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# Definition and Densification of the Puerto Rico Vertical Datum of 2002

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**ABSTRACT:** The mission of the National Geodetic Survey (NGS) is to "define, maintain and provide access to the National Spatial Reference System to meet our nation's economic, social, and environmental needs." One component of that mission is to provide accurate geodetic control, including a vertical datum, for all territories of the United States. The islands of the territory of Puerto Rico have had a mixed, patchwork series of geodetic control over the last century, when they have had any geodetic control at all. This has included the lack of a comprehensive vertical datum for the entire territory. In accordance with its mission, NGS underwent an effort beginning in 1993, which has culminated in the Puerto Rico Vertical Datum of 2002. This paper defines that datum and describes the work leading up to its definition.

**KEYWORDS:** PRVD02, NSRS, vertical datums, leveling, tide gauges

## Introduction

The ability to determine heights accurately and precisely is a vital part of nearly all surveying and mapping activities. The zero height reference surface of a height system has historically been realized by a network of very stable and accessible physical survey control monuments, commonly referred to as bench marks (BMs), each with a computed height that is consistent within the whole system. These monuments are crucial to a wide range of activities including: flood plain mapping, storm water and sewer utility management, large scale engineering projects, hurricane evacuation and recovery planning, topographic mapping, subsidence, and crustal motion. This network of BMs with very accurately determined heights referenced to the zero surface can define regional, national, or international geodetic datums, such as the North American Vertical Datum of 1988 (NAVD 88). The definition and maintenance of vertical and horizontal datums in the United States and its territories is the responsibility of the National Geodetic Survey (NGS), a Program Office of the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS). Although the agency has had several name changes, this responsibility goes back to the establishment of the Survey of the Coast by President Thomas Jefferson in 1807. These datums are among the fundamental components of the National Spatial Reference System (NSRS), which provides accurate positions, elevations, gravity, scale and temporal position changes. Many of the issues detailing the importance of accurate heights and well defined datums are documented in the June 1998 "*National Height Modernization Study*" report to Congress (National Geodetic Survey 1998).

This paper outlines the creation of a new vertical datum for Puerto Rico, which will be known as the Puerto Rico Vertical Datum of 2002 (PRVD02).

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### Types of Heights

Because there are various definitions of "height," and because the heights which will be used in PRVD02 differ slightly from those used in NAVD 88, a brief note on these definitions is warranted.

Of greatest significance is the "orthometric" height. This has a very precise definition, being the distance along the plumb line from the geoid up to the point of interest. However such heights are not measured (i.e., nobody pulls a tape measure physically along the curving plumb line down to the geoid) but are rather approximated from surface measurements of leveled height differences as well as gravity. One of the most frequently used approximations to the orthometric height is the "Helmert height", (also called the "Helmert orthometric height") which is computable from

leveling and surface gravity. The heights in NAVD 88 are Helmert orthometric heights.

When gravity data are unavailable, there are other, less accurate estimates of orthometric heights which can be obtained. One is the "normal orthometric height" (not the same as a "normal height"). Normal orthometric heights were used in NGVD 29 and are still in use in the Canadian Geodetic Vertical Datum of 1928 (CGVD28). They rely on the use of *normal* gravity (a simple mathematical formula), rather than true gravity. While normal orthometric heights are a less accurate estimate of true orthometric heights than the Helmert orthometric heights, they are a reasonable choice for a small area such as Puerto Rico. The heights in PRVD02 are normal orthometric heights.

## History of Geodetic Vertical Control in Puerto Rico

At least four different geodetic vertical datums have existed in Puerto Rico, prior to 2002—all "defined" as "Mean Sea Level" (MSL). The U.S. Geological Survey (USGS) established the first two datums between 1928 and 1941 to provide vertical control for their topographic mapping program, commonly called "7.5 minute topo quads." The realization of these two earliest datums consisted of vertical control surveys, leveling, performed to Third-Order accuracy (Federal Geodetic Control Committee 1984), and connecting approximately 709 permanent BMs across the island of Puerto Rico, with ties to 10 U.S. Coast & Geodetic Survey (USC&GS) tide gauges. Furthermore there were 21 additional monuments tied to one separate tide gauge on the nearby island of Vieques. In addition, the U.S. Army Corps of Engineers (USACE) maintains considerable vertical control around the island, based on a variety of reference stations, though information about these marks is difficult to obtain, and will not be counted in the "historic four" vertical datums.

During 1982 and 1995; NGS effectively established the next two (local) geodetic vertical datums. First, in 1982, on the south side of the main island, NGS conducted limited high-accuracy First-Order, Class II leveling from the NOS tide gauge at Muelle de Ponce (#9757487, #1 on Figure 1) to Cerrillos Dam (#2 on Figure 1), labeling the heights as "Local Mean Sea Level" on NGS datasheets (NGS publications of height, position, and gravity values). Then, in 1995, a second (local) datum was established by leveling from the gauge at La Puntilla, San Juan (#9755371; #3 on Figure 1) to Luis Muñoz Marin International Airport and the nearby Federal Aviation Administration (FAA) Wide Area Augmentation System (WAAS) reference station (#4 on Figure 1). Both of these datums contained leveling lines which were less than 20 km long and established very few permanent BMs. A single USGS BM, in the vicinity of Ponce on the south coast of Puerto Rico was recovered and connected in the 1982 survey. The results of this survey showed a difference of 0.05 m (0.2 ft) between the USGS and NGS geodetic datums at this point. No USGS BMs were recovered in the 1995 campaign.

While the data for the NGS surveys are available on-line from the NGS web site (http://www.ngs.noaa.gov), the USGS and USACE data have never been automated by those agencies. Consequently, finding these data is not a very easy process for surveyors, cartographers, and engineers. Each of these networks contained valuable, accurate control points, however the lack of a comprehensive island-wide network adjustment of the leveling data essentially created at least four independent vertical datums.

Other than marks at NOS tide gauges used to support the delineation of the national shoreline as required for the production of nautical charts, it appears no geodetic vertical control surveys were ever conducted on the nearby islands of Culebra or Mona.

There continues to be a very common misconception that the historic height systems mentioned above are defined as part of the National Geodetic Vertical Datum of 1929 (NGVD 29) or as part of NAVD 88. None of the height data in Puerto Rico has ever been connected to either NGVD 29 or NAVD 88. Heights from any source that indicates a relationship to either NGVD 29 or NAVD 88 in Puerto Rico should be suspect as to the origin and accuracy of the data.

Natural forces, such as storms and erosion, and human activities, including road and infrastructure improvements, land development, agriculture, and unfortunately vandalism, have destroyed or disturbed the vast majority of the previously-established monuments. As neither the USGS, nor any other Federal or Commonwealth agency, conducted a comprehensive maintenance or recovery effort, the exact status of the various networks is unknown, although USGS records dating from 1975 indicate that, by that time, 212 (29 percent) of the BMs were reported as disturbed, destroyed, or not recovered. Considering the tremendous development of many communities in Puerto Rico in the past 38 years,

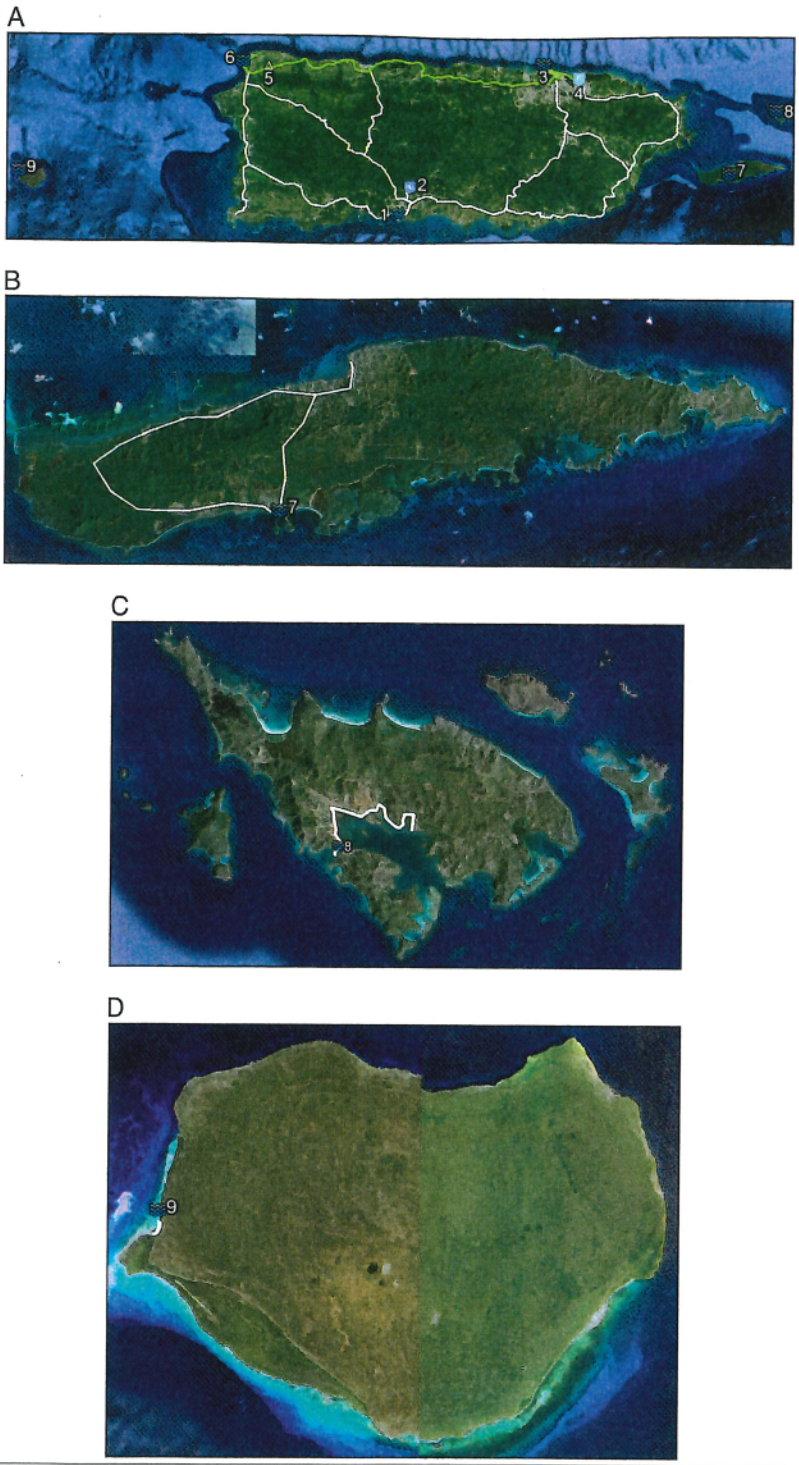


**Figure 1.** A) Leveling lines and key points of interest for PRVD02. B) Close-up of leveling on Vieques Island. C) Close-up of leveling on Culebra Island. D) Close-up of leveling on Mona Island.

it is probably safe to conclude that few of the original monuments still exist—a factor that has led the majority of surveying and mapping programs in the country to establish heights based on either assumed elevations, or tied to unchecked surveys connected to a single BM. This issue is complicated by the fact that the island is experiencing tectonic motions associated with the nearby boundary between the Caribbean and North American tectonic plates; both horizontal and vertical velocities are difficult to resolve, but appear to be in the range of 19 mm per year to the north-northeast in the horizontal and –0.1 mm in the vertical based on NGS's multiyear solution of the national network of Global Positioning System's (GPS) Continuously Operating Reference Stations (CORS) (Griffiths et al. 2010).

In one way or another, the four vertical datums were all connected to one or more of the 27 tide gauges established by the U.S. Coast & Geodetic Survey (USC&GS; renamed "NOS" in 1970) in Puerto Rico. Some of these tide gauges date back as far as 1899. These gauges were installed to ensure the accurate definition of the various tidal datums required (among other things) for the delineation of the shoreline for the United States national nautical charting program. Most of these gauges were short-term (three to six months) sites with typically three to five BMs established within about 1 km of the tide gauge site. Currently, the NOS Center for Operational Oceanographic Products and Services (CO-OPS) provides tidal datum information for 10 sites located around the Commonwealth, including the islands of Culebra, Mona, and Vieques. Two of these stations—including the previously noted gauge at La Puntilla in San Juan, and at Magueyes Island (#9759110), near the town of La Parguera—have been operational for more than 20 years and are part of the National Water Level Observation Network (NWLON) maintained by CO-OPS.

## Planning for the Puerto Rico Vertical Datum of 2002

In an effort to address the deterioration of the USGS leveling monumentation, the sparse USC&GS/NGS control, and the problems caused by four separate leveling datums, NGS, in collaboration with Colegio de Ingenieros y Agrimensores (CIAPR) (Puerto Rico Professional Land Surveyors Association) and the University of Puerto Rico at Mayagüez (UPRM) began planning a comprehensive releveling effort in 1993. The network was designed to attempt to encompass the entire island along main highways, with cross loops generally in a north-south direction to strengthen the network and provide improved information for future geoid models. The campaign would also include new leveling on the islands of Culebra and Vieques, as well as existing CO-OPS leveling on all four islands (including Mona). Considering the size of the islands, and the estimated cost, no plans for collecting new gravity data were made with the understanding that the datum heights would be normal orthometric heights.

Unfortunately, the lack of funding for such a major effort kept the program in the planning stages until 2001. Even then, there was only sufficient funding for NGS to complete a very small portion of the entire leveling network required for the main island. Specifically, and in response to a commitment to perform high-accuracy vertical network connections to U.S. Coast Guard NDGPS sites incorporated into the NGS CORS network, a plan was developed to observe a First-Order Class II level line approximately 150 km long from the primary tide gauge at La Puntilla (#3 on Figure 1), through the Coast Guard DGPS (#5 on Figure 1) site west of the town of Isabella, and terminating at the previously established BMs at the CO-OPS tertiary level tide gauge site just north of the town of Aguadilla, locally referred to as Crash Boat Dock (#6 on Figure 1). As mentioned, the FAA WAAS station (#4 on Figure 1) had been previously connected to the tide gauge at La Puntilla during the 1995 leveling. This combined line of 2001 and 1995 leveling effectively ran east-west along the north side of the island and will be referred to herein as "the north line" (shown in green on Figure 1).

The north line became the foundation of the (planned-to-be) island-wide modern vertical datum called the Puerto Rico Vertical Datum of 2002 (PRVD 02). In fact, it stood as the only complete portion of PRVD02 from 2002 until 2013.

After surveying, adjusting and publishing just the north line (as PRVD02), NGS then developed a densification plan that would add approximately 765 km of additional First-Order Class II leveling for the remainder of Puerto Rico, including the islands of Culebra, Vieques, and possibly Mona, to be observed by contract survey crews from the Puerto Rican surveying community with technical oversight by NGS. The plan was negotiated with the Puerto Rico Office of Management and Budget, the Department of Transportation and Public Works, and the Electric Power Authority. The negotiations led to the signing of a multiagency Memorandum of Agreement (MOA-2002-171) between these organizations and NGS, signed in March 2007. Subsequent to the signing, funding was transferred from the Commonwealth government to NGS to begin the contracting process.

## On Choosing Datum Origin Points for Island Datums

The conventional understanding by many users of geodetic data is that elevation values are referenced to MSL. However, with a few notable exceptions, this is seldom the case. Due to a variety of conditions, such as changes in tidal regimes (e.g., diurnal, semidiurnal or mixed tides), the underlying geological structure of the coastline, prevailing local wind patterns, periodic storms etc., MSL is not a level surface (a level surface being one of equal gravity potential energy and an ideal choice for the zero elevation surface of a vertical datum). Nor is the difference between MSL and the geoid (by definition a true level surface) the same at all locations. That is, local mean sea level (LMSL), defined over a complete 19-year Metonic cycle at San Juan, does not have the same relationship to a given level surface (such as the geoid) as LMSL observed for the same period at Magueyes Island or any other location in Puerto Rico; and neither LMSL surface is equipotential (level) at all. This is well known and was the principal reason NGS changed the name of the national vertical datum of the conterminous United States in 1973 from the Sea Level Datum of 1929 to the National Geodetic Vertical Datum of 1929 (NGVD 29). Puerto Rico's location near the swiftly flowing Gulf Stream and the North Atlantic Gyre and their related currents exacerbates the conditions and can cause significant differences in LMSL from the north to the south side of the island.

Nonetheless, there exists, in many vertical datums, a connection between MSL and the level surface which serves as the zero elevation surface. For example, while heights in NAVD 88 are (by definition) relative to a level surface which extends around the entire North American continent, the actual level surface used had to be chosen from the infinite set of such surfaces available. In the case of NAVD 88, the level surface chosen was that one which passed through a point 6.271 m (along the plumb line) below the geodetic mark at "Father Point/Rimouski". This value (6.271 m) was chosen because it was the LMSL value of Father Point/Rimouski over the 18.6 year tidal epoch 1970-1988. It should be made very clear that only at this one point, of all the places where NAVD 88 exists, are the MSL surface and the level surface of the datum both known, and expected, to be coincident. In similar fashion, a LMSL value was used to identify the particular level surface which serves as the zero elevation surface for a vertical datum in the Virgin Islands (Doyle and Smith 2011) and in the territories of Guam, American Samoa, and the Commonwealth of the Northern Marianas Islands (Carlson et al. 2009).

While the above history shows an NGS consistency in method for choosing one and only one LMSL value to identify which level surface will serve as the zero elevation surface for a new vertical datum for any contiguous land mass, there are other options. In fact, two options were considered for the definition of PRVD02 on each of the two islands of Puerto Rico where *multiple* National Water Level Observation Network (NWLON) stations existed (Puerto Rico and Vieques):

1. Hold multiple NWLON stations fixed at their LMSL elevations; or
2. Hold a single station fixed.

The first option was quickly dismissed because the difference in LMSL between two stations and a single level surface would eventually be forced into the height system once the leveling linked both sites, such as occurred with NGVD 29 in the conterminous United States. The remaining option was to hold the LMSL value at one tide station per island. The question, however, would be which one?

For the island of Puerto Rico, the tide gauges at Magueyes Island (on the southwest side of the island) and San Juan (on the north side of the island) were considered. The site at San Juan was selected for several important reasons: this station has a long history as a primary NWLON station, and the 1995 leveling to the San Juan airport and FAA facilities (mentioned previously) originated at this station. In addition, a level line along the north side of the island was already planned, and would serve a more significant percentage of the population of Puerto Rico than a line from the southwest following the western coastline to the NDGPS/CORS site.

For the island of Vieques, the longest running station, Esperanza, was chosen. For the islands of Mona and Culebra, only one NWLON station is available per island, removing the necessity of choosing.

Options for the datum definitions were discussed at great length in public forums, including two seminars held in December 2001 cosponsored by NGS, CIAPR, and the UPRM Department of Civil Engineering and Surveying in San Juan and Mayagüez, as well as a regional conference of the International Federation of Surveyors (FIG), hosted by UPRM at Mayagüez in October 2002.

## Puerto Rico Vertical Datum 2002 Definition

A decision was made to define the realization of PRVD02 on each of the four islands (Puerto Rico, Culebra, Vieques, and Mona) by holding fixed the 1983-2001 National Tidal Datum Epoch (NTDE) Local Mean Sea Level (LMSL) value at a single bench mark of the longest active CO-OPS tide gauge on each island. This method was chosen, as it was the same method used in the Virgin Islands Vertical Datum of 2009 (VIVD09; Doyle and Smith 2011) and was considered superior to that used in the Commonwealth of the Northern Marianas Islands (also multiple Islands with one datum) in defining the Northern Marianas Vertical Datum of 2003 (NMVD03; Carlson et al. 2009). In the case of NMVD03, NWLON stations were not available on each island of interest and "inter island correctors" were needed. In the case of Puerto Rico, each island had its own long-term tide gauge to serve as a datum origin, and did not rely on inter island tide "correctors" being calculated. The datum origin points for each of the four islands are described below. PRVD02 does not exist on any other islands in Puerto Rico at this time.

For the purposes of scientific completeness, it should be pointed out that by choosing four different LMSL values, one on each island, each island's "zero elevation level surface" will differ from each other island, despite the use of one datum name to describe this set of four unique

height systems. However self-consistency within each island and the use of one common name was seen as the most critical issue. In the future, a truly common datum using a single level surface for the entire North American region is planned as part of NGS's Ten Year Strategic Plan (National Geodetic Survey 2013).

*Puerto Rico*

The bench mark designated "975 5371 A TIDAL" (PID[1] TV1513 in the NGS Integrated Database; see Figure 3), and defined by CO-OPS as the primary bench mark of the La Puntilla, San Juan, Puerto Rico NWLON site (#9755371; #3 on Figure 1, see also Figure 2) was selected as the datum origin bench mark for PRVD02 on the island of Puerto Rico. The LMSL value of 1.334 m relative to the 1983-2001 National Tidal Datum Epoch (NTDE) was adopted at this bench mark as the fixed height from which all other PRVD02 heights on Puerto Rico are referenced.

*Vieques*

The bench mark designated "975 2695 A TIDAL" (PID DN8535 in the NGS Integrated Database), and defined by CO-OPS as the primary bench mark of the Esperanza, Vieques NWLON site (#9752695; #7 on Figure 1, see also Figure 4), was selected as the datum origin bench mark for PRVD02 on the island of Vieques. The LMSL value of 1.962 m relative to the 1983-2001 National Tidal Datum Epoch (NTDE) was adopted at this bench mark as the fixed height from which all other PRVD02 heights on Vieques are referenced.

*Culebra*

The bench mark designated "975 2235 D TIDAL" (PID DN8624 in the NGS Integrated Database), and defined by CO-OPS as the primary bench mark of the Culebra NWLON site (#9752235; #8 on Figure 1, see also Figure 5), was selected as the datum origin bench mark for PRVD02 on the island of Culebra. The LMSL value of 0.973 m relative to the 1983-2001 National Tidal Datum Epoch (NTDE) was adopted at this bench mark as the fixed height from which all other PRVD02 heights on Culebra are referenced.

*Mona*

The bench mark designated "975 9938 A TIDAL" (PID DN8596 in the NGS Integrated Database),

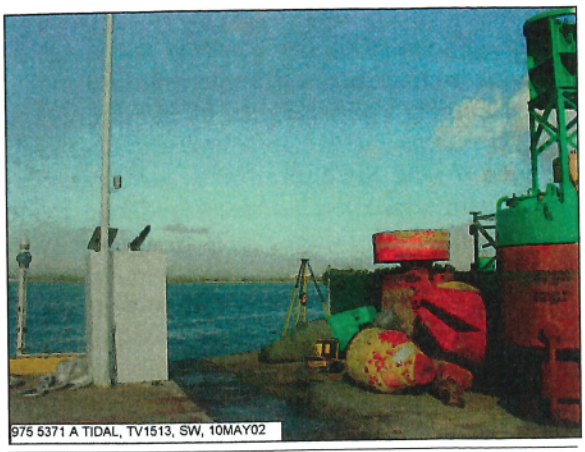


**Figure 2.** Tide gauge (NWLON site #9755371) La Puntilla, San Juan, Puerto Rico.


**Figure 3.** Datum origin point for PRVD02 on the island of Puerto Rico, designated as "975 5371 A TIDAL" PID TV1513).

and defined by CO-OPS as the primary bench mark of the Mona Island NWLON site (#9759938; #9 on Figure 1, see also Figure 6), was selected as the datum origin bench mark for PRVD02 on the island of Mona. The LMSL value of 1.158 m relative to the 1983-2001 National Tidal Datum Epoch (NTDE) was adopted at this bench mark as the fixed height from which all other PRVD02 heights on Mona are referenced.

## Leveling to Create and Expand the New Datum

*North Line*

Reconnaissance and mark setting operations for the north line on the island of Puerto Rico began

[1] Permanent Identifier.

**Figure 4.** Tide gauge (NWLON site #9752695) Esperanza, Vieques.

**Figure 6.** Tide gauge (NWLON site #9759938) Mona Island.

**Figure 5.** Tide gauge (NWLON site #9752235) Culebra.

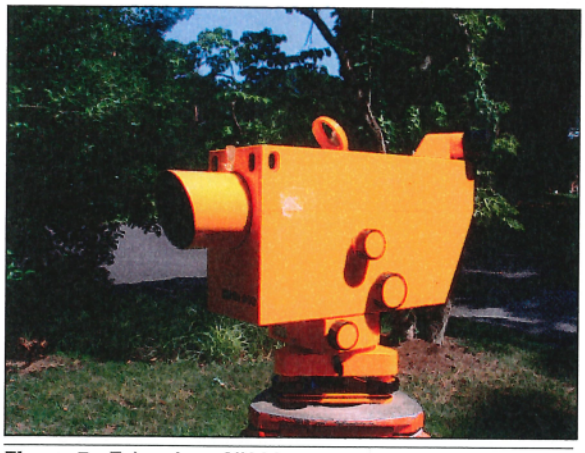

**Figure 7.** Zeiss-Jena Ni002.

on January 24, 2002. All leveling was performed to First-Order Class II specifications, double run using a Zeiss-Jena Ni002 (Figure 7) compensating optical micrometer level and 3-m calibrated, single piece, ½ cm graduated invar level rods. Starting from the tide gauge at La Puntilla located at the U.S. Coast Guard facility and winding through old town San Juan, the level line generally followed highways 22 and 2 west. Near the town of Barceloneta, the level line temporarily left highway 22 and followed highways 684, 681, 2, and 10, before returning to highway 22 near Arecibo. Initial leveling operations were finalized on May 3, 2002, terminating at the existing tidal BMs at Crash Boat Dock north of the town of Aguadilla, which had been set by CO-OPS in 1975 (Station # 9759412). Unfortunately, the stability of the 1975 tidal data was highly suspect and never computed by CO-OPS, so a validation of the determination of LMSL on the western end of the island was not possible. Total leveling (double-run) amounted to approximately 325 km in 5,292 setups, connecting 105 new and 58 previously-established control moments.

Publication of the final PRVD02 heights was delayed slightly, awaiting the completion of the national readjustment of the NTDE by CO-OPS. Fixing the LMSL height of the primary bench mark at the La Puntilla tide gauge at the new tidal epoch ensured the definition of PRVD02 was directly linked to LMSL, until the next readjustment of the NTDE in approximately 20 years.

*Expansion Beyond the North Line*

For the next few years, PRVD02 was only accessible via bench marks along the north line of the island, though without a publicly available definition documentation (e.g., this paper).

After a lengthy review process in October 2005, NGS selected the firms of Javier E. Bidot & Associates (JEB), located in Caguas, and RLDA Surveying & Mapping from San Juan, to perform the

geodetic mark setting and leveling operations. Field and office employees of both companies participated in a two-day geodetic leveling workshop conducted by NGS and hosted by CIAPR at their facility in San Juan in October 2007 (Figures 8-10). After the training seminar, both companies dispatched their leveling teams to perform a test of their procedures against several existing marks from the existing PRVD02 network. Both crews passed their tests.

Having completed the NGS training, both firms were prepared to begin leveling operations. After considering several alternatives, NGS technical staff decided to provide similar task orders to each company consisting of lines of approximately 30 km. Because the existing network would not provide any loop closures until the completion of several hundred kilometers of leveling, it was decided that two lines of modest length would provide the contractors an opportunity to establish their ability to conduct the work in a manner consistent with the highest standards required to define the datum. Assuming a successful completion of these initial lines (as reviewed by NGS), the subsequent lines would be of considerably longer length, in the range of 100 to 130 km. The initial task orders instructed JEB to start in San Juan in the vicinity of the Luis Muñoz Marin International Airport, proceed eastward along Route A-26 to the intersection with Route 3, and continue west to the boundary between the municipalities of Rio Grande and Luquillo. The other line, to be observed by RLDA, would begin near Aguadilla at the end of the 2002 line and proceed south along Route 2 to Mayagüez to tie to the existing tidal BMs at the Mayaguez NWLON tide gauge site (#9759394). This tide station had recently been reinstalled by the UPRM Department of Geology as part of the Puerto Rico Seismic Network (PRSN). Additional PRSN stations were eventually tied to the leveling network as the contract work progressed.

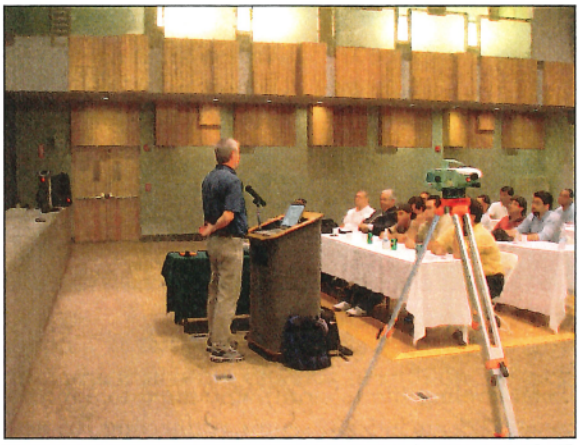

**Figure 8.** Curt Smith, NGS instructing.

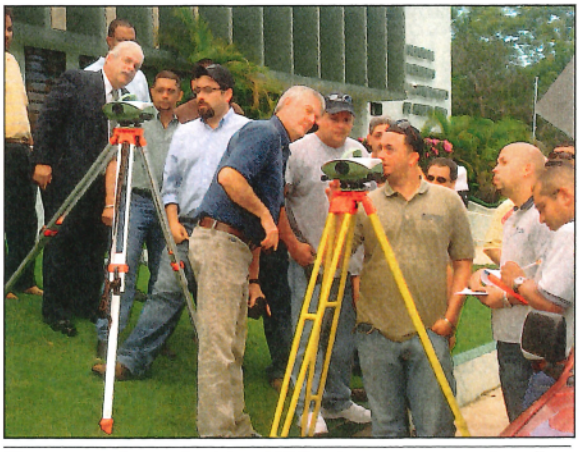

**Figure 9.** Curt Smith, NGS demonstrates leveling techniques.

**Figure 10.** Contractors practice proper procedures.

New BMs were set by the contractors following NGS specifications, during November 2007 to early January 2008. All new marks are standard NGS vertical control markers set in bedrock; stable concrete structures, such as bridge abutments; or are poured-in-place concrete posts. NGS decided to not require the contractors to set stainless steel rod marks driven to refusal, due to the excessive costs, training of the contract crews, and the lack of frost heave in Puerto Rico. (Resisting frost heave is a prime advantage of this type of marker.) Where possible and practical, the contractors were directed to tie to existing marks of others Federal and local agencies, such as USGS and USACE. Progress by the contractors continued to improve as their field units

developed a greater knowledge of the procedures required to perform First-Order leveling. During 2009, the contract team made a connection to the second CO-OPS long-term tide gauge located at Magueyes Island (NWLON Station #9759110), which included a short, but difficult, water crossing observation. The team from JEB eventually completed the first loop closure: the line from San Juan to Rio Grande to Ceiba to Humacao to Caguas and returning to San Juan.

Leveling was complete on the main island on January 27, 2012; on Culebra on March 5, 2011; on Vieques on February 4, 2012; and on Mona (using CO-OPS data only) on January 24, 2012. Once the data were all turned in and checked, various adjustments of the leveling data were performed in order to determine whether the north line would stand as published or whether it would need to be recomputed (with the possibility of a new datum being defined). However, the quality of the leveling and the general lack of vertical motion along the north line yielded results which indicated that the north line would stand, and PRVD02 would simply be expanded by the new leveling, without the need to define a new datum. Of the 163 bench marks on the north line with published PRVD02 heights since 2002, only four showed definitive vertical motion by 2012. As such, those points were given newly computed heights, but the rest of the line was held at their fixed values.

Statistically speaking, aside from the four points which showed clear vertical motion, the differences between the existing PRVD02 heights and those generated by a new adjustment of all leveling on the main island (holding the same datum origin point fixed as before) had only a 2.9 mm average, with a standard deviation of 1.3 mm. These small differences were viewed as the primary reason not to change the published heights from the 2002 values. As such, based on the above data, a decision was made not to readjust the PRVD02 north line, but rather to hold this data fixed (except in the case of four points that had proven vertical motion) and use least squares adjustment techniques only to expand PRVD02 along the post 2002 leveling lines on the main island. For the other three islands, there were no existing PRVD02 heights prior to the 2013 adjustment, so all published heights on those islands are entirely new.

In August of 2013, all adjustments of leveling data on all four islands of PRVD02 were finalized and the heights made available in the NGS Integrated Database through NGS datasheets.

## Summary

A comprehensive vertical datum covering the four primary islands of Puerto Rico has been defined by the National Geodetic Survey and adopted by the Federal Geodetic Control Subcommittee (see Federal Register Notice 2012-17600) as an expansion of the National Spatial Reference System. This new datum is collectively known as the Puerto Rico Vertical Datum of 2002. This datum has been available (along the north line of the main island only) since 2002. However, the entire leveling network has been expanded since then, and NGS did not issue a definitional document for PRVD02 with its original release. Now that the leveling is complete, adjusted and checked, and PRVD02 has been fully expanded to four islands, this document contains all of the necessary information to describe the vertical datum in its entirety. Thankfully, aside from four points that had proven vertical motion, the entire "north line" of PRVD02 was deemed stable and the newly published heights on the rest of the main island as well as the three other islands of Culebra, Vieques and Mona are merely expansions of the existing PRVD02 and not a replacement of it.

## ACKNOWLEDGMENTS

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