

**GEODETTIC FACILITY FOR THE ADVANCEMENT
OF GEOSCIENCE (GAGE)**

**\$14,050,000
+\$100,000 / 0.7%**

**Geodetic Facility for the Advancement of Geoscience
Funding
(Dollars in Millions)**

FY 2020 Actual	FY 2021 Estimate	FY 2022 Request	Change over	
			FY 2021 Estimate Amount	Percent
\$13.90	\$13.95	\$14.05	\$0.10	0.7%

Brief Description

GAGE is a distributed, multi-user facility that enables a diverse PI community to make advances in understanding Earth processes that would otherwise not be possible, through broad access to geodetic instrumentation, field training and support, and data services. GAGE operates networks of Global Positioning System (GPS) and Global Navigational Satellite Systems (GNSS) instruments; provides geodetic and related geophysical instrumentation for field experiments; supports data archiving, quality control, and distribution; and provides education and outreach activities that serve a wide range of audiences.

Scientific Purpose

GAGE serves an extremely broad spectrum of geosciences disciplines that use geodetic instrumentation and data, including Earth, atmospheric, and polar sciences. GAGE data support transformative advances in our understanding of the Earth system, including crustal deformation, plate boundary processes, landscape evolution, the earthquake cycle, earthquake, volcano, tsunami, and hurricane hazards, continental groundwater storage and soil moisture dynamics. Data from GAGE real-time, high-rate GPS/GNSS observations also support the commercial surveying and engineering industries, particularly in the western U.S.

Status of the Facility

GAGE is currently in year three of a five-year award, and the current capabilities provided by the facility have evolved based on input from a series of community engagement activities held in 2015, including a NSF-sponsored workshop entitled “Future Seismic and Geodetic Facility Needs in the Geosciences”.¹ The Division of Earth Sciences (EAR) in the Directorate for Geosciences is deliberating the path forward for evolving NSF’s geophysical facilities to best enable emerging research directions. In 2018, EAR commissioned a National Academies of Science, Engineering, and Medicine-led decadal survey that identified the top research priorities for the Earth sciences for the next decade. Released in July 2020, *A Vision for NSF Earth Sciences 2020-2030: Earth in Time*² reaffirmed the importance of NSF’s seismic and geodetic facilities in advancing Earth science research over the next decade.

As part of the decadal survey process, a workshop entitled *Management Models for Future Seismological and Geodetic Facilities and Capabilities* was held to review the strengths and weaknesses of different management models for NSF geophysical facilities³. Following the release of the workshop report, EAR announced that, at the time of the next competition for their management and operations, the current Seismological Facility for the Advancement of Geoscience (SAGE) and GAGE facilities would be

¹ www.iris.edu/hq/files/workshops/2015/05/fusg/reports/futures_report_high.pdf

² www.nap.edu/catalog/25761/a-vision-for-nsf-earth-sciences-2020-2030-earth-in

³ www.nap.edu/catalog/25536/management-models-for-future-seismological-and-geodetic-facilities-and-capabilities

consolidated into a single facility with a single operator.⁴

To further inform its planning for the future geophysical facility, the Directorate for Geosciences commissioned from a subcommittee of its Advisory Committee a portfolio review of possible geophysical instrumentation and sensor networks that a new facility might support to address the science priorities highlighted in the decadal survey. The portfolio review highlights the capabilities that a new facility should support in order to best enable the community to address the science priorities in the 2020 decadal survey. Additionally, the portfolio review report emphasizes the importance of developing partnerships in support of elements of SAGE and GAGE that are mission critical for other Federal agencies. EAR is now strategizing to define the best path forward for a future facility and undertaking efforts to expand existing federal partnerships.

In FY 2019, NSF issued a Dear Colleague Letter (NSF 19-072) to let the community know of the intent to divest 10% of the GPS/GNSS stations that comprise the Network of the Americas (NOTA) as part of GAGE. EAR received requests to adopt 95 of the 128 stations for continued operations, and all station adoptions will be completed by July 2021. The remaining stations are expected to be removed from the ground by end of FY2022.

The impact of COVID-19 on GAGE has been relatively minor. Data are delivered by remote stations that generally do not require local presence of people, and data can flow while staff work remotely. In June 2020, UNAVCO began permitting GAGE staff to work at UNAVCO facilities if desired. In mid-November 2020, UNAVCO moved back to “Phase 1” operations, where only essential staff were allowed at UNAVCO facilities, with all others required to work from home.

Meeting Intellectual Community Needs

GAGE users can access data and many educational products via the internet at no cost. Scientists making use of equipment, training, and other resources provided by GAGE typically are funded via awards from NSF, the U.S. Geological Survey (USGS), the National Aeronautics and Space Administration (NASA), and other agencies. The Geophysics, Geochemistry and Petrology, GeoPRISMS, Tectonics, Geomorphology and Land Use Dynamics and Hydrological Sciences programs in EAR; the GeoPRISMS and Marine Geology and Geophysics programs in the Division of Ocean Sciences (OCE); and the Earth Science and Glaciology programs in the Antarctic Research Section of the Office of Polar Programs (OPP) and the Arctic System Sciences and Arctic Natural Sciences programs in OPP provide most of the funds for NSF-sponsored research making use of the GAGE facility. Funds permit ongoing operations and maintenance of continuous GPS regional networks, deployment of portable geodetic instruments and use of data managed by GAGE Data Services to solve major Earth science problems.

Demand for data, equipment, and other resources provided via GAGE remains high. Over the last year of support for GAGE:

- The volume of data requested by users increased from about 30 TB in Q2 FY 2019 to over 130 TB in Q2 FY 2020;
- Field experiments using equipment and field engineering assistance continue at an average annual level of approximately 100 projects.

NSF’s awardee for the GAGE facility, UNAVCO, operates the premier internship program in the Geosciences focused on broadening participation of underrepresented students. As a result of COVID-19 restrictions, UNAVCO’s internship programs were conducted fully online this past year. Their evaluation metrics suggest that student learning outcomes were similarly positive to those of the in-person internship

⁴ www.nsf.gov/pubs/2020/nsf20037/nsf20037.jsp

Major Facilities

program.

Governance Structure and Partnerships

NSF Governance Structure

GAGE, together with SAGE, is overseen by a single Integrated Project Team (IPT) whose charge is to: 1) establish a collaborative team with a broad spectrum of expertise and perspective to help address current facility challenges and identify potential barriers to project success; 2) ensure effective and timely communications regarding facility activities and issues across NSF organizations by sharing knowledge and information on a regular and recurring basis; and 3) provide a formal mechanism to coordinate agency-wide oversight, take effective action, and remain accountable in support of the program of activities.

The IPT membership includes a core group consisting of the GAGE and SAGE managing Program Officer (PO), a DACS Grants and Agreements or Contracts Officer, and an LFO Liaison. The GAGE and SAGE PO serves as chair of the IPT. The IPT remains active through the planned five-year duration of the GAGE and SAGE awards. The IPT chair is responsible for uploading all IPT documentation into the official electronic records for the GAGE and SAGE awards. The IPT may periodically be assisted by other NSF staff as expertise is needed (e.g., OGC staff, OD staff).

External Governance Structure

The GAGE facility awardee, UNAVCO, Inc., is a 501(c)(3) nonprofit corporation governed by a nine-member Board of Directors elected by the UNAVCO institutional member representatives. The UNAVCO consortium currently has 119 full voting member institutions, representing nearly all U.S. university and nonprofit organizations with a major commitment to research and teaching programs in geodesy and related geoscience fields, and 111 non-voting associate member institutions. Six of the Board members are drawn from member institutions, and three serve as directors-at-large. Board members, who serve two-year terms, vet all internal program decisions associated with GAGE management and operation through consultation with UNAVCO staff and GAGE advisory committees (one for each major GAGE component and additional *ad hoc* working groups appointed for special tasks). The board appoints a president of UNAVCO to a renewable two-year term. The president is responsible for UNAVCO operations, which are managed through the UNAVCO Corporate Headquarters in Boulder, CO, and at three regional offices in San Clemente, CA; Portland, OR; and Anchorage, AK.

Partnerships and Other Funding Sources

While the GAGE facility is primarily funded by EAR, it also receives about \$1.20 million in funding from OPP, and \$1.15 million from NASA via interagency transfer each year. UNAVCO will be leveraging the GAGE award to partner with commercial entities in support of autonomous vehicle navigation. That activity is expected to generate program income in FY 2022 of about \$500,000 that will be used to support recapitalization of aging infrastructure.

Besides its role in providing the observational data essential for basic Earth science research, GAGE also provides real-time geodetic data in support of the missions of other agencies. GAGE provides operational and maintenance support for 58 NASA-supported stations and the GNSS network that support satellite orbit and clock corrections and the refinement of the International Terrestrial Reference Frame (ITRF). The ITRF is the foundation for high-precision global Earth science. USGS relies on GAGE stations for its ShakeAlert earthquake early warning program and its volcano hazard monitoring program. The National Oceanic and Atmospheric Administration (NOAA) utilizes data from GAGE for its management of the national reference frame for oceanic vessel navigation and support of survey professionals. USGS, NASA, NOAA, and other state and local agencies also utilize the GAGE portable geodetic station pool for support of field projects.

Funding

Total Obligations for GAGE

(Dollars in Millions)

	FY 2020	FY 2021	FY 2022	ESTIMATES ¹				
	Actual	Estimate	Request	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027
Operations & Maintenance	\$13.90	\$13.95	\$14.05	\$14.55	\$14.55	\$14.55	\$14.55	\$14.55

¹ Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2023.

To serve the research needs of the broad Earth science community, GAGE is organized under three primary service areas:

Geodetic Infrastructure

- Currently, NOTA includes 1,257 continuous GPS and GNSS stations (more than 800 of which transmit data in real-time with sub-second latency) distributed across the U.S., Mexico, and the Caribbean, with focus on the active plate boundaries. The FY 2022 Request includes funds to support a network that includes about 1,100 stations.
- The GAGE facility also provides operational and maintenance support for a network of 87 borehole strainmeters and 79 borehole seismometers deployed along the San Andreas Fault and above the Cascadia subduction zone and volcanic arc. Tiltmeters (26) and pore pressure sensors (23) are also collocated with the other borehole instruments. Together, data collected by these instruments enable scientists to study the full range of deformation in the solid Earth, from the rapid shaking associated with earthquakes, through more gradual motions related to slow slip events on faults and to Earth’s evolving water cycles, up to long-term plate tectonics.
- Global geodetic arrays outside of the NOTA footprint are supported by GAGE in partnership with investigators. Eight hundred continuous GPS stations from over 60 networks around the world are now maintained and monitored, and have their data compiled into the GAGE data system. In addition, GAGE provides operational and maintenance support for 58 NASA-supported stations, and the GNSS network that supports satellite orbit and clock corrections and the refinement of the ITRF. The ITRF is the foundation for high-precision global Earth science and other applications of geodesy such as land surveying.
- Community GPS/GNSS receiver and geodetic technology pool consists of over 700 GPS and GNSS receivers, ancillary equipment, and six terrestrial laser scanners, which can be used by investigators for short- and long-term deployments on research projects supported via multiple EAR and OPP science programs funded by NSF.
- GAGE supports the polar GPS network in Antarctica (ANET) and development of specialized GPS monumentation, power, and telemetry solutions for use in harsh environments. GAGE also provides portable campaign deployment geodetic instrumentation, training, and field support for experiments in the polar regions.
- Investigator Project Support includes project management, field engineering, and technical support services to plan and execute GPS surveys and permanent station installations. GAGE also maintains a staff focused on geodetic technology equipment testing services to evaluate new geodetic technologies and improve performance for science applications.

Geodetic Data Services

- Geodetic Data Services manages an archive of over 300 terabytes of data from GPS, terrestrial and airborne laser scanning, Synthetic Aperture Radar (SAR), and borehole geophysical instruments from all GAGE components including NOTA, global continuous geodetic networks, and campaign GPS observations; operates automated and manual systems to ensure the quality of all data stored in the archive; and provides systems to give the national and international research community timely access

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to these data.

- The archive of SAR imagery maintained and distributed by GAGE to support interferometric SAR imagery of continuous surface deformation at scales of 100 km to 1,000 km is complementary to discrete GPS measurement of displacement. UNAVCO, as the manager of GAGE, brokers for cost-effective community access to the SAR imagery acquired by foreign SAR satellite systems.

Education and Community Engagement

- The GAGE Education and Community Engagement program enables audiences beyond geodesists to access and use geodetic data and research for educational purposes, including technical short courses, student internships, web-based materials, and programs for strengthening workforce development and improving diversity in the geosciences.
- Scientific community activities include scientific and technical workshops that bring together the international geodetic community and publications designed to communicate GAGE activities and results to the community.
- GAGE operates the Research Experiences in Solid Earth Science internship program, which is widely recognized as the most outstanding program for broadening participation of underrepresented students in the geosciences.

External affairs maintain outreach efforts to policymakers and planning for coordination with the international geodesy community.

In addition to the three services mentioned, EAR plans to implement recommendations from the 2019 and 2020 management reviews. These include innovations in multi-constellation instrumentation for more precise measurements of Earth's surface to improve studies of near-surface processes (e.g., water storage and flux); moving data services for the Facility to the cloud; and recapitalization of aging instrumentation. A pilot cloud service program was initiated in 2020 in a partnership with SAGE and EAR plans to expand this capability over the existing award period. The EAR is evaluating different strategies and scales of aging instrumentation and plans to phase in recapitalization over the existing award period.

Reviews

NSF externally reviews components of the GAGE facility on an annual basis. NSF reviewed the GAGE instrumentation services programs in late June 2020 and the data services programs in September 2019. Both reviews noted the outstanding management and the critical services these programs provide to the research community. As per the reviews' recommendations, EAR, in collaboration with SAGE, GAGE and the NSF Office of Advanced Cyberinfrastructure, is implementing a pilot program to move facility data services to the cloud. NSF will conduct a full management review of the facility in FY 2021.

Renewal/Recompetition/Termination

The current GAGE award will fund the facility until the end of FY 2023. NSF is considering the recommendations contained in the *Earth in Time* decadal survey as well as the interagency context in which the facility operates in formulating a strategy for continued support of this important community research resource.