DETERMINATION OF BENCH-MARK ELEVATIONS AT BETHEL ISLAND AND VICINITY, CONTRA COSTA AND SAN JOAQUIN COUNTIES, CALIFORNIA, 1987

By *J.C. Blodgett, M.E. Ikehara,* and *W.F. McCaffrey*

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For readers who prefer to use metric (International System) units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter
foot per year (ft/yr)	0.3048	meter per annum
inch	25.40	millimeter
mile	1.609	kilometer

DEFINITIONS

Sea level: In this report, sea level refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

BRAND NAMES

Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

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ABSTRACT

Elevations of 49 bench marks in the southwestern part of the Sacramento-San Joaquin River Delta were determined during October and November 1987. A total of 58 miles of level lines were run in the vicinity of Bethel Island and the community of Discovery Bay. The datum of these surveys is based on National Geodetic Survey bench mark T934 situated on bedrock 10.5 miles east of Mount Diablo and near Marsh Creek Reservoir. The accuracy of these levels, based on National Geodetic Survey standards, was of first, second, and third order, depending on the various segments surveyed. Several bench marks were noted as possibly being stable, but most show evidence of instability.

INTRODUCTION

Land subsidence is a long-term occurrence in the Sacramento-San Joaquin River Delta area. It affects the longevity and adequacy of the levee system and other flood-protection measures. Subsidence is becoming an issue in the delta as more private-sector developments, such as Bethel Island and Discovery Bay (figs. 1 and 2), are built and public programs to rehabilitate levees and recover delta islands are proposed. The causes of subsidence are uncertain, but may be a combination of surface (peat) decomposition, deflation, subsurface compaction caused by shallow (<500 ft) ground-water withdrawal, and compaction caused by deep (>500 ft) natural-gas extraction.

Studies by Moffatt and Nichol, Engineers (1987) for the San Francisco Bay Conservation and Development Commission of sea-level rise and its implications indicated rates of local land subsidence of about 0.009 ft/yr near Antioch. Moffatt and Nichol also stated that in order to predict future relative sea level around San Francisco Bay adequately, precise vertical-land-motion data are essential.

This study, done in cooperation with the Federal Emergency Management Agency, Region IX, documents the elevation of 16 National Geodetic Survey (NGS) bench marks and 33 supplemental bench marks in the vicinity of Bethel Island and Discovery Bay (fig. 2). These bench marks are referenced to a single bench mark located on bedrock near Marsh Creek Reservoir, as well as to a network of bench marks included in the 1985 and 1986 Global Positioning System (GPS) surveys that encompassed all the delta and the lower part of the Sacramento Valley. Bench marks U481 and R478 (fig. 2) are included in the GPS survey network.

SURVEYING PROCEDURE

Vertical-control surveys to various bench marks in the survey area were of first, second, and third order standards of accuracy as defined by the National Geodetic Survey (National Oceanic and Atmospheric Administration, Federal Geodetic Control Committee, 1980). Segments A and B (fig. 2) are first order; segments C, D, E, and F are second order; and segments G and H are third order. Equipment used in the surveys included the Zeiss Ni1 and Ni2 automatic compensating levels, maintained in adjustment, and invar rods or rods of the precise series. Foresight and backsight distances were carefully balanced to reduce collimation error.

A total of 58 miles, which included segments A-H (fig. 2), were surveyed. All level lines were looped. Segments D and F were each more than 14 miles long. The various segments were then adjusted for differences in closure.

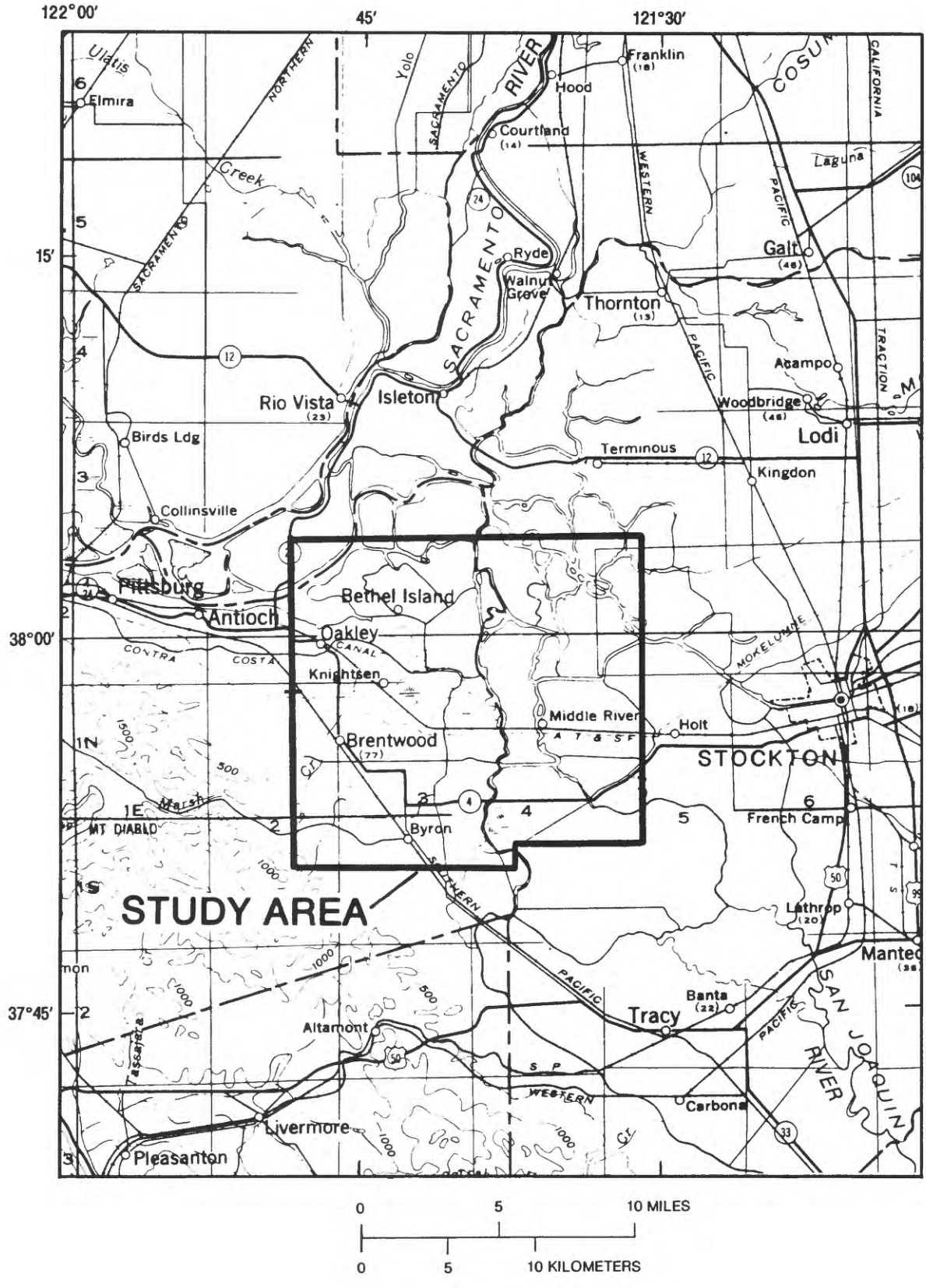
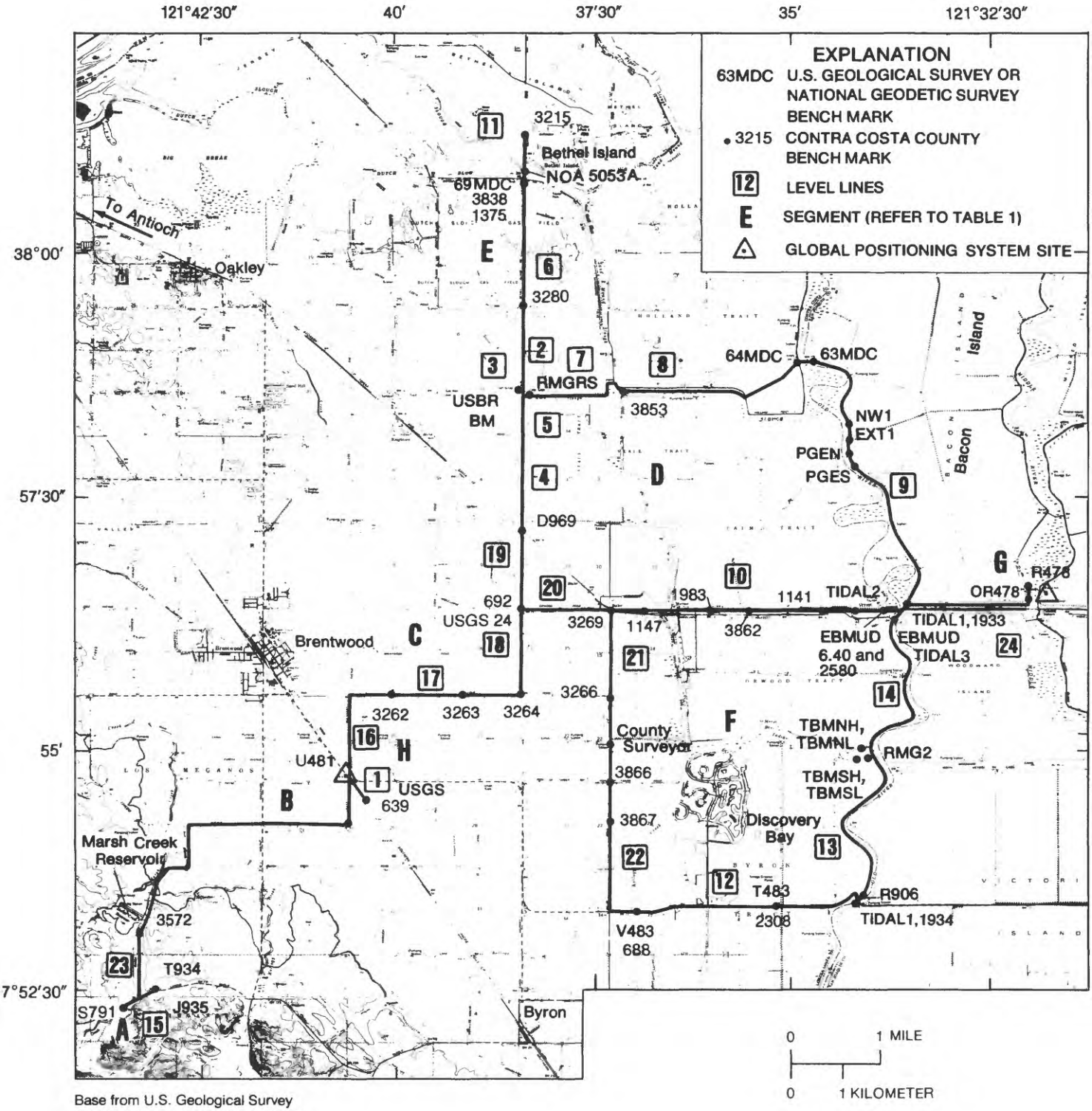


FIGURE 1. – Sacramento-San Joaquin River Delta and study area.



Base from U.S. Geological Survey
Bouldin Island, Jersey Island, 1952;
Byron Hot Spring, 1953; Brentwood,
1954; Woodward Island, 1978; California,
1:24,000

FIGURE 2.– Survey area in detail.

The segments were surveyed during October and November 1987, except segment G, which was surveyed in October 1986. Field conditions, such as temperature and wind, were ideal during this period and tended to reduce the magnitude of error caused by refraction and by expansion and contraction of survey rods. The survey included eight water crossings ranging from 215 to 758 ft in width.

The accuracy of the U.S. Geological Survey 1987 leveling surveys is based on closure differences for the various level lines. Closure differences ranged from 0.000 to 0.042 ft and had an absolute average of 0.018 ft. A summary of the leveling closures for the segments (fig. 2) is given in table 1.

DESCRIPTION OF BENCH MARKS

Bench marks used in these surveys were established previously by the National Geodetic Survey, U.S. Geological Survey, California Department of Water Resources, Contra Costa County, and East Bay Municipal Utility District. Descriptions and elevations of most of these bench marks are given in vertical-control-data summaries prepared by the National Geodetic Survey or Contra Costa County. The designation and approximate location of the bench marks leveled

TABLE 1.--*Accuracy of U.S. Geological Survey 1987 leveling surveys*

[National Geodetic Survey standards]

Segment	Level line	Segment length (mile)	Closure (foot)	Standard of accuracy[1]
A	15	1.19	+0.000	First order
B	23	9.64	+0.021	First order
C	16,17,18,19	9.74	-0.007	Second order
D	4,5,7,8,9, 10,20,19	14.33	-0.021	Second order
E	3,2,6,11	5.94	+0.020	Second order
F	19,20,21,22, 12,13,14,10	15.89	+0.042	Second order
G[2]	24	---	---	Third order
H	1	1.20	-0.001	Third order

[1]Accuracy of U.S. Geological Survey 1987 leveling is based on Survey procedure and closure error.

[2]Segment leveled in 1986. Closure of +0.10 is from 8.3-mile loop that included line 24.

to in these surveys are shown in figure 2. During the field surveys, bench marks U483 (NGS line 110), Q484 (NGS line 108), and T465 (NGS line 108) were found destroyed.

Four new bench marks were established in 1986 and 1987. A description of these bench marks is given in table 2.

BENCH-MARK ELEVATIONS

Elevations of the various bench marks leveled to during the surveys are given in table 3. The approximate location of these bench marks is shown in figure 2. Elevations in table 3 are based on surveys by the National Geodetic Survey, Contra Costa County, and U.S. Geological Survey. All elevations for the U.S. Geological Survey 1987 leveling surveys are based on the elevation of bench mark T934, which is located east of Marsh Creek Reservoir (fig. 2).

TABLE 2.--*Description of new bench marks established in the survey area*

OR478	(GPS[1] site) Southeast end of Bacon Island. Brass cap on top of 6-inch-diameter concrete cylinder, located on streamward side of the levee about 300 ft south of bench mark R478, and about 100 ft south of tide gage. Established July 1986. This bench mark is an offset from bench mark R478 and used in the GPS surveys. Established August 1986.
NW1	West side of Bacon Island near Rock Slough. Brass cap on top of northwest corner of concrete foundation slab for extensometer-gage shelter. Shelter is an 8- × 12-ft steel building, located near center of farm building complex, 20 ft east of drainage ditch and 400 ft east of Old River. Established March 1987.
EXT1	West side of Bacon Island at same site as bench mark NW1. Inside shelter, at top of shoulder of 2-inch-diameter steel pipe, about 1.5 ft above concrete extensometer-gage-shelter slab. The 2-inch-diameter steel pipe is inside a 6-inch-diameter pipe casing, and embedded in concrete 440 ft below land surface. Established March 1987.
PGEN	(Future GPS[1] site) at west side of Bacon Island near Rock Slough and 400 ft south of farm building complex and bench mark NW1. Top of 1/2-inch-diameter steel pin at ground level, encased in concrete inside 4-inch-diameter steel pipe, on east side of levee and on north side of Pacific Gas and Electric Co. (PG&E) gas line crossing of Old River. PGES, constructed similarly to PGEN, is located 100 ft south of PGEN. Bench marks constructed by PG&E prior to October 1986.

[1]Global Positioning System.

TABLE 3.--*Bench-mark elevations based on surveys by the National Geodetic Survey, Contra Costa County, and the U.S. Geological Survey*

[CCC, Contra Costa County; NGS, National Geodetic Survey; USGS, U.S. Geological Survey]

Bench mark	Date of adjustment	Elevation, in feet, above or below (-) sea level		
		NGS	CCC	USGS 1987 surveys
T934	1959	221.355	---	221.355
J935[1]	1975	193.684	---	193.475
S791	1975	195.974	---	195.877
CCC 3572	1964	---	206.197	206.252
U481	1975	62.976	---	63.028
USGS 639	1975	62.254	---	62.314
CCC 3262		---	55.384	55.409
CCC 3263		---	42.758	43.314
CCC 3264	1964	---	29.339	29.373
D969	1975	18.110	---	18.067
RMGRS		---	---	8.939
USBR BM (Contra Costa Canal intake).		---	---	11.14
CCC 3280	1964	---	-1.016	-1.193
USGS 69MDC, CCC 3838	1974	10.145	10.305	10.085
CCC 1375		---	10.269	10.050
NOA 5053A (Reset 1979)		---	---	9.528
CCC 3215		---	-4.621	-4.822
CCC 3853		---	9.903	9.710
USGS 64MDC	1974	[2]2.184	---	2.222
USGS 63MDC	1974	[2]9.165	---	9.188
NW1		---	---	-7.141
EXT1		---	---	-5.481
PGEN		---	---	9.572
PGES		---	---	8.533
USGS 24, CCC 692 (EBMUD23.656 1964).	1967	23.730	23.694	23.685

See footnotes at end of table.

TABLE 3.--*Bench-mark elevations based on surveys by the National Geodetic Survey, Contra Costa County, and the U.S. Geological Survey*--Continued

Bench mark	Date of adjustment	Elevation, in feet, above or below (-) sea level		
		NGS	CCC	USGS 1987 surveys
CCC 3269----------	1964	---	16.178	16.128
CCC 1147----------	1964	---	11.119	11.142
CCC 1983----------		---	606.900	-3.934
CCC 3862----------		---	-4.154	-4.191
CCC 2580, EBMUD 6.40---		---	6.427	6.414
CCC 1141----------	1964	---	7.556	6.954
TIDAL1, 1933----------	1967	12.513	---	12.592
TIDAL2----------	1967	14.587	---	14.005
CCC 3266----------	1964	---	10.687	10.688
County Surveyor--------		---	---	8.544
CCC 3866----------		---	15.170	15.116
CCC 3867----------		---	9.874	9.806
V483, CCC 688----------	1975	11.644	11.736	11.614
T483, CCC 2308---------	1975	-7.838	-7.864	-7.888
RMG2----------		---	---	11.014
TBMSH----------		---	---	7.938
TBMSL----------				7.115
TBMNH----------		---	---	8.293
TBMNL----------		---	---	5.652
EBMUD, TIDAL3----------		---	---	16.536
R478----------	1975	4.603	---	4.51
OR478 (GPS site)-------		---	---	8.91
TIDAL1, 1934----------	1975	17.513	---	17.478
R906----------	1975	0.118	---	.103

[1]Bench mark found disturbed.
[2]Elevation determined by USGS.

Bench mark T934 is on a sandstone outcrop of the Moreno Formation (Pampeyan, 1964; Brabb and others, 1971), which is located on stable terrain along the east flank of the Coast Ranges. Analysis of the surficial deposits and hill slopes in the vicinity of the bench mark shows the sandstone outcrop to be stable ground, and not subjected to active fault displacement or recent mass movement (Nilsen, 1972; Nilsen and Turner, 1975; Hart and others, 1981).

Studies of Cenozoic uplift in the Sierra Nevada (Huber, 1981) and folding of the southern Coast Ranges (Page, 1981) indicate that average uplift rates for the two regions are in the order of 0.0008 ft/yr. This rate is much less than the rate of 0.005 ft/yr suggested for bench mark T934 on the basis of level adjustments made between 1959 and 1975 (table 4). As such, the adjustment of bench mark T934 probably is due to variations in balancing level networks for this area rather than tectonic movement of the bench mark.

It was assumed that a bench mark located on bedrock, such as T934, would be the most stable and, therefore, the best point of reference to use when documenting land subsidence. The 1959 adjustment elevation of bench mark T934 was used as the reference in establishing other bench-mark elevations in the vicinity of Bethel Island and Discovery Bay during the 1987 surveys. Other bench marks besides T934 that may be stable because they are situated on piling or deep foundations include bench marks 64MDC, 63MDC, R478, CCC 1375, EXT1, 69MDC (CCC 3838), and TIDAL1, 1933 (table 3).

TABLE 4.--*History of selected National Geodetic Survey bench-mark elevation adjustments*

[EBMUD, East Bay Municipal Utility District; NGS, National Geodetic Survey; USGS, U.S. Geological Survey]

Bench mark	NGS line number	Date of adjustment and elevation, in feet, above or below (-) sea level								
		1935	1939	1951	1957	1959	1960	1962	1975	1987[1]
T934	105					221.355	221.355		221.440	221.355
J935	105					193.586	193.586		193.684	193.475
S791	105					195.882	195.882		195.974	195.877
U481	106			63.094	63.054	63.054		63.031	62.976	63.028
USGS 639	106	62.690	62.582	62.401	62.333	62.333		62.313	62.254	62.314
D969	108								18.110	18.067
EBMUD 23.656	109					23.845			23.730	23.685
EBMUD 6.40	108					6.591			6.427	6.414
TIDAL1, 1933	102					12.615	12.615	12.530	12.513	12.592
TIDAL2	102					14.970	14.970	14.797	14.587	14.005
EBMUD, TIDAL3	102					16.716	16.716	16.611	16.578	16.536
R478	102					4.777	4.777	4.672	4.603	4.51
V483	110					11.736			11.644	11.614
T483	110					-7.723			-7.838	-7.888
R906	113					.279	.279	.157	.118	.103

[1]Elevations determined during U.S. Geological Survey leveling surveys, 1987.

HISTORY OF SELECTED BENCH-MARK ELEVATION ADJUSTMENTS

There is concern that the published adjustments to bench-mark elevations as given by National Geodetic Survey may reflect the combined effects of unstable bench marks in the network plus leveling errors that occurred during the surveys. It is difficult, therefore, to evaluate the magnitude and rates of land subsidence in an area on the basis of changes in bench-mark elevations without determining which elevation in a series of lines and adjustments has been used for reference. A listing of published adjustments to the elevation of selected bench marks is given in table 4.

Estimates of land subsidence usually are based on a comparison of historic bench-mark elevations. The magnitude of the alleged change in elevation of bench mark T934, 0.085 ft, suggests that some of the elevation adjustments at other sites given in table 4 are also not related to land subsidence. Much of the variance (on the order of 0.1 ft or more), as indicated by elevation changes of bench mark USGS 639 between 1935 and 1987 (table 4), is related to leveling adjustment procedures instead of land subsidence.

GUIDELINES FOR APPLICATION OF SURVEY DATA

The following guidelines are included to assist users of elevation data assembled in this report as well as elevation data for other bench marks in the study area:

1. Bench marks of relative stability can be identified by comparing historic bench-mark elevation adjustments (table 4).

2. Bench marks located on structures that are supported by piling or deep footings, such as the extensometer well on Bacon Island (bench mark EXT1), probably are stable. Other bench marks in the level network with extensive footing support include 64MDC, 63MDC, R478, and TIDAL1, 1933 (at Atchison, Topeka, and Santa Fe Railway bridge).

3. The apparent inconsistency in elevation shown in table 3 for bench marks TIDAL1, 1933 and TIDAL2 is related to bench-mark construction. Bench mark TIDAL2 is located on a concrete pad situated on railroad fill that has been placed on top of peat. Levels run in 1986 and 1987 show that this bench mark is subsiding. Bench mark TIDAL1, 1933 is situated on a pier footing on the railroad bridge, which is supported by piling. This bench mark is considered relatively stable even though the elevation shows an apparent increase. This increase is related to various adjustments to different level lines in the area and would be even greater if the 1975 adjusted elevation of 221.440 ft had been used instead of 221.355 ft for bench mark T934.

4. Until additional data are available, surveys referenced to National Geodetic Survey bench marks in the study area may assume that the published adjusted elevations reflect changes caused by both land subsidence and adjustment procedures. As such, elevations to a new site based on a bench mark with adjusted elevations could be in error by as much as 0.6 ft, but will probably average about 0.1 ft.

5. Because elevations for bench marks that are published by National Geodetic Survey reflect changes caused by both land subsidence and adjustment procedures, estimates of current or potential land subsidence using these data may not be accurate.

6. U.S. Geological Survey 1987 elevations given in table 3 are suggested for use; current elevations can be determined periodically by follow-up surveys.

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