The Height Modernization Program in the United States and the Future of the National Vertical Reference Frame

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Key words: GPS, GNSS, orthometric height, elevation, vertical datum

SUMMARY

In the United States, NOAA's National Geodetic Survey (NGS) is charged with defining, maintaining, and providing access to the National Spatial Reference System (NSRS), the country's official national reference frame for geospatial data. The North American Vertical Datum of 1988 (NAVD 88) is the current national vertical datum for the conterminous United States (CONUS) and Alaska, and it is realized through a leveling network that, despite its high level of accuracy, is expensive to update, difficult to maintain, and vulnerable to systematic error. In order to address the deficiencies of the NAVD 88, NGS has been engaged in a National Height Modernization Program, enabling better access to accurate heights through the use of modern technologies like Global Navigation Satellite Systems (GNSS) combined with traditional surveying techniques, remote sensing, and gravity data. In addition, NGS now has a Ten-Year Plan, which includes redefining the geopotential (vertical) national datum.

Through Height Modernization, NGS has developed guidelines for establishing accurate orthometric heights using GNSS observations and an accurate geoid model refined to be consistent with NAVD 88. A high-accuracy gravitational geoid model derived from the gravity data collected through a project plan called Gravity for the Re-definition of the American Vertical Datum (GRAV-D), together with accurate ellipsoid heights from the national network of Continuously Operating Reference Stations (CORS), will be used to realize a new national vertical datum. Height information referenced to this kind of datum will be accurate, reliable, current, and consistent. In addition, access to this new vertical datum will be easier, faster, and more cost effective. The Height Modernization Program will pave the way for implementation of this new vertical datum.

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1. BACKGROUND

The National Geodetic Survey (NGS) is the agency in the United States responsible for defining, maintaining, and providing access to the national reference frame for geospatial positioning known as the National Spatial Reference System (NSRS). NGS is part of the National Oceanic and Atmospheric Administration (NOAA), a scientific agency within the U.S. Department of Commerce, and its roots go back over 200 years to the establishment of the Survey of the Coast by President Thomas Jefferson on February 10, 1807. With the first triangulation survey in 1817 by Ferdinand Hassler, the agency's first Superintendent, the Survey of the Coast began a tradition for excellence in the science of geodesy. Over the course of the next 200 years horizontal and vertical geodetic control networks spanning the North American continent were established.

2. TRANSITION TO THE PRESENT

Just as the Survey of the Coast underwent changes over the 200 years (renamed Coast Survey in 1836, the Coast and Geodetic Survey in 1878, and the National Geodetic Survey, as an office in the National Ocean Service of NOAA, in 1970)(Dracup 1995), changes in technology redefined how the mission of providing a national spatial reference frame would be accomplished. For the first 150 years the basic process of geodetic surveying remained the same. Over that time frame there would be improvements in surveying equipment (rods and bars to invar tapes, improvements to theodolites) making them easier to transport and to use. Other developments, like steel observing towers invented by Jasper Bilby, electric signal lights, and communications radios, would speed and simplify field operations. But geodetic control networks would still be established through triangulation, trilateration, traverse, and azimuth determination. The control networks for the United States were updated in the 1920s. The North American Datum of 1927 (NAD 27) and the Sea Level Datum of 1929, later named the National Geodetic Vertical Datum of 1929 (NGVD 29), provided horizontal and vertical geodetic control that spanned the North American continent.

In the 1940s two advances would change the face of surveying in the world. In the early 1940's the first electronic data processing machines were developed, allowing for the processing of large amounts of data in a short amount of time. Then in 1953, the Geodimeter, the first Electronic Distance Measuring (EDM) instrument became commercially available, so baseline measurements that had taken weeks, now took hours (Dracup 1994). These two developments would enable the Coast and Geodetic Survey to efficiently make improvements to the control network where known deficiencies existed. In order to improve the consistency of the reference frame, in the 1970s, NGS began two projects that would take advantage of these new tools – NGS would automate and readjust both the horizontal and vertical geodetic control networks.

Computer formats were developed to automate and store observations, as well as survey and project metadata, for all archived control surveys, including direction, distance, azimuth, and leveling data. Where weaknesses in the network were known, new surveys were performed, using EDM to improve ties in the network. Cooperative surveys, previously done for special projects, became more common allowing NGS to enhance the network with the help of the local surveying community. Since that time surveys performed by other U.S. Federal agencies like the U.S. Army Corps of Engineers (USACE) and U.S. Geological Survey (USGS), State Departments of Transportation, and other local surveyors became part of the geodetic control network along with those performed by NGS field parties (Dracup 1994). When the projects were completed, two new datums were released: the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88).

The new datums were a tremendous improvement over their predecessors. The vertical control network grew from 100,000 bench marks in the NGVD 29 to 450,000 bench marks, with one million kilometers of leveling. NAVD 88 was controled by a single tide gage located at Rimouski, Quebec, Canada rather than the 26 that had been constrained for NGVD 29 (Zilkoski et al 1992). Distortion to the vertical network caused by constraining those 26 tide gages was now removed with the NAVD 88 adjustment.

The NAD 83 horizontal control network had grown from approximately 25,000 stations in the previous adjustment, the NAD 27, to 250,000 stations. The number of base lines in the adjustment increased from several hundred to more than 30,000 EDMI base lines. In addition, the new datum point was now Earth mass center, and space observations available at that time, Transit Doppler and Very Long Baseline Interferometry (VLBI), contributed to defining the new horizontal datum. However, NGS did not yet realize the extent to which it had paved the way into the future. Even as the new datums were being released, another new technology was being developed that would challenge the confidence in them. The Global Positioning System (GPS) was just being developed. In 1983, before NAD 83 was even published, NGS began using GPS technology for geodetic control surveys. By the late 1980s, GPS was on its way to becoming fully operational, and the way geodetic surveying would be done by NGS in the future was to change dramatically.

Figure 1~~1~~. Digital Geodetic Leveling

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2.1 Height Determination through Traditional Leveling

Traditional geodetic leveling techniques for height determination have enabled measuring height differences at the millimeter level. Rigorous geodetic leveling (Figure 1) requires very precise field techniques for handling and setting up equipment, performing double run observations (forward and back), and monitoring and correcting for error buildup along a level line to ensure tight closure. No other surveying technique can yet achieve an order of precision equal to what is achieved by leveling.

But leveling has several drawbacks that make it a difficult way to measure and check heights. First, leveling is a very time consuming and hence costly operation. Technological improvements to leveling equipment, such as the electronic digital level/bar-code systems, have sped up observing time, but the rigorous observation procedures are still needed (FGCS 1995). It requires a minimum of 3 people observing between known points in a leapfrog fashion. It is a line of sight observation method, and in rough terrain, the lines between instrument and rod must be shortened, increasing the number of setups and hence the error that can be introduced in the process. Also highly stable, passive control monuments, commonly referred to as bench marks, are needed to provide vertical control connections to the vertical component of the NSRS. Known monuments must be in place for a point of beginning, and additional marks must be set to control error, and to provide a network of control at a level of densification sufficient for practical uses. Passive control monuments can be compromised when development, road expansion, storms, or crustal motion processes cause the marks to be moved or destroyed. Because of the leveling survey process, laying level lines along roadways or railroad lines was common, and an entire level line can be destroyed with a single transportation project to widen a road. For horizontal control, historically other monuments are available nearby, set either under the surface monument or as reference monuments. These other marks can either serve as replacements for the destroyed mark, or can aid in establishing a replacement mark. Re-establishing a destroyed or disturbed bench mark may mean recreating an entire level line. Survey marks in dynamic areas, subject to severe subsidence or tectonic motion, were often not re-observed for decades, making their published values obsolete. Over time, NGS discovered that many sections of the network it had worked so hard to create were becoming increasingly unreliable or unavailable.

2.2 Using GNSS for Height Determination

It was soon determined that GPS could be used to obtain very accurate horizontal positions. It was common for geodetic surveys done using GPS to meet or exceed first order standards according to the Geometric Geodetic Accuracy Standards and Specificiations for Using GPS Relative Positioning Techniques published by the U.S. Federal Geodetic Control Committee (FGCC, 1989), NGS quickly adopted GPS as a way to close gaps and strengthen weaknesses in the NAD 83 network, apparent now because of the long baselines GPS could measure that had not been possible with traditional line-of-sight surveys. Beginning in 1989 NGS instituted a campaign of high accuracy GPS projects, establishing High Accuracy Reference Networks (HARNs) on a state-by-state basis. With all historic survey data already archived in the NGS Integrated Database, it was possible to retrieve the survey observations for an entire state or region and readjust it using the HARNs as control. Achieving the same level of accuracy in the vertical component was far more challenging.

NGS began evaluating the capability of using GPS to measure orthometric heights in the early 1990s. GPS was already beginning to replace line of sight surveys for horizontal control, and achieving better accuracy than traditional methods in a fraction of the time. Determining the vertical component of this three-dimensional Earth-centered coordinate was inherently more difficult than getting accurate horizontal positions. Also the vertical component of this coordinate was reference to the ellipsoid, not to the NAVD 88. Converting this “ellipsoid” height into an orthometric height made the problem even more challenging. But NGS anticipated there would be appropriate applications for using this new technology for height determination.

The effort to find a way to use GPS to determine heights was accelerated when in 1994 representatives of the California surveying community contacted NGS to discuss problems they were having with their vertical control network. California is positioned at the juncture of the North American and Pacific tectonic plates. California and other parts of the western United States and Alaska are all subject to a variety of tectonic motions. Survey data available when the NAVD 88 adjustment was being performed were difficult to integrate into the network, and much of the data was excluded entirely. As a result, the densification of the NAVD 88 passive control network in California was not adequate for their positioning needs. The California users asked NGS if they felt GPS was a tool that could help them address the problem.

To identify the scope of the need for accurate height determination, in 1998 NGS began a study (Figure 2) with forums in California and North Carolina to identify and document requirements of geospatial data users, traditional (surveyors, engineers) and non-traditional (GIS, agriculture, coastal managers) (NGS1998). In addition, NGS conducted several pilot projects and case studies, comparing use of GPS with traditional surveying techniques to evaluate cost benefits. Various field and adjustment procedures were used which NGS developed into guidelines for surveying with GPS. Using these guidelines guaranteed (to acceptable levels of probability) two centimeter relative (or “local”) accuracy between co-observed stations, and five centimeter absolute (or “network”) accuracy in the ellipsoid heights. This improvement in accuracy was a major leap. All that was needed now was an accurate geoid height model that would enable conversion from ellipsoid heights to orthometric heights.

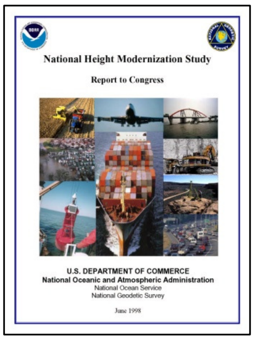

Figure 2. National Height Modernization Study, January, 1998

2.3 Building an Accurate Geoid Height Model

NGS has produced national geoid models only since the early 1990s. Gravity surveys have been part of Coast and Geodetic Survey’s operations since 1875. An understanding of the Earth’s gravity field is critical for calculations of survey data, to determine deflections of the vertical, and for making astronomic determinations of latitude and longitude. Gravity data can be related to geoid heights because both are functions of the distribution of the masses of the Earth. Until the mid-1990s geoid models with stated accuracies in the range of a meter or more were considered very accurate. As GPS became more widely used, and the Height Modernization study showed the value of using GPS for determination of heights, NGS knew a one meter geoid model would not be sufficient. In addition, if the geoid model was to be useful in determining GPS derived orthometric heights in the national vertical datum, it would have to be referenced to the NAVD 88.

NGS decided the state-by-state HARN surveys should be repeated with the new precise guidelines in order to determine the most accurate ellipsoid heights. In addition, NGS realized that if those points with accurate ellipsoid heights also had leveled orthometric heights, this data could be used to 'tune' the geoid model to be referenced to the NAVD 88. Efforts were made to ensure that GPS projects observed to a high level of accuracy included connections to the NAVD 88 bench mark network, especially if the network could be validated through re-leveling or the existing published heights were in stable areas and considered reliable.

NGS' geoid height models were generally published in pairs, four over the past 13 years (Smith and Milbert 1999, Smith and Roman 2001, Roman et al 2004). A gravitational model was developed using NGS' existing gravity holdings. This was considered the scientific model, but it did not provide a connection to the NAVD 88. As geoid height modeling theory was refined, the models became accurate at the decimeter level (NGS 2007). The second geoid model included the scientific model as a base, but incorporated the ellipsoid-orthometric height differences measured in Height Modernization projects. The modified, or "hybrid," geoid height model provided a fit between the ellipsoid and the NAVD 88. The accuracy of the geoid model in any given region is dependent on the accuracy of the "GPS on bench mark" data used.

While the NAVD 88 covers the continental United States, for a variety of reasons the condition of the vertical control network in different parts of the country varies considerably, but it is all connected through the leveling network. NGS is also responsible for providing a vertical reference frame for the island state of Hawaii, and for U.S. island territories, such as Guam, American Samoa, Puerto Rico and the Virgin Islands, and for islands like Martha's Vineyard and Nantucket that are part of, but offshore from, the state of Massachusetts. Each of these islands should have its own vertical reference frame, tied to a tide gage. The geoid height models developed have included these islands, but the resulting orthometric vertical datum is defined and named as a separate island datum (if available).

2.4 NOAA's National Height Modernization Program

After the first meeting in 1994 with California users, NGS spent the next 10-15 years developing and implementing the National Height Modernization Program (NHMP). Height Modernization is defined as the establishment of accurate and reliable heights using GNSS technology in conjunction with traditional leveling, gravity, and remote sensing information. From the 1998 study, a common theme heard at the user forums was the need to improve access to the NSRS, particularly the height component. Specific desired improvements, cited by users, included a network of survey points (at 10 kilometer spacing), densification of CORS, and improvements to geoid models (NGS 1998). The goal was to enable access to accurate heights without the need for expensive and time consuming leveling. This was not something NGS could do with the dwindling resources it had. In addition, the issues and needs in different parts of the country required different approaches. NGS' mission was to provide access to a National Spatial Reference System. In implementation, budget support provided for the program by the U.S. Congress was directed at specific states and organizations to address issues on a regional scale. NGS worked with California and North Carolina to develop plans to upgrade their vertical control network with a combination of all the processes and technologies available. CORS were expanded to enable better control for GPS surveys. Leveling surveys were done coincident with GPS to provide the data to improve the geoid model. Other states also expressed interest in implementing Height Modernization, and began developing plans to address their problems.

Budgetary support for a state was directed either at a state government agency, usually a transportation agency or one responsible for surveying in the state, or a university. These chosen organizations, with guidance from NGS, engaged in a variety of activities to address the immediate needs of the user community (including surveying and engineering, Geographic Information Systems, Coastal managers, agriculture and machine control, and others), and the issues in the state (crustal motion, coastal storms, decimated control network, flooding, environmental issues). In addition to improving their geodetic control infrastructure, both passive (survey monuments) and active (CORS), states developed software tools to assist with collection or processing of survey data. They held workshops and developed training programs for using these new technologies effectively and understanding the data and products that were created. Several states established what came to be called Spatial Reference Centers-ranging from volunteer groups of users in the form of a Board or Steering Committee to individual offices-which coordinated a variety of activities and helped fill a gap where NGS' limited resources could not keep up with geodetic control needs of an expanding user community. Everyone's goal was to rebuild an infrastructure that restored their ability to access the NSRS vertical component and would contribute to an improved geoid model so they could one day use GNSS to establish accurate orthometric heights. NGS support included providing guidelines and procedures, developing software and models, and helping with education and training.

By 2009, 17 states had received some U.S. Federal funding, in addition to resources within the state, to support their activities. Countless other states were engaged in "Height Mod" activities with their own resources alone. But the results of all this activity from a national perspective were inconsistent. Some states had well developed networks of vertical control whose heights had been checked with new

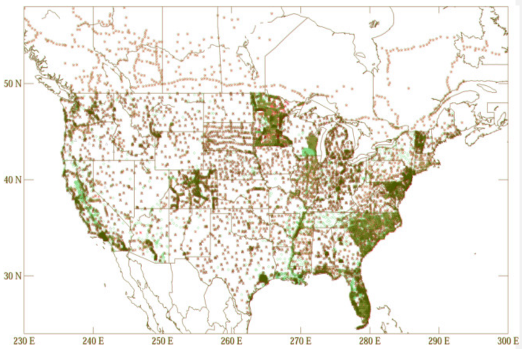

Figure 3. Stations with precise ellipsoid and orthometric heights

leveling and with high accuracy GPS surveys, providing the basis for improving their geoid model (Figure 3). Others had dynamic areas where lack of resources limited their ability to update their vertical control network. The gravity holdings at NGS which would be the basis for the geoid model were evaluated and, much of it was found to be outdated and unreliable. NGS' responsibility to provide consistent reliable access to the National Spatial Reference System, specifically the vertical component of the NSRS, was not being met. Additionally, in the 10 years since the study was done, it was becoming apparent that maintaining a passive control network in many parts of a dynamic nation was never going to be practically achievable. It was time to consider a new approach.

3. THE TEN-YEAR PLAN OF THE NATIONAL GEODETIC SURVEY

When Height Modernization was in the early stages of planning and implementation, the focus was still on obtaining heights in the NAVD 88. NGS had not yet considered, at least in the short term, changing the definition of the vertical datum. But providing access to the horizontal component of the NSRS through the CORS network, which was monitored daily and included velocities, provided a model for maintaining a reference frame through active control. GPS was efficient and effective for performing repeat surveys to monitor temporal changes in areas subject to tectonic motion, subsidence, and post-glacial isostatic adjustment. GPS and the CORS network also provided connections to global reference frames, so motions between tectonic plates could now be measured and monitored. Maintaining the NSRS in its previous realization, as a passive 'stable' control network, was no longer feasible in that context.

In 2008 NGS leadership approved a Ten-year plan (Figure 4) (NGS 2008), in which their mission "to define, maintain, and provide access to the National Spatial Reference System (NSRS) to meet our nation's economic, social, and environmental needs" was re-affirmed. The Plan emphasized the need for NGS to modernize and adapt in order to better accomplish its mission. NGS acknowledged the impact of the changes in technology on the science of geodesy and accurate positioning. The accuracy achievable by GNSS had reached a point where it could not only be used to access the NSRS but could be used to define the NSRS.

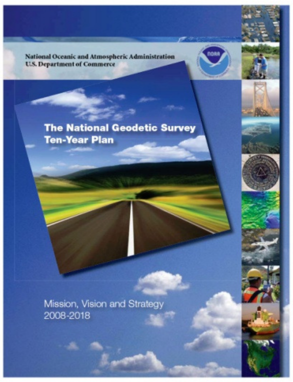

Figure 4. NGS Ten-Year Plan

To achieve the vision outlined in the Ten-Year Plan, NGS highlights five *technical improvements* to focus on in the coming years. Two of those are to modernize the geometric ("horizontal") and the geopotential ("vertical") datums. With GNSS, these datums can no longer be treated separately.

3.1 Modernizing the Geometric and Geopotential Datums

Elements of the geometric datum include both the horizontal and vertical components relative to the ellipsoid. NGS has for many years considered CORS to be the basis for the horizontal datum. The current horizontal datum that is considered part of the NSRS is defined based on a reference frame whose origin is Earth Mass Center (EMC) as it was known when the datum was defined in 1983. Unfortunately, since NAD 83 was published before the International Terrestrial Reference Frame (ITRF) was available its origin is offset from that of the ITRF by over 2 meters, which manifests in median coordinate offsets from the latest ITRF of about one meter in both the horizontal and ellipsoid height components across CONUS (Snay 2008). With a better understanding of the precise location of EMC, and the global nature of a reference frame whose definition is tied to GNSS orbits, NGS decided it was time to redefine this datum to be more consistent with ITRF.

The ellipsoid height component of the geometric datum will be a key part of defining the geopotential datum. The other factor in redefining the vertical/geopotential datum will be gravity. Gravity is the basis of an accurate geoid model, which is necessary for converting ellipsoid heights to orthometric heights. If NGS could develop a one-centimeter geoid height model, the possibility of defining a vertical datum through GPS ellipsoid heights and a geoid height model would be nearer to becoming a reality.

3.2 Gravity for the Re-definition of the American Vertical Datum (GRAV-D)

Over the past two years a comprehensive evaluation of the NGS gravity data holdings has showed significant problems with the data. The distribution of gravity data was inconsistent, with voids along the near offshore regions of coastline and the terrestrial data at varying degrees of density. Data had also been collected from a wide range of sources, methods, and levels of accuracy, and much of it dated back 30-50 years. Combining such data can be problematic, and the accuracy of the older data, especially in those areas where dynamic processes have been at work, is suspect. A comprehensive gravity survey over a short span of time will provide the data needed to model the gravity field with a great measure of confidence. GRAV-D will be the path NGS takes to update its gravity holdings (NGS 2007).

The GRAV-D project (Figure 5) includes several components. The biggest undertaking is a complete aerogravity survey that will cover CONUS, Alaska and Hawaii, and all U.S. possessions – Puerto Rico, the U.S. Virgin Islands, Guam, the Northern Marianas, and American Samoa. The airborne data will be collected in a consistent manner designed to produce a seamless gravity dataset extending from offshore all around the North American landmass to the center of the region. With sufficient resources, this will take 7-10 years. Puerto Rico, the Gulf Coast, and parts of Alaska have been completed already. While an ordered plan has been designed for the completing the gravity collections in various parts of the country, this has been flexible as opportunities have opened up to share resources through partnerships with other U.S. Federal agencies.

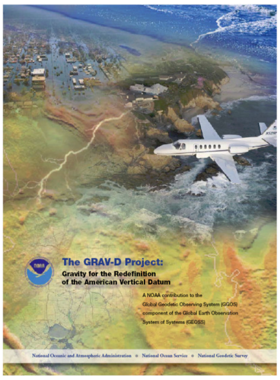

Figure 5. GRAV-D Plan

Absolute and relative gravity ground surveys will be performed as needed to resolve potential errors in the geoid not resolved by the airborne data.

The second stage of the survey will be recurrent absolute gravity surveys. While the exact number and location of these stations has not yet been determined, the sites will be chosen at a strategic spacing across CONUS, Alaska, Hawaii, and all U.S. possessions (Figure 6). These will be re-observed over time to measure changes in the gravity field in those locations. This data together with satellite gravity data will assist in monitoring the changes in the geoid and modeling those changes.

Figure 6. Recurrently Terrestrial Gravity

The third and final component of GRAV-D will likely be accomplished through partnerships with the local surveying community. These will be terrestrial surveys to track finer scale gravity values in areas where there are anomalies or where frequent re-surveys would be valuable.

Additional data will be collected and used in the development of the model, some from within NGS and some from other sources. Digital Elevation Models will be an integral part of the process because they capture the shortest wavelengths of the gravity field, representing the variations in the rock formations nearest the Earth's surface. Other data include geoid slope data as measured by ellipsoid and orthometric height differences in large areas, rock densities of the largest mountain ranges, bathymetry of major bodies of water including near shore regions, and satellite gravity data (Gravity Recovery and Climate Experiment (GRACE) and Gravity field and steady-state Ocean Circulation Explorer (GOCE)).

With the problems inherent to maintaining the NAVD 88 previously discussed, NGS will eventually stop producing a hybrid geoid model. NGS will use the gravimetric model produced from its new and improved gravity data, DEMs and other height data (bathymetry, etc.) to compute a one-centimeter geoid height model. In order to include all the United States' territories, the area of computation will cover the North American continent, spanning from the North Pole to 5^{o} North latitude, and from 172^{o} East longitude to 50^{o} West longitude (Figure 7) (NGS 2008). Combined with the CORS ellipsoid heights from the new geometric datum this will be used to redefine the geopotential datum. This vertical datum will serve as the single datum for all the United States and its territories.

Figure 7. North American Geoid Model Coverage

Because of the continental scale of the project, NGS has been conducting discussions with neighbor countries, Canada, Mexico and the Caribbean nations, on possible collaborations that can support common goals. Data and expertise will be shared, just as they were when the

NAD 83 and NAVD 88 were computed and published (NGS 1996). Like many other countries around the world, Canada has made the policy decision to redefine its vertical reference frame around a geoid height model and GNSS ellipsoid heights. It is not yet known if the vertical reference frame that is chosen to serve the needs of the United States will also be ideal for Canada or Mexico.

The process for monitoring the gravity field is also still under discussion. A meeting was hosted by NGS in September, 2009 with representatives of the international geospatial science community to discuss the feasibility of monitoring changes in the gravity field to maintain the accuracy of the geoid height model. One of the requirements of the new vertical datum will be the ability to maintain the datum at the stated accuracy over time. A plan to monitor changes in the gravity field will be a critical part of the implementation of the new datum.

3.3 The Future of the National Height Modernization Program

Height Modernization began as a program driven by the needs of NGS' users for accurate orthometric heights. It focused on the need to provide passive vertical control and an accurate geoid model to enable measurement of heights referenced to NAVD 88 using GNSS technology. The program will continue to be driven by the needs of users for accurate orthometric heights. But the way NGS fills that need will change. Control previously referenced to the NAVD 88 will be referenced to a new geopotential datum. Primary access to the reference frame will now be through the use of GNSS and a high accuracy geoid height model. Passive control will be used locally to measure precise height differences with leveling where sub-centimeter precisions are still needed. Where there are obstructions prohibiting effective use of GNSS, such as under heavy tree canopy or in urban canyons, people will still rely on traditional surveying methods. But for some parts of the country, the day may come when the accuracy achievable with GNSS alone will replace the need for ties to a static network and those monuments will be used less frequently.

While NGS has a general idea of how it will define and maintain the new datums, the details of these definitions are still being discussed. But defining the datum is just the first step in designing and implementing a new national reference frame. The NHMP recognizes the need to provide users with accurate orthometric heights today, while preparing them for the changes in store over the next decade. Balancing current needs and future goals, some activities will support the current paradigm-GNSS on bench marks-to build the geoid height model needed to transform GNSS ellipsoid heights into NAVD 88 heights. The vertical control network resulting from today's efforts will contribute to a better transformation tool later.

NGS will determine the optimal infrastructure needed for the foundation of the new datums. Models, tools, and guidelines will be needed to assist users with using the new datums, accessing control, and transforming their own coordinates and data. Outreach, education, and capacity building will be critical to ensure proper implementation of the new datums with minimal impact on user productivity. Except for a few regional exceptions, NGS' user community has been accustomed to a stable environment, where geospatial control is static.

NGS must provide the bridge for the users to adapt to a reference frame that has a temporal component to make the most effective use of the dynamic nature of the new datums. NGS will be working closely with its state and U.S. Federal partners and user community to coordinate all these activities and ensure their needs are being met.

In the month following the XXIV FIG International Congress 2010 in Sydney, NOAA will hold a Federal Geospatial Summit for users in other U.S. Federal government agencies with significant geodetic and mapping programs, such as the Federal Aviation Administration (FAA), the Department of Homeland Security's Federal Emergency Management Agency (FEMA), USGS, USACE, the Federal Highway Administration (FHA),and others to hear their concerns and issues and discuss the impact this change will have on them and their products and services. Neighboring countries will be invited to discuss opportunities to collaborate efforts to achieve mutual goals. This will be the first of several such meetings as NGS advances on its ten-year objectives.

4. CONCLUSION

As stated previously, GNSS has forever changed the way positioning is done. While access to the NSRS through the passive control network, provided through an integrated database of coordinate information and metadata, is still common, more and more frequently the surveying community is accessing the NSRS through GNSS differential positioning relative to the CORS network. Levels of accuracy over large areas can be achieved with this positioning technology at a fraction of the cost that was needed for traditional line of sight surveying. Maintaining the NSRS, one of the components of the NGS mission, is accomplished by tracking temporal changes in the reference frame. This will be possible for the geopotential datum through daily monitoring of the CORS, and periodic monitoring of the gravity model. While determining current, accurate heights in this dynamic world is a challenge no matter what survey methods are used, the capability can only improve as the technology improves. As the needs of the users evolve, NGS will continue to change how it defines and provides access to accurate orthometric heights.With virtually any level of accuracy possible, the applications are limitless. It may not be realistic to say GPS will fill all positioning requirements, but the possibility is closer than it has ever been before.

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BIOGRAPHICAL NOTES

Ms. Shields is a Senior Geodesist in the Geodetic Services Division of the National Geodetic Survey (NGS). She received a bachelor's degree in Mathematics from the University of Massachusetts/Boston in 1976. Ms. Shields has been with NGS since 1980, and has experienced major involvement in the geodetic adjustments for the North American Datum of 1983, and integration of new Global Positioning System (GPS) projects into the National Spatial Reference System (NSRS). This included assisting in the development of the constrained adjustment guidelines, primary responsibility for the High Accuracy Reference Networks adjustments, and the state-wide readjustment of several states. She has extensive experience in GPS and Geoid Height analysis, and has successfully used this experience to develop and conduct workshops around the country on incorporation of data into the NSRS. Renee is currently Project Manager for the National Height Modernization Program, an effort that has 17 states as regular participants and additional activities in a number of other states. She coordinates and manages the program, through outreach activities, education, and development of policies and guidelines, with the goal of establishing nationwide implementation of Height Modernization.

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