Review of the Global Seismographic Network

Prepared for the Instrumentation and Facilities Program

Earth Sciences Division

National Science Foundation

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From

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Introduction

This report on the Global Seismographic Network is submitted to the Instrumentation and Facilities Program of the Earth Sciences Division in fulfillment of a special requirement in Cooperative Agreement EAR-0004370 between NSF and IRIS: "Exploring the Earth at High Resolution: The IRIS 2005 Program Plan".

The core of this document is a report from a special committee appointed to review the operations and status of the GSN and provide adv ice and recommendations to the IRIS President and Executive Committee. The Review Committee visited the GSN operational facilities in Albuquerque and San Diego, February 10-12, 2003 and met with network staff as well as representatives from NSF, USGS and IRIS. The Committee provided its report to IRIS in April 2003. The report was distributed for comment to the IRIS Executive Committee and Standing Committees for the GSN and DMS and the ASL and IDA network operators. Responses to the principle recommendations of the Review Committee were endorsed by the IRIS Executive Committee.

This report consists of the following sections:

I. Charge to the Review Committee
II. Report of the Review Committee
III. Responses to Review Committee Recommendations
IV. Summary of IRIS actions

IRIS wishes to express its sincere appreciation to the members of the Review Committee and its Chair, Henry Pollack, for the time, effort and insight they contributed in development of their review. Their report provides a thoughtful and well-articulated endorsement of the quality and value of the GSN and points to a number of significant opportunities for future stability and improvement.

IRIS is committed to working with the research community, the network operators, NSF and the USGS to implement the recommendations of the Review Committee to ensure a viable future for the Global Seismographic Network and continue the long-standing and productive traditions of international cooperation in seismology.

Charge to the Review Committee for the Global Seismographic Network

GSN Review

The Review Committee for the Global Seismographic Network (GSN) is to provide an assessment of the operational quality and state of health of the GSN. The Committee is asked to provide recommendations and advice to the IRIS Executive Committee and President and to the National Science Foundation on ways to maintain the quality and improve the operations, efficiency and scientific return of the network.

The review should take a long-term perspective and consider how to ensure the continued viability of the network and quality of operations over the next decade.

While the primary purpose of the committee is to review and report on those activities that fall under the IRIS/NSF program, it is recognized that the GSN is a collaborative project that includes the USGS and international partners. NSF and IRIS will work closely with the US Geological Survey to ensure that the deliberations of the committee and the implementation of its recommendations are coordinated with those activities of the GSN that involve the US Geological Survey. International GSN partners and the Federation of Digital Seismographic Networks will be informed of the review, invited to provide input and provided with a summary of the Committee's recommendations.

Major emphasis will be placed on the Global Seismographic Network itself – i.e. "operations, personnel and instrument costs" as supported through the IRIS GSN Program. However, the review also should include those activities related to quality control and data management and distribution related to the GSN that fall under the IRIS Data Management System.

Mandate

The Cooperative agreement between the IRIS Consortium and the National Science Foundation requires IRIS to:

"Carry out and report to NSF by July 1, 2003, an in-depth study of the operation, personnel and instrument costs, and support of the Global Seismographic Network, in collaboration with NSF, USGS, representatives of the Federation of Digital Seismic Networks (FDSN), and GSN network operators."

Membership

The committee will be appointed as specified under Article V, Section 4 of the IRIS By Laws, which states: "The President may appoint advisory committees or panels to assist in carrying out the business of the Corporation".

The Review Committee for the Global Seismographic Network will consist of a Chair plus six members. Members of the committee will be appointed by the IRIS President in consultation with the IRIS Executive Committee, the Program Manager for the Instrumentation and Facilities Program of the Earth Sciences Division of the National Science Foundation and the Program Coordinator for the GSN program at the US Geological Survey.

Members will be chosen to minimize real or perceived conflicts of interest with IRIS or the GSN network operators

Schedule

It is anticipated that the committee will require at least one three day meeting early in 2003. A final report will be presented to IRIS and NSF by April 15, 2003.

The committee will be briefed by IRIS Program staff and governance (including representatives of ExCom, GSN and DMS Standing Committees), representatives of the GSN network operators, and other interested parties. If required, site visits will be arranged to network operations centers in San Diego and Albuquerque and the Data Management Center in Seattle.

The Committee will be provided with written documentation on the history and current status of the GSN and budgetary information.

Key Questions

GSN Goals

The original concept for the GSN set the following goals: "a global network of uniformly spaced stations (~2000 km spacing), capable of recording the full range of seismic signals, with data collection in real time".

- Are these goals still appropriate?

Technology

The GSN technical specifications, established in 1984, established new standards for seismological instrumentation both nationally and internationally.

- Has GSN instrumentation kept pace with technological development over the past twenty years?
- Are there investments in new technology that could enhance the scientific return, performance or efficiency of the GSN?
- What should be the process by which technology R&D is supported and new technology is brought into the GSN?

Management, Coordination and Oversight

The IRIS/USGS Global Seismographic Network includes two sub-networks (IDA and USGS) plus a limited number of independent university-operated stations. Capital equipment and installation costs are supported by the NSF. Operational costs are provided by the NSF and USGS. Management coordination for IRIS is provided by the IRIS GSN Program Manager. Policy oversight is provided by the GSN Standing Committee and the USGS has agreed to consider, and when possible accept, the oversight of this committee.

- Is the current management structure appropriate and sufficient?
- Would there be significant advantages or disadvantages to a substantially different mode of operation?

Costs

A major challenge for the long-term survivability of the GSN will be to contain operational and maintenance costs.

- Are the current costs appropriate and well-substantiated?
- Are the current staffing levels appropriate and well-substantiated?
- Are there specific operational models that could significantly reduce costs?
- Are there investments in new technologies or mode of operation that can help to minimize future operational and maintenance costs?

Partnerships

Partnerships with other FDSN networks are essential to provide global coverage in areas not covered by the GSN. In recent years, regional networks with modern digital instrumentation have started to provide high-quality observations at in many parts of the world.

- Are there ways in which improved collaborations between the GSN and other networks could enhance global seismological observations and/or improve the efficiency of the GSN?

GSN expansion

The IRIS/USGS GSN now consists of 138 stations completed or planned. Combined with stations of cooperating FDSN networks (especially Geoscope, Pacific 21, Geofon and Mednet) and possible cooperation with the CTBT IMS network, the coverage on land have reached that envisioned in the original GSN siting plan. Coverage in many oceanic regions is still sparse. The infrastructure provided by the global extent of the GSN offers opportunities for other types of geophysical or environmental observations.

- Should the GSN siting plan be re-visited?
- What efforts should IRIS undertake to encourage the installation of permanent observatories on the sea floor?
- Should IRIS be proactive in encouraging the installation of other types of sensors at GSN sites?

Data Management

The IRIS Data Management System has the responsibility to provide access to all GSN data. In addition, as part of its commitment to the FDSN, IRIS is a permanent FDSN archive for continuous data and can provide coordinated access to many FDSN stations.

- Is there appropriate interaction between the IRIS Data Management Center and the Data Collection Centers operated by IDA and USGS?
- Are there ways in which IRIS DMS procedures for GSN data management and quality control can be improved?
- How can IRIS help to improve linkages between other global, national and regional data centers?

Report of the Committee appointed to review the Global Seismographic Network of IRIS

Review Committee Members:

Don L. Anderson, California Institute of Technology (retired)

Bob Engdahl, USGS (retired), University of Colorado

Domenico Giardini, ETH Zurich

David McCormack, Geological Survey of Canada

Henry N. Pollack (Chair), University of Michigan

Gerardo Suarez, International Monitoring System, CTBTO

Dan Weill, National Science Foundation (retired)

15 April 2003

Introduction

The Incorporated Research Institutions for Seismology (IRIS[1]) is a consortium of universities with seismological research programs, established in 1984 for the purpose of creating and managing new research facilities in seismology. The Global Seismographic Network (GSN), the subject of this review, and the Data Management System (DMS) are principal components of IRIS.

Ultimate oversight of the GSN rests with the National Science Foundation (NSF) and the U.S. Department of Interior (DOI) by virtue of their financial support. The NSF funds for the GSN come via a 5-year Cooperative Agreement with IRIS, and the DOI support for the GSN comes through an annual "line-item" appropriation to the U.S. Geological Survey (USGS). This dual agency support of the GSN is reflected in the GSN's two separate network operators, the Albuquerque Seismological Laboratory (ASL) of the USGS, and Project IDA of the University of California, San Diego (UCSD). The NSF and the DOI periodically review their financial support of the GSN according to established internal procedures that are outside the purview of this Review Committee.

The cooperative agreement between IRIS and the NSF requires IRIS to:

"Carry out and report by July 1, 2003 an in-depth study of the operation, personnel and instrument costs, and support of the Global Seismographic Network, in collaboration with NSF, USGS, representatives of the Federation of Digital Seismic Networks (FDSN) and GSN network operators."

Accordingly, IRIS President David Simpson appointed a Review Committee comprising:

Don L. Anderson, California Institute of Technology (retired)
Bob Engdahl, USGS (retired), University of Colorado
Domenico Giardini, ETH Zurich
David McCormack, Geological Survey of Canada
Henry N. Pollack (Chair), University of Michigan
Gerardo Suarez, International Monitoring System, CTBTO
Dan Weill, National Science Foundation (retired)

The Charge to the Review Committee is attached to this report as an Appendix.

To provide background to the review, IRIS sent the Review Committee (RC) an extensive briefing book which included technical, operational and financial information; the agenda and documents distributed at the October 2002 GSN Standing Committee meeting; and the most recent IRIS five-year proposal to the NSF (August 2000), along with reviewers' comments. The review process included site visits to both the ASL and

[1] In this report we make use of many common acronyms and abbreviations. However, for the benefit of readers perhaps less familiar with these terms, we list and define them all in a Glossary found on page 16.

UCSD in the period 10-12 February 2003, where the network operators presented overviews of their respective operations, provided additional documentation, and engaged in discussion with the Review Committee. The President of IRIS and the GSN Program Manager accompanied the RC on the site visits, and were available to the Committee whenever needed. Representatives of the NSF, the USGS, the GSN Standing Committee (GSN SC) and the DMS Program Manager also made presentations to the RC. The RC had ample time for candid private discussion and for outlining the report we submit here. Subsequent preparation of the report was a joint effort, with every Committee member contributing.

At the outset the Review Committee is obliged and pleased to note that this community enterprise, the GSN, has been an extraordinary success. The establishment of a high-quality global digital network has been achieved, and it now serves as the primary source of data for seismologists worldwide. This data has revolutionized the solid Earth sciences. It is becoming ever clearer that understanding the way our planet works requires a whole-Earth perspective, and the highly successful GSN, along with the International Ocean Drilling Program, illustrate the immense value that international research facilities present to the entire Earth science community.

The Review Committee recognizes the GSN as a major accomplishment that calls for congratulations to all contributing parties: the IRIS supervisory team responsible for GSN coordination and oversight, the IRIS DMC that provides the essential interface to the user community, the USGS, UCSD and the other international network operators that provide the backbone of operational management, and the many individual station operators around the world. And of course not to be overlooked are the funders of this extraordinary enterprise, the National Science Foundation, the USGS, scientific funding agencies in other countries, and international funding in support of the Federation of Digital Seismographic Networks (FDSN/IASPEI) and the International Monitoring System of the Comprehensive Test Ban Treaty Organization (IMS-CTBTO).

The report the Review Committee submits here addresses the present status of the GSN (and to some extent the DMC) in the context of its original design goals, and presents perspectives on the future operation and development of the GSN. The report addresses all the principal topics that the RC was asked to address[2], albeit not in the same structure or order as presented in the Charge to the Committee.

A summary of the principal conclusions and recommendations of the Review Committee is presented on page 15. The report of the RC represents an unambiguous consensus. The conclusions reached and the recommendations made have the full endorsement of the entire Review Committee.

[2] GSN goals, Technology, Management Coordination and Oversight, Costs, Partnerships, GSN expansion, Data Management

Historical Perspective

From its modern beginnings in the late 19th century seismology has been a global science, one in which data has been collected and shared internationally. Originally these data were principally used to locate earthquakes and estimate their size, but today global seismic data has manifold applications, including the mapping of Earth's internal structure and composition, understanding the dynamics of earthquake generation, differentiating anthropogenic from natural seismic sources, assessing seismic and tsunami hazards, and of course continuing to locate earthquakes and determining their magnitude. It is no exaggeration to say that the modern paradigm of whole-Earth structure and geodynamics owes its genesis to high-quality global seismic data.

Throughout the first half of the 20th century seismograph stations were installed at various places around the globe without any overall coordination. This unplanned development and deployment of seismological observatories resulted simply from a growing research interest in earthquakes. However, in the second half of the century, the notion of a structured global network of seismograph stations with common instrumentation became both attractive and fundable. Such entities as the World Wide Standardized Seismograph Network (WWSSN), the Seismic Research Observatories (SRO), and the Global Telemetered Seismograph Network (GTSN) came into existence and functioned effectively for as long as several decades.

While the first such global networks were still based on band-pass instrumentation (short or long period) and used analog recording, in the late '70s very-broad-band high-dynamic-range instrumentation became available. At that time the concept of a global network of digital broadband stations, capable of recording large local earthquakes as well as faint free oscillations, became viable. The first projects to embrace the new digital technology were the USGS's Global Digital Seismograph Network (GDSN), UCSD's International Deployment of Accelerometers (Project IDA), and the French GEOSCOPE.

In 1984 IRIS, a consortium of universities with seismological research programs, was established for the purpose of creating and managing new research facilities in seismology. From the outset, the GSN and the DMC have been principal components of IRIS. The GSN collects seismic signals, and the DMC archives and distributes seismic data (principally waveforms) from the GSN and other international networks to the worldwide user community. The GSN was created under the supervision of IRIS by joining the two United States-led global networks, the GDSN and Project IDA, operated respectively by the USGS and UCSD.

Since the beginning the GSN has allied with other global operators (GEOSCOPE, GEOFON) and regional networks such as the Canadian Digital Seismic Network (CDSN), the China Seismic Network (CSN), and the Mediterranean Network (MEDNET) to enable wide distribution of high-quality stations around the world. IRIS has played a major role in the coordination of technical standards, data exchange and station siting, within the structure of the FDSN. In more recent years, the IMS-CTBTO

came into existence, as a response to the need to monitor compliance with the nuclear test-ban treaty globally.

GSN Goals

Geographic Siting and Network Density. The GSN was originally conceived as a network of 128 digital seismographs arrayed uniformly around the globe, a configuration that yields a station spacing of about 18 arc degrees or about 2000 km. In 2003, almost two decades after the birth of IRIS, there are 126 stations installed and 12 additional planned. These stations are distributed over all continental landmasses, several key island sites, and an ocean bottom location between Hawaii and the west coast of the U.S. Of the installed stations the USGS manages 73, UCSD manages 38, and other universities and affiliated institutions operate 15. When the GSN stations are combined with stations from the FDSN and the IMS-CTBTO, the number of land-based stations exceeds that called for in the original GSN plan. Although the exact number of stations and their locations will continue to be subject to change due to the installation of a few additional stations and/or the possible closing of some stations, future perturbations to the existing system are expected to be small. Clearly, in terms of numbers alone, the design goal has been met and the network is essentially complete.

The geographic distribution of stations (both IRIS and FDSN) over the globe, however, has still not achieved the design goal of uniform spacing, particularly in oceanic regions where most of the geographic coverage comes from installations on oceanic islands. On the continents there remains unevenness in distribution, with a higher than necessary station density in some regions, and a paucity of stations in other regions. Nevertheless, the Review Committee believes that the geographic distribution of stations is adequate for most of the scientific purposes for which the GSN was designed. Improvements may come with deployment of ocean bottom seismometers, but that technology is still in its infancy, and compared to land-based installations, very expensive. The RC encourages continued development of such technology, but recognizes that much of the funding and progress in this area will probably come from outside of IRIS. Expanded coverage, including ocean instruments, will continue to require that IRIS collaborate with other groups and countries. In the development of such collaboration IRIS brings to the table a strong and tested network infrastructure, and a smoothly functioning DMC. The DMC, as the official FDSN data repository, already archives and distributes data from non-IRIS supported networks, and it is the logical entity to continue in that role as new data sources emerge.

Operation and Maintenance of the Network: The emerging GSN primary mission. The GSN has now come very close to meeting its initial goal of installing a worldwide network of broadband digital seismic stations. With the exception of a few sites that are still planned, the GSN installation is essentially complete. Henceforth, effective operation and maintenance of the network must be the primary mission of the GSN. The Review Committee believes that the biggest challenge to the GSN for the immediate future is the transition from the planning, development and installation stage (now nearly complete) to the long-term operation and maintenance mode (O&M). This new role

brings on new challenges that may require changes in the structure and perspectives of the three principal GSN actors: IRIS management, the USGS/ASL, and UCSD/ IDA. As part of the long-term O&M perspective, relevant issues include the overall quality of the GSN stations as well as those in other networks, the outlook for very-long-term sustainability, and provisions to maintain a global distribution, should one of the global networks interrupt its operations. The GSN should continue to maintain strong and cordial connections to other networks, and should give careful consideration to operating certain key stations in other networks temporarily or even permanently, in case the original network operator interrupts or withdraws support and services. All these topics are discussed more fully in later sections.

Archiving and distributing regional data: an expanding IRIS/DMC activity. In the near future, it is likely that high quality broad-band data will be recorded by dense regional seismic arrays. Although the data may not be of quite the same quality as that produced in the GSN, owing to different sensor characteristics and site and installation parameters, the data will be complementary to GSN data for source and structural investigations. The task of ensuring long term archiving and easy access to waveforms recorded by regional networks should be embraced by the IRIS/DMC.

Network Technology

The GSN has from its outset sought to install three-component seismic sensors with wide dynamic range and very broadband response, and convey the seismic signals to the DMC in a digital format. The Review Committee believes that these instrumentation goals need no essential revision. In the following we discuss the instrumentation under the broad categories of sensors, data loggers, data transmission, and DCCs.

Sensors. The sensor of choice has been the STS-1, with the KS-54000I an acceptable alternate. Both sensors have yielded high quality data, but the STS-1 has a significantly broader band of response. The future availability of the STS-1, however, is in question for two reasons: (a) the high quality and uniformity of the sensor depends on the personal skill of the designer/assembler, who has intimated that he no longer wishes to build the instrument, and (b) the original supply of fabrication material is nearly exhausted, and the uniformity depends in part on use of this common material.

As the GSN begins a decade of O&M, sensor failure will become more common. The question arises as to where replacement STS-1 instruments can be obtained, and ultimately whether a suitable replacement for the STS-1 can be developed. One possibility is to close poorly performing stations and recycle their instruments; another is to purchase spare instruments from other networks with surplus equipment. But in the long run, a replacement broadband sensor needs to be developed. The IRIS GSN SC should re-energize its Instrumentation Committee (IC) to address this problem (among others) and to explore possible solutions, including perhaps some explorations with the existing NSF program that supports the development of scientific instrumentation, as well as within the FDSN framework.

Data loggers. The GSN network operators, the USGS/ASL and UCSD/IDA, have been guided by different philosophies in acquiring their field instrumentation, with the ASL employing commercial off-the-shelf products whereas IDA has pursued in-house development and assembly. As a result, ASL and IDA use different data loggers, each with its own problems (according to the other operator) in timing, polarity, noise levels, and power requirements. Not only are the data loggers different, but they are also incompatible, and thus spares of one cannot be used to repair or replace a failed logger of the other type. Additionally, the difference in field instrumentation and in the telemetry protocols results in a substantially different architecture at the two Data Collection Centers (DCCs).

This situation is highly inefficient and undesirable. We note that essentially the same critique is set forth in the 26 August 2002 report of the GSN ad hoc Design Goals Subcommittee (p.3): "…there are significant non-uniformities in the instrumentation comprising the GSN today [that] seriously complicates maintenance of the network." Clearly, a more unified and coordinated policy in equipment selection is essential. Because many older stations will soon be in need of new station equipment, and because of the new role played by continuous telemetry, IRIS needs to rethink its data collection strategy. We return to this topic below, in the paragraphs under *Network Standardization* and in the section on *Management Coordination and Oversight*.

Data transmission. Transmitting data from the station site to the contractor's Data Collection Center is accomplished in many ways, ranging from tapes sent by mail, dial-up and direct link internet connections, and real-time on-site satellite telemetry. Both operators are rapidly moving to continuous telemetry, and it will soon be in operation at about 75% of the sites. The Review Committee stresses that an important near-term priority goal of the whole GSN should be achieving real time telemetry at as many of the global stations as possible. This has both scientific and humanitarian benefits, and will result in operational efficiencies and long-run cost effectiveness. The RC learned that GSN stations that are part of the IMS network can be incorporated into the CTBT communications network at relatively low cost. This possibility has already been tested at three stations, and the RC urges IRIS to use this option at as many GSN stations as possible.

With a reliable telemetry system in place, field instrumentation could perhaps be simplified, to eliminate local recording and/or moving parts, which would in turn result in lower power requirements and reduced field maintenance. Other goals of the GSN, such as increasing the spatial coverage of the network, improving the instruments, or developing noise suppression techniques should be secondary to assuring a fast and reliable data stream from source to user across the existing network.

Data Collection Centers (DCCs) The parallel DCCs operated by the USGS/ASL and UCSD/IDA were created in response to requirements during the early period of development of the GSN. Then, much time and effort were necessary to perform quality control and recovery on tapes arriving from the stations of the network, and in the case of UCSD/IDA, translation of data formats was also necessitated by the choice of field

hardware. As an ever-increasing number of stations become connected in real-time to the DCCs, the emphasis of DCC activity should shift increasingly from a batch processing role to a continuous, and to the extent possible, automatic station performance monitoring role in support of field operations. The first opportunity to detect station problems and initiate remedial steps is at the DCCs. The overarching principle defining future DCC activities should be the maintenance of data quality. IRIS should give increased focus to development of tools for further automation of data quality monitoring. The RC urges increased coordination between the two DCCs in developing quality control procedures and data transmission protocols, and more generally in avoiding duplication of effort.

In principle the division of responsibilities between the DCCs and the IRIS DMC is clear: the DCCs exercise quality control over data prior to sending it to the DMC, whereas the DMC archives and distributes received data to the user community. However, as real-time data increasingly becomes a paramount requirement not only for end-users such as the Tsunami Warning System (TWS) but more generally for the entire scientific community, the present set-up for rapid data distribution should be restructured. The present practice of the DCCs maintaining a complex data archiving and distribution architecture and providing data directly to external users, in essence acting as mini-datacenters, is an unnecessary duplication of effort that undermines both the clear division of responsibilities and the organizational structure of IRIS. The Review Committee recommends that the DCCs should implement procedures for on-line quality control on incoming data, and for real-time transmission of all data to the DMC. All data distribution to end-users including the TWS should ultimately be handled by the DMC. This will require some modification of DMC operating procedures as well.

Network Standardization. There are voices in the community in favor of homogeneous instrumentation for the future of the GSN. Admittedly, homogeneous instrumentation would ease considerably the task of operating and maintaining the network, and probably would result in some cost reduction. Nevertheless, the Review Committee feels that homogenization is not absolutely necessary. A case can be made for different types of equipment, *provided* that all instrumentation meet established criteria of performance and compatibility. The GSN *ad hoc* Design Goals Subcommittee expressed similar views: "…efforts toward network-wide standardization of instrument performance, if not instrumentation, should be a priority…". The Review Committee believes that all equipment should pass an established method of quality control and technical specification validation, before deployment in the network. The operating network should not be an arena in which frequent technical innovation leads to unending heterogeneity. The present *laissez faire* policy that allows unilateral decisions about selection of equipment or protocols, and leads to equipment incompatibility across the GSN, is clearly detrimental to the long-term future of the GSN.

Multi-sensor observatories of the future. In principle, the IRIS infrastructure, in addition to its primary purpose of monitoring seismic signals, could accommodate the monitoring of a variety of environmental and tectonic parameters. It is easy to envision instrumentation that, along with land and ocean seismic observatories, might be included

in global monitoring networks of the future: laser strain meters, tilt meters, micro-gravimeters, differential GPS, micro-barographs, high-frequency geophones and temperature sensors in deep boreholes, meteorological and ionosphere monitors, monitors of gaseous emissions at volcanic sites, hydrophones, pressure sensors, ocean bottom temperature, salinity and current monitors, and so on. The Review Committee encourages IRIS to be proactive, and seek out opportunities for multidisciplinary collaboration, keeping in mind, however, that a major responsibility of IRIS, in the near term, is the reliable and cost-effective O&M of the backbone GSN.

Partnerships

As is already apparent, the GSN is a collaborative project that includes many international partners. Currently GSN stations are linked to 105 organizations in 62 nations. The integration of the IMS-CTBTO and FDSN networks (especially Geoscope, Pacific 21, Geofon and Mednet) has resulted in contributed resources that are absolutely essential to providing a truly global network. The statement expressed earlier that the design goals of the GSN have been essentially achieved could not have been made in the absence of the contributions from the FDSN.

The Review Committee believes that there are ways in which these collaborations between the GSN and other networks could be expanded to enhance global seismological observations and/or improve the efficiency of the GSN. There is a need for the GSN to move beyond its current passive partnerships, to a new stage of engagement that results in expanded and mutually beneficial interactions with these partners. Below we list a number of activities in which IRIS/GSN might fruitfully engage international partners.

International instrument development. GSN should explore and evaluate international expertise in instrument development and testing, for the eventual replacement of the STS-1 sensor, the development of OBS technology, and for improved telemetry.

Telemetry. The GSN is already working with the CTBTO to establish satellite communications with the more than 50 IMS-designated GSN stations. The GSN can further encourage and expand international cooperation in the implementation of real-time communications, by expanding the installation of VSAT and local links to Internet Service Providers (ISP) with FDSN networks.

Oceanic sites. Ten to twenty well-selected ocean sites would complete the envisaged GSN global coverage. IRIS should encourage OBS development, and maintain a close liaison with oceanic seismic network (OSN) programs being developed within the USA and in Japan. IRIS should work closely with the institutions involved about directing the OSN data stream into the IRIS/DMC.

Cost and task sharing. In some countries or regions, there are experienced seismological institutions that could take a more active role in maintaining the stations in their own country or region. Clearly, central coordination, training, and standard operational procedures would be required. However, a potential reduction in operational costs and

more committed local operators could result. Travel costs would be reduced and station performance might be improved through more rapid remedial responses to station deterioration or failure.

Maintaining the global distribution. IRIS/GSN should explore joint partnerships for sustaining geographically or otherwise critical non-GSN sites. This support might take the form of providing instrument upgrades and/or telemetry connections, or in rare cases taking over the operation of stations that face a shut-down by their present operators.

Archiving and distribution of regional data. As noted on page 5, we encourage the IRIS/DMC to continue and expand its important role in linking regional and national networks in different continents, by acquiring and distributing data from a time-varying configuration of global and regional networks, within the framework of the FDSN.

Quality assurance. As the quality of data is a paramount concern for the whole global community, we encourage IRIS to provide leadership within the FDSN framework in developing quality control procedures, formalizing the reporting of data inconsistencies, and delegating to qualified institutions specific tasks in monitoring the quality of the GSN digital data

FDSN participation in GSN policy committees. With a goal of increasing global participation and cooperation, we encourage IRIS to consider including a representative nominated by the FDSN in both the GSN SC and the DMC SC.

Management Coordination and Oversight

Operation and Maintenance of the Network. As already noted elsewhere in this report, the Review Committee believes that installation of the GSN is approaching a steady-state. Hence, the earlier emphasis on site selection, equipment acquisition, and station installation must now undergo a transition to an emphasis on the effective operation and maintenance of the network. This new focus brings new challenges that may benefit from some changes in the structure of both the IRIS management and the network operators. The recommendations from the Review Committee that follow are made in the spirit of promoting a successful transition of the GSN to the O&M mode.

Standardization. Network-wide standardization of instrumentation and data handling, as discussed above in the section on *Technology*, is essential for the long-term success of the GSN. It should be pursued steadily (i.e., without delay, but without pressure to do it all at once) and intelligently (i.e., with the realization that standardization does not necessarily mean homogenization) over the next few years. Closer coordination among the GSN SC, the GSN Program Manager, the UCSD/IDA Project team and the USGS/ASL group should enable the GSN to pursue a steady course of standardization without disruption or significant additional costs. Any additional costs will have to be justified in terms of the long-term savings to be achieved by standardization.

The Review Committee accordingly urges the GSN SC and IRIS management to establish technical specifications and compatibility requirements for all instrumentation that is to be used in the GSN. Presumably, these specifications can be formulated by a re-energized and reconstituted GSN Instrumentation Committee (IC). The membership of both the GSN SC and the IC should be strengthened in technical expertise on instrumentation, data handling and network operations. The Review Committee recognizes the strong scientific leadership and vision that has characterized the GSN SC over the years, while at the same time observing that technological issues have not had adequate representation in the membership of the SC. Even a modest shift of membership in this technical direction could strengthen the quality and authority of the SC's recommendations to the network operators. IRIS should make it unambiguously clear that the recommendations of its GSN SC, as expressed through the management decisions of the GSN Program Manager, have the full backing of the IRIS Executive Committee and President.

Once specifications exist, IRIS management might consider a requirement that all equipment being considered for network deployment be submitted to a reputable and impartial outside testing laboratory for specification validation. IRIS management should implement an acquisition policy that will guarantee that only validated and approved equipment can be installed in the GSN. IRIS management should consult and negotiate with the USGS/ASL and UCSD/IDA project managers how best to implement this policy.

Dual Network Operators. The Review Committee also considered various issues related to the current mode of operation involving dual operators for the GSN. We consider the present funding arrangement as a positive example of interagency cooperation, with the clear benefit that should either of the two funding sources become imperiled, there exists the assurance of some continuity during a period of adjustment. At the operations level, we also see advantages in combining the expertise of a government laboratory group with that of a project team based at a research university.

That said, the Review Committee considers it necessary to add that the advantages of dual GSN stewardship and dual GSN operators can be realized only if the organizations involved consider themselves partners supporting and working toward a jointly accepted goal. The common goal in this instance is a reliable and cost-effective GSN. During our meetings with the USGS/ASL group and the UCSD/IDA team we were assured that both parties agree on these principal points. Yet the Review Committee was left with an uncomfortable feeling that IRIS is sometimes viewed simply as a bridge to obtain funding, and that IRIS management is sometimes viewed as an impediment rather than a facilitator.

At the policy and design level, the responsibility and authority for defining the GSN rests with the IRIS GSN SC. This authority is explicitly recognized by the USGS in the MOU between NSF and the USGS, but to the Review Committee's knowledge has not been explicitly acknowledged by UCSD/IDA. IRIS negotiates a contract annually with UCSD for funding of the UCSD/IDA component of the GSN. In parallel with the inter-agency

MOU, the contract could be written to incorporate an explicit agreement on the part of UCSD to accept the recommendations of the GSN SC in matters pertaining to the operation of the GSN. The Review Committee believes that, if the USGS can agree to this in the context of an MOU between two agencies of the U.S. government, there is no good reason for it to be an impediment to a contract between UCSD and IRIS.

As a more uncertain and riskier alternative, IRIS could evaluate the pros and cons of a competitive approach to GSN operation. For example, IRIS might consider turning to a Request for Proposals (RFP) for the purpose of soliciting competitors to operate all or parts of its GSN network. Such an RFP would state clearly the conditions of the competition, among them an agreement on the part of respondents to accept direction from the GSN SC. A similar RFP competition was used successfully by IRIS to establish its current PASSCAL Instrument Center. This would not be the first choice of the Review Committee; clearly, the existing knowledge and experience that exists today in both USGS and UCSD are valuable assets that one should strive to conserve. However, it may be prudent for IRIS to explore the ramifications of opening the GSN O&M to competition as a backup *modus operandi.*

Coordination Meetings. The GSN PM should be encouraged to sponsor regular meetings (semi-annual or more frequent) between representatives of the two sub-network operators to discuss matters of instrumentation and routine operations. The two network operators could use these meetings to bring up technical matters in greater detail and depth than is possible at GSN SC meetings where much time is necessarily devoted to general policy and budgets. Desirable side benefits of such meetings could be an increase of mutual respect between the two GSN operator groups and a concomitant sense of common enterprise. We note that a comparable meeting with the two operator groups to discuss common data handling issues is sponsored by the IRIS Data Management System Program Director, and it has helped the two groups to improve their data handling operations.

Expanded IRIS Management. The Review Committee reiterates here that the primary focus of IRIS in the next decade should be the reliable and cost-effective O&M of the backbone GSN. Other considerations and other activities of IRIS must not impede that primary focus through diversion of either funds or effort. The Review Committee sees a need for someone to commit fulltime effort to coordinating the operation and maintenance tasks of the GSN, and serving as the principal administrator of the network.

However, there are also other important activities that require considerable attention and leadership. These activities include, but are not limited to: (*i*) improving the coordination between the GSN and FDSN and IMS networks in order to exploit the full potential of the combined systems; (*ii*) pursuing opportunities of adding ocean floor sites using undersea cables for power and data transmission; (*iii*) collaborating closely with other national and international programs that are developing initiatives for ocean floor observatories; (*iv*) playing an active role in developing colocated geophysical/environmental instrumental arrays; (*v*) establishing common financial and technical practices across the GSN; (*vi*) developing a rational approach to identifying

stations for closure; (*vii*) envisioning and ensuring the next generation of instrumentation for the GSN; and (*viii*) stimulating discussion within the GSN SC of future scientific directions, so that the necessary long-term planning for the GSN may take place.

This latter array of activities is easily shunted aside in the face of more urgent aspects of keeping the GSN up and running on a day-to-day basis. Yet a failure to address these topics will lead to accumulating problems in the future. Therefore, the Review Committee recommends that IRIS consider hiring an Assistant Program Manager (APM) for the GSN, perhaps to manage the O&M of the GSN. The exact breakdown of duties between the GSN PM and APM would need careful definition, but the totality of work associated with the GSN management is more than can be accomplished by a single person.

GSN Public Visibility. The Review Committee urges that IRIS take every opportunity to inform its funders, the NSF and DOI, and ultimately the U. S. Congress and Administration, of the importance of the GSN and the scientific, diplomatic, and humanitarian services it provides. While this type of self-promotion may seem awkward at times, it is in the long-term interest of the GSN to call attention as frequently as possible to the outstanding value-for-money that the GSN provides to both the scientific community and the public. Monitoring in the minds of many connotes a passive and routine activity that might be easily cut in times of constrained budgets. IRIS must therefore take every opportunity of reminding its patrons *why* monitoring is important, by calling attention to significant achievements that result from the GSN. Every time there is a tsunami warning issued, every time there is a significant contribution to CTBT issues, every time there is an important scientific advance made possible by GSN data, all are worthy of a press release.

Costs

The fiscal challenge to the GSN in the transition to O&M mode will be to meet changing needs within a budget that is unlikely to grow dramatically. The Review Committee does not believe that the GSN will be favored with substantial budget increases over the coming decade. The reliable operation and gradual improvement of the network will have to be funded principally by decreasing costs and doing cost-benefit analyses. Accordingly, we address the fiscal future below with a few recommendations about fiscal management and cost-containment.

Station Operating Costs. The manner in which the network operations costs are currently presented have made it difficult for the Review Committee to reach any solid conclusions about the relative or absolute cost effectiveness of the network operators. As presented to the RC in a bewildering array of documents, the apparent cost per station for UCSD/IDA stations is approximately $70,000 per year, and for the USGS/ASL stations about $55,000. The difference may not be real, and perhaps arises simply from the way each of the network operators categorizes cost estimates. On the other hand, the difference may indeed be real, arising from such items as a different salary structure, different stipends paid to local operators/institutions, inclusion or exclusion of instrument development

costs, or different amortization schedules for essentially the same type of equipment. The Review Committee feels strongly that IRIS management should establish a standard procedure and format for estimating and reporting costs. This will be an essential tool to keep operational costs homogeneous across the network and under control.

The Review Committee also questions whether exactly the same budget that was appropriate for the development and installation phase of the GSN is necessarily the appropriate budget for the O&M phase. The RC repeatedly heard ominous predictions that a smaller annual budget would inevitably result in diminished station performance. However, it is entirely possible that continuous telemetry and simplified, standardized low-power field electronics might result in significant cost reduction while *enhancing* network performance. We urge IRIS management and the GSN operators to work together to develop and evaluate various budgetary scenarios that will characterize the transition from installation to O&M. The RC does not have preconceptions about the outcome of such discussions, but believes that the process is a necessary exercise that has not yet taken place.

Instrument Development. UCSD/IDA emphasized that research into new instrumentation is vital for the successful operation of the network, and that it should be intimately linked to operations. The RC recognizes the need for instrumentation R&D, and in the earlier section on Technology has recommended a greater engagement of the GSN SC in issues of instrumentation. However, in that same section we caution against the frequent introduction of new technology into the network because of the problems of O&M in a heterogeneous network. Until the GSN SC seriously addresses and provides guidance on instrumentation development and standardization, any R&D efforts should be clearly separated budget-wise from operation and maintenance of the network. UCSD/IDA and IRIS management should clearly identify and separately track the funding that supports these two different purposes.

Station closures. The GSN must investigate ways to optimize the scientific return on investment. In particular, GSN should consider and evaluate the closing of some stations. Among the candidates might be (*i*) those GSN installations that are nearby other stations operated in a reliable and continuous manner by other network operators, (*ii*) stations with such a high level of seismic noise that they contribute little to the network performance, and (*iii*) stations which have a historically poor record of reliable operation (keeping in mind that performance may improve with continuous telemetry and new instrumentation). The Review Committee urges IRIS management and the network operators together to develop a 'Scientific Value Index' that attempts to quantify in an objective way the many factors affecting a station's importance to the GSN (the USGS/ASL group has made a step in this direction with its Maintenance Priority Factor).

Station closures may provide financial flexibility for the GSN, as new programmatic needs may require some self-financing through an internal re-allocation of funds (we note that the costs associated with the new APM position recommended above could be derived entirely from approximately two station closures). Additionally, re-deployment of equipment from poorly performing stations in order to maintain sites that have greater 'scientific value' will provide another boost to cost-effectiveness and cost-containment.

Station 'trading'. GSN should also explore the possibility of redistributing stations between the two network operators so that their sub-networks become more contiguous and internally homogeneous. In many cases, both operators have stations, in the same country or region, which use different types of equipment. Although this may have been a result of an opportunistic build-up phase, it is now hard to justify this duplication of effort. Travel and maintenance costs could be reduced if the same operator were responsible for all stations in the same region or country and could visit several sites on one service trip. The GSN should also consider promoting the active involvement of other networks in maintaining sites in well-served areas such as Europe or Japan, as well as in countries where American technical personnel may not have easy access because of political concerns.

Concluding Remarks

As we come to the end of this report, let us once again recognize that the success of the GSN as the primary tool of the worldwide seismological community today is largely due to the dedication and technical prowess of UCSD/IDA, the USGS/ASL, the international partners, and the IRIS DMC. The seismological community, indeed all of Earth science, has been the blessed beneficiary of this remarkable international collaboration. The Review Committee, mindful of the success of the GSN program to date, and prompted by the conventional wisdom of "if it ain't broke, don't fix it," is well aware of its responsibility to do no harm with its recommendations.

The IRIS/GSN would not have succeeded if various elements of the seismological community had not put aside concerns about support for their own operations and finances, and put science ahead of more parochial issues. The great fear at the inception of IRIS was that some in the community would be so strongly possessive of their own networks and operational styles that the community effort would not succeed. To overcome those trepidations, it was necessary for university, government and international scientists to cooperate in order to build a smoothly functioning high-quality network, one that in many respects obviated the need for existing programs. The GSN of today, even with the imperfections and inefficiencies that we have identified in this report, is testimony to the willingness of all the participants to yield a little autonomy, in order to obtain a global facility of immense scientific value.

The GSN of the future will require that same commitment. IRIS has the special role of representing and advocating for the entire seismological community. IRIS management must provide the leadership that will lead to a clear definition of the goals and procedures governing the GSN, supported by important guidance from the appropriate GSN committees.

Summary of Principal Conclusions and Recommendations

1. The GSN is essentially complete. The number and geographic distribution of stations is adequate for most of the scientific purposes for which the GSN was designed. The most important challenge the GSN faces is making the transition from network planning and station installation to network operation and maintenance. (p.4)
2. The GSN SC needs to address the problem of resuming manufacture of the STS-1 sensor, or finding a replacement. (p.5, 8)
3. Heterogeneity in data loggers comprises a weak link in the network data quality and reliability, as well as leading to unnecessary complications in network operation and maintenance. GSN equipment should move toward standardization, in the sense that all equipment should pass quality control and technical specification validation prior to deployment. (p.6, 7, 9)
4. Achieving real-time satellite telemetry from all GSN stations should be a priority target. (p.6)
5. The DCCs should implement procedures for on-line quality control of incoming data, and for real-time transmission of all data to the DMC. The DCCs should not serve as mini-data centers that function as alternatives to the DMC. The DMC should strive to develop the capability to provide urgent real-time data to such end-users as the Tsunami Warning System. (p.7)
6. The DMC should continue to selectively acquire, archive, and distribute data from regional (and sometimes temporary) networks, to complement GSN data. (p.5, 9)
7. GSN management should be pro-active in seeking mutually beneficial international collaborations that could improve both network geographic coverage and network instrumentation and reliability. (p.8, 9)
8. The GSN SC and IC should be substantially strengthened in technical expertise (p.10, 13)
9. In negotiating the annual contract with UCSD/IDA, IRIS should include a clause that recognizes the authority of the GSN SC in matters pertaining to instrumentation and operation of the GSN, similar to that contained in the MOU between the NSF and USGS. (p.11)
10. IRIS should study and evaluate the pros and cons of a competitive bidding approach to network O&M. (p.10, 11)
11. GSN should consider hiring an Assistant Program Manager, to assist in the management of the network O&M, so that longer range issues affecting the GSN can be regularly and carefully addressed (p.11, 12)
12. IRIS/GSN should make the media aware of its significant achievements, in order to reinforce the importance of maintaining funding for the GSN. (p.12)
13. GSN management should establish a standard procedure for estimating and reporting costs that will be used uniformly by both network operators. (p.12, 13)
14. The GSN should consider closing some stations and move the funding and equipment to improve other sites and/or aspects of the network operations. (p.13, 14)

Glossary of Acronyms and Abbreviations

ASL	Albuquerque Seismological Laboratory
CDSN	Canadian Digital Seismic Network
CSN	China Seismic Network
CTBTO	Comprehensive Test Ban Treaty Organization
DCC	Data Collection Center
DMC	Data Management Center
DMS	Data Management System
DOI	Department of Interior
FDSN	Federation of Digital Seismograph Networks
GEOFON	Broadband seismograph network operated by German scientists
GEOSCOPE	Broadband seismograph network operated by French scientists
GSN	Global Seismograph Network
GSN DGS	GSN Design Goals Subcommittee
GSN IC	GSN Instrumentation Committee
GSN PM	GSN Program Manager
GSN APM	GSN Assistant Program Manager
GSN SC	GSN Standing Committee
GTSN	Global Telemetered Seismograph Network
IASPEI	International Association of Seismology and Physics of the Earth's Interior
IDA	International Deployment of Accelerometers
IMS	International Monitoring System
ISP	Internet Service Provider
IRIS	Incorporated Research Institutions for Seismology
MEDNET	Mediterranean Network
MOU	Memorandum of Understanding
NSF	National Science Foundation
OBS	Ocean Bottom Seismometer
OSN	Ocean Seismic Network
O&M	Operations and Maintenance
PASSCAL	Program for Array Seismic Studies of the Continental Lithosphere
RC	Review Committee
R&D	Research and Development
RFP	Request For Proposal
SRO	Seismic Research Observatory
TWS	Tsunami Warning System
UCSD	University of California, San Diego
USGS	United States Geological Survey
VSAT	Very Small Aperture Terminal
WWSSN	World-Wide Standardized Seismograph Network

IRIS Responses to the Summary of Principal Conclusions and Recommendations by the GSN Review Committee

[Review Committee recommendations in *italics.* IRIS response in normal text]

1. The GSN is essentially complete. The number and geographic distribution of stations is adequate for most of the scientific purposes for which the GSN was designed. The most important challenge the GSN faces is making the transition from network planning and station installation to network operation and maintenance. (p.4)

The land-based coverage of the GSN meets or exceeds the target density of coverage (2000 km spacing) in most parts of the world. While there are still minor exceptions, the natural process of improving and re-locating stations will over time rectify these perturbations, and a few logistically challenging stations are yet to be deployed. Partnerships with other international networks, especially through the FDSN, are essential to sustaining and improving continental and oceanic island coverage. Oceanic coverage still remains problematical, but will be approached as a coordinated adjunct to other oceanographic observatory efforts.

The GSN has recognized that the transition to routine operations and maintenance has occurred, and appreciates that the health and sustainability of this effort is the sine qua non of continuing scientific success. Efforts are currently underway to strive toward efficiencies in the network operation, including standardization of station equipment, detailed assessment of variable site conditions that may allow instrumentation flexibility or which may lead to station redeployment, and ongoing interaction with other networks regarding telemetry, instrumentation exchange and coordination on long-term operations.

2. The GSN SC needs to address the problem of resuming manufacture of the STS-1 sensor, or finding a replacement. (p.5, 8)

In much the same way in which new concepts for telescopes are developed, seismological instrumentation funds and expertise will need to be raised and focused on the GSN sensor challenges. The need for a next generation sensor has an international scope, and seeking partnership with the Japanese and the Federation of Digital Seismic Networks (FDSN) may be a viable option. From a broader perspective, paucity of instrumentationalists in graduate school is a fundamental shortcoming, and can only be rectified by encouraging the training of the next generation of instrumentation specialists.

As a short-term effort, the GSN Program Manager has been actively scouring the community for inactive or underutilized STS-1 systems, with some success. The IRIS Instrumentation Committee has been asked to take up the issue and to assess possibilities such as improvement of the long-period performance of STS-2 systems and potential development of the French Mars and CMG-1 sensors. The group at UCSD is exploring the use of interferometric techniques for sensing mass position in a modified STS-1 sensor and this may lead to new design possibilities. A budget item has been established by IRIS to seed instrumentation development projects that might affect both sensor and data acquisition systems.

Longer term approaches could include working with NSF instrumentation development programs to establish funding sources for very broadband sensor development along with possibly setting up a research funding program to support graduate student and postdoctoral opportunities in sensor and data acquisition systems development.

3. Heterogeneity in data loggers comprises a weak link in the network data quality and reliability, as well as leading to unnecessary complications in network operation and maintenance. GSN equipment should move toward standardization, in the sense that all equipment should pass quality control and technical specification validation prior to deployment. (p.6, 7, 9)

The GSN recognizes that improved standardization of its data acquisition equipment—not only among its Network Operators, but potentially with EarthScope/USArray, PASSCAL and ANSS —will lead to better coordination and cost reductions in operations, maintenance, and system sparing.

As the next generation of GSN data acquisition systems is acquired, the standardization of equipment will be a leading consideration. The IRIS Instrumentation Committee, guided by an update of the GSN design goals document, has developed specifications for the next generation GSN data acquisition system that meet standardization criteria. The new system(s) will need to be integrated with both Network Operators, entailing changing procedures for both field and data operations, which will require a transition period of several years.

The IRIS Executive Committee has endorsed the concept of moving toward commercially available systems with modular compatibility, as this is deemed to be the most efficient approach to long-term O&M for the GSN. The GSN will guide the gradual replacement of equipment by assessment of site characteristics and assessments of station importance, recognizing that reasonable flexibility in equipment capabilities is desirable for efficiency. The GSN has already established that all instrumentation deployed at GSN stations will require approval and compliance with technical specifications.

IRIS Executive Committee Resolution on Standardization of GSN Instrumentation
Adopted June 20,2003

Whereas:

The IRIS Executive Committee has determined that the GSN has reached a state of operational maturity in which the adoption of standardized, commercially available instrumentation with compatible and interoperable components is essential for achieving cost-effective operations and maintenance of the GSN;

The nearly two decades of experience accumulated by the IRIS community enable it to establish specifications for standardized GSN instrumentation;

The cost-effective operation and maintenance of the GSN is one of the highest priorities of the GSN program;

Therefore be it resolved:

The IRIS Executive Committee directs IRIS to:

I. Develop and distribute specifications for standardized GSN instrumentation;

II. Solicit instrument designs that conform to these specifications, and designate certain commercially available, conforming designs as standard GSN instruments through a compliance-testing and selection process;

III. Require adoption and initiate integration of the new standardized instrumentation at GSN stations within one to two years after the selection of such instrumentation, or as soon as logistically feasible.

4. Achieving real-time satellite telemetry from all GSN stations should be a priority target. (p.6)

GSN remains committed to real-time access to data from all stations, as this has proven to be effective in improving station up-time, along with encouraging active monitoring of earthquake activity and enabling many rapid research applications of the data. Costs are the main consideration here (although logistical issues are often limiting), so cost-effective strategies are being pursued. While uniform satellite telemetry is becoming a viable option in many parts of the world, the GSN considers real-time access via any reliable, standardized mechanism (eg direct Internet connection) to be more important than adoption of a uniform infrastructure. GSN will continue to work with the IMS to implement telemetry through the Global Communications Infrastructure (GCI) at remaining GSN stations that are part of the International Monitoring System (IMS) of the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO), and possibly at additional stations. As Internet access becomes more ubiquitous, GSN will take advantage of emerging opportunities to establish full real-time connections with stations where telemetry is currently absent, incomplete or unreliable.

5. The DCCs should implement procedures for on-line quality control of incoming data, and for real-time transmission of all data to the DMC.

The IRIS DMS is actively developing a framework of automated procedures for quality control of data and has recently issued subawards for the initial steps in this process. Due to differences in field recording systems and telemetry systems, some aspects of data handling are necessarily different requiring different solutions even in quality control, The DCCs and DMC are working toward exploiting the framework to reduce duplication of effort.

All data that are available in real time are directly forwarded to the DMC for coordinated re-distribution to users via standardized request tools. Procedures are being developed, in collaboration with the DCC's to streamline the process of incorporating QC procedures in real-time processing and archiving.

The DCCs should not serve as mini-data centers that function as alternatives to the DMC.

The primary distribution node for archived data is through the IRIS DMC. Both DCCs have developed real-time systems that can forward data from stations to the DCC and to other interested users of real time data, but the IRFIS DMC remains the designated archive for authoritative, quality-controlled data. An Annex on Data Management to the NSF/USGS/IRIS MOU is being developed to clarify the responsibilities of IRIS and USGS in data distribution. In addition to GSN data, this Annex will clarify arrangements and responsibilities for archiving of national and regional ANSS data.

The DMC should strive to develop the capability to provide urgent real-time data to such end-users as the Tsunami Warning System. (p.7)

It is important that IRIS not introduce any delays of complications into data paths that are critical to operational agencies such as USGS (NEIC) and NOAA (Tsunami Warning Center). Since the DMS does not have mission-critical responsibilities or resources (e.g. fully staffed 24/7 operations) IRIS cannot assume responsibility for provision of real-time of data. Mission

agencies are provided with access of GSN real-time data through the connection of their choice, as early in the communication path as possible (eg directly from the stations or through communications hubs). All archived data are openly available to these agencies from the DMC through the regular access services.

6. The DMC should continue to selectively acquire, archive, and distribute data from regional (and sometimes temporary) networks, to complement GSN data. (p.5, 9)

It is IRIS policy that all data from PASSCAL deployments are archived at the DMC and all of the broadband PASSCAL data are accessible through standard DMS request mechanisms, identical to GSN data. IRIS also encourages regional networks (national and international) to provide data (especially broadband) for archival storage at the DMC or through networked data centers. This has proven to be very successful, but policies need to be developed to establish standards for accepting (or rejecting) data from other networks. Standards for the definition and exchange of metadata are especially critical. IRIS will work through the FDSN to establish these procedures and possibly identify a new category of "global capable" stations, explicitly intended to augment global coverage, to be included as part of the FDSN archive.

7. GSN management should be pro-active in seeking mutually beneficial international collaborations that could improve both network geographic coverage and network instrumentation and reliability. (p.8, 9)

The GSN recognizes the importance of collaboration with national and international efforts in seismic data acquisition, and remains committed to mutually beneficial interactions and adaptation of the network. The FDSN plays a key role in coordinating the international seismological community, and GSN closely follows developments in the various FDSN networks, particularly as some are struggling to maintain their station coverage. The International Monitoring System of the CTBTO is a large international seismological, hydroacoustic, and infrasound network focused on nuclear testing treaty monitoring, with a substantial overlap with the GSN. The Air Force Technical Applications Center (AFTAC) operates seismological stations and arrays for the US monitoring community. GSN would benefit from closer collaboration with all three of these networks, and closer links will be established through improved communication, invited participation in workshops and meetings and possible liaison to the GSNSC. .

Several GSN stations currently involve explicit partnerships with FDSN organizations, and an effort will be made to identify additional high quality stations that could be shared between networks, particularly when such stations may otherwise cease operation. Inviting an FDSN liaison member to GSNSC is one possibility to enhance coordination on both station operations and new instrumentation development. Discussions about cost-sharing with host country organizations in developed nations where GSN instrumentation is located will also be undertaken. GSN is closely following international developments in the deployment of ocean bottom networks and in potential re-use of underwater communications cables.

8. The GSN SC and IC should be substantially strengthened in technical expertise (p.10, 13)

The GSN SC has substantial expertise in instrumentation via the UCSD group and ASL, and technical advice is readily available and routinely gathered from these institutions.

Representatives from the ASL and UCSD technical groups routinely participate as liaison members in GSN SC meetings. The USGS also contributes expertise to the GSN through their ANSS technical liaison. GSN also routinely seeks technical advice from members of the commercial instrumentation community, as well as from the National Labs. With the IRIS Instrumentation Committee once again becoming active, detailed technical advice can be sought within the IRIS community. Additional GSN members can be sought from the community currently serving on the Instrumentation Committee.

9. In negotiating the annual contract with UCSD/IDA, IRIS should include a clause that recognizes the authority of the GSN SC in matters pertaining to instrumentation and operation of the GSN, similar to that contained in the MOU between the NSF and USGS. (p.11)

The GSNSC has explicitly, by unanimous vote, asserted its oversight and direction for all GSN operations and instrumentation. Effective with the 2003-2004 funding cycle, IRIS will add the appropriate relevant clauses to annual subawards to UCSD.

The following clause has been added to the GSN/IDA subaward to UCSD effective July 2003:

> "Equipment and software to be purchased under this subaward for the Global Seismographic Network shall be identified in the annual work proposal and must have been approved in advance by IRIS, based on standards developed by the GSN Standing Committee."

10. IRIS should study and evaluate the pros and cons of a competitive bidding approach to network O&M. (p.10, 11)

The GSN is a complex network operated by both NSF (through IRIS) and USGS (via ASL). The USGS O&M field contract to Honeywell is competitively bid, through a process that is internal to the USGS. IRIS operates the major portion of its part of the GSN via a UCSD subaward. UCSD has purchased and donated many of the seismometers for the GSN, and has institutional connections at a number of sites. Nonetheless, in the context of moving toward instrument standardization across the network, there may be advantages in opening up all or parts of the network to competitive bidding. A common approach to seismic network O&M is to have a commercial company provide such support at many sites, although various Universities may be interested as well. The pros and cons of various operational strategies will be assessed by the GSN.

11. GSN should consider hiring an Assistant Program Manager, to assist in the management of the network O&M, so that longer range issues affecting the GSN can be regularly and carefully addressed (p.11, 12)

It is important that GSN network O&M not become subordinated to other GSN development activities, so the tasking of oversight of the network should remain at the Program Manager level. Depending on the evolution of nascent activities such as those involving re-use of ocean cables, special opportunities associated with Antarctic sites, and Ocean Observations Initiative (OOI) collaborations, IRIS will reassess the overall staffing needs for the GSN and

related programs. Preferably, increases in management positions in response to evolving opportunities will be funded through the associated external activity and not by taxation of existing core programs of IRIS.

12. IRIS/GSN should make the media aware of its significant achievements, in order to reinforce the importance of maintaining funding for the GSN. (p.12)

GSN will undertake an effort to document and quantify the scientific advances resulting from the GSN data. This effort will be coordinated with IRIS Education and Outreach efforts and the USGS, ideally with posters and other graphical presentations that convey GSN achievements. Synoptic articles highlighting the results could also be produced for popular science magazines with wide distribution. GSN needs to foster greater acknowledgment and attribution practices within the research community as well.

13. GSN management should establish a standard procedure for estimating and reporting costs that will be used uniformly by both network operators. (p.12, 13)

Uniform and transparent accounting and reporting is essential to GSN O&M efforts, and future subcontracts will specify the format for full personnel costs, field time and travel costs, and equipment and depot sparing costs. With the move toward modular compatibility of standardized GSN equipment, improved coordination and collaboration between network operators will be viable and encouraged. As recommended by the Review Committee, regular joint meetings of the network operators will be required at which standardized accounting and budget procedures will be coordinated, in addition to technical issues.

14. The GSN should consider closing some stations and move the funding and equipment to improve other sites and/or aspects of the network operations. (p.13, 14)

The GSN is not a static collection of stations. While there is recognition that data from a site collected over a long time has greater value, poor performance cannot be accepted. The goal of the GSN is to provide real-time access to excellent, very-broadband seismic data with uniform coverage from a fiducial reference global network that is efficiently operated and maintained for science. No station should be deemed sacred. Nor should stations be moved or changed precipitously. The current collection of stations and their network operator affiliation grew out of logistic necessity and historical context in rolling out the new GSN. It is time now to reflect upon the network configuration and make appropriate adjustments that will enhance the GSN goals and O&M efficiency. Efforts are underway to assess site noise characteristics and overall station importance for scientific applications. This information will guide decisions regarding instrumentation flexibility and possible station upgrade or relocation.

Summary of IRIS Actions
in Response to the Recommendations of the GSN Review Committee

Technical

Standardization – The IRIS Executive Committee acted in June 2003 with a resolution that directs the GSN on a path towards standardization of GSN instrumentation across the network. IRIS will work with the GSN Standing Committee, Network Operators, Instrumentation Committee and instrument manufacturers towards achieving this goal.

Sensors – The GSN Standing Committee and the IRIS Instrumentation Committee will continue to investigate ways to encourage the development of a new very-broad-band (VBB) sensor as an eventual replacement of the STS-1. IRIS acknowledges that because this type of sensor finds limited application outside of the academic research community, it may be necessary to provide special resources to stimulate development. In a broader context, IRIS will consider way to encourage a new generation of scientists and engineers to become engaged in research and development in geophysical instrumentation.

Telemetry – In the development of annual budgets, IRIS will place high priority on developing and supporting communication infrastructure to reach the goal of complete real-time data access from all GSN stations. IRIS will continue to collaborate with the International Monitoring System on use of the Global Communications Infrastructure for communication with GSN stations. The first GSN stations to be enhanced in this way are now on-line.

Stations

Station assessment – A major shift in emphasis as the GSN enters the operational phase will be to begin a careful assessment of quality of data from GSN stations. This will involve investigations of noise characteristics and the utility of the data across a variety of research applications. These assessments, in conjunction with cost considerations, will be used as a basis for prioritization of station upgrades and improvements and (in rare cases) possible re-location or closure of poorly performing stations.

International – Enhanced involvement of international partners holds considerable promise for ensuring the long-term viability of the GSN. IRIS will continue to work with individual foreign networks and through the FDSN to explore ways to encourage in-country support of GSN station operation and develop multi-use applications of GSN sites.

Management

Contractual – IRIS will take under advisement the Review Committee's recommendation that consideration be given to competitive bidding for operations and maintenance the entire GSN. At this time, the merits of the diversity of talents and interests represented by the two network operators groups are considered to outweigh any benefits to be gained by placing the operations under one group. If the plans to evolve to standardized equipment are successful, and if there is evidence of improved interaction in operational and development activities between the two operators, we are confident that efficiencies can result and that the involvement of the two network operators can be maintained without adverse economic impact.

Program Manager – IRIS will also take under advisement the Review Committee's recommendation for expansion of the GSN office. Recent activities in the re-use of ocean cables and other areas, led by the GSN Program Manager, may result in sufficient long-term, external support to warrant additional staffing, without impacting resources for network operations. Any expansion will be considered in the context of overall IRIS operations and will be implemented in a way that maintains a level of effort necessary to maintain quality operation of the GSN.

Budget development and reporting – In a stable mode of network operation, and with increasing standardization of equipment, annual budgeting for station operation and maintenance will become less complex and variable. Standard models and procedures for annual budget development will be initiated and O&M expenses will be more carefully segregated from costs for equipment upgrade/replacement and development of new instrumentation.