GEODETIC PROGRAMS NEEDS OF

LOUISIANA AND WISCONSIN

Report to Congress

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service
National Geodetic Survey

August 2001

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EXECUTIVE SUMMARY

DIRECTION FROM CONGRESS

This document was prepared in response to the direction contained in House Report 107-139 (to accompany H.R. 2500 - Departments of Commerce, Justice, and State, the Judiciary, and Related Agencies Appropriations Bill, Fiscal Year 2002) that the National Oceanic and Atmospheric Administration (NOAA) "... *is directed to work with the states of Louisiana and Wisconsin to assess their requirements for similar [NOAA Geodesy] programs and report back to the Committee by September 15, 2001."* This report assesses the requirements and potential benefits of Louisiana and Wisconsin participating in the National Height Modernization System and geodetic spatial reference programs.

OVERVIEW

Height Modernization Study to Height Modernization System

Height modernization is an effort, led by the National Geodetic Survey (NGS), to enhance the vertical component of the National Spatial Reference System (NSRS). NSRS is a consistent national reference framework that specifies latitude, longitude, height (elevation), scale, gravity, and orientation throughout the United States, as well as how these values change with time. NSRS provides accurate knowledge of the size, shape, and position of our environment, as seen daily in the construction and safety of roads and buildings, the transportation of goods and people by car, ship or plane, as well as in the monitoring and protecting of our environment. Height modernization includes a series of activities designed to advance and promote the determination of high accuracy elevations through the use of Global Positioning System (GPS) surveying, rather than by classical line-of-sight leveling.

In 1998, the United States Congress directed NGS, an office within the National Ocean Service of NOAA, to conduct a National Height Modernization Study[1] to determine the effectiveness of height modernization in California and North Carolina. Major findings of the study concluded that the height modernization needs that could benefit all states are:

[1] U.S. Department of Commerce, June 1998, **National Height Modernization Study**, Report to Congress.

- A reliable, cost-effective, standardized, legally established national vertical reference datum (i.e., North American Vertical Datum of 1988 (NAVD 88)) and the infrastructure (i.e., NSRS) through which to access and utilize it.

- The capability to easily interrelate the many vertical datums currently in existence, but particularly with respect to a standardized national vertical reference datum (coordinate system).

- National technical standards and guidelines for using GPS to determine heights.

The study addressed the national need for and benefits to be derived from enhancing the vertical component of NSRS, while focusing specifically on the states of California and North Carolina. In Fiscal Year (FY) 2000, NGS received funding "for initial planning of the National Height Modernization System Demonstration, based on the recommendations contained in the National Height Modernization Study, in California and North Carolina." NGS received additional funding in FY 2001 in support of height modernization activities in California and North Carolina. In California, the California Reference Spatial Center (CSRC) was created. The CSRC offers a state-of-the-art position and height system to aid public health and safety, preservation of valuable resources, and improved business productivity. In North Carolina, four urban areas will soon receive height modernization surveys, conducted through contracts with the private sector, that will modernize their transportation, land survey, and emergency response systems. This funding has led to the implementation of the National Height Modernization Study and the development of a height modernization system in these states.

Assessment of Louisiana and Wisconsin

Rapid land loss and continuous elevation (height) changes in Louisiana require a well-managed and monitored federal/state geodetic control network to protect the environment, ensure safety of its citizens, and enhance prosperity within the state. Currently, 25 to 35 square miles of wetland per year are lost in Louisiana due to ground subsidence (sinking of the land) and coastal erosion.[2] Cities and cultures are at risk of losing their

[2]Louisiana Coastal Wetlands Conservation and Restoration Task Force and Wetlands Conservation and Restoration Authority, 1998, **Coast 2050: Toward a Sustainable Coastal Louisiana**, Executive Summary, Louisiana Department of Natural Resources.

land and having to relocate. Flooding and sea level rise threaten the coastal region, most of which is only three feet above sea level. Flood plain models and evacuation plans, developed using outdated elevations, put the citizens of the low-lying areas at great risk during heavy rains. The current available geodetic control does not support the state's needs to evaluate and manage the changes in its environment and the impact on its economy and ecosystem. Problems with historic surveys, land movement, and sea level rise have made the current vertical geodetic control in Louisiana obsolete, inaccurate, and unable to ensure safety.

In Wisconsin, the existing federal/state geodetic control network simply does not support today's design and construction projects. Land in Wisconsin is susceptible to frost heave (uplifting of land) and post-glacial rebound (rising of the Earth's surface). As the land moves, often the survey monuments move, making the previously determined height information for the points inaccurate. Additionally, in most parts of the state, 50 percent or more of all bench marks have been destroyed due to construction and land development activities. The critical nature of the shortfall of accurate geodetic control, especially vertical control, prompted the Wisconsin Land Information Board to establish a State Elevation Data Task Force to assess the needs and uses for vertical control and directly address the deficiencies. National, state, and local agencies, as well as the private sector, need consistent and accurate geodetic control for use in highway and land development, monitoring and modeling of shoreline and flood plains, and safe and economical transportation of goods.

Process of Assessment

This report identifies and documents the user requirements in Louisiana and Wisconsin for height information, including those requirements utilizing both horizontal and vertical data. To identify and document this information, a two-step process was followed. First, the NGS state advisor and NOAA program coordinator in Louisiana and the NGS state advisor in Wisconsin contacted the users within their state and documented their input. Next, NGS conducted user forums on August 8 in Madison, Wisconsin, and on August 13 in Baton Rouge, Louisiana, to obtain further insights and recommendations from state and local governments, the private sector, and the academic community. Due to the short time frame for completing the report, NGS believes Louisiana and Wisconsin are in general agreement with our assessments, however, the states did not have the opportunity to review and comment on the report.

FINDINGS

Based on the above information which was analyzed by NGS, it has been determined that participation by Louisiana and Wisconsin in the National Height Modernization System could result in:

- improved disaster preparedness;
- accurate digital elevation models, enabling better flood plain analysis and determination of flood plain needs;
- improved coastal and harbor navigation, enabling safer and more cost-effective shipment of goods;
- improved aircraft navigational aids, and safer approach and landing procedures;
- accurate determination of coastal erosion rates and flood plain boundaries;
- advanced surface transportation control and monitoring;
- improved land and marine geographic information systems (GIS) and assessment of environmental effects on regions influenced by water level changes;
- enhanced agricultural practices resulting in reduced run-off water pollution;
- more efficient fish farming, including crawfish farming;
- infrastructure monitoring of subsidence and erosion;
- better management of natural resources through the use of reliable GIS;
- improved understanding of tectonic movement; and
- significant time and cost savings in field surveying.

Both Louisiana and Wisconsin require improved vertical geodetic control that would make possible the applications and benefits listed above. They each have unique geophysical situations that represent problems specific to their regions that would be improved through participation in the National Height Modernization System.

RECOMMENDATIONS

The report clearly identified the need for height modernization in Louisiana and Wisconsin. Based on our assessment of their needs, NGS provides the following recommendations:

Louisiana

1. **Perform additional GPS measurements and leveling on bench marks to establish the basic framework of survey points needed to support height modernization in Louisiana as recommended in the 1998 National Height Modernization Study.** The framework, designed specifically to meet Louisiana’s needs, would be funded through outside sources and grants and would provide

accurate, reliable, and consistent height information referenced to NAVD 88 to be included in NSRS.

2. **Expand the current network of CORS and explore the use of additional height monitoring stations (i.e, Port-A-Measures (PAMs) and extensometers) in Louisiana.** The combination of CORS throughout the state and mobile and stationary height monitoring stations concentrated in subsidence areas together provide an accurate statewide height monitoring system referenced to the highly accurate National CORS network.

3. **Establish a Louisiana Spatial Reference Center (LASRC).** Like California, Louisiana does not have a state agency coordinating efforts to improve the geodetic reference frame and requires a Spatial Reference Center to work in conjunction with NGS to support height modernization within the state.

Wisconsin

1. **Accelerate the Wisconsin Height Modernization Program (WI-HMP) from ten to five years. Analyze data collected in the early phases of the WI-HMP to determine possible modifications to field procedures and the design of the program.** Specifically, assess the amount of leveling to be completed and the current specifications and guidelines of the field observations to ensure accurate, yet economic, development of height modernization.

2. **Promote Wisconsin as a role model and trainer in height modernization.** Since Wisconsin's height modernization effort is already underway, the state would be in a position to advise neighboring states in the development and uses of height modernization. Transfer of technology through NGS with Wisconsin as a regional leader could help address the entire region's economic and environmental issues.

3. **Investigate opportunities for additional funding for the height modernization in Wisconsin.** Additional resources would result in more outsourcing opportunities, as well as technology transfer, to private surveyors.

GEODETIC PROGRAM NEEDS OF LOUISIANA AND WISCONSIN

REQUIREMENT FOR THE REPORT

This report was prepared in response to the direction contained in House Report 107-139, to accompany H.R. 2500, Departments of Commerce, Justice, and State, the Judiciary, and Related Agencies Appropriations Bill for Fiscal Year 2002, that the National Oceanic and Atmospheric Administration (NOAA) "... *is directed to work with the states of Louisiana and Wisconsin to assess their requirements for similar [NOAA Geodesy] programs and report back to the Committee by September 15, 2001."* This report assesses the requirements and potential benefits of Louisiana and Wisconsin participating in the National Height Modernization System and geodetic spatial reference programs.

INTRODUCTION

The National Geodetic Survey (NGS), an office within the National Ocean Service of NOAA, is responsible for managing the National Spatial Reference System (NSRS), a consistent national reference framework that specifies latitude, longitude, height, scale, gravity, and orientation throughout the United States, as well as how these values change with time. NSRS provides accurate knowledge of the size, shape, and position of our environment, as seen daily in the construction and safety of roads and buildings, the transportation of goods and people by car, ship or plane, as well as in the monitoring and protecting of our environment.

Prior to 1983, NGS relied on classical line-of-sight survey measurements to establish the national reference framework. Full-scale development of the Global Positioning System (GPS) which began with the launching of four satellites in 1979, enabled positioning without the need to see between the points being surveyed. Today, GPS is a constellation of 24 satellites that transmit signals to GPS receivers all over the world. Using GPS, a survey that once took days to complete now can be done in a few hours at a much lower cost. Modern technology and "real-time" positioning techniques are continuously being developed for modern day challenges and applications.

NGS, through the use of GPS, has completed the major portion of the horizontal (latitude/longitude) component of NSRS. The vertical

component of NSRS still requires better accuracy and modernization through the use of GPS technology.

Height modernization is an effort, led by NGS, to enhance the vertical component of NSRS. Height modernization includes a series of activities designed to advance and promote the precise determination of heights (elevations) of the land through the use of GPS surveying. These activities include:

- research and development activities seeking to improve the determination of heights (elevations) by GPS surveys;
- improvements in the accuracy of geoid heights [Geoid models are derived from measurements of the Earth's gravity field and are important in translating GPS heights to orthometric heights (heights above mean sea level)];
- the development of technical standards and guidelines for using GPS to determine heights;
- technical advice, aid with planning GPS height surveys, workshops, and other training forums to educate the surveying community; and
- funds provided by Congress for grants to appropriate partners that wish to implement height modernization in their jurisdictions.

In 1998, the United States Congress directed NGS, an office within the National Ocean Service to conduct a National Height Modernization Study to determine the effectiveness of height modernization in California and North Carolina. Major findings of the study concluded that the height modernization needs that could benefit all states are:

- A reliable, cost-effective, standardized, legally established national vertical reference datum (i.e., North American Vertical Datum of 1988 (NAVD 88)) and the infrastructure (i.e., NSRS) through which to access and utilize it.

- The capability to easily interrelate the many vertical datums currently in existence, but particularly with respect to a standardized national vertical reference datum (coordinate system).

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The study addressed the national need for and benefits to be derived from enhancing the vertical component of NSRS, while focusing specifically on the states of California and North Carolina. In Fiscal Year (FY) 2000, NGS received funding "for

initial planning of the National Height Modernization System Demonstration, based on the recommendations contained in the National Height Modernization Study (NHMS), in California and North Carolina." NGS received additional funding in FY 2001 in support of height modernization activities in California and North Carolina. This funding has led to the implementation of the National Height Modernization Study and the development of a height modernization system in these states.

In California, the California Reference Spatial Center (CSRC) was created. The CSRC offers a state-of-the-art position and height system to aid public health and safety, preservation of valuable resources, and improved business productivity. The CSRC has established a Coordinating Council, adopted a constitution and bylaws, and currently is developing a master plan to design and document the proposed development of the California Spatial Reference System geodetic control network. Current projects of the CSRC include:

- development of a full-service data portal for Continuously Operating Reference Station (CORS) data;
- provision of NAVD 88 heights for all California CORS;
- addition of a real-time GPS infrastructure to the existing San Francisco Bay Height Modernization demonstration project network; and
- exploration of the use of Interferometric Synthetic Aperture Radar for monitoring land subsidence (sinking of land).

In North Carolina, four urban areas will soon receive height modernization surveys, conducted through contracts with the private sector, that will modernize their transportation, land survey, and emergency response systems. Contractor selection is currently underway. In addition, the initial groundwork for the height modernization surveys is complete with the incorporation of four additional CORS into the National CORS system and the conclusion of the field observations for the Federal Base Network (FBN)/Cooperative Base Network (CBN) survey in North Carolina.

This report focuses on the states of Louisiana and Wisconsin and their requirements for similar programs to advance and promote the enhancement of NSRS, focusing on the vertical component, through the use of GPS technology.

Geodetic control is a highly accurate, consistent, and reliable set of information about the locations (latitude/longitude), heights (relative to a common point), and characteristics of points (stations) within an area. NSRS is the Nation's geodetic control framework. It is this geodetic control (precisely determined

positions) that serves as the basis for all other mapping, construction, transportation, agricultural, and public safety industries. Without geodetic control, correct locations, distances, and directions between places are impossible.

Ground subsidence and the resulting loss of land are critical issues in Louisiana and other states along the Gulf of Mexico. Subsidence, the sinking of land primarily caused by the withdrawal of groundwater from below the Earth's surface, can fracture roads and building foundations and can burst water, sewer, and gas lines. It is of particular concern to coastal areas where sea level rise is a real threat. Without accurate monitoring of subsidence, it is impossible to accurately gauge sea level rise and its potential impacts. Establishing a modernized NSRS in Louisiana would assist in coastal restoration, transportation and public safety, not just in Louisiana, but for similar actions in other Gulf Coast states.

Wisconsin and states in the Great Lakes region have vertical problems associated with frost heave, post-glacial rebound, and other unique geologic features. Wisconsin is taking the lead in addressing these problems resulting from vertical movement, having already initiated a statewide Height Modernization Program to strengthen its geodetic control system.

Louisiana and Wisconsin are focusing on the 1998 National Height Modernization Study and use of GPS technology to establish, monitor and develop a highly accurate, vertical federal/state geodetic control network to enhance their economies, ensure safety of life and property, and protect their unique environments.

This report identifies and documents the user requirements in Louisiana and Wisconsin for height information, including those requirements utilizing both horizontal and vertical data. To identify and document this information, a two-step process was followed. First, the NGS state advisor and NOAA program coordinator in Louisiana and the NGS state advisor in Wisconsin contacted the users within their state and documented their input. Next, NGS conducted user forums on August 8 in Madison, Wisconsin, and on August 13 in Baton Rouge, Louisiana, to obtain further insights and recommendations from state and local governments, the private sector, and the academic community. Due to the short time frame for completing the report, NGS believes Louisiana and Wisconsin are in general agreement with our assessments, however, the states did not have the opportunity to review and comment on the report.

Participants in the user forum held in Madison, Wisconsin, on August 8, included representatives from: Department of

Administration (Office of Land Information Services); Wisconsin Department of Natural Resources; Wisconsin Department of Transportation; University of Wisconsin; and the Minnesota Department of Transportation. Participants in the user forum held in Baton Rouge, Louisiana, on August 13, included representatives from: United States Army Corps of Engineers (USACE); Louisiana Department of Transportation; Louisiana Department of Natural Resources; Louisiana Professional Engineer and Professional Land Surveyor Licensing Board; Department of Public Works for Baton Rouge; Amite River Basin Commission; Mid-Continent Oil and Gas Association; Louisiana State University (LSU); University of Louisiana at Lafayette (ULL); Baffle and Baffle Consultants; C.L. Jack Stelly and Associates, Inc.; Meyer, Meyer, LaCroix & Hixson; 3001, Inc.; T. Baker Smith, Inc.; Morris P. Hebert, Inc.; and N.E.I.

Based on the above information which was analyzed by NGS, it has been determined that participation by Louisiana and Wisconsin in the National Height Modernization System could result in:

- improved disaster preparedness;
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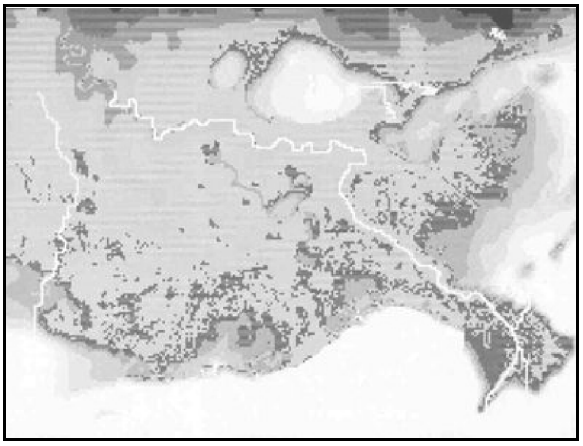
- better management of natural resources through the use of reliable GIS;
- improved understanding of tectonic movement; and
- significant time and cost savings in field surveying.

Both Louisiana and Wisconsin require improved vertical geodetic control (height or elevation reference) that would make possible the applications and benefits listed above. Each state has unique geophysical situations that represent problems specific to its region that would be improved through participation in the National Height Modernization System.

LOUISIANA

Background

Louisiana's land is moving. Subsidence, the sinking of the land, is occurring at a rate of up to one inch every three years in some areas of the state. Most of the vertical elevations (heights) used by surveyors and engineers have not been calibrated, or checked, since 1988 and may currently be in error of one foot or more. The state's southern region, affected over the years by the changing courses of the Mississippi River, currently is undergoing the largest loss of land in the nation because of subsidence and erosion, especially in the New Orleans area. Currently, 25 to 35 square miles of marsh are lost each year. While many projects exist to examine, monitor, prevent, and restore land that is lost due to settling, the key element to understanding the true relationship of the ongoing processes is a common, accurate federal/state network of elevations. This can be done through highly accurate GPS technology. The next generation of information based on this technology is needed to better guide the massive public investments that are foreseeable in upcoming decades in the areas of coastal restoration, transportation infrastructure, and public safety.



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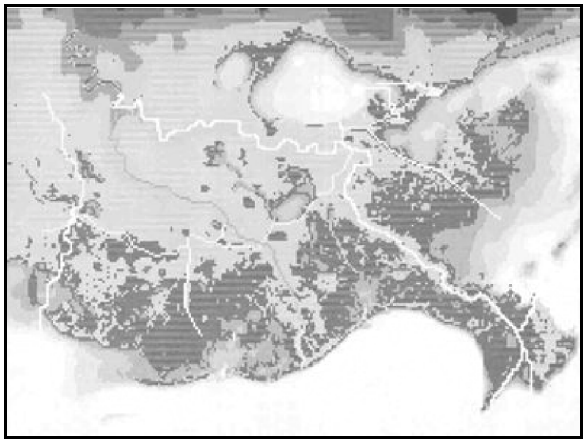

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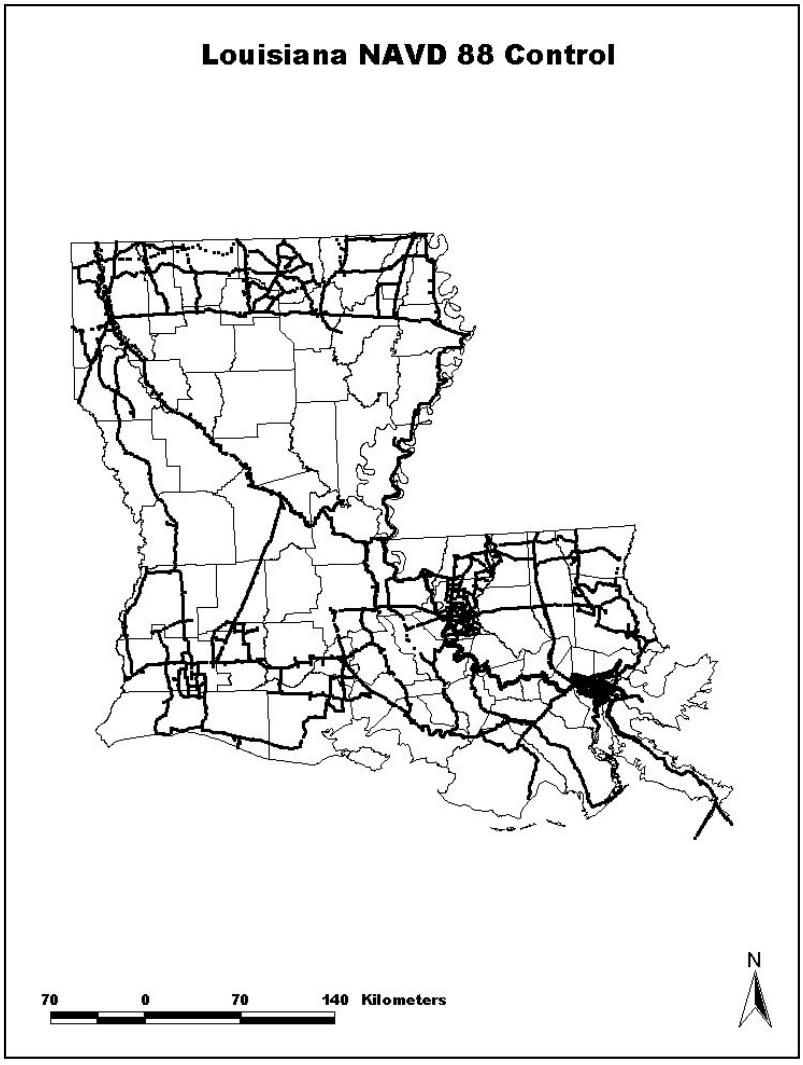
Dark areas indicate wetland loss - past and near future.

The state of Louisiana is in need of a statewide, reliable, vertical federal/state geodetic control network. Historic survey measurements, made by pre-GPS, classical line-of-sight leveling techniques, show that existing bench marks (vertical geodetic control marks, consisting of metal disks or rods that monument

points on land) throughout the southern portion of the state have undergone dramatic changes in elevation, making existing height information unusable. Quality survey work with reliable accuracy is a major challenge for surveyors in the southern part of the state. In addition, the central portion of the state has very few known elevations based on NAVD 88 (see figure below). [NAVD 88 is the latest vertical coordinate system for consistently defining heights and is similar to defining an elevation relative to mean sea level.] Problems with adjustments and lack of vertical geodetic control have kept the data from being loaded into the NSRS data base. [Adjustments "change" or "fit" the survey data to improve the final results of the survey.] The earliest estimates of having the Louisiana leveling data readjusted is three to five years from now.

NAVD 88 control in Louisiana



Another unique problem for Louisiana due to its subsidence and poor historical data, is the use of several vertical datums (coordinate systems) within the state. In areas of severe subsidence, such as the New Orleans area, several adjustments of survey monuments have been performed to update heights (elevations) for a particular year. Often these adjustments rely on the elevation of only one station, rather than on a network of stations. If the elevation on the one station is in error, the error will affect all the stations being adjusted resulting in inaccurate elevations on several survey monuments.

Needs

Examples of specific uses of height modernization identified by Louisiana are indicated in the following text boxes, according to the general need they describe. Based on the information obtained from the state, the major needs (and supporting information) identified are:

1. **A reliable, cost-effective, standardized, legally established national vertical reference datum (i.e., NAVD 88) and the infrastructure (NSRS) through which to access and use it.**

Port of Iberia

A standard, reliable vertical federal/state geodetic control network does not exist in Louisiana. An example of this is in the area near New Iberia. The Port of Iberia recently contacted NGS asking for technical services and support to establish vertical control along the coast and the Port of Iberia access routes. The Port of Iberia, which recently underwent an expansion, serves as a major hub for the construction, oil and gas industries, coastal exploration and production activities. Future studies are underway to deepen access channels to the port to support an increase in shipping and marine operations. Accurate vertical control would enable precise positioning of the dredges as well as efficient use of the dredged material. The Port of Iberia, as well as other ports in Louisiana, needs vertical control established to efficiently modernize access to its facilities.

Development of evacuation plans

Elevations used in current evacuation plans are based on unreliable vertical control. Louisiana is impacted by more flooding and storm-induced damage to communities and housing than any other state. In June 2001, Tropical Storm Allison hit Louisiana. *"A state of emergency was declared in 25 parishes as a week's worth of rain generated more than two feet of water. Freshwater submerged U.S. Highway 90* [the primary evacuation route in southern Louisiana] *for over 12 hours."*[3] About 90 percent of the coast of Louisiana is less than three feet above sea level. Because of the inaccuracies of surveys and models, the "true" heights in this region are only known to within a foot. Inaccurate heights lead to inaccurate flood plain models and unreliable evacuation plans. The state needs an established, consistent vertical control system to accurately assess flooding and its threat to coastal populations.

2. **The capability to easily interrelate the many vertical datums currently in existence, but particularly with respect to a standardized national vertical reference datum (i.e., NAVD 88).**

Gauge data

USACE stream gauge data is often erroneous, citing that streams run north when actually they are running south. Gauge data and datums need to be referenced to NAVD 88. Tide and water level gauges managed by USACE are in the process of being switched over to NAVD 88.

Pipeline and wellhead mapping

Exposed pipelines and capped wellheads pose a hazard for navigation and the environment. To prevent disasters such as pipeline bursts and marine accidents, accurate positioning and identification of pipes and wellheads in coastal waters, especially in areas of subsidence and coastal erosion, are needed.

[3]Chartuk, Robert, July 2001, "Tropical Storm Allison is Nation's Costliest Ever," **NOAA Report**, Volume IX, No. 7, p. 2.

Agriculture and the watershed[4]

In Louisiana, an established vertical federal/state geodetic control network that relates to various industries is needed to promote business and reduce environmental hazards.

Gulf coast fishery harvests (principally Louisiana) provide about 40 percent of the nation's annual seafood supply in tonnage and value. Forty percent of all coastal wetlands in the country are found in Louisiana. Extensive hypoxia (low oxygen) events, referred to as the "Dead Zone," have very large impacts on the state and the fisheries in the Gulf of Mexico.

This "Dead Zone" off the Louisiana coast covers an estimated 8,000 square mile area and is being called the largest ever hypoxic area on record. Heavy rains from Tropical Storm Allison fueled this lifeless moving area in the Gulf of Mexico as storm run-off along the Mississippi River carried nutrients down river into the Gulf of Mexico. The most prevalent run-off nutrients include fertilizer from farms and industrial and urban wastes from the 32 states in the river's watershed.

A consistent vertical control network is needed to allow the agricultural industry to better manage the fertilizers used on fields and to allow better monitoring and assessment of run-off and its affect on the wetlands and fishing industry.

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[4]Rogers, Al, July 27, 2001, "Dead Zone Now Called Largest Ever," RodnReel.com featured article.

Barataria Hydrologic Basin[5]

The National Geodetic Survey is working with the state and LSU to create a comprehensive monitoring of processes in the Barataria Hydrologic Basin, combining the need for height modernization with the monitoring of coastal subsidence and sea level rise.

The Barataria basin is currently losing approximately 12 square miles of wetlands annually, making it among the most rapidly disappearing estuaries on Earth. Restoration, monitoring, and analysis projects such as a coast-wide network of monitoring stations, monitoring stations for the Davis Pond diversion project, and the development of a comprehensive hydrodynamic model will soon be in place. These studies will document the dynamics of vegetative communities, fish and wildlife assemblages, bathymetry, and comprehensive hydrology of the basin. Collectively, they will bridge the gap from a project-level understanding to a more systems-level understanding, strengthening the ability to forecast future scenarios and allowing for better planning strategies.

A methodology will also be developed in conjunction with Louisiana Department of Natural Resources personnel that will allow for reproducible measurements of marsh heights during the duration of the project. Real-time kinematic (RTK) GPS surveying methods will be used to measure marsh heights at the centimeter level.

3. **National technical standards and guidelines for using GPS to determine heights.**

Potential Benefits

The benefits of height modernization to the state of Louisiana, categorized by area of industry and described with examples in text boxes, include:

[5]Center for GeoInformatics, Louisiana State University, "Establishment of subsidence rates, net surface changes, and relative sea-level rise rates between 2001 and 2006, Barataria Hydrologic Basin," Draft proposal.

Safety/Flooding

- Improved emergency response routes:

  S improve time models and routes for evacuation;
  S decrease number of people stranded; and
  S improve models for river flood stage predictions as well as measurements.

Hurricane sheltering in hospitals

Critical care, special needs patients are at heightened risk during large evacuations, due to the potential for long travel times with limited or no access to medical facilities. A study sponsored by Jefferson Parish and conducted by the LSU Hurricane Center is underway to assess the capacity of midrise hospital buildings in the New Orleans area to be used for special needs shelters. Storm surge flood modeling, building systems assessments, and future modifications to hospital utilities and infrastructure are highly dependent on accurate elevation data.

- More accurate models of storm surges, coastal erosion, and trajectories of oil and chemical spills that enable better response to these hazards.
- Accurate digital elevation models, enabling better flood plain analysis and determination of flood insurance needs.

Flood plain management

Height modernization would provide accurate, standardized, vertical geodetic control for the flood management program of Amite River Basin Commission. Additionally, it would improve the flood plain models used by the Federal Emergency Management Agency.

- Improved flood control and the cost/benefit ratio for USACE projects, including levee and subsidence projects and development of hurricane protection systems.

Navigation/Ports

- Improved coastal and harbor navigation, enabling safer and more cost-effective shipment of goods.
- Precise positioning of dredges and dredge materials.

Modernization of ports and waterways

The Port of Iberia and other ports and waterways in Louisiana would benefit from the cost effective methods of determining accurate depths and elevations resulting from height modernization.

- Determination of the "true" rate of sea level rise aside from the vertical subsidence along the coast.

Agriculture/Aquaculture

- Real-time positioning of farm equipment and reduction of production costs.
- More efficient fish farming, including crawfish farming.
- Better management of natural resources through the use of reliable GIS.
- Decreased run-off of contaminants as a result of controlled applications of water, fertilizers, and pesticides in precision farming.

Precision farming

In addition to mapping and monitoring the wetland, height modernization will contribute to the reduction of fertilizers and pesticides introduced into the coastal wetland ecosystem through the use of precision farming. In precision farming, computers mounted in farm equipment are guided by GPS and regulate the use of water, seeds, fertilizers, and pesticides precisely to their fields to within a foot, thus decreasing production cost and contaminate run-off.

Scientific

- Improved understanding of tectonic movement.
- Improved modeling of the geoid (equipotential surface of the Earth's gravity field which best fits mean sea level).

Land Survey

- More accurate horizontal and vertical geodetic control for public and private sector users.
- Ability to achieve greater accuracy in parcel mapping efforts.
- Remote sensing and shoreline mapping support.

Grand Isle - Port Fourchon
topographic/bathymetric demonstration project

In the Grand Isle and Port Fourchon area of coastal Louisiana, a collaborative effort between NOAA, the United States Geological Survey (USGS), and ULL is underway that will merge bathymetric and topographic data to develop a prototype elevation surface that can be used by coastal communities, planners, and managers for a wide range of coastal projects. The demonstration project uses accurate geodetic control for its kinematic GPS techniques, airborne data collection using Light Detection and Ranging (LIDAR), and data transformation tools.

Recommendations

Based on our assessment of the needs of Louisiana, NGS provides the following recommendations:

1. **Perform additional GPS measurements and leveling on bench marks to establish the basic framework of survey points needed to support height modernization in Louisiana as recommended in the 1998 Height Modernization Study.** The establishment of the framework would be funded through outside sources and grants and completed within five years. The framework, designed specifically to meet Louisiana's needs, would provide accurate, reliable, and consistent height information referenced to NAVD 88 to be included in NSRS. With NGS oversight, state and local agencies would work with the private sector to perform the geodetic survey projects.

   Rapid land loss and continuous elevation (height) changes in Louisiana require a well-managed and monitored federal/state geodetic control network to protect the environment, ensure safety of its citizens, and enhance prosperity within the state. Currently, 25 to 35 square miles of wetland per year are lost in Louisiana due to ground subsidence (sinking of the land) and coastal erosion. Cities and cultures are at risk of losing their land and having to relocate. Flooding and sea level rise threaten the coastal region, most of which is only three feet above sea level. Flood plain models and evacuation plans, developed using outdated elevations, put the citizens of the low-lying areas at great risk during heavy rains. The current available geodetic control does not support the state's needs to evaluate and manage the changes in its

environment and the impact on its economy and ecosystem. Problems with historic surveys, land movement, and sea level rise have made the current vertical geodetic control in Louisiana obsolete, inaccurate, and unable to ensure safety.

Adequate spacing of high accuracy GPS measurements coinciding with current existing height information, from classical line-of-sight surveys, also improves the geoid model(model derived from measurements of the Earth's gravity), which relates GPS heights to orthometric heights (leveling elevations). This results in more efficient and economic applications of GPS technology to determine elevations.

2. **Expand the current network of CORS and explore the use of Port-A-Measures (PAMs) and extensometers in Louisiana.** The combination of CORS throughout the state and mobile and stationary height monitoring stations concentrated in subsidence areas together provide an accurate statewide height monitoring system referenced to the highly accurate National CORS network. To serve as the essential framework for height modernization, special emphasis is required in the southern part of the state.

Photograph of a PAM

PAMs are mobile monitoring systems that use GPS to determine height changes to monitor subsidence. Extensometers are permanent devices for measuring small changes in the distance between two points on the Earth, and are used to detect subsidence without the use of GPS. Continuous monitoring by use of CORS across the state would allow for accurate information of subsidence at the ground level. Plans are already underway for expansion of the National CORS network in

the state, but additional state and local CORS are needed in the southern part of the state undergoing the most serious land loss. [National CORS is a nationwide network of hundreds of CORS which have been positioned so that their elevations are assumed to have zero errors relative to the center of the Earth. CORS provide data for high accuracy GPS post-processing of elevation data. Some of the CORS are also radio beacons that instantaneously transmit differential GPS corrections for users with RTK GPS applications.]

3. **Establish a Louisiana Spatial Reference Center (LASRC).** Like California, Louisiana does not have a state agency coordinating efforts to improve the geodetic reference frame and requires a Spatial Reference Center to work in conjunction with NGS to support height modernization within the state. [With assistance and grants from NGS, the California Spatial Reference Center was established to better address California's geodetic control needs.] The creation of a LASRC would serve as a regional center for height modernization and foster technology transfer not only between NGS and the state, but also between Louisiana and its neighboring states.

   Louisiana's active coastal wetlands and shorelines create unique referencing issues that cannot be addressed solely by the national program. The coastal processes and monitoring programs, including remote sensing and shoreline mapping, that examine subsidence and shoreline retreat require more timely action that can be done more effectively at the state and local level. NOAA is currently engaging in a partnership agreement with Louisiana State University to enhance NSRS in Louisiana. The LASRC would provide an Internet link to the NSRS data base, develop specifications and guidelines for GPS surveys not otherwise available at the national level, and educate users on spatial data referencing issues and applications.

WISCONSIN

Background

Before GPS, the vertical federal/state geodetic control network consisted of orthometric heights (vertical heights relative to mean sea level). The vertical control stations (bench marks) were surveyed using classical leveling to differentially determine the height between bench marks. In Wisconsin, the vertical federal/state geodetic control network established by NGS was conducted primarily in the 1920's and 1930's, with additional control established by USGS in the 1950's. The figure below indicating NAVD 88 control in Wisconsin represents elevation (height) information currently in the NSRS data base.

NAVD 88 control in Wisconsin

Much of the NAVD 88 control information is outdated, however, since many of the stations have not been revisited or surveyed in recent years and may no longer be useable. When NGS updated Wisconsin's vertical control to NAVD 88 in 1991, there were 7400 vertical control monuments (points with precisely determined heights). Today, fewer than half of these monuments can be found. Many of

the monuments were destroyed during construction and development projects. Of the remaining monuments, many cannot be tied to the GPS network because overhead obstructions such as trees, buildings, and utility lines block GPS signals, and many others are unstable with substantial discrepancies between published elevations and current measurements. A recent report from the Wisconsin Department of Transportation (WisDOT) states that out of the vertical control marks searched for to support their statewide height modernization effort, only about 15 percent of the most stable quality marks (coded in the NSRS data base as A- or B-stability) were found useable.

The current vertical federal/state geodetic control network in Wisconsin is insufficient. Most of the bench marks are old and subject to environmental disturbances, namely frost heave and post-glacial rebound. Frost heave occurs when water-saturated soil is deformed and uplifted during periods of freezing. Post-glacial rebound is the rising of the Earth's surface which occurs in land that was compressed by glaciers during the last ice age. The land is still rebounding in the Great Lakes region today. Additionally, in most parts of the state, 50 percent or more of all bench marks have been destroyed due to construction and land development activities.

In 1991, Wisconsin was one of the first states to establish a High Accuracy Reference Network (HARN). The HARN was a nationwide effort led by NGS to upgrade the horizontal positions and GPS (ellipsoid) heights of the national geodetic control network using GPS techniques. In 1997, with continuing improvements in GPS technologies coupled with the development of the very highly accurate CORS network, NGS launched a new effort - the Federal Base Network (FBN) campaign. The FBN is a very high accuracy network of high accuracy network of monumented stations (points) with 100-km nominal spacing throughout the United States and its territories. The FBN, observed and managed by NGS, also contains additional stations as needed in areas of subsidence, crustal motion, or special interest. NGS recognized that the state and local governments, as well as the private sector, were interested in a network of geodetic control with less distance between stations. While establishing the FBN, NGS invited all interested parties to simultaneously observe additional stations, known as the Cooperative Base Network (CBN). The CBN is a very high accuracy network of monumented stations with 25- to 30-km nominal spacing, established and maintained through cooperative agreements with other Federal, state, and local government agencies. The focus of the FBN/CBN surveys was to cooperatively reobserve the HARN stations as either FBN or CBN stations with personnel from NGS, state and local communities. The FBN and CBN stations would then

be positioned relative to the highly accurate CORS, dramatically improving the GPS vertical component of NSRS.

WisDOT and NGS have a history of cooperative effort in the use of GPS technology to improve both the horizontal and vertical control data within the state. Even with these efforts however, there are still gaps and need for improvement in the state's geodetic network.

Needs

In Wisconsin, the existing federal/state geodetic control network simply does not support today's design and construction projects. The critical nature of the shortfall of accurate geodetic control, especially vertical control, prompted the Wisconsin Land Information Board in April 2001, to establish a State Elevation Data Task Force to assess the needs and uses for vertical control and directly address the deficiencies. National, state, and local agencies, as well as the private sector, need consistent and accurate geodetic control for use in highway and land development, monitoring and modeling of shoreline and flood plains, and safe and economical transportation of goods.

Wisconsin was one of the first states to realize it needed to enhance its vertical height system. As a result, in 2000, WisDOT and NGS agreed to collaborate on the Wisconsin Height Modernization Program (WI-HMP). The agencies drew from the 1998 National Height Modernization Study in formulating a 10-phase plan to improve elevation data throughout the state. The goal of the WI-HMP is to eliminate inconsistencies between horizontal and vertical control data, supplement control where marks have been destroyed, and create a network that can use GPS technologies as a cost-effective positioning tool in place of conventional equipment and procedures. While the HARN and FBN/CBN campaigns provided highly accurate horizontal and GPS ellipsoid heights to the state, the WI-HMP will provide highly accurate and precise primary vertical control (orthometric heights), as well as densify (add more stations to) the federal/state geodetic control network, to all of Wisconsin.

> *Of the 43 bench marks with published NAVD 88 heights leveled to in Phase I of the WI-HMP, only 19 (44%) could be constrained in the final NGS vertical adjustment. The other 24 (56%) had elevation changes ranging from -20.4 cm (-8.0 inches) to 19.2 cm (+7.5 inches) from the published NAVD 88 heights.*[6]

[6]NGS vertical adjustment of WI-HMP, Phase 1.

Planned as a 10-year effort, but more practical and cost-efficient as a five-year plan, the WI-HMP will establish a three-dimensional federal/state geodetic network using GPS and conventional leveling techniques throughout the state. Accuracies of 2 cm are expected in the horizontal and vertical components. The plan follows NGS guidelines and calls for the submission of all data collected and processed to be submitted to NGS for inclusion in NSRS. Implementation of the WI-HMP consists of:

- researching and recovering existing NSRS bench marks;
- plotting high accuracy GPS and bench marks;
- densifying GPS at three different levels;
  - primary base stations at 25 kilometer (km) spacing;
  - secondary base stations at 12-14 km spacing;
  - local network stations at 6-8 km spacing;
- creating new level lines incorporating high accuracy GPS and existing bench marks;
- locating new bench marks at 2 km spacing along level lines;
- performing conventional leveling on bench marks, HARNs, and primary base stations;
- performing GPS on all levels of GPS stations to transfer elevations;
- processing, analysis and adjustment of GPS and leveling data; and
- submitting adjusted data to NGS for review and inclusion in the NSRS data base.

Potential Benefits

The benefits of height modernization to the state of Wisconsin, categorized by industry and described by examples in the text boxes, include:

Safety

- Improved emergency response routes:

  S improve time models and routes for evacuation;
  S decrease number of people stranded; and
  S improve models for river stage predictions as well as measurements.

- More accurate models of storm surges, coastal erosion, and trajectories of oil and chemical spills that enable better response to these hazards.
- Accurate digital elevation models, enabling better flood plain analysis and determination of flood insurance needs.

Dam burst analysis

The Wisconsin Department of Natural Resources is responsible for the analysis of more than 20,000 dams. Accurate vertical heights are needed to show downstream flooding that would occur if a dam failed. Many of these dams are old and dam burst analysis is critical for the protection of human life.

Navigation/Transportation

- Improved coastal and harbor navigation, enabling safer and more cost-effective shipment of goods.
- Combined bathymetric and vertical height information in shoreline models.

Highway Construction and Improvement

- More accurate vertical data for preliminary highway design.

WI-HMP and RTK GPS method success

WisDOT used RTK GPS to verify both the horizontal and vertical positions of a group of photogrammetric targets that had been placed in the field for a highway design/mapping project. Using the current method of static GPS and conventional leveling took 280 staff-hours to complete. With WI-HMP completed, the RTK GPS method took only 30 staff-hours, more than nine times faster than the current methods employed. Again, these savings will continue to accrue for WisDOT and other local and state agencies as the WI-HMP expands.

- Improved ability to delineate drainage basins for bridge and culvert sizing.
- Improved data quality to provide more accurate, more detailed digital elevation models.
- Nearby bench marks for use in highway design and construction which are more reliable and cost effective.

Agriculture

- Real-time positioning of farm equipment and reduction of production costs.

Crop dusting

Digital elevation models of agricultural areas would allow crop dusters to fly their fields without requiring manual flagging of the fields, thus reducing costs.

- Decreased run-off of contaminants as a result of controlled applications of water, fertilizers, and pesticides in precision farming.

Central Sands agricultural region

The Central Sands area of Wisconsin, a major producer of vegetables, relies heavily on irrigation and the use of fertilizers and pesticides. Improved height information and the use of precision farming techniques will reduce run-off and reduce production costs in this agricultural region.

Property Description

- Expedited gathering of information for flood plain determination.
- Allow incorporation of topographic files as part of tax parcel maps to provide more detailed information about property parcels.

Land Surveying

- Facilitated registration of Public Land Survey System data in the computer aided design environment.
- Greater accuracy in parcel mapping efforts.
- More accurate horizontal and vertical geodetic control for public and private sector users.

High speed rail project

A recent problem with elevations occurred in a project mapped by WisDOT for a high speed rail project. Because of a lack of accurate heights, GPS-derived heights were miscalculated, resulting in over 100 hours of additional survey work, a three-month delay in the project, and an additional 50 hours of mapping work to correct the problem. Improved and consistent heights would have prevented these costly errors and delays.

Land Information Systems

- Greater accuracy for field checks on digital orthophotos (digital version of a rectified (corrected) aerial photograph).

Verification of orthophoto products

Dodge County conducts substantial amounts of photogrammetry each year. As part of the quality control program, the digital orthophoto products are checked for accuracy. Before the WI-HMP was in place, it took 24 hours to conduct field checks necessary to verify horizontal and vertical positions of check points in a single 36 square mile Public Land Survey System Township. With WI-HMP completed, RTK GPS procedures make it possible to complete the verification in four hours. This 6:1 savings translates into hundreds of thousands of dollars annually for Dodge County, when taking into account the many highway projects for which they are responsible.

- Provided field reference points for verifying accuracy of resource grade GPS collected data.
- Improved data quality for more detailed terrain modeling and three-dimensional visualization activities.

Land Conservation

- Better determination of wetland boundaries.
- Better determination of Great Lakes erosion and lake level rise.
- Soil erosion assessments.
- Increased data visualization and three-dimensional modeling.

Land Use Planning

- Better determination of slope gradients.

Dairy modernization

Topographic surveys are used for proper site selection of dairy operations. Sites with a slope of 2 to 6 percent allow for drainage without erosion.

- Better determination of elevations for flood plain delineations.

- Facilitate evaluation of property characteristics for permits, petitions, and parcel combinations.

Scientific

- Improved understanding of tectonic movement (post-glacial rebound).
- Improved modeling of the geoid.

Recommendations

Based on our assessment of the needs of Wisconsin, NGS provides the following recommendations:

1. **Accelerate the Wisconsin Height Modernization Program (WI-HMP) from ten to five years. Analyze data collected in the early phases of the WI-HMP to determine possible modifications to field procedures and the design of the program.** Specifically, assess the amount of leveling to be completed and the current specifications and guidelines of the field observations to ensure accurate, yet economic, development of height modernization.

   The potentially substantial economic benefits to the state and nation through the transportation, agriculture, construction, and public safety industries realized five years sooner would make Wisconsin a prototype for height modernization for the region, as well as the country. NGS acknowledges the tremendous effort underway by the WisDOT to complete its 10-year WI-HMP, but cautions that technology will outpace the effort unless the work is accelerated through modified procedures and guidelines.

2. **Promote Wisconsin as a role model and trainer in height modernization.** Since Wisconsin's height modernization effort is already underway, the state would be in a position to advise neighboring states in the development and uses of height modernization. Transfer of technology through NGS with Wisconsin as a regional leader could help address the entire region's economic and environmental issues.

3. **Investigate opportunities for additional funding for the height modernization in Wisconsin.** Additional resources would result in more outsourcing opportunities, as well as technology transfer, to private surveyors. Funding would also ensure that the efforts of the state are recognized as it has developed and implemented a valuable resource for all users of spatial data.

GLOSSARY OF TERMS AND ACRONYMS

ADJUSTMENT

The process of finding a set of “best” values from a set of redundant survey observations. An adjustment changes, or fits, the survey data to improve the final results of a survey.

BENCH MARK

A bench mark is a vertical (elevation) geodetic control mark, consisting of a metal disk or rod, that monuments a point on land.

CBN

The Cooperative Base Network is a very high accuracy network of monumented stations with 25- to 30-km nominal spacing, established and maintained through cooperative agreements with other Federal, state, and local government agencies.

CLASSICAL LEVELING

Classical, or conventional, line-of-sight leveling required crews of surveyors to walk and carry survey equipment, taking geodetic survey measurements approximately every 100 yards, to establish and maintain a national coordinate system of extremely accurate heights (elevations). The survey equipment required that the points being measured were visible to one another.

CONVENTIONAL LEVELING

Conventional, or classical, line-of-sight leveling required crews of surveyors to walk and carry survey equipment, taking geodetic survey measurements approximately every 100 yards, to establish and maintain a national coordinate system of extremely accurate heights (elevations). The survey equipment required that the points being measured were visible to one another.

CORS

Continuously Operating Reference Stations provide GPS data for high accuracy GPS post-processing of elevation data. Some CORS are also radio beacons that instantaneously transmit differential GPS corrections for users with RTK GPS applications.

CSRC

California Spatial Reference Center

DATUM

A datum is a set of values used as a reference or basis for a coordinate system.

DEM

A digital elevation model is a digital cartographic representation of the elevation of the land.

DEPARTMENT OF COMMERCE

The U.S. Department of Commerce is the parent organization of NOAA. Its mission statement includes promotion of job creation, economic growth, sustainable development, and improved living standards by working in partnership with business, universities, communities, and workers.

DIGITAL ORTHOPHOTO

A digital orthophoto the digital version of a rectified (corrected) aerial photograph.

ELLIPSOID HEIGHT

An ellipsoid height is based on an ellipsoid model of the surface of the Earth. A geoid height value must be applied to compute an elevation (height) relative to mean sea level.

EXTENSOMETER

An extensometer is a permanent and highly accurate device used for measuring small changes in height over time on the Earth. Extensometers, which do not use GPS, are used to detect subsidence.

FBN

The Federal Base Network is a very high accuracy network of monumented stations with 100-km nominal spacing throughout the United States and its territories. The FBN also contains additional stations in areas of subsidence or crustal motion, or as needed in support of Federal aircraft navigational requirements.

FROST HEAVE

Frost heave is the uplifting of land which occurs when water-saturated soil is deformed and uplifted during periods of freezing.

GEODESY

Geodesy is a branch of applied mathematics concerned with the determination of the size and shape of the Earth and the exact positions of points on its surface, with a description of its gravity field.

GEODETIC CONTROL

Geodetic control is a highly accurate, consistent, and reliable set of information about the locations (latitude and longitude), heights (relative to a specific point), and characteristics of points within an area.

GEOID

The geoid is the equipotential surface of the Earth's gravity field which best fits mean sea level.

GEOID HEIGHT

Geoid height is the difference between a GPS height (ellipsoid height) and an orthrometric height (elevation relative to mean sea level).

GEOID MODEL

A geoid model is derived from measurements of the Earth's gravity field and is important in translating GPS heights to orthometric heights.

GIS

Geographic Information Systems are computer systems used for integrating, manipulating, analyzing, and displaying data related to the positions on the Earth's surface. The data may be represented on different layers where each layer contains data about a particular kind of feature.

GPS

The Global Positioning System is a satellite based positioning system funded and operated by the Department of Defense, but available to civilian users. GPS provides very accurate and economical positioning.

HARN

High Accuracy Reference Network is a nationwide effort by NGS to upgrade the horizontal positions and ellipsoid heights of the national geodetic control network using GPS techniques.

HEIGHT MODERNIZATION

Height modernization is an effort, led by NGS, to enhance the vertical component of NSRS, by promoting the precise determination of heights through the use of GPS surveying.

LASRC

Louisiana Spatial Reference Center

LIDAR

Light Detection and Ranging is an aircraft-mounted laser measuring system that uses a laser to transmit and receive optical pulses for water surface and sea bottom detection to determine sea water depth.

LSU

Louisiana State University

NATIONAL CORS

National CORS is a nationwide network of hundreds of CORS, managed by NGS, which have been positioned so well that their elevations are assumed to have zero errors relative to the center of the Earth.

NATIONAL OCEAN SERVICE

The National Ocean Service, one of NOAA’s five line offices, provides a wide range of products and services, established on a scientific basis, for the protection of life, property, and the environment.

NAVD 88

North American Vertical Datum of 1988 is the latest vertical coordinate system for consistently defining heights and is similar to defining an elevation relative to mean sea level.

NGS

The National Geodetic Survey is an office within the National Ocean Service, which is a subset of the National Oceanic and Atmospheric Administration. NGS’s role is to ensure that the United States has a consistent, high accuracy geodetic reference framework to support mapping, surveying, and other infrastructure applications.

NOAA

The National Oceanic and Atmospheric Administration’s role is to describe and predict changes in the Earth’s environment and conserve and manage the Nation’s coastal and marine resources to ensure sustainable economic opportunities.

NSRS

The National Spatial Reference System is the national reference framework that specifies latitude, longitude, height, scale, gravity, and orientation throughout the Nation, as well as how these values change with time.

ORTHOMETRIC HEIGHT

An orthometric height, or elevation, is a height relative to mean sea level.

PAM

A Port-A-Measure is a mobile monitoring system which uses GPS to monitor ellipsoid height changes to monitor subsidence.

PORT-A-MEASURE

A Port-A-Measure, or PAM, is a mobile monitoring system which uses GPS to monitor ellipsoid height changes to monitor subsidence.

POST-GLACIAL REBOUND

Post-glacial rebound is the rising of the Earth’s surface which occurs in land which was compressed by glaciers during the last ice age.

PRECISION FARMING

In precision farming, computers mounted in farm equipment are guided by GPS and regulate the use of water, seeds, fertilizers, and pesticides to the foot, not to the field, thus decreasing production cost and the run-off of contaminants.

RTK GPS

Real-time kinematic GPS is a technique used to provide GPS positioning. The technique involves tracking the carrier phase of the GPS signals and requires a GPS base station close to the user.

SUBSIDENCE

Subsidence is the sinking of land, often caused by the withdrawal of groundwater from below the Earth’s surface.

ULL

University of Louisiana at Lafayette

USACE

United States Army Corps of Engineers

USGS
: United States Geological Survey

WI-HMP
: The Wisconsin Height Modernization Program is a program developed by WisDOT and NGS, drawing from the National Height Modernization Study recommendations, which utilizes GPS and leveling techniques to improve elevation data throughout the state.

WisDOT
: Wisconsin Department of Transportation