

Grids & Datums

ELEVATIONS IN SOUTH LOUISIANA

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During the summer of 2006, the U.S. Army Corps of Engineers – New Orleans District asked me to write answers for some Frequently Asked Questions (FAQs) for their Engineering Staff. These answers are specifically targeted toward the problem of using elevations in a rapidly-subsiding region that had been devastated by the Katrina and Rita hurricanes of 2005. Rebuilding efforts are directly dependant on an understanding of the inherent problems in the reliable determination of current elevations referenced to our National Geodetic Vertical Datum of 1988 (NAVD88) for South Louisiana. The U.S. Army Corps of Engineers – New Orleans District covers an area that is approximately the southern half of the state, from the City of Alexandria, Louisiana south to the coast, and from the Mississippi State Line to the Texas State Line.

Is NGVD29 the Same as Mean Sea Level?

No, it is not. Once thought to be close to Mean Sea Level (MSL), it was within a couple of feet for most of the northern rim of the Gulf of Mexico. The original datum was called the “Sea Level Datum of 1929,” and it was the first vertical (elevation) datum for an entire continent in the history of the world. With observations that started in the 19th century, a series of 26 Tide Gauges were recorded for over 19 years to establish Local Mean Sea Level (LMSL) for all of the coasts of the United States. However, since LMSL varies from place to place due not only from astronomical phenomena but also due to local winds, river stages, storms, and local gravity ... LMSL was not equal to “0.00 ft” everywhere. They needed “zero” to be somewhere, so they picked Galveston, Texas as the “Primary Benchmark of the United States,” and LMSL there was equal to “0.00 ft.” That elevation of the mean sea in Galveston was within a couple of feet or so to what it was in Biloxi, Mississippi where the closest Tide Gauge was to New Orleans, back in the late 19th and early 20th centuries. In an attempt to avoid confusion, the name of the “Sea Level Datum of 1929” was changed in 1972 to the “National Geodetic Vertical Datum of 1929,” or NGVD29. No computations were performed, and no observations were made.

How Do I Convert Old Surveys to NAVD88?

The only way to accomplish that in the 21st century is to re-observe each and every benchmark used for an old survey of interest. There is absolutely no way to compute it; there are no computer programs that are reliable for such a conversion; old benchmarks must be re-occupied to perform a re-determination of the current elevation of

the mark. Many parts of the United States are areas of relatively stable elevations. Everywhere in the State of Louisiana is an area of crustal motion – we subside different amounts in different places and at different times! The speed at which we subside changes at the same spot, and the speed of subsidence differs from spot to spot. We are unable to predict crustal motion exactly, whether it’s in Louisiana, Tokyo, or Southern California.

To obtain a current elevation at an arbitrary spot or at a benchmark in Louisiana, the procedure requires the services of a Registered Land Surveyor that uses a geodetic-quality, dual-frequency survey-grade GPS receiver with a ground plane antenna and fixed-height tripod. That type of contraption is very different from the GPS receivers one can purchase at a department store or fishing and sporting goods emporium.

“In metropolitan New Orleans, we sink approximately 3 feet per century or about 1 inch every 2 ½ years. Along the Louisiana coast, some areas are subsiding at the rate of 6 feet per century or 1 inch per year!”

When the North American Datum of 1988 (NAVD88) was published for South Louisiana in 1992, some benchmarks that had NGVD29 values were included in the short list of benchmarks that had new NAVD88 elevations. For a few years, a computer program called VERTCON, sometimes used within another program called CORPSCON, was used to convert those specific areas from one old datum to the new datum. That relation is no longer possible, since the surface of the Earth has changed so substantially since then due to subsidence. If that software is used for South Louisiana during the 21st century, the answers are guaranteed to be wrong.

What is CORS?

CORS is the acronym for a GPS “Continuously Operating Reference Station.” Originally established in the United States by the U.S. Coast Guard to provide a precise positional reference for shipboard navigators, the system has become popular with Land Surveyors, Engineers, and Geologists that research the movements of the Earth’s continental plates. Congress asked for a solution to improve the way **reliable** el-

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evations and heights were being determined in the United States, and the National Geodetic Survey responded with a proposal for a Height Modernization Program to utilize GPS CORS sites as the basic elevation reference tool for the 21st century. Around the same time, the U.S.S.R. fell with the Iron Curtain, and the U.S. Department of Defense began to de-classify the secret gravity model of the Earth that had been used for targeting Inter-continental Ballistic Missiles. That secret gravity model is now available to the general public, and it is one of the key components of the National Height Modernization Program. Since GPS does not provide elevations, the gravity model termed the "Geoid" is the connection between GPS heights and elevations. Useful for most areas of the world, the Geoid has been specifically refined and its accuracy enhanced for the United States. In fact, it is especially precise for the State of Louisiana because it represents the only way we can obtain current, up-to-date elevations! Using the CORS with the latest version of the Geoid is how Land Surveyors and Engineers are now obtaining reliable, current elevations for the rebuilding of the areas devastated by Katrina and Rita.

The old way of doing things was based on "spirit leveling," which had its roots in the old surveys of the Babylonians, dating back some 3,000+ years. When the government establishes the elevation of a Benchmark, that elevation is good as long as the Benchmark does not move up or down. Louisiana is subsiding, and Benchmarks become useless because they do not keep their elevations for more than a few years at best, some only for a year when located near the coast! The CORS sites have GPS antennae bolted to buildings and structures in Louisiana. As the ground and the buildings subside, so does the antenna such that the reference elevation is computed and re-determined every few days - the value is always up-to-date!

Why Did We Switch from NGVD29 to NAVD88?

Revolutionary in 1929, the old way of doing things has been improved with research in geodesy, as well as the fact that some areas of the country's topography have changed since then. NGVD29 was based on what is called a "constrained least-squares network adjustment." Since that original system was devised, our knowledge of the Earth's crust has increased such that we can now measure tiny incremental changes in our system of elevation benchmarks. New surveys have become increasingly difficult to "fit" into the old system without warping the new observations as they are forced to be compatible with the old values. A study by the National Academy of Sciences found that the old system of NGVD29 had deteriorated to become an incompatible reference system, and that the North American Continent needed to start all over again with something better. The new North American Vertical Datum of 1988 is a great improvement over its predecessor in terms of mathematical techniques employed as well as being based on the Earth's *observed* gravity field. NAVD88 is compatible in principle with the Geoid, the mathematical system of describing the relation of the Earth's gravity field to elevations.

Why Did the Elevations Change When we Switched to NAVD88?

Actually, elevations of benchmarks have been changing for decades while we were still using the NGVD29 system. Each time Federal surveyors would come through Louisiana to re-observe benchmarks, a new "epoch" of benchmark elevations would be published by the National

Geodetic Survey. With time, we discovered that the methodology was flawed because local benchmarks in the region were used as starting points, and their old elevations were used for the new surveys. Since those starting points had also subsided but were forced to retain the same old elevations; each new survey provided different elevation values that were subsequently warped more and more. With the new adjustment of the NAVD88, warps and the forcing of new surveys to fit old surveys are no longer done. The new elevations were compatible with each other when published in Louisiana in 1992, and although the original NAVD88 values are no longer valid (because of subsidence), the system of GPS CORS sites in Louisiana now allow elevation surveys to remain current as they are observed.

Did we Sink that Much?

In metropolitan New Orleans, we sink approximately 3 feet per century or about 1 inch every 2 ½ years. Along the Louisiana coast, some areas are subsiding at the rate of 6 feet per century or 1 inch per year! We will continue to subside, but for different amounts in different places. Research at Louisiana State University has discovered that the rates of subsidence are not constant, but appear to be episodic in some areas. That applies to both the surface-related differential subsidence that is due to the local soil conditions as well as to the deep-seated subsidence that appears due to consolidation of deltaic materials, the presence of geologic faults, and the bending of the lithosphere (the Earth's crust) due to the sheer weight of the deltaic overburden.

Can't I Use CorpsCon to Convert from NGVD29 to NAVD88?

In Missouri, yes; but in Louisiana, absolutely NOT! The NAVD88 was developed as a replacement for the NGVD29 because the NGVD29 had become unreliable and out-of-date. The NAVD88 was published for most of the country by 1990, except for those regions of known crustal motion which included Louisiana. In 1992, the NAVD88 was published for Louisiana, but because of the continuing crustal motion of subsidence the "lifespan" of the NAVD88 benchmark elevations in Louisiana was limited to a few years. CorpsCon uses the data files developed for VertCon by the National Geodetic Survey. The data files represent a snapshot in time for the instant when the NAVD88 was *first* published for Louisiana. Those data files are static; they do not change, and they only represent the differences in elevations at certain benchmarks in Louisiana in 1992. Using CorpsCon and/or VertCon in Louisiana in the 21st century will provide conversions that are **at least 6 inches in error**, an amount that is not acceptable for Engineering applications.

What is the Conversion from NGVD29 to NAVD88?

Because of crustal motion in Louisiana, such a determination is impossible in the 21st century. Subsidence due to crustal motion is a fact in the Lower Mississippi Valley, and research at Louisiana State University has shown that NAVD88 elevations as far north as Memphis, Tennessee are now in error by **at least 0.20 foot** since the new datum was published in 1990.

What is the Conversion from MLG to NAVD88?

The relation varies from place to place and from time to time, because Mean Low Gulf is a Hydrographic Tidal Datum that is based on astronomical tides, prevailing winds, prevailing currents, and the variation in flow of the Mississippi River. NAVD88 is a Geodetic Datum

that is based on the current gravity field of the Earth (as realized in this context) in the Louisiana littoral zone. Both datums vary in time and in place, both collectively and individually. As of June 2006, the only locations where the conversion between MLG and NAVD88 have been preliminarily determined by NOAA CO-OPS have been at (Rigolets 0.118 ft. - 0.78 ft = -0.662 ft NAVD88), at New Canal (17th Street Canal 0.252 ft - 0.78 ft = -0.528 ft NAVD88), and at (East Bank, Bayou Labranche 0.407 ft - 0.78 ft = -0.373 ft), all points being on the south shore of Lake Pontchartrain.

Can I Get a Gauge Set to MLG?

Yes, but it will require the erection of a short-term continuously recording tide gauge to determine the local realization of Mean Low Gulf. How long an observation period needs to be occupied depends on the accuracy needed for the determination as well as the distance from a permanent tide gauge reference station. For the eastern part of Louisiana, the Waveland, Mississippi Tide Gauge is commonly used. As one goes further west, other gauges will necessarily be required and the period of occupation may vary concomitantly.

What is an Epoch?

An epoch is a time stamp that is associated with a group of benchmarks that have been observed and adjusted on a particular date. That epoch also refers to any engineering or construction work designed and/or built based on those published benchmark values. Because all of the New Orleans District is in a crustal motion zone, every benchmark has a limited lifespan because its elevation will be valid *only* for a limited amount of time. The same phenomenon affected old benchmarks published on the NGVD29, and Land Surveyors were aware that it was impossible to run differential spirit levels from a benchmark published on one epoch to another benchmark published on a different epoch. The same rule holds today, except that based on recent research at LSU and published in NOAA NGS TR 50; the *actual* rates of subsidence are now recognized as they vary across the New Orleans District. The only way to avoid epochs in determining elevations in the New Orleans District is to use GPS Leveling techniques based on the LSU system of GulfNet Continuously Operating Reference Stations (CORS). However, each point that has an elevation determined by GPS Leveling will itself have an epoch based on the date of that determination. That point will subside with time and will need re-determination based on local vertical velocities.

NGVD29 Epochs in Southeast Louisiana:

- 1938 - adjustment based on SLD 1929
- 1951 - adjusted forward in time to 1955
- 1955 - tied to Morgan City and Mobile ('29)
- 1963 - tied to Norco well ('29 value)
- 1968 - tied to '63 lines
- 1976 - tied to Index, AR. and Logtown, MS.
- 1984 - Orleans and Plaquemines Parishes tied to Waggaman and Rigolets '76 values.
- 1986 - Jefferson and St. Bernard Parishes tied to '84 values.

NAVD88 Epochs in Louisiana:

- 1992 - Original adjustment
- 1994 - Observations in Orleans Parish
- 2004.65 - Adjustment to GPS observations to validate NGS TR 50 subsidence rates.

Why Doesn't my Benchmark Show Up on the NGS WebSite?

There are several reasons why this can occur. 1.) A particular "benchmark" was never part of the National Spatial Reference System (NSRS) to begin with. Perhaps another federal agency, even the U.S. Army Corps of Engineers, established the elevation of a benchmark but did not "bluebook" the observations and descriptions nor submit the data to the National Geodetic Survey for incorporation into the NSRS. 2.) A benchmark was originally published on the NGVD29, but was not included in the readjustment to the NAVD88 because it was not observed (re-leveled) in South Louisiana during the 1980s through the early 1990s. 3.) The published elevation has been deemed by the National Geodetic Survey to be unreliable and has been "pulled" from the published records in 2006. Dokka and Shinkle published NOAA NGS TR 50 that predicted subsidence rates of several thousand First-Order benchmarks in Louisiana, Mississippi, and Alabama. During 2004, geodetic survey crews of the NGS and of LSU observed elevations of 99 selected benchmarks in South Louisiana to verify the predicted subsidence rates listed in NOAA NGS TR 50. That collection of 99 rapidly-subsiding benchmarks has now been the only benchmarks remaining to be published for South Louisiana, and their subsidence rates have been validated by direct observation with GPS Leveling techniques. Those 99 benchmarks are the only benchmarks that are expected to be maintained by the National Geodetic Survey and the Louisiana Spatial Reference Center of LSU. The published epoch of those 99 benchmarks is termed "2004.65."

Why is the Elevation Rounded to the 0.1 Foot on the DataSheet?

The benchmark has been updated to a current elevation using GPS Leveling techniques. Since the elevation is reported to the closest 0.1 foot, then that published value is considered accurate to within one-half of that tenth of a foot, or ± 0.05 foot. The benchmark has been updated to a GPS Leveling vertical accuracy criterion of ± 2 centimeters. That corresponds to ± 0.06 foot, which will round off to a value of 0.1 foot.

My Handheld GPS Gives me Bad Elevations. Why?

All GPS receivers provide ellipsoid heights; they do NOT provide elevations. The difference between zero elevation on the North American Datum of 1988 (NAVD88) and zero ellipsoid height for South Louisiana is about *twenty-seven meters* = 88.5 feet. Handheld GPS receivers (consumer grade), receive single frequency *Coarse Acquisition* code (CA code), where with *Selective Availability* turned off, has a nominal positional accuracy under good conditions of about ± 15 feet. Since the vertical accuracy of GPS receivers is about seven times worse than horizontal positions, $15 \times 7 = 105$ feet + 88.5 feet = ± 194 feet vertical accuracy under good conditions! That's not bad for a \$99 GPS receiver. For about \$30,000 one can purchase a dual-frequency geodetic-quality GPS receiver that can provide ± 2 centimeter accuracy over two days' observations of at least 30 minutes each day, depending on baseline length. Of course, post-processing will require additional computer time to reduce the observed ellipsoid height to an elevation referenced to NAVD88. That is not possible with a handheld GPS receiver.

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Why Do We Keep Changing the Benchmark Elevations?

The elevations of all benchmarks in the New Orleans District are constantly changing as we subside or sink. They change at varying rates from perhaps 10 mm/year to over 27 mm/yr. That corresponds from 1 inch every 2½ years to 1 inch every year, and at times even more than that! Since we are concerned about where we are with respect to the water around us, it only takes a few years for the accumulation of subsidence rates to sizeable amounts that adversely affect our engineering designs and our constructed works. We don't change the elevations, the elevations change on us!

Is GPS More Accurate than Levels?

ac·cu·rate (ăk'yər-īt) **1.** In exact conformity to fact: ERRORLESS.

Yes, GPS is more accurate than levels. The reason for that is because the accuracy criterion for First-Order Geodetic Leveling is an error of closure of ($\pm 3\text{mm} \sqrt{\text{km}}$). To achieve accurate leveling results in the New Orleans District *better than the capability of GPS*, it would therefore be necessary to start at an accurate benchmark within 28 miles of the eastern border of Louisiana. However, research at LSU has proven that the closest accurate (*reliable*) benchmark to Louisiana is east of Mobile Bay, Alabama! Therefore, GPS is more accurate than levels in the New Orleans District, because of subsidence. There are no accurate benchmarks close enough to the New Orleans District to allow leveling results equal to or better than what is possible on a day-to-day basis with dual-frequency GPS receivers.

What is MLLW and How Do I use It?

Mean Lower Low Water is a hydrographic datum and is dependent on locality. Since tidal regimes vary with river stages, weather, prevailing winds, currents, etc., the relation of MLLW to NAVD88 changes from place to place. MLLW is commonly associated with Mean Low Gulf (MLG).

Who Else Has Subsidence Problems (Texas?) and What are They Doing About It?

The Harris-Galveston Subsidence District (metro Houston) has severe subsidence problems that originate from copious groundwater pumping. The U.S. Army Corps of Engineers Reservoir at Addicks (West Houston) subsides at approximately 27mm/year! There are a series of ordinances that attempt to moderate the subsidence through rationing the amount of groundwater takeoff, and there has been some success in decreasing the subsidence rates. However, faults still account for some subsidence, and there seems to be less coordination of subsidence monitoring and publication of benchmark epochs in Houston than in the New Orleans District.



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