in this field has led to the formation of a cadre of experienced personnel and development of extensive technical and logistical network support facilities. The contribution of these resources through the active participation of the USGS in development and management of the new network will substantially reduce program costs and help to insure the success of the IRIS initiative.

Since the USGS and IRIS have common goal~ and objectives with respect to global seismograph networks and related activities, it will be advantageous to set up a cooperative arrangement whereby each organization contributes to the program. The purpose of this agreement is to establish guidelines that will govern program coordination and the division of IRIS and USGS responsibilities. This agreement is not intended to limit the USGS or IRIS in developing or operating other networks or performing related activities.

Joint Responsibilities

IRIS and the USGS will jointly develop a "Technical Plan for a New Global Seismographic Network", which will serve as the master planning document for development of the new network. Material for the plan will be drawn from the Science Plan, the work of IRIS Technical Committees, and other sources. The document will be revised and updated periodically to reflect current planning, scheduling, and budgeting.

Instrumentation Plans and Concepts

The development of concepts, plans, and preliminary budget estimates for network instrumentation, communication, and data collection will be a joint responsibility of IRIS and the USGS. It is understood that the development of concepts and plans will be assigned by IRIS to Technical Committees established under the IRIS Standing Committee for the Global Seismic Network. The USGS will be represented on the Committees that are responsible for planning tasks that may involve the USGS.

Network Configuration Plans

The development of network configuration plans and priorities for siting new stations, relocating existing stations, and selecting existing stations to be upgraded with new instruments will be a joint responsibility of IRIS and the USGS. It is understood that this planning may be assigned to an IRIS Technical Committee on which the USGS will be represented.

Data Collection and Initial Distribution

The establishment of procedures to be used for collection and initial distribution of the network data, the determination of any costs that may be assessed for the data, and the selection of organizations that will receive network data on a regular basis will be a joint responsibility of IRIS and the USGS. The USGS and IRIS may provide network data to other organizations and individuals as well. IRIS also plans to establish a seismological data center which will institute procedures for general distribution of the data.

Data Exchange

The establishment of formal data exchange agreements with international scientific organizations or foreign governments will be a joint responsibility of IRIS and the USGS.

Technical Evaluation of Proposals

Any source evaluation boards convened for the purpose of evaluating major technical proposals submitted by commercial firms for network instrumentation and related hardware and software will include representatives of IRIS and the USGS, and may include outside experts as well.

Funding

IRIS will initiate requests to NSF for the additional funds needed for

IRIS and USGS activities related to the development, installation, and operational support of the new or upgraded network and associated communication and data collection facilities. The USGS will endeavor to provide funds at least at current levels to support the existing or upgraded networks and related activities.

IRIS RESPONSIBILITIES

Scientific Guidance

IRIS will provide the guidance needed to insure that the data produced by the new network and the procedures used to organize and distribute the data adequately meet the needs of the scientific community.

Technology Studies

IRIS will initiate and fund technology studies that may be needed to investigate or develop innovative techniques for the acquisition, telemetry, or management of network data.

Scientific Data Center

IRIS will plan and initiate the establishment of a scientific data center that will be used for the processing and analysis of network data for research purposes.

Plans and Priorities

IRIS will have responsibility for final approval of the Technical Plan, detailed instrumentation plans and specifications for new network instruments and new data collection facilities, and for network configuration plans and priorities for siting new stations and selecting existing stations to be upgraded.

USGS RESPONSIBILITIES

The USGS will be responsible for the management and administration of tasks that may be assigned to the USGS within the context of this cooperative agreement, including the following.

Test and Evaluation

The USGS will be responsible for performing test and evaluation of new instruments and systems purchased by or for the USGS. Test plans may be developed jointly and results will be provided to IRIS.

Station Agreements

The USGS will be responsible for negotiating and executing agreements with individual stations or foreign governments for operation of network

stations and communication facilities. The USGS is responsible for decisions regarding the modification of existing agreements with stations in the USGS managed network.

Station Sites

The siting of new stations (at locations designated by IRIS) and any site testing or site preparation that may be required will be the responsibility of the USGS working together with the host organization.

Installation and Training

The installation of station and communication equipment and the training of station operators will be the responsibility of the USGS.

Network Support

The USGS will be responsible for the management and support of the network and communication facilities, a depot maintenance center, and any regional maintenance centers that may be established.

Data Collection

The USGS will be responsible for management and operation of the data processing facilities used to collect, validate, organize, merge, and distribute the digital data to data centers.

Earthquake Information

The USGS will develop and perform routine standardized processing of network data for earthquake information which will continue to be published and disseminated by the National Earthquake Information Center.

PROGRAM COORDINATION

Policy and Management Coordination

IRIS and the USGS will each designate a Program Coordinator from their respective organizations. The

IRIS/USGS Program Coordinators will resolve issues of policy and management that affect the joint activities; they will establish the management procedures needed for general review and oversight of the activities assigned to the USGS; and they will establish the administrative arrangements that may be needed in the performance of joint activities.

Technical Coordination

IRIS and the USGS will each designate a Technical Coordinator from their respective organizations. The IRIS/USGS Technical Coordinators will establish liaison between IRIS and the USGS on technical matters during the planning and establishment of the network; they will work closely with the Technical Committees to insure that the interrelated work of the various Committees is coordinated and integrated; and they will be jointly responsible for drafting the Technical Plan.

Signed:

Thomas V. McEvilly
University of California, Berkeley
Acting President and Chairman, Board of Directors
Incorporated Research Institutions for Seismology
August 30, 1984

Dallas L. Peck
Director
U.S. Geological Survey
November 16, 1984

APPENDIX 8.

SUPPLEMENTARY ARTICLES OF THE INTERAGENCY ACCORD

Article 1

USGS AND NSF ROLES AND RESPONSIBILITIES IN THE GLOBAL DIGITAL SEISMIC ARRAY AND DATA MANAGEMENT

It is agreed that a major element in the program for implementing the Committee on Science, Engineering, and Public Policy (COSEPUP) recommendations is the development of the Global Digital Seismic Array (GDSA), with the goal of 100 low-noise, wide-band, high dynamic range worldwide stations to be telemetered in near real-time to a central data collection facility. It is also agreed that, while IRIS will play a leading role in the planning, design, prototype testing, siting and operational oversight of the new GDSA, it is clear that much of the new array will be built on existing and new U.S. Geological Survey (USGS) stations, and thus be jointly managed and supported by the National Science Foundation (NSF) through the Incorporated Research Institutions for Seismology (IRIS) and the USGS.

Previous Agreement:

This Article acknowledges the existence of the IRIS/USGS Cooperative Agreement, signed in August 1984, which sets out in some detail the joint and individual responsibilities of IRIS and USGS, and the plan for program coordination. The Agreement (appended hereto) is considered to be a part of this Article, and its provisions are mutually acknowledged as being in effect.

USGS Role in New Global Digital Seismic Array

The USGS role and responsibilities in implementing the new GDSA can be summarized in the following list of plans for participation:

1. Participate through various IRIS committees and assist otherwise in the design of the station instrumentation, the Data Collection Center, and the network configuration.
2. Install and maintain the majority of the new GDSA stations, including all new stations resulting from upgrades at present USGS-maintained stations. Other GDSA stations could include existing university-operated stations, foreign networks being run by other countries, and any special situations where it may not be possible to have formal U.S. Government involvement or where it may be advantageous to have a university-to-university arrangement.
3. Operate the primary Data Collection Center for the GDSA stations. The Center would be collocated with the Albuquerque Seismological Laboratory,
4. Provide data from the USGS-operated Data Collection Center to the IRIS-operated scientific Data Management Center.

NSF Role in the Global Digital Seismic Array

The NSF role and responsibilities in implementing the new GDSA stations can be summarized as follows:

1. Provide substantial funding for the new GDSA development, deployment, and for operation of IRIS-operated facilities.
2. Provide substantial funding for the IRIS scientific Data Management Center.
3. Insure coordination of IRIS activities with appropriate Government agencies.
4. Provide oversight for IRIS program.

Joint Agreements

1. The NSF and USGS jointly agree that the NSF-sponsored IRIS Data Management Center will be used for the processing and analysis of network data for research purposes and will not duplicate the operational activities and services of the USGS-sponsored National Earthquake Information Center.
2. The NSF and USGS jointly agree to seek through their own budget processes the funds necessary to carry out their own activities and functions as called for by this agreement. In the event that transfer of funds between these agencies occurs, such transfer will be made directly and not through a third party.
3. The NSF and USGS agree that the USGS will be responsible for negotiating and executing agreements with individual stations or foreign governments for operation of network stations and communication facilities.

Signed:

Dallas L. Peck, Director
U.S. Geological Survey
Department of the Interior
U.S. Geological Survey

February 24, 1986

Erich Bloch, Director
National Science Foundation

February 3, 1986