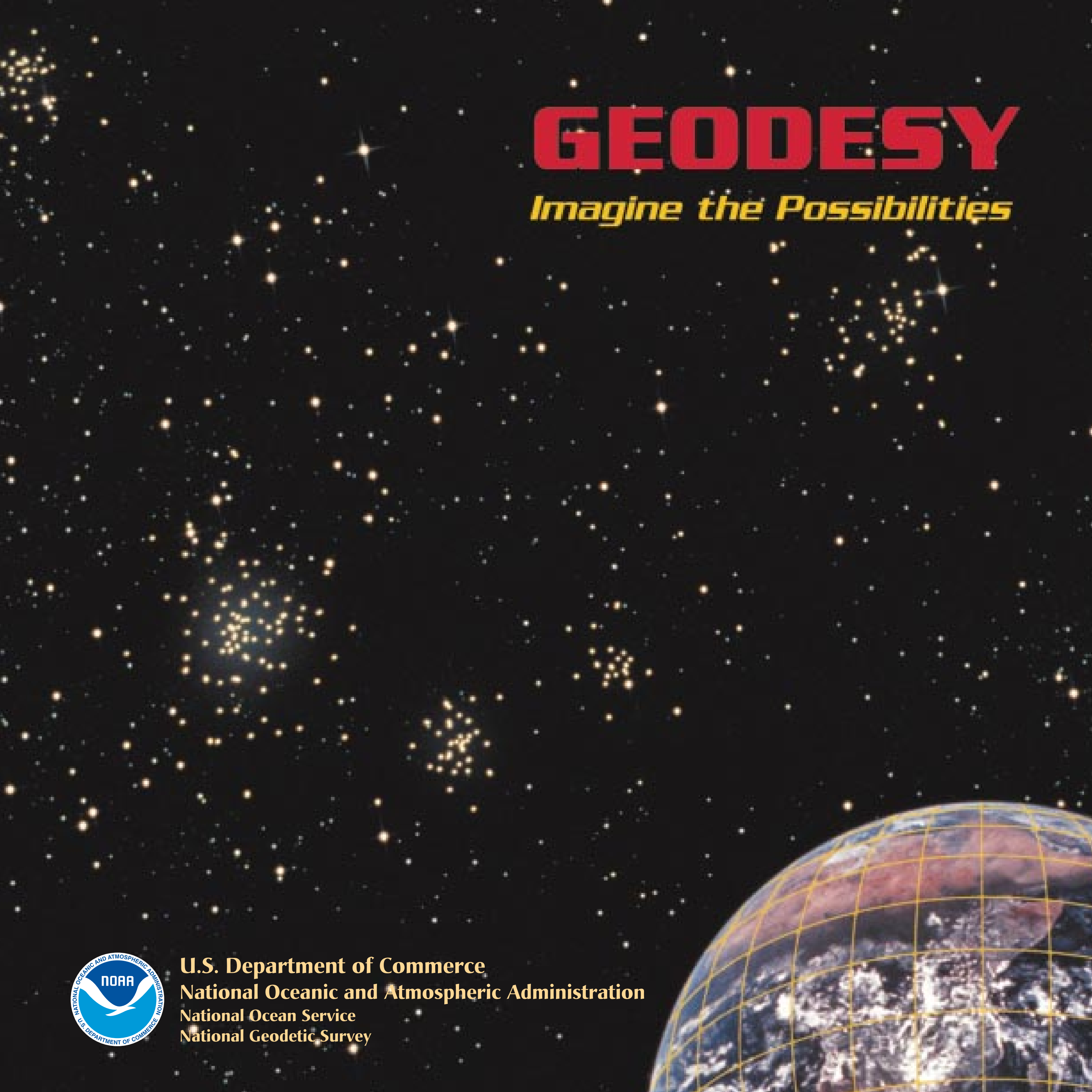
# GEODESY

## *Imagine the Possibilities*



**U.S. Department of Commerce**
**National Oceanic and Atmospheric Administration**
**National Ocean Service**
**National Geodetic Survey**

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**1999**

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# Imagine… Life Without Geodesy— Sheer Chaos!

Imagine bridges not meeting in the middle, planes landing next to – rather than at – airports, ships frequently running aground, and the north-bound commuter train on the same track at the same time as a south-bound freight…. And imagine the Internet forever gridlocked.

This is just a glimpse of what our lives would be like without geodesy. Geodesy is the science of measuring the size and shape of the Earth and precisely locating points, or coordinates, on the Earth. These geodetic coordinates can tell us exactly where we were, where we are, and where we'll be when we get there.

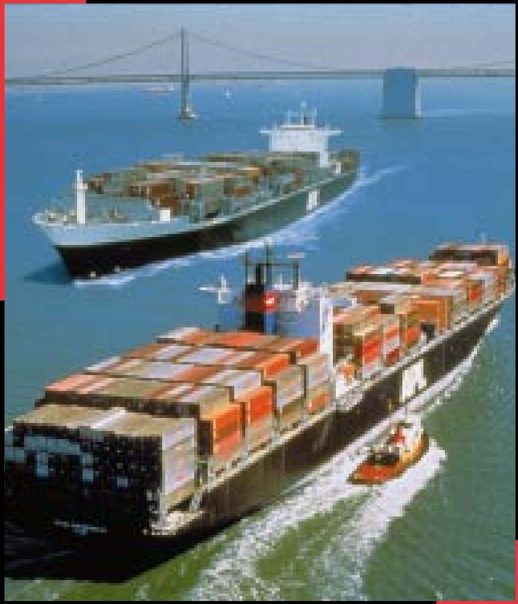
But the mere application of geodesy alone doesn't create order out of chaos. Geodesy shapes our lives today through a combination of three innovative tools:

- the Global Positioning System (GPS), which supplies the coordinates;
- NOAA's National Spatial Reference System (NSRS), which gives the GPS coordinates integrity; and
- Geographic Information Systems (GIS), which make the coordinates useful.

As our society and economy become increasingly dependent on complex technologies, the need for precise positioning and consistent, reliable data intensifies. This imaginative trio of GPS, NSRS, and GIS is providing the order needed for ensuring public safety, enhancing economic prosperity, and protecting environmental quality throughout the nation.

*"Geography without geodesy is a felony."*

*–Gunther Greulich, Past President,*
*American Congress on Surveying and Mapping*



LEFT: **More than 98 percent of the nation's tonnage in international commerce moves by sea. Without accurate geodetic information, nautical charts would be fraught with errors, and accidents, groundings, and spills of hazardous cargo could become the rule rather than the exception.** ***(Photo: American President Lines)***

BELOW: **This dramatization of construction of a bridge across a large intercoastal waterway demonstrates how chaotic our lives would be not only without geodesy but without NOAA's National Spatial Reference System. Geodetic data on the mainland came from one source, while the data on the barrier islands came from another.... And never the twain shall meet!** ***(Photo: Zurich U.S.)***

# Imagine...

# A Space-Age Address— For Your Home... and Your Mailbox

The Global Positioning System (GPS) is a constellation of 24 satellites that transmit signals to receivers throughout the world. With this system, it's possible to assign every point on Earth its own unique address – its latitude, longitude, and height.

For example, the coordinate counterpart of 18 Poplar Street might be 40 degrees 35 minutes 20 seconds N by 78 degrees 00 minutes 30 seconds W by 60 meters. NOAA's National Spatial Reference System provides a consistent framework for identifying those GPS coordinates. Each feature of the property at 18 Poplar – the house, the underground oil tank, the sewer line – has its own coordinate address. Fortunately, we won't have to remember all those coordinates, since our technologies will do that for us.

Complementing this space-based system is a growing multi-agency network of Continuously Operating Reference Stations (CORS). These ground stations provide real-time navigation information 24 hours a day, 7 days a week, to guide our transportation and communications systems and manage our natural resources. As a major component of NOAA's National Spatial Reference System, the CORS network corrects GPS satellite signals to accuracies within $^{1}/_{32}$ of an inch, and then distributes the corrected data to users.

Standard civilian GPS can tell us which field a football is on. With CORS we can determine which yard line and, sometimes, which blades of grass the ball is on. NOAA sets the standards for CORS stations, processes the standardized satellite observations, ensures the quality of the stations' positional accuracy and operation, and makes the data available to users.

*"The National Geodetic Survey, under NOAA, effectively launched our industry."*

*– Charles Trimble, Chair, U.S. GPS Industry Council*

## *Where we were...*

**LEFT: Before the advent of satellite technology, NOAA line-of-sight surveys were made at night with a theodolite, an instrument combining a telescope with a way to measure angles accurately. Temporary towers were built directly over the geodetic control points, which were brass disks set in concrete, similar to the one shown above, to the right. From the top of each tower, NOAA surveyors would observe lights set on top of the other towers, and then compute the coordinates of the control points.** ***(Photos: National Geodetic Survey)***

## *...and where we are.*

**RIGHT: With GPS, a survey that once took days can now be completed in a few hours, with 10 to 100 times more accuracy. GPS satellites beam signals in real time to GPS receivers, like the one shown here, revealing their coordinates – exactly where they are in space at any given time. With that information, a microprocessor in the receiver can calculate the receiver's position.** ***(Photo: William Stone)***

**INSET: Like calculators, GPS equipment is becoming less expensive with time. Hand-held devices are available today for under $200.** ***(Photo: William Stone)***

# Imagine...
## The World at Your Fingertips

America's 95,000 miles of coastline are subject to natural and man-made processes that continually alter its shape and character. The accuracy, consistency, and currency of our national shoreline need to be frequently ensured, especially during this era of rapid coastal development.

Countless applications depend on NOAA's National Spatial Reference System to determine where the land meets the sea, including:

- producing state-of-the-art nautical charts for safe, efficient, and competitive maritime commerce;
- defining America's marine territorial limits;
- constructing safe buildings, roads, and bridges; and
- delineating property lines to minimize boundary disputes.

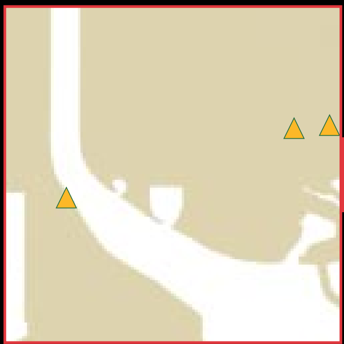
NOAA has led the way in developing new applications for GPS. For example, using GPS with aerial photography, we can locate any point on the land below to within about a foot.

The remarkable efficiencies made possible by such precise positioning data can be magnified by feeding the data into a Geographic Information System (GIS). A GIS assembles information from a wide variety of sources, including ground surveys, existing maps, and aerial photos. In a GIS, specific information about a place – such as the locations of utility lines, roads, streams, and buildings – is layered over a set of geodetic control. With a computer, regional planners can use the layers individually or in various combinations – for example, to determine how to improve traffic flow, merge construction with existing utility systems, or protect the public from potential natural disasters. And because a GIS stores data digitally, information can be quickly and economically updated, easily reproduced, and made widely available.

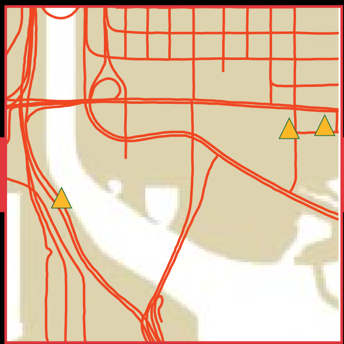
*"The world is but a canvas to our imagination."*
*–Henry David Thoreau*

This aerial photo of the Port of Long Beach was taken in 1954 as the basis for depicting the land features on NOAA's nautical charts.

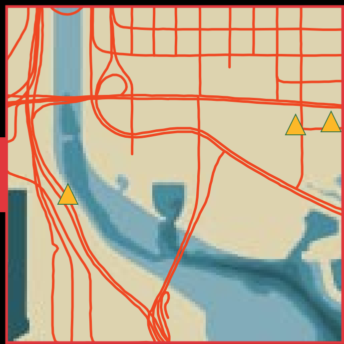
This high-accuracy NOAA photo, taken in 1997, clearly shows radical changes in the port's shoreline during the 43-year period.



The first step in assembling a GIS involves creating a foundation "layer" of virtual geodetic control, shown above as ▲. These reference points serve as the basis – the "brass tacks" –for successive data layers, such as land and water boundaries.



In a stepwise fashion, additional layers are each referenced to NOAA's National Spatial Reference System. Here, the base geodetic control layer, plus the land and water demarcations, are used as a "backdrop" for additional features, such as roadways.



A bathymetric layer depicting the contours of the ocean bottom serves a variety of purposes, such as showing ships' captains the location of the deepest waters and indicating where marine life and habitats may need special protection.

# Imagine...
# A Seamless System for America's Infrastructure

Most of the nation's infrastructure – our transportation, utility, energy, and communications systems – depends on the teamwork provided by GPS, GIS, and the National Spatial Reference System.

## Transportation

New-age geodesy is helping many U.S. transportation sectors to simultaneously reduce their operational costs and increase their safety and reliability. For example, this trio of tools:

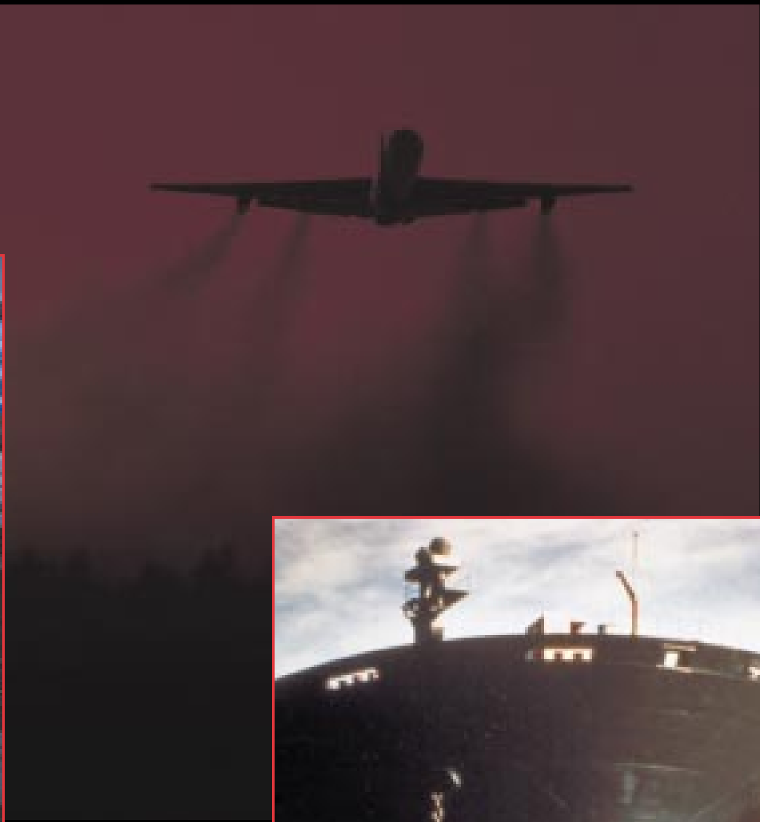
- Provides the essential foundation for our air navigation and traffic management systems, reduces fuel consumption by shortening flight paths, and ensures smooth, safe take-offs and landings.
- Serves as a common reference between a ship's electronic chart and the real-time position of its keel in relation to the bottom of the channel, thus promoting safe navigation and reducing the idle time ships spend outside ports waiting for ideal conditions.
- Allows railroads to route cars seamlessly and accurately in crowded shipping yards and to maintain a safe distance between trains on the same track.
- Helps companies calculate the most direct routes to their destinations for just-in-time delivery.

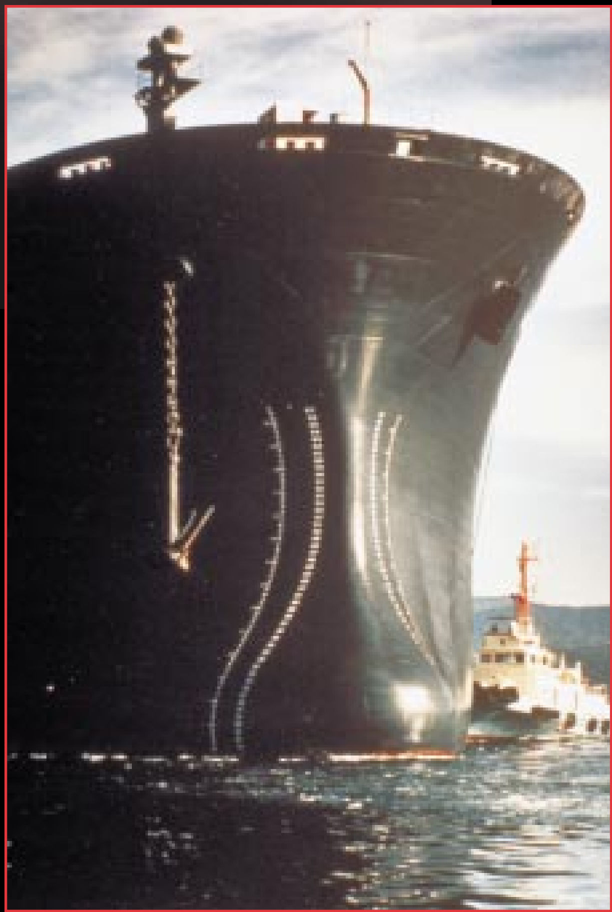
Receivers connected to electronic map displays are available to new car buyers today, and some rental car companies are offering this technology to their customers. In the not-too-distant future, GIS will be a standard feature in automobiles.

## Utilities and Energy Systems

Utility companies are using geodetic coordinates to compile maintenance data bases on ser-

*"If you can dream it, you can do it."*
*– Walt Disney*





ABOVE: **The National Spatial Reference System and GPS have made possible the development of an improved air traffic control system. Work is under way on developing highly accurate zero-visibility landing systems.**

RIGHT: **Some vessels today draw up to 60 feet of water — the equivalent of a five-story building plunging toward the ocean floor. Accurate spatial data can alert ships' captains to shoals or other obstructions they may find in their course.** ***(Photo: American Petroleum Institute)*** vice equipment, such as underground pipes and manholes. When a piece of equipment needs service, maintenance personnel can return to its exact location, even if it's below the street or obscured by ground cover. If equipment is changed or moved, its new location can be easily updated in a GIS.

GPS, GIS, and the National Spatial Reference System team up in all phases of coal, oil, and gas exploration, extraction, and delivery. This trio of tools is indispensable in designing, constructing, and mapping pipelines and utility lines – especially gas lines, which can save lives as well as millions of dollars.

In earth moving, mineral extraction, and construction projects, these tools help to simultaneously dispatch and route vehicles and to excavate according to precise specifications and environmental regulations. They also aid in documenting the land's condition and topography before excavation begins, so the area may be restored as naturally as possible.

As groundwater is withdrawn from below the Earth's surface, the ground above settles. This sinking, known as subsidence, can fracture roads and building foundations and can burst water, sewer, and gas lines. Through partnerships with local agencies, NOAA is using GPS to measure subsidence at a fraction of the cost of traditional surveying methods.

## Communications Systems

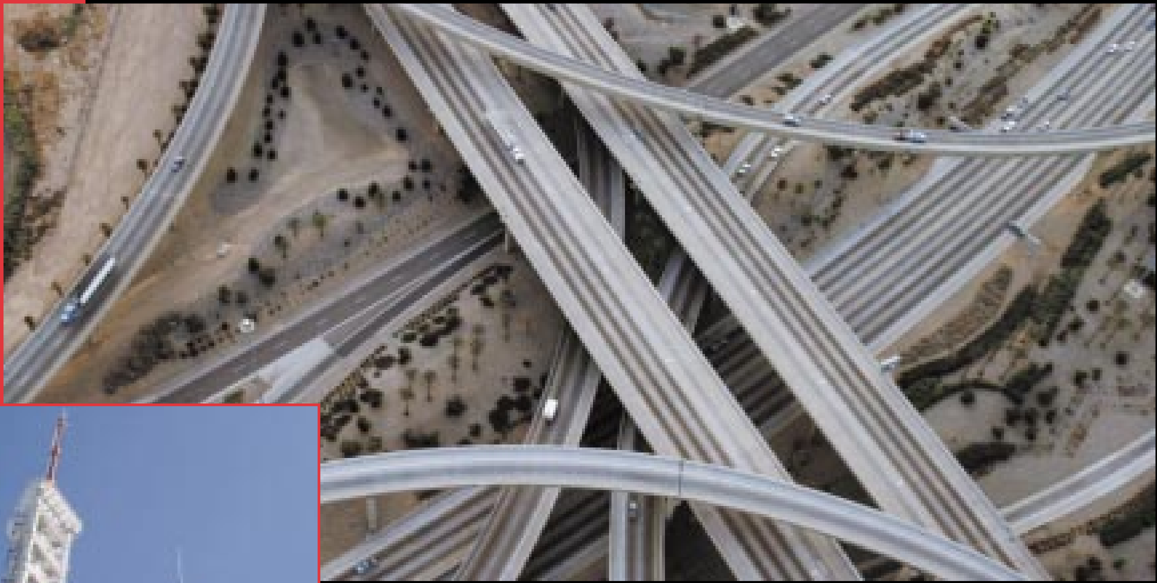
Automated teller machine (ATM) banking and other financial transactions, voice communication, high-speed computing, and the Internet all depend on precise timing.

Without the extremely accurate clocks within the GPS satellites, the Internet would have gridlocked years ago and would never have achieved anywhere near the utility it has today. The GPS clocks, in turn, depend on the precise positioning derived from NOAA's National Spatial Reference System.

Although GPS satellites broadcast correct timing information, the signal becomes susceptible to errors during the eight-hundredths of a second it takes to travel up to 15,000 miles to the receiver. Any error in the position of the receiver causes errors in timing.

A packet of information on a fiber-optic cable or a radio transmission will travel one foot in a nanosecond, or a billionth of a second. Every foot of error in the positions of the electronic message transmission and receiving sites equals one nanosecond of error in timing, increasing the probability of collision and jamming.

As our communications become more sophisticated and the use of new technologies grows exponentially, nanosecond – even sub-nanosecond – timing dependent upon accurate positioning becomes ever more critical.



ABOVE: The cost of transporting goods across state lines would increase significantly without the quality control inherent in NOAA's National Spatial Reference System. Because reliable maps wouldn't exist, truckers couldn't determine the shortest route to their destination – or worse, would frequently get lost.

LEFT: Using the tools provided by GPS, GIS, and NOAA's National Spatial Reference System, utility companies can pinpoint the location of every piece of service equipment in an area, even if it's below the street or obscured by ground cover.

RIGHT: Real-time GPS, an on-board GIS, and positions referenced to the National Spatial Reference System enhance the efficiency of heavy equipment and provide enormous savings in time and money in many applications in mining, construction, forestry, agriculture, and public services.

# New Heights, New Opportunities

NOAA's leadership in establishing the National Spatial Reference System has been key to the imaginative application of myriad new-age technologies. Its recently launched Height Modernization effort, which will accelerate NOAA's completion of the system's network of vertical (height) coordinates, is setting the stage for applications of tomorrow's technologies. This NOAA aerial photo of the San Francisco Bay area highlights how access to accurate, reliable, real-time height information can save time and money and protect lives, property, and the environment.

Knowing the vertical distance between a ship's bottom and the channel floor minimizes ship groundings, envi-ronmental damage, and the time spent waiting for ideal conditions to enter or leave a port.

Knowing how high an aircraft's landing gear is above the runway ensures safe, smooth landing, even in zero-visibility weather.

Knowing the vertical distance between the bottom of a bridge and the top of a ship allows captains to navigate safely and precisely and avoid damaging the ship and the bridge.

Knowing the changes in heights of elevated infrastructure can help trigger warning systems, alerting motorists to the potential collapse of roadways in an earthquake.

Knowing the height of the bulldozer blade with respect to the coal pile and loading equipment helps prevent damage to the conveyor belt and costly delays in loading, which are ultimately paid for by consumers.

# Imagine...

## A Place in Space... For Saving Lives

Local 911 emergency response systems are relying on positioning derived from GPS and NOAA's National Spatial Reference System. Using geodetic coordinates in a GIS, dispatchers can quickly guide vehicles to their destination. GPS receivers connected to map displays mounted on the dashboards of emergency vehicles can guide drivers to a specific address. Centralized routing GIS displays depict evacuation routes and show emergency response managers how their resources are deployed.

One of several imaginative uses of GPS positioning technologies is in an automobile accident-alert system. When the system senses the vehicle's impact with an object, it automatically calls for help and transmits the vehicle's precise coordinates to emergency service providers.

Mayors, city planners, and community leaders can consult information fed into a GIS – for example, to determine what areas are prone to fires and whether several fires in an area might signal arson. A GIS can tell police where a high number of accidents occur, suggesting potential problems with the roads, lights, signs, or speed limits.

Measuring water vapor is essential for accurately forecasting storms. GPS provides the measurements needed for updating forecasts, works continuously under all weather conditions, doesn't require calibration, and is inexpensive when compared to other monitoring systems.

Flooding is by far the costliest of U.S. natural disasters. The National Spatial Reference System provides reliable elevation information for Flood Insurance Rate Maps, which cover about 9 million flood-prone buildings across the nation. GPS surveys enable models to accurately predict future flood damages in or near a community's designated flood hazard area.

*"Reason can answer questions, but imagination has to ask them."*
*– Ralph Gerard, American Physiologist*

**LEFT: Firefighters have traditionally relied on street addresses and landmarks to report their positions. But in a major disaster, these landmarks may be destroyed or obscured by smoke. Real-time geodetic data can guide emergency crews to disaster areas quickly, accurately, and efficiently.**

**LEFT: The extensive resurveying necessitated by the 1994 earthquake in Northridge, California, cost over $1 million. NOAA is working with other federal agencies to replace traditional labor-intensive, high-cost line-of-sight survey procedures with new cost-efficient GPS technology.** ***(Photo: U.S. Geological Survey)***

**BELOW: GPS is a reliable, low-cost technology for measuring water vapor, which is essential to predicting storms.**

# Imagine...

# Producing More ... Paying Less

NOAA's National Spatial Reference System is critical to our nation's productivity and to the conservation of our rich natural resources.

Following the 1989 *EXXON Valdez* spill, Congress mandated that response plans be practiced by the entire oil spill response community. Central to an exercise – and a real spill – are tracking and predicting the movement of the waterborne oil and estimating the likely environmental impacts. NOAA's coastal mapping, whose foundation is the National Spatial Reference System, provides information for managing cleanup activities, characterizing marine habitats, and assessing environmental damage.

Wetlands are disappearing at an alarming rate, placing our ocean and coastal resources at serious risk. By analyzing digital chart data using the National Spatial Reference System, GPS, and GIS, coastal managers can develop maps that identify wetlands, local sources of pollution, and other data critical to sustaining healthy coasts.

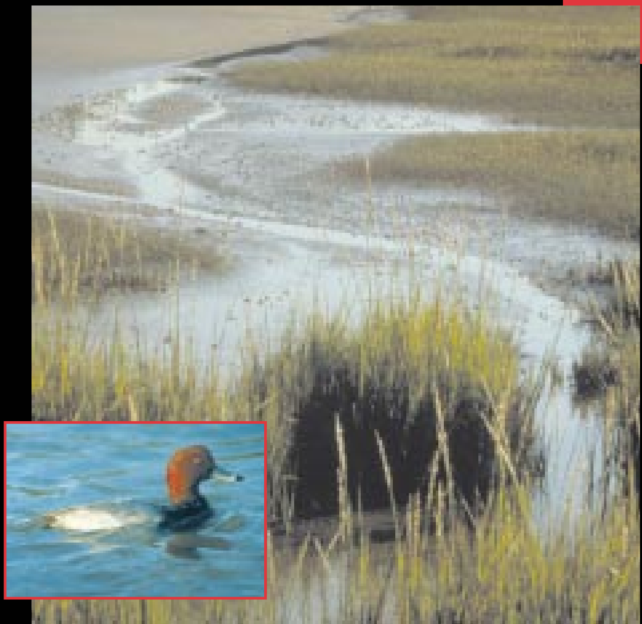
Some farms have 20 or more different soil types within one field. Until recently, farmers have addressed this variability by applying high rates of chemicals to entire fields – a "one size fits all" approach – because they couldn't determine the optimal application precisely enough on an acre-by-acre basis. Precision farming uses NOAA's National Spatial Reference System, GPS, and GIS to tailor applications of seed and chemicals to small areas of land, decreasing both production costs and the runoff of contaminants.

*"We are harnessing power in the sky to chart a prosperous new course on the ground."*

*– Vice President Al Gore*

**LEFT: Using precision farming techniques based on geodetic coordinates, farmers can farm by the foot – not by the field. Computers in huge spreader machines guided by GPS regulate the precise amount and mix of chemicals for every square foot.** ***(Inset photo: U.S. Agricultural Research Service)***

**RIGHT: Environmental sensitivity maps and spill-response models help cleanup managers identify the most vulnerable ecological areas near a spill and predict how the spill will respond to weather, current, and tide conditions.** ***(Photo: U.S. Fish and Wildlife Service)***



**LEFT: Estuarine and coastal wetlands are decreasing nationwide by an average of 31 square miles a year. GPS and GIS technologies are helping coastal managers make more informed decisions about fisheries programs, stock assessment, algal blooms, and other issues affecting the health and vitality of coastal ecosystems.** ***(Photos: Stephen C. Delaney, U.S. Environmental Protection Agency)***


NOAA's National Geodetic Survey is working to make what is only imagined today tomorrow's reality. Automatic construction equipment, self-guided automobiles, robotic cranes – these are only a few of the endless possibilities awaiting us, thanks to the reliable accuracy of GPS and NOAA's National Spatial Reference System.

NOAA's plan for the new century is to work closely with its partners to develop technologies that advance the smart, efficient growth of our economy, the prudent development of our natural resources, and the long-term sustainability of our communities. NOAA's National Geodetic Survey will continue to imagine – and make real – the possibilities of exciting new technologies that will dramatically enhance our everyday lives and our nation's competitiveness in today's global economy.

*"Anything one man can imagine,*
*other men can make real."*
*– Jules Verne*



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