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National Oceanic and Atmospheric Administration
NATIONAL OCEAN SURVEY
Rockville, Md. 20852

RELEVELING OF THE VERTICAL NETWORK

ISSUE PAPER

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NATIONAL VERTICAL NETWORK

RELEVELING AND NEW ADJUSTMENT

SUMMARY

A report by the Office of Management and Budget, dated July 1973, states that 29 federal agencies are dependent on the geodetic control furnished by the National Vertical Control Network. Due to vertical land movement, insufficient accuracy in earlier surveys and the loss of many bench marks approximately 80 percent of the existing network is not adequate for present needs. In Fiscal Year 1975, federal agencies submitted specific requests for over 28,000 kilometers of leveling to the chairman of the Federal Geodetic Control Committee.

More than 436,000 kilometers of level lines have been added to the Vertical Network since the General Adjustment of 1929, which utilized 64,000 kilometers of U.S. leveling and 32,000 kilometers of Canadian leveling. Tectonic, isostatic, and eustatic changes in elevations have caused relative movement between the land and mean sea level, on which the 1929 Adjustment was based. Destruction of monuments through natural causes and the activities of man has reduced the available points in this reference system. Changes in accuracy requirements for vertical geodetic control have also reduced the utility of the existing networks.

The present effort to meet the national vertical control requirements is not succeeding. The National Vertical Network is continuing to deteriorate and delayed implementation of a viable program will result in further valuable resources being lost.

The Federal Mapping Task Force recommends that the federal effort for vertical surveys be "doubled" and that a new adjustment of the vertical datum be undertaken. This is to be accomplished by program increases, federal inter-agency assistance and reprogrammed funds. The U.S. Geological Survey has provided some monetary ($100 K) assistance and is preparing vertical geodetic control data for transmittal to NOAA. New funding of $2,600,000 per year will be required for the basic framework releveling and the new vertical adjustment.

The plan developed for the basic framework releveling must be accomplished within a constrained time period. This is to insure the most economical use of existing network bench marks that will be salvaged by upgrading. In addition, 26,257 kilometers of leveling have been accomplished in recent years and will be a part of the basic framework. The new adjustment will result in the upgrading of 200,000 bench marks to meet modern specifications.

The design of the basic framework maximizes the benefit to federal agencies. Present and future requirements in the vicinity of drainage systems, transportation routes, coastal areas and in seismically active areas are included in the framework leveling program.

The planned framework of basic vertical control, together with the upgraded portions of the existing network, will provide a reference system for densification of control by NOAA and other federal agencies. These surveys will then become additions to the nation's resources, providing a continuing stream of future benefits. The proliferation of single purpose surveys will be lessened by the introduction of the new vertical reference system.

There are also many state and local agencies undertaking densification surveys with connections to the National Vertical Control Network. This Network serves as a standard of reference for these activities, and unless its elevations are accurately determined, much of the value of such efforts is lost.

The releveling program has been planned utilizing a regional approach to facilitate the block adjustment and upgrading of other bench marks. Each region contains both summer and winter working areas so the surveys can proceed on a year-round basis. The regions will be completed in a sequential fashion with the most seismically active region being completed last to insure the maximum network homogeneity.

The impact of not receiving this budget request would be increases in cost to all users of the Vertical Control Network. Duplication of survey effort and increased costs for adjustments by various federal, state and local agencies will result if the recommended actions are not taken. Delay in approving this request will result in a loss of potential savings from utilization of 26,000 kilometers of prior leveling and upgrading other bench marks.

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I. PURPOSE

This report presents the need for releveling the primary lines of the National Network of Vertical Control and a new general adjustment of the entire Vertical Control Network of North America. The fundamental objective is an effective vertical reference datum for present and future surveying, mapping, engineering, and scientific projects. This report gives background information and identifies and describes the requirements and benefits of an updated National Network. The tasks required to update the Network and a time constrained procedural plan are described.

II. BASE PROGRAM DESCRIPTION

The National Oceanic and Atmospheric Administration, through component agencies[1], develops, maintains, and disseminates data for the Vertical Geodetic Control Network.

This geodetic data provides fixed or reference control for:

- o surveying
- o engineering
- o mapping
- o scientific studies
- o coastal zone management
- o real estate recordation
- o national defense
- o land-use plans
- o ecological assessments
- o natural resources exploration
- o tidal studies
- o international and state boundaries
- o flood plain studies

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1. Principally, the National Ocean Survey.

III. RESPONSIBILITY - LEGISLATION, DIRECTIVES & COMMITTEES

A. Authority

The basic authority for the U.S. Department of Commerce to perform vertical control surveys, adjustments, and distribution of geodetic data is contained in Public Law 80-373 and its amendments.[2] This authority has been delegated to the National Oceanic and Atmospheric Administration. Public Law 80-373 authorizes the following activities:

> . . . Geodetic control surveys . . .
>
> . . . Processing and publication of data, information, compilations and reports.
>
> . . . developmental work for the improvement of surveying and cartographic methods, instruments and equipments . . .
>
> . . . cooperative agreements with, and to receive and expend funds made available by, any State or subdivision thereof, or any public or private organization, or individual, for surveys or investigations

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2. See appendix A

authorized herein, or for performing related surveying and mapping activities, including special-purpose maps, and for the preparation and publication of the results thereof.

> . . . contract with qualified organizations for the performance of any part of the authorized functions . . . when he deems such procedure to be in the public interests . . .

B. Directives and Circulars

Executive Office of the President Circular A-16,[3] revised May 6, 1967 (Issued by Bureau of the Budget, now Office of Management and Budget) describes the responsibilities of federal agencies with respect to coordination of federal surveying and mapping activities . . .

> . . . The Department of Commerce is responsible for the National Networks of Geodetic Control and

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3. See appendix B

publishes status maps of geodetic control which meet the standards for inclusion in the national networks.

In carrying out this function the Department exercises Government-wide leadership in assuring coordinated planning and execution of its national geodetic control surveys and the related survey activities of federal agencies, including activities financed in whole or in part by such agencies, to the end that:

(1) The geodetic control needs of Government agencies and the public at large are met in the most expeditious and economical manner possible with available resources; and

(2) All surveying activities financed in whole or in part by federal funds contribute to the National Networks of Geodetic Control when it is practicable and economical to do so.

The Department of Transportation has distributed Transmittal 48, dated August 5, 1974, to State Highway Departments outlining their responsibility under Circular A-16, revised May 1967 (described on page 3). This directive contains the following statements that levy requirements on NOAA's geodetic program:

> . . . All geodetic survey work performed as a federal-aid highway project will conform to NOS specifications. The NOS will, as the representative of FHWA, be responsible for the inspection and verification of the work to ascertain that the specifications for the work have been met. Final project acceptance by FHWA will be predicated on a finding of acceptability by NOS . . .
>
> . . . All geodetic survey projects shall be coordinated by the FHWA Division Engineer, the State Highway Department and NOS . . .

> . . . Some station markers may be in such locations or placed in such a manner as to interfere with future highway construction or maintenance. When such situations occur, advice should be forwarded to the Director, National Geodetic Survey, Rockville, Maryland, who will take corrective measures or arrange with other agencies for this service.

State Highway Departments have the option, when undertaking geodetic surveys as part of federal-aid highway projects to:

(1) Perform surveys with their own crews . . .

(2) Contract with private firms . . .

(3) Enter into cooperative agreements for NOAA to perform the surveys.

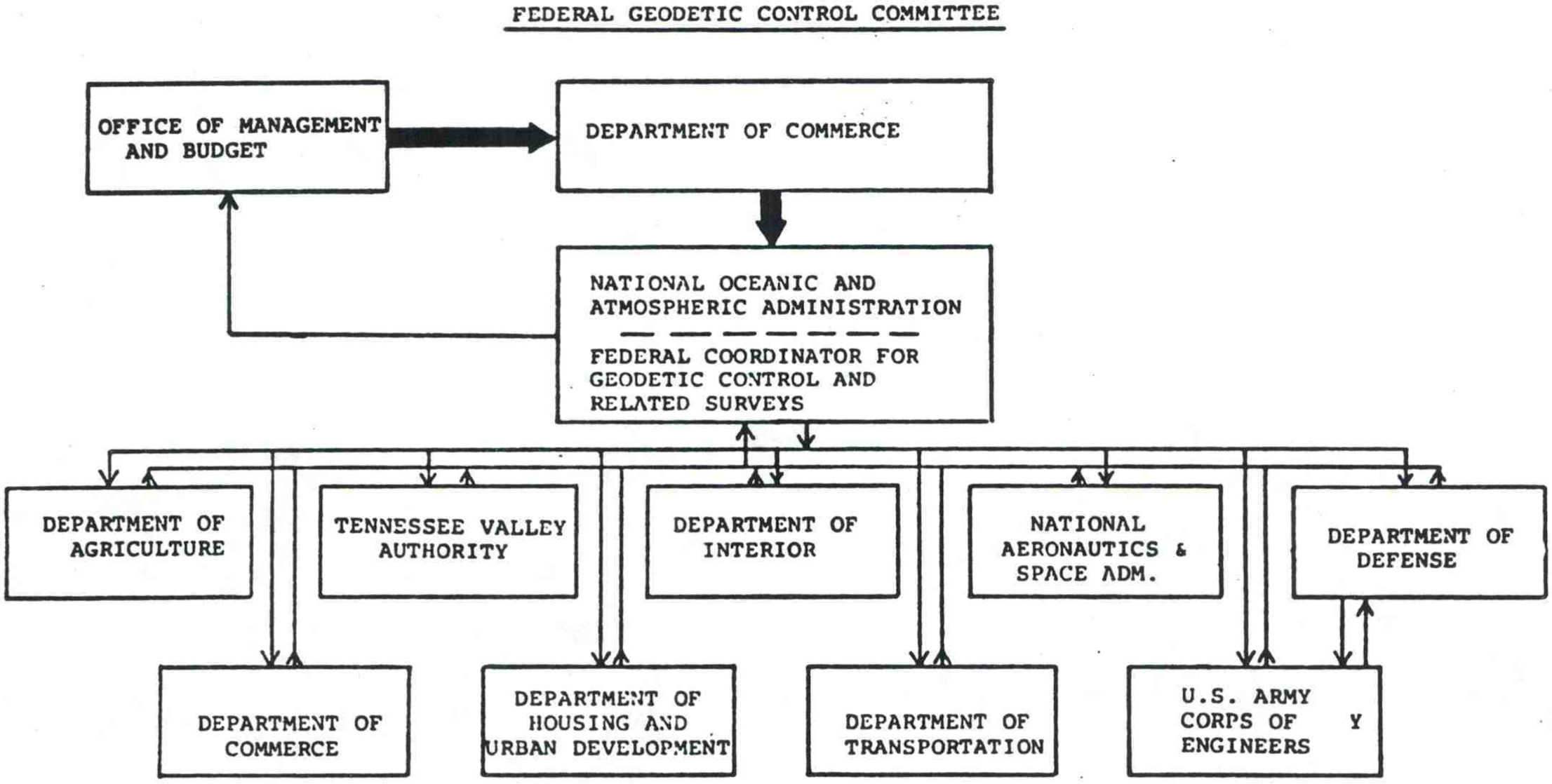
Regardless of which option or combination of options are utilized, the NOAA responsibility for coordination, inspection, and validation remains the same.

C. Committees

The Federal Geodetic Control Committee (FGCC), an interagency committee, was established in 1968 to assist in implementing the requirements outlined in OMB Circular A-16. The FGCC is an authoritative coordinating body whose members can speak for their agencies on programs and actions under consideration. Figure 1 shows the member agencies of the FGCC.

FIGURE 1

FEDERAL GEODETIC CONTROL COMMITTEE



The heavy lines between the Office of Management and Budget, the U.S. Department of Commerce, and the National Oceanic and Atmospheric Administration represent the delegation of authority for implementation of OMB Circular A-16. The thin lines trace the flow of information within the Committee.

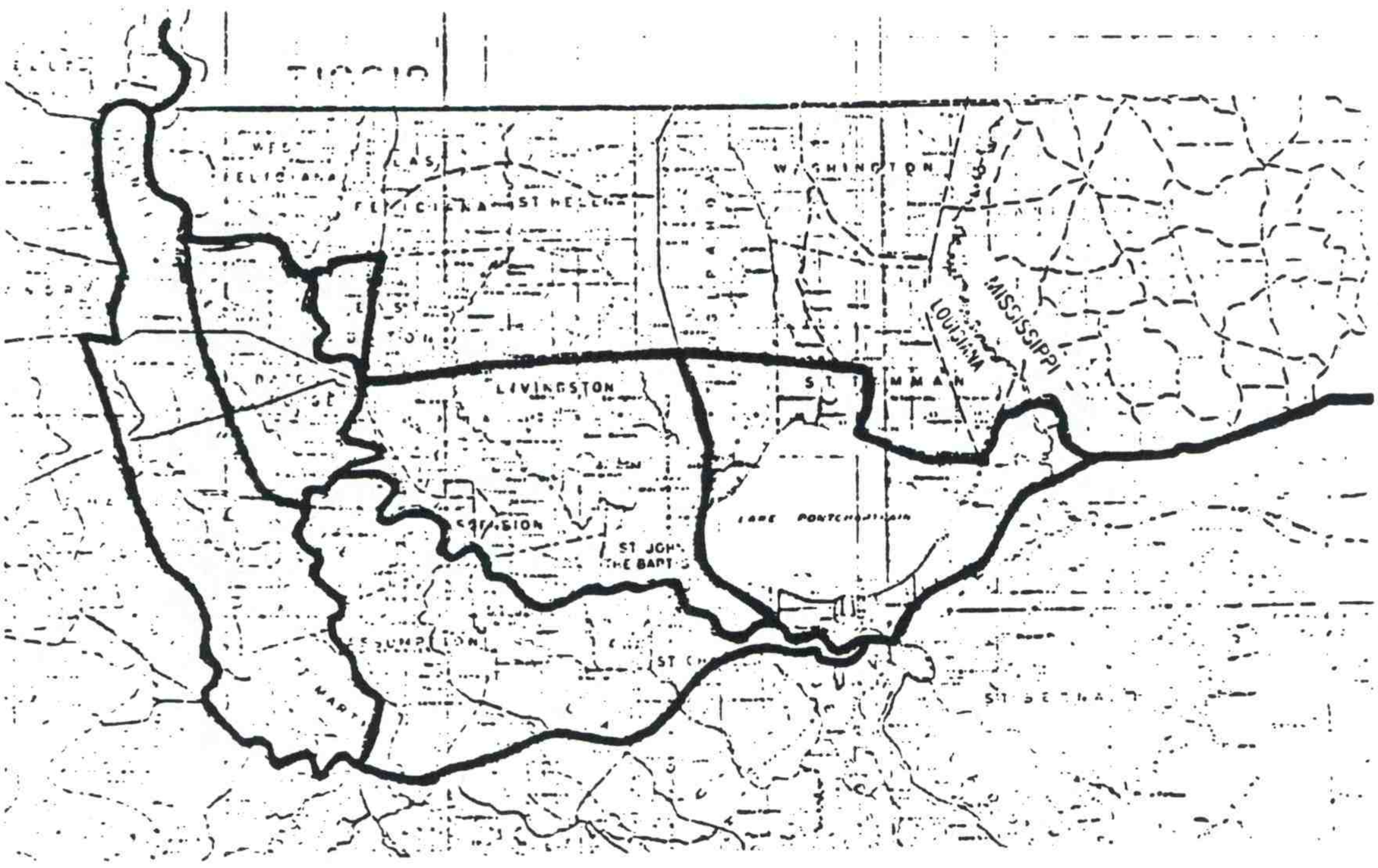
The list of federal vertical control requirements shown in Figure 7, page 28, was obtained through the FGCC coordination effort.

D. Agreements

The catalog of Federal Domestic Assistance, issued by the Office of Management and Budget, outlines the basic conditions for geodetic survey cooperative agreements. These conditions are contained in Section 11.400, Geodetic Surveys and Services.

A wide range of agreements are negotiated by NOAA with states, countries, and other local agencies under the terms of this section. Frequently, these agreements are in areas that have critical problems with vertical earth movement such as the Houston, Texas area and southern California. These projects are always geodetically tied to the National Vertical Control Network and often form a part of it. Rates of change and the extent of vertical earth movement would be impossible to determine without this reference network.

Agreements with other federal agencies for vertical control coverage are usually in support of large scale federal projects. An example is the leveling of the Vertical Control Network in the Lower Mississippi Valley. The U.S. Army Corps of Engineers is updating the vertical control along levees and channels to establish an organized system of monitoring the status and performance of their flood control system. The project costs were shared by NOAA and the Corps of Engineers.



IV. BACKGROUND

A. Terminology

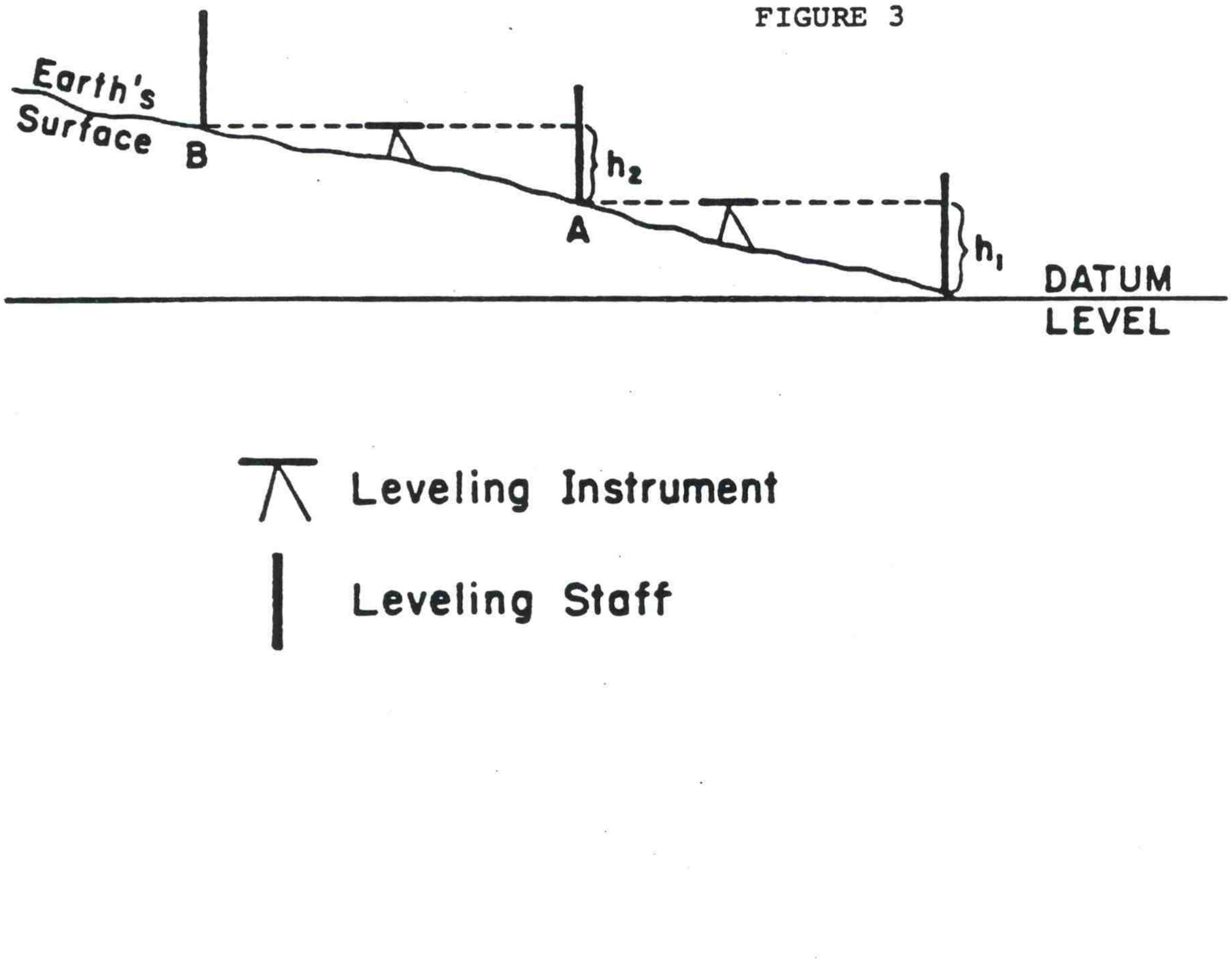
Some of the terminology used throughout this paper is explained in the following paragraphs.

Vertical Geodetic Surveys - Vertical geodetic surveys are conducted primarily to provide measures of the difference of elevations between bench marks and a selected datum of reference, generally sea level. The national system of related bench mark elevations is called the Vertical Control Network. Figure 2 shows a bench mark with a bronze disk, inscribed with its unique designation.

FIGURE 2

Leveling - Leveling is the procedure for measuring the elevation of bench marks and other discrete points with respect to each other and the National Geodetic Vertical Datum. The leveling procedure is illustrated in simple form in Figure 3. The leveling instrument is used to establish the horizontal or level line of sight; h_1 and h_2 represent the differences in elevation or height above the datum level.

FIGURE 3



Adjustment - Adjustment is the process by which leveling survey measurements are statistically treated to distribute small accidental errors throughout the network.

Vertical Datum - A vertical datum is a "level" surface to which elevations are referred. The National Geodetic Vertical Datum of 1929 is the base reference surface for the United States. Elevations of bench marks and other points are expressed as the vertical distance above or below this surface.

B. Evolution of the National Vertical Control Network

The National Network of Vertical Geodetic Control is composed of data from tidal observations and accumulated geodetic leveling surveys made by NOAA, its predecessors, and other federal, state, and local agencies since 1878.

1. Historical Development

Precise geodetic leveling was first undertaken by the predecessor agencies of the National

Ocean Survey in 1878. Measurements were started on a line of precise levels following the transcontinental arc of triangulation extending from New Jersey to California. This first line of levels furnished elevations for use in reducing the horizontal network measurements to a uniform surface (sea level). Bench marks were also established at intervals along the route and in towns for the use of engineers and surveyors. Other lines of leveling were measured in following years for the same purpose. By 1898, these lines formed 25 large loops across the country connected to sea level at tidal stations. In 1899, an adjustment was made to distribute the discrepancies and errors in the network elevations.

Interim adjustments were made in 1903, 1907, and 1912 to include new leveling and sea level connections that had accumulated. By 1929, the network included 72,000 kilometers of precise leveling, and a complete new general adjustment was made.

2. Sea Level Datum of 1929

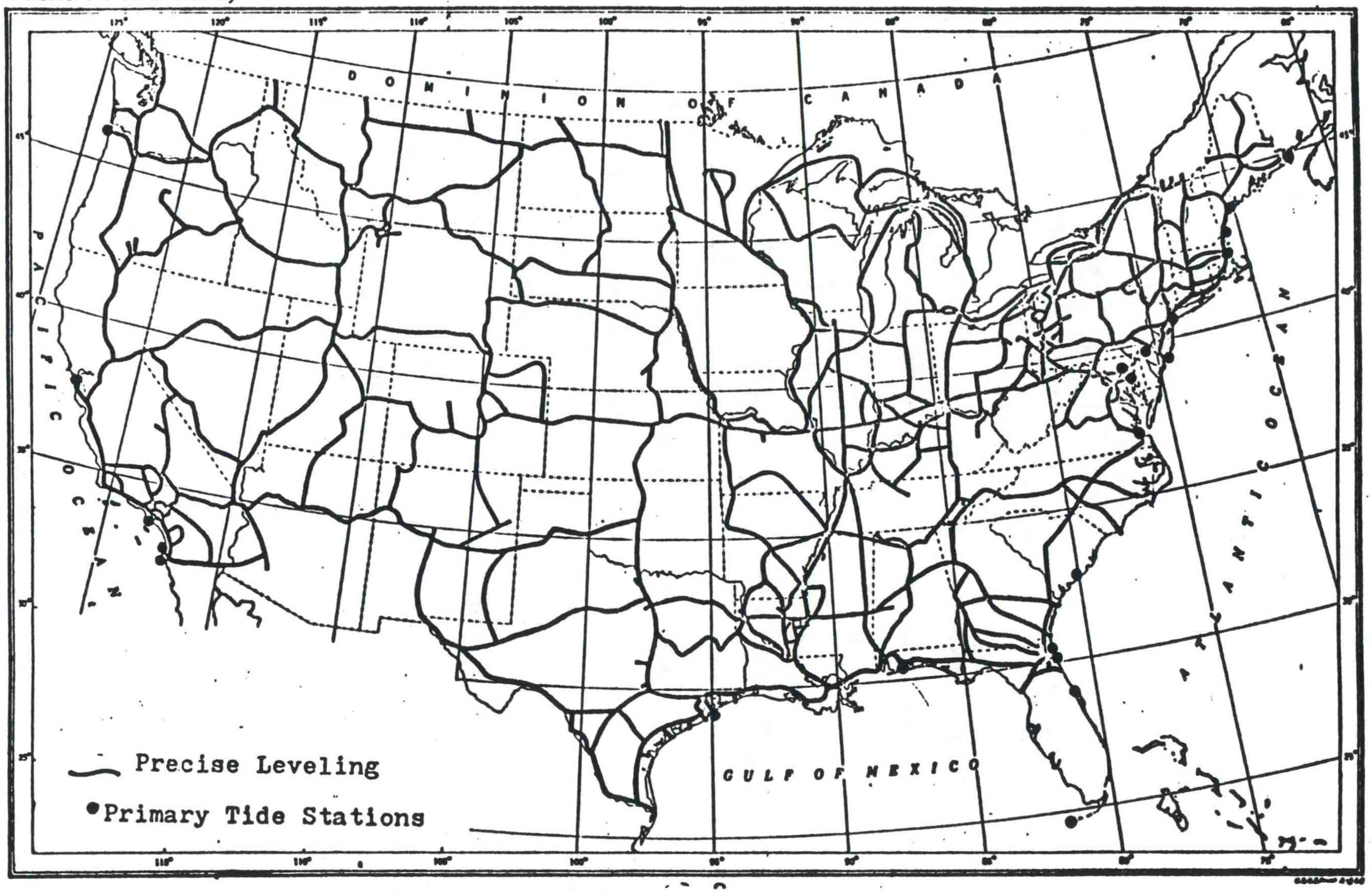
The General Adjustment of 1929 was a cooperative effort between the geodetic agencies of the United States and Canada to provide a comprehensive adjustment of the network covering a large part of North America. The total length of lines actually used included 64,000 kilometers of U.S. leveling and 32,000 kilometers of Canadian leveling as shown on Figure 4. Sea level was held fixed at twenty-six stations. Twenty-one were located in the United States and five in Canada. The datum resulting from this adjustment was designated the Sea Level Datum of 1929. Effective July 2, 1973, its name was changed to National Geodetic Vertical Datum of 1929.

3. The Interim Since 1929

More than 436,000 kilometers of level lines have been added to the network since 1929.

FIGURE 4

FIRST-ORDER LEVELING



VERTICAL CONTROL USED IN THE 1929 ADJUSTMENT

The kilometers of lines added to provide needed elevation data for expanded federal programs throughout the country has increased the useful content of the network by seven hundred percent since 1929. The following programs, coinciding with intensive national growth, resulted in increased need for vertical geodetic control:

- o flood control
- o mapping
- o transportation development and construction
- o recreational facilities

C. Status

The National Network of Vertical Control is comprised of 500,000 kilometers of leveling as shown in Figure 5.

- o 64,000 kilometers of the basic network leveling established between 1878 and 1929.

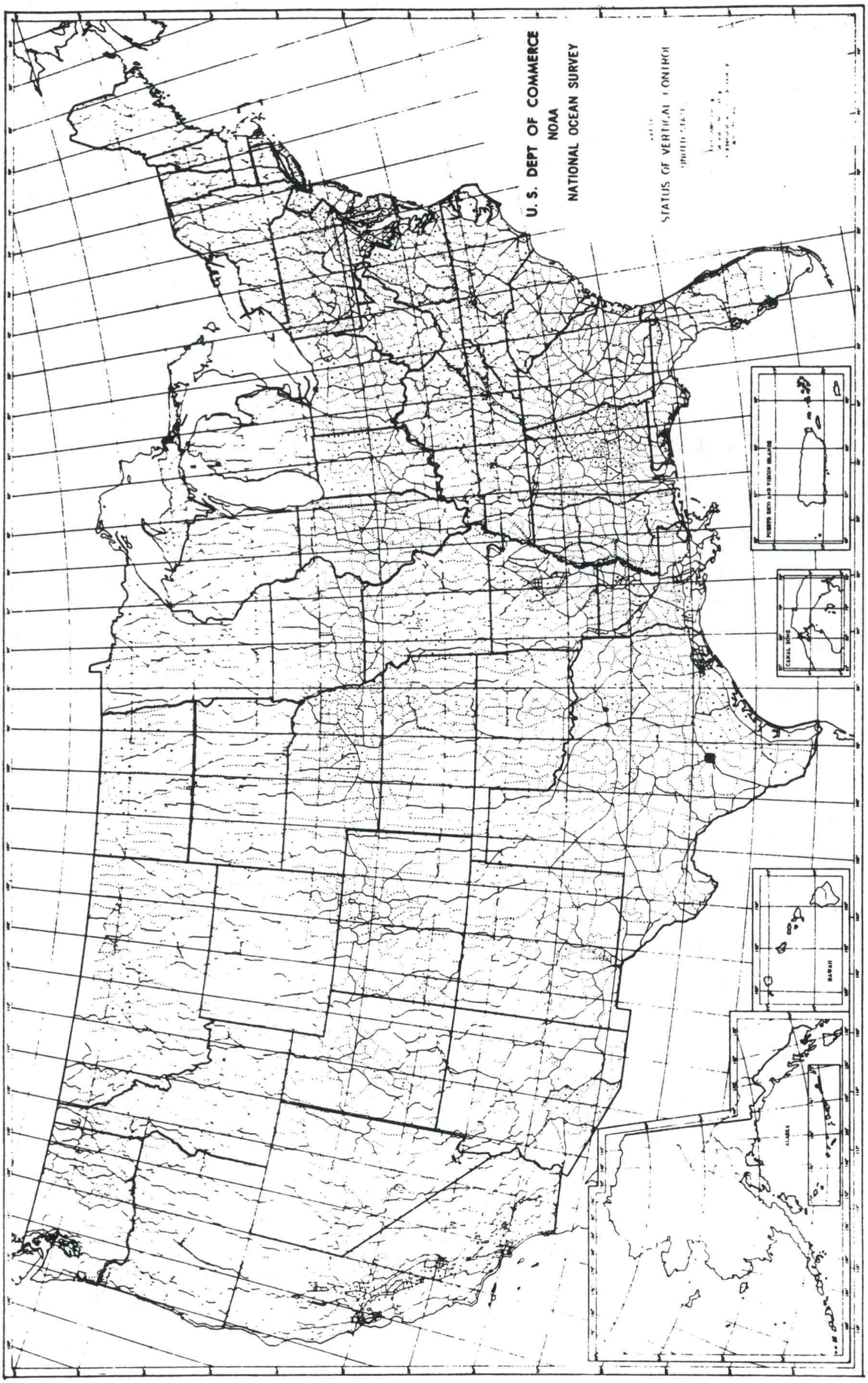

U. S. DEPT OF COMMERCE
NOAA
NATIONAL OCEAN SURVEY
STATUS OF VERTICAL CONTROL
PUERTO RICO AND VIRGIN ISLANDS
CANAL ZONE
HAWAII
ALASKA

FIGURE 5

- 120,000 kilometers of additional precise leveling established between 1929 and 1974.
- 316,000 kilometers of subsidiary leveling to establish vertical network control and meet federal program needs.

This Network was adjusted to the level lines which made up the Sea Level Datum of 1929 with some modifications in the interim.

Any discussion of the status of the Network must take into consideration the condition of level lines, sea level changes, crustal movements, and bench mark destruction.

1. Inventory of the Network - The network of leveling lines shown in Figure 5 was monumented by approximately 468,000 bench marks. The spacing of lines and distance between monumented points (bench marks) are generally closer in densely populated or intensively developed areas. Physical destruction of monuments in the Network is conservatively estimated at more than 100,000 of the 468,000 marks.

2. Crustal Movements Effect on Elevations

There are three types of movement causing change in relative height between the land and mean sea level. They are:

- o tectonic
- o isostatic
- o eustatic

a. Tectonic movements are the result of shifting and tilting of large portions of the earth's crust. Elevation changes due to tectonic movement are large and dramatic when they are the result of earthquakes. They are very subtle, but measurable, when they result from gradual uplift or subsidence.

b. Isostatic change in elevation is evident in areas recovering from submersion under the glaciers of the Ice Age. Isostatic change is prevalent in the Great Lakes Region of the United States and Canada.

c. Eustatic change in sea level is caused by the growth or melting of the polar ice caps.

Figure 6 shows the probable location of elevation changes resulting from crustal movement.

The following observations can be made:

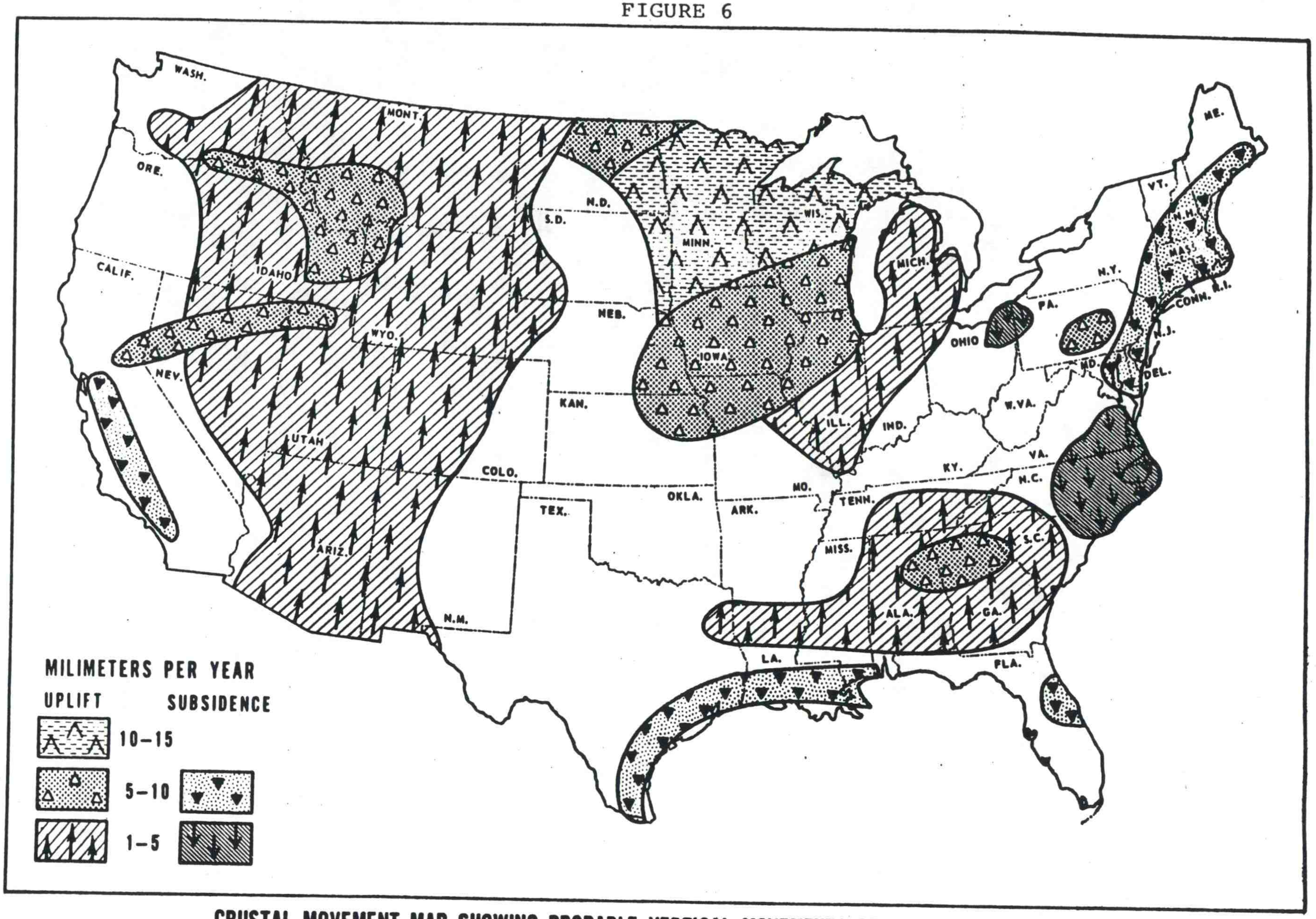
- The land area along the Atlantic Coast is subsiding at the same time the eustatic changes are causing a rise in sea level.

- Uplift in the Great Lakes area is causing shoreline changes and navigation problems for deep-draft vessels.

- Tilting of large river basins portends significant navigation and flood-control problems.

- The Gulf Coast is subsiding as a result of underground water removal;

FIGURE 6



CRUSTAL MOVEMENT MAP SHOWING PROBABLE VERTICAL MOVEMENTS OF THE EARTH'S SURFACE
AUGUST 18, 1972

causing severe flooding in the Houston-Galveston area where subsidence is as great as one-half foot per year.

- The San Joaquin Valley in California is subsiding as much as one foot per year.

The subsidence in the San Joaquin Valley, totaling as much as 27 feet, has damaged irrigation systems covering more than 2,000 square miles.

Earthquakes have caused other movements across the country, particularly in the West. More than four billion dollars in damage claims have been made as a result of the San Fernando earthquake of 1971. It caused vertical movement of five feet, affecting a broad area.

Continuing subsidence of major Gulf Coast cities has forced consideration of alternate ways of obtaining water for industry to avoid:

- Submerging valuable real estate.
- Altering wildlife habitat.
- Corrupting the fresh-water supply by salt water intrusion.

D. Engineering and Technical Factors Affecting the Network

The network of leveling established during the period 1878 to 1929, with some modification, serves as a framework for the National Network of Vertical Control. Although the most advanced instrumentation of the period was used, most of the 64,000 kilometer network established is inadequate because of crustal movement and the following deficiencies:

- Substandard leveling instruments and procedures.
- Astronomical corrections omitted.
- Refraction corrections omitted.
- Procedures designed to get maximum network coverage. Prior to 1929, marks were established at five-mile intervals along the lines of leveling.

Improvements in instrumentation and computing devices, the greater complexity of engineering problems, and the increasing value of land and new government policies have all contributed to a rising need for accuracy. One of the engineering principals governing the accuracy of leveling surveys is that the basic control system should be several times more accurate than the dependent survey.

E. Network Destruction

Our previous estimate was that approximately 100,000 of the bench marks established have been destroyed. The July 1973, Report of the Office of Management and Budget (OMB) of Mapping, Charting, Geodesy, and Surveying (MCGS) substantiates this estimate.

> . . . based on the quantity of leveling which has been accomplished, one could conclude that little remains to be done. But only a small percentage of the control established is now usable because . . .

the loss of many bench marks (about half of the bench marks established more than 30 years ago are lost). . .

This destruction persists despite a significant federal expenditure for maintenance and voluntary assistance by state, local, and private engineers

Many of the marks have been destroyed due to the effects of expanding construction including:

- Building and widening of roads.
- Economic development
- Utility construction
- Natural resource removal
- Canal and waterway development
- Flood control projects

V. REQUIREMENTS FOR A RENEWED VERTICAL NETWORK

The OMB Task Force on Mapping, Charting, Geodesy, and Surveying found evidence of dramatic national problems pertaining to the environment, the use of land and natural resources, and management of the coastal zone related directly to vertical movement of the earth's crust.

Federal, state, and local users of National Vertical Control Network view this system of monuments as the standard to which all other surveys are referenced. These users require that the elevations of monuments be accurately determined since errors in the NVCN are proliferated into other surveys. An incorrect starting elevation of a network monumentation can cause corresponding errors in hundreds of other points in surveys referenced to the network monument.

Errors in federal, state, and local secondary leveling surveys are translated into incorrectly delineated maps and construction project plans. These errors create engineering problems, which must be corrected by the expenditure of additional funds.

A. Federal Agency Requirements

The 1973 OMB Report found that 39 federal agencies are dependent on the National Vertical Control Network. Specific vertical control requirements of federal agencies are developed annually by the Federal Geodetic Control Coordinator. Figures 7 and 8 list the requirements documented by these agencies for FY 1976.

FIGURE 7

Dept.	Agency	Program Requirements	Requested Leveling Kilometers [3]
DOI	Geological Survey	National Map Series	3,920
DOI	Bureau of Land Management	Land and Resource Management	120
	Tennessee Valley Authority (Independent Gov't Agency)	Power Plant Siting; Crustal Movement	2,000
	National Park Service	Park Management and Conservation	512
	Alaska Power Administration	Powerlines and Facilities	112
DOC	National Oceanic & Atmospheric Administration	Marine Surveys & Charts; Aeronautical Charts; Vertical Datum Maintenance & Update	1,040
		Great Lakes Water Level Monitoring	640
HUD		Urban Development & Renewal	420
DOD	Corps of Engineers	Public Work	6,176
DOS	International Boundary Commission	U. S. Mexico Boundary	96
			15,036

3. 1 Kilometer equals 0.6 miles
NOS has used the Metirc System internally since 1807.

FEDERAL AGENCIES VERTICAL CONTROL REQUESTS FOR FY1976

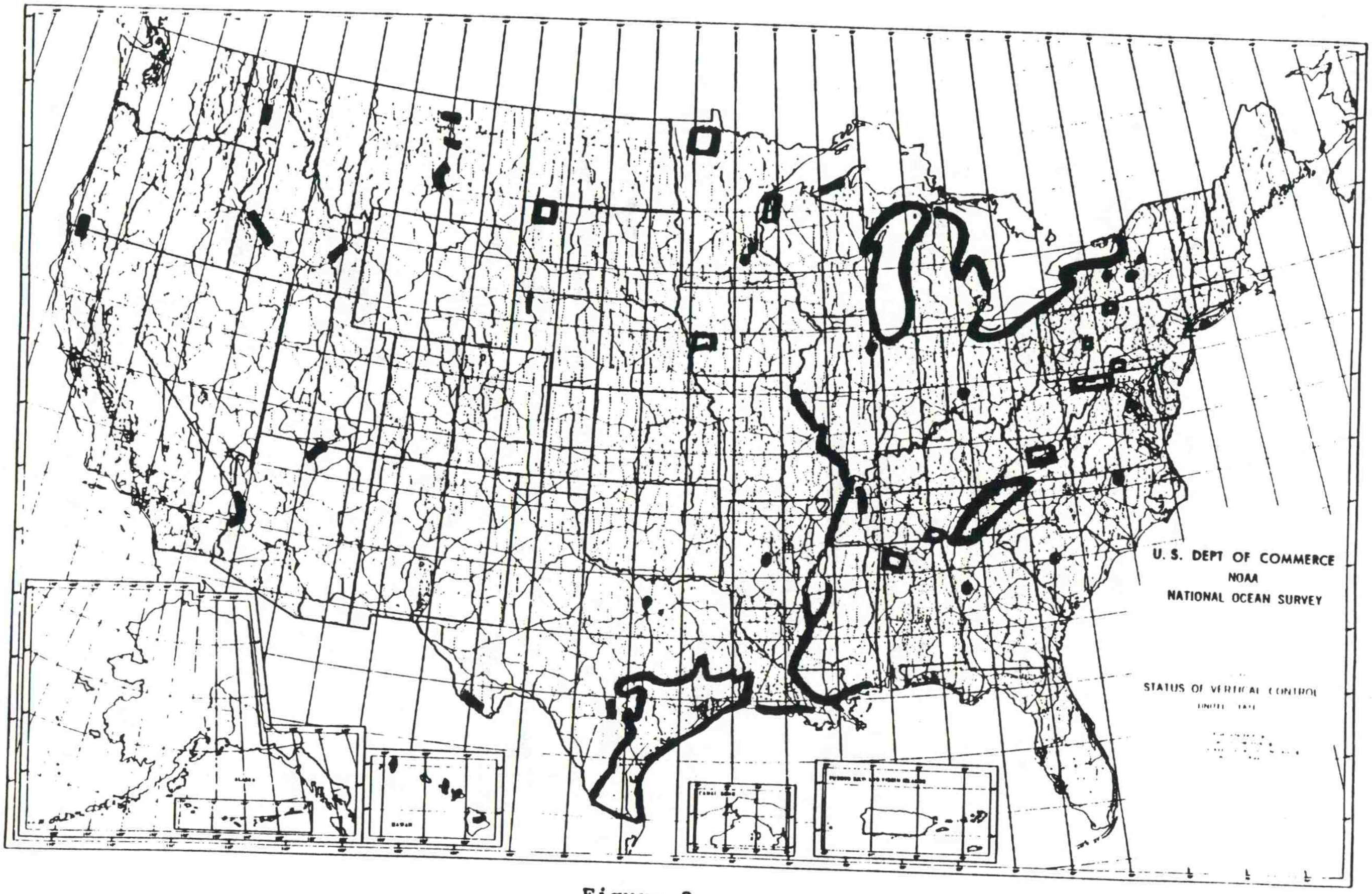


Figure 8

B. State and Local Requirements

State and local agencies require a single and unambiguous vertical network to which their surveys can be referenced. There are no formal listings of state and local survey requirements, but it is estimated that their needs are as great as those of the Federal Government. For example, all highway and utility survey locations are referenced to bench marks, many of which are tied to the National Vertical Network.

In a study[4] completed in 1971, 30 states report having agencies specifically authorized to establish geodetic control for general use within the state. The opinion of the authors was that an appreciable number of other states performed surveys which they hesitated to class as geodetic many of which could, with some improvements, conform to at least third-order standards.

Many counties and cities have large survey organizations. Los Angeles County, for instance,

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4. Roy Williamson and Lt. Cdr. Kenneth F. Burke, "The States and Control Surveys."

employs approximately 150 personnel in their survey department.

The high value placed on the National Vertical Network is exemplified by the willingness of the users to assist in the preservation of control points. Replacement bench marks are often established by non-federal surveyors who donate their services and materials to preserve the network in their locality. Last year the NGS supplied other organizations with bronze disks for approximately 150 replacement monuments. During that same year 1547 witness posts and 3682 witness signs were placed by private industry.

C. Network Criteria

The National Vertical Network provides the interrelated elevations of bench marks throughout the country as starting or reference points for all surveying, mapping, engineering, and planning activities where elevation is a significant factor.

Level lines chosen for inclusion in the releveling of the basic vertical datum are based upon the following criterion:

- Provide primary control along coastlines and connections to major tide gages.

- Take optimum advantage of the prior leveling that meets the criteria for vertical datum.

- Connections to the Canadian and Mexican vertical networks.

- Provide primary control along major waterways and drainage basins.

- Provide vertical control for monitoring active seismic areas.

- Establish the new leveling required in accordance with the Classification, Standards of Accuracy and General Specifications of Geodetic Control Surveys.

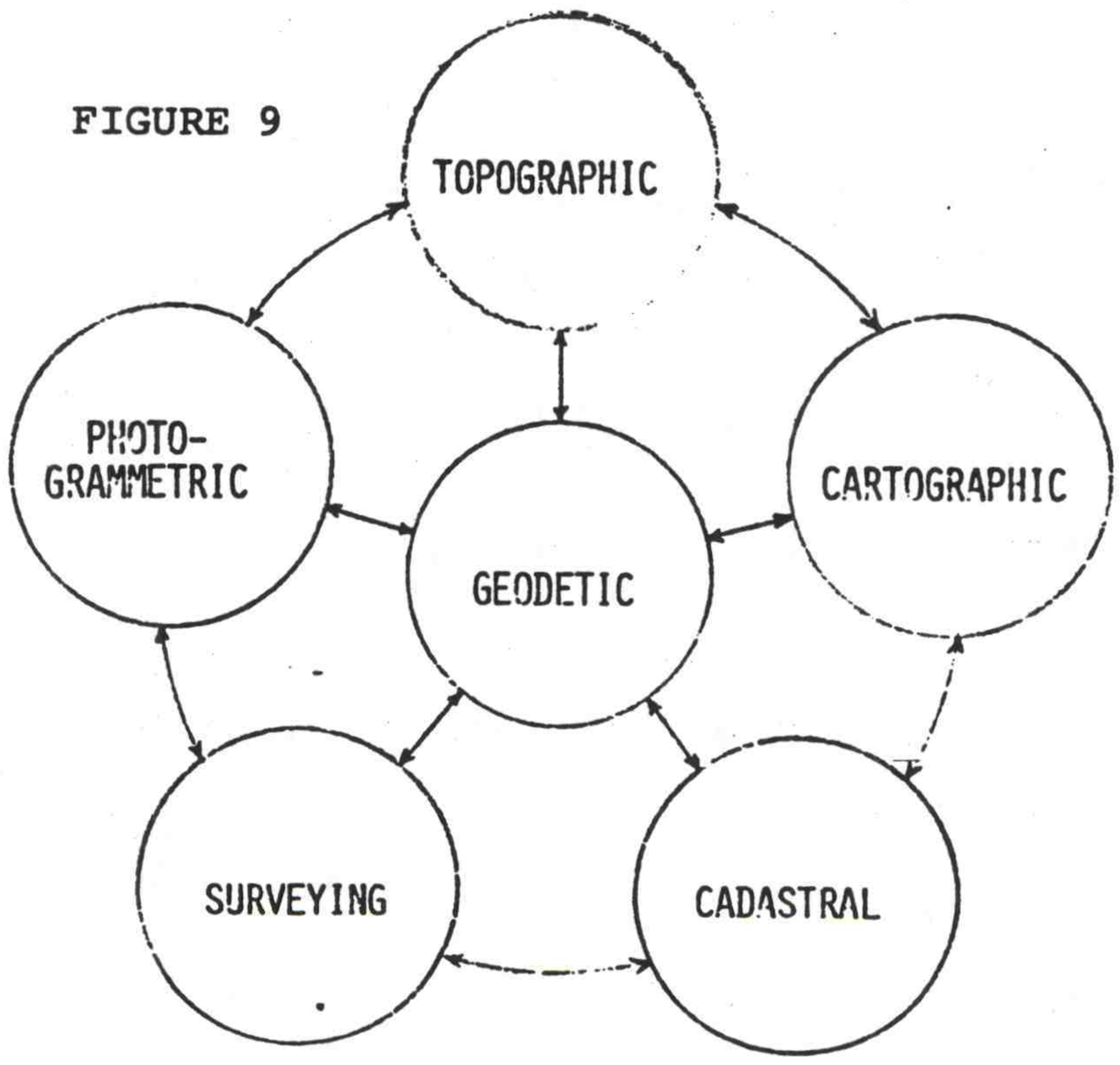
- Meet federal geodetic control requirements to the extent possible.

- Complete the new leveling within the recommended time period.

VI. IMPACT ON OTHER NOAA PROGRAMS

The relationship of Geodesy to other NOAA oriented disciplines is exemplified by Figure 9.

FIGURE 9



The releveling and new adjustment of the Vertical Control Network does impact on other ongoing NOAA programs. This section will examine the most prominent of these factors.

A. Marine Surveys and Maps

Primary lines will be leveled along all coastlines where no modern surveys exist. These lines will tie to the major tidal bench marks in use along the coastal areas of the United States, thereby assuring more reliable data for reliable data for Marine Boundary and Tidal Datum Surveys.

B. Coastal Zone Management and Coastal Mapping

Subsidence rates and erosion are primary concerns within the Coastal Zone Management Program. As previously stated, primary lines will be leveled along all coastlines where no modern surveys exist. A study of elevations from repeat levelings give an accurate indication of subsidence and erosion rates. In addition, densification of bench marks in the coastal zones as a result of planned releveling, will provide added control for utilization in the preparation of nautical charts.

C. Lake Survey Center

The Lake Survey Center has established vertical control in the vicinity of the Great Lakes. This

control is presently referenced to the Great Lakes Datum. The Great Lakes Water Level Gaging and Control System is tied to this control. A new adjustment of the North American Vertical Datum will include the vertical control of the Lake Survey Center. As a result, the data will be homogeneous and more readily utilized by the community of geodetic users.

VII. DETAILED DESCRIPTION OF TASKS TO BE PERFORMED

A. Data Conversion

The initial steps have already been taken to develop techniques for conversion of vertical control data presently in the National Geodetic Survey to an automated format. This process is needed for the later mathematical adjustment of the entire NVCN. The existing data will then be in a compatible format with the releveling data which will be received in machine readable form from the field surveys.

B. Releveling of Framework

There are approximately 40,851 kilometers of level lines to be completed for the basic framework of the National Vertical Control Network. The regional approach as explained later in this section will be utilized in accomplishing the releveling. A region will be completed before commencing operations in another region. The releveling tasks include the following:

- Recovery of existing bench marks along the lines of levels and replacement of missing bench marks at one-mile intervals.

- Level over the bench marks and obtain observation data in machine readable format.

The magnitude of the leveling to be accomplished necessitates an approach based on divisions or regions. The designation of the county into regions also facilitates the accomplishment of the preliminary and new general adjustment on a "block" basis.

Figure 10 shows the regions and framework level lines. The framework leveling consists of approximately 67,108 kilometers. The leveling will be inaugurated in Region 1 and progress westwardly as each region is completed. Approximately 26,257 of the 67,108 kilometers of the framework leveling have been leveled since 1963 and can be utilized; therefore, 40,851 kilometers of leveling will be required to complete the framework.

The working areas assigned for leveling will be dependent upon weather conditions. The northern portion of a region will be leveled from mid-spring to mid-fall and the southern portion from mid-fall to mid-spring.

Figure 11 shows the total kilometers to be leveled for the framework and the breakdown per region.

Figure 10

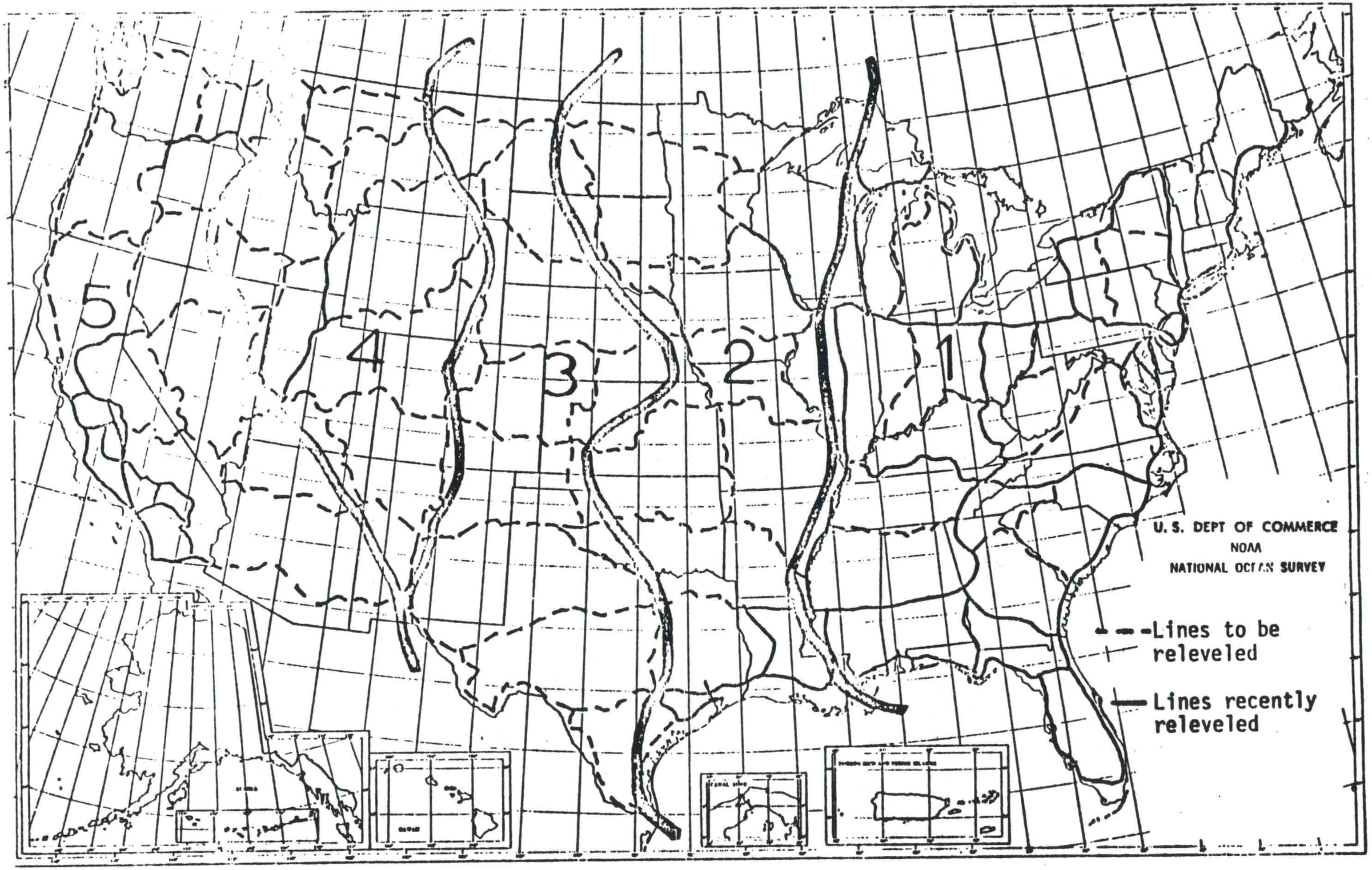
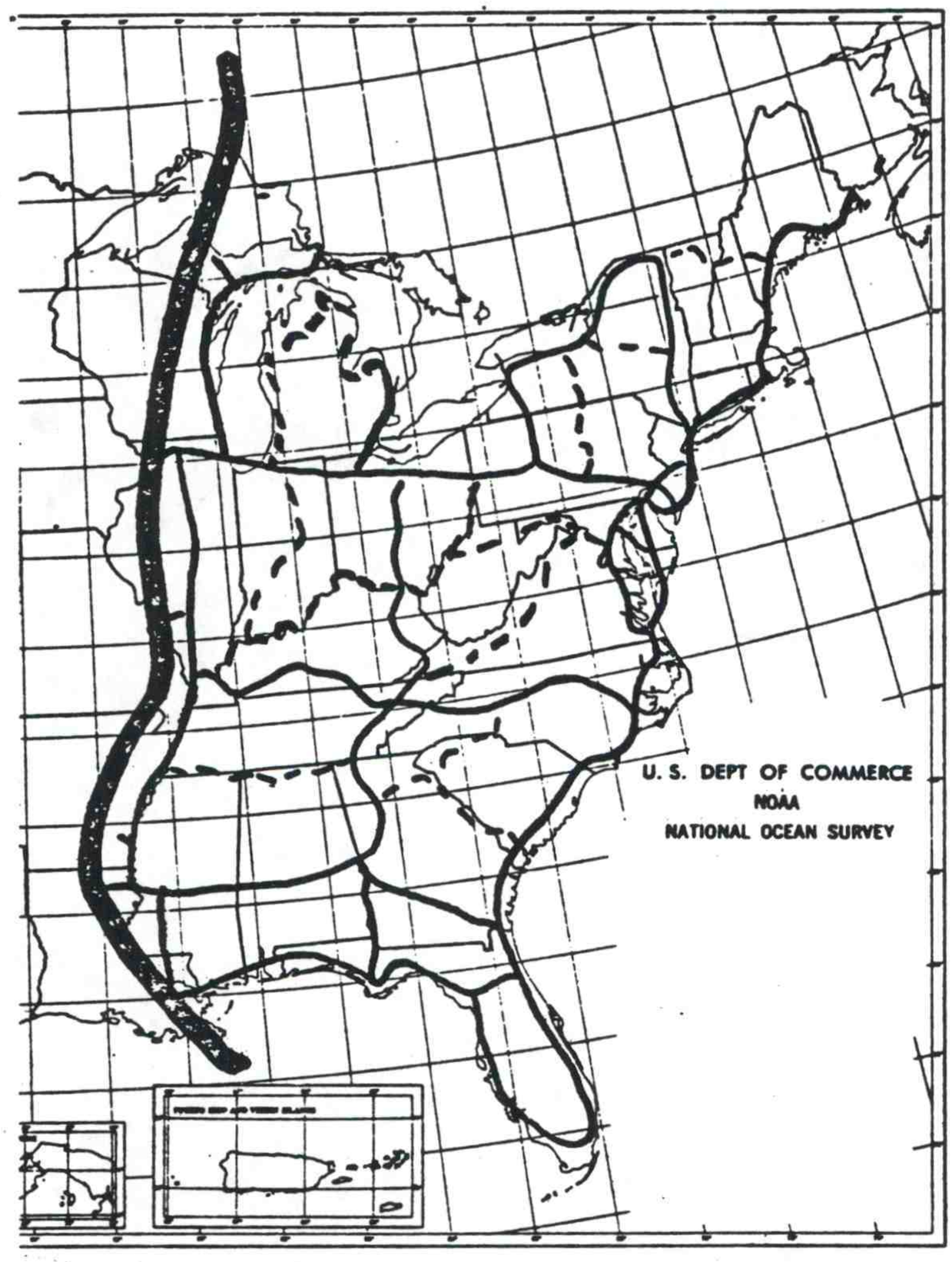

5
4
3
2
1
U. S. DEPT OF COMMERCE
NOAA
NATIONAL OCEAN SURVEY
Lines to be releveled
Lines recently releveled

FIGURE 11

Region	Lines to be Leveled (km)	Ties to Tide Gauges (km)	Total New Leveling (km)	Lines Recently Leveled (km)	Total Framework Leveling (km)
1	7,780	540	8,320	17,255	25,575
2	8,730	100	8,830	3,096	11,926
3	8,250	0	8,250	0	8,250
4	7,122	0	7,122	925	8,047
5	8,139	190	8,329	4,981	13,310
Total	40,021	830	40,851	26,257	67,108

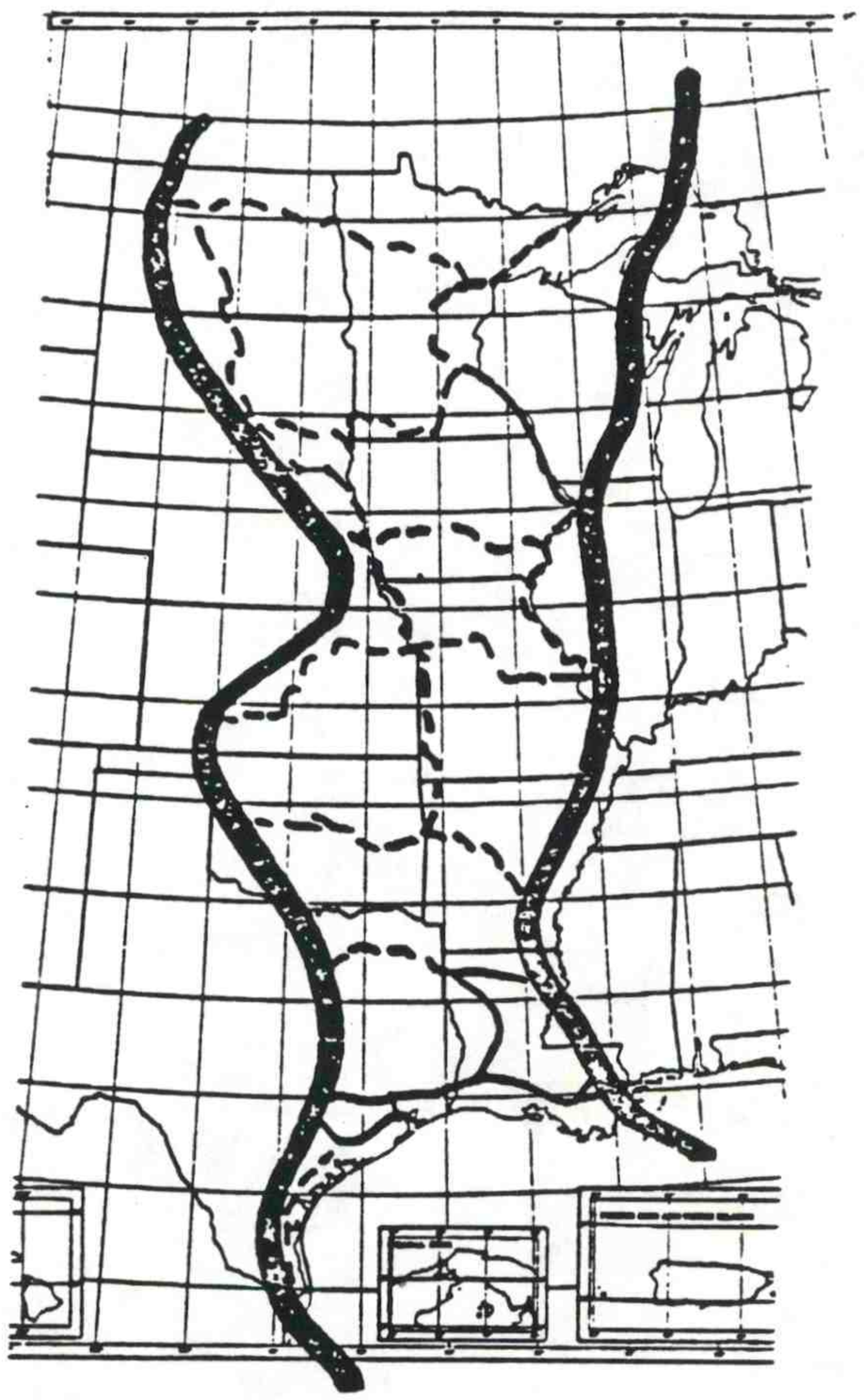


- - - Lines to be releveled.

——— Lines recently releveled.

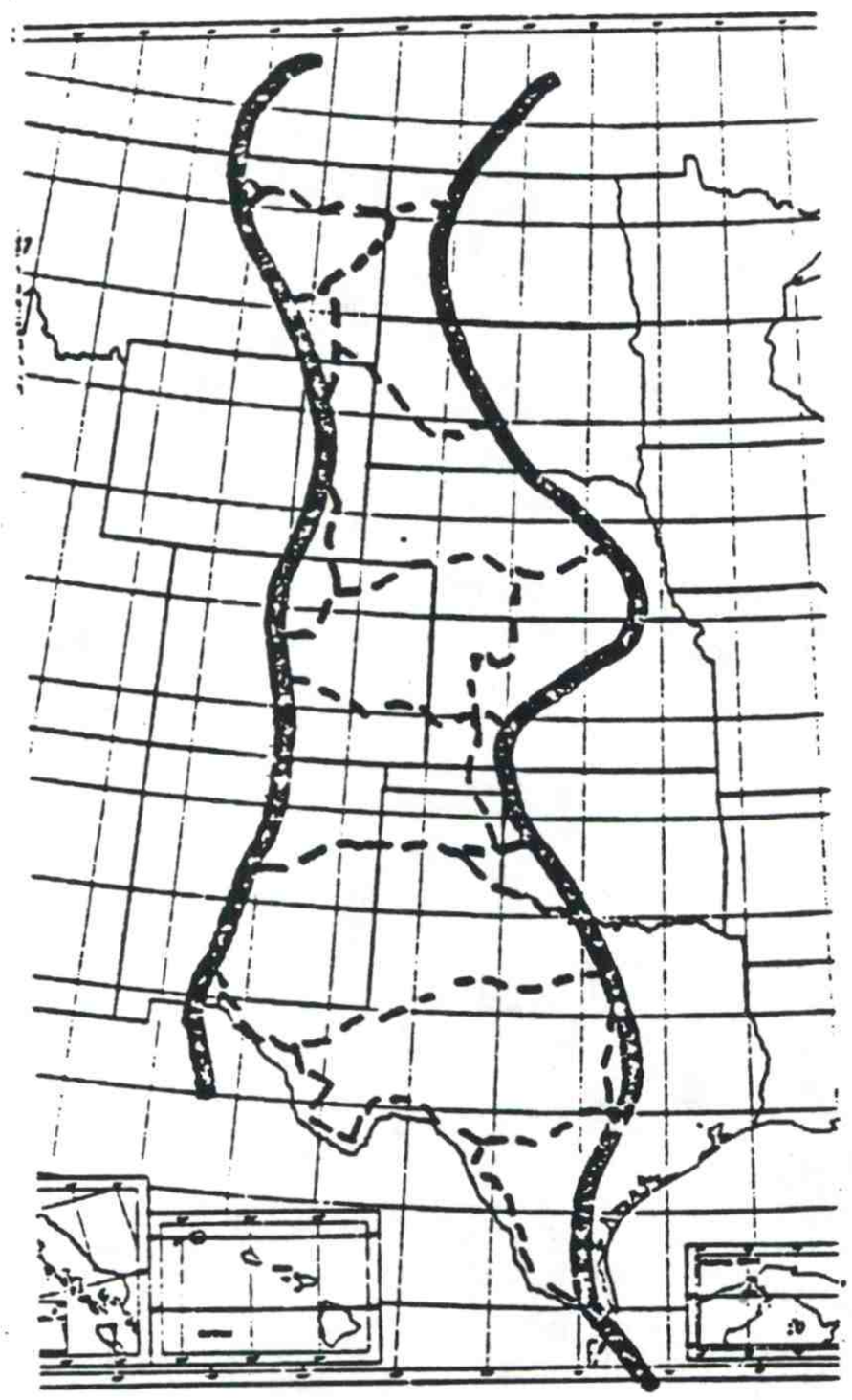
Region 1 will require approximately 25,575 kilometers of framework leveling. Since 1963 approximately 17,255 kilometers have been leveled and will be utilized for the framework. This leaves approximately 8,320 kilometers of new leveling to be accomplished to complete the region. Approximately 540 kilometers of the 8,320 kilometers will be used to tie in bench marks at 54 tide gauges along the Atlantic and Gulf of Mexico Coasts.

Region 2

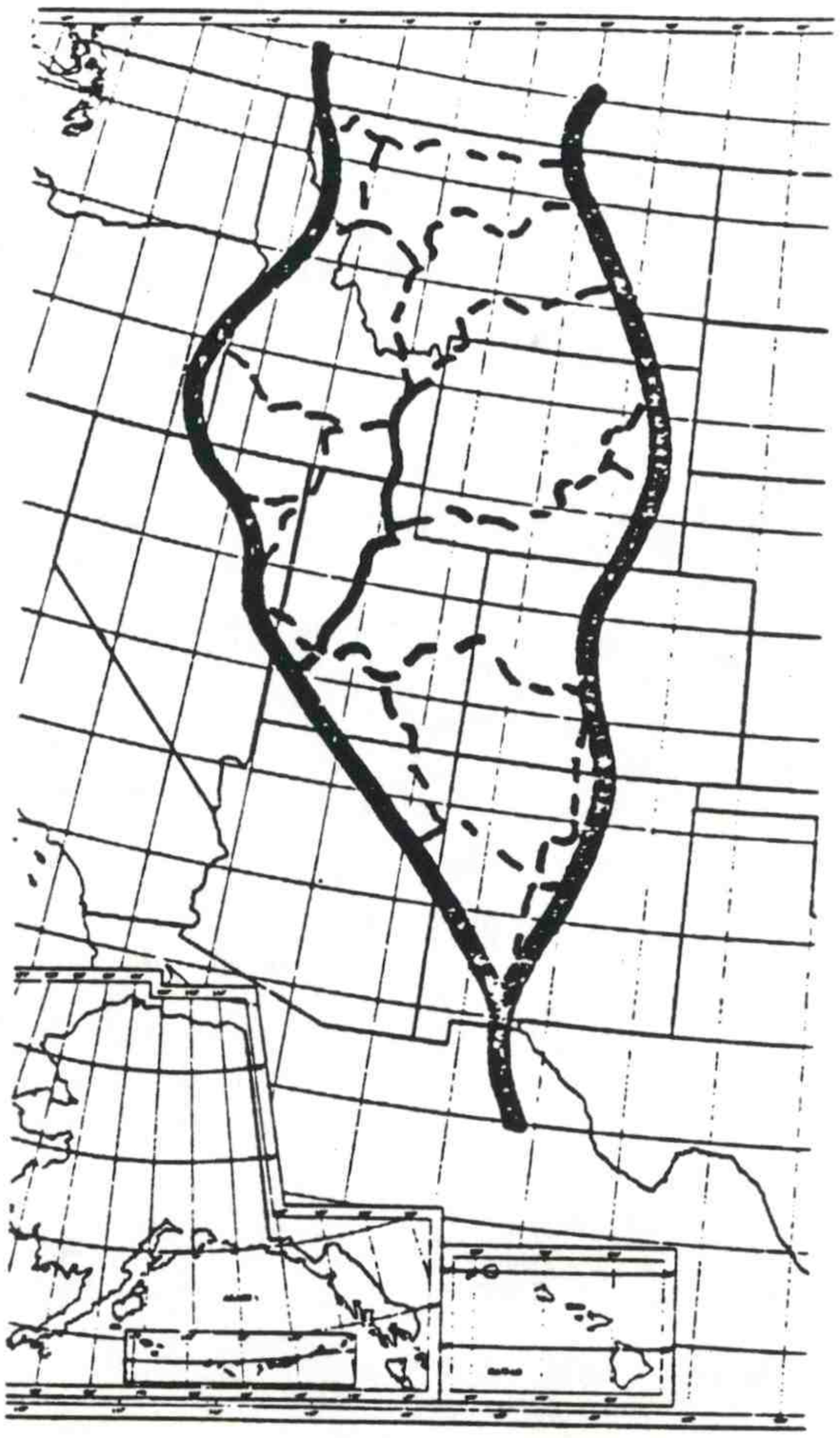


Region 2 will require approximately 11,926 kilometers of framework leveling. Since 1963 approximately 3,096 kilometers have been leveled and will be utilized for the framework. This leaves approximately 8,830 kilometers of new leveling to be accomplished to complete the region. Approximately 100 kilometers of the 8,830 kilometers will be used to tie in bench marks at 10 tide gauges along the Gulf of Mexico Coast.

Region 3



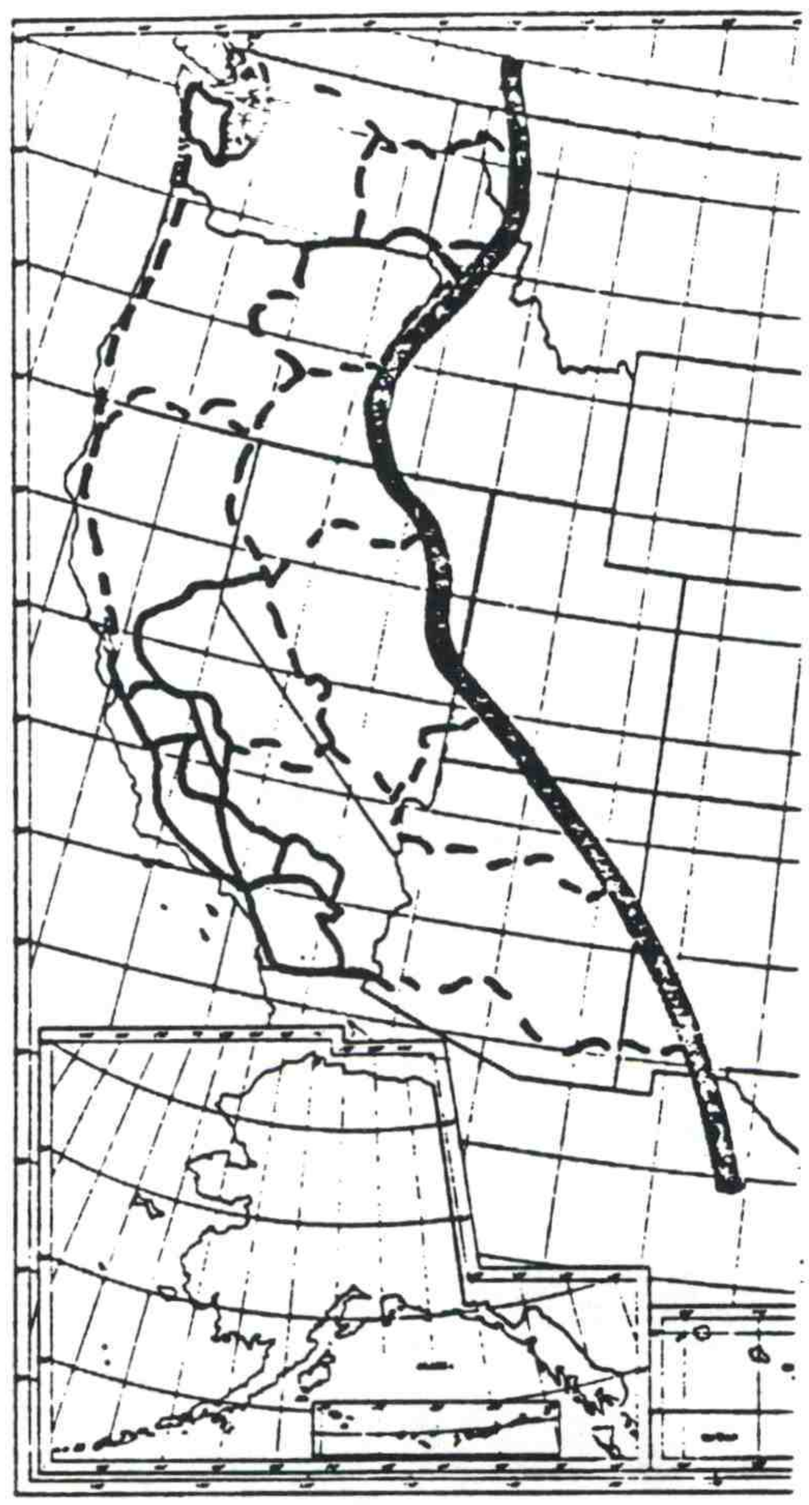
Region 3 will require approximately 8,250 kilometers of framework leveling. The requirement to complete the region will be all new leveling.



Lines to be releveled.

Lines recently releveled.

Region 4 will require approximately 8,047 kilometers of framework leveling. Since 1963 approximately 925 kilometers have been leveled and will be utilized for the framework. This leaves approximately 7,122 kilometers of new leveling to be accomplished to complete the region.



— — — Lines to be releveled.

——— Lines recently releveled.

Region 5 will require approximately 13,310 kilometers of framework leveling. Since 1963 approximately 4,981 kilometers have been leveled and will be utilized for the framework. This leaves approximately 8,329 kilometers of new leveling to be accomplished to complete the region. Approximately 190 kilometers of the 8,329 kilometers will be used to tie in bench marks at 19 tide gauges along the Pacific Coast.

C. Preliminary Adjustment

The initial step in the preliminary adjustment is the assimilation of releveling data and historic data for a region for analysis. The data is checked for obvious mistakes or missing data. The refractive, gravity, astronomical, and calibration corrections are then applied.

After the preliminary processing, the level loops from the "completed" region will be assembled on the computer in contigious chains. These loops will be preliminary least squares adjusted.

These preliminary elevations will be available for users, shortly after the preliminary least squares adjustment has been performed for an entire region.

D. Delineate and Define a New Vertical Datum

The new vertical datum or zero (0) point can be delineated after the releveling is completed in all five regions. The 26,000 kilometers of precise leveling and contributory leveling from other sources will be mathematically treated to develop the datum. The 200,000 monuments to be upgraded will then be fitted to the framework derived.

E. General Adjustment

The general adjustment will include all available leveling data:

1. 41,000 kilometers of releveling accomplished under this program elements.

2. 26,000 kilometers of prior precise surveys used in the framework.

3. 200,000 bench marks "upgraded" as a result of framework releveling.

4. Data developed from ties to approximately 130 of the 236 major tide gages in the primary tidal network.

5. Data from the leveling connections to the Canadian and Mexican lines.

6. Data developed and included in the National Geodetic Data Bank (NGDB) from federal, state, and local services.

F. Publishing and Dissemination

Index or status maps will be published showing the availability of the new National Vertical Control Network data. Dissemination of data will be accomplished in automated format from the NGDB.

VIII. Operations Plan

The task outlined in the preceding sections must be accomplished systematically and undertaken in a coordinated manner to accommodate sequential integration as the work proceeds. The operational plan which follows is recommended for implementation and provides for:

a. Completion of framework surveys of the National Vertical Control Network by the end of the seventh year.

b. Completion of a general adjustment and new National Geodetic Vertical Datum by the eighth year.

c. Publication of the new datum for all conterminous states by the eighth year.

d. Maximum and efficient utilization of base program resources and facilities.

e. The beginning of benefits returned to the public by the fifth year.

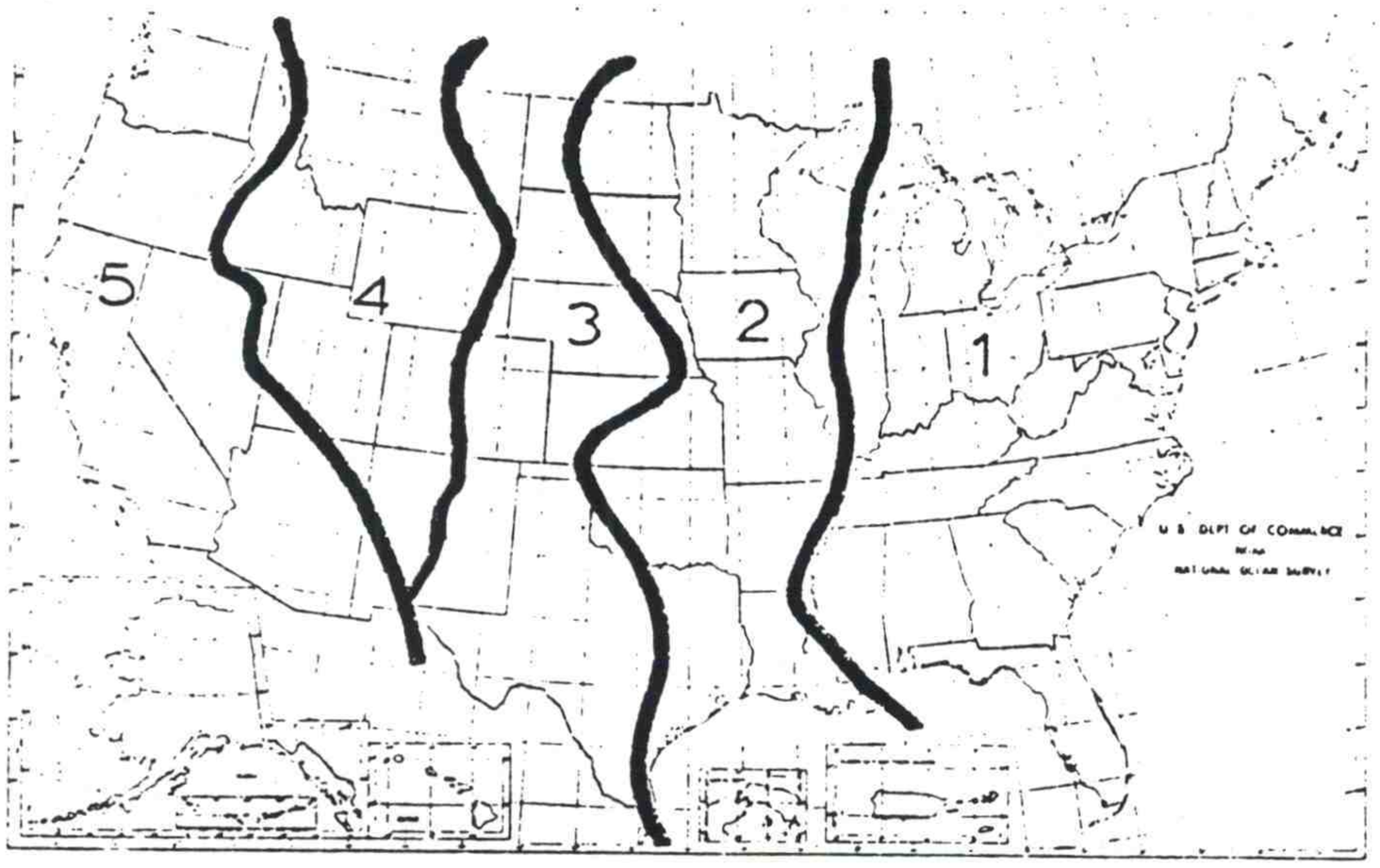
The plan to achieve a new adjustment of the National Geodetic Vertical Datum is relatively straightforward. The tasks to

be performed have been sequentially scheduled, and milestones to mark significant events have been established. Figure 12 shows the schedule of milestones to be completed during the eight-year period, and the regions in the Table are outlined on the accompanying diagram of the United States.

Figure 12

OPERATIONS SCHEDULE - NEW ADJUSTMENT NATIONAL GEODETIC BERTICAL DATUM

Milestone	Fiscal Years 1	2	3	4	5	6	7	8
Perform vertical control surveys forming a framework for updating the National Geodetic Vertical Network.		Region 1 Completed MAR.	Region 2 Completed JUL.		Region 3 Completed DEC.	Region 4 Completed MAY	Field Work of All Regions Completed SEP.	
Conversion of archival data to an automated format.		Region 1 Completed MAR.	Region 2 Completed JUL.		Region 3 Completed DEC.	Region 4 Completed MAY	Archival Data Conversion of All Regions Completed SEP.	
Acquisition of equipment needed to do vertical control for the National Geodetic Vertical Datum.							Acquisition of Equipment Completed SEP.	
Development of data processing or other software for adjusting the National Geodetic Vertical Datum.		Breadboard Adjustment in Operation OCT.					Development of Computer Software Completed. SEP.	
Perform a preliminary adjustment of framework and subsidiary nets within the framework of the National Geodetic Vertical Network.							Preliminary Adjustment in All Regions Completed SEP.	
The finish of the new adjustment for the 48 conterminous states. Distribution of the new National Geodetic Vertical Datum.								Final Adjustment in All Regions Completed SEP.



IX. ECONOMIC CONSIDERATIONS

A. Vertical Network Benefits

A wide range of activites depend upon or benefit from the accuracy and reliability of vertical network data. This listing of activities and users that benefit from accurate geodetic information gives a qualitative glimpse of their extent:

1. Data base applications for all levels of Government.

2. Scientific users, evaluation of earthquake risk, development of building codes, study of earthquake mechanisms.

3. Coastal zone management, shore boundary demarcation, storm inundation, erosion and subsidence studies.

4. Management of water resources; planning and construction of dams, canals, levees; flood control and watershed management.

5. Environmental impact assessments.

6. All large-scale mapping and charting work.

7. Mining and related engineering surveys.

8. Rural, urban, city, and regional engineers; planning and construction of transportation systems and utilities.

9. Land-use inventory and planning.

10. Crustal movement information for atomic power plant siting evaluations.

The improved vertical datum will produce more reliable data for comparison of the historical elevation changes through time. Time related crustal movement studies are of practical engineering utility and contribute to scientific studies. There are many scientific endeavors that attempt the understanding of basic earth processes. There is no substitute for vertical data in these studies and the value obtained is not

commensurate with usual cost-benefit measures.

In an effort to bring out the prime rationale behind vertical control, NOS calculated the economic benefits of improved densification in the Houston, Texas, area. Continuing subsidence in this area is creating a need for new bench marks and a continual releveling of the bench marks already established. The benefit/cost analysis was based on the premise that a higher percentage of the leveling done in the Houston area will be tied into the regional first-order network if more stations are available for use by local private and government surveys.

The comparison of hypothetical benefit/cost ratios resulting from reduced construction surveying costs nationwide utilized the study by Lieutenant Commander

Phillip C. Johnson with respect to urban horizontal geodetic control surveys.[5] The study indicates a benefit/cost ratio of 2.3 for a five-year program. This means that, annually, $2.30 of additional cost to local surveyors is eliminated by each $1.00 of federal cost in vertical control projects in the Houston area.[6]

The figures indicate that such a vertical control nationally would represent a tremendous cost saving if initiated within the recommended time frame.

The additional releveling and upgrading will also provide reliable reference points in closer proximity to projects of Federal, state, and local agencies.

Another benefit of timely implementation of this effort will be savings resulting from the utilization of precise

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5. Johnson, Phillip C., A Measure of the Economic Impact of Urban Horizontal Geodetic Control Surveys. Department of Commerce, August 1972.

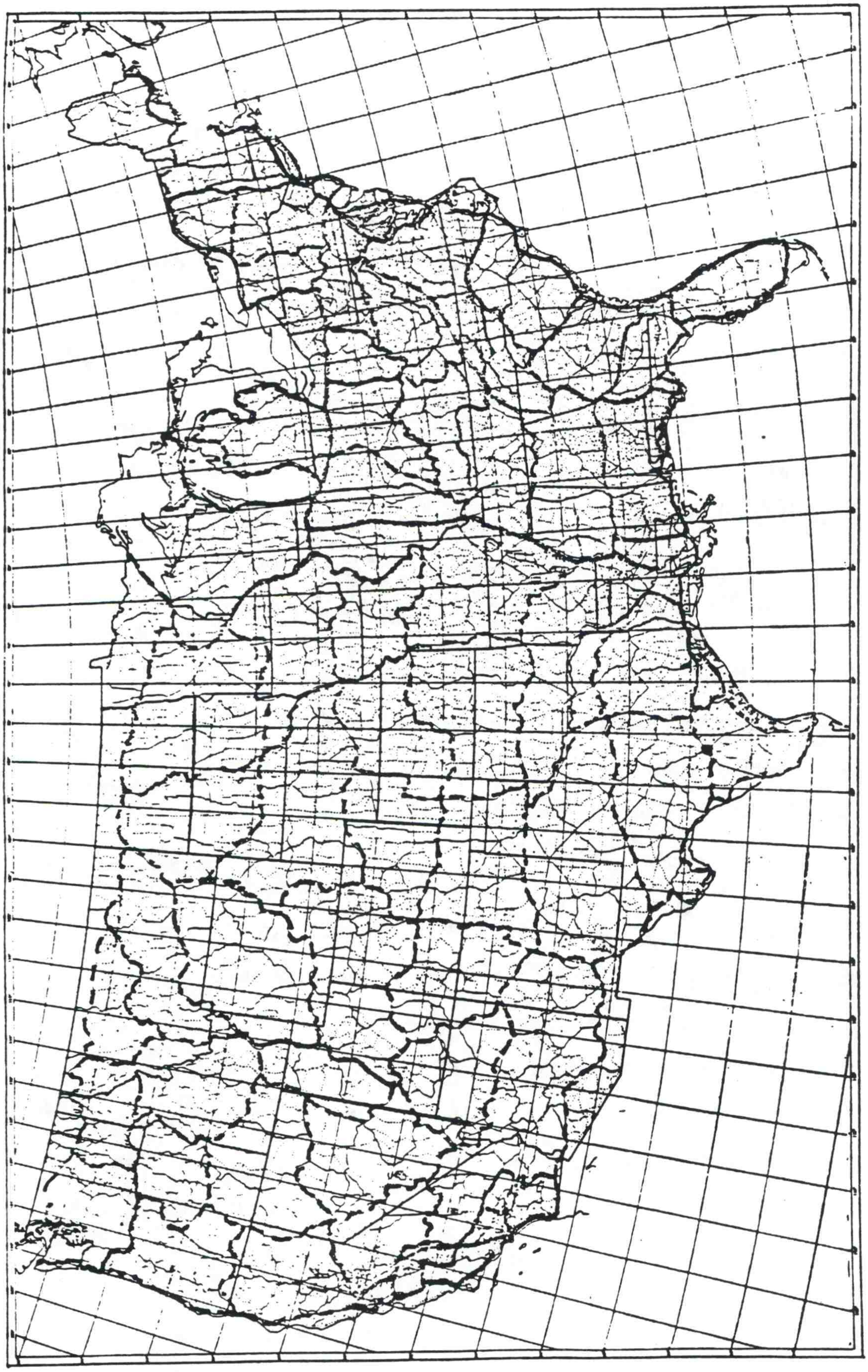
6. See Appendix C

leveling done during the period 1963 to 1974. Approximately 26,000 kilometers of leveling can be used to form a part of the proposed basic framework as shown on Figure 13. The framework leveling must be completed expeditiously as possible to obtain maximum benefit of this precise leveling.

The Federal Insurance Administration requires reliable elevation information for the delineation of flood plains. Insurance rates in these areas are based on the data available. Lack of vertical control coverage or inaccurate data can result in higher rates.

At a minimum, additional Federal expenditures will be involved to develop elevation data. Often the data obtained under these conditions could be unreliable over large geographical areas and serve only a single purpose.

Advanced earth science studies have led many scientists to believe that we are on the verge of understanding fundamental earth processes that relate to mountain building, volcanism, and earthquake mechanisms. Historically, periodic updating and evaluation of the geodetic datum have provided the only measurements of physical changes in the earth's crust in North America.



New measurements and a new adjustment of the National Vertical Control Network will provide updated and new information necessary for the furtherance of these studies.

B. Resource Requirements

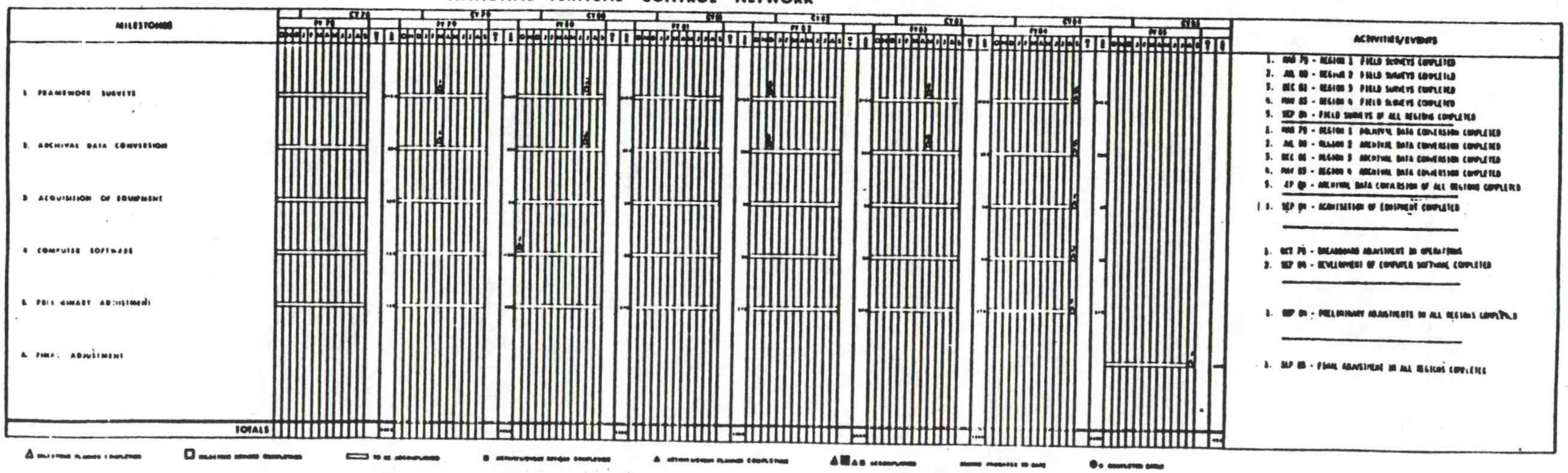
Figure 14 shows the cost breakdowns by fiscal years for releveling and adjustment of the Vertical Network. Cost estimates are based on current operating costs including field work and placement of observed data into machine-readable format.

The schedule of costs covers an eight-year period, although only seven years of new funding are programmed. Accomplishing the releveling and new adjustment tasks will require resources in excess of those available from base funding during the life of the project.

Resources required to produce the releveling and new adjustment will total $20 million during the eight-year course of the project. Of this amount, $1.8 million will be made available from base program funding and new funding amounting to $18.2 million ($2.6 million in each of the seven years) will be required.

Preliminary Adjustment Costs listed in Figure 14 include the cost of checking data for accuracy, applying all necessary corrections, and mathematically adjusting the data to be consistent. This adjustment cost is based upon the assumption (interface with proposed National Geodetic Data Bank necessary) that historic data will also be in machine-readable format and can be adjusted with the new leveling data.

NATIONAL VERTICAL CONTROL NETWORK



FY	REGIONAL	FUNDING ($)	TOTAL
79	700	2600	2800
79	700	2100	2200
80	700	2500	2800
81	700	2600	2800
82	700	2600	2800
83	700	2600	2800
84	700	2100	2400
85	500		600
TOTAL	5000	18,200	20,000

X. IMPACT OF NOT RECEIVING INCREASE

The National Vertical Control Datum of 1929 exists in name only. It is an incomplete mosiac--a composite of layers of historic elevation determinations. Valuable observations are missing or not properly adjusted into the network. The present field leveling surveys are directed principally at dramatic problem areas.

Failure to approve the requested new funding will have the following adverse effects:

1. Increased costs of adjustment processes to minimize the computational distortions; unavoidable with present layers of leveling.

2. Continued proliferation of the inaccuracies of the 1929 network into new surveys.

3. Increased costs of Federal, State, and local projects utilizing vertical data, because of inaccuracy or inaccessability of the National Vertical Control Network.

4. Delay the benefits and savings resulting from centralization of leveling data for inclusion in the NVCN.

5. Proliferation of single-purpose leveling surveys that do not contribute to NVCN and frequent duplication of effort.

6. Loss of the savings from using 26,000 kilometers of prior leveling as part of the basic framework, and the benefits from 200,000 bench marks to be upgraded.

[H. R. 3511]

AN ACT

To define the functions and duties of the Coast and Geodetic Survey, and for other purposes

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That, to provide charts and related information for the safe navigation of marine and air commerce, and to provide basic data for engineering and scientific purposes and for other commercial and industrial needs, the Director of the Coast and Geodetic Survey, hereinafter referred to as the Director, under direction of the Secretary of Commerce, is authorized to conduct the following activities:

(1) Hydrographic and topographic surveys;

(2) Tide and current observations;

(3) Geodetic-control surveys;

(4) Field surveys for aeronautical charts;

(5) Geomagnetic, seismological, gravity, and related geophysical measurements and investigations, and observations for the determination of variation in latitude and longitude.

SEC. 2. In order that full public benefit may be derived from the operations of the Coast and Geodetic Survey by the dissemination of data resulting from the activities herein authorized and of related data from other sources, the Director is authorized to conduct the following activities:

(1) Analysis and prediction of tide and current data;

(2) Processing and publication of data, information, compilations, and reports;

(3) Compilation and printing of aeronautical charts of the United States, its Territories, and possessions; and, in addition, the compilation and printing of such aeronautical charts covering international airways as are required primarily by United States civil aviation;

(4) Compilation and printing of nautical charts of the United States, its Territories, and possessions;

(5) Distribution of aeronautical charts and related navigational publications required by United States civil aviation;

(6) Distribution of nautical charts and related navigational publications for the United States, its Territories, and possessions.

SEC. 3. To provide for the orderly collection of geomagnetic data from domestic and foreign sources, and to assure that such data shall be readily available to Government and private agencies and individuals, the Coast and Geodetic Survey is hereby designated as the central depository of the United States Government for geomagnetic data, and the Director is authorized to collect, correlate, and disseminate such data.

SEC. 4. To improve the efficiency of the Coast and Geodetic Survey and to increase engineering and scientific knowledge, the Director is authorized to conduct developmental work for the improvement of surveying and cartographic methods, instruments, and equipments; and to conduct investigations and research in geophysical sciences (including geodesy, oceanography, seismology, and geomagnetism).

SEC. 5. The Director is authorized to enter into cooperative agreements with, and to receive and expend funds made available by, any State or subdivision thereof, or any public or private organization or individual, for surveys or investigations authorized herein, or for performing related surveying and mapping activities, including special purpose maps, and for the preparation and publication of the reports thereof.

SEC. 6. The Director is authorized to contract with qualified organizations for the performance of any part of the authorized functions of the Coast and Geodetic Survey when he deems such procedure to be in the public interests.

SEC. 7. The Secretary of Commerce is hereby authorized to accept and utilize gifts or bequests of money and other real or personal property for the purpose of aiding or facilitating the work of the Coast and Geodetic Survey and such gifts and bequests and the income therefrom shall be exempt from Federal taxes.

SEC. 8. The President is authorized to cause to be employed such of the public vessels as he deems it expedient to employ, and to give such instructions for regulating their conduct as he deems proper in order to carry out the provisions of this Act.

SEC. 9. There are hereby authorized to be appropriated such funds as may be necessary to acquire, construct, maintain, and operate ships, stations, equipment, and facilities and for such other expenditures, including personal services at the seat of government and elsewhere and including the erection of temporary observatory buildings and lease of sites therefor, as may be necessary for the conduct of the activities herein authorized.

SEC. 10. The following statutes are hereby repealed:

(1) The Act of January 31, 1925 (ch. 121, 43 Stat. 802; 33 U.S.C. 866).

(2) Section 4681 of the Revised Statutes (33 U.S.C. 881).

(3) Section 4682 of the Revised Statutes (33 U.S.C. 882).

(4) Section 4683 of the Revised Statutes (33 U.S.C. 883).

(5) Section 4684 of the Revised Statutes (33 U.S.C. 883).

(6) Section 4686 of the Revised Statutes (33 U.S.C. 885).

Approved August 6, 1947.

Amended by Public Law 86-409, Approved April 6, 1960.

EXECUTIVE OFFICE OF THE PRESIDENT
BUREAU OF THE BUDGET
WASHINGTON, D.C. 20503

May 6, 1967

CIRCULAR NO. A-16
Revised

TO THE HEADS OF EXECUTIVE DEPARTMENTS AND ESTABLISHMENTS

SUBJECT: Coordination of surveying and mapping activities

1. Purpose. This revised Circular describes the responsibilities of Federal agencies with respect to coordination of the Federal surveying and mapping activities described in paragraph 2, below. It rescinds and replaces Circular No. A-16, dated January 16, 1953. Exhibits A, B, C, and D to that Circular will remain in effect until replaced pursuant to paragraph 4 of this Circular.

2. Coverage. The coordinating procedures established by this Circular extend to all surveying and mapping activities financed in whole or in part by Federal funds which:

a. Can contribute to the National Topographic Map Series of the United States and outlying areas of sovereignty and jurisdiction, the National Atlas of the United States of America, the National Networks of Geodetic Control, or such other national geodetic control and topographic mapping programs as may be established; or

b. Result in cartographic representation of international boundaries other than those of the United States with Canada or Mexico.

Surveying and mapping activities conducted or supported by a Federal agency to meet specific program needs of the agency which are not met by the national surveying and mapping programs specified in paragraph 2a above and which cannot practicably or economically contribute to the national programs are excluded from coverage. Determination of the surveying and mapping activities which are required to meet program needs is the responsibility of the program agency. However, evaluation of the potential contribution of those activities to a national surveying or mapping program should be made by such agency in consultation, or pursuant to a general agreement, with the responsible agency as described below.

3. Responsibility for coordination.

a. The Department of the Interior is responsible for the National Topographic Map Series of the United States and outlying areas of sovereignty and jurisdiction and for the National Atlas of the United States of America. It also operates the Map Information Office, which collects

and furnishes to potential users information concerning aerial photography, topographic mapping, and survey data available from Federal agencies for general use, and the sources from which they may be obtained.

In carrying out these functions the Department exercises Government-wide leadership in assuring coordinated planning and execution of its national topographic mapping, National Atlas, and map information activities and the cartographic activities of other Federal agencies related thereto, including activities financed in whole or in part by such agencies, to the end that:

(1) The topographic mapping, National Atlas, and map information needs of Government agencies and the public at large are met in the most expeditious and economical manner possible with available resources;

(2) All mapping activities financed in whole or in part by Federal funds contribute to the national topographic mapping program when it is practicable and economical to do so; and

(3) Aerial photography, topographic mapping, and survey data produced by Federal agencies are conveniently accessible for use in meeting the cartographic needs of other Federal agencies and federally assisted programs.

The Department will also arrange, through periodic meetings or other appropriate means, for an exchange of information among Federal agencies concerning technological developments in civilian agencies with respect to cartographic activities.

b. The Department of Commerce is responsible for the National Networks of Geodetic Control and publishes status maps of geodetic control which meet the standards for inclusion in the national networks.

In carrying out this function the Department exercises Government-wide leadership in assuring coordinated planning and execution of its national geodetic control surveys and the related survey activities of Federal agencies, including activities financed in whole or in part by such agencies, to the end that:

(1) The geodetic control needs of Government agencies and the public at large are met in the most expeditious and economical manner possible with available resources; and

(2) All surveying activities financed in whole or in part by Federal funds contribute to the National Networks of Geodetic Control when it is practicable and economical to do so.

c. The Department of State exercises Government-wide leadership to assure that cartographic representations of international boundaries, other than those of the United States with Canada or Mexico, by all

Federal agencies are consistent and conform to United States foreign policy.

4. Establishment of coordinating mechanisms. Each agency named in paragraph 3 above will, in consultation with other Federal agencies concerned, establish such standards, procedures, interagency agreements, and other mechanisms as are necessary to carry out its Government-wide coordinating responsibilities and to replace, where required, Exhibit A, B, C, or D of this Circular.

5. Responsibilities of other Federal agencies. Each Federal agency is responsible for (a) cooperating as requested in the development of appropriate coordinating mechanisms; (b) supplying necessary information to the coordinating agency concerning its cartographic requirements, programs, activities, and products; and (c) conducting its surveying, mapping, and product distribution activities in a manner which provides effective Government-wide coordination and efficient service to the general public.

6. Differences among agencies. Any major differences which cannot be resolved through consultation among agencies with respect to the coordination of cartographic activities covered by this Circular may be referred by the head of any agency concerned to the Director of the Bureau of the Budget.

PHILLIP S. HUGHES
Acting Director

Economic Analysis of Vertical Geodetic Control Surveys

It is always desirable to compare the benefits of large-scale public projects to the cost over a specific time. One technique which is used by federal agencies is benefit-cost analysis. In August 1972 Commander Phillip C. Johnson published a paper on the benefit-cost analysis of urban horizontal geodetic surveys.[1] We have essentially utilized Commander Johnson's economic analysis techniques and benefit model to determine if the densification of vertical geodetic control is economically justified.

As the first stage in such an analysis, we have concentrated our efforts on the Houston-Galveston area. In 1972 through the continued recommendation of local as well as congressional interests, a study of subsidence through vertical displacement measurements was undertaken in this area. The results of the work were collected and published in 1973.[2]

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1. Johnson, Phillip C., A Measure of the Economic Impact of Urban Horizontal Geodetic Control Surveys. Department of Commerce, August 1972. Hereafter cited as Johnson.

2. National Ocean Survey, Report 1973: Releveling of the Houston-Galveston Area Texas. Department of Commerce, January 1974.

We felt that these results would provide an accurate as well as current reflection of releveling in a densified network. To quote from this report:

> "In low-lying coastal areas, subsidence could be a major deterrent to economic growth. Some of the Houston-Galveston area communities may be vulnerable to flooding caused by very high tides during storms, and continued subsidence could contribute to economic deterioration due to flood plain growth."

If such forces are to be adequately tracked, we feel there must be a standard reference network. Moreover, the examination of over one urban area should provide some indication of the measurable economic benefits involved.

Results

With reference to Johnson's report, we have obtained the following formula:

Benefit/cost

$$\frac{B}{C} = \frac{\sum_{t=1}^{T} \frac{B_a}{(1+i)^t}}{\left[\sum_{t=1}^{T} \frac{0}{(1+i)}\right] + K}$$

Where:

T = time in years

B_a = annual benefits

O = annual maintenance costs

K = capital investment

i = discount factor

Deviation of B_a utilizing Johnson's paper

N = number of bench marks before densification

N' = number of bench marks after densification

a. $1 - \frac{N}{N\ N}$, = $1 - \frac{567}{1150}$ = (.507)

b. Up = the sums of average distances x probability of a tie to network.

P = $\sqrt{3000 \text{ sq.mi.}/567 \text{ bench marks}}$ = 2.39

P' = $\sqrt{3000 \text{ sq.mi.}/1150 \text{ bench marks}}$ = 1.61

Up = .79 + (.3) (.67) = .99

Up' = .39 + (.61) (.40) - .634

Up - Up' = .99 - .634 - (.356)[3]

c. There are an estimated 80 individual leveling[4] ties per year per organization x 205 local/federal/ state organizations x 75% of all leveling tied to the national network = 12,300 leveling ties made annually.

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3. Johnson, Table 3.6, p. 47.

4. Based on estimates, Pliney Gale, Chairman, Houston Branch ASCE, hereafter cited as Gale.

Drawing from Johnson's paper, the miles of leveling saved annually can be computed from:

d. $B_{p,p'} = \left[1 - \frac{N}{N + N'}\right] (U_p - U_{p'}) (C)$ [5]

$= (.507)\ (.356)\ (12{,}300)$

$=$ 2,220 miles saved per year

e. Total savings in dollars of miles saved

$= \frac{(\text{Number of connections})'}{\text{Average length of connection}} \times (\text{cost per crew day})$ [6]

$= \frac{(2{,}220)}{2.5} \times (400)$

$=$ $355,200 saved annually

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5. Johnson, p. 46.

6. Gale

f. Annual Maintenance Cost estimated at $73,600 per year.

g. Capital Investment = $300,000 for densification.

h. Discount factor = 10%

i. Time period for 5 years

Then from the formula for benefit-cost analysis:

$$\frac{B}{C} = \frac{\sum_{t=1}^{5} \frac{\$355,200}{(1 + .10)^t}}{\left[\sum_{t=1}^{5} \frac{73,600}{(1 + .10)^t}\right] + \$300,000}$$

B/C = 2.3

Interpretation:

What this above figure means is that in the 5th year of this project's economic life society would have experienced a return of $2.30 for each $1.00 invested. Therefore, the Houston project was economically justified.