A NEW AGE OF GEODESY BEGINS: 1970-1990

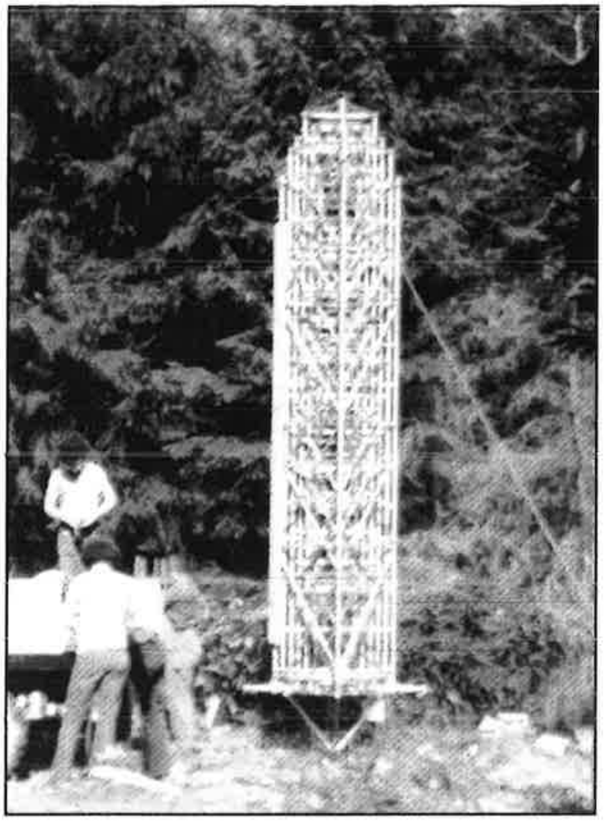
By Joseph F. Dracup

The decade of the 1970s began with the reorganization of federal agencies, including the Coast and Geodetic Survey (C&GS). The C&GS was renamed the National Ocean Survey (and renamed again later as the National Ocean Service, NOS), bringing protests from many in the surveying profession. In 1991, the old name was restored to part of the bureau, then taken away again in 1995. The Geodesy Division became the National Geodetic Survey (NGS), alternating as a division or an office in the several reorganizations within NOS. The National Oceanic and Atmospheric Administration (NOAA) was created in 1970 under the Department of Commerce.

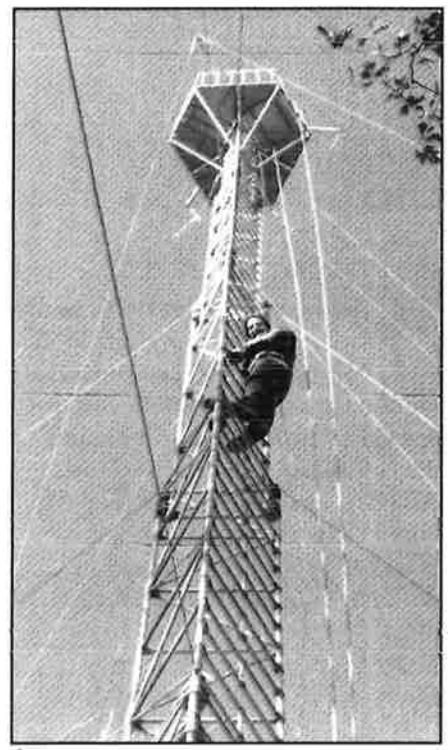
Above: in 1970, NGS marked the "Center of Population" of the United States in cooperation with the U.S. Census.

Cost-Cutting Measures Increased

With the reorganization came pressure to cut costs and, as is usually the case, that meant changes in field operations. Specifications for urban surveys were modified—yet, no savings were realized. Mixed-mode surveys including triangulation, trilateration and traverse had the best chance to save money, and a number of projects were proposed and carried out. Several excellently designed truck-mounted towers and masts had been built specifically for such work, but there were never enough of them available for efficient operations and little savings



Surveying towers reached their peak in the early 1970s with easy-to-install, prefabricated units. They were later made obsolete by GPS.



PHOTOS COURTESY NATIONAL GEODETIC SURVEY

resulted. Motorized leveling techniques developed in Sweden were only moderately successful in the more congested U.S., and their cost savings were minimal.

Devices for recording leveling observations and programmable desktop calculators contributed to more efficient and accurate field computations. Eventually, all field parties were equipped with computers connected to office facilities. Computations became easier to make, but the cost savings, if any, are difficult to ascertain.

Applications of New Technology

The 1970s saw the introduction of several pieces of new instrumentation and, in one case, a precision application of an older technology. In 1971 the first direct-positioning, all-weather system using satellites became operational. Based on the Doppler principle, and using radio signals from the U.S. Navy TRANSIT satellites, the system gave results that were accurate to about one meter in each component. As a general rule, Doppler positions were spaced at about 200 km (125 mi.) or more when used to control first-order networks. By 1977, the instruments were lightweight and portable, but they had little practical application by 1977.

Very Long Base Line Interferometry (VLBI) using extraterrestrial radio signal sources produces super accurate distances and azimuths over continental distances. Early observations were from fixed antennas, but some progress was made later in making the instrumentation portable.

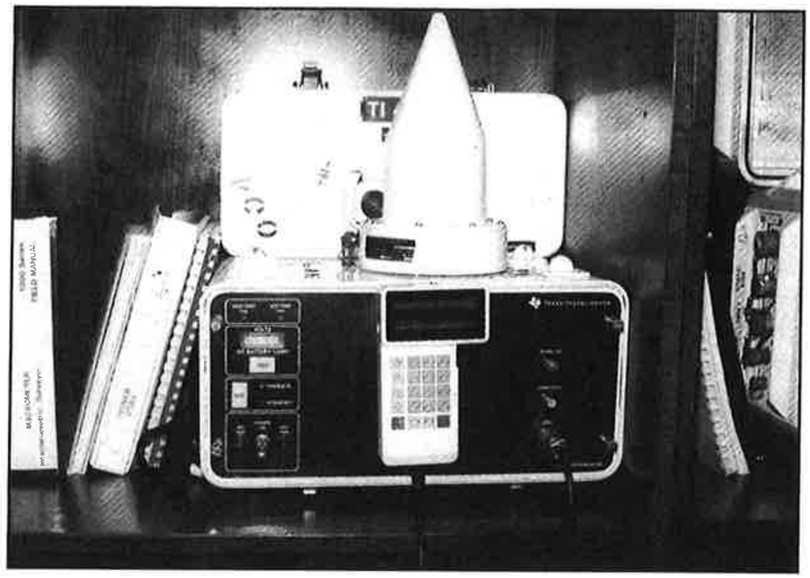
The all-weather, day and night methodology of Inertial Positioning Systems (IPS) arrived in 1978, promising an answer to densification work because of its capability to rapidly position points to an acceptable accuracy. Several federal agencies including NOS/NGS used the systems for secondary surveys, and a number of cities used it to establish local grids. The usefulness of IPS faded away by 1983 because of various factors, including the high cost of the instrumentation.

High Precision Photogrammetry (HPP) was employed in 1978 to locate 346 section corners in Ada County, Idaho, to second-order class II accuracy (1:20,000) quickly and at a moderate cost. Then, the system was never used again. One reason for the lack of interest might be that the only generally available report dealt largely with the photogrammetric reduction and adjustment phases of the project, while nothing was said about the relative ease of field operations.

GPS Operational

The most important development in the history of surveying occurred early in the 1980s when the

Macrometer (left) was the first commercial satellite receiver used in geodetic surveying. It could measure short baselines to millimeter accuracy and long baselines to one part per million. The first GPS surveys were performed in late 1982 using Macrometers. NGS produced processing software for the Macrometers. NGS also participated in the development of the Texas Instruments (TI-4100) (below), a dual frequency receiver that could track four satellites. First purchased in 1984, it was developed for military use. It was more accurate than the Macrometer and could collect satellite information without a complicated synchronization routine. It was used from 1984 through 1992, including in the Gulf War, where it was used to establish survey control.



Early GPS Receivers at the National Geodetic Survey

In 1986, Trimble introduced a rack-mounted GPS receiver called the 4000 (lower left). It could handle only one GPS frequency, but it could receive eight channels. It was much smaller and easier to move than the Macrometer or TI4000. By 1989, it was upgraded to handle dual frequencies. It was the first viable commercial receiver, and in the late 1980s, NGS began to convert to Trimble equipment. The price of the early Trimble receiver was about $45,000, or about one third of the original Macrometer or Texas Instrument units.

PHOTOS BY K. C. FLYNN

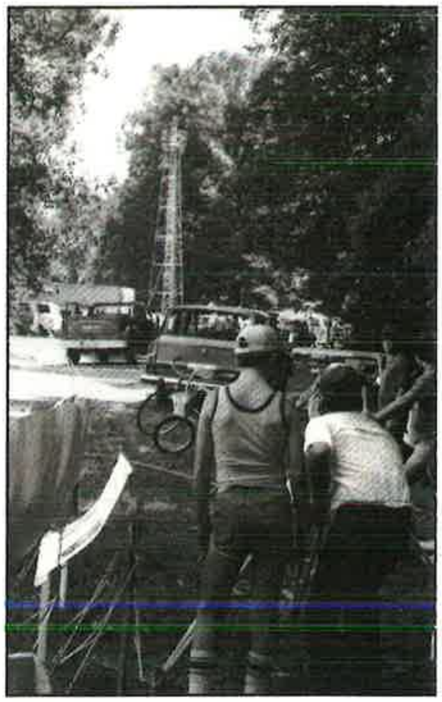
These instruments are on display at the headquarters of the National Geodetic Survey in Silver Spring, Maryland. Thanks to Paul Spofford, Technical Adviser to the Chief of the Spatial Reference Branch, for the historical information.

PHOTOS COURTESY NATIONAL GEODETIC SURVEY

Public information continued to be important to the geodetic surveying profession in the 1970s. NGS participated in several Boy Scout programs, including this jamboree in Nebraska.

NAVSTAR Global Positioning System (GPS) became operational. Surprisingly, few in the profession were initially aware of its potential. Tests made early in 1983 showed conclusively that when employed in the differential mode, GPS routinely gave one part in a million accuracy between points spaced 1 to 25 miles apart. With the announcement of these results, the geodetic world turned topsy-turvy. Theodolites, electronic distance measuring instruments (EDMI), and Bilby towers became obsolete overnight. The last Bilby tower to be erected by the NGS was in September 1984 at a station near Hartford, Connecticut, that was named, appropriately, BILBY.

There was no doubt, quite early, that GPS would be the *modus operandi* for establishing new horizontal networks, upgrading existing nets, and, eventually, establishing vertical control nets as well. Observations for the first regular GPS survey—an urban-type network for Summit County, Ohio—were completed by NGS in October 1983; the second GPS survey was completed in December 1983, at Fort Stewart, Georgia. Early tests gave indications that The results of the surveys confirmed that GPS in the kinematic mode (that is, in a moving vehicle) was the rapid positioning technique long sought for densification nets.



Total Stations and CBLs

Early in the 1970s, a plethora of new instruments became available, including short-range EDMI, modern transits, theodolites, and, eventually, the marriage of the two, the Total Station. By the late 1980s, most surveyors were equipped with at least one of these instruments. There was a problem, though; EDMI required periodic accuracy evaluations and verification of the instrument constant. A cooperative program was initiated by NGS in 1973 to provide Calibration Base Lines (CBLs) at sites selected nationwide. L.S. Baker, NOAA Director of the Survey, and a man always looking for ways to benefit the profession, was responsible for the creation of the program.

The first CBL was measured in October 1973 at Liverpool, New York, using standard first-order baseline taping procedures; by 1975, three other CBLs were similarly measured. Beginning in 1974, a new procedure combining precise taping and high-accuracy EDMI observations was adopted. The method was proposed and developed by Raymond W. Tomlinson who was also the first to employ it in July 1974 on the Rockingham-Hamlet (North Carolina) CBL.

A standard CBL has monuments at 0 m, 150 m, 430 m and 1,400 m. By 1990, more than 275 CBLs had been measured.

Standards of Accuracy Revised Once Again

Updated and revised standards of accuracy for geodetic control surveys were issued in 1974, replacing the 1957 version. Detailed specifications were published, for the first time, in 1975 and revised in 1980. Accuracy standards and specifications based on 10 years of extensive field tests were provided for trilateration, also for the first time. The 1984 standards were basically the same as those of 1974, and less detailed specifications were provided. They were raised primarily to introduce different statistical philosophies. Trilateration was omitted, probably because there was less interest in such information with the GPS becoming operational. Provisional standards and specifications for DGPS (differential GPS) surveys were made available in 1988.

The Training Craze

Have you ever wondered when and where the present-day workshop/seminar craze began? The idea came up following a successful symposium sponsored by C&GS in 1969 on the automation of surveying equipment and data acquisition. The first Surveying Instrumentation and Coordinate Computation (SICC) Workshop was held in Madison, Wisconsin, on February 8-10, 1971. The workshop was sponsored by the University of Wisconsin Extension Service under the able direction of the late William R. Baker and NGS. The agency provided seven instructors and educational materials and manufacturers donated the instruments. The cost of the SICC workshop was $60 including lunches and coffee, and it was limited to 72 attendees. SICC workshops became affiliated with ACSM in 1972 and remain available today. More than 35 workshops were presented by 1990.

The Palmdale Bulge Controversy

One of the biggest geodetic controversies since the British-French debate in the 18th century as to whether the Earth's shape was prolate or oblate erupted in the late 1970s over the Palmdale Bulge geologic mystery. According to one group the historic leveling and releveling showed conclusively that the plateau centered near Palmdale, California, had uplifted 10 to 16 inches. Another group claimed that the difference in measurements was due to instrument and systematic errors resulting from observation practices and atmospheric effects, especially refraction. Field tests carried out in the 1980s showed that the latter conclusion was correct. However, not everybody was convinced by the tests and some hold to their original views to this date.

Women in Geodesy

Women have long played important roles in American geodesy, mostly in the office, and, prior to 1900, usually in clerical positions. After the turn of the century, however, their names started appearing in professional and scientific accounts. John F. Hayford, then Chief of the C&GS Computing Division, commended in his 1902 report on the adjustment of the USLS triangulation Lillian Pike of his office and five USLS women employees for their efforts in completing the project on schedule. Then, in 1925, Sarah Beall's report on *Astronomic Determinations by United States Coast and Geodetic Survey and Other Organizations* was published as Special Publication No. 110.

Few Women in Field Positions

Field work was considered too arduous for women: building and climbing towers; handling heavy instrumentation; spending long hours in the field, especially on leveling parties; and undertaking lonely and sometime dangerous assignments as lightkeepers were not assignments women were expected to undertake. Yet, there were a few women who served in those capacities.

Prior to World War II no record could be found of women working on field parties. Among field people a tale is told of how Jasper Bilby tried to hire a young lady as his clerk in the 1930s by putting only her initials on the application. The Personnel Office requested the applicant's first name, however, and the matter was quietly dropped. Some say he hired her anyway, paying her salary from his own funds. Whether the story is true or not, the record shows that up to 1980, only four women had been employed in the field; one was a NOAA Corps officer assigned as chief of a leveling party. In 1943, Mary Smith Jahn became the first woman to be employed on a triangulation party, coming on board as lightkeeper and moving up later to recorder and then to field computer, the top-rated position on the observing side. She resigned in 1950 to raise a family. In the mid-1960s, two office geodesists, Jeanne H. Quinn and Margaret Wiss, were temporarily assigned to triangulation parties.

Good Office Representation

The extra work load brought on by the loss of male employees to the military during World War II provided the impetus to bring more women into the C&GS office force. Most held degrees in mathematics and were integrated into the highly professional (once mostly a man's) world with little or no rancor or pettiness.

PHOTO COURTESY NATIONAL GEODETIC SURVEY

Right: Grace Sollers and Sharon Faber of the NOAA Archives.

Among the women making important contributions to American geodesy during the 1940-1990 period were, at C&GS/NGS: Catherine C. Mortenson and Madeline E. Murphy in triangulation computations; Rosemary E. Riordan in computer programming; Helen Stettner in horizontal crustal motion studies; Roma Miller in astronomy and gravity; Mary R. Oleson in data processing; Jeanne H. Quinn in computer programming and administration; Elizabeth B. Wade and Maralyn L. Vorhauer by their work on NAD 83; Nancy L. Morrison in vertical crustal motion studies and data collection; Janice M. Bengston in her work on NAVD 86; M. Christine Schomaker (NOAA) by writing the 1980 leveling manual; Eleanor Andree by editing technical publications; Grace C. Sollers in archives; Beverly L. Thompson in administering field operations; and Louise Voelker, a DMA employee, by providing instruction in geodetic surveying to the military.

Flaws Found in NAD 27

Ten years after the completion (about 1931) of NAD 27, it was evident that the datum was seriously flawed because of too few base lines and Laplace azimuths overall and very large loops in the west, some 1,000 miles or more long. The eastern half had problems too, due to large junction figures which allowed, in some cases, too little triangulation to absorb position closures; by fixed points on the 98th Meridian arc adjusted in the western half and the need to readjust a large portion of the Great Lakes triangulation to fit one point to the International Boundary work. The expression "throw it in the lake" originated from this predicament.

NAD 83 and John D. Bossler

Little could be done, though, until much more of the network was completed. That time arrived about 30 years later. In-house discussions led by L.S. Baker (C&GS), then Chief of the Geodesy Division, and Charles A. Whitten, the Chief Geodesist, began in 1968. A year later, meetings with the Canadians were held. This exchange of ideas culminated in a 1971 report by a special committee of the National Academy of Science (NAS) which endorsed the need for a new adjustment.

The official kickoff date for the project was July 1, 1974. John D. Bossler (NOAA) was named NAD Project Manager, serving in that capacity until 1983 when he became Director of C&GS Charting and Geodetic Services. He was named Director at NGS in 1980 and following his retirement in 1986, he founded and presently is Director of the Center for Mapping at Ohio State University. Bossler's strong leadership combined with excellent technical and scientific skills and an ability to deal with high-level bureaucrats had much to do with the successful conclusion of the project without any major change from the original plan.

NAD 83 includes, in addition to the entire U.S. network, the primary systems of Canada, Mexico, Central America, and Greenland. The statistics are mind-boggling. The U.S. net alone comprised about 5,000 projects containing 259,000 points which involved 1,734,000 weighted observations requiring the solution of some 929,000 unknowns. Only large computers could handle it.

The parameters of the Geodetic Reference System of 1980 (GRS 80) were adopted, replacing the Clarke spheroid of 1866 that had been used for more than 100 years. The datum was earth centered by the introduction of 655 Doppler positions as observations. Also included were 112 VLBI measurements.

Few computers available in 1974, if any, had the capability to handle this enormous amount of data. Fortunately, capacities were increased significantly in the 1980s. All data, including descriptions of points, are now in a computer data base. The NAD 83 project was completed on July 31, 1986, and cost 37 million dollars.

HARNs Upgrade NAD 83

Even before NAD 83 was completed there was concern that it was not accurate enough to satisfy future needs. Some argued that its use was limited because too many points were located on hilltops and other, not easily, accessible places.

The cause for the uproar was GPS had become operational earlier and was compounded by all the razzmatazz that followed about its accuracy and ease in making observations almost anywhere. C&GS studied the problem and, while not agreeing with all of the arguments put forward, it developed a plan to provide under cooperative arrangements GPS High Accuracy Reference Networks (HARN) on a state-by-state basis. The emphasis was on statewide nets. Depending on certain conditions, stations are spaced at 15-60 miles with an internal accuracy of about 1 ppm or better. The end result was a statewide, independent, upgraded NAD 83 network. By the Fall of 1993, HARNs were in place (or were expected to be) in 27 states, with points spaced at 60 miles or less. This piecemeal approach has satisfied most users. However, some time down the road there will be a new adjustment of NAD. When, is another story.

Landmarks No Longer Positioned

Once GPS became the sole method for making horizontal geodetic surveys, landmark stations such as church spires, water tanks, and radio masts (usually referred to as intersection points) were no longer positioned. The points in the files that were and may still be used for local azimuth control, resections and even as position control will physically disappear with time. By then we can assume that surveying will be dominated by satellite technology, and their loss will cause little concern.

CORS Program Begun

In 1992, NGS formulated a plan to establish a network of Continuous

Operating Reference Stations (CORS) throughout the country in support of marine and navigation systems. CORS has the potential for accurate 3-D positioning to the datum within a 20-30 mile radius of the sites, and promises higher accuracies over longer ranges later. By early 1996, more than 50 CORS were in place, positioned to accuracies of 3 cm horizontal and 5 cm vertical. The ultimate accuracy goal of 3 mm in all dimensions is expected to be achieved in the near future. There is little reason to doubt now that the age of single-person survey parties is upon us!

NAVD 86

NGS started contracting out geodetic surveys in the 1970s, when Vernon F. Meyer and Associates, Sulphur, Louisiana, successfully undertook first-order leveling surveys.

By 1980, the National Geodetic Vertical Datum of 1929 (NGVD 29), known prior to 1973 as the Sea Level Datum of 1929 (SLD 29), had grown to 435,000 miles of first- and second-order leveling. As with NAD 27, fitting new leveling to the old network was a continuing problem. In 1978, a committee of NAS endorsed a 1975 NGS position paper that defined the steps necessary to make a new adjustment.

Technical discussions were held with the Geodetic Survey of Canada and later with representatives of Mexico and Central America. One of the decisions reached was to include Canadian and Mexican leveling in the adjustment. To reflect this situation, the name was changed to the North American Vertical Datum of 1988 (NAVD 88). The datum replaces the International Great Lakes Datum of 1985 (IGLD 85).

Leveling field work was accelerated in 1977 and completed in the late 1980s. More than 50,000 miles of first-order relevelings were carried out. David B. Zilkoski, named NAVD Project Manager in 1986, ably directed the investigations, evaluations and the new adjustment completed in June 1991. The results were published later in that year.

The datum is defined by the IGLD 85 elevation for the primary tidal bench mark at the mouth of the St. Lawrence River at Father Point/Rimouski, Quebec, Canada. The adjustment is a minimum-constraint computation involving 875,000 unknowns. It provides the best possible differences of elevation available from the observations while also minimizing the impact on the USGS mapping projects.

About 20% (or 90,000 mi.) of the old leveling either is in crustal motion areas or did not fit the new observations. These data, identified as POSTED, will be adjusted separately and the results published in the near future.

One last point. It's most likely that, as the last decade of the 20th century comes to an end, the surveyors' levels and rods will fall victim to GPS, as did theodolites, EDMI and Bilby towers before them.

Postscript

On June 25, 1995, as a result of yet another governmental reorganization, the name Coast and Geodetic Survey ceased to exist. This was the second time since 1970 that such a decision has been made. Whether the action is the final disposition of a proud and highly honored name remains to be seen. If indeed this is its fate, geodetic surveying in the U.S. and, in fact, worldwide will have lost a distinct and continuous link to its earliest days, and a major player in its history.

Keeping the Archives

Most of the photographs in Joseph Dracup's series on the history of geodetic surveying, published in the *Bulletin* over the past two years, have come from the National Geodetic Survey's archives in Silver Spring, Md. For each article, we worked closely with Joe Dracup and with Sharon Faber Records Management Coordinator of NGS and proprietor of the NGS archives. Sharon helped find some fairly obscure illustrations for this series, and when no photographs were available, helped us take the photos and get someone to help explain it all (see, for example, page 29 of this issue).

Sharon has worked on a variety of projects for NGS, including the development of Hassler Memorial Park, a small monument at NOAA headquarters honoring the first director of the Coast and Geodetic Survey and the "father" of geodetic surveying. The park has a relief sculpture of Ferdinand Hassler, plaques with information on the history of surveying, and a survey marker. Hassler Park was dedicated on November 15, 1995. The design of the park, as well as its funding, came from NOAA and the U.S. Coast & Geodetic Survey Society. Attendees at the ceremony included Ferdinand R. Hassler IV, descendent of the honoree.
—*Kevin Flynn*

PHOTO BY K. C. FLYNN

Sharon Faber at Hassler Memorial Park