Maintaining California's Geodetic Control System Strategic Assessment

Version 1.0

Approved by the California GIS Council:
December 14, 2017

Prepared by the California GIS Council's
Geodetic Control Work Group

CALIFORNIA GIS COUNCIL

December 14, 2017

To Whom It May Concern,

The California GIS Council is pleased to adopt the findings documented in the report "Maintaining California's Geodetic Control System Strategic Assessment" and endorses the included recommendations. At its December 14th, 2017 meeting the Council discussed the document and voted to adopt the assessment of the status and maintenance required to provide a high quality statewide geodetic control network as a product of the California GIS Council. California's Geodetic control system is a fundamental underpinning to determining accurate positions across the state. Failure to maintain the system will compromise the State's ability to support the high precision calculations of location used across wide variety of technologies and standards including the production of high precision GIS data, the operations of autonomous vehicles and drones/UAVs, precision agriculture, and public safety such as monitoring fault movements and physical infrastructure.

The report is the product of many months of dedicated work, by a team including representatives, most of whom are licensed professional surveyors, from both the public and private sectors who are recognized as leaders in their craft. Following the drafting of "Maintaining California's Geodetic Control System Strategic Assessment," the report received peer review from an independent selection of licensed surveyors with many years of experience, and from members of the State's GIS community who depend on the accurate representation of location.

The California GIS Council agrees with the assessment provided here and with the need to identify and implement solutions to a looming challenge to the State. Adopting the report and its recommendations are consistent with the GIS Council's mission and charter to promote the benefits of GIS and facilitate cooperation through the State of California by supporting the collection, acquisition, sharing, and dissemination of high quality GIS data, standards, and policies.

Sincerely,

Phil Beilin

Phil Beilin

California GIS Council Chair

Maintaining California's
Geodetic Control System
Strategic Assessment

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Acknowledgement

The Work Group would like to thank the geospatial professionals who provided peer review of this document. Their valued input was critical to the finalization for delivery to the California GIS Council.

Disclaimer Statement

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. This publication does not constitute a standard, specification or regulation. This report does not constitute an endorsement by any entity, employer or department of any product described herein

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Executive Summary

The National Spatial Data Infrastructure (NSDI) defines seven core framework themes of geographic data, depicted in Figure 1. National and state surveys indicate these data themes are required by the majority of users, form a critical foundation for the NSDI, and have widespread usefulness. The California Spatial Data Infrastructure (CSDI) recognizes the NSDI core framework themes, and an additional eleven California-centric framework themes, including critical infrastructure.

The seven core framework themes form the data backbone of the CSDI. Three aspects of the framework entail the people, data and technology required to make geographic information system (GIS) data more accessible to the public by establishing key partnerships with federal, state, counties, cities, tribal nations, academia and the private sector.

The Geodetic Control theme provides a common reference system for establishing coordinates for all geographic data. All NSDI and CSDI framework data and users' applications data require geodetic control to accurately register spatial data. Concerns about the sustainability of California's geodetic control theme have been raised to the State Geographic Information Officer, though the California GIS Council, a technical forum in the State's GIS governance model.

The State currently leverages approximately $40 million in geodetic infrastructure paid for and maintained by other agencies and institutions at an approximate cost of $6-7 million per year. This infrastructure has an estimated economic benefit to the State of approximately $500 million per year. This figure is prorated from the estimated value of $2.4 billion per year of the nationwide Continuously Operating Reference Station (CORS) system in 2009 by the National Geodetic Survey (NGS).

There is no official steward of California's geodetic control theme, nor a stable source of funding to maintain the physical monuments or transmit and archive the data. Access to the information about these geodetic monuments for use in geospatial technology, particularly by other framework themes, is not established.

A foundational set of geodetic control monuments and scientific models for horizontal and vertical geodetic positioning in California needs to be defined and maintained by a steward for utilization in land surveying and correct alignment by other GIS themes identified in the CSDI.

The Geodetic Control Work Group (GCWG) was chartered by the California GIS Council to develop a vision, goals and recommendations for technical enactment, ongoing development and leadership by appropriate state and local agencies, stakeholders and partners. This document assesses the current situation and provides a basis for further direction by policy makers and stakeholders to address the vulnerabilities of California's geodetic control to ensure a sustainable future to meet current and future CSDI needs.

Geodetic Control Work Group
Vision, Goals and Recommendations

Vision and Goals

The GCWG vision of a geodetic control reference network consists of durable, continuously maintained monuments, an archive of geodetic data, and a core body of software, data models, and technology necessary to acquire, process, analyze, refine, and distribute geodetic control data. The Geodetic Control Framework Theme (GCFT) will be an accurate representation of statewide geospatial coordinate and height reference systems that adhere to NSDI standards. A steward will provide timely updates in response to the State's dynamic geological environment, and will facilitate spatial registration with other GIS themes.

Recommended Program Option

Develop a perpetual State funded program with adequate personnel and resources to operate, maintain, and service a statewide framework of approximately 180 continuous Global Positioning System (GPS)/Global Navigation Satellite Systems (GNSS) stations that include Real Time Kinematic (RTK) capabilities with a network solution. This would include the resources and infrastructure required to archive, analyze, and process the data, as well as providing real time correction services for system users. Also included would be site permit agreements and costs where stations are located on private properties.

Estimated annual cost (2017): $2.8 million

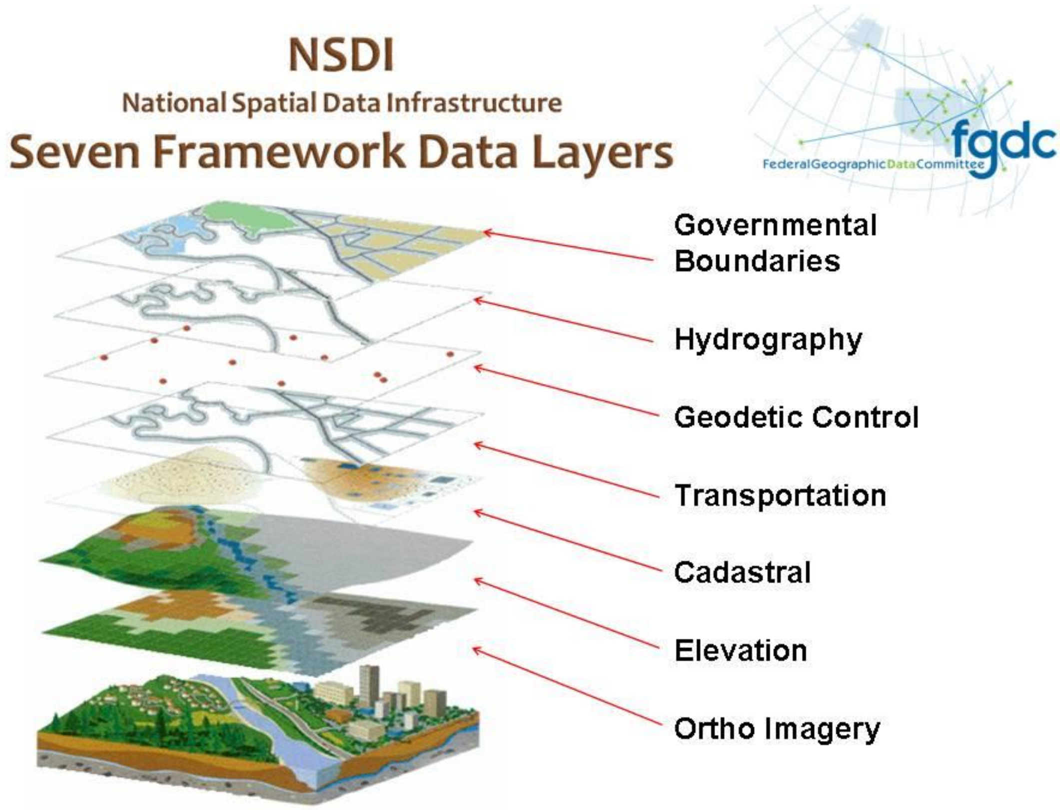

Figure 1. National Spatial Data Infrastructure (NSDI) core framework themes. Geodetic Control provides a common reference system for all geographic data.

1.0 California's Geodetic Control Infrastructure

California currently has approximately 850 operating Continuous Global Positioning System (CGPS) stations, approximately 250 of which are currently included by the NGS as National CORS stations, in accordance with the NGS mandate to maintain the National Spatial Reference System (NSRS) framework.

Figure 2. Left – UNAVCO station P231 at the Hopkins Marine Station in Monterey Bay is a SDBM (short drilled-braced monument) with stainless steel legs extending 1.75 meters and epoxied into bedrock. The station was installed by UNAVCO during the National Science Foundation-funded EarthScope project originally to measure earthquake and tectonic deformation along the San Andreas and San Gregorio faults. In addition, now the station is used by a variety of stakeholders for surveying, sea level analysis, tropospheric water vapor studies, soil moisture, coastal LiDAR surveys, and ionosphere electron count that can be used for tsunami early warning. Data is streamed from this site via direct Internet connection. Right – Station P466 Cerro Gordo in the Inyo Mountains is a DDBM (deep drilled-braced monument) with stainless steel legs extending 10m into bedrock that was installed to monitor the Owens Valley and Death Valley faults systems. Now it also serves as a critical station for water resource monitoring (reference Borsa, 2014 and others)

These very high precision GPS stations are permanently anchored in the ground, with telecommunication devices and often an autonomous power source, that automatically transmit the GPS satellite signals they receive into an archive database, with a subset of real-time stations that stream one sample per second to public users. Each CGPS or CORS station continuously determines its locational coordinates, as measured from GPS signals. When these observations are averaged over long timeframes, they provide an accurate determination of their location and velocities, becoming the reference points from which all other locations based on GPS measurements can be derived. Velocity precision is commonly millimeter for the horizontal and sub-5mm for the vertical for the most stable monuments.

In addition to the CGPS stations, the geodetic control infrastructure includes the database archive, the computer and telecommunication equipment and software to make it operate, and the staff needed to design, operate, maintain, negotiate land use permit renewals with landowners, and update the system and physical stations, as well as to provide the outreach and instruction that enables professional communities to use it. The estimated to-date investment in this infrastructure is $33 to $40 million with over 75% of this cost borne by the National Science Foundation (note: $27-32 million is NSF infrastructure). The value or savings realized by the users of this infrastructure is addressed below.

The California Spatial Reference Center (CSRC)[1] has the sole codified authority, through the California Public Resources Code (PRC §8850-8880), to compute and publish coordinates for the California Spatial Reference Network (CSRN). The CSRC archives and maintains the data from California's 850 CGPS stations and publishes their positions and accuracy estimates, thus defining the CSRN. In addition, the NGS archives the data from the CORS-certified CGPS stations and includes their data in the National Spatial Reference System (NSRS). None of the CGPS stations are actually owned by CSRC, and only a handful of CORS stations are owned, operated, and maintained by NGS or U.S. Geological Survey.[2] Due to the State providing no funding to support the CSRC, it has not been able to regularly perform the adjustments necessary to keep the CSRN consistently aligned with the NSRS. Because of the unique geophysical environment in California, factors such as secular tectonic plate motion, subsidence, seismic events, and even volcanic activity, the absolute positions of the CSRN stations, relative to the NSRS reference frame, are degrading differentially over time.

Approximately 550 stations in the State have telemetry with hardware/software configurations that allow streaming data at one sample per second for real-time corrections provided by a variety of networks. Of these, data from approximately 380 of California's streaming CGPS stations are redistributed and available through the California Real Time Network (CRTN), operated by the CSRC. For the balance of the 850 stations, the observations (satellite signals) are downloaded, archived and available to the public for post-processing to determine locations throughout California.

The CSRC provides the staff and computer resources required to administer and operate the CRTN, but do not operate, maintain, or control more than 90% of the physical stations that comprise it. Real-time processing provides an on-site in the field location based on GPS observations at nearby CGPS stations received by CRTN users over the Internet. The real-time solutions for location are calculated using a single-baseline method.[3] There are currently (as of August, 2017) over 870 CRTN account holders utilizing these services for myriad of applications requiring accurate real time positions.

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1 http://csrc.ucsd.edu/

2 The owners of CORS stations in California are:
Plate Boundary Observatory (PBO) - 207
Berkeley Seismology Laboratory – 11
US Coast Guard - 8
Scripps Orbital & Permanent Array Center (SOPAC) – 7
US Geological Survey (USGS) – 7
Private vendors, Leica and Trimble – 5
NASA Jet Propulsion Laboratory – 3
Federal Aviation Administration – 2
NGS – 1
City of Modesto – 1
Esri – 1

3 Access to the CSRC and CRTN is available at: http://sopac.ucsd.edu/crtn.shtml.
The CRTN White Paper description, dated October 16, 2008, can be accessed at:
http://csrc.ucsd.edu/docs/CRTNProposal_version5.0.pdf

2.0 Relation of Geodetic Control to Other Geographic Themes

California's GPS-based geodetic control points (active and passive) provide the foundational framework for California's mapping products tied to a common reference frame. Through the inclusion of metadata, including date of survey, epoch date of the North American Datum 1983 (NAD83), and points/values used for constraints, these mapping products can be accurately aligned, despite movement of Earth's surface from tectonic movement, seismic activity and events, and subsidence that has transpired between data capture dates. This network of sensors (CGPS receivers) can also be used to update the Geodetic Control "Framework" CSDI theme; e.g., the geodetic control data in official government GIS databases, using a regular, systematic, and increasingly automatic process. The Geodetic Control Framework (GCF) theme is intended to be used to align and update the other CSDI Framework geographic themes and the additional geographic layers identified with CSDI.

However, when compiled, many of the framework themes and CSDI layers were not mapped relative to geodetic control points. Control points are not depicted in many geographic themes or layers. Moving forward, a regimen of guidelines and procedures for the ongoing use and maintenance of California's geodetic control stations will need to be implemented. This will need to include requirements, standards, and procedures for the maintainers of CSDI Framework GIS themes to properly align their datasets with the NSRS or CSRN. This can only be accomplished through the use of sufficient geodetic control (along with appropriate metadata) and would greatly improve the accuracy and quality of the CSDI layers.

Some themes (imagery, transportation, elevation) are constructed using classical photogrammetry techniques or remote sensing technology, such as Light Detection and Ranging (LiDAR). Photogrammetric compilation and LiDAR data registration require adjustment and registration relative to ground control points referenced to geodetic control. Photogrammetric products and services procured by public funding should state that all deliverables be tied to the CSRN/NSRS and the meta-data for the controlling stations (points) be included in the mapping products and project reports.

3.0 Geodetic Control Benefits

California's geodetic control system enables surveyors, engineers and many others to make accurate measurements of location that are necessary for building and maintaining our physical infrastructure, and for conducting the services that drive our economy.

Need for Accurate Mapping and Measurement

Surveyors, engineers, geospatial professionals, and many others use a variety of methods for measuring location and determining positional coordinates, with GPS becoming the most popular, practical, and economic. This positional data is relied upon for many facets of our world today, including the planning, design and construction of all civil works, land and asset management, navigation, vehicle tracking, autonomous vehicle research, Unmanned Aerial Systems (drones), precision agriculture, ground and aerial mapping/photography, monitoring sea level rise, and perhaps most important, emergency preparedness and response.

For the millions of independent measurements to fit coherently on our maps, they all must relate to a standard reference system, the CSRN. The CSRN is aligned with the NSRS that is defined and managed by the NGS as a consistent national coordinate system that specifies latitude, longitude, heights, scale, gravity, and orientation for the Nation, as well as how these values change with time.[4] It is the fundamental, or fiducial, geodetic control for the United States. Historically, access to the NSRS consisted of "passive" control monuments; generally objects embedded in the ground, the coordinates of which were officially published by the NGS. With the emergence of GPS technology, combined with diminishing internal resources, the NGS has moved away from supporting passive monuments, now providing primary access to the NSRS only through "active" control stations. These are permanently installed GPS receivers/antennas known as CORS. The positions of these CORS stations are monitored and maintained by NGS and serve as the fiducial framework defining the NSRS

Modern society is becoming increasingly dependent upon accurate spatial information for making critical decisions regarding such varied activities as environmental monitoring, civil infrastructure planning and management, earthquake research, and emergency response operations. These activities require the use of an accurate geodetic control network that is seamless throughout California for all spatial referencing activities.

Geodetic Control Improves GPS Accuracy

The autonomous GPS signal one gets when finding a location with a device such as a cell-phone can be accurate to several meters. Atmospheric and ionospheric weather, as well as the proximity of buildings, trees, and terrain distort GPS signal accuracy. Every GPS observation made at the same location will read slightly different. The precise and accurate measurements needed to locate our physical infrastructure, economy and public services are derived by comparing GPS signals with the received signals at geodetic control stations that have certified, known coordinates. A surveyor or engineer records GPS signals at the location of interest, and then compares them with the signals recorded by nearby geodetic control stations, which are stored and distributed by the CSRC or the NGS. This adjustment can be made via subsequent post-processing to align with the CSRN/NSRS, or in real time via cell-phone linkage to the geodetic control network as the satellite signal is being received. The instantaneous method, called Real Time Kinematic (RTK), has many practical applications when immediate positions are required, such as in precision agriculture, autonomous vehicle tracking, or staking of construction projects. However, the accuracy and precision achieved is about two to three times less than using geodetic observation and post-processing methods.

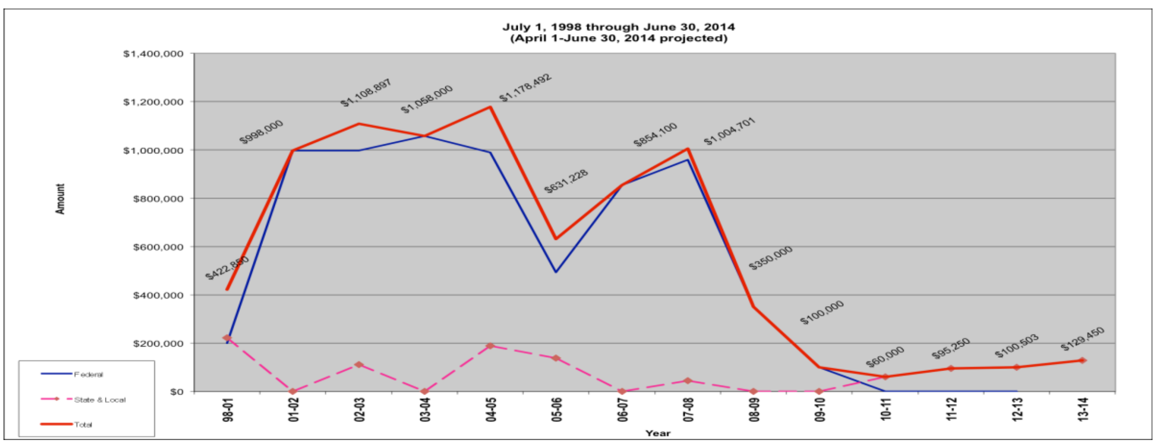
[4] NGS Products and services are available from the National Oceanic and Atmospheric Administration (NOAA) website at http://www.ngs.noaa.gov/.
NSRS description download from http://www.ngs.noaa.gov/INFO/OnePagers/NSRSOnePager.pdf

4.0 Geodetic Control Infrastructure Sustainability Problem

Because California's geodetic control infrastructure is dependent on many independent organizations for its existence, operation, and maintenance, it faces a crisis of uncertainly about its future. As noted, none of the CGPS stations are owned by the CSRC, the legislated entity designated to maintain the positional integrity the CSRN. The owner of the majority of the CSRN stations (615, or 72%) is UNAVCO, previously referred to as the University NAVSTAR Consortium, which operates the Plate Boundary Observatory through the EarthScope Project (described below). The EarthScope funding from the National Science Foundation is scheduled to expire in 2018.[5] The disposition of its CGPS stations is unknown. This situation also places 207 of the 253 NGS CORS in California at risk. The status of the Geodetic Control theme of California's SDI, and the infrastructure supporting it, are defined in more detail in the Report Card prepared by the Geodetic Control Work Group (GCWG) and approved by the California GIS Council on June 9, 2016.

http://cgia.org/cagiscouncil/wp-content/uploads/2015/04/California-SDI-Report-Card-approved-6-9-16-final.pdf

When the CSRC was formed in 1998, funding for its mission was primarily provided by the NGS with smaller contributions from state and local agencies. However, due to NGS budget reductions over the years, they no longer fund the CSRC.



Currently, the CSRC functions on a funding level approximately 10% of what is needed for responsible stewardship of the CSRN. This funding comes through the purchase of access to the CRTN by State and local agencies and small donations. This is not an adequate, nor sustainable funding source to support the CSRC, and as mentioned above, does not cover any of the costs associated with operating or maintaining the physical reference stations.

As a public resource, access to the geodetic control database is free to the public. However, without a secure, long term funding source, this resource is at risk. Currently, CSRC can do little more beyond the bare minimum required to maintain operations of CRTN.

5 See http://www.unavco.org/community/meetings-events/2014/pbo-future-14/pbo-future-14.html Click on "Final Workshop Report."

Deferred CSRC services include performing periodic adjustments to remain aligned with the NSRS, studying and acquiring new geodetic control technology and applications, and providing immediate extraordinary services after a major seismic event.

5.0 California GIS Council's Geodetic Control Work Group (GCWG) Study

In 2006, the California Geospatial Framework Data Plan[6] was developed and later approved by the California GIS Council (CGC)[7] as a roadmap for developing a unified statewide approach to acquiring, standardizing, and sharing geospatial data in a cost-effective manner. Geospatial data is categorized by seven themes[8] that are the "Framework" core of the NSDI, and eleven additional themes[9] that are critical to geospatial professionals in California that comprise the CSDI. The fundamental geospatial data theme that integrates and aligns these 18 themes is the NSDI Geodetic Control theme. In October 2010, the CGC voted to establish a GCWG to address the governance of statewide geodetic control resources.

The goals of the GCWG are to provide expertise and develop recommendations that will enable the State of California to maintain an accurate and spatially-sufficient geodetic control network and provide this data as a Framework Theme to the citizens of California. This report's recommendations should serve as the draft strategic plans to fulfill these goals. These recommendations reflect not only the aggregate contributions of the geospatial professionals comprising the Work Group, but include input obtained from more than two dozen outreach presentations given by work group members, consultations with the owners/operators of existing CGPS/CORS stations, and research into how geodetic control infrastructure is successfully sustained in many other U.S. States.

The system has been constructed over time through the collective effort and resources of many entities, but its future is uncertain due to lack of resources, cohesive ownership and stewardship and sustainable funding for its maintenance. This study reviews California's current situation and recommends solutions.

This study addresses the problem with recommendations for these questions:

- What is the optimum configuration that best benefits Californians while supporting the Geodetic Control theme of the California SDI?
- How can California's geodetic control system be maintained?
- How can its maintenance, modernization and operation be funded?

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6 See http://cgia.org/wp-content/uploads/2011/10/CA_GeoFrame_DDP_FINAL_for_Publication.pdf and http://cgia.org/wp-content/uploads/2011/10/CA-StrategicPlan-P2.pdf

7 http://cgia.org/cagiscouncil/

8 Geodetic Control, Orthoimagery, Elevation, Governmental Boundaries, Cadastral Boundaries, Transportation, Hydrography

9 Street Addresses, Utilities, Public Land Conveyance Records, Buildings and Facilities, Flood Hazards, Vegetation, Biological Resources, Cultural and Demographic Statistics, Soils, Wetlands, Earth Cover

Program Options

A - Maintain all, or most, of the 850 CGPS stations.

Description: Full coverage statewide continued use of the existing infrastructure investment to support a wide variety of applications, including; scientific research, emergency responses, surveying and mapping, driverless car technology, and earthquake early warning systems, among many others. Some regions in the state have a very high densification of stations, which creates redundancy and higher accessibility in urban environments.

Impact: This option would provide far more coverage than what would be needed to support the basic framework required to support the geospatial community in California. The majority of these stations were located and installed to support deep earth science and research and therefore are not positioned or spaced to effectively support positioning services.

Annual Cost: Maintain Infrastructure: $6,000 * 830 = $5.0 M
Annual Cost: GNSS & Telemetry modernization subset = $1.0 M
Annual Cost: Maintain Real-Time Capabilities $2,500 * 830 = $2.1 M (only applies to (b) & (c) below

Operations (a - post processing only)	.6 M
Total (a):	$6.6 M
Operations (b - multi-baseline RTN)	.75 M
Total (b):	$8.85 M
Operations (c - single-baseline RTN)	.7 M
Total (c):	$8.8 M

B - Maintain CGPS Framework (~ 180 stations) with Real-Time streaming capability

Description: The accuracy of positions obtained from a given field observation depends on the distance and geometry of the CGPS stations. The CSRC "Master Plan for a Modern California Geodetic Control Network", published in 2002, and approved by NGS in 2003, recommended a spacing of 80 km for the framework stations to achieve acceptable positional accuracies for most applications. With approximately 830 active CGPS stations in California, it is highly likely that the specific 180 stations needed to support this recommendation already exist and are operational. However, none of them are currently being supported by funding from the State of California. Approximately 250 of the 830 CGPS stations have been accepted as National CORS stations by the NGS. Status as a National CORS will be very highly weighted as a station selection criteria under this option, second only to fitting the required spacing.

Impact: This option would provide an adequate framework to provide statewide coverage to support the geospatial community in California for real time and post-processed data collection. Beyond maintaining stations for 24 hour daily downloads, it covers the additional cost of dedicated field and software engineers, communication charges, and associated operational costs to deliver 85% completeness of streaming one sample per second. These costs assume efficiencies including access to State resources such as telemetry relays, State IT support, and 40 hours of helicopter time annually. There is already demand for multi-constellation-capable receivers (GNSS) and a line item for modernizing the network incrementally is included. A high percentage of the framework stations would be National CORS, ensuring the California framework is rigorously aligned with the NSRS.

Annual Cost: Maintain Infrastructure: $6,000 * 180 = $1.1 M
Annual Cost: GNSS & Telemetry modernization subset = $0.5 M
Annual Cost: Maintain Real-Time Capabilities $2,500 * 180 = $0.45 M (only applies to (b) & (c) below

Operations (a – post processing only)	$0.6 M
Total (a):	$2.2 M
Operations (b - Network RTN)	$0 .75 M
Total (b):	$2.8 M
Operations (c - single-baseline RTN)	$0.7 M
Total (c):	$2.75 M

C - No Action

Impact: The number of stations available is undetermined because CSRC doesn't currently have funding to pay for maintenance of the CGPS infrastructure and owns none of the stations. With PBO funding scheduled to sunset in September of 2018, up to as many as 615 of the existing 850 CGPS stations could eventually cease operation. The level of operational service is undetermined because CSRC funding (currently ~ $120,000 per year through voluntary subscriptions) is less than the estimated cost of full operations. There would be fewer services offered and longer times between network recalibrations, resulting in fewer users of the system. California's geodetic control would be reduced to a few CORS stations owned by the NGS, and privately operated networks. Costs to users would go up, accuracy and availability would diminish. Earthquake research and early warning capabilities could cease.

Direct Costs:	$0
Costs to California's economy in unrealized benefits	$ 30 M - $ 40 M

Recommended Program Option

Option B (b), Maintaining a minimum of approximately 180 CGPS stations with Real Time capability provides the most cost-effective benefit to California.

This option maintains sufficient CGPS stations to cover all of the state with accurate positional data, for both post-processing and real-time capabilities. The cost differential of providing real-time network corrections over post-processing techniques alone is very small compared with the additional benefit derived from providing real time positions to a far wider range of users and applications. This option most closely represents the geodetic infrastructure models implemented and maintained by many other States.

6.0 Strategy for Promoting Recommendations

The GCWG has created comprehensive presentation materials and made more than two dozen outreach presentations explaining what geodetic control is, why it is important, and what roles and resources are currently being filled by the CSRC and the NGS. Presentations have been made to both the land surveying and GIS communities, primarily at conferences, workshops, symposiums, and user group meetings. Their purpose was to raise awareness of the importance of geodetic control to surveying, mapping, and GIS products and to explain the current resources available to do so. They were also intended to solicit feedback from attendees regarding use of geodetic control resources and deficiencies of access (real or perceived). This feedback was considered in the development of this document. Additionally, the presentations were intended to bolster awareness and support for efforts to develop a sustainable geodetic control backbone to support the fundamental themes of the CSDI. These presentations could be updated and offered, if requested.

7.0 Implementation Outline

To implement and manage the recommended Program Option in a consistent, sustainable manner, an administrative organization must be established and recognized as the "Steward" of the CSRN, and adequate funding must be provided with enough stability to enable long-term planning and short-term execution of its operations. The CSRC has been acting as the designated Steward of the CSRN under Public Resources Code (PRC) §8850-8880. CSRC's funding, however, is not mandated nor assured by State law, to continue to effectively perform this function. Additionally, the CSRC maintains none of the physical stations. This is currently done by staff of the owner/operators of the stations.

There are currently very limited available resources and expertise available within state government to absorb these duties. These resources would need to be created internally, outsourced or some combination.

A Task Force needs to be assembled to develop a detailed Implementation Plan. This Task Force will need to address the following, at a minimum, in the development of this plan:

- Identify possible mechanisms to develop secure and sustainable funding for a public entity (or entities) to steward, govern, operate, and maintain the CSRN backbone.
- Make a recommendation of what entities should be tasked with these duties and identify resource needs accordingly.
- Identify which specific CGPS/CORS stations to incorporate in the CSRN backbone based on a weighted selection criteria already conceptually developed by the GCWG.
- Identify the owners of the included stations and develop templates for agreements or ownership transfers to facilitate sustainable State support.

- Develop a communication and outreach program and presentations tailored to specific audiences, including the non-geospatial community and the State Legislature.

Maintaining California's Geodetic Control System Strategic Assessment

Appendices

September, 2017

California GIS Council's
Geodetic Control Work Group

Appendix 1. Geodetic Control Community in California

Many entities in both the public and private sectors have a reliance on California's geodetic control infrastructure, either directly, or indirectly. Large State agencies, such as Caltrans and Water Resources are direct users of the system to establish geodetic quality survey control for major infrastructure and environmental restoration projects. Local counties, cities, public works departments, and flood control agencies are similarly direct users. At all levels, emergency preparedness and response agencies, and law enforcement, rely on geodetic control in a more indirect way, by using aerial imagery and mapping that has been aligned through the direct use of geodetic control to create accurate and seamless products to which other data can be aligned. When correctly constructed to obtain the highest possible accuracy, all GIS products are reliant on geodetic control.

National Geodetic Survey (NGS)

The primary, and eventually the only method of accessing the NSRS that will be provided and supported by the NGS is through CORS stations. In 2022, the NGS is scheduled to release and implement a new geometric datum to replace the North America Datum of 1983 (NAD83) and a new vertical datum to replace the North American Vertical Datum of 1988 (NAVD88). One of the most critical components of the successful implementation of these new reference frames will be the development of robust transformation and modeling tools by the NGS so users will be able to move existing data forward to the new reference frames within acceptable accuracies. With this need in mind, along with other objectives, the NGS has developed several tools for users of geodetic control to submit observation data to NGS, such as the Online Positioning User Service, or OPUS. When users submit observation data to NGS through OPUS, a position is computed for the occupied station(s), based on the surrounding CORS stations, and emailed back to the submitter, typically within a matter of minutes. This allows the user to align their data with the NSRS, via an NGS computed solution, in a fairly simple and expeditious manner. However, the submitted data and computed solution(s) also have value to the NGS.

These data are used to improve NGS products such as hybrid geoid height models, and horizontal velocity models, and will eventually be used in developing the robust transformation tools needed to roll out the new reference frames in 2022.

Except in limited cases, such as for research or testing, the NGS no longer performs traditional geodetic control surveying using field survey crews. Instead, the CORS system allows NGS to provide user's access to the NSRS. However, less than 2% of NGS CORS stations are owned and maintained by the NGS. This means that the NGS provided access to the NSRS is almost completely reliant on stations owned, funded, operated, and maintained by more than 200 partners. The risks this partnership poses in California will be discussed in detail later in this document.

U.S. Geological Survey (USGS)

The U.S. Geological Survey contributes 7 stations to the NGS CORS network in California and operates many other stations in the State, Nation, and around the world to support their earth science missions. Although the USGS has no need or use for published NSRS/CSRN positions for surveying purposes, they utilize the data from CGPS stations (their own and others) similar to SOPAC and PBO discussed later in this document. One of their primary uses is to assess the amount of movement and deformation that has occurred from a seismic event and how far reaching that deformation is. The data is also used to study and analyze, in conjunction with data from other instrumentation, the source and nature of the seismic event for earthquake probabilities and earthquake risk. The USGS is also involved in research and development of early earthquake warning systems (in partnership with many earth science entities), of which CGPS data, especially real-time, are a critical component.

California Spatial Reference Center (CSRC)

The California Spatial Reference Center (CSRC),[10] based at Scripps Institution of Oceanography, University of California San Diego (UCSD), was established in 1998 to expand the geodetic control infrastructure in California, by using GPS methodology and practices developed by NGS. Additionally, the CSRC partnered with others to establish hundreds more Continuous Global Positioning Stations (CGPS) in the State, and in the past several years, developed real-time capability for them.

The CSRC has statutory recognition, via the California Public Resources Code (§8850-8861 and §8870-8880), to produce geodetic products such as coordinates, ellipsoid heights, and velocities. The CSRC's responsibilities includes:

- Establish and maintain the legal spatial reference network for California (CSRN).
- Utilize, promote, and manage the active, state-wide geodetic control network.
- Provide the necessary geodetic services to ensure the availability of accurate, consistent, and timely spatial referencing data for all California's citizens.
- Monitor temporal changes in geodetic coordinates due to tectonic motion, earthquakes, volcanic deformation and land subsidence.
- Collaborate, and coordinate with surveying, engineering, geophysical and GIS professional organizations.
- Operate the California Real Time Network (CRTN).

The California Spatial Reference Center developed a Master Plan that was approved by the NGS in 2003, to establish a modern, statewide geodetic control network.[11] The planned statewide geodetic control network adheres to such policies as:

a. The network shall be part of the National Spatial Reference System and comply with the National Spatial Data Infrastructure standards.
b. The network shall conform to the datum, accuracy classifications, guidelines, and methodologies accepted by NGS.
c. The network shall meet the goals and objectives of the federal National Height Modernization initiative, as determined by the CSRC Coordinating Council in consultation with NGS.
d. The basis of the network shall be CORS that have NGS-sanctioned geodetic values.
e. The network design shall facilitate establishment, maintenance, and monitoring through GPS survey procedures.

10 http://csrc.ucsd.edu/

11 The entire Master Plan document is at: http://csrc.ucsd.edu/input/csrc/csrcMasterPlan.pdf

f. The network design also shall facilitate the utilization of other modern surveying and remote sensing technologies; e.g., InSAR.
g. The accuracies of the network stations shall be the "best" that are technically and fiscally feasible.
h. Stations shall have, at a minimum, values for horizontal position, ellipsoidal and orthometric heights (vertical values), horizontal velocity (also vertical velocity on certain CORS), and a stated accuracy standard for each value.
i. The stations in the network shall be maintained (repaired or replaced if destroyed, disturbed, or failed).
j. The network stations shall be monitored and their geodetic values kept current, or supplemental information shall be provided to enable the user to determine the current geodetic values.
k. The network shall provide stations suitable for GPS positioning techniques; and the related database and Internet data portal shall provide appropriate geodetic data in a user-friendly, convenient manner.
l. The statewide geodetic control network, including access to the basic geodetic data, is to be available "free of charge" to all users.
m. The network shall provide a statewide geodetic control network.

The California Spatial Reference Network's 850 stations essentially fulfill the goals of the CSRC's Master Plan. However, the CSRC does not have a statutory requirement, nor funding, to provide or to maintain the geodetic control stations, nor does CSRC have a continuous, regular, reliable source of funding with which to operate.

Scripps Orbital Permanent Array Center (SOPAC)

Located at Scripps Institution of Oceanography, UCSD, SOPAC uses the CSRN network to conduct scientific research regarding tectonic motion and earthquakes.[12] It is developing a prototype early warning system along the West Coast using Real Time GPS, Meteorological, and Velocity data. SOPAC has been subsidizing some of the archive database operations and functions of CSRC because they are necessary for its geophysical research. The use of the database for surveying, engineering, and location determination purposes is purely incidental to SOPAC's mission.

SOPAC's primary scientific role is to support high precision geodetic and geophysical measurements using Global Positioning System (GPS) satellites, specifically for the study of earthquake hazards, tectonic plate motion, plate boundary deformation, and meteorological processes. SOPAC investigators also conduct research on the implementation, operation and scientific applications of continuously monitoring GPS arrays.

SOPAC is a major participant in the International GPS Service (IGS), serving as a Global Data Center and a Global Analysis Center. SOPAC is the archive for the 250-station Southern California Integrated GPS Network (SCIGN), as well as an analysis center and a data retrieval facility.

12 http://sopac.ucsd.edu/index.shtml The CSRC offices are located in the same facility.

Plate Boundary Observatory (PBO)

The PBO is the geodetic component of EarthScope that is operated by UNAVCO[13] and funded by the National Science Foundation. The EarthScope Project is designed to assess the geologic processes and evolution of the North American Continent including deep earth science, earthquakes, and volcanic and tectonic motion. PBO's geodetic observatory consists of a carefully designed and integrated network of over 1,100 continuous GPS receivers, plus borehole strainmeters, borehole seismometers, long-baseline laser strainmeters, meteorological sensors, and tiltmeters. Taken together, these instruments record plate boundary deformation across a broad temporal and spatial spectrum. GPS is ideal for sensing Earth movements from days to decades, as well as permitting estimates of long-term and transient strain accumulation and tectonic plate motions. UNAVCO archives data for continuously operated USGS stations as well campaign data from a wide range of researchers. For North America alone, data and metadata from 1,919 CGPS stations and several thousand campaign stations are archived at UNAVCO, including many stations in California.

Currently 615 of California's 850 CGPS stations (72%) are operated, permitted and maintained by UNAVCO on behalf of the National Science Foundation. These stations represent $27-32M of construction investment and currently cost approximately $3 million per year to operate with 85% uptime and no commitment for real-time. 207 of PBO's CGPS stations in California have been accepted by NGS for inclusion in the National CORS network (accounting for 82% of California's CORS stations). Although the PBO mission is not to directly support the geodetic control framework in California, the network of stations it has constructed and operates has become an integral part of the California's geodetic control infrastructure. PBO's funding for the EarthScope project expires in September, 2018, and annual funding levels have been reduced as the end of the project approaches, thus resulting in a range of cost cutting measures including deferred maintenance (effective currently) and considerations for careful but methodic decommissioning of GPS stations. Beyond 2018, the funding for PBO is uncertain, thus continued operation and maintenance of its CGPS and CORS stations is not secure.

State Agencies and Departments

California Department of Transportation (Caltrans)

Caltrans carries out its mission of improving mobility across California by managing more than 50,000 lane miles of California's highway and freeway lanes, providing inter-city rail services, overseeing more than 400 public-use airports and special-use hospital heliports, and working with local agencies.

Because of the often-lengthy duration of an active project, substantial geographic coverage, and the need to integrate legacy data with recently collected data, tying all work to a common spatial reference frame is critical. All Caltrans programs and projects are mapped, designed, constructed, and maintained in reference to a geodetic datum, primarily the California Coordinate System of 1983 (CCS83) and the North American Vertical Datum

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13 UNAVCO is a non-profit university-governed consortium that facilitates geoscience research and education using geodesy. http://www.unavco.org/
See http://www.unavco.org/projects/major-projects/pbo/pbo.html

of 1988 (NAVD88). Depending on the geographic area, various techniques are utilized to tie the work to the reference frame. These methods include: utilizing a real time spatial reference network such as CRTN or a commercial service provider, and using CORS/CGPS stations as primary control to develop project-specific control.

Caltrans has historically taken a lead role supporting the development and maintenance of geodetic control in California. In partnership with the NGS, Caltrans took the lead in the 1990's to establish the statewide High Precision Geodetic Network, and to support the rapidly emerging use of GPS technology for Caltrans' surveying work. These projects also created an NGS Geodetic Advisor program in California through a cooperative agreement with NGS.

In recognition of the importance of geodetic control to Caltrans surveying operations, a budgetary program has been established to fund labor and operating expenses supporting annual maintenance and perpetuation of critical geodetic control stations in each Caltrans district. Caltrans has developed and maintains a Surveys Manual (http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/Manual_TOC.html) that establishes policy, standards, and procedures to be employed on all Caltrans projects. This manual discusses geodetic datums and control in detail to enable users to understand and work with the various reference frames utilized on Caltrans projects over the past 50 years and beyond.

Caltrans has been actively involved with the California Spatial Reference Center (CSRC) since the Center's creation, through representation on the CSRC Coordinating Council and Executive Committee, utilizing the CSRC expertise through several contacts, and by providing in-kind services to augment and improve height modernization projects directed by the CSRC.

Department of Water Resources (DWR)

DWR owns, operates, and maintains the California State Water Project comprised of over 700 miles of pipelines, canals, and tunnels, and several lakes, reservoirs, and pumping and power plants. DWR is also responsible for inspection and maintenance of over 1,600 miles of Federal project levees in the flood control system, operations of flood control facilities, and flood forecasting and warning systems. A vast majority of DWR programs and projects include a critical dependency on accurate geodetic control, especially in the vertical component.

Examples of contributions to geodetic control densification and maintenance in the past 15 years include:

- Establishment of the Delta/Suisun Marsh geodetic control network in cooperation with NGS in 1997-98.
- Height modernization survey of the Delta/Suisun Marsh network in 2002 (published with NGS) consisting of approximately 125 stations.
- Establishment of the Sacramento Valley Height Modernization network in 2008, containing approximately 330 stations and covering approximately 5,000 square miles. Network resurveyed beginning in May 2017.
- Resurvey of Delta/Suisun Marsh network in 2011 and published with NGS
- Approximate investment in geodetic control development and maintenance since 1997 = $2M.

Examples of programs or projects employing geodetic control:

- Central Valley Floodplain Evaluation and Delineation Program - developed FEMA mapping, covering approximately 9,000 square miles of the Sacramento and San Joaquin Valleys based on airborne LiDAR, photogrammetry, orthoimagery, terrestrial topographic surveys, and bathymetric surveys.
- Delta Risk Management Study Program - study of levee structures, materials, and surfaces to determine risk of failure factors under different scenarios. Study used airborne LiDAR data and orthoimagery to create digital elevation models.

Department of Forestry and Fire Protection (CalFire)

CalFire performs boundary surveys for department held facilities, which are referenced to the California Coordinate System of 1983, based on published California Spatial Reference Network (CSRN) control. It files Records of Survey of boundary surveys in compliance with the Professional Land Surveyors' Act. CalFire also performs mapping based on the CSRN for planning, engineering design, land acquisition, and construction purposes, which allows for sharing this mapping with other agencies that use GIS extensively, especially, the Fire and Resource Assessment Program. Fire response requires rapid mapping in a common spatial reference system that enables dynamic situations to be shared easily among multiple fire-fighting agencies. The California Real-Time Network is an essential tool for fire fighters.

State Lands Commission

The California State Lands Commission has jurisdictional authority over the sovereign lands of the State of California. The boundaries of these lands are often along bodies of water, such as the Pacific coast or inland rivers. The horizontal location of these boundaries are legally defined by specific vertical stages of these bodies of water, such as mean low water. The elevation of these legal boundary lines vary greatly by location, depending on many factors, such as tides, topography, geomorphology, and sand migration, and are in many cases, moving boundaries. In areas of tidal influence, geodetic control is required to establish the relationship between tidal and geodetic datums so that the State boundaries can be established and surveyed on the ground. With emerging development and predicted magnitude of sea level rise along the coast, accurately establishing the relationship between tidal and geodetic datums will be even more critical to facilitate planning and design to accommodate this phenomenon.

Counties, Cities, and Local Agencies

California is comprised of 58 counties. Governance at the State level to require standardized engineering and surveying procedures in local government does not exist. There are no State statutes or codes that compel standardization and consistency, specifically requiring the use of a common reference frame for data collection. While the California Public Resources Code does define certain requirements for survey products (maps, reports, etc.) that are referenced to the California State Plane Coordinate (SPC) System, it does not require that all filed maps (Records of Survey, Parcel, Subdivision, etc.) be tied to the SPC system. A recent poll by the League of California Surveying Organizations revealed that only five local entities require, through local ordinances, survey products within their jurisdiction to be tied to a common reference system, typically based on the California Coordinate System of 1983. Some notable examples implementing such a policy are:

Orange County

Orange County completed a parcel-based land information GIS database in 1995. The 800 square mile "land base" is aligned with a County established geodetic control network consisting of 2,700 (passive) geodetic control points spaced every half mile for horizontal control, and 1,700 benchmarks for vertical control. The land base contains over 700,000 parcels mapped with an accuracy of plus or minus 1 foot. The land base is maintained by a County Ordinance (Sec. 7-9-337. – Ties to horizontal control/digital map submission) that requires all new subdivisions to be tied to the County established and published control network, which is based on the California Coordinate System, and to be submitted digitally. The land base aligns the orthorectified aerial imagery layer in the GIS database, along with a multitude of other layers, including those used for emergency response. The parcel fabric and geodetic control is the backbone for all GIS mapping and services provided by the Orange County Surveyor's Office.

San Bernardino County

San Bernardino County's parcel basemap project created a County wide geodetic control network consisting of over 400 passive control points. The geodetic control points are used to align a countywide parcel layer and to control annual aerial flights that provide the county with orthorectified aerial imagery.

Santa Clara Valley Water District

SCVWD manages an integrated water resources system that includes the supply of clean, safe water, flood protection and stewardship of streams, for Santa Clara County's 1.8 million residents. The District effectively manages 10 dams and surface water reservoirs, three water treatment plants, nearly 400 acres of groundwater recharge ponds and more than 275 miles of streams. It provides wholesale water and groundwater management services to local municipalities and private water retailers that deliver drinking water to homes and businesses in Santa Clara County.

SCVWD utilizes the California Real Time Network (CRTN) on a daily basis for survey work. The CSRN is used for positioning control in the planning, design, and execution of the District's capital projects. Epoch-based geodetic control ensures consistency, and complies with US Army Corps of Engineers guidelines. The District is using CRTN for its asset management program. Currently, it is georeferencing pipeline vault locations to the CSRN, using CRTN, and will include this data in the District's GIS.

SCVWD conducts annual benchmark surveys to comply with the National Flood Insurance Program's Community Rating System (OMB No.1660-0022), which results in accurate reference marks for use on Flood Elevation Certificates. In 2013, the requirements were changed from requiring Class II elevation data to requiring 3 CORS stations within 50 miles of the community. This resulted in a 15:1 cost-saving (from $150,000 annually to run differential levels to $10,000 per year to operate three CORS stations). The CORS method also reduced flood insurance costs for Santa Clara County taxpayers. FEMA now allows GPS data when submitting Flood Elevation Certificates. The use of GPS provides significant cost savings to property owners.

Appendix 2. Economic Value of Geodetic Control to California

Real-time correction services and archived GPS measurement data from CGPS/CORS stations are the two primary products/services of geodetic control network operators. Professionals use these data for surveying, mapping and constructing, for maintenance and operation of the built infrastructure, and for agriculture, navigation, public safety and academic studies. Estimates of the economic benefit observed in other states range from direct benefits from not having to pay for private network services ($1 million per year), to end-user project benefits of consistent, accurate, and timely locational measurement ($30 million per year).[14] Additionally, the use of public control stations relieves surveyors of setting up additional equipment; they save time, cost, and with fewer surveyors needed for a project, their working conditions are safer by reducing exposure.

http://www.dot.ca.gov/newtech/researchreports/preliminary_investigations/docs/real_time_gps_networks_preliminary_investigation.pdf

The majority of California's CGPS stations were installed to study plate tectonics, to better understand and prepare for earthquakes. A few seconds, from the moment an earthquake movement is recorded by a nearby CGPS station until the earthquake wave hits a populated area, can be enough time for automated systems to close water supply valves, disconnect power transmission lines, or close tunnels to subway and rail traffic. Lives and property can be saved by the earthquake monitoring equipment that is incidentally being used for the State's geodetic control network.

Excerpts from NGS' Socio-Economic Benefits Study

The following excerpts are from a cost-benefit study commissioned by NGS to assess the value of the NSRS CORS network.[15] The value of $2.4 billion per year was estimated in 2009. It has increased since then as more and more professionals are using the system. Twenty percent of this benefit value can reasonably be ascribed to CORS-related activities in California, including EarthScope related research and applied technologies.

> Great challenges abound in supporting our technological society and economy and dealing with broadly defined environmental needs. These include addressing issues such as the increasing concentration of population near shorelines and in other vulnerable areas, the growing importance of drought, flooding and water quality and

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[14] *Statewide Real-Time Global Positioning System or Global Navigation Satellite System Network Implementation*, a study conducted by Caltrans Division of Research, Innovation and System Information, produced by CTC & Associates LLC, February 2015.

[15] *Scoping the Value of CORS and GRAV-D*, FINAL REPORT
revised January 2009, Prepared for the National Geodetic Survey,
U.S. Department of Commerce, contract No. NCNL0000-8-37007
By Leveson Consulting

availability, and the upswing in the solar cycle. Among the greatest concerns is climate change, bringing greater variability and the long run effects of sea level rise.

Meeting these challenges requires increasingly precise information about the world around us, and systems to facilitate its use. Demands for geospatial information can be expected to grow as conditions evolve and as availability of data increases, ease of use improves and new uses arise. The National Geodetic Survey's Continuously Operating Reference Stations (CORS) system, the new vertical datum proposed in the GRAV-D Project and the National Spatial Reference System of which they are a part are critical in providing a sound scientific basis for action.

CORS data are used extensively for traditionally horizontal positioning (latitude and longitude), including asset inventory as in locating property boundaries, and for establishing the relative location of natural features and of man-made structures such as roads, buildings, water pipes and power lines. CORS data also allows monitoring of the motion of critical structures such as dams, bridges and nuclear power plants. The use of CORS for determining vertical (ellipsoid heights) information is growing, and accuracy needs are getting stricter. CORS plays a central role in maintaining the integrity of the National Spatial Reference System in all three dimensions. CORS uses include:

- Developing geographic information systems for planning and service management functions. These include boundary determination for site planning, land use regulation, hydrology and soil conservation.
- Determining legal marine and land boundaries, determining wetlands, fishing areas, mineral rights, insurance coverage, cadastral, etc.
- Shoreline mapping, primarily in ports and other areas of man-made coastal infrastructure.
- Calibrating tide gauge data for monitoring sea level rise and creating accurate storm surge models.
- Determining coastal resilience and monitoring sea level and coastal change.
- Facilitating coastal habitat restoration efforts.
- Monitoring subsidence (sinking of the earth's crust) to predict vulnerability to flooding.
- Monitoring horizontal and vertical crustal motion and plate tectonics for earthquake prediction.
- Determining the travel path of a moving platform, including positions of aircraft doing photography and remote sensing. This contributes to many types of mapping, assessing airport approaches and runway obstructions and assessing hurricane damage.
- Monitoring the distribution of precipitable water vapor in the atmosphere for weather prediction.

There were 10.6 million CORS downloads in Fiscal Year 2008, with the vast majority using the Internet's anonymous file transfer protocol (FTP). The number of CORS data downloads, weighted by the estimated values per download of each type, has been growing by 22% per year since 2003.

A preferred approach to benefit measurement is the economic productivity approach which emphasizes incremental cost savings and productivity gains to users. The use of avoided costs is a valid conceptual way of determining the efficiency gains that are at the heart of the economic productivity approach. Incremental value estimation considers the benefits above those that would have existed in the absence of a program. The approach takes into account the technological alternatives that would be manifest if CORS and GRAV-D were not available and their relative use and cost. Estimation for GRAV-D focuses on the costs avoided by not having to do long line leveling and the benefits to floodplain management.

An illustrative order of magnitude of benefits of NSRS is $2.4 billion per year. This is derived by building on revenue from private surveying and mapping, adding assumptions for the government and not-for-profit sectors and adding a factor for societal benefits. The $2.4 billion per year, extended over 15 years and discounted at 7%, leads to a present value for the NSRS of $22 billion.

Appendix 3. Experience of Other States

California's geodetic control situation is very different from the establishment of CORS networks in many other states, where almost all of the NGS CORS stations are funded, owned, operated, and maintained by the state, typically the state's Department of Transportation (DOT). These State agencies have control of this very critical positioning infrastructure, ensuring the long term sustainability and availability to end users internally and externally. One exception is Washington where the network is operated by a consortium comprised of 80 public agencies. Quantities of state-owned and operated CORS stations elsewhere include:

Alabama DOT	39
Florida DOT	80
Indiana DOT	36
Iowa DOT	24
Michigan DOT	92
Minnesota DOT	120
Minnesota DOT	58
Missouri DOT	67
New York DOT	46
North Carolina Geodetic Survey	75
Ohio DOT	45
Oregon DOT	30
Tennessee DOT	39
Texas DOT	153

California's situation is unique because shortly after the release of the CSRC Master Plan in 2003, which recommended the establishment of approximately 275 CORS stations to define the geodetic control framework for California, the EarthScope project, as described earlier in this document, began. In support of the EarthScope project, hundreds of GPS stations were installed in California. This precluded the need for to the State to provide the resources, governance, and stewardship to develop a statewide geodetic control network via CORS as recommended by the CSRC Master Plan. Although saving the State tens of millions of dollars on construction and maintenance costs over the past 13 years, the State now needs to develop a sustainable plan to support this framework as the EarthScope project comes to an end in 2018.

Caltrans' study[16] indicates that most of the other states:

- Provide Real-Time Network corrections (network or single-baseline)
- Provide correction services at no or minimal charge to users
- Are funded from the state's DOT budget and operated by the DOT
- Align their networks with the NSRS; all GPS stations are CORS-aligned
- Use DOT information services rather than relying on statewide IT
- Have between 50 to 2,000 users, both public agencies and private

[16] Ibid. *Statewide Real-Time Global Positioning System or Global Navigation Satellite System Network Implementation*

Appendix 4: Analysis

Issues Considered

At the commencement of this study, the Geodetic Control Work Group outlined issues of concern related to the chartered mission. This listing now includes the Work Group's conclusions.

Does California need to continue to build its geodetic control infrastructure?

The build-out of 850 CGPS stations has been completed, primarily by the efforts of the geophysical science community. However, this physical infrastructure, or a subset thereof, along with the data collected and transmitted from it, needs to be maintained and administered by some ongoing entity with a stable source of funding.

Should California's geodetic control be real-time, or just post-processing services?

Approximately 550 of California's 850 CGPS stations provide real-time data streams. This enables convenient and cost-effective correction immediately, while the users are present on the observation site, although the corrections are slightly less accurate than what can be obtained later with post-processing. Post-processing provides more accurate positions utilizing longer periods of observations with data available from the CGPS stations after about 24 hours. The 380 stations with Real-time corrections currently available from the CSRC use a single-baseline method of positioning. A Real-Time Network solution requires additional CGPS stations, software and processing. The CSRC currently does not have the resources to provide real-time network solution services, as some private companies currently do, but this problem could be resolved with increased funding for CSRC's operation.

Do private companies play a role?

Some private companies have established their own "for pay" GPS-control networks, with real-time capabilities, but these only exist in areas where there is a sufficient potential user base to warrant operation. This is primarily in high population areas and areas of major row crop agriculture production. None of the private systems currently in operation in California offer certification or documentation regarding alignment with the NSRS or CSRS. Therefore, they alone are not valid for performing work required to be tied to the NSRS or CSRN. Other procedures must be employed by the users to correctly align their data with a published reference frame. Many of the stations included in these networks are not constructed to the standards required to be included as NGS CORS stations, although five NGS CORS stations in California are owned by private RTN vendors.

Do we even need a state sponsored RTN?

A primary goal is to make geodetic control easily and widely available with little or no cost to the user, and to enable certified-accurate positioning for locational data collection. Private RTN service providers, as profit-making businesses, charge their users for access to their systems. No private services cover the entire state.

Importantly, there is currently no process for validation of these services by a Federal (NGS) or State (CSRC) authority. Although some private CGPS stations have been registered with NGS as CORS stations, the private networks cannot yet guarantee that the adjustment corrections they provide to their users are registered to the CSRN/NSRS. Private services do not broadcast NSRS or CSRN coordinates to the users. Users must include existing public control monuments with published coordinates to “localize” or “calibrate” their RTN data to the NSRS or CSRN. Technically, this shortcoming could be remedied. However, there is also the problem of willingness of private companies to take on the liability of guaranteeing their data is correctly registered in the CSRN framework. Besides the liability, there is also a question of legality. In accordance with the Professional Land Surveyors’ Act (8726 (f)) only licensed land surveyors are legally authorized to establish the positions of geodetic control points or stations using California Coordinate System coordinates. Therefore, each private service provider would have to employ a licensed land surveyor to provide California Coordinates and to perform large scale network adjustments necessary to periodically align their network with the CSRN or the NSRS.

In most states, a State agency establishes the network and provides administration, permitting access to registered user for free or a nominal fee. In states where a State owned system is available, private networks rarely exist, or target users with different, specific needs than are served by the state operated system.

The Great Lakes Region Height Modernization Consortium issued a White Paper in this topic in 2013: https://www.ngs.noaa.gov/web/surveys/heightmod/RTNPositionPaper.pdf

Should California maintain its passive geodetic control monuments?

In 1991, a cooperative effort between NGS and Caltrans created the High Precision Geodetic Network (HPGN) consisting of 245 passive survey monuments in the ground at a spacing of approximately 40 miles across the State. With California's tectonic motion, the original published coordinates for these passive control points become obsolete. Some HPGN station positions have changed horizontally by more than a meter from their 1991.35 position. This means that to keep the positions current, within acceptable tolerances, periodic readjustments are required, using CORS/CGPS positions as constraints. NGS included passive survey control in the last realization (adjustment) of NAD83, but is unlikely to do so in the future. Therefore, maintaining accurate positions for the HPGN will be left to the individual states and locals. The estimated cost to perform a Statewide re-observation of the HPGN is $1.3 million (approximately $1 million for reconnaissance and field observations and $300,000 for office support, mission planning, and data processing). Because of the velocities of crustal motion in some areas of California, up to 5 centimeters per year, this work would need to be repeated periodically or the absolute and relative accuracies of the stations would deteriorate beyond usefulness in just a few years. The more realistic approach is localized maintenance by users of the HPGN or other passive marks, using CORS stations as constraints. Unlike CORS (or active stations) the positions of which are tracked and computed daily, each time a passive mark needs to be updated, it will need to be re-observed in the field and reprocessed.

Static HPGN monuments are still relied upon by some surveyors to reference their products to the NSRS/CSRN, either as primary control for static, post-processed GNSS/GPS surveys, or as calibration points for RTK/RTN surveys. Passive monuments' coordinates can be adjusted using velocity models, but the resulting position is not as accurate as performing direct observations referenced to the CORS/CGPS network. Additionally, the published positions can only be considered reliable as of the date of the last field measurement which may be as far back as 1991. Despite the installation of many hundreds of CORS/CGPS stations in California since the inception of the HPGN, the HPGN is still a primary form of geodetic control for some surveyors.

One other consideration is that passive survey marks in the ground are much more susceptible to destruction. It is estimated that 20% or more of the original HPGN monuments have been destroyed or significantly disturbed, primarily by construction activities. CORS type stations are highly visible above ground structures that cannot be inadvertently destroyed.

How should the California network interact/relate to the Federal network?

The CSRN network integrates with the NSRS framework through NGS CORS. However, the CSRC performs an independent adjustment of the CSRN, resulting in slightly different positional values for the stations common to both systems. These difference are typically on the millimeter level and insignificant for use as geodetic survey control. To maintain acceptable absolute accuracy relative to the reference frame, the CSRN requires more frequent network adjustment due to tectonic motion than the NGS schedules for the Federal network. Seismic episodic events (earthquakes) can require CSRC to perform a post-quake readjustment of CSRN stations displaced by the event.

What is the demand level for RTN services, and by whom?

The users of real-time services cover a wide variety of applications. In California, and in many other states where real-time services are available, this positioning technology is being used for such purposes as; surveying and mapping, automated machine guidance for construction, subsurface utility location technology, mobile laser scanning, guidance for precision agriculture applications and autonomous vehicles, civil infrastructure asset management, navigation, and transportation routing and tracking. Additionally, real-time data is emerging as a critical component to the development of a viable early earthquake system based on research being performed by SOPAC, Cal-Tech, University of California Berkeley, and others. The number of unique user accounts issued for CRTN has increased from around 200 to over 800 in just the past three years. Recent account requests have come from autonomous vehicle research entities, unmanned aerial systems (drone) operators and research companies, and agriculture research organizations, to name a few. The demographics of accounts holders has expanded greatly beyond the surveying, engineering, and GIS communities in the past two years.

Is there an understanding of the importance of geodetic control?

Although California's geophysical environment is dynamic, there is very little understanding of what geodetic control is, much less grasping its importance, by anyone other than land surveyors and geodetic/geophysical scientists. Very few GIS professionals have adequate understanding of what geodetic control is and why it is important to their work. This lack of understanding has been confirmed from audience interaction at the more than two dozen outreach presentations given by members of this Work Group. The general public, who are neither surveyors nor GIS professional, have far less awareness of geodetic control, even though their buildings, housing, transportation, food and water supply depend on accurate geodetic control. This needs to change in order to build enough support for allocating the resources to ensure sustainability. This would be a primary objective of developing a communication plan when the recommendations of this document are endorsed by appropriate State level decision makers.

How can geodetic control get funded, and what agency should take responsibility?

This study has analyzed several alternatives for stewardship of the CSRN and options for funding its ongoing sustainability. A range of costs, with corresponding benefits, have been assessed. The decision of which alternatives to pursue remains with those designated fiscal and administrative responsibility in our State's government, however, it is recommended that decision makers take counsel from knowledgeable professionals who have studied the problems. The experiences of other states also offers guidance.

Appendix 5. Standards and Legal Requirements

The Federal Geographic Data Committee (FGDC) document FGDC-STD-014.4-2008 “Geographic Information Framework Data Content Standard Part 4: Geodetic Control” date May 2008, defines the standards necessary to support the exchange of geodetic control data by establishing a common baseline for the semantic content of geodetic control databases for public agencies and private enterprises:

https://www.fgdc.gov/standards/projects/FGDC-standards-projects/framework-data-standard/GI_FrameworkDataStandard_Part4_GeodeticControl.pdf

The California Public Resources Code (PRC) §8801-8819 define the California Spatial Reference Network (CSRN), and the requirements for referencing or generating California State Plane Coordinates in the performance of a survey. Because the CSRN is comprised entirely of Continuous GPS (CGPS) stations (as opposed to tradition passive survey monuments in the ground) the only way to reference positions to the CSRN is through CGPS stations.

Additionally PRC §8850-8861 define the official geodetic datums and spatial reference network for use within the State of California.

Appendix 6. Program Elements

CGPS Infrastructure

The initial costs to acquire and install the 850 CGPS stations and their supporting equipment (solar power, batteries, telecommunications, fencing, and permits and fees to occupy the land) have already been invested. If UNAVCO receives no more funding after 2018 for the operation of the PBO, it is unclear how their CGPS assets will be sustained.

PBO's experience with maintaining this infrastructure indicates an annual cost of between $5,000 - $6,000 per unit. This includes replacing equipment that has failed or been vandalized, upgrading software, data handling and renewing permits and fees to keep the network operational at the NSF-promised uptime of 85% for once-daily downloads. While UNAVCO does provide real-time streams from a subset of stations, the network is not funded at the level to provide any guarantee of completeness or latency. Any expectation of streaming performance, hardening telemetry or modernization from GPS to GNSS systems adds costs. A lot of staff time has been spent negotiating permits and fees, and there are significant travel expenditures for servicing remote CGPS stations, including helicopter and boat support. These costs are averaged in the per-unit maintenance figure. However, a large number of units will require re-permitting after 2018, because UNAVCO knew about the closing date of its NSF grants from their inception. Therefore, the higher estimate number for maintenance will be used.

With "sunk costs" of this investment amounting to nearly $40 million, along with the ongoing need for survey control in California, as well as the ongoing need to monitor, study, and prepare for earthquakes, abandoning this infrastructure would jeopardize all Californians.

CGPS Operations

Operations include maintaining the communications technology to receive CGPS data at the central database archive, maintaining the database archive, recalibrating the CSRN network periodically and episodically (after an earthquake), maintaining the user access communication portals, providing both static and real-time adjustment services for users (using either single-baseline or network computation), engaging new users, teaching and helping users, researching technology for future system improvements and upgrades, and managing these complex tasks. The cost of maintaining these services has been estimated by CSRC at $600,000 per year.

There are four options for providing locational data services to users of the CSRN:

a) "Post-processing" –The user downloads satellite observations from the CSRC archive data base for specific CSRN CGPS stations and along with satellite observations collected on site computes an accurate position for the user's location.

b) Real-Time Network Solution– The system calculates the coordinate corrections based on data collected at numerous nearby CGPS stations for the users location in real time and applies them to the coordinates computed on-site in the field. Real Time solutions are convenient for finding and locating survey points, and for guiding precision-controlled construction and agriculture equipment. This Network calculation is highly accurate, although slightly less accurate than Post-processing. It will require CSRC to acquire additional software and telecommunications equipment, estimated to cost $150,000 per year.

c) Real-Time Single-Baseline Solution - calculates the coordinates for the user's location in real-time relative to a single CGPS station in the CSRS. Real Time adjustment is convenient for finding and locating survey points, and for guiding precision-controlled construction and agriculture equipment. The Single-Baseline calculation is slightly less accurate than the Network Solution. It will require CSRC to continue upgrading and maintaining software and telecommunications equipment, estimated to cost $100,000 per year.

d) No adjustment - just provides the archived GPS signals that were received by user-specified CGPS stations. This requires the user to process the raw data into corrections for adjusting the user's observed locational coordinates. NGS provides such a processing service called OPUS. No additional cost, however does assume the CGPS data archive will be maintained.

Appendix 7. Supporting Organizations

Many associations of professionals who use GPS and rely on the CSRN are aware of the problem of maintaining it in the future, past 2018. Their experience and active engagement in promoting these recommendations will significantly help to achieve the goals.

California Land Surveyors Association (CLSA)

The goal of the California Land Surveyors Association is to promote and enhance the profession of surveying, to promote the common good and welfare of its members, to promote and maintain the highest possible standards of professional ethics and practice, and to elevate the public's understanding of the profession. CLSA represents all land surveyors, whether they are employees or proprietors, whether in the public or private sector.

CLSA recognizes that Land Surveying professionals can provide valuable expertise in establishing and maintaining geodetic control for survey work and also for collecting data used in GIS databases. CLSA has established a website to facilitate finding land surveyors that specialize in establishing GPS-based geodetic control.[17] CLSA supports the effort to establish a statewide geodetic control network for GIS projects. Geodetic control is a crucial element that is vital to the success of any statewide effort to establish GIS datasets.

League of California Surveying Organizations (LCSO)

LCSO has been serving the public for over 40 years. Its mission is to standardize mapping and the practice of Land Surveying across the State of California through active dissemination of information. Its members include County and City Surveyors, Caltrans, representatives from special districts, professional organizations, and private consultants whose primary focus is providing surveying services to the Government sector. Meetings are held in various locations throughout California. The League is comprised of the Northern and Southern Regions which have different documents, meetings, and items of interest.

American Council of Engineering Companies, California (ACEC-CA)

The purpose of ACEC-CA is to strengthen California's engineering and land surveying businesses to build a better California. Membership is by firm, not by individual, and includes corporations, companies and sole proprietorships that offer all disciplines of engineering such as mechanical, electrical, traffic, civil, and land surveying. Most of the membership is civil and surveying firms, and many of the surveyors utilize NSRS and CSRN stations on a regular basis.

County Engineers Association of California (CEAC)

CEAC is comprised of County Engineers, Public Works Directors, County Road Commissioners, County Surveyors, and other professional personnel throughout California's 58 counties. Its purpose is to advance county engineering and management

[17] http://www.californiasurveyors.org Clicking on the "Find a Surveyor" button located on the right side of the website.

by providing a forum for the exchange of ideas and information aimed at improving service to the public. Members strive to affect "maximum efficiency and modernization in engineering and administrative units of local Government." Providing a convenient, accurate, common horizontal, and elevation datum for all of the state, county, and city government agencies to use and share data is a very important objective of CEAC's activities.

California GIS Council (CGC)

As the originator of the Geodetic Control Work Group, the CGC will review this report and decide on its endorsement. The CGC is comprised of GIS professionals from all "sectors" of California's geospatial community: state government, federal government, local governments, utilities, universities, professional associations, and private enterprises. The CGC develops recommendations (through its designated work groups) to promote the efficient coordination of geospatial activities within the state (both governmental and private). Building the seven NSDI themes of geospatial information, along with the eleven CSDI themes, for statewide coverage and free public accessibility is one of CGC' principal objectives.

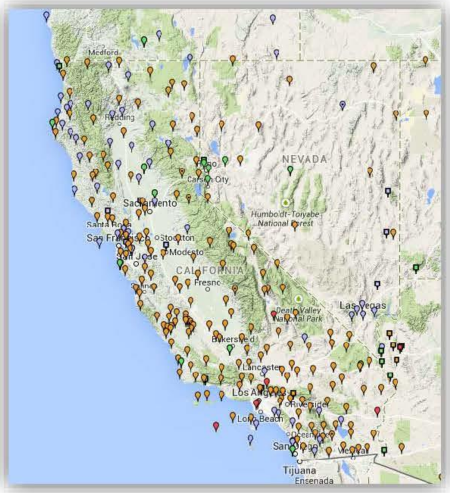
With CGC' endorsement, these policy recommendations will be transmitted to the State Geographic Information Officer, for consideration by the Information Technology Agency and the Governor's office. CGC members, and particularly GCWG members may also share these recommendations with other State agencies, legislators, and interest groups.

Several GCWG members, as well as other geospatial professionals, have agreed to be available to serve on a team to develop an Implementation Plan, if requested.

Appendix 8. Geodetic Control Report Card

GEODETIC CONTROL THEME

CURRENT GRADE: B+
POTENTIAL GRADE: D or F



NGS CORS stations in California

Discussion: On February 6, 2015 the Coalition of Geospatial Organizations (COGO) released its report titled "*REPORT CARD ON THE U.S. NATIONAL SPATIAL DATA INFRASTRUCTURE*", which included the Geodetic Data Theme (GDT). Of the seven themes evaluated and graded in the COGO report, the GDT received the highest grade of a B+. The next highest grade was a C+ for Elevation Data and Orthoimagery Data. This high grade was awarded primarily due to the efforts of the National Geodetic Survey (NGS) to provide robust access to the National Spatial Reference System (NSRS) through the network of Global Positioning System (GPS), Continuously Operating Reference Stations (CORS), known as National CORS. Additional high value was given language contained in the NGS "*Ten Year Strategic Plan 2013-2023*".

Specifically, Goal 3 of that plan, as paraphrased in the COGO report states:

"Expand the National Spatial Reference System (NSRS) Stakeholder Base through Partnerships, Education, and Outreach."

With approximately 253 active NGS CORS stations in California, it is reasonable to apply the same evaluation criteria to the California Geodetic Control theme, thus yielding a current similar grade of B+ or better.

However, more than 98% of all NGS CORS stations, approximately 2,500 total, are not funded, owned, or operated by NGS, but by other entities that make the data from the CORS stations available to NGS to provide access to the NSRS. This relationship was only briefly mentioned in the COGO report in this paragraph:

The CORS network is a near-perfect example of the recent success in national collaboration. The network is operated by over 200 organizations, with the data managed and maintained centrally by NGS. It is utilized by thousands of unique users every month.

What is not discussed in the COGO report is the long-term vulnerability and risk such a partnership model presents, especially in California.

A. Background in California

As satellite based, high precision position capabilities were developed and implemented through GPS technology in the 1980's, then progressing rapidly in the 1990's, NGS promoted the development of high precision geodetic control networks in all States to support the use of GPS. These networks are referred to as High Accuracy Reference Networks (HARN) or High Precision Geodetic Networks (HPGN).

In 1991, the original HPGN in California was designed, installed, observed, and implemented through a joint effort between NGS and Caltrans (lead State agency) with contributions from many local stakeholders. The

HPGN was comprised of traditional survey monuments of high stability, with clear views of sky for GPS occupations.

The concept of CORS stations began to emerge a few years after the establishment of the HPGN. Some of the early CORS stations in California date back to the mid 1990's.

Because of the geophysical properties and challenges existing in California in the form of secular tectonic plate drift along fault zones, earthquakes, subsidence, and even volcanoes; geodetic control positions are unstable over time and require periodic updating to remain accurate, in an absolute sense, to the NSRS. Given these unique challenges, and the lack of NGS resources available to properly and adequately address them, the California Spatial Reference Center, Scripps Institute of Oceanography, University of California San Diego (UCSD), was created in 1998 through support and funding from the NGS. The CSRC has the sole codified authority, through the California Public Resources Code, to compute and publish coordinates for the California Spatial Reference System (CSRS). However, due to diminished funding, the CSRC has not been able to keep the CSRS consistently aligned with the NSRS for the past several years.

In 2002, a CSRC committee was formed to develop a CSRC Master Plan. In March of 2003, the CSRC document *"A MASTER PLAN for a MODERN CALIFORNIA GEODETIC CONTROL NETWORK"* was approved by NGS. This document can be accessed in entirety here:

http://csrc.ucsd.edu/docs/csrcMasterPlan.pdf

It is stated in this document that the CSRC's ultimate goal was to establish a California geodetic control network consisting entirely of CORS stations, rather than the type of monuments used for the HPGN, which are referred to as passive survey marks. The proposal was for an evenly spaced (80 km), grid like network covering California, with increased density in more urban areas. The estimated total number of stations to fulfill that need was 275.

Although not entirely as a result of CSRC efforts and resources, a very dense and robust population of roughly 830 Continuous GPS stations (CGPS) has been developed in California in the 12 or so years since the Master Plan was written. This was mostly to support geophysical scientific research. Of the 830 CGPS, 253 are currently incorporated into the NGS CORS network, approximating the original CSRC estimate of 275 installed CORS. As a result, the density and distribution of CORS stations in California is very high when compared to many U.S. states and lower than several others.

The current network provides excellent access to the NSRS in California, so a B+ grade is warranted at this time. However, without dedicated state and local funding to own, operate, or maintain California CORS stations, long-term sustainability of this grade is at high risk.

B. Theme Definition and Relationships

The *"California Geospatial Framework Draft Data Plan"* prepared by Michael Baker Jr., Inc. for the California Geographic Information Association, dated September 2006 stated the following regarding theme description and the relationship to other themes:

"Geodetic control provides a common reference system for establishing coordinates for all geographic data."

"The Geodetic Control theme is used in conjunction with Ortho Imagery to improve the accuracy of many data themes."

C. Lead Agencies

The NGS is the responsible agency for this framework data layer of the National Spatial Data Infrastructure (NSDI) by virtue of maintaining and providing access to the NSRS. No lead agency for California has been identified. For now, the CSRC remains responsible for determining and publishing positions for the approximately 830 CGPS stations included in the CSRS (including the 253 CORS) while receiving no funding from the State to perform this codified function.

No NGS CORS stations in California are currently owned or funded by the State of California.

The owners of California CORS stations are:

Plate Boundary Observatory (PBO) - 207
Berkeley Seismology Laboratory – 11
US Coast Guard - 8
Scripps Orbital & Permanent Array Center (SOPAC) – 7
US Geological Survey (USGS) – 7
Private vendors, Leica and Trimble – 5
NASA Jet Propulsion Laboratory – 3
Federal Aviation Administration – 2
NGS – 1
City of Modesto – 1
ESRI – 1

Examples of State owned CORS stations elsewhere:

Texas DOT – 153
Michigan DOT – 92
North Carolina Geodetic Survey – 75
Missouri DOT – 67
Minnesota DOT – 58
Ohio DOT – 45
New York DOT – 40
Tennessee DOT – 39
Alabama DOT – 39
Indiana DOT - 36
Iowa DOT – 24

D. Collaboration and Partnering

The CSRC partners with eight other entities that own stations to provide robust, single-baseline, real time network (RTN) access to a subset of the CSRS through the California Real Time Network (CRTN). These partners are; USGS, PBO, SOPAC, Metropolitan Water District of Southern California, Orange County, San Diego County, UC Berkeley, and Caltrans.

CRTN is comprised of 376 stations of which 138 are NGS CORS. A single user account to CRTN is free upon request. Additional accounts are available on a fee basis.

The CRTN White Paper Proposal, dated October 16, 2008 can be accessed here:

http://csrc.ucsd.edu/docs/CRTNProposal_version5.0.pdf

The CRTN Business Plan, dated July 30, 2009 can be accessed here:

http://sopac.ucsd.edu/docs/CRTN_BusinessPlan_09July.pdf

Similarly, the CRSC provides free access to CSRS station data files for user post-processing purposes.

The primary partner of the CSRC providing stations included in the CSRS is PBO, owning approximately 74% of the 830 total stations. The PBO investment in this infrastructure in California is over $30 million to date. Other partners include; USGS, PBO, SOPAC, NASA Jet Propulsion Laboratory, Metropolitan Water District of Southern California, Orange County, San Diego County, UC Berkeley, and Caltrans. Caltrans, as the only State Agency on the list of partners, contributes 21 stations to the CSRS.

E. Standards

The standards for this Fundamental theme are the same as defined in the COGO report, all produced by the Federal Geographic Data Committee.

F. Estimation of completeness

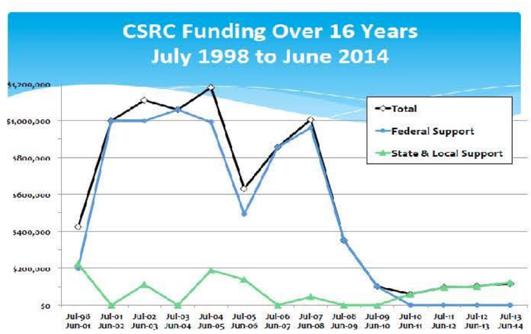
With 253 currently active stations, the CORS component of the NSRS in California provides excellent access to the NSRS statewide for end-user post processing of CORS data. This data is used to determine high accuracy horizontal and vertical geodetic survey control for positioning cadastral data and orthoimagery. CORS solutions also improve the accuracy of many other data themes. NGS also provides the free tool, Online Positioning User Service (OPUS), to compute static point positions relative to the CORS network.

G. Accessibility

NGS Products and services are available from the National Oceanic and Atmospheric Administration (NOAA) website at http://www.ngs.noaa.gov/. Access to the CSRC and CRTN are available at http://csrc.ucsd.edu/ or http://sopac.ucsd.edu/index.shtml.

H. Issues with sustainability of California CORS

Although the CSRC still exists, it no longer receives funding from the NGS, or large state partners. Therefore the primary source of CSRC income is through "pay for access" subscriptions to the California Real Time Network (CRTN) operated by the CSRC. Annual funding for CSRC peaked at about $1.2 million in 2004-05, but is now less than $100,000/year through the CRTN revenue stream.



Of the minimal CSRC funding remaining, none is used to maintain any California CORS stations.

The Scripps Orbital and Permanent Array Center (SOPAC), also located at UCSD, owns seven California CORS, funded by SOPAC, not the CSRC. Currently, the NGS owns only one CORS station in California. This means that more than 99% of California CORS are funded, operated, and maintained by various other partners, including the US Geological Survey (USGS), US Coast Guard, academic institutions, scientific research based organizations, private vendors, and even local governments.

This model is very different than CORS networks established in many other states, such as Texas, Michigan, and North Carolina, where almost all of the NGS CORS stations are funded, owned, operated, and maintained by the state, typically the Department of Transportation. These State agencies have complete control of this very critical positioning infrastructure, ensuring the long term sustainability and availability to end users internally and externally.

Of the 253 currently operational CORS stations in California, 207 (82%) are owned and funded by the National Science Foundation (NSF) and operated and maintained by the Plate Boundary Observatory (PBO), in support of the NSF project, EarthScope. The 15 year EarthScope project began in 2003 and is operated by UNAVCO, Inc. As part of EarthScope, PBO installed various types of instrumentation to monitor and measure tectonic plate movement, detect and characterize volcanic activity, and record seismic events.

Approximately 1,100 CGPS stations were constructed as part of this instrumentation array, approximately 615 (74%) of which are in California and solely PBO funded. This puts a substantial majority of the California geodetic control infrastructure in one PBO supported basket. Herein lies a major concern with sustainability.

On September 30, 2018 the NSF funding for the EarthScope project will end. This means that 82% of the California CORS stations will be unfunded beyond that date if no replacement resources are identified and implemented. Efforts to find solutions began in early 2014 and have ramped up steadily since, led by outreach from UNAVCO Directors. NGS is unable to fund these stations and would at most maintain about 5 foundational CORS stations in California. The USGS uses much of the data obtained from PBO instrumentation for scientific purposes, but they also lack funding to take over the PBO stations. Any science based entities that might step up to maintain stations beyond 2018 would select specific stations based on scientific value, not spacing and location to support geodetic control. In many remote areas of California, the only existing CORS/CGPS station(s) available to provide coverage and access to the NSRS or CSRS are PBO owned stations.

I. Conclusion

Without a minimum of State and/or local funding, or a completely State owned and operated CORS geodetic control network in California, as has been successfully implemented in many U.S. States; a crisis situation is near. In this senario, accessibility to a current and common reference frame through the NSRS or the CSRS will remain almost completely reliant on various and undeclared outside sources. This model is risky and uncertain, especially considering that PBO has already begun plans to decommission some stations beginning in 2015 with the end of the EarthScope project and all funding in September, 2018.

This is an unacceptable situation that needs to be addressed and corrected at the State level to ensure long term geodetic control access in the support of the California Spatial Data Infrastructure.

If the State fails to develop and implement a plan to provide long term sustainability, the grade for this fundamental theme will certainly fall from the current B+, to a low D or a complete fail almost instantly.

APPENDIX A REFERENCES and INFORMATIONAL SOURCES

Bossler, Dr. John D., Dr. David J. Cowen, James E. Geringer, Susan Carson Lambert, John J. Moeller, Thomas D. Rust, Robert T. Welch. Report Card on the U.S. National Spatial Data Infrastructure – Compiled for the Coalition of Geospatial Organizations. February 6, 2015.
http://www.cogo.pro/uploads/COGO-Report_Card_on_NSDI.pdf

CORS station information was compiled from the National Geodetic Survey CORS website:
http://www.ngs.noaa.gov/CORS/

NGS Ten Year Strategic Plan 2013-2023 available here:
http://www.ngs.noaa.gov/web/news/Ten_Year_Plan_2013-2023.pdf

UNAVCO/PBO information accessed at:
http://pbo.unavco.org/

The *"California Geospatial Framework Draft Data Plan"* prepared by Michael Baker Jr., Inc. for the California Geographic Information Association, dated September 2006 available here:
http://cgia.org/wp-content/uploads/2011/10/CA_GeoFrame_DDP_FINAL_for_Publication.pdf

The California Public Resources Code Sections 8801-8819, pertaining to geodetic control, can be accessed here:
http://www.leginfo.ca.gov/cgi-bin/displaycode?section=prc&group=08001-09000&file=8801-8819

National Spatial Reference System information here:
http://geodesy.noaa.gov/INFO/OnePagers/NSRSOnePager.pdf
http://celebrating200years.noaa.gov/foundations/spatial/welcome.html
http://geodesy.noaa.gov/INFO/WhatWeDo.shtml

More CORS information here:
http://www.ngs.noaa.gov/INFO/OnePagers/CORSOnePager.pdf
http://geodesy.noaa.gov/INFO/OnePagers/FoundationCORSOnePager.pdf

General information on high accuracy Global Positioning System (GPS) and Global Navigation Satellite System (GNSS) technology:
http://igscb.jpl.nasa.gov/faqs.html#id2839478
http://www.ngs.noaa.gov/PUBS_LIB/pub_GPS.shtml
http://en.wikipedia.org/wiki/Global_Positioning_System