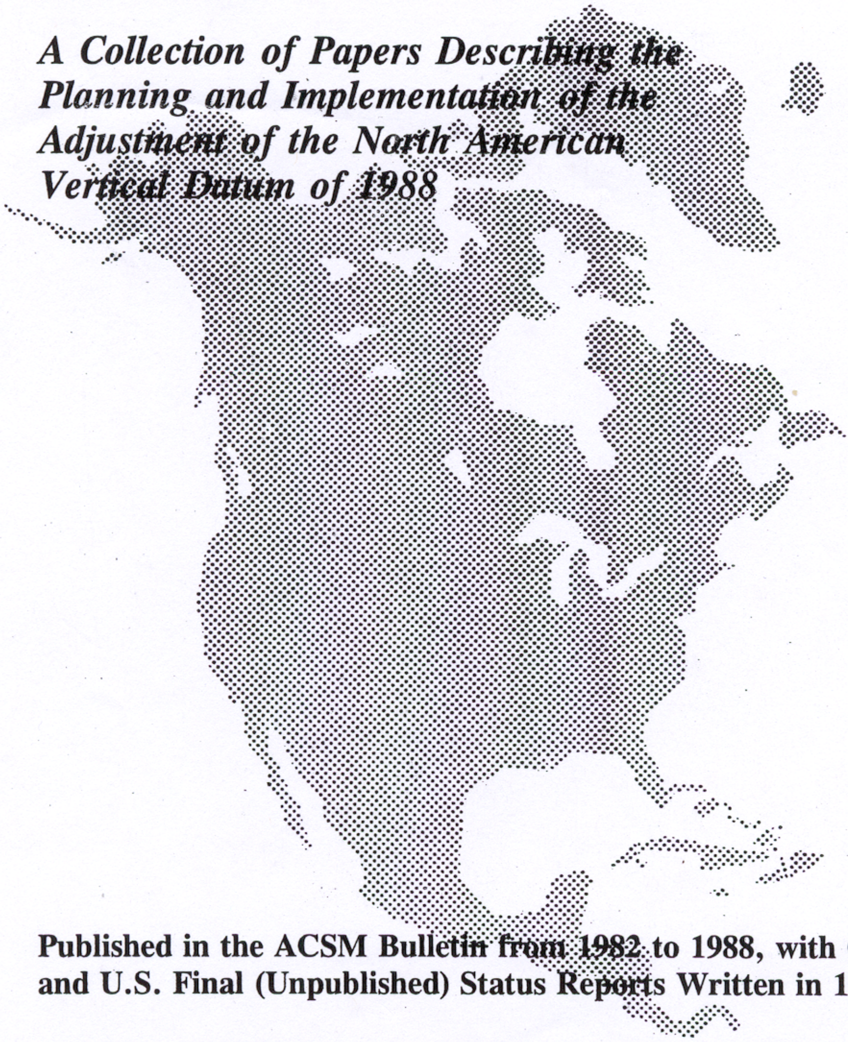
The New Adjustment of the North American Vertical Datum

A Collection of Papers Describing the Planning and Implementation of the Adjustment of the North American Vertical Datum of 1988



Published in the ACSM Bulletin from 1982 to 1988, with Canadian and U.S. Final (Unpublished) Status Reports Written in 1990

A Preface and Bibliography of Related Papers Are Also Included

Compiled by the Spatial Reference System Division
National Geodetic Survey, Silver Spring, MD 20910

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PREFACE

This is a collection of 25 articles about the wide range of activities associated with the New Adjustment of the North American Vertical Datum. The first 23 articles were published in ACSM Bulletin between June 1982 and February 1988. Articles No. 24, NAVD 88 Status Report for Canada, and No. 25, NAVD 88 Datum Definition Study, are presented here for the first time. Collectively, the 25 articles describe the major aspects of the new adjustment methods used by the United States and Canada.

Although not covered in detail in these articles, the cooperation of the other countries of North America is evident in the published proceedings of the three international conferences (Canal Zone, Panama, 1979; Ottawa, Ontario, 1980; and Rockville, Maryland, 1985) that discussed NAVD 88. These proceedings are listed in the Bibliography portion. The general adjustment of the new datum, completed in June 1991, was designated the North American Vertical Datum of 1988 (NAVD 88). Note that the new datum was called North American Vertical Datum of 1988 (instead of the present National Geodetic Vertical Datum of 1929) to reflect the international scope of the project.

The general purpose of the articles was stated in Article No. 1 (June 1982) by Charles Whalen, the first project manager of the U.S. portion of NAVD 88: "A series of articles written by members of the National Geodetic Survey (NGS) and other organizations participating in the new adjustment of the North American Vertical Datum will appear in future issues of ACSM Bulletin. Every effort will be made to provide articles of wide interest that are easy to read and understand. The primary purpose will be to inform the surveying community about the progress and problems associated with the new adjustment...[of the North American Vertical Network]."

As was the case with American Association for Geodetic Surveying (AAGS) Monograph No. 2, The North American Datum of 1983 (available from ACSM), which described the readjustment of the North American Horizontal Network, these articles about NAVD 88 were not a preplanned series. The articles do not follow a strict chronology. The topics were often assigned on an ad hoc basis when significant developments were identified as being of general interest to the readers of ACSM Bulletin.

Publication of the NAVD 88 series in ACSM Bulletin was coordinated by Eleanor Andree (formerly with NGS; now retired) and Gary Young, NGS. Further guidance was provided by Charles Whalen (formerly with NGS; now retired) and the present U.S. NAVD 88 project manager, David Zilkoski (also at NGS). Comments or questions concerning specific questions about the implications of the NAVD 88 readjustment should be directed to Mr. Zilkoski. Finally, thanks to each of the authors who took the time to document the details of their NAVD 88 activities.

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The New Adjustment of the North American Vertical Datum

Article No. 1

by Charles T. Whalen
Program Manager, National Geodetic Vertical Datum Readjustment

*National Geodetic Survey, NOS, NOAA
Rockville, Maryland*

A series of articles written by members of the National Geodetic Survey (NGS) and other organizations participating in the new adjustment of the North American Vertical Datum will appear in future issues of the *ACSM Bulletin.* Every effort will be made to provide articles of wide interest that are easy to read and understand. The primary purpose will be to inform the surveying community about the progress and problems associated with the new adjustment. Technical terminology that has developed during the new adjustment effort, and not in common usage elsewhere, will be explained in detail.

Note that the new reference surface will be designated as the *North American* Vertical Datum of 1988 (instead of the present *National* Geodetic Vertical Datum terminology) to reflect the international scope of the project.

This lead article provides some of the reasons for performing the new adjustment, an overview of the program from the U.S. perspective, and an introduction to some of the topics that will be addressed in detail in future articles. An excellent reference paper on the new adjustment, written by R. Adm. H. R. Lippold, Jr., Director, National Ocean Survey, NOAA, titled "Readjustment of the National Geodetic Vertical Datum," appeared in *Surveying and Mapping*, Vol. XL, No. 2, June 1980.

The informal beginning of the U.S. involvement in the new adjustment program occurred in the early 1970's, when NGS geodesists began an extensive inventory of the U.S. National Geodetic Vertical Control Network. As expected, they identified thousands of vertical control points (bench marks) that had been destroyed, primarily due to construction and widening of highways. In addition, NGS scientists found that a large number of bench marks had changed heights significantly due to such physical phenomena as crustal motion, post-glacial rebound (uplift), and subsidence (sinking) caused by the withdrawal of underground liquids. The problem was compounded by an ever-increasing number of new surveys which were being unacceptably distorted by forcing them to fit previously determined National Geodetic Vertical Datum (NGVD 29) elevation values.

In 1973, a federal task force published *Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying* and stated, in part:

The fundamental geodetic networks have become incomplete through obsolescence and need new surveys and a new National Adjustment to meet modern demands. . . . based on our requirements study, we conclude the vertical control program is falling short of meeting national needs, and, therefore, must be expanded. . . . We recommend doubling the National vertical control program.

A position paper, prepared by NGS, soon followed, specifying the tasks and amount of effort required to modernize the vertical control network. In 1978, the National Research Council's National Academy of Sciences Committee on Geodesy stated in their publication *Geodesy: Trends and Prospects*:

We recommend that the computations and additional observations for the new adjustments of the North American Horizontal and Vertical Control Networks by the National Geodetic Survey be given the support necessary to bring about their completion in an orderly way.

We endorse for scientific, as well as practical reasons, the adjustment of the North American Vertical control network. . . .

The committee endorses the efforts of the National Geodetic Survey to systematize, update and adjust the national horizontal and vertical control networks. . . . these data constitute a valuable framework for decades to come.

The dynamic nature of the vertical control network demands that a valid readjustment include a framework of newly observed leveling data. With this in mind, NGS has identified and is in the process of replacing destroyed bench marks and releveling 100,000 km (62,000 mi.) of leveling lines. NGS is also actively encouraging state and local agencies to participate in this phase of the program. These data, together with slightly older leveling data that are consistent with the new work, will form the framework of the improved network. To date 30,000 km of leveling have been accomplished. The total field releveling effort is scheduled for completion in September 1987.

Another major effort was the conversion of descriptive and observational data from paper copy (primarily field records) to computer-readable form. The key-punching of the descriptions of the 600,000 bench marks comprising the network was completed in January 1980. The conversion of existing (archival) leveling, dating back to the turn of the century, has just been completed (June 1982). These milestones mark the completion of two of the major "office" efforts.

Other important tasks not yet completed include (scheduled completion dates are shown in parentheses):

- Determining scaled geographic positions for the 600,000 vertical control points (September 1984).
- Observing or interpolating gravity values for the 600,000 points (September 1985).
- Completing provisional (clean-up) analysis and adjustment of the points (September 1987).
- Determining improved elevations for the points by a general least-squares readjustment. Publishing and distributing the descriptions and improved elevations on the North American Vertical Datum of 1988 (September 1988).

In addition, major efforts will be expended in: producing software (computer programs) to manipulate, analyze, edit, store, adjust, and distribute the data; researching and correcting for systematic errors in the data, e.g., properly accounting for atmospheric refraction effects; assessing the relationship between tide and water-level observations and conventional precise leveling; and maximizing field leveling progress while maintaining acceptable quality. These and other topics, including bench mark monumentation, survey instrumentation and procedures, field recording systems, height systems, datum definition, and periodic status reports, will be presented in future issues.

As you read the articles in this series, I would welcome your comments concerning additional topics that would be of general interest to the readers of the *ACSM Bulletin*. ■

METRIC CORNER continued

Would it not be confusing if surveyors were to retain a system different from that of the future planner, designer, architect, builder, geodesist, and other scientists? Will it not be cheaper in the long run to have just one system for all? And what about condominiums? Riparian rights? Tidal benchmarks? Mill rights? Reservoirs? Flood insurance? Mine surveying? Pipe lines? Is it not wise to advocate only one system for both First Order and Third Order control? One system for both horizontal and vertical boundaries?

As a Minnesota county recorder remarked "Those (of us) working in the Land Records Industry are in the unique situation where we are inevitably and forever tied to the use of past, present, and any future new units of measurement."

There is no easy way out. Ignoring or fighting SI will not solve the problem. Admit it, Charlie, land surveyors, both ordinary and not so ordinary, cannot afford to stay behind alone.

Dr. Whitten, first chairman of the ACSM Metric Committee, has reminded us that the surveyor of the future must be trained to think "globally."

Let me assure you that neither I nor my committee are "obsessed to impose the metric system" on you. We are merely concerned surveyors who in the best public interest and in the best professional tradition are trying to pave the way for a painless transition into a system which is as inevitable as progress itself.

Sincerely,

GUNTHER GREULICH

P.S. My first name has nothing to do with that either, nor am I related to that Gunter, whom you think of as an "idiot" and whom you pointed out was the one "who dreamed up the decimal chain unit long ago," although I wouldn't mind if I were—Cheers!

- **Remember:**
  1 foot (Industrial/industrial) = 0.3048 m
  1 U.S. Survey foot = 0.30480061 m approx.

[**Ed. Note:** See Charlie's letter to Gunther Greulich under heading "What They Say," this issue.] ■

The New Adjustment of the North American Vertical Datum

Article No. 2
International Cooperation

by Gary M. Young
Assistant Chief, Vertical Network Division

National Geodetic Survey, NOS, NOAA
Rockville, Maryland

The first article in this series, written by Charles T. Whalen of the National Geodetic Survey, appeared in the June 1982 issue of the *ACSM Bulletin* and provided an overview and a brief history of the new vertical adjustment program, plus an introduction to some of the future topics. This present article focuses on the international cooperation required to complete the tasks that will provide improved elevations for the geodetic vertical control points (bench marks) that will be referenced to the North American Vertical Datum (NAVD). The new adjustment is scheduled for completion in 1988. If all countries cooperate, geodetic-quality elevations, based on a single, consistent height reference system, will be available for the first time for North America.

The international cooperation needed to accomplish this major geodetic task is already underway. Several meetings have been held with our Canadian and Mexican counterparts to determine the most appropriate "boundary monuments" to connect the countries' vertical control networks. Through the auspices of the Pan American Institute of Geography and History (PAIGH) and with strong support from personnel at the Defense Mapping Agency's Inter American Geodetic Survey Cartographic School, the First International Conference on the Redefinition of the North American Geodetic Vertical Network was held at Fort Clayton, Canal Zone, in January 1979. The conference was attended by representatives from Canada, Costa Rica, El Salvador, Equador, Federal Republic of Germany, Guatemala, Honduras, Mexico, Nicaragua, Panama, United States, and Venezuela. This was followed in May 1980 by the Second International Symposium on Problems Related to the Redefinition of the North American Vertical Geodetic Networks in Ottawa, sponsored by the Canadian Institute of Surveying, and the Surveys and Mapping Branch. Representatives from 21 countries attended. A third international conference is tentatively scheduled for 1985.

Early in 1982, Canada and the United States reached agreement on many of their cooperative efforts for the new adjustment and signed a formal Memorandum of Understanding concerning the NAVD 88 readjustment project. The agreement, which was signed by officials of the Canadian Surveys and Mapping Branch and the U.S. National Oceanic and Atmospheric Administration, stated:

Adoption of a Common North American Vertical Datum (NAVD 88)

Purpose and Participants

The National Oceanic and Atmospheric Administration, an agency of the Government of the United States of America, and the Surveys and Mapping Branch, an agency of the Government of Canada (hereinafter the "parties"), both having responsibilities in the geodetic field and both desirous of ensuring the adoption and implementation of a common geodetic vertical datum by the two agencies, agree as follows:

1. The parties agree to cooperate in the 1988 North American Vertical Datum (NAVD 88) project and work toward its completion by the end of 1988.

2. The parties agree to coordinate and share research and development related to the project.

3. The same reference surface, as near the geoid as practicable, will be used by both parties as the common datum.

4. The practical or technical realization of a common NAVD will be defined by both parties and will be determined and adopted in a mutually agreeable manner.

5. Both parties agree to adopt the same system of heights and to use compatible mathematical models of corrections to account for systematic errors in the observation of height differences and compatible procedures to incorporate tidal, gravitational, and atmospheric loading effects.

6. For the common adjustment, both parties agree to provide potential differences, based on observed gravity and elevation differences, corrected for systematic error.

7. The parties will agree on the "border junction points" to be used in the adjustment and will confer on the other details associated with the adjustment. For this purpose, their representatives shall meet at least once each year until the completion of the project.

8. The parties agree to utilize NAVD 88 upon completion of the project or as soon as practical thereafter.

9. The rate at which new maps and charts will incorporate NAVD 88 will vary between the parties and will be determined in each case by practical and economic considerations.

10. Costs incurred under this agreement shall be borne by the party incurring such costs.

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• Reply to "The Law Dictates Procurement Practice, Not Personnel" [*ACSM Bulletin*, No. 78, June 1982, p. 41, letter from William C, Sheffield, Jr., in reply to Guillemette letter]. I get the impression that some surveyors in the employ of the various Forest Service areas took my remarks personally [*ACSM Bulletin*, No. 75, Nov. 1982, p. 54]. I was talking about the *system*.

If some private sector surveyors are climbing on bounds set in the field, and these bounds are not yet recorded, then they have forgotten or do not know one of Walter's (Robillard) axioms. "Finding (and using) an unrecorded bound is worse than no bound at all."

One question I have is, what are all those bounds doing out there before the survey is completed? Are surveyors putting the cart before the horse?

In your reply, you made two statements: "...and their (Agencies) respective counsels who have assured them that what they do is not *illegal*" and "...we do not operate under, but *they are legal*" (italic emphasis added).

Because something is "not illegal" or "legal" doesn't necessarily imply an imprimatur of "ethical" or even "professional." If you do not like many of the practices that you must enforce, what are *you* doing to correct them?

The Forest Service and other government agencies who contract with private surveyors on the basis of "low bid" should be the first in line to endorse the Proposed Modifications for Surveying Procurement Procedures. (See the abstracts on the page facing your letter in the *ACSM Bulletin*).

Jim Weidener's article, in the same issue, is far more eloquent in saying what I mean. Read it, then read it again.

By the way your "unique" southern phrase "fish or cut bait" is known here in the North, also. The way it is now, Government agencies have all the fish (private surveyors) in a barrel and are using a shot gun.

The system is wrong. Let's change it.—Pierre H. Guillemette, P.L.S., 176 Greenwood Ave., Rumford R.I, 02916.

• Professional Ethics Committee Polices Ad Claims. Dear Mr. McGarvey [Frank X. McGarvey, president, Micron Corporation]: A number of complaints have been received from registered professional surveyors objecting to advertising claims promoting the sale of the above equipment. The profession of surveying requires special training and experience plus a demonstration of competence as a prerequisite to obtaining a license to practice in a state. Standards of performance have been adopted and are enforced by most states.

The claims set forth in your advertising indicating 99+ percent accuracy and the ability to "do the same job as an entire survey crew" are misleading and cannot be supported. The standards of performance cannot be compared because of the great difference in accuracy. This device may be compared to the measuring wheel producing dimensions within that range of tolerance, but it cannot be compared with the precision achieved by today's registered professional surveyor.

It, therefore, is requested that the advertising for this device be revised to eliminate the improper reference to surveys. The Micron will not do the same type of survey the registered professional will perform and neither will the survey be certified and accepted by title insurance companies, abstractors, and attorneys. Yours sincerely, Leonard L. Lampert, chairman, NSPS Professional Ethics Committee. [February 10, 1982]

Dear Mr. Lampert: Thank you for your letter of February 10, 1982. I appreciate your concern about our advertising on the Micron Surveyor.

I believe that this is a case where our advertising agency have been overzealous in an attempt to establish our product in another market. The unit is quite accurate in measuring distance and area, but it certainly will not replace an entire survey crew. I have requested that our advertising agency change the advert to conform with reality and I can assure you that once the initial advertising has been run, the next series of adverts should meet with your approval. Very truly yours, Frank X. McGarvey, president, Micron Corporation. [March 4, 1982]

[Note: A phone call was made to the agency requesting that one line be removed in the revised ad, which seemed misleading. The change was made immediately.—*Ed.*]

[Another letter will appear in this column concerning this matter in the next issue of the *ACSM Bulletin*. Watch for it! It is a superb letter from William B. Marum, P.L.S.—*Ed.*] ■

The New Adjustment of the North American Vertical Datum—continued

11. It is understood that the ability of the parties to implement this agreement is subject to the availability of appropriated funds.

12. This agreement may be amended at any time by the mutual consent of the parties concerned.

13. This agreement will become effective upon the signature of both parties and will remain in effect until terminated by mutual agreement or upon 30 days' written notice by either party to the other.

14. Nothing herein is intended to conflict with respective laws and regulations applicable to each of the parties. If the terms of this agreement are found inconsistent with existing regulations or law applicable to each of the parties, then those portions of the agreement which are determined to be inconsistent shall be invalid; but the remaining terms and conditions of this agreement not affected by any inconsistencies, shall remain in full force and effect.

This Memorandum of Understanding is important for three reasons: It not only indicates, in general terms, several of the highly technical aspects of the new adjustment, but documents the commitment of Canada and the United States to undertake and complete the new adjustment project. Equally significant, it demonstrates an understanding of the multilateral nature of the venture.

All agencies that will be involved in the NAVD 88 adjustment project are encouraged to reach similar agreements with their neighboring countries in order to provide formal commitment to the project. ■

The New Adjustment of the North American Vertical Datum

Article No. 3
The NAVD 88 Project in Canada

by Fred W. Young
Head, NAVD Project Section

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Surveys and Mapping Branch
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The North American Vertical Datum (NAVD 88) project in Canada is the redefinition and readjustment of the geodetic vertical control network. The primary network is to be adjusted as part of the North American vertical readjustment in cooperation with the U.S. National Geodetic Survey. Following the adjustment of the primary network, an adjustment of the secondary control will be coordinated by the Geodetic Survey of Canada (GSC), but with the provinces assuming responsibility for work within their boundaries.

The need for such a project is most apparent. Our national vertical control datum has remained unchanged since it was established in 1928, based on mean sea level as determined from hydrographic tidal records at five coastal stations. The 1928 network has been augmented by the addition of more than 83,000 km of first-order leveling with no comprehensive national readjustment. Also, many secondary and lower-order networks have been established by other federal, provincial, and municipal agencies. Several local readjustments have been carried out to minimize distortions caused by the need to fit new surveys to existing control. There are numerous weaknesses and anomalies evident in the overall network.

Canada's involvement in the NAVD project began in November 1976 when a study group was formed in the Geodetic Survey Division to investigate problems related to the existing vertical reference system. In June 1977, an internal report was produced, entitled "Recommendations for the Redefinition of the Vertical Reference System in Canada," by G. Lachapelle, D. Boal, N. Frost, and F. Young. An immediate step taken was the initiation of contracts, through our Earth Physics Branch, to make extra gravity measurements along leveling lines in mountainous areas. This would complete the gravity coverage necessary to ensure that gravity interpolation could be done without undue systematic effects on the computation of geopotential values. The work is expected to be completed in 1983.

In September 1977, a 3-year research contract was negotiated with the University of New Brunswick to investigate problems related to the redefinition of the vertical reference system. Of major concern was the investigation of a 2.2-m discrepancy between old and new Trans-Canada leveling lines. This research was complemented by research and development within our division, and resulted in the automation (conversion from field books to computer-readable form) of all observed data related to the investigation. From 1977 to 1979, the Primary Vertical Control Section automated data for about 90,000 sections (nearly 30 percent of our primary geodetic vertical network). In 1980, a complete review of automation procedures and formats resulted in changes to make our automated data compatible with NGS data. Automation of data is continuing.

In December 1977, the study group produced its first status report, entitled "The Redefinition of the Vertical Reference System in Canada." This paper was rewritten by G. Lachapelle and published in *The Canadian Surveyor*, Vol. 33, No. 3, September 1979. The highlights of this report included the present status of the vertical control networks in Canada, related problems, the need and benefits of a redefinition, and a tentative plan for the redefinition.

In March 1978, at one of our annual technical exchange meetings with NGS, an agreement was reached that we would cooperate in a redefinition of the geodetic vertical control networks in Canada and the United States, and would invite other interested North American countries to participate. It was tentatively agreed that three symposia should be held: 1979, 1980, and 1984.

The first symposium was held at Fort Clayton, Canal Zone, in January 1979. This was basically a workshop-type symposium with the main purpose being to exchange information on the status of the vertical networks in the countries likely to participate in redefining the North American vertical network, and to prepare a list of tasks to be accomplished for successful completion of the program. Some 32 delegates from 12 countries attended; 18 papers were presented.

The second symposium, held in Ottawa, May 1980, was attended by more than 160 participants from 21 countries; 62 papers were presented during six technical sessions. The objective of the symposium was to discuss problems related to the computations and adjustment of geodetic leveling networks and the definition of reference systems. Following the symposium, GSC prepared the first NAVD Project Plan covering all activities associated with the continental readjustment.

In 1981, discussions with NGS led to the drafting, and later signing, of a formal Memorandum of Understanding regarding "Adoption of a Common North American Vertical Datum (NAVD 88)." In September 1981, a special NAVD

Project Section was formed to fulfill our commitment to the new adjustment project.

The NAVD Project Section is comprised of two subsections. The Data Automation Group carries out the preparation of data to be evaluated and analyzed by the Data Analysis Group. Data preparation includes the extraction of observed data from field books and other pertinent data from existing abstracts and historical files, and storing these data on computer files to be retrieved for analysis and adjustment at a later date.

The first task performed by the Data Analysis Group was to design a primary vertical framework in Canada that is compatible with that of the United States. The loops in the southern part of our network are generally consistent in size and shape, up to about 300 km across. The northern loops are somewhat larger due to natural restrictions, such as a lack of suitable routes for first-order leveling. The density of secondary vertical control is generally suitable for present needs.

For the continental readjustment, the basic net in Canada will consist of about 55,000 km of first-order leveling lines, compared to about 100,000 km in the U.S. Basic Net A. Another 75,000 km of first-order leveling will be integrated into the basic net.

Further discussions with NGS are required to finalize data compatibility, to determine the criteria for acceptance of the work in the basic net, and to agree upon the corrections to be applied to the observed data.

Preliminary analysis of leveling lines in the basic net will determine the need for any additional field work required to ensure that all leveling lines will meet specifications. The Primary Vertical Control Section is responsible for the necessary field work. Some 3,800 km of primary leveling in Nova Scotia have been designated as a "Test Net" for the purpose of designing analysis procedures. This net represented about 6 percent of the total basic net and consists of leveling done since 1952. We are presently investigating the changes in loop closures and section discrepancies due to the application of various corrections to observed data.

Other studies being conducted or coordinated by the Geodetic Survey of Canada include:

- the use of the newly acquired motorized-leveling capability to improve production and/or quality;
- the incidence of systematic errors;
- the use of water transfers, especially in northern areas where leveling on land is not feasible; and
- the development of software for the automated recording and analysis of field data.

Crustal movement studies and systematic error investigations are in progress at universities through research contracts with our department.

Future activities of the NAVD 88 project include the selection of an appropriate datum and height system to be used in the readjustment, integration procedures for secondary and lower-order vertical networks, and the filing and distribution of adjustment results. ■

The New Adjustment of the North American Vertical Datum

Article No. 4
Program Cost

by Steven A. Vogel

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The task at hand, the resurveying and simultaneous adjustment of virtually all the primary lines of the National Geodetic Vertical Network, is admittedly a huge and costly undertaking. Its value to the Nation, however, will be more than realized as a result of universal cost savings by eliminating duplicate surveys and costly adjustments performed by a variety of federal, state, and local agencies, in addition to minimizing the propagation of inaccuracies from the National Geodetic Vertical Datum of 1929 into newer survey data.

The National Geodetic Survey (NGS) published an issue paper in June 1975, entitled "Releveling of the Vertical Network," specifying a plan for releveling and readjusting the national vertical network. According to that plan, the releveling and new adjustment could be accomplished with $17.5 million in new funding ($3.5 million each year for 5 years) and a total of $1.7 million of reprogrammed NGS funds over a period of 6 years, for a total program cost of $19.2 million. The field survey portion of the plan comprises 67,000 km of leveling, 26,000 km of which had been recently surveyed, leaving 41,000 km of first-order, double-run leveling to be completed for the program.

The budgetary initiative calling for the program to begin in fiscal year 1977 was not approved. The plan was revised in June 1976 to accomplish a similar objective with $18.2 million in new funding ($2.6 million each year for 7 years) and a total of $1.8 million of reprogrammed NGS funds over a period of 8 years, for a total of $20.0 million, with the additional funding required as a result of inflation and the longer time period. The revised plan was approved, and the program began in fiscal year 1978 (October 1, 1977). That plan also provided for 41,000 km of double-run leveling, covering approximately one-half of the Nation's first-order vertical network.

Late in 1976 NGS adopted a new field method for resurveying the vertical network: first-order, class II, single-run leveling, using the "double-simultaneous" technique. The new method would allow NGS to resurvey most of the primary lines of the first-order network with the limited funding available for the releveling program.

The releveling program using the new single-run procedure encompassed 100,000 km of primary leveling lines, compared to 41,0000 km in the original plan. This new approach to the releveling program brought the additional capability of replacing missing and "disturbed" survey marks over most of the primary vertical network, rather than over a relatively small portion of it. NGS realized that these major changes in the releveling program would mean higher overall program costs, but we also knew that the higher costs would be more than offset by the comprehensive network coverage afforded by the 100,000-km releveling plan.

At the outset of the releveling program in 1978, NGS undertook a comprehensive study of vertical control point (bench mark) stability. As a result of the study, NGS developed a new stainless steel rod mark encased in a polyvinyl plastic pipe, replacing the copper-clad steel rod marks previously used by NGS. This change increased the overall cost of the releveling program as envisioned in the original plan, but also ensured a much greater degree of control mark stability.

The long-term result of using the new bench mark will be cost-effective because the new marks resist movements from surface impact, frost heave, soil expansion and contraction, and a variety of other local effects. Accordingly, the longer life of these marks will reduce the overall cost for establishing and maintaining a reliable system of precisely determined elevations nationwide.

Despite the factors mentioned previously that contribute to increased overall program costs, NGS experience in conducting large-scale field survey programs and concern for efficiently using its limited field forces have enabled us to cope effectively with these inflationary factors. A recent study of the first 3 full years of the NAVD releveling program, 1979 to 1981, showed that per-person leveling productivity had increased by 13 percent from 1980 to 1981, and by 47 percent from 1979 to 1981; the field cost per kilometer surveyed (setting marks and leveling) decreased by 7 percent from 1980 to 1981; and the cost of setting marks per kilometer surveyed decreased by 10 percent from 1980 to 1981. The increasing skill of NGS leveling and mark setting personnel in conducting a massive field program with relatively new procedures is evidenced by these cost and productivity figures.

Moreover, these trends are continuing. We expect a 10 to 15 percent increase each year in per-person leveling productivity through 1983 as we continue to augment the efficiency of our field operations with more motorized leveling units and with improved hand-held field data collectors/computers to encode, compute, and verify leveling observations.

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Sustaining Members' NEWS

Scitex Announces New Capabilities for Automatic Digitizing, Plotting

Scitex America Corporation has announced enhancements to their Response-180 product line for data capture and display.

The R-280/DGS automatic digitization subsystem, which scans and converts color or monochrome maps, photographs, or other graphics into vector form for input to CAD systems, has been augmented with new digital analysis software for post-processing of the vector data. Called "DIANA," the software is used to (1) adjust the placement of nodes at junctions, (2) unify lines broken into segments into single lines, (3) recognize arcs and circles, (4) recognize clusters such as crosshatching, and (5) recognize text.

The R-280/output subsystem, which translates vector data into raster formed graphic-arts-quality symbols, text, lines area patterns and screens for output on the 42- × 73-in. Scitex laser plotter, has been expanded to include support for additional CAD formats, including Intergraph's Standard Interchange Format (SIF) and Gerber's 2000, 4000, and 6000 controller formats.

Brochures describing both subsystems are available by writing to Scitex America Corporation, Eight Oak Park Dr., Bedford, Mass. 01730.

Corrigendum: In the profile of Scitex America Corporation, a Sustaining Member of ACSM, carried in *Surveying and Mapping*, Vol. 42, No. 2, June 1982, p. 198, the word "systems" should be added to the first sentence: Scitex produces turnkey computer graphics *systems* for cartography and engineering graphics.

AGA Geodimeter Lowers Price of EDMs

Continued strength of the dollar in foreign exchange, particularly against the Swedish krona, has enabled AGA Geodimeter, Inc., to lower prices of its five mount-on EDMs by up to 34 percent.

For instance, Hans Edvardsson, product manager, noted that the top-of-the-line Geodimeter 122 instrument, which, mounted on a quality theodolite and with optional Geodat 122 data recorder, provides virtually all the operational attributes of a Total Station, is now available at $10,950. In fact, he added, considering its built-in instant true slope reduction feature, Tracklight, which allows the rodman to get on line quickly, and Unicom, one-way voice communication via the measuring light beam, it is more productive than most Total Stations. The new price offers a savings of almost $3,000.

The basic Geodimeter 110, traditional Geodimeter quality in a short-range instrument, is now priced at $3,950, compared to $5,995.

LKB Announces New Environmental Program Manager

Lockwood, Kessler & Bartlett, Inc., a Syosset, N.Y., consulting engineering firm, has announced that Alfred Angiola has joined the staff as environmental program manager. In this capacity he will be responsible for the firm's environmental assessments, industrial waste projects, and all permitting activities.

Prior to joining LKB, Angiola was regional director of the New York Office of WAPORA, Inc., a national environmental consulting firm. He also spent 8 years with Parsons, Brinckerhoff, Quade & Douglas, Inc., the last 3 years of which he was manager of the Advanced Technology Division. The first 5 years of Angiola's professional career were spent with the Grumman Aerospace Corporation. While at Grumman, he was named a Masters Fellow. He received his B.S. and M.S. degrees in civil engineering from Columbia University and has authored several publications. ■

Vertical Datum—continued from page 25

The NGS field cost for a kilometer of leveling (mark setting, observations, and field support activities) was essentially the same in 1981 as in 1977. In light of the unavoidably higher cost for labor, equipment and supplies, travel, per diem, and data transmission during that period, this cost stability is testimony to the combined diligence of our field and office personnel, whose innovations continue to maximize productivity without compromising quality.

The labor-intensive and computer-intensive tasks required for the office portion of the new adjustment are being accomplished almost entirely by NGS personnel. A major milestone of the NAVD program, the conversion of more than 750,000 km of archival survey data to computer-readable form, was recently completed at a cost of approximately $2.50 per point. The preliminary adjustment is approximately 10 percent completed and is being accomplished at a cost of about $16.50 per point. Another integral data processing task is the preparation of new field leveling data for adjustment (110,000 km), at an average cost of $20.50 per kilometer.

NGS is in the midst of a large and costly program to resurvey the primary lines of the National Geodetic Vertical Network and readjust the entire height system. The expansion of the original network releveling plan from 41,000 to 100,000 km and the use of new stainless steel rod marks will significantly increase the overall NAVD program costs, compared to those envisioned in the June 1975 issue paper. The alternative—delaying the releveling and the new adjustment—would be much more costly. The early detection and monitoring of vertical crustal movement is essential to protecting human life, property, natural resources, inland navigation routes, and wildlife habitats. Only with an up-to-date and reliable record of height changes can corrective measures, such as early warning and flood control systems, be effectively planned and executed. The costs may be large, but the benefits are widespread and vital. ■

The New Adjustment of the North American Vertical Datum

Article No. 5
The Processing of Archival (Historic) Leveling Data

by John H. Till
Chief, Vertical Projects Section
Vertical Network Branch

National Geodetic Survey Division
NOS, NOAA
Rockville, Maryland

This article details the effort being expended by the National Geodetic Survey (NGS) in converting its archival leveling data, dating back to the turn of the century, into computer-readable form. The processing of archival leveling data can be broken down into three distinct stages. The first stage is the conversion to computer-readable form of all original leveling data held by NGS. The second stage is the editing, validation, review, and correction of these data. The final stage involves the application of a unique identifier to each bench mark on all lines of leveling. The unique identifier is designated Archival Cross Reference Number (ACRN). The remainder of this article will expand on each of these three categories of processing archival leveling data.

In 1975, under the supervision of Mr. Charles L. Gilliland, and with the assistance of Ms. Grace C. Sollers, NGS began retrieving all its original leveling records held in the National Archives and the Washington Federal Records Center. Because of the large volume of data (approximately 50,000 field books), it was necessary to acquire the data over a period of several years. The retrieval of data was accomplished on a state-by-state basis, following the manner in which the data were stored in the archives. Because this undertaking involved a large volume of data, it was decided that instead of keying individual leveling-rod readings, as is presently done with new NGS surveys, only the stadia intervals, section elevation difference, date, time, "sun code," "wind code," temperature, and number of setups would be converted to computer-readable form.

The conversion to computer-readable form was initiated using personnel of the Vertical Network Branch. After a period of about 1 year, it was decided that these personnel would not be able to key the observations within the time frame set for the readjustment of the North American Vertical Datum. Subsequently, in July 1976, a private contract was awarded to convert and validate the archival leveling data. In April 1978, this contract was replaced by one which was responsible for keypunching only. (It was learned from the original contract that data validation was best accomplished by NGS.) Beginning with the second contractor, the Vertical Network Branch provided direct technical supervision of the conversion to computer-readable form, and was solely responsible for the validation and review processes. This proved to be very successful. In January 1982 the conversion of all NGS archival leveling data to computer-readable form was completed.

The data were processed through a series of computer programs which included "range" checks on individual data fields to assure the data were "reasonable." Verification of the leveling observations was accomplished by computer recomputation of the leveling lines. The resulting computations were compared against abstracts of the original field computations. Comparisons between individual section lengths and between individual section elevation differences are two of many checks the programs accomplish. The programs also indicate excessive corrections for instrument collimation. When a leveling line is double run, additional comparisons are made. In comparing a forward run against a backward run, the program indicates (1) when the running distances differ by more than 0.05 km, (2) when the number of instrument setups varies by more than five for the section, and (3) when no forward/backward pair can be found within the proper tolerance limit. The editing, validation, and review of all archival leveling data were completed in November 1982.

Assignment of ACRN's is accomplished by matching the bench mark designations of the individual leveling lines with those residing in a "master" file. The master file was derived from published bench mark descriptions. The "mismatches" encountered are then resolved. The master file also contains the geographic position of each bench mark. As a further check on the bench marks' geographic positions and the assignment of ACRN's, stadia distances are compared against distances computed from the geographic positions. The data are then transferred to the NGS geodetic data base. This task is scheduled for completion in March 1986.

NGS has processed more than 15,000 archival leveling lines through the first two stages of processing. These leveling lines contain approximately 1,300,000 km (including "reruns" and double-running") of leveling observations. The North American Vertical Datum readjustment project is scheduled for completion in 1988.

CURRENT NOAA GEODETIC PUBLICATIONS

The National Geodetic Information Branch sells NOAA serialized geodetic publications, selected publications of the Federal Geodetic Control Committee, and many works of the former Coast and Geodetic Survey. To obtain a price list, telephone (301) 443-8316 or write NOAA/National Geodetic Information Branch, Rockville, Maryland 20852.

NOAA Manual NOS NGS 3, Geodetic leveling, by M. C. Schomaker and R. M. Berry, 209 pp. (unbound), 1981, $9.00.

Input Formats and Specifications of the National Geodetic Survey Data Base, Federal Geodetic Control Committee, Vol. I—Horizontal control data, $11.20; Vol. II—Vertical control data, $9.00

NOAA Technical Memorandum NOS NGS 37, Vertical movement in the Los Medanos and Nash Draw area, New Mexico, as indicated by 1977 and 1981 leveling surveys, by E. Balazs, 18 pp., $2.60.

NOAA Technical Report NOS 95 NGS 24, Proceedings of Symposium No. 5: Geodetic applications of radio interferometry. International Association of Geodesy, May 7-8, 1982, Tokyo, Japan, W. E. Carter (convenor), A. Tusuchiya (co-convenor), 334 pp., $14.00.

NOAA Technical Report NOS 96 NGS 25, Allocation of inertial surveying system model parameters, by C. W. Challstrom, 94 pp., $4.85.

NOAA Technical Report NOS 97 NGS 26, An inertial survey adjustment program: implementation and validation by E. Milbert (in press).

NOAA Technical Report NOS 98 NGS 27, Preliminary data analysis of inertial survey system test in southwest Arizona, by G. E. Leigh (in press).

Availability List of Geodetic Publications, by G. Sollers, 16 pp. (free). ■

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The New Adjustment of the North American Vertical Datum

Article No. 6
NAVD 88 Status Report

by Gary M. Young

National Geodetic Survey
Charting and Geodetic Services, NOS, NOAA
Rockville, Maryland

This series of articles, the first of which appeared in the June 1982 issue of the *ACSM Bulletin*, has thus far provided general background information as well as further detail for specific topics. The previous articles were:

1. "Introduction" by Charles T. Whalen: June 1982
2. "International Cooperation" by Gary M. Young: August 1982
3. "The NAVD Project in Canada" by Fred W. Young: October 1982
4. "Program Costs" by Steven A. Vogel: December 1982
5. "The Processing of Archival (Historic) Leveling Data" by John H. Till: February 1983

This article provides an update of the progress by the National Geodetic Survey (NGS) on the North American Vertical Datum of 1988 (NAVD 88) readjustment project. The article will identify many of the major tasks that have been completed, are underway, or scheduled as future initiatives.

The first major "office" effort to be completed was the conversion to computer-readable form of NGS archival descriptive data for 457,000 bench marks in the National Vertical Control Network. These data include type of monument, stamping, instructions to recover the mark, and other descriptive information. The task was begun in early 1976 and completed in January 1980.

As stated in the article by John H. Till, the conversion to computer-readable form of NGS archival observational leveling data was begun in 1975 and completed in January 1982. The preliminary editing, validation, and review of these data were completed in November 1982. These data involve 15,000 lines of leveling containing a total of 1,300,000 km (808,000 mi.) of first- and second-order leveling.

The dynamic nature of the vertical control network requires a framework of newly observed elevation differences in order to obtain realistic contemporary height values from the readjustment. To accomplish this, NGS has selected 100,000 km of the network for releveling. Replacement of disturbed or destroyed monuments precedes the actual leveling. Field leveling is being accomplished to first-order, class II specifications, using the "double-simultaneous" method. An increase in leveling progress (while maintaining acceptable accuracy) is being accomplished by equipping NGS field leveling units with specially modified subcompact trucks for rodmen as well as observers. This form of "motorized" leveling promises to increase production by at least 30 percent as compared to former leveling procedures. To date, nearly 40,000 km of leveling progress have been accomplished. Completion is scheduled for September 1987.

In order to provide automated retrieval capability and apply position-dependent corrections to the observations, a geographic position (latitude, longitude) must be determined for each bench mark. For those monuments not connected to the horizontal control network, the effort involves plotting bench marks on appropriate maps (using the descriptive data mentioned previously) and then determining a "scaled" position using digitizing equipment. To date, positions have been determined for 325,000 of the 600,000 bench marks in the vertical control network. Completion is scheduled for September 1984.

Significant progress has been made to account for atmospheric-refraction error. This error, which until recently was considered insignificant, has been found to be of such magnitude as to invalidate many previous investigations of aseismic crustal motion, e.g., in many areas of California. In mid-1981, the U.S. Geological Survey (USGS) and NGS participated in a cooperative leveling survey to: determine the magnitude of the discrepancy between elevation differences observed using both "short" and "long" sight distances for an identical line of leveling between Saugus and Palmdale, California; determine if existing atmospheric-refraction correction models would minimize the differences between observations obtained with short- and long-sight lengths; and determine the adequacy of temperature-difference mathematical precision *models* as compared to *observed* temperature differences.

Based on this survey (a distance of 50 km), a refraction correction using observed vertical temperature differences reduced the discrepancy between the short- and long-sight surveys from +51.0 mm to −4.8 mm, while the correction using modeled (predicted) temperature differences reduced the discrepancy to +6.4 mm. This result implies that much of the so-called "Palmdale Bulge," which has been the subject of debate for several years, could be the result of leveling refraction error.

NGS has begun observing vertical temperature differences for all new leveling surveys and now applies a refraction correction based on these observed temperature differences. For past surveys (for which temperature differences are not available), corrections will be applied using modeled temperature differences.

Several investigations must be completed prior to the readjustment. Some of the most important events (with proposed completion dates shown in parentheses) are:

• Determine the influence of the Earth's magnetic field on precise surveys performed with compensator (automatic) leveling instruments (April 1983).

• Develop and/or evaluate mathematical models to accommodate regional aseismic vertical movement of the Earth's surface (October 1983).

• Determine the proper *a priori* standard error estimates for leveling observations, accounting for the wide range of instrument types and observational procedures that have been used to develop the network (October 1983).

• Investigate the role that Global Positioning System (GPS) data can play in strengthening the vertical control network (October 1984).

• Determine the optimum use of tide gage and water level data for the readjustment (October 1985).

• Select height system/datum for the readjustment (October 1985).

Other tasks required by the readjustment include:

• Observing or interpolating gravity values for the 600,000 bench marks in the network (September 1985).

• Completing provisional analysis and adjustment of the network (September 1987).

• Completing a general least-squares adjustment of the network. Publishing and distributing the descriptions and improved heights referred to NAVD 88 (September 1988).

Many of the items mentioned here will be topics of future articles in this series. Your questions and comments are welcome. Write to: National Geodetic Survey (N/CG13), National Ocean Service, NOAA, Rockville, Maryland 20852. ■

The New Adjustment of the North American Vertical Datum

Article No. 7
The Processing of Descriptive Leveling Data

by Michael W. Day

Chief, Vertical Data Section
National Geodetic Information Center
National Geodetic Survey, NOS, NOAA
Rockville, Maryland

As part of the National Geodetic Survey's (NGS) program to readjust the National Geodetic Vertical Network, descriptive data for "active" bench marks have been converted to computer-readable form (automated). This article gives a brief history of how the task was accomplished and the current status of these data files.

Keying such large data files is highly labor-intensive and of relatively short duration. Athough NGS had begun keying descriptions as part of its effort to automate publication procedures, personnel ceilings eliminated the possibility of in-house completion of the project in time to support the readjustment project. Contracting the work proved to be a viable alternative.

In early 1975, NGS applied for and received 1 year of funding under an amendment to the Public Works and Economic Development Act of 1965. The legislation required the funds be spent in an area of high unemployment. Detroit, Michigan, was selected as the potential contract site and the Department of Commerce solicited bids on the project. By January 1976, the contract was awarded.

Preliminary preparation included finalizing formats, preparing conversion instructions, and selecting an on-site technical representative. Descriptions were organized into job-code areas based upon their geographic location within blocks of 1-by-2 degrees of latitude and longitude. The descriptions were sequenced by line numbers in the order desired for publication, updated with recent recovery reports, edited for data omissions or obvious errors, and assigned unique identifiers (designated archival cross-reference numbers). This identifier was to serve as the link between bench mark data stored in various computer files. Preprocessing of descriptions had to be completed at a rate at least equal to the contractor's production rate.

The contractor assumed the responsibility of returning automated descriptions (in the sequence submitted) in separate data sets corresponding to the job code area. Acceptable error rates were stipulated to be less than 0.3 percent per data set. All data were key-verified and copied to magnetic tape for shipment. Agency personnel proofread a sample of submitted data sets. Software was developed to read each data set and check for format errors or data omissions. Despite lost data shipments, a parcel delivery service strike, and tornado damage to the contractor's plant, this contract was successfully completed in March 1977 with a minimum of data-set rejections.

Approximately 60 percent of the active descriptions contained in agency files were automated at a cost of $330,000. In October 1977, a similar contract was awarded to a Rockville, Maryland, firm. Work proceeded smoothly, and by January 1980, the entire file had been automated. A total of 457,000 stations had been keypunched over the 4-year period at an approximate cost of $600,000.

Today all new station descriptions and recovery notes are automated by NGS as standard operating procedure for all new field projects. This information is merged into existing files with software programmed to adhere to specifications as stated in the Federal Geodetic Control Committee's publication *Input Formats and Specifications of the National Geodetic Survey Data Base*, Volume II: Vertical Control Data. The descriptions reside on five off-line disk packs and can be retrieved by archival cross-reference number, state, quadrangle, or county.

NGS has derived several benefits from this automation effort. Data formats are now standard, and retrieval of descriptions can be accomplished from any remote site equipped with a computer terminal and telephone communication line. Updating or correcting is easily accomplished by batch programs or text-editing software. Physical storage of the descriptions has been reduced to a fraction of the original space requirement. Because the data are machine readable, automated publishing methods have been adopted, including the use of sophisticated printing equipment. Copies of publications can be microfilmed to reduce costs further, and large inventories of surplus paper copies are no longer necessary.

To obtain further information on data formats or to order automated geodetic data, telephone (301) 443-8658 or write: National Geodetic Information Center (N/CG17), National Geodetic Survey, National Oceanic and Atmospheric Administration, Rockville, MD 20852. ■

The New Adjustment of the North American Vertical Datum

Article No. 8
Survey Plans for Basic Net A

by Emery I. Balazs

Vertical Network Branch
National Geodetic Survey, Charting and Geodetic Services, NOS, NOAA
Rockville, Maryland

This article discusses the major criteria for selecting lines for releveling in preparation for the North American Vertical Datum of 1988 (NAVD 88). A 1975 National Geodetic Survey (NGS) issue paper, entitled "Releveling of the Vertical Network," described the need for the redefinition of the National Geodetic Vertical Datum, and stated that a major part of the network, a "basic framework," must be releveled. This basic framework, now called Basic Net A, was designed to provide maximum benefit to users, without significantly affecting network geometry. Loop sizes, connections to tide stations, and connections to the Canadian and Mexican Geodetic Vertical Networks were influenced by anticipated future requirements in certain areas. Areas of high priority were coastal areas, major rivers and transportation routes, densely populated areas, and seismically active zones.

The program to readjust the National Geodetic Vertical Network and relevel 41,000 km of the more than 100,000 km of first-order lines was approved in 1976. In order to provide a denser basic framework and replace missing bench marks on most of the first-order leveling lines in the network. NGS developed and tested (in late 1975) a new method of leveling. Using state-of-the-art instrumentation and an automatic on-site data recording system, NGS survey teams leveled (single run) a 100-km test line four times using the new procedure, designated the "double-simultaneous" method. Comparison of the observed elevation differences of each single-run survey to the mean differences of the other three surveys showed no significant change in results when the line was measured in one direction only. Based on the results of the test leveling, NGS decided to relevel in one direction (single-run) 100,000 km of the network using the double-simultaneous method, instead of releveling 41,000 km using a double-run procedure. Only those lines (spurs) which do not form closed loops will be leveled in both directions. Lines are being observed according to first-order, class II specifications. The decision to "single run" the lines greatly affected the selection of lines for releveling because, with the double-simultaneous method, practically all first-order lines of the existing network could be releveled for the approximate cost of the previously approved program.

Some first-order leveling lines considered for inclusion into Basic Net A had already been releveled. About 26,000 km of leveling data, observed since 1963, were provisionally accepted as part of Basic Net A. These lines were establishing to first-order, class I specifications by observing with modern geodetic leveling instruments equipped with optical micrometers, and with double-scale Invar leveling rods. When such surveys agree with the newer surveys, evaluated primarily by loop misclosures, the data are included in Basic Net A.

Other major factors, in order of importance, which influenced the selection of lines for releveling, are:

1. **Age:** In an area where several first- and second-order lines are available, the line which has not been leveled for the longest period of time is usually selected.
2. **Geometry:** Guidelines for average loop sizes are 500 km in high-priority areas, 800 km in other areas. A few loops in the Rocky Mountain area, and in areas of low population density, are more than 1,000 km in circumference.
3. **Questionable Surveys:** Those lines of the Net where loop misclosures of previous surveys exceeded tolerance limits are selected.
4. **Population Density:** Loop sizes are reduced in areas of high population density to provide additional bench marks for users.
5. **Tide Station Connections:** All leveling lines connecting primary tide stations established by the National Ocean Service are selected if the tide station is less than 1 mi. offshore and/or less than 50 km from the nearest Basic Net A line. Secondary and tertiary tide stations are connected to a Basic Net A line if the leveling can be accomplished in ½ day or less.
6. **Border Ties to Canada and Mexico.** With the cooperation of the other nations of North America, NGS will participate in an adjustment of the geodetic vertical networks in North and Central America. Meetings have been held with representatives of the Geodetic Survey of Canada and the Dirreccion General de Geografia del Territorio Nacional (DGGTENAL) of Mexico to identify the most beneficial border junctions of leveling lines. Twenty-seven connections have been identified along the U.S.-Canadian border, and 13 along the U.S.-Mexican border.
7. **Accessibility to the Public:** Due to restrictions by railroad companies, as well as for safety reasons, NGS is relocating leveling lines from railroad right-of-ways to highways near the railroads. Also, interstate highways are not selected if a nonrestricted highway is available.

The decision to use double-simultaneous single-run lev-

continued on page 69

Conference & Exposition. Place: Washington, D.C. Convention Center

October 10-14

SORSA Forum. Sponsor: Spatially-Oriented Referencing Systems Assoc. Place: Univ. of Maryland, College Park, Md. Contact: Dept. of Geography, Univ. of Maryland, College Park Md. 20742.

October 18-21

Sixth International Symposium on Automated Cartography (Auto-Carto Six). Theme: Computer Assisted Cartography, International Perspectives on Achievements and Challenges. Sponsors: ACSM, ASP, National Commission for Cartography of the Canadian Institute of Survey, and several Canadian Government agencies. Place: Ottawa Hull Ont., Canada. Contact: Auto-Carto Six Secretariat, Dept. of Geography, Carleton University, Ottawa, Ont. K18 5B6. (613) 231-2652.

October 20-22

North American Cartographic Information Society. Place: Hyatt Regency, Wilwaukee, Wis. Contact: (program) Ron Bolton, NOAA/NOS, 8060 13th St., Silver Spring, Md. 20910, (301) 427-7650; (local arrangements) Christopher Baruth, AGS Collection, Box 399, UW-Milwaukee, Milwaukee, Wis. 53201, (800) 558-8993.

December 5-9

AGU (American Geophysical Union). Place: San Francisco, Calif.

December 5-9

Second South East Asian Survey Congress. Sponsors: Royal Institution of Chartered Surveyors (Hong Kong Branch) and the Hong Kong Institute of Land Surveyors. Theme: Regional Development Potential. Contact: Hong Kong Institute of Land Surveyors, P.O. Box 515, Kowloon Central Post Office, Kowloon, Hong Kong.

1984

January 23-25

Annual Surveyors' Conference. Sponsors: The Pennsylvania State University, University, Pa., in cooperation with the Pennsylvania Society of Land Surveyors. Contact: G. Warren Marks, Penn State Univ., 212 Sackett Bldg., University Park, Pa. 16802. (814) 863-0578.

March 10-11

1984 Engineering Surveys Conference in conjunction with ASP-ACSM Annual Convention, Washington, D.C. Sponsor: F.I.G. Commission 6 (Engineering Surveys); Harry Feldman, president.

April 7-13

26th Australian Survey Congress. Theme: What About The People? Sponsor: The Institution of Surveyors, Australia. Place: Brisbane, Australia

August 4-13

12th ICA Conference. Perth, Western Australia. Contact: Barbara B. Petchenik, 872 Pine, Winnetka, Ill. 60093. (312) 326-8187.

August 27-31

25th International Geographical Congress Conference. Sponsor: IGU. Place: Paris France. Contact: Robert R. Aangeenbrug, ACSM Representative to the U.S. National Committee for the International Geographical Union, Dept. of Geography, Univ. of Kansas, Lawrence, Kans 66045.

1985

September

6th International Congress of Internal Society for Mine Surveying. Place: Harrowgate, England. Contact: Peter Gilbert, R.I.C.S., 12 Great George St., Landon, GB.

ACSM-ASP WORKSHOPS AND SEMINARS

1983

August 20, 1983

Adverse Possession and Other Unwritten Rights: How They Affect the Land Surveyor. Place: Quality Inn, Arlington, Tex. Instructors: Walter G. Robillard and Roy Minnick.

August 26-27

Evidence and Procedures for Boundary Location. Place: Louisiana State University, Baton Rouge, La. Instructors: Walter G. Robillard and Roy Minnick. Cosponsor: Louisiana Society of Professional Surveyors.

September 9-10

Evidence and Procedures for Boundary Location. Place: Worcester Inn, Worcester, Mass. Instructors: Walter G. Robillard and Donald A. Wilson.

September 10

Closing Corners. Place: Holiday Inn—Metro Center (Holidome), Phoenix, Ariz. Instructors: Robert Bell and Homer Gilson. Presented by BLM. Sponsor: Central Chapter, Arizona Professional Land Surveyors. Contact: David Horner, 10130 E. Jenan Dr., Scottsdale, Ariz. 85260; (602) 991-2969.

September 23

Effective Communication. Place: Hotel Utah, Salt Lake City, Utah. Instructor: Robert S. Brewer. Offered in conjunction with ACSM-ASP Fall Convention.

September 30-October 1

Restoration of Lost Corners by Proportionate Measurement, Corner Point Identification, and Introduction to Water Boundaries. Place: Defiance College, Defiance, Ohio. Presented by BLM. Cosponsor: Northwest Chapter, Professional Land Surveyors of Ohio, Inc.

October 3-7

Basic Hydrography. Place: Essex Inn, Chicago, Ill. Sponsor: ACSM Marine Surveying and Mapping Committee.

October 12

Marketing Professional Services for Surveyors and Photogrammetrists. Place: Doubletree Inn, Monterey, Calif. Instructors: Joseph P. Burns and Milton Denny. Offered in conjunction with ACSM/ASP California Conference. Contact: Gerry Sample, Towill Inc., 605 Howard St., San Francisco, Calif. 94105; (415) 982-1758.

October 15

Coordinate Transformation: The 1983 North American Datum Adjustment and the California Coordinate System. Place: Doubletree Inn, Monterey, Calif. Instructor: Edward J. McKay. Offered in conjunction with ACSM/ASP California Conference. Presented by NGS. Contact: Bob McClary, P.O. Box 3362, Eureka, Calif. 95501; (707) 442-5761, ext. 293.

November 4-5

Evidence and Procedures for Boundary Location. Place: Sheraton-Denver Airport, Denver, Colo. Instructors: Walter G. Robillard and Roy Minnick.

November 9-11

Surveying Instrumentation and Coordinate Computation. Place: Keller Conference Center, The Pennsylvania State University, University Park, Pa. Presented by NGS. Sponsor: Pennsylvania State University. Contact: G. Warren Marks, 212 Sackett Bldg., University Park, Pa. 16802; (814) 863-0578.

November 12

Adverse Possession and Other Unwritten Rights: How They Affect the Land Surveyor. Place: DeSoto Hilton, Savannah, Ga. Instructors: Walter G. Robillard and Donald A. Wilson.

November 18-19

Evidence and Procedures for Boundary Location. Place: Scheman Continuing Education Bldg., Iowa State University, Ames, Ia. Instructors: Walter G. Robillard and Roy Minnick. Contact: Patty Campbell, (515) 294-7834.

For further information on workshops or seminars where specific contact is not listed, information can be obtained from: Director, 210 Little Falls St., Falls Church, Va. 22046; (703) 536-8320.

AS WE GO TO PRESS: **Surveying Measurements and Their Analysis**, a new book by R. B. Buckner, will be available for purchase at the Landmark Enterprises suite in Salt Lake City. Watch ACSM publications for descriptive advertisement.

Survey Plans for Basic Net A — continued from page 29

eling instead of double-run procedures for the releveling of Basic Net A drastically altered NGS survey plans. But users will benefit from the doubling of newly surveyed bench marks, which will result in a much denser releveled network, strongly connected to the Canadian and Mexican geodetic vertical networks. These new lines will further increase the value of the New Adjustment of the North American Vertical Datum. ■

The New Adjustment of the North American Vertical Datum

Article No. 9
Deployment of Field Personnel and Cooperative Participation

by Florence S. Fulop

Plans and Resources Staff
National Geodetic Survey, Charting and Geodetic Services, NOS, NOAA
Rockville, Maryland

Since 1978, the National Geodetic Survey (NGS) has had a major program underway to improve the National Geodetic Vertical Network. This program involves the following field tasks:

1. Replace destroyed bench marks on approximately 100,000 km of the vertical control network;
2. Relevel this portion of the network; and
3. Perform gravity measurements at North American Vertical Datum (NAVD) bench marks and other points.

To undertake the massive amount of field survey work required for the NAVD readjustment effort, two decisions had to be made early in the program:

1. How to deploy NGS leveling parties throughout the United States, and
2. How to obtain additional field support to augment NGS leveling parties.

With respect to the first decision, a regional concept of the releveling of 100,000 km of NAVD leveling lines in the continental United States was adopted. (See Fig. 1.) The conterminous United States was divided into six regional areas and NGS leveling parties were deployed to each region (with the exception of region 6, which will be releveled last, because of the instability of the area) to begin first-order releveling operations within each region. Originally assigned NGS field personnel have basically remained within the same region since that time, working in the northern states in the summer and the southern states in the winter. In general, winter working grounds are assumed to be anything below 37° in latitude.

With respect to the second decision, NGS determined that it would solicit the participation of other highly qualified and interested survey departments at the federal and state levels to augment NGS leveling units in the field. Budgetary restriction precluded the hiring of additional NGS personnel to increase the number of NGS leveling units. In the spring of 1978, NGS sent letters to geodetic survey departments, highway administrations, and mapping and charting departments in 46 states inviting them to participate in the field effort for the NAVD program within their respective states. As a result of those invitations (which offered training, equipment loans, and partial reimbursement for travel and labor expenses), the following federal and state agencies entered into cooperative agreements with NGS and performed leveling or gravity observations which contributed to the total NAVD readjustment effort:

- Department of the Army 30th Engineer Battalion (TOPO), Ft. Belvoir, Va., and 524th Engineer Company (TOPO), Ft. Hood, Tex.: In 1979 and 1980, survey units from the 30th and 524th were detached to NGS field leveling parties and performed NAVD leveling in conjunction with NGS field personnel.
- Defense Mapping Agency, Hydrographic-Topographic Center, Geodetic Survey Squadron (DMAHTC/GSS), F. E. Warren Air Force Base, Wyo.: In 1978 and 1979, DMAHTC/GSS performed gravity measurements over NAVD bench marks to obtain gravity values along the Atlantic coastal states. They provided NGS with a total of 2,830 measurements which have been integrated with other gravity values obtained by NGS personnel and entered into the NGS gravity data base. These values will also be incorporated into the National Gravity Base Network established by NGS.
- State of North Carolina, Department of Natural Resources and Community Development (NCDNRCD): In 1979, 1980, and 1982, NCDNRCD geodetic survey personnel leveled approximately 1,178 km along NAVD lines in North Carolina after receiving NGS training.
- State of Ohio, Department of Transportation (ODOT): From 1980 to 1982, ODOT geodetic survey personnel leveled approximately 402 km along a NAVD east-west line in Ohio after receiving NGS training.
- State of South Carolina, Geodetic Survey (SCGS): From 1980 to 1982, SCGS geodetic survey personnel leveled approximately 538 km along NAVD lines in South Carolina after receiving NGS training.

During the 1970's and early 1980's, the following federal, state, and county government agencies established cooperative reimbursable leveling projects with NGS:

- U.S. Army Corps of Engineers (New Orleans, Memphis, St. Louis, Sacramento, Ft. Belvoir, and Jacksonville districts)
- U.S. Department of Energy
- Harris-Galveston Coastal Subsidence District
- Sandia National Laboratories
- Brookhaven National Laboratory
- U.S. Geological Survey

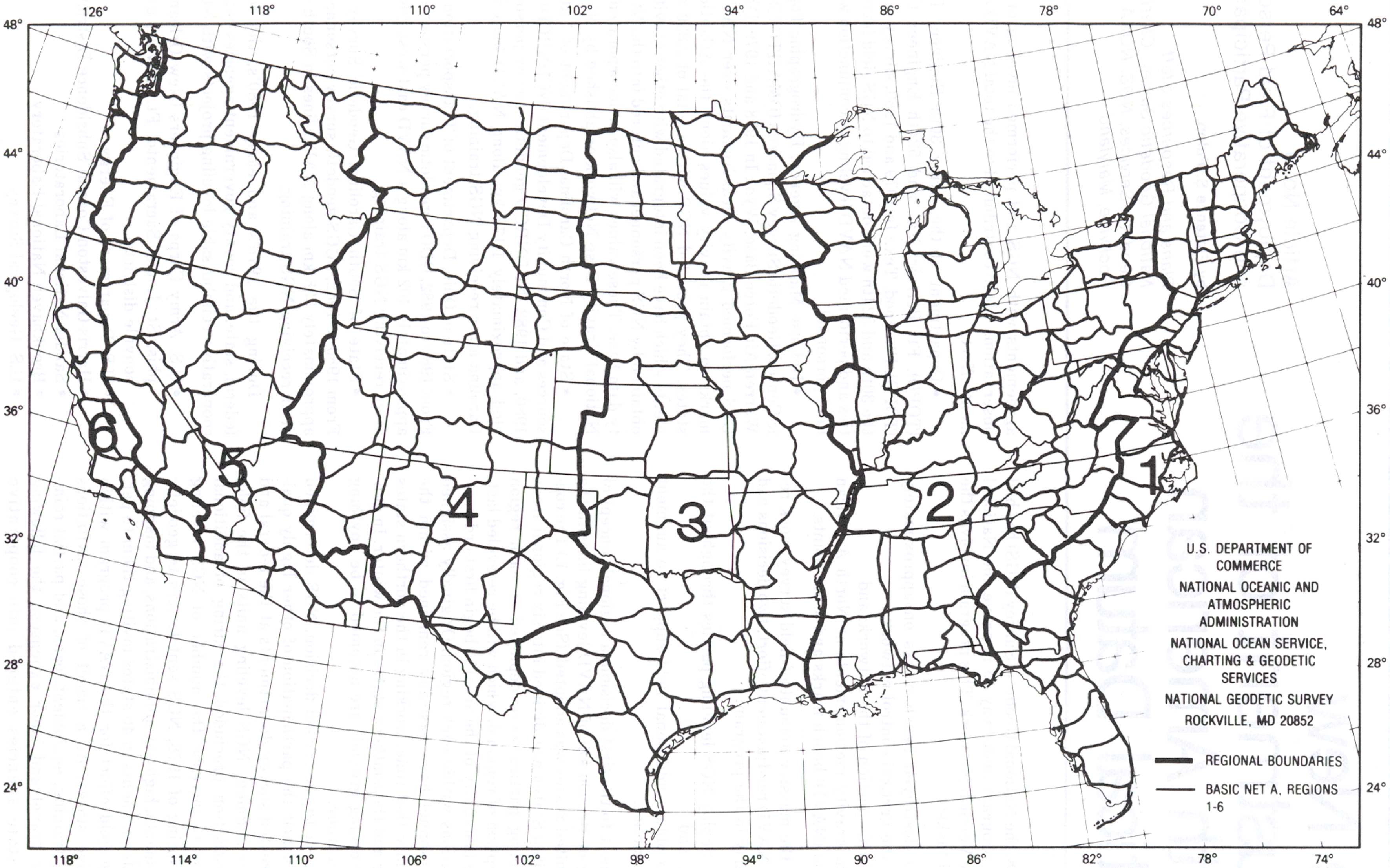


Figure 1. Regonal concept for the North American Vertical Datum program.

- Department of Public Works, Imperial County, Calif.
- Federal Emergency Management Administration
- National Aeronautics and Space Administration
- National Academy of Sciences
- California Department of Water Resources
- The Coordinating Committee on Great Lakes Basic Hydrographic and Hydrologic Data
- Arizona Department of Transportation
- The Museum of Science, Boston, Mass.
- Alameda County, Calif.
- Louisiana Geological Survey

Many of the cooperative projects performed for these agencies will be adjusted and published with the NAVD leveling data, becoming an integral part of the new adjustment of the NAVD, scheduled for completion in 1988.

NGS appreciates the cooperative field efforts of the 30th and 524th Army survey units; DMAHTC/GSS; and the North Carolina, Ohio, and South Carolina survey personnel who participated in the NAVD program. This field participation, and the additional leveling lines established as a result of the cooperative survey projects performed for the other agencies, greatly contribute to NGS's goals of maintaining and improving the integrity of the National Geodetic Reference System, and to the new adjustment of the North American Vertical Datum. ■

Index to Advertisers

The New Adjustment of the North American Vertical Datum

Article No. 10
Bench Mark Monumentation

by Dennis A. Hoar

Operations Branch
National Geodetic Survey, Charting and Geodetic Services, NOS, NOAA
Rockville, Maryland

In 1978 the National Geodetic Survey (NGS) initiated a program to redefine the National Geodetic Vertical Datum of 1929. The resulting datum will be called the North American Vertical Datum of 1988 (NAVD 88). This task will require approximately 100,000 km of new first-order leveling. Bench marks (vertical control monuments) are being established at 1- to 3-km intervals along the new leveling lines to support this leveling effort. This relatively close spacing (compared to the 5- to 15-km spacing of the first major leveling program) serves to densify the network, allowing greater accessibility to users of these bench marks.

Studies related to crustal motion, subsidence, and other researches have dramatically increased the requirements for highly accurate elevations. Bench marks that are used as reference points for these precise surveys must have very high stability and longevity. Prior to the start of any precise survey, the user needs to know the reliability of the bench marks that are being used as reference points. NGS has divided the monuments into the following four classes, based upon their reliability:

Quality	*Bench Mark Description*
A	Monuments of the most reliable nature which are expected to hold their elevations very well.
B	Monuments which probably will hold their elevations well.
C	Monuments which may hold their elevations but are commonly subject to surface ground movements.
D	Monuments of questionable or unknown reliability.

The 100,000-km framework for NAVD 88, which is called Basic Net A, is comprised of quality A and B monuments. Although it is desirable to have every monument of quality A, a compromise had to be reached between what is desirable and what is most cost effective. The majority of the monuments established for NAVD 88 are of quality B, with quality A monuments set at 16-km intervals, at junctions of leveling lines and at the "base" of each spur line to water level gages.

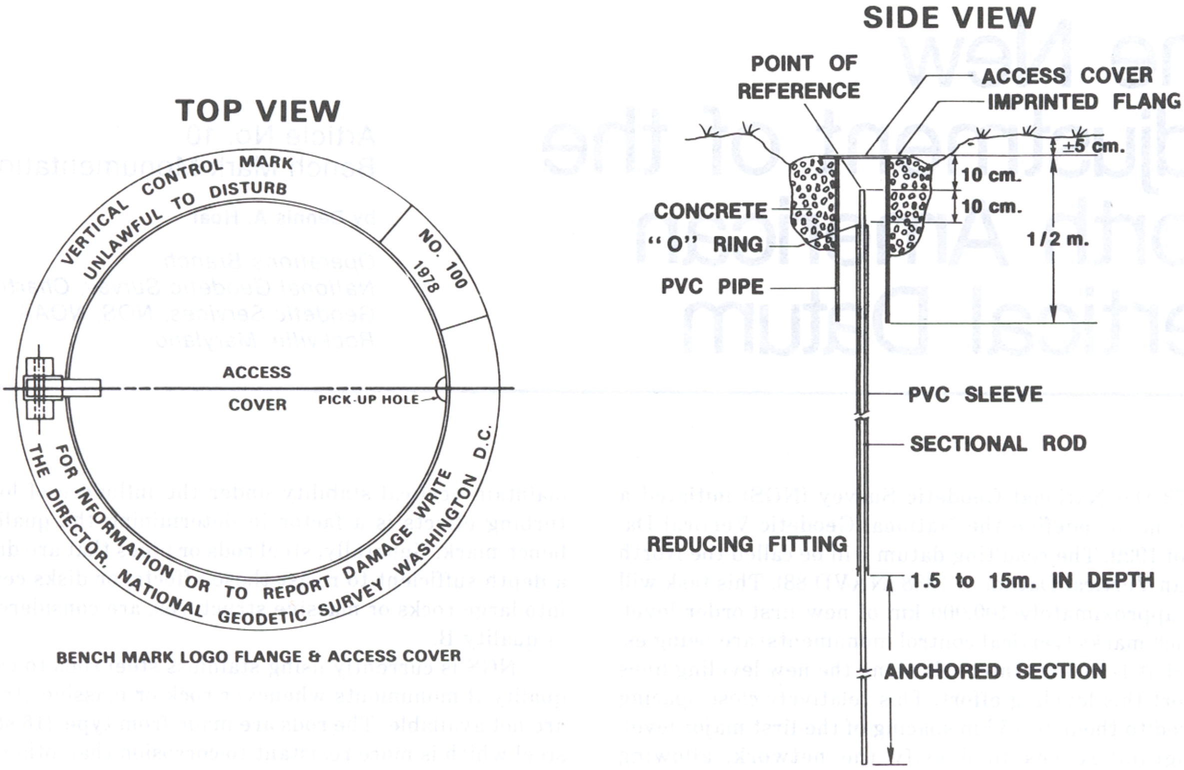
Frost depth, soil conditions, and local subsidence are some factors which work upon bench mark monuments causing vertical movement. The degree to which monuments maintain vertical stability under the influence of local disturbing effects is a factor in determining the quality of a bench mark. Generally, steel rods or pipes that are driven to a depth sufficient to resist these effects, or disks cemented into large rocks or massive structures, are considered to be of quality B.

NGS is currently using stainless steel rods to establish quality B monuments whenever rock or massive structures are not available. The rods are made from type-316 stainless steel which is more resistant to corrosion than other affordable alloys. The rods are 4 ft. long and are connected by stainless steel studs. The rods are assembled and driven to refusal or a minimum depth that is determined from local frost and soil conditions. A type-316 stainless steel cap with a hemispherical end is crimped to the top of the rod as the reference point. A 5-in.-diameter PVC pipe, ½ m in length, is placed around the top of the rod for protection. An aluminum logo cap, with a hinged cover for accessing the monument, is stamped with the appropriate bench mark designation and glued to the top of the pipe.

A quality B rod monument that is set in an area having nonexpansive soil and frost penetration of less than ½ m can be expected to hold its elevation very well. Under these conditions, the monument is upgraded to quality A.

Large rock outcrops, bedrock, massive structures with deep foundations, and large structures with foundations on bedrock are generally not affected by frost, soil conditions, or local subsidence. These conditions are ideal for establishing quality A monuments. The cost of materials and the amount of labor are minimal. A typical bench mark monument, set in these instances, is a bronze disk, stamped with a designation and cemented into a drill hole. Unfortunately, the conditions allowing for relatively "simple" establishment of quality A monuments do not always exist at the desired location.

In 1978 NGS developed a method for establishing quality A monuments wherever they are required. The monument is similar to the quality B stainless steel rod monument. The major difference is that the monument is isolated from local movement caused by frost, soil conditions, and local subsidence by a "sleeve" of PVC pipe. The sleeve is installed by utilizing a drill rig mounted on a large truck. A hole, large enough to accommodate a 1-in.-diameter PVC pipe, is drilled to a depth of three times the frost penetra-



Top and side views of a quality A NGS geodetic bench mark.

tion or below the depth of the shrinking and swelling of expansive soils, whichever is greater. A length of 1-in. PVC pipe, approximately 20 cm less than the depth of the hole, is filled with grease and placed into the hole. Stainless steel rods are connected and placed inside the PVC pipe. The rods are then driven to refusal or until a driving rate of 1 ft. per minute is obtained. The stainless steel cap, 5-in. PVC pipe, and logo cap are then put in place as for a quality B monument.

A comprehensive 52-page manual, entitled *NOAA Manual* NOS NGS 1, "Geodetic Bench Marks," covers site selection and installation of highly stable bench marks of the types established by NGS. This publication is available from the National Geodetic Survey, N/CG17x2, NOS, NOAA; Rockville, MD 20852.

Thus far, NGS has established more than 17,000 quality A and B monuments to support the NAVD 88 program. This includes approximately 1,000 quality A rod monuments in sleeves, 1,200 quality A rod monuments without sleeves, 10,300 quality B rod monuments, and 4,600 quality A and B disks set in rock or massive structures.

Establishing quality A and B bench mark monuments at such a close spacing requires considerable resources of staff and materials. However, the results are worthwhile. The surveying community will utilize these bench marks of dependable, precise elevations for many years to come. ■

The New Adjustment of the North American Vertical Datum

Article No. 11
Survey Instrumentation and Procedures

by Harold G. Beard

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Until 1973, the existing network of geodetic vertical control was referred to as the "Sea Level Datum of 1929." At that time it was renamed the "National Geodetic Vertical Datum of 1929" (NGVD 29). This reference system includes leveling observations made with a variety of procedures and leveling instruments such as the Fischer spirit leveling instrument (designed by the U.S. Coast and Geodetic Survey), Breithaupt Nabon, Jenoptik Ni004, Zeiss Ni2, and the Zeiss Ni1.

In 1978, the National Geodetic Survey (NGS) initiated a releveling program in support of the forthcoming North American Vertical Datum of 1988 (NAVD 88). Before this program began, decisions were made on instrumentation, leveling techniques, and procedures. The primary consideration was how to get the most leveling from programmed funds without compromising the integrity of the network.

In 1975, a search began for an instrument that would be the backbone of the NAVD releveling program. After analyzing the design characteristics of several instruments, a tentative decision was made to use the Jenoptik NI 002 compensator level. Specifications were then developed for a "double-simultaneous" leveling procedure, and testing began in December 1975. This method is not a new concept. In fact, double-simultaneous leveling was conducted in the 1890's, but abandoned due to excessive costs and necessary supporting logistics.

The test site was a first-order line between Waldorf and Baltimore, Maryland. (Test results are published in *NOAA Technical Report* NOS 68 NGS 4.) Throughout 1976, testing and evaluation of the NI 002 with the double-simultaneous method continued on several projects in the United States. At the end of the year, NGS decided to use the Jenoptik NI 002, together with the double-simultaneous leveling method, for the NAVD releveling program.

The present-day design of geodetic leveling rods and the advantages of the NI 002 with its reversing compensator and swiveling eyepiece permit efficient surveying using the procedure known as first-order, class II, double-simultaneous leveling. This method has significantly increased the total amount of possible network coverage for the NAVD program.

Geodetic leveling rods used by NGS are rigid one-piece rods, 3 m in length with an aluminum housing. The invar strip is graduated at 0.5 cm (half-centimeter) intervals. The rod is ruggedly built to withstand daily use for several years. A circular level is mounted on the back of the rod housing in easy view of the rod person. Telescoping, swiveling brace poles are attached to the top of the rod to minimize movement as observations are made. A "rod pin guide" is attached to the bottom of the rod to ensure the rod is properly placed on the rod turning point. The rods are calibrated at every graduation when first purchased, and are scheduled for recalibration every year or whenever severe jolts occur which might affect the most recent calibration. (See Fig. 1.)

Figure 1. Geodetic level rod with brace poles.

Mention of a commercial company or product in this article does not constitute an endorsement by the National Oceanic and Atmospheric Administration.

The turning points which support the rod are designed to be stable enough to resist movement while the points are temporarily holding the elevation as the instrument and "back" rod are moved to a new setup. NGS primarily uses two types of turning points: a steel pin with a spherical head, which has a driving cap attached, and the turning plate. The steel pin is about 36 cm long. To facilitate driving, it is tapered to a point at the bottom. The pin should not be driven on a slant but rather set in the most vertical position possible. The turning plate (turtle) weighs about 7 kg (15 lbs.) and has three flat removable feet, allowing a masonry nail to be inserted through the bottom of each foot. The nail protrudes about 5 mm and prevents horizontal slippage, yet allows the weight of the plate and rod to be distributed over the flat surface of the feet. (See Figs. 2, 3, and 4.)

As a result of tests conducted for systematic refraction errors in differential leveling, a decision was made to account for refraction errors for all leveling in the NAVD project. To assist in this endeavor, temperature readings are now taken via aspirated temperature probes mounted on the instrument tripod at 0.3 m and 1.3 m above the ground. These readings are recorded at every setup from both probes.

NGS procedures for first-order double simultaneous leveling involving closed loops permits leveling of the line in one direction only, thereby eliminating the traditional method of running forward and backward (both directions) on the line. This is accomplished with the use of double-scaled geodetic invar leveling rods. One side of the invar scale is graduated from zero; the opposite side is offset by an arbitrary constant. The second rod has the invar scale graduated from zero, and its opposite side is offset by a different constant, creating an unmatched pair of rods. The unmatch-

Figure 3. Turning plate.

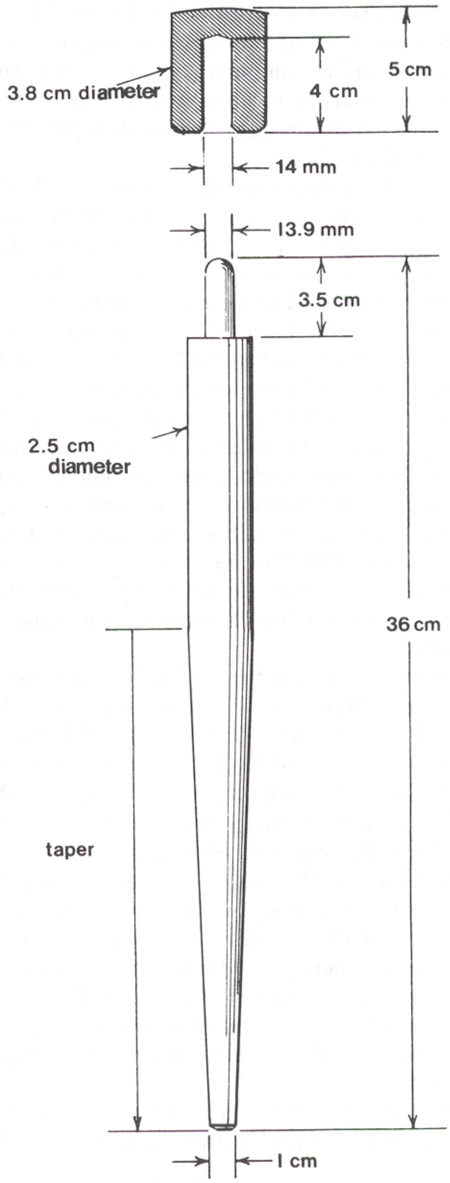


Figure 4. Turning pin dimensions.

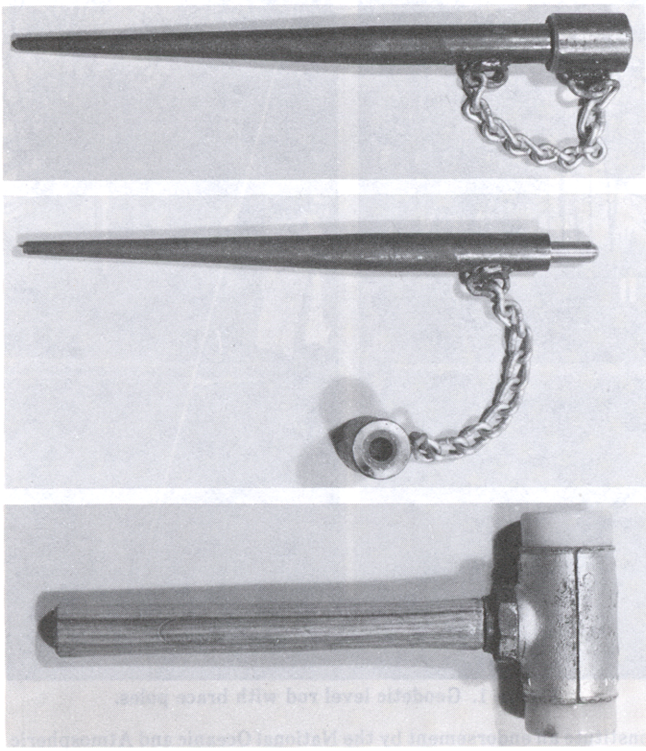


Figure 2. Turning pin and hammer.

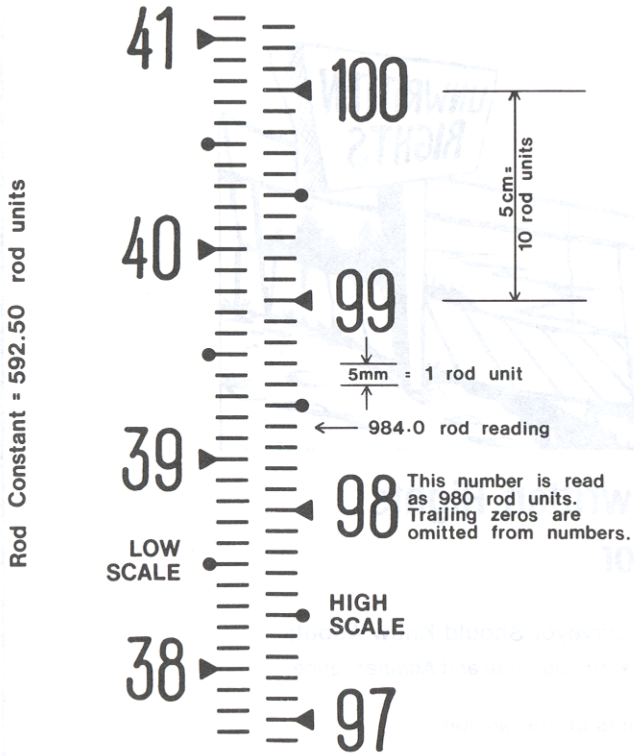


Figure 5. Double-scale rod with half-centimeter line graduations.

ed pair of rods guards against transposing foresight and backsight observations. The rod with the lower constant is designated as the number 1 rod and observations are always made on this rod first. (See Fig. 5.)

A typical setup as leveling proceeds from a bench mark is as follows. The number 1 rod is placed on the bench mark and the number 2 rod is placed some distance (as much as 120 m) from the number 1 rod in the direction of the planned leveling. The instrument is placed at a point equidistant between the two rods. The observing routine is executed in this sequence: (1) Place the instrument's rotating compensator knob in position 1. (2) Read the backsight low scale (number 1 rod) and the stadia wire. (3) With the compensator still in position 1, rotate the instrument to the foresight (number 2 rod) and read the foresight low scale and the stadia wire. An elevation difference and the distances between the instrument and both rods have now been determined with the low scale readings. (4) While still pointed on the foresight rod, change the instrument compensator to position 2 and read the foresight high scale. (5) Rotate the instrument to the back rod and read the backsight high scale. A second elevation difference has now been determined and the two must agree within certain tolerances.

The above procedure is repeated by moving the instrument and back rod into the second setup position. The only change in the procedure is that the compensator position at the completion of the first set remains in position 2 until the low scales have been read for the second setup. In other words, the compensator should be in position 1 at the beginning of every odd number of setups and in position 2 at the beginning of every even number of setups.

The swivel eyepiece on the instrument obviously saves the observer many steps during the course of a day's work. In addition, this technique has enabled NGS to develop a motorized level system, now in its third generation. Current equipment consists of three modified front-wheel drive mini-pickup trucks. Two are used as rod vehicles and one serves as the instrument vehicle. In certain areas of the country a 30 percent increase in leveling has been achieved.

The development of new observing procedures, electronic equipment, and techniques has solved the problem of recording leveling data. Traditional hand-recording in field books had become a nightmare. NGS now uses a recording system designed to collect and record data in computer-readable form. A programmable Monroe 326 calculator with a model 392 cassette tape recorder is presently used for this purpose.

The tape cassettes containing the raw field data are processed through the field office via a time-sharing computer system and a Texas Instrument 742 terminal. When the field party releases its field work for the season, all data are in computer-readable form and reside on a disk pack at the NGS headquarters computing facility. NGS expects to have a completely new field system (field recorder and mini-computer) in the field within several months. (This system will be described in the June 1984 issue of the *ACSM Bulletin*.) ■

ACCREDITATION FORUMS

1984 ASP-ACSM Annual Convention, Washington, D.C.

Each forum deals with the policies and procedures of the Accreditation Board for Engineering and Technology (ABET) and focuses particularly on the responsibilities and commitments of the "ad hoc visitor." Forums are open, and all who are interested are welcome. Attendance at an accreditation forum is required of anyone who wants to participate in accreditation as an ad hoc visitor.

Accreditation Forum: Engineering Accreditation Commission (EAC)
March 14, 9:00 a.m. to noon

Accreditation Forum: Technology Accreditation Commission (TAC)
March 14, 9:00 a.m. to noon

Anyone wishing to participate with the **Engineering Related Accreditation Commission (RAC)** may attend either the EAC or TAC Accreditation Forum.

The New Adjustment of the North American Vertical Datum

Article No. 12
NAVD 88 Status Report for Canada

by Fred W. Young

Head, NAVD Project Section
Geodetic Survey of Canada
Energy, Mines and Resources
Ottawa, Ontario, Canada

Article No. 3 of this series (October 1982) presented the historical background and events leading to Canada's involvement in the New Adjustment of the North American Vertical Datum, identified as NAVD 88. It outlined several areas in which Canada is doing research and development, as well as the actual collection and processing of data. The NAVD Project Section has increased in size to a staff of 12, as additional people have been hired or transferred from other sections.

Progress has been made in various phases of the project. Preliminary link details have been completed for all of the basic primary networks (374 links), about 55,000 km of leveling lines. These include the definition of each link, assignment of unique line numbers, and determination of the stability of bench marks at connection points. Preliminary closures are being computed for all loops in the basic net. This preliminary analysis has identified some areas where additional field work is necessary. It is expected that more than 4,000 km of first-order leveling done by the provinces of Ontario, Quebec, and Saskatchewan will be included in the basic net. It is also projected that another 75,000 km of first-order leveling, 25,000 km of second-order leveling, 50,000 km of lower-order leveling, and 30,000 stations with trigonometric heights will be integrated into the basic network.

Conversion of observational leveling data to computer-readable form is continuing. As of December 1983, 30 percent of the estimated one million records of data have been compiled in preparation for entry into the computer. Seventeen percent of the data have been keypunched and about 10 percent have been edited and verified. The target date for completion of this phase of the project is 1986, assuming present resources and production rates. The recent development of a Forms Management System (FMS-11), in conjunction with direct keying of data from field books, promises a significant improvement in the rate of data entry.

Rod and leveling instrument data are being stored on computer files to facilitate the application of calibration and collimation corrections to observed data. Other files are being created with historical information for bench marks. A digitizer was recently purchased to assist in the determination and verification of scaled geographic coordinates of bench marks.

Development of analysis procedures has begun with the designated Nova Scotia Test Net (3,800 km of primary leveling) and two basic net loops in the Rocky Mountains of southern British Columbia. We are investigating the effects on section discrepancies and loop closures of the application of various corrections to observed data.

To fulfill Canada's role in the International Great Lakes Datum (IGLD) reevaluation project, we are now automating data for all basic net loops adjacent to the IGLD line from Pointe-au-Père, Quebec, to Thunder Bay, Ontario, via the St. Lawrence River and Great Lakes. This should be completed during 1984.

Field procedures are being revised and tested in an effort to improve the quality of the observed data and the rate of data collection. All field crews now use Hewlett Packard HP-85 automated recording systems, mounted in vehicles. Data are stored on cassette tapes and are transferred, via the HP-85 terminal, to the departmental CYBER mainframe computer for processing. Rod Invar temperatures and air temperature profiles are measured along survey lines, to enable us to apply relevant corrections. Historical data will require a mathematical model of the refraction effects. Improved calibrations of leveling rods are leading to more accurate determinations of graduation and index errors. Additional gravimeter measurements have been made in mountainous areas to allow accurate computations of geopotential units. Motorized leveling has proven to be effective in some areas, with improvements in both production and quality of the work.

One-way leveling is now being tested in the field as a means of increasing production. Two basic loops in the Nova Scotia Test Net have been designated for releveling, using procedures similar to the National Geodetic Survey's "double-simultaneous" method.

Water level transfers were conducted among three gauge sites on Great Slave Lake during the 1983 field season, with the cooperation of the Canadian Hydrographic Service. It is hoped that this method, as used for IGLD, may prove to be feasible in the extension of our first-order vertical control network, especially in the north.

Investigations are in progress to determine the effects of the Earth's magnetic field on automatic compensator leveling instruments. Systematic-error and crustal-movement studies are underway at Canadian universities through research contracts with our department.

Various aspects relating to the redefinition of the vertical datum are being investigated. Some areas of research include harmonic analyses of long-term tide gauge records, modeling of sea surface topography using terrestrial data and satellite altimetry collection and analysis of Global Positioning System data for differential positioning, and the use of absolute gravity measurements. ■

The New Adjustment of the North American Vertical Datum

Article No. 13
NAVD 88 Status Report

by Gary M. Young

Vertical Network Branch
National Geodetic Survey, Charting and Geodetic Services, NOS, NOAA
Rockville, Maryland

Background

In 1973, the need for a new adjustment of the U.S. national vertical control network was recognized by the Office of Management and Budget in the documented study, "Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying." The report stated in part:

"The fundamental geodetic networks have become incomplete though obsolescence and need new surveys and a National Adjustment to meet modern demands.... based on our requirements study, we conclude the vertical control program is falling short of meeting national needs, and, therefore, must be expanded. We recommend doubling the National Vertical control program."

During the next 4 years, feasibility studies were compiled, new adjustment strategy completed, and, in October 1977, following congressional approval of a budgetary initiative, the new adjustment project began formally.

The first step in modernizing the vertical control network was to identify a framework of leveling lines (most of the first-order leveling lines in the United States) that should be releveled to provide realistic contemporary height values to the new adjustment. To accomplish this, the National Geodetic Survey (NGS) selected 100,000 km of the network for releveling.

Status

Replacement of disturbed or destroyed monuments precedes the actual leveling. Field leveling is being accomplished to first-order, class II standards, using the "double-simultaneous" method. Important field assistance is being provided by several state and local agencies. To date, 51,000 km have been surveyed.

In order to accomplish this task most efficiently, advanced forms of instrumentation are being studied. In September 1983, Rear Admiral John D. Bossler, director, Charting and Geodetic Services, initiated an international cooperative effort to develop new leveling technology. A preliminary evaluation performed by NGS indicates a new leveling system can be developed that would increase field efficiency by a factor of 4 to 6. At the same time, it should be possible to reduce systematic errors significantly. This development project is not committed to any specific type of leveling system. Possibilities include "hydrostatic" leveling (which compares elevation differences at either end of a tube containing a liquid), and precise, simultaneous zenith distance measurements.

Research on Atmospheric Refraction and Magnetic Errors

Additional progress has been made to account for atmospheric refraction error. The final analysis of the 1981 U.S. Geological Survey-NGS Saugus to Palmdale, California, leveling refraction test was completed, and published in *NOAA Technical Report* NOS 98 NGS 27. A magnetic calibration test facility is operational at NGS's Operations Branch, Instrumentation and Equipment Section, Corbin, Virginia. Most of NGS's compensator (automatic) leveling instruments have been calibrated at this facility. The influence of d.c.-induced magnetic fields (e.g., the Earth's geomagnetic field) on NGS compensator leveling instruments is now well understood. The effect of a.c.-induced magnetic fields (e.g., those associated with major electric generator/transporter systems) is still a question mark, and undergoing further evaluation. When the magnetic calibrations of all NGS compensator leveling instruments are completed, NGS will, on a cost-recovery basis, calibrate other agencies' compensator instruments.

Other NAVD 88 Activities

The conversion to computer-readable form of NGS archival observational data was completed in January 1982. The preliminary editing, validation, and review of these data were completed in November 1982. These data involve 15,000 lines of leveling, containing a total of 1,300,000 km of first- and second-order surveys. In addition, NGS is responsible for the analysis, adjustment, and publication of recent leveling data incorporating the present vertical reference surface, designated the National Geodetic Vertical Datum of 1929 (NGVD 29). As the completion date of the new adjustment approaches, it will be necessary to discontinue constraining new leveling data submitted by other agencies to NGVD 29. This was formulated into a NGS policy statement distributed in October 1983:

"Due to continually increasing emphasis on the North American Vertical Datum of 1988 (NAVD 88) readjustment project, NGS must reserve the right to determine which recent first- and second-order leveling projects will be processed and adjusted to the present National Geodetic Vertical

Datum of 1929 (NGVD 29). All acceptable leveling data will continue to be processed and stored for later incorporation into the NAVD 88 readjustment project.

"At some future 'cut-off' date (probably 2-3 years from now), leveling projects will be accepted and stored, but will not be included in the completion of the NAVD 88 readjustment project."

The systematic preparation of all leveling data that will be incorporated into the new adjustment will be completed by September 1987. Following this "provisional adjustment" phase, the data will undergo a Helmert-blocking process to determine a solution equivalent to a general, simultaneous least-squares readjustment of all appropriate leveling data in North America.

1985 NAVD Symposium

The Third International Symposium on the North American Vertical Datum (NAVD Symposium 85) will be held on April 22-26, 1985, in Rockville, Maryland (metropolitan Washington, D.C. area). NAVD Symposium 85 will address topics that are crucial to the success of the new adjustment. The symposium will focus on crustal motion models, vertical datum definition, systematic and random errors in leveling, data-processing procedures, and new leveling techniques. Scientists from around the world will participate and provide guidance on the direction in which the NAVD 88 project should proceed.

If you are interested in further information about any of the topics mentioned in this article, please write the author. ■

Robert W. Foster

The Liability Environment

One type of liability suit that plagues professionals is the suit of doubtful merit. Further, it plagues the judicial system and is apt to bring frustration to all the actors in the drama, including the plaintiff. A recent case will illustrate:

Plaintiff brought suit for $6,000 against defendant land surveyor over the issue whether surveyor should have provided advice beyond the scope of their contract.

Five years after filing of suit, case was called in Massachusetts Superior Court. Judge advised plaintiff he had only 30 or 40 percent chance of favorable judgment and advised parties to settle out of court. The judge suggested a settlement of $2,500.

Defendant surveyor offered $1,500 to settle. Defendant's professional liability insurance company determined that defense costs to date had reached $3,500, and that with defendant's offer of $1,500 to settle, the $5,000 deductible limit of the policy had been reached. The insurance company resolved the matter by providing $1,000 to accompany defendant's offer of $1,500. Plaintiff accepted the $2,500 in final settlement.

As a result defendant's out-of-pocket costs (not including his own time) totaled $5,000. Defendant's attorney was paid $3,500. Plaintiff received $2,500, but one-third went to his attorney. Plaintiff netted about $1,667, but much of this probably went to pay other expenses such as deposition costs and so on. Plaintiff's attorney received about $883, an apparent loss to him compared to plaintiff's attorney's fee.

It appears that the plaintiff received very little for his 5-year effort and far less than his claim. The defendant surveyor was hurt by a nuisance action dragged out over half a decade—and was out $5,000 as well.

In hindsight it appears that the parties would have done well to settle for half the original claim before the attorneys got involved. But the plaintiff was adamant; and professional liability insurers do not usually allow negotiations between the parties without legal counsel, probably with good reason. Besides, whose hindsight is that acute? In cases like this nobody wins; the best advice is to write airtight contracts, do a professional job, communicate well with your client. Then, if things still do not turn out well, exercise a little "claims repair" before everybody loses control. ■

The New Adjustment of the North American Vertical Datum

Article No. 14
NGS Field Recorder and Microcomputer

by Gordon W. Adams

Systems Development Branch
National Geodetic Survey
Charting and Geodetic Services, NOS, NOAA
Rockville, Maryland

This summer the National Geodetic Survey (NGS) is introducing a new automated data recording and processing system to NGS vertical control observing teams. These teams are releveling 100,000 km of the National Geodetic Vertical Network in support of the new adjustment of the North American Vertical Datum, which is scheduled for completion in 1988. The previous NGS recording system was in place for 7 years and has been surpassed technologically by major improvements in the electronics and computer industries. New equipment has been purchased that takes advantage of these improvements, which will dramatically improve field operations and decrease costs.

The field surveying teams are equipped with programmable hand-held data-loggers (Fig. 1) and microcassette storage units to record and store leveling observations. NGS field offices have a microcomputer system with terminals, as well as a printer and modem, to accomplish preliminary data processing in the field (Fig. 2). Along with the new equipment, new data processing procedures and routines have been instituted. The teams no longer transmit, via telephone lines, raw observational data to a large host computer near NGS headquarters in Rockville, Maryland. Instead, the data remain at the field-office site, on the microcomputer, until all appropriate data-verification checks have been completed. The data are then sent to NGS headquarters on floppy disks.

Figure 1. Programmable data-logger, data-storage device.

No product endorsement is intended or implied by NOAA.

Data collection begins with the keying, at the observing site, of survey information into the data-logger. The data-logger is programmed to prompt field personnel to enter leveling instrument and equipment information, collimation data, bench mark identification data, and individual leveling setup observational data. As the information for each day is logged, data are stored in the solid-state memory of the data-logger. The unit has the capacity to hold approximately 450 leveling setups, which is 2 to 3 days' worth of data. However, standard procedure is to download the data from the data-logger to microcassette tape at the end of each workday. In this way the data can be mailed to the field office on a regular basis, and the memory of the data-logger is purged for the next day's work.

In addition to the recorded data, field personnel also complete a hard-copy backup sheet containing information about the instrumentation and equipment used, bench marks leveled to, and "ending" data for each section of leveling. This backup sheet aids in organizing daily work and provides verification of the data keyed into the data-logger. These backup sheets are mailed to the field office along with each day's microcassette tape.

When the microcassette tape is received at the field office, the data are transferred to floppy disk on the microcomputer. The data are processed through a program to per-

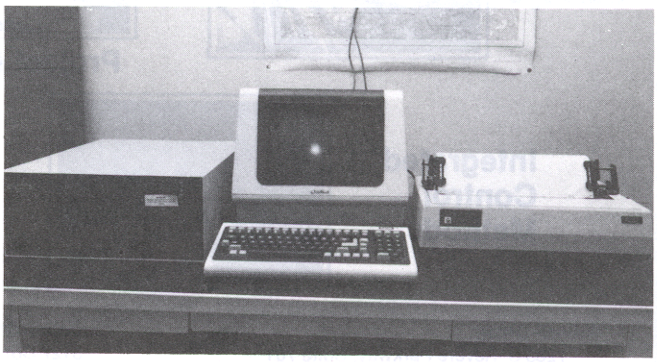


Figure 2. Microcomputer, terminal, and printer in NGS field office.

form preliminary range checks for invalid entries and transmission errors. The program also generates a listing which is compared to the backup sheets to avoid additional errors.

The next step is to run the data through a program that recomputes each of the field setups, checks for other errors, computes rod and refraction corrections, computes section distances and elevation differences, and reformats the data into standard NGS formats. This program generates an output file of the reformatted data along with a listing of other possible errors. These are then evaluated and corrected where possible.

A third program is designed to aid in the entry of bench mark descriptive texts. The program prompts the user for the same information given in standard NGS bench mark description forms, then formats these data, and creates a field that becomes input to a fourth program which checks for additional selected data entry problems in the description file.

Once the observation and bench mark description files are created for a leveling line, a fifth program is run to generate a field abstract. The program computes a line order from the section running data and uses it (and a starting elevation) to compute mean elevation differences, line distances, and observed (field) elevations. The program outputs an abstract listing along with a data file containing combined bench mark and section running data.

When all work on a leveling line is completed, the observations and bench mark description files are transferred to floppy disks to be mailed to NGS headquarters. Also mailed are the field observation backup sheets and bench mark description sheets.

This new NGS field system eliminates the need for expensive telecommunication links to NGS' host computer. Thus, a savings of approximately $6,000 per month in long distance telephone charges has been realized. These savings will quickly pay for the cost of buying and programming the new system. ■

Award Nominations: The American Cartographic Association Honors Award Committee is requesting nominations for its 1984 Award for Outstanding Achievement in Cartography. Past recipients of this Award, which was initiated in 1980, have been Arthur H. Robinson, Richard Edes Harrison, George Jenks, and Hal Shelton.

Please send nominations and supporting materials by December 15, 1984 to: Joseph W. Wiedel, Chairperson, ACA Honors Award Committee, Department of Geography, University of Maryland, College Park, Maryland 20742.

The New Adjustment of the North American Vertical Datum

Article No. 15
NGS Input Formats and Specifications for Vertical Control Data

by Katherine S. Koepsell and R. Bruce Ward

Vertical Network Branch
National Geodetic Survey, Charting and Geodetic Services, NOS, NOAA
Rockville, Maryland

In the mid-1970s, the National Geodetic Survey (NGS) began to establish a standard set of procedures for converting raw geodetic data into computer-readable form. Ludvik Pfeifer documented these procedures, which resulted in the Federal Geodetic Control Committee (FGCC) publication entitled *Input Formats and Specifications of the National Geodetic Survey Data Base.* Volume I (chapters 1-4), written by Pfeifer, covers requirements for submitting horizontal control data into the horizontal data base; volume II (chapters 5-7), coauthored by Pfeifer and Nancy L. Morrison, provides guidance for submitting leveling data into the vertical control data base; and volume III, prepared by Warren T. Dewhurst, details format requirements for the submission of gravity control data into the gravity data base. An overview of volume II follows.

Chapter 5—Vertical Control (VERT) Data: Explains the types of data sets generated in a vertical control survey project (observation data, descriptive data, and elevation data), job code and survey point numbering, and the media for submitting the data.

Chapter 6—Vertical Observation (VERT OBS) Data: Provides detailed specifications and instructions for coding and keying an observation data set of a vertical control job. Each type of record in the VERT OBS data set is identified, and the structure of the data set is outlined. The purpose of each of these records is explained, and specific information for entries on these records is detailed. In addition, for each record in the VERT OBS data set, a block diagram illustrating the respective format is included.

Chapter 7—Vertical Descriptive (VERT DESC) Data: Provides detailed specifications and instructions for coding and keying a descriptive data set. As in Chapter 6 each record is identified, structure of the data set outlined, purpose of the records explained, a detailed explanation of each record entry given, and format diagrams included. Examples of a coded and keyed description and a description in publication format are also included.

Annex A—NGS State and Country Codes: Lists the names of countries, states, provinces, territories, and islands along with their respective two-letter identification codes.

Annex C—Contributors of Geodetic Control Data: Contains a list of organizations that have contributed geodetic control data intended for maintenance or densification of the national horizontal and vertical control networks. A unique identification code has been assigned to each organization listed.

Annex D—Guidelines for Survey Point Names and Designations: Provides guidelines for assigning designations to bench marks. Examples of several different types of designations and the use of special characters are included.

Annex F—NGS Survey Equipment Codes: Provides a three-digit identifier for each item of survey equipment commonly used in connection with horizontal and vertical control surveys in the United States. There are 10 categories which have been divided into subcategories and assigned unique three-digit codes intended to reflect the level of accuracy attained in common usage.

Annex H—Standard Time Zones.

Annex J—Summary of Codes Used in Bench Mark Descriptions: Contains lists of codes used in the preparation of original and recovery descriptions pertaining to vertical control points.

Annex K—Data Transmittal Instructions: Describes requirements for project reports. Lists the point of contact at NGS for questions concerning the input formats and addresses for transmitting data via the U.S. Postal Service or a commercial carrier.

Policy. On July 1, 1977, the following guidelines were published: *Policy of the National Ocean Service with Regard to the Incorporation of Geodetic Data of Other Organizations into the National Geodetic Data Base.* "Survey data must be submitted in the format specified in the Federal Geodetic Control Committee (FGCC) publication *Input Formats and Specifications of the National Geodetic Survey Data Base.* [NGS] has determined that the value, to the National Network, of geodetic observations performed by other Federal, state, and local organizations compensates for our costs in analyzing, adjusting, and publishing the associated control.... the final decision of acceptance of data will be the responsibility of the [Chief], NGS."

In addition to the format criteria discussed above, persons submitting data must adhere to the following requirements:

Reconnaissance. Reconnaissance reports must be submitted in advance, describing proposed connections to the national networks, and the instrumentation and field procedures to be used. This will enable NGS to comment on the proposed connections, drawing on the information available in the geodetic control data base concerning the accuracy and condition of these points, and to determine if the proposed survey can meet its anticipated accuracy. This project review saves the submitting agency the expense of placing data that would fail to meet accuracy criteria into computer-readable form. Work schedules and computer requirements can also be developed from this information. NGS will respond to such reports within 10 working days.

Accuracy. Vertical control surveys must be accomplished in accordance with third-order or higher standards and tied to the National Geodetic Vertical Network. Standards are given in *Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys* (1974, reprinted 1980), and supplemented by *Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys* (1975, revised 1980). However, due to a limited capability to review and edit survey data before they are loaded into the NGS data base, third-order data will be held until sufficient staffing and funding permit processing.

Monumentation. The monumentation must be uniquely identified and meet acceptable NOS standards.

Field Records. The original field records, including sketches, record books, and project reports, are requested. NGS will retain these records in the National Archives and Records Service in the event questions arise concerning surveys on which the adjusted data are based. In lieu of original notes, photocopies or microfilm are acceptable. The material in the original field books or sheets are needed, not the abstracts or intermediate computations.

Charges. NGS does not charge for this service at the present time. However, any survey points which have failed to meet the requirements of the project review, but are subsequently submitted with a project for processing, may be subject to a charge; furthermore, these points will not be published as part of the national network. If on-site instruction with respect to data input formats is requested, there may be a charge.

For additional information, contact James E. Stem, N/CG1x4; National Geodetic Survey, NOS, NOAA; Rockville, MD 20852; telephone (301) 443-8749.

To obtain the publications mentioned in this article, write National Geodetic Information Center, N/CG17x2; NOS, NOAA; Rockville, MD 20852; telephone (301) 443-8316. ■

Gunther Greulich

Water Mark

A 'CRAB-ELTA'

The Wilmington, North Carolina, District of the U.S. Army Corps of Engineers has built a rather unique beach buggy. CRAB stands for Coastal Research Amphibious Buggy and is described in detail ty two U.S. Army hydrographers, Birkemeier and Mason, in the March '84 issue of the *Journal of Surveying Engineering* of the American Society of Civil Engineers.

The buggy is a 35-ft.-high motorized tripod platform, designed primarily for accurate surveys of the nearshore and surf zones. With only two operators, it rapidly collects accurate bathymetric and other coastal engineering data.

The CRAB-ZEISS system consists of a tripod of 8-in. aluminum tubing resting on three liquid-filled tires and is driven by a Volkswagen engine at a top speed of 4 km/hr. Its platform is equipped with a leveling rod and a Zeiss Elta-2 total station. Surveys can be conducted from the beach out to a water depth of 30 ft.

A typical cross-shore profile consists of about 50 data points and takes about 45 minutes to complete. Each point takes about 10 seconds to obtain. Because wave action can cause rapid scour around the wheels, the CRAB does not remain in one position for more than a minute.

The authors are quite excited at the reduction of survey costs and the improved accuracy. The cost for a single bathymetric survey of 26 profiles has been reduced from $35,000 to $2,000, they claim. Owing to the Zeiss Elta-2, the accuracy of elevations during actual repeat surveys in a fairly stable offshore region was found to be within a range of 0.12 m. The typical standard deviation of elevations was found to be ± 0.03 m.

The Corps has used the Coastal Research Amphibious Buggy for other purposes as well. Geologists, photographers, and scuba divers have collected sediment samples, accoustical and optical data and otherwise operated from this mobile research platform.

Thanks to the CRAB, hydrographic surveying will never be the same again. ■

Index to Advertisers

The New Adjustment of the North American Vertical Datum

Article No. 16 Preliminary Vertical Data Reduction Procedures

by Emery I. Balazs
Vertical Network Branch

National Geodetic Survey
Charting and Geodetic Services, NOS, NOAA
Rockville, Maryland

In Article No. 15, Katherine Koepsell and Bruce Ward described the requirements for submitting geodetic leveling data for inclusion into the National Geodetic Survey data base. Before being entered into the data base, the data are reviewed, analyzed, and corrected for known systematic errors. This procedure, termed preliminary processing, is described in this article.

Data received in the Vertical Network Branch are of two kinds: vertical observations and vertical descriptions. The former must also include instrument and rod information, and rod standardization (calibration) records. The Data Set Identification Record or Job Code (*JC*), and the Survey Point Serial Number (SPSN) must be the same in both data sets. The *JC* identifies the project and the SPSN identifies the common bench marks in the two sets.

If the leveling observations are recorded by automated systems, the *30*, *40*, and *41* records of the observation data set (see the NGS publication *Input Formats and Specifications of the National Geodetic Survey Data Base Volume II, Vertical Control Data* for details) can be generated from them.

First the *40* and *41* records are generated by the RECOMP program, which recomputes elevation differences and approximate distances from the observed rod readings and performs several checks on the data. In addition, it prints the rod readings and computed values. This printout replaces the hand-recorded field book when the data are archived.

The next program, ABSTRA, generates the *30* records. The inputs to this program are the file created by RECOMP and the description file. Based on the SPSNs entered on both files, the program transfers the designations, Archival Cross Reference Numbers (ACRNs), and positions (latitude and longitude) of the bench marks from the description file to the *30* records. It also computes field elevations and accumulated distances. ABSTRA also performs several checks and prints a field abstract for preliminary distribution and for NGS archives. The RECOMP and ABSTRA programs are usually run by NGS field personnel. For data from other agencies, or when data are corrected, these programs are run in the Vertical Network Branch.

If the observation data set is converted to computer-readable form from hand-recorded data, the *30* records are keyed from the field abstract, and the *40*, *41*, and *42* records are keyed from the field books. The accumulated distances and field elevations of the *30* records are used in the REDUC4 program to verify data entry or computational errors. The final step in the preliminary processing is running the REDUC4 program, the main function of which is computing and applying corrections to the observations for known systematic errors: rod-scale, rod-temperature, level-collimation, refraction, astronomic, and orthometric corrections. For compensator leveling instruments only, a correction for the Earth's geomagnetic field is also applied. *NOAA Technical Memorandum* NOS NGS 34 "Corrections Applied by the National Geodetic Survey to Precise Leveling Observations," June 1982, by Emery Balazs and Gary Young, describes these corrections in detail.

The output of REDUC4 is an updated observation data file and a hard copy, called the office abstract. The final observation data file consists of those records described in the input formats, and a *43* record for each running, generated by REDUC4, containing the corrections for systematic errors. This file is then entered into the NGS vertical data base.

The office abstract lists SPSNs, ACRNs, DESIGNATIONS, "SPUR" CODES, ACCUMULATED DISTANCES (kilometers), OBSERVED HEIGHTS, and NORMAL ORTHOMETRIC HEIGHTS (meters), the number of forward and backward runnings per section, and positions (scaled). Both heights listed on this (REDUC4) office abstract include all corrections computed to minimize the effects of systematic errors.

Before data are entered into REDUC4, Vertical Network Branch employees perform the following checks:

Observation Data Set Checks:

- The accession number, dates of leveling, tolerance limits, and project and line titles are entered correctly.
- Collimation checks were performed at recommended time-intervals and collimation errors are within tolerance limits.
- Beginning and ending temperatures of the leveling rods' Invar strips are entered for each running of a section.
- Designations are available for every SPSN.
- Rejected observations are noted in the data set.
- All required information is available in the NGS Rod and Instrument file for the instruments and rods used in the project.

• Error flags by RECOMP and ABSTRA programs have been verified and rectified.

Descriptive Data Set Checks:

Vertical-description-edit programs RUNJOB and RUNOUT, run by the field office, flag most of the missing or incorrect records of the description file. These error flags are checked and corrections are made to the description file if necessary.

Previously assigned ACRNs are entered for each recovered bench mark, and new ACRNs are assigned for those bench marks which were leveled for the first time. ACRNs are also checked for possible duplication against the data base.

After the description file has been checked, a project specific synoptic file (PSSF) is created and the description file is transferred to the National Geodetic Information Center for publication. The PSSF, which includes all information from the description file except the text, is then merged into the synoptic file of the NGS vertical data base.

These are only the major steps in the preliminary data processing procedure. Several other smaller items are checked and other programs are run. Computer software now makes data reduction much faster, but there is still a need for experienced geodesists to investigate possible problems identified by the software, and to make an overall review of the acceptability of the data. ■

Doug Wilcox

Members in Government (MIG)

A Members in Government Committee membership meeting was held at the ASP-ACSM Fall Convention in San Antonio, Texas, on September 9 in the Bonham Room of the Marriott Hotel. MIG Co-chairman Steve Vogel presided. The MIG meeting members present voted unanimously to support Co-chairman Vogel in a request to ASP Executive Director William French that ASP: appoint an ASP MIG co-chairman to the position that is vacant, have their MIG co-chairman supply the editor with ASP news on events and concerns, and make it possible to publish the MIG column in the ASP journal. These actions will help to inform all MIG members of both ACSM and ASP and provide more opportunities to ASP members for involvement in society activities. The next MIG Joint Committee meeting will be at the Spring Convention during the week of March 10-15, 1985, in Washington, D.C.

Announcement

R. G. Corbert, Southern Lake Michigan Section, ACSM, has announced the Section's plan to host a 2-week cartography exhibit at the Chicago Civil Center beginning November 2, 1984. They also plan to sponsor a tour of the City of Chicago to include the Bureau of Maps and Plats' computer mapping program and the Chicago Title and Trust Company facilities. ■

The New Adjustment of the North American Vertical Datum

Article No. 17
NAVD 88 Status Report

by Gary M. Young

Vertical Network Branch
National Geodetic Survey
Charting and Geodetic Services, NOS, NOAA
Rockville, Maryland

Note: *This report is a continuation of a series of articles on the new adjustment associated with the North American Vertical Datum of 1988 (NAVD 88). Previous articles in this series were published in the* ACSM Bulletin *from June 1982 through December 1984. Future articles will focus on the progress and problems associated with new adjustment efforts, as well as the benefits that will result from the revitalized network of bench marks in the National Geodetic Reference System (NGRS).*

The NAVD 88 readjustment project has dominated Vertical Network Branch activities since the project received approval and funding, beginning in fiscal year 1978. The total project includes several production and research efforts. A few of the most important are described here.

Approximately 625,000 km of leveling have been added to NGRS since the last general readjustment of the vertical control network in 1929, designated the National Geodetic Vertical Datum of 1929 (NGVD 29). In the intervening years, a large number of bench marks have become unusable due to crustal motion caused by earthquake activity, post-glacial rebound (uplift), and subsidence resulting from withdrawal of underground fluids. Additionally, holding each local mean sea level value fixed (at 0.0 height) for the tide gage stations involved in the 1929 General Adjustment and forcing the 625,000 km of subsequent leveling to fit previously determined NGVD 29 height values have introduced other significant errors into the vertical control portion of NGRS. The approximate magnitudes of such effects are listed in the following table.

Error source	*Approximate maximum amount* (meters)
"Patching" 625,000 km of leveling to 75,000 km network of 1929	0.3
Fixing tide gage heights in NGVD 29	0.7
Ignoring true gravity in NGVD 29	1.5
Refraction errors	2.0
Post-glacial rebound; north central U.S.	0.6
Subsidence caused by withdrawal of underground fluids	9.0
Crustal motion associated with earthquakes	2.0
Bench mark frost heave	0.5

An additional source of error, caused by the effect of magnetic fields (including the geomagnetic field) on the compensators of certain "automatic" leveling instruments, has recently come to light. This error, which amounts to as much as 2-3 mm per km of north-south leveling observed with certain automatic instruments, contaminates approximately 25,000 km of recent NGS first-order leveling. An NGS investigation is underway to determine magnetic factors, either by laboratory calibration or empirical determination, that can be applied retroactively to magnetically influenced observations to account for most of the error. A future article will provide details on this magnetic error study.

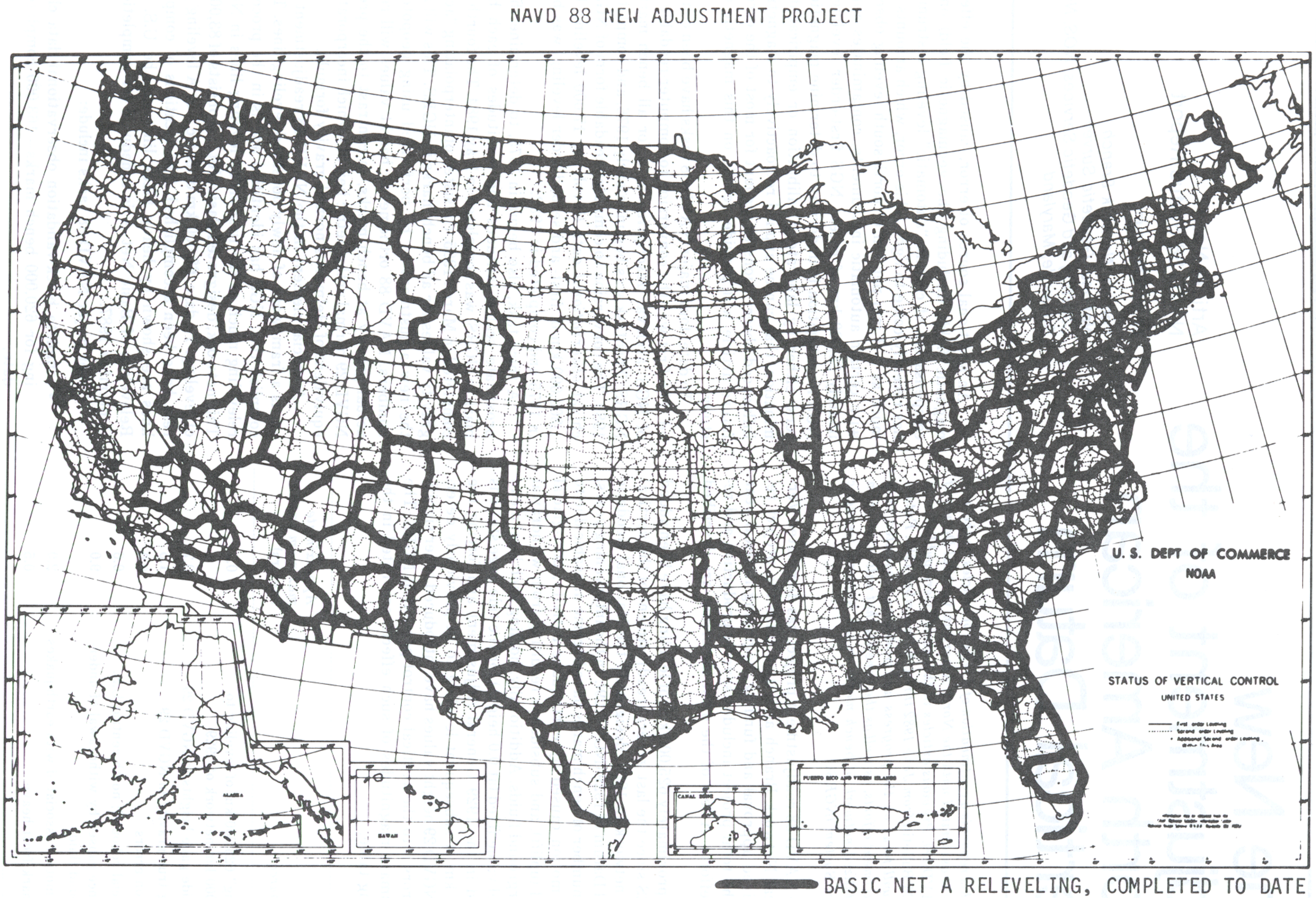
To date, four major NAVD 88 tasks have been completed. The first was the conversion to computer-readable form of NGS' archival *descriptive* data for all bench marks in NGRS. This task was begun in early 1976, and completed in 1980. The conversion to computer-readable form of NGS' archival *observational* data (involving 17,000 leveling lines; 1,300,000 km of first- and second-order leveling) was begun in 1975 and completed in 1982.

A third task, also begun in 1975, to determine the approximate scaled latitudes and longitudes of each bench mark in NGRS, was completed in May 1984. The fourth task, completed in March 1985, consisted of interpolating "actual" gravity values for all bench marks in NGRS. This will allow the new adjustment to be performed using geopotential numbers. NAVD 88 orthometric height values will reflect actual gravity at bench marks, in contrast to the present NGVD 29 normal orthometric heights which incorporate the equivalent of Helmert's normal gravity formula.

A crucial element in the NAVD 88 readjustment project is a framework of newly observed leveling lines. To accomplish this, NGS has identified and is in the process of releveling much of the first-order leveling lines in NGRS. This network, designated Basic Net A, consists of 83,000 km of leveling. To date, 62,000 km of Basic Net A leveling progress have been accomplished. The locations of completed lines are shown by heavy black lines on the U.S. map. Releveling of Basic Net A is scheduled for completion in September 1987.

Other major NAVD 88 tasks include:

- complete block-validation observational data cleansing for 620,000 bench marks—163,000 completed to date,



Status of NAVD 88 New Adjustment Project as of October 1, 1985.

- investigate the role of Global Positioning System (GPS) data in NGRS,
- determine the optimum use of tide gage and water level data in the new adjustment,
- determine the appropriate a priori standard errors of observations,
- select a new reference datum for the readjustment,
- complete a least squares general adjustment using the Helmert blocking technique, and
- publish and distribute the improved NAVD 88 heights.

These are some of the tasks that will be explained in detail in future articles. The new adjustment and publication of NAVD 88 heights are scheduled for completion in 1988-89. ■

MIG—continued from p. 50

the applicant's order of responsibilities and duties. It is felt by many reviewers that the provided information indicates the writer's understanding (perception) of the position. For instance, if an applicant for a licensed land surveyor position indicates that "drafting a survey map" is more significant than "supervising the research of legal records and organization of field surveys for a boundary retracement," a reviewer, including this writer, would interpret the application to mean that the applicant prefers preparing boundary survey maps (a technician-class job element) to supervising research of legal documents and organizing field surveys (a definite professional-level job element). It is important that the applicant carefully prepare this "statement" to reflect the applicant's organization's work. Do not write the statement in an attempt to reflect the new position. The "statement" is not a compromise and should *never* change.

The format of the statement is not cast in concrete. The applicant must scrutinize the application and decide upon the most appropriate format. The narrative statement utilizes a series of concise—even terse—phrases, separated by emphatic punctuation (the semicolon). The alternative is to employ the classical outline format. This writer has employed both styles. It is difficult to determine which style is preferred by evaluators, but unless inside information is available, either format is acceptable.

The contents of the statement describe the applicant's duties and responsibilities, rather than listing the specific projects. The applicant may have difficulty preparing this statement, but as mentioned before, the position description, KSAPs, etc., are used. Non-federal employees may have access only to general or briefer documentation, which hampers writing. However, ACSM and MIG can provide invaluable assistance. State professional societies, ACSM, and ASPRS provide forums (publications, technical meetings/conventions, symposia, etc.), where employees from all sectors of the profession can become acquainted with each other. This writer has utilized these forums in this manner, and subsequently, we have called upon each other to assist in a matter which is the other's forte. Furthermore, knowledge of fellow professionals' capabilities and expertise, in both private and government sectors, helps to identify the appropriate professional to solve a knotty technical problem.

It was recommended earlier that the applicant should not mention specific projects. There are several reasons for this. First, there are other opportunities to mention specific projects. In federal agency applications, the applicant submits a written statement (KSAPs). In this document the applicant has an opportunity to "blow his own horn" about work and accomplishments. Second, the name/title of many projects does not impart any significant information about the applicant's duties/responsibilities. However, there may be an opportunity to mention projects, particularly in association with a specific job skill, function, or procedure. The applicant should exercise caution in mentioning a particular project. When doing so, the statement should be generic but descriptive (e.g., legal records research/abstract for the boundary surveys for the XYZ Urban Renewal Housing Project). Third, a special format is available, but it is primarily employed by land surveyors. The applicant prepares a chronological and geographical list of projects performed, including duties and responsibilities. Prospective employers and state licensure/registration boards are interested in an applicant's land/legal/boundary work, and his/her involvement.

Once the applicant has written a work statement for each position held (remember that several different positions may have been held while working for the same employer), the work begins. The writer now must divorce himself from the writing and become a supercritical editor. It is important to remember that a good work statement is not necessarily the result of good writing, but results from critical editing. There are no set rules on how to edit the statement. In recent years, several books on "how to write a resume" have been published. These may provide some helpful insight.

Preparation of the work statement is not a simple project. The effort requires considerable research of one's own personnel records and diaries, tough writing, hard assessment, and editing. However, once the statement has been prepared for a particular position, if it has been done correctly, there will be no need to rework or rewrite. All that is required will be to "dust-off" the statement and insert it into the proper place in the application. Remember, in general, readers of applications are human. Although they attempt to be impartial in evaluating the submitted credentials, there is an element of subjectivity. A well written, neat document impresses. In several instances this writer has witnessed the importance of the impression made when two applicants had identical qualifications, but the documents of one were superior in appearance.

In closing, the writer would like to paraphrase a commercial motto that is appropriate in preparing a work statement: "The applicant cared to submit the very best." ■

The New Adjustment of the North American Vertical Datum

Article No. 18
NAVD 88 Status Report for Canada

by Rachid Mazaachi

Head, NAVD Data Analysis Sub-Section
Geodetic Survey of Canada
Dept. of Energy, Mines and Resources
Ottawa, Ontario, Canada K1A 0E9

This article focuses on the plan, progress, and problems related to the Canadian effort directed toward the North American Vertical Datum of 1988 (NAVD 88) readjustment project. Other articles in this series pertaining to the Canadian portion of the new adjustment were published in *ACSM Bulletin*, Nos. 88 [Feb. 1984, p. 33-35] and 89 [Apr. 1984, p. 25].

Background

The Canadian leveling network comprises approximately 150,000 km of leveling (about 60,000 bench marks) of different orders of precision, mainly distributed in the southern portion of the country. It was recognized, in the early 1970s, that our present vertical reference system no longer met modern requirements. Therefore, a special Geodetic Survey of Canada section was formed in September 1981 to spearhead the redefinition effort and to allow Canadian participation in the readjustment of the North American Vertical Network.

For further information on the historical background and events leading to Canada's involvement, and a review of the various phases of this project, see the two articles mentioned in the first paragraph.

Data Automation

Data automation consists of the conversion of geodetic leveling data to computer-readable form, obtained mainly from two sources: data collected manually in notebooks in the field (prior to 1982) and those recorded automatically on HP-85 mini-cassettes. For this purpose, the data are grouped into sets called "jobs." A job is defined as a leveling data set collected by one field supervisor in 1 year. The work may or may not be done in the same area or province. A job is divided into subsets called "leveling lines." A leveling line is defined as a subset of leveling data of interconnected bench marks along a leveling route.

Data validation is based on a comparison of two independent compilations for each leveling line. The first compilation contains information on the runnings, which is collected from the field book and from the HP-85 cassettes. The second compilation defines the leveling line, i.e., it localizes the spurs, the starting bench marks of different leveling routes, and their order along the given paths.

At the present time, 80 percent of the notebook data has been coded and 60 percent has been keypunched and stored on permanent files in the computer (CDC 730). Relating to data validation, 37 percent of the field book data has been checked. None of the HP-85 mini-cassette data has been processed because the corresponding data validation system is being developed and tested.

Data Preprocessing

The purpose of data preprocessing is to compute and remove all effects of possible systematic errors. This involves the study and development of related software of various corrections such as refraction, rod calibration, expansion and index error, gravity interpolation, temporal homogenization, and sea surface topography effects.

To assess the importance of the systematic effect of atmospheric refraction in precise leveling and the efficiency of existing models in correcting for that effect, refraction tests were conducted. The average temperature difference between heights of 0.5 m and 2.5 m above the ground was -0.55°C. The total accumulated refraction error agreed well with the value of refraction computed from Kukkamaki's equation using measured temperature gradients.

A rod information file has been created. It contains information needed to compute rod excess, expansion, and index errors. The file is monitored by a data base management system called Scientific Information Retrieval, which was developed by SIR, Inc., Evanston, Illinois.

Two-peg collimation tests, extracted from field books, have been analyzed. A preliminary investigation showed that several jobs were performed without a sufficient number of two-peg tests observed on a daily basis. The decision whether to apply the correction due to collimation error depends on the number of two-peg tests, their time spacing, their stability, and the confidence band they represent. The average value of the error rarely exceeds 0.2 mm/10 m.

Tests on gravity interpolation have been made using two predicition methods: a surface fitting technique and least squares collocation. Interpolation by applying the collocation method for which the software was developed in-house appears to work very well in areas such as the Maritimes, Central Canada, and the Prairies. Further investiga-

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tion will be done with more complete data sets in the Rocky Mountains of western Canada. In this area, we require height data on a regular grid to produce terrain corrections for all grid points, evaluated by the Fast Fourier Transform, in order to improve the gravity anomaly prediction which is so important in mountainous regions.

An investigation pertaining to the temporal homogenization of the Canadian leveling network, i.e., the movement of bench marks with time, and sea surface topography was undertaken by the Canadian Government (Department of Energy, Mines and Resources) through a research grant awarded to the University of Toronto (Erindale College).

For crustal movement, the task of identifying the epochs and locations of the leveling lines of the basic net has been completed and the related software developed and tested. All tidal bench mark corrections have also been obtained for tide gauges. Temporal corrections and their accuracies for 331 leveling links of the network have been computed. Three different solutions have been produced, each corresponding to the three solutions of the map of vertical crustal movements determined by Vaníček and Nagy in 1980. The corrections observed in all of these results range from -40 mm to +40 mm.

Sea level records, river discharge, water temperature, and meteorological data for analysis of sea surface topography effects have been prepared in computer-readable form. A surface-fitting subroutine used to model the wind in eastern Canada and the Vancouver area has also been developed. Also, least squares spectrums for mean sea level, air temperature, river discharge, water temperature, and atmospheric pressure time series have been computed.

Data Analysis

Determination of the links with stable junction points against basic net standards and computations of closures based on observed elevation differences for all loops of the primary network have been completed. The design of the data base management system, which will automate this information, has begun. It is monitored by INFOFETCH software developed by MAGNA Business Systems Corp., New York. From this analysis it appears that approximately 2,000 km of releveling, mainly in hinterland areas, will be required prior to the redefinition.

A pre-analysis of section discrepancies in several areas of the country was made to estimate a reliable standard deviation of leveling observations and consequently to find a realistic relative weighting scheme. Two methods have been investigated. The first considers samples of normalized discrepancies of forward runnings against backward runnings, and the second one studies normalized ranges ("normalized" meaning divided by the square root of the section length). Both converge toward 1.4 mm per square root of the running length in kilometers.

Data series analysis and multiple linear regression techniques, and their related software, have been applied to facilitate analysis of the leveling data. This is also being performed under the University of Toronto's research contract. A preliminary one-dimensional analysis was performed with a few leveling lines in Nova Scotia. From these results there appear to be significant effects due to both rod settlement and refraction in a few of the lines.

A study of modulated normal distribution and its possible application to leveling errors was performed. The results were presented by the author at the 1985 Third Internationl Symposium on the North American Vertical Datum in Rockville, Maryland. A significant leptokurtic tendency was noticed by analyzing the histograms relating to the normalized discrepancies across several areas of the country.

The establishment of a data analysis procedure based on the block validation approach has begun. The procedure will be compatible with the one followed by the (U.S.) National Geodetic Survey. It will be divided mainly into four steps: (1) study of the variation of profiles of a line from a given leveling to one or more relevelings, (2) automatic detection of loops, (3) preliminary least squares adjustments, and (4) automatic network design. This method will result in a final adjustment of the North American Vertical Network by the Helmert blocking technique.

Datum Definition

Four approaches have been outlined in a preliminary investigation defining geometric aspects of vertical datums: geoid modeling, the spectral analysis of long-term tide gauge records, modeling of sea-surface topography, and satellite altimetry.

Regarding satellite altimetry processing, data obtained from the SEASAT satellite have been received from NASA. They were grouped into quadrangles in the Atlantic, Hudson Bay, and Pacific areas. The sea surface heights of all the crossover points on the south-north and north-south passes have been completed. The software performing the least squares adjustment of these observations has been developed and tested.

Finally, a research contract has been signed between the Geodetic Survey of Canada and McElhanney Group, Ltd., Calgary, Alberta, to study a weighting scheme for all the observations that will be included in the North American Vertical Datum readjustment. These include leveling, transit Doppler, Global Positioning System data, and the gravimetric determination of geoid undulation. ■

Editors please note! The address of the editor of the ACSM BULLETIN has changed. Inasmuch as the Post Office will only forward mail, such as your newsletters or news releases, for a few months, please check the address you are using so there will be no lapse in receiving your news. **New address:** Jane R. Kennedy, editor, Kennedy Associates, 307 S. Washington St., Alexandria, VA 22314. The phone number is the same: (703) 683-4665.

The New Adjustment of the North American Vertical Datum

Article No. 19
NAVD 88 Impacts and Benefits

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Previous articles written for this series described many phases of the new adjustment of the North American Vertical Datum of 1988 (NAVD 88). This article discusses some of the benefits and impacts of NAVD 88 to users.

Benefits of NAVD 88

The NAVD 88 project, which is requiring an enormous amount of effort, has dominated activities of the Vertical Network Branch/NGS since approval and funding in FY 1978. The benefits of NAVD 88 justify the tremendous amount of effort required, as shown in Table 1.

Table 1. Benefits of NAVD 88 to Users

1. A single datum for North America.
2. Improved set of heights for North America.
3. Destroyed bench marks replaced and new leveling performed for an 83,000-km framework.
4. Improved leveling procedures with higher production and lower error rates.
5. All U.S. national vertical network data validated in a single data base, with easy access by the user for crustal motion studies, adjustments, latest official heights, and descriptions.
6. Improved geoid modeling using Global Positioning System and NAVD 88 data.
7. Improved base for smoother transition into satellite and gravity-derived orthometric height differences.
8. Results of research activities performed in support of NAVD 88.

A national vertical control network containing a consistent, accurate set of adjusted heights has been needed for over a decade. Other products and services resulting from the project will be used for years to come. For example, the observed elevation differences, which are now in computer-readable form, are available for future crustal motion studies and regional readjustments. NGS is currently using the data to perform crustal motion and other systematic error studies. Major crustal motion analyses in support of the NAVD 88 readjustment project are planned for California. Users can request data on magnetic tapes for their own special studies. The real benefits will become more apparent when people begin using the results of the new adjustment.

Impact of NAVD 88

The impact of NAVD 88 will be slightly different in each area of the country. At this time only a few general statements can be made. First, in "stable" areas relative height changes between adjacent bench marks should only be a few millimeters. The absolute height value could change by as much as a few decimeters, depending upon how the datum is defined. Because datum definition could change the absolute height by a large amount, the NAVD 88 datum definition deserves serious consideration by everyone involved. In many areas a single bias factor, describing the difference between the present National Geodetic Vertical Datum (NGVD 29) and NAVD 88, could be estimated by comparing common bench mark heights in both systems. Even with this factor, NAVD 88 will still have a major impact on mapping agencies, e.g., the U.S. Geological Survey (USGS) and the Federal Emergency Management Agency (FEMA).

The Federal Emergency Management Agency states that if the relative height changes between bench marks remain fairly constant over a given geographic area, the impact to the National Flood Insurance Program (NFIP) will be minimal. As long as the relative hydrographic conditions shown on the FEMA maps remain correct, FEMA only has to ensure that consistent data are used when comparing flood elevation to structure elevations. Therefore, a bias shift in heights, because of a datum definition, will not have a major impact on NFIP. FEMA requests assistance in educating the user. There are more than 17,500 communities that participate in NFIP. More than 150,000 insurance agents deal with 2 million flood insurance policyholders. FEMA suggests technical reports be prepared for engineers and surveyors, and non-technical reports for others. NGS is planning several reports documenting the NAVD 88 project; some will be technical in nature, others non-technical.

USGS stresses that datum definition is critical to the National Mapping Program (NMP). USGS produces 60,000 different map products, among which the 7.5-minute series will be most affected by a datum change. USGS has approximately 100 spot elevations on every 7.5-minute quad, as well as various contour intervals. A tenth of a contour interval can be handled by adding a statement for the datum shift between NGVD 29 and NAVD 88. In flat terrain a datum shift of more that 1 ft. will present problems. In mountainous regions 8 ft. or more will create problems. The total conversion of all USGS maps could cost as much as $45 million.

Because of these costs, one solution being considered is holding each tide gauge height fixed at a zero value to minimize impact upon the mapping community. This would give the local surveyor amply accurate heights with minimum inconvenience, while still allowing the geodetic theorists their research datums, thanks to modern computer capability (see section in this article titled "Future Activities Related to NAVD 88 Datum Definition").

There are thousands of other data bases and maps referred to NGVD 29 heights which may have to be updated for NAVD 88 heights. All published NGS bench marks will have NAVD 88 heights. Updating these heights will not be a difficult task, but it will be time-consuming and expensive. The real problem will be estimating heights for bench marks that are not part of the NAVD 88 adjustment. The only rigorous method of incorporating these bench marks into NAVD 88 is to process and analyze the original observations, and then fit them to NAVD 88. This could also be time-consuming and expensive. Once again, a factor describing the approximate separation between NGVD 29 and NAVD 88 could be estimated. Depending upon the user's requirements, this factor may be sufficient. The Vertical Network Branch (VNB) is willing to assist users in evaluating their situation and developing a plan to convert their heights from NGVD 29 to NAVD 88.

In areas of crustal motion, relative height changes will be dependent upon the magnitude of actual ground movement. NGS will be developing crustal motion models and publishing estimates of bench mark velocities wherever enough data exist, e.g., portions of California.

Future Activities Related to NAVD 88 Datum Definition

The National Geodetic Survey has undertaken a special study to compile a primary vertical control network using the latest data available. Analyses of this network will be helpful in determining the effects of various datum constraints, magnitudes of height changes from the NGVD 29 datum, influences of systematic errors, deficiencies in network design, and additional releveling requirements. Other studies comparing local mean sea level to geodetic leveling along the U.S. east and west coasts have already been performed. These studies will continue until all primary tidal station connections are analyzed. It is anticipated that NGS will be ready to discuss specific effects of NAVD 88 on the user community within 1 year.

The following questions need to be answered before NGS and cooperating organizations define the NAVD 88 vertical datum.

1. Although it is a well-known fact that local mean sea level values measured at various tide gauges are not on the same equipotential surface, should NGS hold each tide gauge height fixed at a zero value to minimize impact to the mapping community? What will be the effect upon others if the tide gauge heights are held at zero?

2. What are the real impacts to the mapping community? Can one tide gauge height be held fixed to define the datum, and then a block shift be performed to minimize the height discrepancies between local mean sea level and NAVD 88 in such a manner that the impact to users is minimal (i.e., the smallest height discrepancies occur in low-lying regions of the country)?

3. How accurately can sea surface topography effects be estimated? Is the cost/benefit ratio of estimating these effects too high, considering that the primary use of NAVD 88 is for engineering purposes?

4. Should NGS define an engineering datum that would meet more than 95 percent of users' needs, and create separate, task-specific, scientific "datums" upon request?

5. What are the legal implications of a datum change? How many state laws, zoning regulations, etc., have NGVD 29 written into them?

All users are encouraged to express their concerns to NGS about the readjustment project. The more we understand each other's needs, the smoother will be the transition to the new vertical datum. NGS requests input from users to determine the "best" datum definition for NAVD 88. The needs of all users will be considered.

Conclusion

The NAVD 88 project is requiring an enormous amount of effort, but the benefits will be worthwhile. A National Geodetic Vertical Network containing a consistent, accurate set of adjusted heights has been needed for over a decade. A major benefit of the NAVD 88 project is the 1.3 million observed elevation differences which are now in computer-readable form. These observations are available to the public for crustal motion studies and regional readjustments. The real benefits will become more apparent when the multitude of users begin using the results of the new adjustment.

The Vertical Network Branch is investigating the impact of NAVD 88 on users. Each area is unique and, therefore, the impact will be slightly different upon each. Analyses of a primary vertical control network using the latest data available will be helpful in determining the effects of various datum constraints. A bias factor describing the approximate separation between NGVD 29 and NAVD 88 will be estimated, comparing bench marks heights in both systems. This factor may be sufficient depending upon users' requirements. NGS encourages all users to obtain a basic understanding of NAVD 88 and to express their concerns about the project. The more NGS understands users' needs, and the more users understand NAVD 88, the smoother the transition will be from NGVD 29 to NAVD 88. ■

The New Adjustment of the North American Vertical Datum

Article No. 20
Correcting for Magnetic Error

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Elimination of systematic errors in the leveling data is one of the most important aspects of the North American Vertical Datum (NAVD) project. Magnetic error influences many automatic (compensator) leveling instruments, is azimuth dependent, and reaches a maximum when leveling in the magnetic north-south direction. Magnetic error is gross compared to random leveling errors, and commonly exceeds 1 mm per km. Most automatic leveling instruments have their compensators suspended by ribbons made of El-invar (Nivarox), which has a residual magnetic sensitivity. The error was first noticed when the first-order level network of the state of Rheinland-Pfalz, Germany, was resurveyed in 1968-74. Subsequently, it was shown by German investigators that leveling instruments from several manufacturers were responsive to magnetic fields in the laboratory,[1] and therefore should also be influenced by the Earth's magnetic field. The sensitivity of a particular automatic level is proportional to the compensator's mechanical tilt amplification. The Zeiss Ni-1 has a mechanical tilt amplification of 15.5×, which is very high by comparison to other instruments; for example the Zeiss Ni-2 has a tilt amplification of 1.7×.

Elimination of magnetic error is important to the success of the NAVD program because 25,000 km of recent leveling were accomplished with the Ni-1 instruments between 1972 and 1980. First attempts to eliminate the error depended on calibrations of these instruments in the laboratory. The response of the level instrument to the Earth's magnetic field is summarized by the expression:

$$M = -C\,H\cos(A)\,S$$

where M is the magnetic error, C is a correction constant derived by calibration (mm km^{-1} $Gauss^{-1}$), H is the horizontal component of the Earth's magnetic field (Gauss), A is the azimuth of the leveling measurement relative to magnetic north, and S is the distance leveled (km). A model of the Earth's magnetic field is used to calculate local magnetic intensity, inclination, and declination, which are then used to calculate H and A. To determine the correction constant, C, in the laboratory, the instrument is surrounded by three pairs of Helmholtz coils corresponding to coordinate axes, and current is varied in the different coil pairs to create magnetic fields of different intensity and direction. The responses of the instrument are recorded and later used to derive C. The results of these calibrations have been reported by several investigators. It was found that applying excessive magnetic fields to the instruments in the laboratory, could cause the response characteristics of an instrument to change drastically if the horizontal component of Earth's field is exceeded by 20×. When this happens the original characteristics of the instrument can no longer be recovered and modeled.

After the National Geodetic Survey (NGS) determined C-values in the laboratory, the constants were evaluated for three of the instruments, and found to correct excessively when applied to actual field data. The evaluation consisted of comparing corrected Ni-1 levelings with previous spirit levelings. From these comparisons it was possible to graphically derive revised calibration constants that made the Ni-1 leveling much more consistent with the spirit leveling for the lines evaluated.

To improve on the laboratory calibrations, an automated empirical approach was developed at NGS. All Ni-1 measurements in the conterminous United States were matched, where possible, with measurements considered to be free of magnetic influence. The repair history for each Ni-1 was used to determine how many compensators an instrument had during its field use. At least one unknown calibration constant was associated with each compensator. An extra unknown constant was needed when a major repair of the compensator or exposure to extreme conditions was suspected of having altered its reponse characteristics. The calibration constants for all instruments were solved for simultaneously. The C-values ranged in value between +1.28 and −10.18, with the weighted aveage being −3.68. This was considerably smaller than the −8.74 average value determined in the laboratory by NGS.

Figure 1 shows a comparison of various Ni-1 levelings accomplished in the period 1974-80, and spirit levelings performed between 1953 and 1963. The profile begins at Norfolk, Virginia, and terminates at St. Augustine, Florida. Without any correction, the divergence, which we take to be magnetic error, accumulates to more than 1 m. The empirical magnetic correction reduces the divergency to 18 cm. The magnetic error correction constants derived in the laboratory overcorrected for the first 900 km, producing a maximum divergence of 32 cm.

The reliability of the same corrected levelings was also assessed by comparing them with local mean sea level (LMSL) values along the coasts. LMSL is determined from

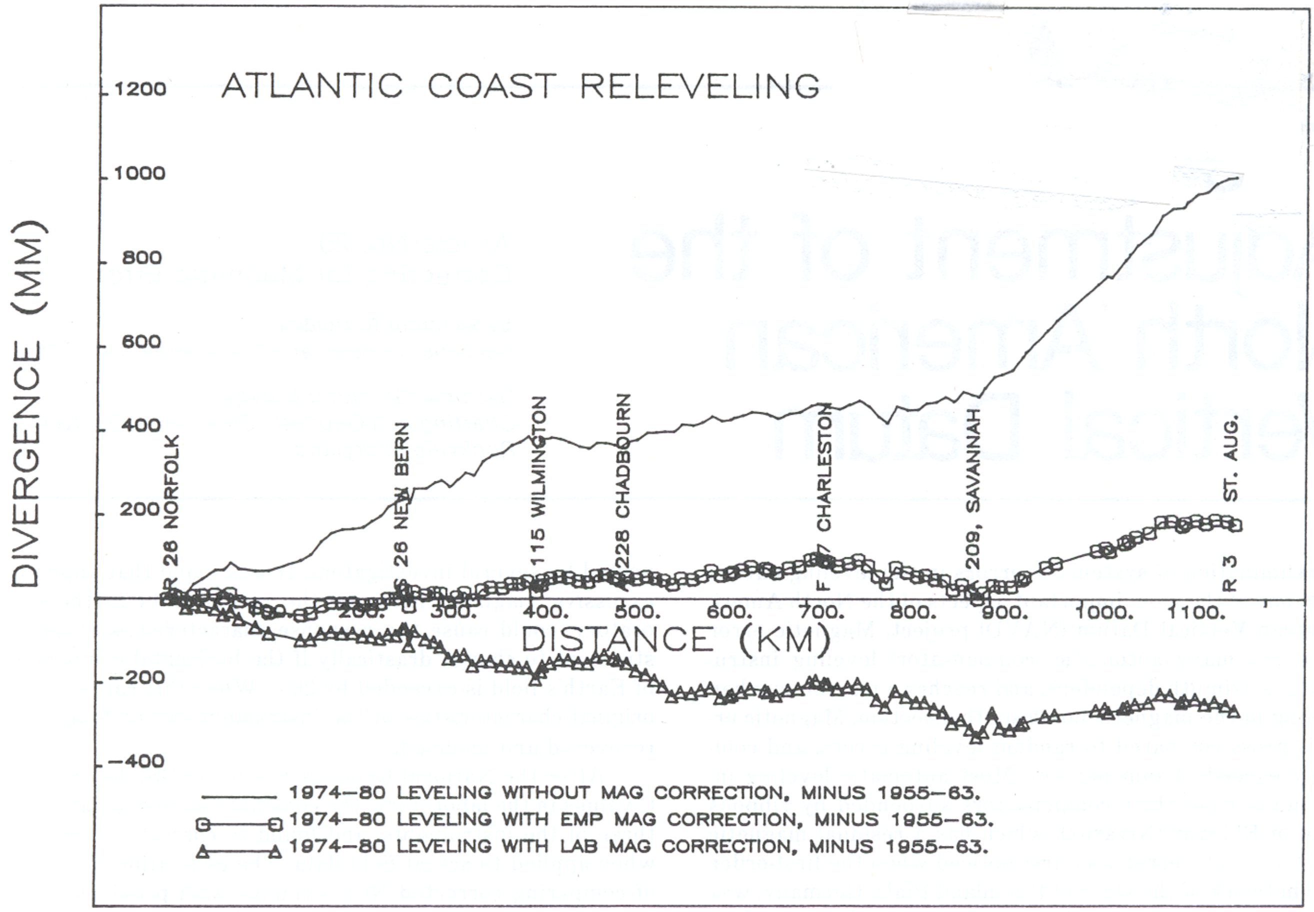

Figure 1. Comparison of Ni-1 levelings and spirit levelings from Norfolk, Virginia, to St. Augustine, Florida. Ni-1 levelings were accomplished in the 1970's, and spirit levelings were performed in 1954-63. Without magnetic correction, error accumulates to more than 1 m.

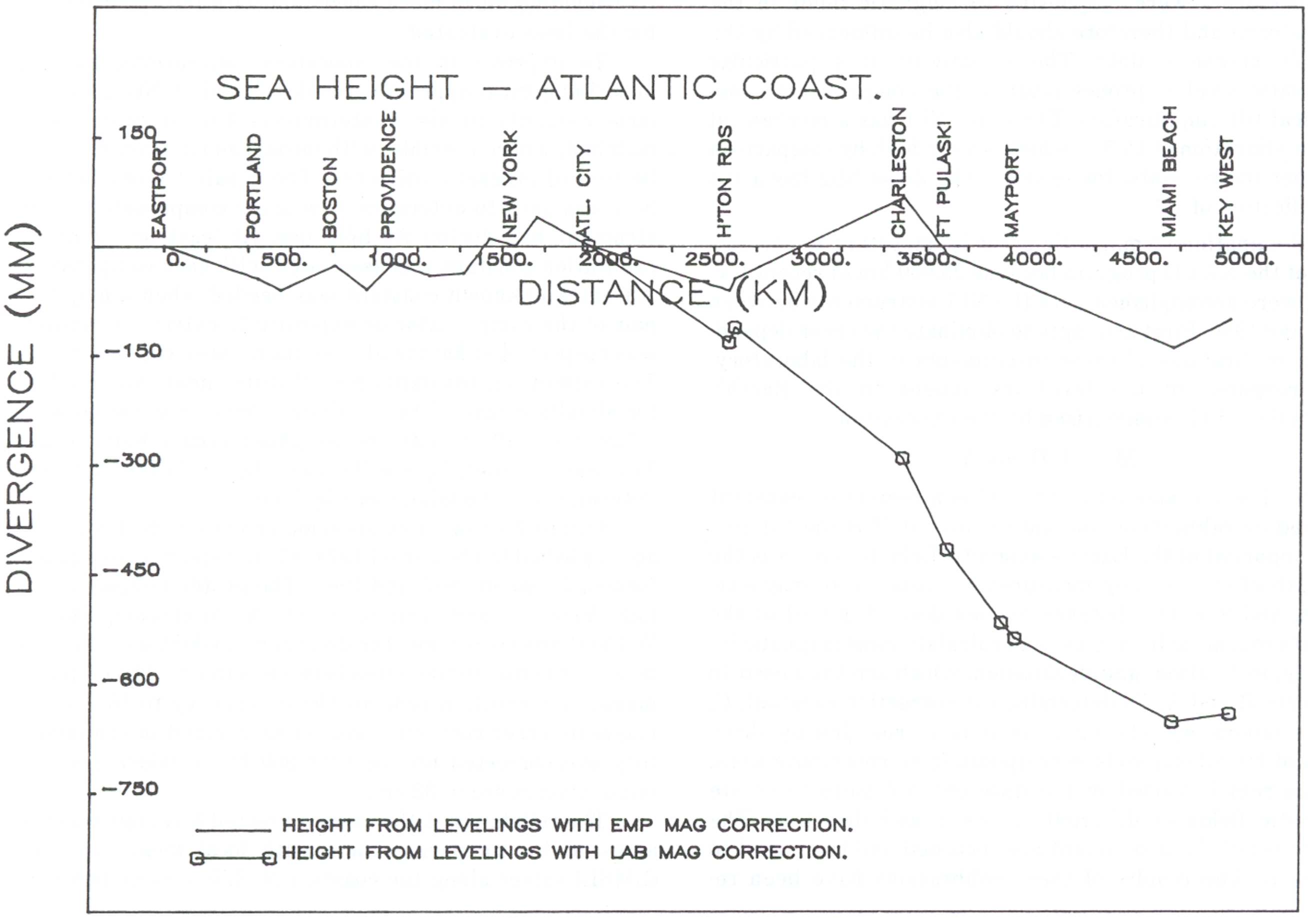

Figure 2. Plot of sea height determined by comparison of geodetic levelings and local mean sea level values. Only the segment between Atlantic City and Key West contains Ni-1 measurements. A reasonable sea slope is deduced when empirical magnetic corrections are used.

tide gauge records. The slope of the sea can be estimated by comparing leveled heights with LMSL at the tide gauges. Sea slope along the southeastern coast of the United States is estimated to be approximately flat when all ocean dynamics are considered. Figure 2 is a plot showing the divergence, leveled height minus LMSL, from Eastport, Maine, to Key West, Florida. Only the leveling between Atlantic City and Key West involves Ni-1 observations. The data corrected with empirically derived magnetic error correction constants show a 10 cm fall in the sea between Atlantic City and Key West. The same leveling data, when corrected with constants from laboratory calibrations, show a fall of 64 cm. Thus leveling data reduced with the empirically determined correction constants give a much more reasonable sea slope.

Confidence has been gained after applying empirically derived calibration constants. Typically, 80 percent of the error/divergence between Ni-1 and spirit leveling, is removed as a result of applying the corrections. Nevertheless, corrected Ni-1 leveling measurements should not be considered quite as reliable as measurements made by other instruments with the same observing procedures. In the adjustment to redefine the NAVD we will downweight the Ni-1 data. The weight of an Ni-1 measurement will consider how well the calibration constant is determined.

For some Ni-1 compensators, there is not enough data from which to empirically derive a calibration constant. This occurs when a low volume of measurements was obtained prior to damage, loss, or major repair of a compensator; or the data were obtained in an area undergoing subsidence or significant tectonic deformation. In such cases we substitute the average correction constant (-3.68 mm km^{-1} Gauss^{-1}) in order to compute magnetic corrections, and the reliability of the observations is considered to be less than for normally corrected Ni-1 measurements.

Too little is yet known about the exact nature of magnetic error. The sinusoidal character of the error with changing azimuth is well established in laboratory simulations, and the empirical correction works well on field data. However, there is evidence that a single compensator is likely to increase its magnetic sensitivity at some point during its operational history. This leads to the supposition that the Ni-1 can become magnetized if exposed to strong magnetic fields during its use, or while being stored or repaired. Magnetic screwdrivers were possibly used in some NGS repairs. Four of the NGS instruments started with smaller response characteristics than they finished with, even though no compensator changes were involved. The empirical calibration approach can cope with this problem, but only after the time of exposure to abnormal magnetic fields is discovered by analysis of leveling profiles. Figure 3 is a profile from New

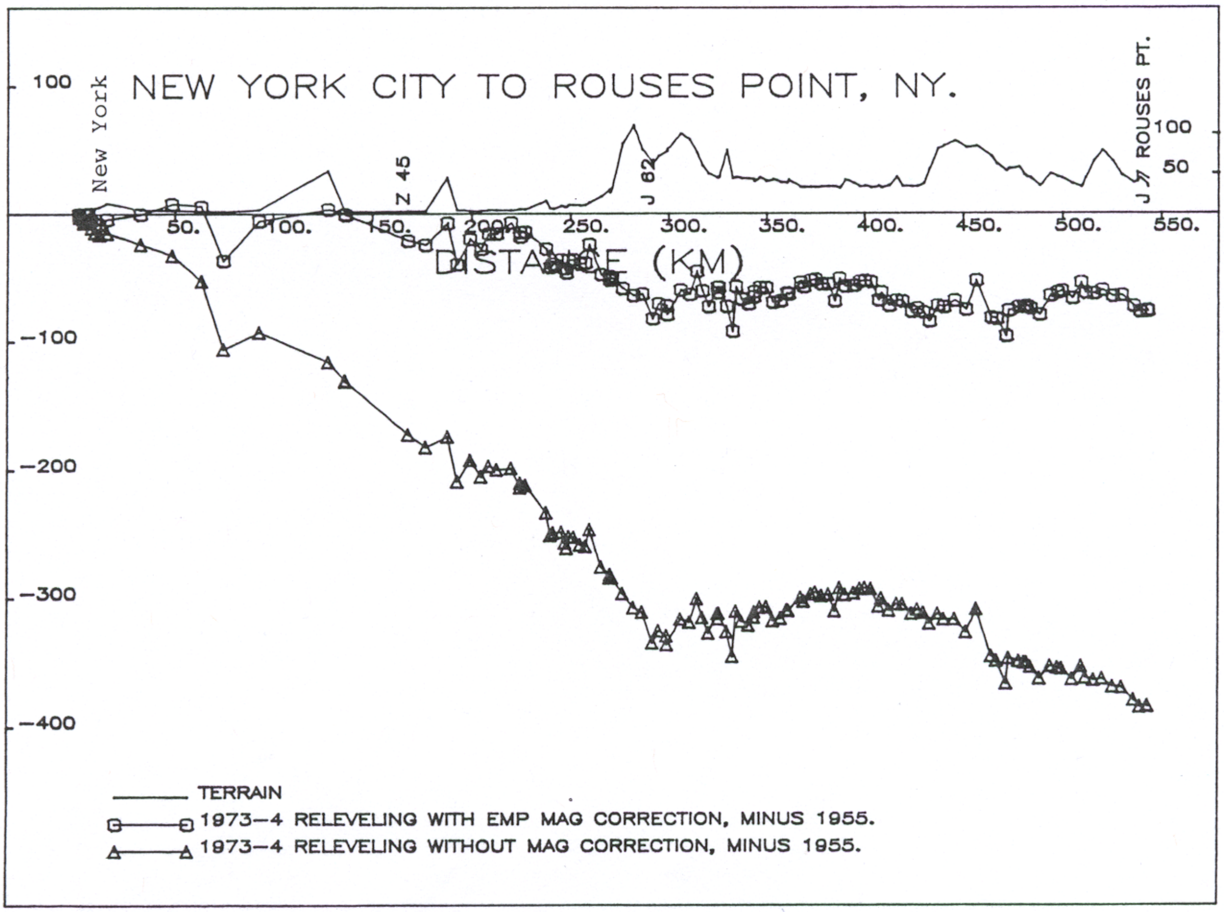

Figure 3. Comparison of 1956 spirit leveling and 1973-74 Ni-1 levelings, from New York City to Rouses Point. Magnetic error of approximately 38 cm is reduced to 8 cm by application of empirical magnetic corrections.

York City to Rouses Point near the Canadian border. Without correction the divergence amounted to 38.4 cm over the 543 km route. The empirical magnetic corrections reduced the divergence to 7.6 cm. Originally, the first half of the profile was badly undercorrected (50%) using results from one of the first calibration solutions. A second solution was obtained wherein separate constants were derived for the periods before and after arrival in New York. For one instrument the constant changed from +1.23 to −5.24, and another changed from −2.13 to −5.83. These drastic changes in magnetic sensitivity appear to be due to exposure to magnetic fields in the city. The leveling route was near large power transmission lines and an electrified train rail. The change in magnetic characteristic of these instrument compensators was permanent. Repair records were not available before the New York survey; therefore, it is also possible the instruments were magnetized during repair.

NGS is pleased with the successful application of empirical calibration constants. The magnetic error problem has served to re-alert manufacturers to the importance of design considerations in leveling instruments to prevent magnetic error, and similarly geodesists are reminded to be watchful for indication that any new instrument may produce a systematic error.

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The New Adjustment of the North American Vertical Datum

Article No. 21
Block Validation

by Janice Bengston

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By now, many readers of the *ACSM Bulletin* are aware of the tremendous project the National Geodetic Survey is undertaking: the readjustment of geodetic leveling in the United States. The task, known as the North American Vertical Datum of 1988 (NAVD 88) project, will result in a single datum for all of North America, specifically a consistent set of heights for more than 600,000 bench marks in the United States plus additional marks in Mexico, Central America, and Canada.

Background

The last general adjustment (in 1929) of the vertical control network in the United States resulted in a datum, the National Geodetic Vertical Datum of 1929 (NGVD 29), of adjusted heights to which future leveling would be made consistent.

Since that adjustment, the basic network has been densified with the addition of many secondary leveling lines. Furthermore, much of the original network has been releveled at least one time.

Some areas of vertical crustal motion such as New Orleans, Houston-Galveston, and southern California have been releveled periodically every few years.

The heights of each succeeding leveling line have been made consistent with previous leveling, which had been "fit" to the NGVD 29 network by a least squares adjustment. Sometimes a mini-network was adjusted independently, utilizing tidal marks as constraints.

As a result, the network has changed dramatically from its original configuration and now requires a new general least squares adjustment to produce a new set of adjusted heights. The new heights will be the framework to which future leveling will be tied. This new datum is called NAVD 88.

The NAVD 88 project will take advantage of the most recent sophisticated methods to compute corrections to leveling observations, e.g., solar radiation modeling to compute corrections due to refraction, determinations of magnetic error for certain compensator leveling instruments, and an improved procedure to compute rod corrections.

The NAVD 88 project involves several critical steps. The first step, processing archival data and converting it to computer-readable form, has been completed. More than 15,000 leveling lines, representing more than 1,200,000 km of leveling, are now included in the NGS data base. (See Article No. 5 of this series.) Correspondingly, descriptive data for almost 500,000 marks have been added to the data base. (See Article No. 7.)

The second step in NAVD 88 is the selection of leveling lines to form the basic framework for the adjustment, known as Basic Net A (BNA). Many lines of this basic first-order framework are being releveled to satisfy contemporary requirements. (See Article No. 8 of this series—Survey Plans for Basic Net A, by Emery I Balazs.)

The interaction of data in each circuit must then be analyzed in a procedure known as block validation, which is the third step in NAVD 88. Each leveling line was checked individually for obvious leveling blunders and errors in transferring data to the computer when the data were automated in the first step of NAVD 88. Block validation will detect additional keying errors, incorrect application of correction formulas, and other errors which could ultimately affect the quality of the adjusted heights. More importantly, block validation will determine the "fit" of leveling lines within the network.

Steps two and three are progressing concurrently. After the field data have been processed and checked for all the lines needed to complete a BNA circuit, and the misclosure of the circuit has been computed and verified, the circuit then becomes available for block validation. After block validation has been completed for all BNA circuits, groups of circuits will be combined, using the Helmert blocking technique, in preparation for the final adjustment.

Block Validation

A typical BNA circuit assigned to an analyst in the Vertical Network Branch includes about 4,000 bench marks and usually requires a period of 3 to 4 months to process. One project consists of: the new BNA leveling lines which form the framework of the circuit, older lines leveled along the same route as BNA (secondary network), all lines in the interior of the circuit, and portions of lines that enter the area enclosed by the circuit. A sample circuit is shown in Figure 2. All lines represent leveling routes; multiple lines indicate releveling. Please note that Figure 2 depicts one of the less dense circuits. Areas of known subsidence or uplift, as well as highly populated areas, are often leveled much more frequently.

At least three progressive adjustment analyses are performed before a single block validation project is completed.

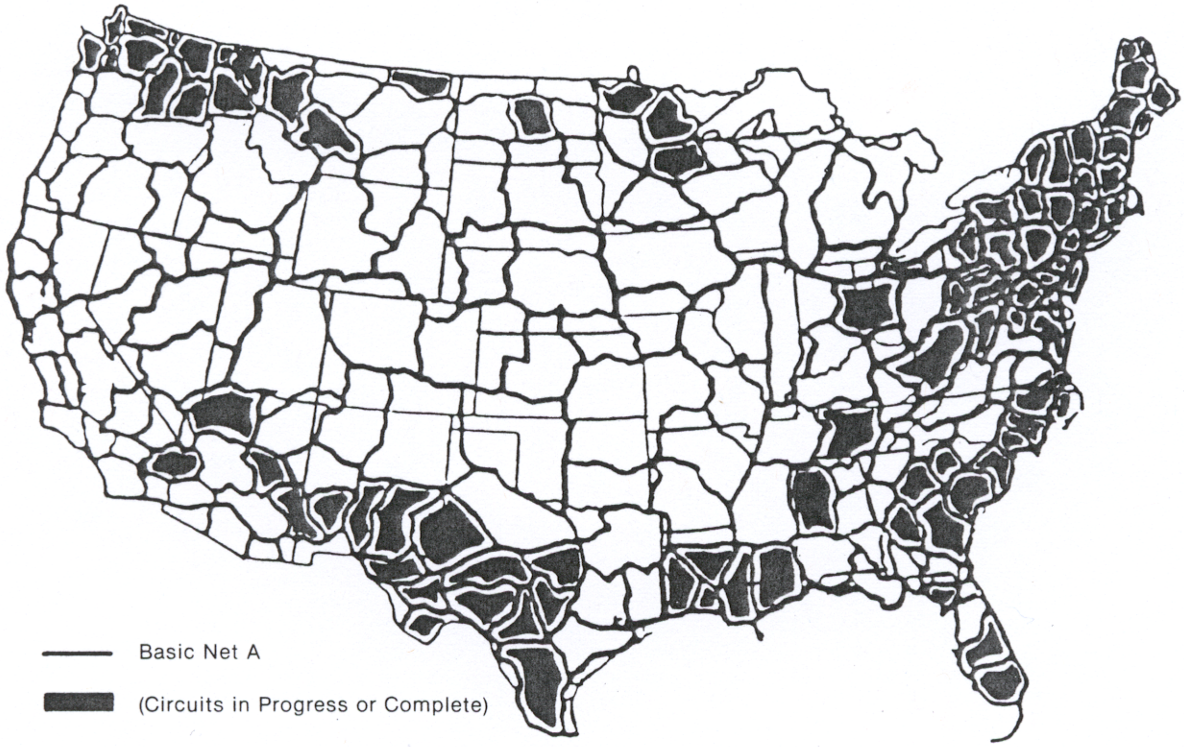

Figure 1. Status of Block Validation.

The BNA lines which represent the latest, first-order leveling are the primary network (BNA1) and are analyzed first. A secondary network (BNA2) includes the BNA lines and all older first-order lines over the same routes. Succeeding analyses include increasingly older and less precise leveling lines (SUP) until all lines included in the project have been analyzed. Leveling data which do not "fit" the BNA network are not included. These problem areas are documented and incorporating the data will be deferred until after the final adjustment.

The first phase in processing a block validation project is identification of the lines to be included in the analysis. A computer program searches a leveling line index file to retrieve a list of the lines with at least one bench mark within a rectangular latitude, longitude "window" enclosing the circuit. Because the circuit is not a perfect rectangle, the analyst must determine which lines and parts of lines are to be included in the project, and which are outside the project area.

At this point, the network is examined to provisionally identify the primary network (BNA1), the secondary network (BNA2), and the subsequent networks (SUP). Each subnetwork will then be analyzed in turn.

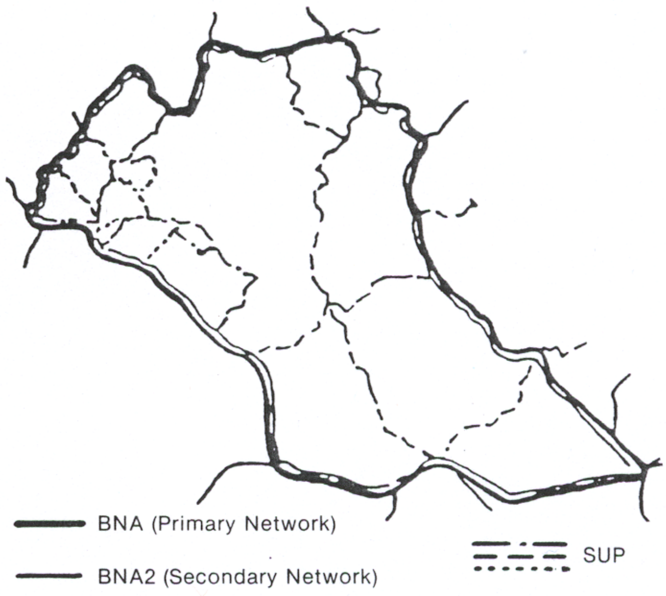

Figure 2. Sample Block Validation Project.

The second phase is extracting the observation and bench mark data from the data base. This is done by a program which also identifies unique marks, computes means of multiple observations between two marks within a leveling line, and lists marks common to two or more lines. Each line, loop, and junction between two or more leveling routes must be examined. Computer programs have been developed to assist the analyst. A profile program computes height differences at common marks between two or more lines which follow the same leveling route. The program also computes misclosures between lines and flags those values which are greater than an "allowable" value. This program is especially useful in analyzing releveled routes. Another program generates loops and computes misclosures.

Modifications to the data can be implemented prior to the adjustment by commands which are created by the analyst and stored on a file. No catalogued data are actually changed unless a keying error, leveling blunder, or misidentified mark is detected. If an examination of misclosures between leveling sections on two or more leveling lines indicates a mark has been disturbed, a "FLOAT" command can temporarily assign another number to the mark on one of the lines, thus making it appear as though they are two distinct marks. By doing this, observations can be "combined." A "DROP" command omits leveling outside the boundary of the project area. "EQUATE" assigns the same identification to marks (especially TBM's) which had not been recognized as being the same mark when the data were automated. Areas of older leveling which cannot be made to "fit" are deferred until after the final adjustment by "POST." As a last resort, single sections of leveling can temporarily be rejected by "REJECT."

When the preliminary analysis of the subnetwork is completed, a further comparison of the "fit" of the lines to the network is made by performing a minimum constraint least squares adjustment, accessing the project data and the command file. Various statistics for the network data are computed, as well as residuals and normalized residuals. Observations which fail statistical tests are flagged. Analysis of the adjustment output aids in determining if lines, sections of lines, or bench marks should be eliminated from the network because of vertical movement. As a result, commands may be revised or additional commands may be created. The network is then readjusted and analyzed until the result of all statistical tests are acceptable. Problems which cannot be resolved are documented, often with a recommendation that a section or line should be releveled by NGS field personnel.

The characteristics and peculiarities of the subnetworks are documented in a project report. The commands in the last subnetwork, which are cumulative from the beginning of the project, are added to a master file of commands categorized by project. The commands can then be retrieved when needed for another project.

Block validation projects are in progress or have been completed for approximately one-third of the BNA circuits. (See Fig. 1.) Early next year, an improved data base system will beome operational. All programs relating to block validation will then be executed using the new system. Interactive graphics programs are being developed which should dramatically increase the efficiency of analysts. Networks, loops, and leveling lines will be diagrammed; the misclosures of user-defined loops will be computed and displayed on a terminal screen or (optionally) printed. This new procedure is expected to decrease the number of undetected errors, as well as significantly reduce the time and effort the analyst must spend in processing the data.

The final step of NAVD 88 is the general least squares adjustment of leveling data in the United States, Mexico, Canada, and Central America, which will result in a consistent set of height differences and an improved set of published heights. The user will be able to refer to one datum, with all verified vertical control data in a single data base. ■

The New Adjustment of the North American Vertical Datum

Article No. 22
NAVD 88 Status Report

by Gary M. Young
Vertical Network Branch

National Geodetic Survey
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Rockville, Maryland

In September 1986, Dr. John D. Bossler, then director, Charting and Geodetic Services, issued the following statement under the heading "New Completion Date for the NAVD 88 Readjustment Project:"

"The date for the completion of the North American Vertical Datum of 1988 (NAVD 88) readjustment project is now September 1991. The following are the primary reasons for the delay.

• Budget reductions have decreased field data acquisition productivity, causing delays in the "Basic Net A" releveling program . . .

• Canada has experienced similar delays in their portion of the NAVD 88 program and is in agreement with the new completion date."

Additionally, a delay will more fully accommodate the use of recent geodetic technology, e.g., global positioning system (GPS) and rapid precision leveling system (RPLS) capabilities. Some GPS considerations are discussed later in this article. RPLS, a new state-of-the-art trigonometric leveling system under development, is the topic of the next article in this series.

Major NAVD 88 tasks underway (with estimated completion dates) include:

• Complete a total of 80,000 km of Basic Net A field leveling. As of October 1, 1986, 68,945 km were completed. Completion of this task is scheduled for September 1988.

• Process a total of 115,000 km (both NGS (National Geodetic Survey) and non-NGS) of new leveling surveys. As of October 1, 1986, 100,465 km were processed. Completion of this task is scheduled for March 1989.

• Complete block validation (final quality assurance) for a total of 620,000 bench marks. As of October 1, 1986, the data associated with 219,934 bench marks were validated. Completion of this task is scheduled for September 1989.

Significant progress has been made on several topics mentioned in previous articles in this series:

• *Magnetic Error Modeling.* As indicated by Sandford R. Holdahl, Geodetic Research and Development Lab, NGS, in article no. 20, an empirical approach, comparing certain leveling lines observed by both spirit- and compensator (automatic)-leveling instruments, to determine magnetic corrections on a compensator-specific basis has proven successful in modeling magnetic error in most instances.

The empirically determined magnetic constants often significantly disagree with previous laboratory calibration values determined at the NGS Corbin, Virginia, facility. NGS is investigating these discrepancies with the goal of discovering deficient laboratory and/or empirical procedures that will explain the differences.

• *Global Positioning System (GPS).* The 2-year delay in the completion of the NAVD 88 adjustment project will allow additional time to evaluate an increased role for GPS-determined heights. Strategically placed GPS stations will be useful to the NAVD 88 readjustment project in that orthometric heights computed from GPS ellipsoiodal heights and geoid heights can provide an upper limit on uncorrected systematic errors in portions of the network.

It is important to note that GPS observations yield ellipsoidal (not orthometric) height differences (dh) relative to a reference ellipsoid. Orthometric height differences (dH), as used in geodetic leveling, are referenced to an equipotential surface, e.g., the geoid. The difference between the two height differences is called geoid height difference (dN). Thus,

$$dH = dh - dN.$$

dN can be determined "directly" at points that are occupied for both geodetic leveling and GPS purposes. Where these data are not available, gravity observations can be used to estimate geoid heights to convert ellipsoidal heights to orthometric heights.

GPS is also a useful tool to monitor vertical crustal movement in that differences in GPS ellipsoidal heights determined from observations (at the same station) separated by a significant amount of time are not degraded by the larger uncertainties inherent in present geoid height values, assuming geoid height at Time 1 is nominally equal to the geoid height at the same station at Time 2 (a condition that is true except in rare instances). In this way, GPS can often determine areas of significant vertical crustal motion more economically than differential leveling. If higher accuracies are required, GPS could indicate the most important lines to relevel by traditional means.

GPS ellipsoid height differences have been determined with uncertainties of about 2 cm for 20-km distances and 5 cm or better for distances up to 50 km. Geoid height difference uncertainty in the United States is on the order of 5-15 cm for distances of as much as 10 km. Orthometric height differences from differential, geodetic leveling can be as accurate as 1 cm, or better, over a 50-km distance.

Therefore, the present combination of GPS and geoid height information to produce orthometric heights is considerably less accurate than present differential leveling. There are, however, many existing engineering requirements that are satisfied by the potentially more cost-effective GPS-geoid height method.

As shown above, less accurate geoid height determinations are the weak link in determining highly accurate orthometric heights from GPS observations. The delay in the completion of NAVD 88 allows additional time to consider the amount of research and data gathering that should be devoted to improving the accuracy of geoid height determinations. This is one of the important questions posed by the present transition from "traditional" to "satellite" surveying.

Other tasks required by the NAVD 88 project include:

- Identifying regional subnetworks that are undergoing vertical crustal motion and implementing proper procedures to incorporate such areas into the readjustment of the vertical control network;
- Exchanging information with Canada, Mexico, and Central America to provide a truly *North American* vertical datum. This includes observations, with accuracy estimates, as well as compatible methods to correct for systematic errors, adjustment strategies, datum definition, etc.;
- Determining the proper role of water-level transfers and tidal information in the new adjustment. This will require additional research and analysis to make full use of the information;
- Determining appropriate a priori estimates of observational standard errors. This task requires distinguishing between the various groups of leveling observations (according to instrumentation, field prodecures, etc.) that must be combined into a coherent vertical control network;
- Compiling preliminary adjustments of framework (skeleton) networks. Analyses of these adjustments will be used to determine deficiencies in network design, additional releveling requirements, influences of systematic errors, magnitudes of changes in height from NGVD 29 to NAVD 88, and the effects of various datum scenarios; and
- Investigating the accuracy of gravity values at each bench mark in the NGS data base. The new adjustment will be performed using geopotential numbers, which require gravity values at each bench mark. An investigation of the accuracy of these gravity values will indicate where additional observed gravity values are required. It appears that very few areas of the country will require additional observations.

These, and other aspects of the NAVD project, will be discussed in detail in future articles in this series. Your suggestions for other topics are welcome. ■

The New Adjustment of the North American Vertical Datum

Article No. 23
NAVD 88 Status Report

by Gary M. Young
Vertical Network Branch

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Rockville, Maryland

[Note: *This report is a continuation of the series of articles on the new adjustment of the North American Vertical Datum of 1988 (NAVD 88). Previous* ACSM Bulletin *articles were published between June 1982 and February 1987. The primary purpose of the articles is to inform the surveying and mapping community, and other interested groups, about the tasks associated with the new adjustment. Your suggestions for future topics are welcome.*]

The U.S. portion of the NAVD 88 project, which will redefine and readjust the geodetic heights of the 620,000 bench marks in the U.S. National Geodetic Reference System (NGRS), continues to be one of NGS' (National Geodetic Survey) major tasks. This project includes the remonumentation and reobservation of an 80,000-km subset of the vertical control portion of NGRS. This subset, designated Basic Net A (BNA), will provide the framework for the development of improved height values for the 620,000 bench marks. The accompanying U.S. diagram shows the extent of BNA leveling completed as of January 1988. Leveling is being accomplished to first-order, class II accuracy, according to Federal Geodetic Control Committee publication *Standards and Specifications for Geodetic Control Networks.* During 1988, most BNA leveling will be in Washington, Oregon, and California. After this West Coast work, BNA leveling in the Great Plains will complete the 80,000-km subset. As of January 1988, approximately 72,600 km (91 percent) of BNA have been releveled. Overall completion of BNA leveling is scheduled for March 1990.

Another important phase of the NAVD 88 readjustment is analyses of the 1.3 million km of leveling observational data in the NGS archives. This evaluation process, called block validation, provides final quality assurance of the observational data involved in the NAVD 88 readjustment. This requires that all observed elevation differences, and associated data, in predefined areas are combined into a single network and analyzed. During this process, the most recent first-order primary network in each of the areas is selected and analyzed. Appropriate remaining leveling data are then incorporated to arrive at the data set for the NAVD 88 readjustment. As of January 1988, approximately 341,000 (55 percent) of the 620,000 bench marks have been "block validated." Completion is scheduled for September 1989.

The readjustment also includes the selection of a new vertical datum to replace the present National Geodetic Vertical Datum of 1929 (NGVD 29). During 1988, two important aspects of the datum definition effort will be completed:

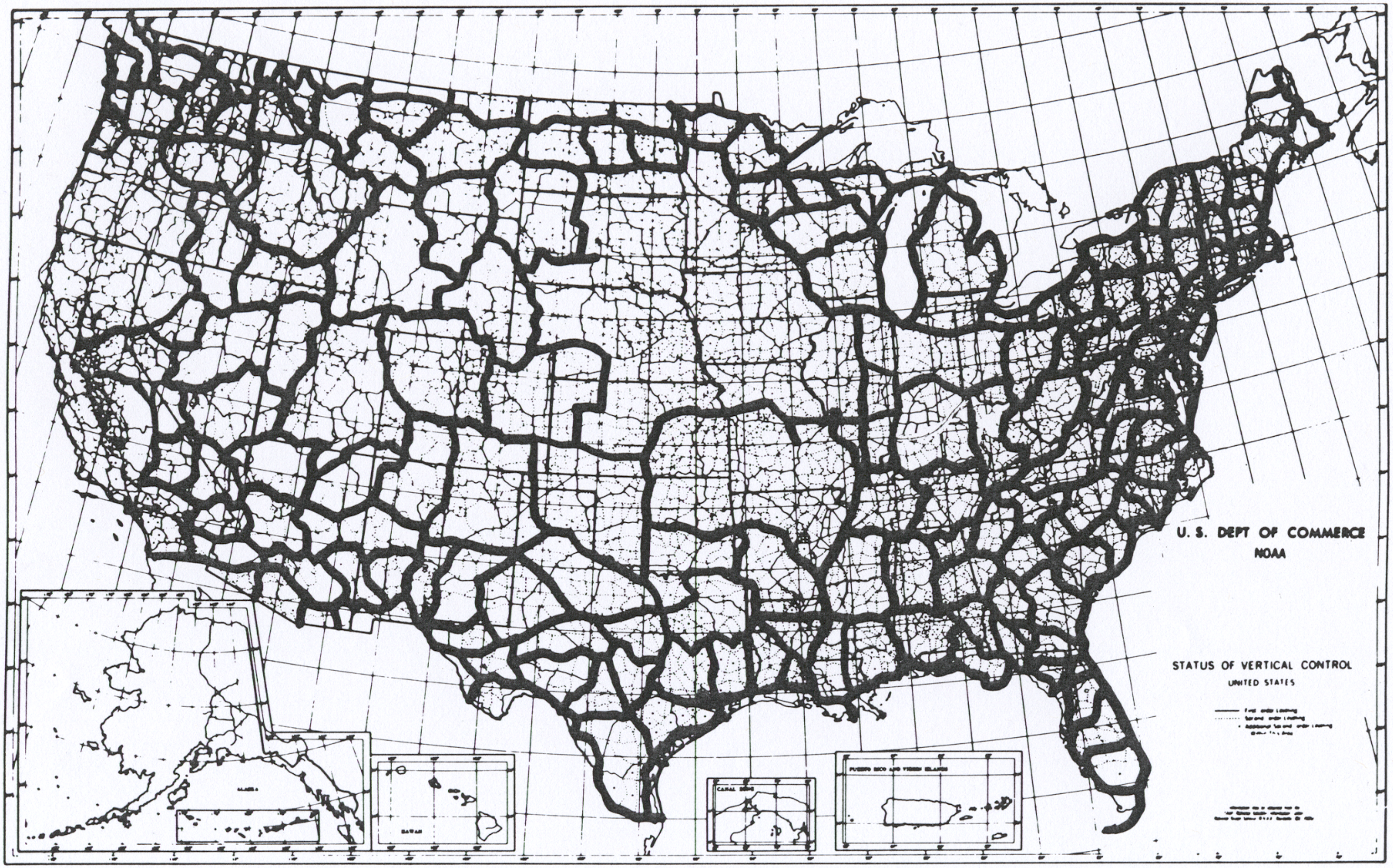
1. Numerical examples, using BNA and other first-order data, are being computed to show the approximate magnitude of height changes from NGVD 29 to NAVD 88 under several datum definition scenarios. Computations will be based on a primary, first-order leveling network which forms approximately 220 loops (800 junction bench marks). This network will be connected to 80 primary tide stations and 26 Great Lakes' water level stations. In addition, 26 connections to the Canadian vertical control network and 14 connections to the Mexican vertical control network will be made.
2. Discussions are being held with other organizations that will use the new datum. These include the U.S. Army Corps of Engineers, Defense Mapping Agency, Dept. of Energy, Federal Emergency Management Administration, National Oceanic and Atmospheric Administration, Tennessee Valley Authority, U.S. Geoglogical Survey, U.S. Bureau of Reclamation, Dept. of Justice, and state and local users.

The selection of a new vertical datum goes beyond purely theoretical considerations, in that an attempt will be made to incorporate the requirements of other agencies, with a goal of minimizing the resources needed to convert their products from NGVD 29 to NAVD 88. Selection of the new vertical datum is scheduled for June 1990. A report on datum definition progress will be in Article No. 25 in this series.

Other major NAVD 88 activities (completion dates in parentheses) include:

1. GPS and NAVD 88 (March 1990)—Orthometric heights obtained by combining Global Positioning System (GPS) ellipsoid heights with associated geoid heights should be helpful in providing upper limits on systematic errors in leveling data and in strengthening deficient portions of the vertical control network. Studies are underway at NGS to improve geoid slope values using GPS and geodetic leveling, as well as to determine orthometric height accuracies using GPS and geoid height information. Where appropriate, orthometric heights (with associated standard errors) derived from GPS and geoid data will be included in the NAVD 88 readjustment.
2. Helmert Blocking (September 1990)—This technique partitions the 1.5 million unknowns and associated observa-

NAVD 88 NEW ADJUSTMENT PROJECT



BASIC NET A RELEVELING, COMPLETED TO DATE

National Geodetic Survey
January 1988

tions into manageable blocks of data and will provide the equivalent of a simultaneous least squares adjustment of the entire observational data set. The software for this effort will be adapted from existing Helmert blocking routines that were used for the North American Datum of 1983 (NAD 83) horizontal readjustment. Helmert blocking in a production mode is scheduled to begin in October 1989, with completion of the final NAVD 88 adjustment by September 1990.

3. Crustal Motion Investigations (June 1991)—In order to maximize data consistency for the 100 years of leveling data that will be included in the new adjustment, it is crucial to identify and segregate data in areas of the United States that have shown significant vertical movement over time from data in relatively stable areas. Many of the unstable areas are well documented: California; the Gulf Coast, including the Houston and New Orleans areas; and portions of the East Coast and the Canadian-U.S. border. Other, less obvious areas are being identified during the block validation process. Predictive geodetic modeling (with geodetic, geologic, and hydrologic data) may be possible for a few limited areas, but most of the effects of crustal motion will be isolated by constraining moving areas to a framework net in the stable region that surrounds the area in question. A major investigation to determine the best method to accomplish this objective is now underway at NGS. The NAVD 88 publication of heights involving crustal motion areas will not be the same as stable areas and will be in the form of special reports for each area.

A final report documenting the NAVD 88 effort and the publication of improved NAVD 88 heights in stable regions will be completed by October 1991. ■

The New
Adjustment of the
North American
Vertical Datum

Article No. 24
NAVD 88 Status Report for Canada (April 1988)

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Previous reports on the status of the NAVD 88 Project in Canada were published in the ACSM Bulletin in October 1982, April 1984, and February 1986. Progress has been made since the last article, in spite of significant cutbacks in resources allocated to the project. Of note is the delay in completion of the automation and validation of the first-order leveling data to be used in the analysis and adjustment of the network. This phase is now expected to be completed about the end of 1988, about 2 years behind schedule. At the end of calendar year 1987, more than one million data records have been extracted from more than 7,700 field books and stored in computer files. About 79 percent of these data records have been processed through our validation programs. After validation, these observed data files will be transferred to our new VAX computer system for further analysis.

The basic network of about 56,000 km of first-order leveling lines, plus nearly 100,000 km of other lines of various orders, will be analyzed in preparation for the adjustment. Block validation procedures, similar to those used by the U.S. National Geodetic Survey (NGS), are being developed. Thus, we will be able to analyze the basic net lines alone, compare them with older first-order lines along the same routes, or include other leveling lines of different orders within the basic net. A computer program called BUILD has been developed which will perform the final checks and reorganize the data, produce statistics, and establish leveling line data bases. Other software, including graphics to facilitate further analysis, is being developed.

Field observations for the NAVD Project have been completed, with the exception of certain lines which had been surveyed with Zeiss Ni-1 leveling instruments and for which the data may be contaminated by systematic errors caused by the Earth's magnetic field. Such lines, which will be reobserved in 1988 and 1989, should be included in the analysis and adjustment.

A recent priority has been the preparation of observed data for a network of leveling lines along the St. Lawrence River and Great Lakes, from Pointe-au-Pere to Thunder Bay. These data were sent to NGS for inclusion in their International Great Lakes Datum analysis.

Next we will send observed data for leveling lines to connect the American Basic Net A to the Canadian primary tide stations, for the NGS datum definition study.

A research agreement is in progress between our department and Dr. A. M. Wassef of the University of Toronto. Observed data, uncorrected for the effects of atmospheric refraction and the magnetic field, were sent to Dr. Wassef. Studies are being carried out on the effects of these error sources on the data.

Possible research contracts in 1988 include the production of a map of vertical crustal movements in Canada. We would supply the observed data for all releveled lines in our network. Crustal motion models may be developed for certain areas to be considered in NAVD analysis and adjustment.

Other developments underway this year include the removal of systematic errors from observed data, a POWERHOUSE data management system on the VAX computer, and a Canadian exchange format for leveling data for the provinces and university researchers.

Status of NAVD 88 Datum Definition

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(This paper is a summary of a draft NGS Technical Report (NAVD 88) Datum Definition Study" by Zilkoski, Balazs, and Bengston (1989). This article was prepared for the collection of ACSM Bulletin NAVD 88 articles.)

INTRODUCTION

The new adjustment of the North American Datum of 1988 (NAVD 88) received approval and funding in fiscal year 1978. In 1982, the National Oceanic and Atmospheric Administration (NOAA) and Canada signed a Memorandum of Understanding (MOU) regarding the adoption of a common, international vertical control network called the North American Vertical Datum of 1988. An important feature of this program is the releveling of 81,500 km of first-order leveling lines to strengthen the network.

In most "stable" areas, relative height changes between adjacent bench marks should be less than 1 cm. Analyses indicate that some absolute height values will change much more. These differences are due to many factors, such as large distribution corrections (residuals) from past adjustments, better estimates of corrections applied to account for systematic errors, and geopotential differences using actual gravity values instead of normal orthometric height differences. Preliminary results indicate that many bench mark height values will change from 50 to 75 cm, with some changing as much as 150 cm. The differences between NAVD 88 and the present National Geodetic Vertical Datum of 1929 (NGVD 29) are caused by many factors. It is difficult to separate the overall change in bench mark height into its individual components such as the effects of systematic error, crustal movement, and datum distortion.

An investigation of NGVD 29 general adjustment results indicates that rather large adjustment corrections (residuals) were distributed in some areas of the country. For example, the accumulated 1929 adjustment correction along a 3,000 km east-west leveling route from Crookston, Minnesota, to Seattle, Washington, was 89 cm.

In areas of vertical crustal motion, relative height changes will be dependent upon the magnitude of the actual physical movement of the bench marks. In many stable areas a single bias factor, describing the difference between NGVD 29 and NAVD 88, can be estimated and used for most mapping applications.

Finally, an important aspect to emphasize is that the bench mark height changes that will result from the NAVD 88 readjustment are primarily due to better estimates of height differences, not because of a change in datum definition philosophy.

NEW DATUM DEFINITION IMPLICATIONS

For the NGVD 29 general adjustment, heights of 26 tidal bench marks in the United States and Canada referenced to local mean sea level were rigidly constrained to define a reference surface (datum) based on a value of 0.0 m at each local mean sea level location. A change in philosophy for NAVD 88 could have a major impact on Federal mapping agencies, e.g., the U.S. Geological Survey (USGS) and the Federal Emergency Management Agency (FEMA).

Because datum definition could change absolute heights by a significant amount, this NAVD 88 study deserves serious consideration by everyone involved. In many stable areas a single bias factor, describing the difference between NGVD 29 and NAVD 88, could be estimated by comparing common bench mark heights in both systems. Even with this factor, NAVD 88 will still have a major impact on mapping agencies.

FEMA states that if the relative height changes between bench marks remain fairly constant over a given geographic area, the impact to the National Flood Insurance Program (NFIP) will be minimal. As long as the relative hydrographic conditions shown on the FEMA maps remain correct, FEMA only has to ensure that consistent data are used when comparing flood elevations to structure elevations.

USGS stresses that datum definition is critical to the National Mapping Program. USGS produces 60,000 different map products. The 7.5-minute series will be most affected by a datum change. USGS has approximately 100 spot elevations on every 7.5-minute quad, as well as various contour intervals. One-tenth of a contour interval can be handled by adding a statement in the margin for datum shift between NGVD 29 and NAVD 88. In flat terrain, a datum shift exceeding 1 foot (30 cm) will present problems; in mountainous regions, shifts in excess of 8 feet (244 cm) will create problems. In stable areas a single bias factor, describing the difference between NGVD 29 and NAVD 88, can be estimated and used for most mapping applications. Preliminary analyses of contour plots indicate that in most small areas, e.g., 15 minutes by 15 minutes, a difference in bias shifts at the boundary corners would be less than 10 cm.

Thousands of other data bases and maps are based on NGVD 29 heights which may have to be updated for NAVD 88 heights. All bench marks presently published by NGS will have new NAVD 88 heights. Updating these published heights will not be a difficult task, but it probably will be time-consuming and expensive.

ANALYSES OF NAVD 88 PRIMARY VERTICAL NETWORK

The NGS Vertical Network Branch has undertaken a special study to compile a primary vertical network (a subset of the entire National Geodetic Vertical Network) using the latest data available. Analyses of this network were helpful in determining the effects of various datum constraints and the magnitudes of height changes from NGVD 29.

This primary network consists of 200 loops containing 909 junction bench marks. Each loop is composed of links based on the latest first-order leveling data connecting the junctions of loops. The network connects to 57 U.S. primary tidal stations which are part of the National Primary Tidal Network and 55 water-level stations along the Great Lakes. In addition, 28 connections were made to the Canadian vertical control network and 13 to the Mexican vertical control network.

Most of the data involved in the study were observed between 1965 and 1986, but some older data, i.e., data obtained in the 1940's and 1950's, were included to reduce the size of some loops. These data are located mostly in the Great Plains and Pacific Coast regions of the country where the releveling program was still in progress at the time of the study. Inclusion of these data did not affect the analysis in a continental sense, but probably did have an influence on the estimates of heights locally. The local effect, however, should be small because many of these older leveling lines were rejected during the analyses. Subsequent studies, re-analyzing the Pacific coast and Great Plains regions, will be performed when the data are available.

Minimum-Constraint Adjustment Results

The first adjustment performed was a minimum-constraint least squares adjustment holding fixed the height of the primary tidal bench mark, referenced to the 1960-78 local mean sea level tidal epoch, at Key West, Florida. This station was arbitrarily selected as the constraint; any station could have been used. The height was referenced to the 1960-78 tidal epoch so all other adjusted heights of tidal bench marks could be compared with their corresponding local mean sea level values.

Figure 1, a "rough" contour map, depicts the differences between heights estimated from the minimum-constraint least squares adjustment and published NGVD 29 heights at the junction bench marks. Referring to figure 1, an east-to-west systematic difference between the minimum-constraint adjusted heights and the published NGVD 29 heights seems to exist. This accumulates to a significant difference of about 160 cm from Maine to Washington. In addition, the difference reaches about 200 cm at some junction bench marks located in the Rocky Mountains.

Adjustments with and without Corrections Applied for Systematic Errors

It is difficult to separate the overall changes in bench mark heights into their individual components, e.g., the effects of systematic error, crustal movement, and datum distortion. In order to estimate the influence of systematic errors on adjusted heights, adjustments were performed using data both with and without corrections applied for systematic errors. Comparisons of adjusted heights, with and without corrections applied, indicate that, except for the magnetic correction, they do not significantly change the adjusted heights in a continental sense, but in some regions they do have a large local effect.

The next step in the study was to investigate the influence of "true" geopotential differences using actual gravity, instead of normal orthometric height differences based on normal gravity. In the NGVD 29 adjustment, normal orthometric corrections, which were based on normal gravity, were applied to the leveling data. Once again, the differences are not significant in a continental sense, i.e., from the east coast to the west coast the overall difference is only 5 to 6 cm. Locally, however, the effect in the mountains reaches significantly large values, i.e, about 50 cm. These differences, however, do not explain the systematic differences between published NGVD 29 heights and minimum-constraint least squares adjusted heights from the special primary vertical control network. In an adjustment of leveling data, errors are distributed throughout the network depending on loop misclosures. The NGVD 29 readjustment was no exception.

DISTORTIONS IN NGVD 29

An investigation of NGVD 29 general adjustment results indicates that rather large adjustment corrections (residuals) were distributed in some areas of the country. For example, the accumulated 1929 adjustment correction along a 3,000 km east-west leveling route from Crookston, Minnesota, to Seattle, Washington, was 89 cm. Analysis of observed leveling data along the single-line route from Seattle to Crookston indicated that the 1988 and 1929 observed leveling data agree within 25 cm over the 3,500 km leveling distance. This indicates that the large systematic height difference of 150 cm from Seattle, Washington, to

Portland, Maine, between the primary vertical control network and the published NGVD 29 heights is due mostly to a large distribution of corrections in the 1929 adjustment results.

Some users feel that NGVD 29 is currently meeting their needs. They question the need for NGS to readjust the National Geodetic Vertical Control Network. There are approximately 40,000 km of new leveling data that have not been incorporated into NGVD 29. Incorporating new data into NGVD 29 consumes large amounts of NGS resources because of existing inconsistencies in NGVD 29. Users are usually unaware of these inconsistencies because NGS readjusts large portions of the vertical network, distributing these inconsistencies over large areas. NGS does not have the resources to continue to maintain NGVD 29 as in the past. If the National Geodetic Vertical Network is not totally readjusted, these inconsistencies will become even more significant. Eventually surveyors will not be able to check their work using NGVD 29. NAVD 88 should be a datum that removes the inconsistencies and distortions in NGVD 29.

DIFFERENT NAVD 88 DATUM DEFINITION SCENARIOS

To assist in the NAVD 88 datum definition decision, several adjustments were performed using different constraints. In addition to the minimum-constraint least squares adjustment discussed previously, four other adjustments, using different constraints, were performed:

(1) the 1960-78 tidal heights of primary bench marks at Key West, Florida, and Portland, Maine, were held fixed;

(2) the 1960-78 tidal height of primary bench marks at Key West, Florida; Portland, Maine; Neah Bay, Washington; and San Diego, California; were held fixed;

(3) the 1960-78 tidal height of Key West, Florida, was held fixed and an observation of 70 gal-cm (standard error equal to 0.1 gal-cm) between the Duck, North Carolina, tidal station, and the Crescent City, California, tidal station was added to the data; and

(4) the 1960-78 tidal height of Key West, Florida, was held fixed and an observation of 70 gal-cm (standard error equal to 10 gal-cm) between the Duck, North Carolina, tidal station, and the Crescent City, California, tidal station was added to the data.

In all five adjustments the observations and weights were identical.

The results obtained from the various adjustments indicate that no matter which datum definition scenario is chosen, including a minimum-constraint solution, changes in heights of 75 to 100 cm will exist between NGVD 29 and NAVD 88. Even constraining the heights of two tidal bench marks on each coast produced large (25 cm) differences between the special NAVD 88 primary vertical control network adjusted heights and published 1960-78 tidal heights.

SELECTION OF A DATUM

An obvious choice of the "theoretical" NAVD 88 datum is a variation of adjustment number 4 discussed in the previous section, i.e, holding the height of one tidal bench mark referenced to the 1969-78 tidal epoch fixed (or minimizing the differences between specific tidal height values and NAVD 88 heights), and adding observations between appropriate tidal stations with their appropriate standard errors.

The selection of a datum where the heights of four bench marks were held fixed would minimize the differences between NGVD 29 and NAVD 88 in the locations of the constraints, but would add large distortions to the data. Differences would still approach 1 meter in the Rocky Mountains. Some Federal agencies have recommended this datum definition scenario because they believe it will minimize the impact on their agencies' products. This type of datum would not be as useful to people estimating precise GPS-derived orthometric heights.

It has always been understood that two vertical datums would be required for a certain time period to meet users needs: (1) a datum defined by holding one height fixed, i.e., minimum-constraint, for surveyors and scientists who require very accurate height difference relationships and (2) a second vertical datum for mappers and others who require less accurate height difference relationships, i.e., one similar to NGVD 29 but not maintained to its current high accuracy standards. This is not the most desirable situation, but may be necessary due to current budgetary constraints of users.

DISCUSSION OF DATUM DEFINITION SELECTION

Regardless of datum definition, large differences between NAVD 88 and NGVD 29 heights will exist. It should be noted that the NAVD 88 heights are better estimates of orthometric heights than are the NGVD 29 heights. Better estimates of orthometric heights will become more critical in the future as surveying techniques continue to become more sophisticated and more accurate. The improvement of geoid height determinations using GPS data requires the best estimate of "true" orthometric heights. Cartographers also want heights on their maps based on the best estimate of "true" orthometric heights.

The registered surveyor should not be significantly affected because the relative height changes between adjacent bench marks should be less than 1 cm. The absolute height values will change much more, but this should not be the surveyor's biggest concern. The biggest problem the surveyor will have is ensuring that all height values of bench marks in the project are referenced to the same vertical datum, preferably NAVD 88. The leveling data associated with 500,000 bench marks established by USGS have not been placed in computer-readable form and will not have NAVD 88 heights. In addition, the U.S. Army Corps of Engineers (COE) has established hundreds of thousands of bench marks across the nation which will not have NAVD 88 heights.

The Federal Geodetic Control Committee (FGCC) and the American Congress on Surveying and Mapping (ACSM) have established committees to investigate the impact of NAVD 88 on themselves and others of the user community. Members of both committees have been briefed on the results of this datum definition study and were requested to document their products and services that will be affected by the readjustment.

Several vertical network adjustment options are currently under evaluation: (1) perform a minimum-constraint least squares adjustment of the data, i.e., hold one height fixed, (2) distort data by fixing local mean sea levels (1960-78 epoch) on the east and west coasts to the same value, (3) distort data by constraining selected published NGVD 29 heights across the United States, and (4) maintain two datums, i.e., implement options (1) and (2) or options (1) and (3) mentioned above.

The FGCC Subcommittee members have been asked to identify specific examples describing the real impact of NAVD 88 on their products and users. These examples will be included in the final report. Examples will be actual, on-going projects, e.g., COE engineering projects-levee systems, leveling network, dam construction, etc., and USGS mapping projects-topographic maps on different terrain, leveling network, and other projects. The impact may vary depending on which option is chosen, as well as on the locations and type of project. The Subcommittee members have also been asked to document the methods required to convert these projects to NAVD 88. Once again, the procedure may vary depending on the option selected, the location, and type of project. These examples should enable FGCC to document the impact NAVD 88 will have on the Federal agencies.

The ACSM committee is performing similar analysis to document the impact NAVD 88 will have on state, local, and private organizations.

CONCLUSION

To assist in identifying and documenting the impact of NAVD 88, NGS has undertaken this special study to compile a primary vertical network using the latest vertical control data available.

It is difficult to separate the overall change in bench mark heights into individual components such as the effects of systematic error, crustal movement, and datum distortion. Comparisons of adjusted heights, with and without corrections applied, indicate that, except for the magnetic correction, they do not significantly change adjusted heights in a global sense, but in some regions they do have a large local effect.

The obvious theoretical selection of the NAVD 88 datum is an adjustment holding the height of one tidal bench mark referenced to the 1960-78 tidal epoch fixed (or minimizing the differences between specific tidal height values and NAVD 88 heights) and adding observations between appropriate tidal stations with their appropriate standard errors.

Analyses indicate that large differences between NAVD 88 and NGVD 29 heights will exist no matter which datum definition scenario is chosen for NAVD 88. These differences are due to many factors, such as large distribution corrections (residuals) from the NGVD 29 adjustment, better estimates of corrections applied to account for systematic errors, and estimating geopotential differences using actual gravity values instead of normal orthometric height differences. The new set of heights is a better estimate of orthometric height than is the NGVD 29 set of heights.

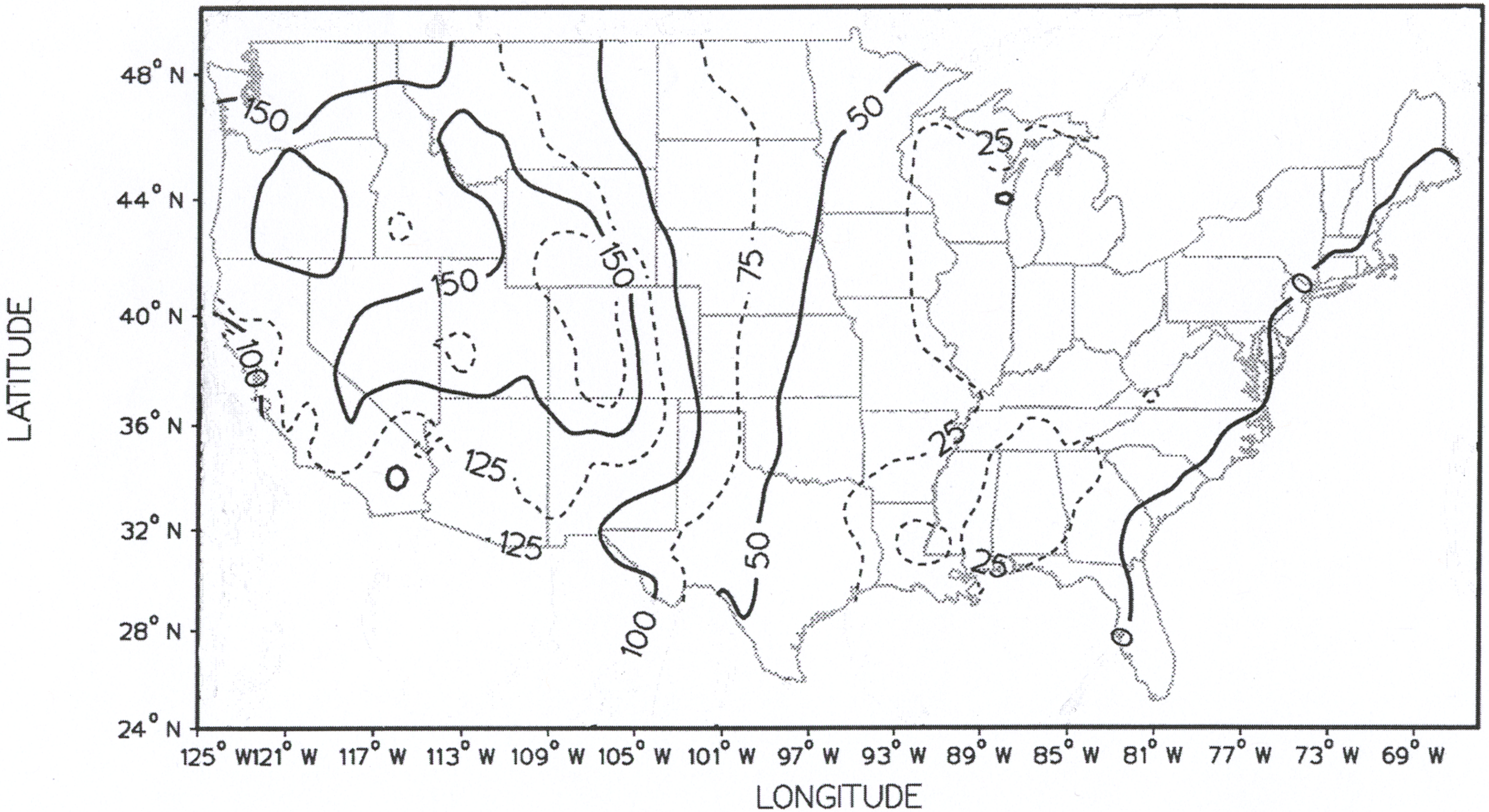
To assist users, NGS can compare published NGVD 29 heights with NAVD 88 heights to estimate a single bias factor which describes the difference between NGVD 29 and NAVD 88 for small areas, e.g., for a 7.5-minute quad. These bias factors could be published in tables and distributed to users. Computer programs using appropriately designed and validated data files could be developed which estimate a bias factor on a point-by-point basis. The accuracy of the bias shift will depend on the number of valid bench marks in the area of interest. Heights of some bench marks may have changed due to crustal movement; obviously, these bench marks should not be used to estimate the bias factor. Preliminary analyses of contour plots indicate that in most small areas, e.g., 15 minute by 15 minute, the difference in bias factors between the extremes of the boundary would be only 10 cm.

Users of orthometric heights require the best estimate of bench mark heights referenced to the geoid. This will become more critical in the future as surveying techniques continue to become more sophisticated and more accurate. The improvement of geoid height determinations using GPS data requires the best estimate of "true" orthometric heights. Cartographers also want heights on their maps based on the best estimate of "true" orthometric heights.

As implied above, undistorted heights will be beneficial to GPS users who are estimating GPS-derived orthometric heights. The largest error in estimating GPS-derived orthometric heights is the uncertainty in estimating geoid heights. The new NAVD 88 adjustment should provide estimates of "true" orthometric height differences which will enable the average user to estimate relative GPS-derived orthometric heights to a sufficient accuracy to meet the requirements of most engineering projects. This should decrease the cost of establishing elevation control in most engineering and mapping projects. It may be necessary to provide two vertical datums in order to meet different user requirements. The committees mentioned above are considering the implication of two datums.

Finally, an important aspect to emphasize is that the bench mark height changes that will result from the NAVD 88 readjustment are primarily due to better estimates of height differences, not because of a change in datum definition philosophy.

Figure 1. -- Contour map depicting height differences between a minimum-constraint adjustment (one proposal for NAVD 88) and published NGVD 29. Minimum constraint for the adjustment was the height of the primary tidal bench mark at Key West, Florida, referenced to the 1960-78 local mean sea level tidal epoch (Units = cm).



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