Extensometer, Water-Level, and Lithologic Data from Bacon and Bethel Islands in Sacramento–San Joaquin Delta, California, September 1987 to August 1993

By Barry D. Kerr *and* David A. Leighton

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CONVERSION FACTORS AND VERTICAL DATUM

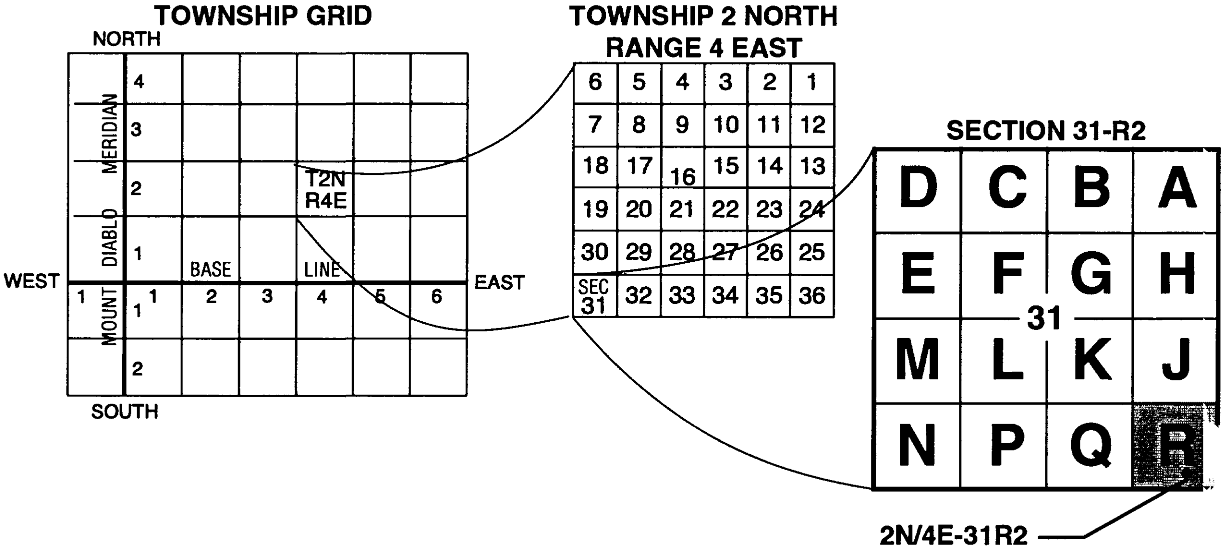
Multiply	By	To obtain
acre	0.4047	square hectometer
cubic yard	.7646	cubic meter
foot (ft)	.3048	meter
foot per year (ft/yr)	.3048	meter per year
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer

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 mean sea level of 1929.

WELL-NUMBERING SYSTEM

The well-numbering system used by the U.S. Geological Survey (USGS) and the State of California designates the location of wells according to the rectangular system for the subdivision of public lands (Bader, 1969). Well identification consists of a township number, north or south; the range number, east or west; and the section number. Each section is further divided into sixteen 40-acre tracts lettered consecutively (except I and O), beginning with A in the northeast corner of the section and progressing in a sinusoidal manner to R in the southeast corner. Within each 40-acre tract, wells are sequentially numbered in the order they are inventoried. The final letter in a well identification number refers to the base line and meridian. Wells in this study area are referenced to the Mount Diablo base line and meridian (M). The diagram below illustrates how the number 2N/4E-31R2 is derived.

The station identification number used by the USGS for wells is principally for correlation and retrieval of computerized data and is not considered a State location number. The Bacon Island extensometer number is 375811121341201 (latitude 37°58'11", longitude 121°34'12", sequence 01), and the water-level well number is 375811121341202. The Bethel Island extensometer number is 380208121372901, and the water-level well number is 380207121372902.



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ABSTRACT

Compaction, water-level, and lithologic data were collected at extensometer sites on Bacon and Bethel Islands, anchored at 436 and 536 feet below land surface, respectively. The data reported here are part of a study of the processes causing subsidence in the Sacramento–San Joaquin Delta. The depths were selected to ensure that they were well below the peat layer and the primary aquifer, which minimized the effects of peat loss and shallow ground-water withdrawal. Compaction and depth to ground water were measured monthly at Bacon Island from September 1987 through August 1993 and at Bethel Island from August 1988 through August 1993. After automatic digital data loggers were installed at Bacon Island in December 1988 and at Bethel Island in September 1989, hourly readings also were made. Calculated rates of compaction were 0.0015 and 0.0016 feet per year at Bacon and Bethel Islands, respectively. Cumulative compaction at the Bacon Island site from September 1987 to August 1993 was about 0.009 feet. Cumulative compaction at the Bethel Island site from August 1988 to August 1993 was about 0.008 feet.

INTRODUCTION

The Sacramento–San Joaquin Delta is located at the confluence of the Sacramento and San Joaquin Rivers, at the eastern end of the San Francisco–Suisun Bay, California (fig. 1). Some of the islands in the central delta are now more than 15 ft below sea level as a result of land subsidence. Prokopovitch (1985) reported subsidence rates in the delta between 0.092 to 0.384 ft/yr. Continued regional subsidence could sufficiently alter the gradients of channels and aqueducts so that transport of fresh water through the delta is adversely affected. Subsidence also can damage storm drains, sanitary sewers, roads, bridges, and railroads and cause well casings to fail due to compressive forces (Bertoldi, 1992).

Subsidence in the delta is caused primarily by oxidation of drained peat soils (Rojstaczer and Deverel, 1993). However, permanent compaction due to ground-water withdrawal also is a concern in the delta. This report presents compaction, water-level, and lithologic data collected at two extensometers. These data will help determine the effects of ground-water withdrawal on subsidence and serve as a reference to which other studies of subsidence in the organic peat layer can be compared.

These data are a result of ongoing studies of processes affecting subsidence in the delta. The studies are being done in cooperation with the California Department of Water Resources.

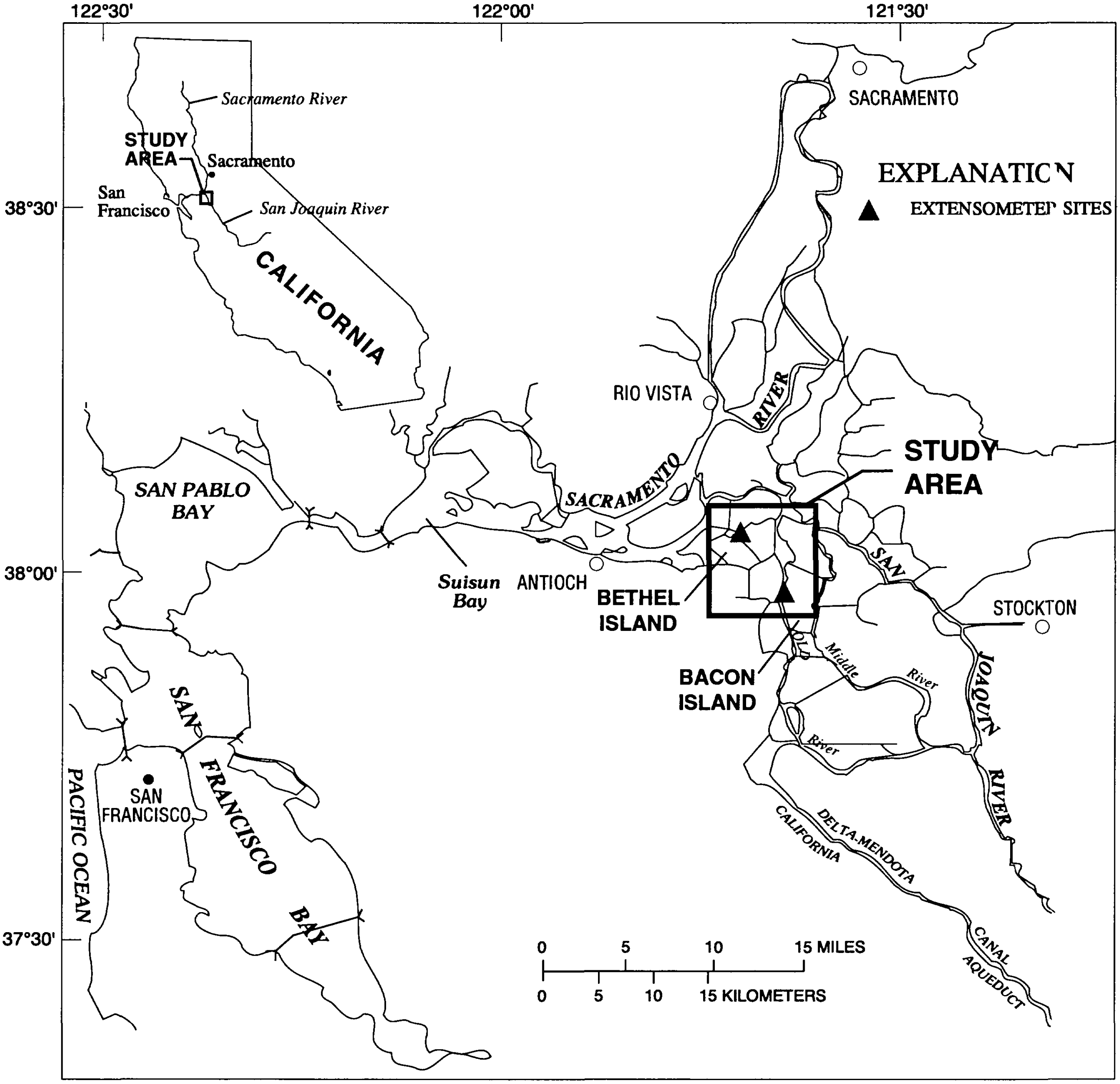

Figure 1. Location of extensometer sites in the Sacramento–San Joaquin Delta, California.

EXTENSOMETER AND WELL DESIGN AND INSTALLATION

Extensometers, which measure compaction, were installed on Bacon Island in November 1986 and on Bethel Island in February 1988, anchored at 436 and 536 ft below land surface, respectively. The depths were selected to ensure that the anchors were well below the peat layer and the primary aquifer in order to minimize the effects of peat loss and shallow ground-water withdrawals on measurements. The construction design is shown in figure 2, and was modified from Hanson (1989) and Riley (1986). The steel instrument table is attached to steel pipes that are anchored in concrete at a depth of about 40 ft below land surface, well below the peat layer. Both extensometers are 2-in. steel pipes that rest on concrete plugs and are centered inside protective 6-in. steel casing. Counterweights are suspended from the fulcrum arm (fig. 2) to relieve most of the weight of the 2-in. pipe. Ground-water monitoring wells were installed on Bacon and Bethel Islands at the same time as the extensometers.

At the Bacon Island extensometer site, a 6-in. pilot hole was drilled to a depth of 445 ft below land surface, and the drill cuttings were used to construct the lithologic log in table 1. The upper 36 ft of the pilot hole was reamed to 22 in. to accommodate a 14-in. steel conductor casing, which was set in concrete (fig. 3). The conductor casing serves as a hanger, from which the protective 6-in. casing is suspended. The pilot hole from 36 ft to the bottom (445 ft) was reamed to 12-1/4-in. diameter to accept the 6-in. casing. A 10-ft louvered screen (0.040-in. slots), which serves as a piezometer at the site, is located between 152 and 162 ft of the 6-in. casing. A concrete basket was attached to the casing 5 ft below the screen. An 18-ft slip joint was installed between 362 and 380 ft. The bottom 18 ft of the borehole was uncased. The 2-in., schedule 80, steel extensometer pipe was centered inside the 6-in. casing and rests on a 9-ft-thick concrete plug, formed by pumping concrete down the 2-in. pipe.

The annulus was allowed to self-fill and seal because: (1) getting the bentonite clay pellets below the runny sand layers would be difficult, (2) the expansive clay layers above and below the screened interval would naturally close in around the 6-in. casing and isolate it, (3) the coarse sand of the formation at the screened interval would serve as a natural gravel pack, and (4) the concrete basket prevented sand from the borehole walls from falling farther down (fig. 3).

At the Bethel Island extensometer site, a 9-7/8-in. borehole was drilled to 39 ft below land surface, then it was reamed to 15-1/2 in. to accept 39 ft of 12-in. steel conductor casing (fig. 4). The conductor casing was cemented in place to act as a support for the 6-in. casing. The 9-7/8-in. borehole was continued to 545 ft, and 535 ft of 6-in. steel casing was suspended from the conductor casing. An 18-ft slip joint was installed between 477 and 495 ft. The 2-in., schedule 80, steel extensometer pipe was lowered inside the 6-in. casing to 539 ft, and concrete was pumped down the 2-in. pipe to form the plug at the bottom of the borehole. The entire annulus at this site was allowed to self-fill and seal because no water-level monitoring well was developed in this borehole.

The water-level monitoring well, called a piezometer, on Bacon Island—as previously mentioned— is the 6-in. steel casing with a 10-ft screened interval. Water-level monitoring wells on Bethel Island (fig. 4) were constructed in a separate borehole about 10 ft south of the extensometer. A 9-7/8-in. borehole was drilled to 79 ft below land surface, then reamed to 15-1/2 in. in diameter. Seventy-nine ft of 12-in. steel casing was cemented in place. The 9-7/8-in. borehole was continued to a depth of 455 ft. Two 2-in. steel casings were installed in this hole. The deeper well has a 5-ft screened interval (0.010-in. slots) from 441 to 446 ft and a 4-in.-long capped blank at the bottom. Sand and gravel from the borehole wall caved in around the screen. Well development showed that the caved-in sand and gravel functioned adequately as a sand-gravel pack for the water-level monitoring well. Bentonite grout was pumped into the annulus from 320 to 380 ft to isolate the well from the upper part of the borehole. The shallower well was screened from 280 to 285 ft (0.010-in. slots), and had a 20-ft-long capped blank at the bottom and a gravel pack from 200 to 320 ft. Bentonite grout was pumped into the annulus from a depth of 200 ft up to the bottom of the 12-in. steel casing.

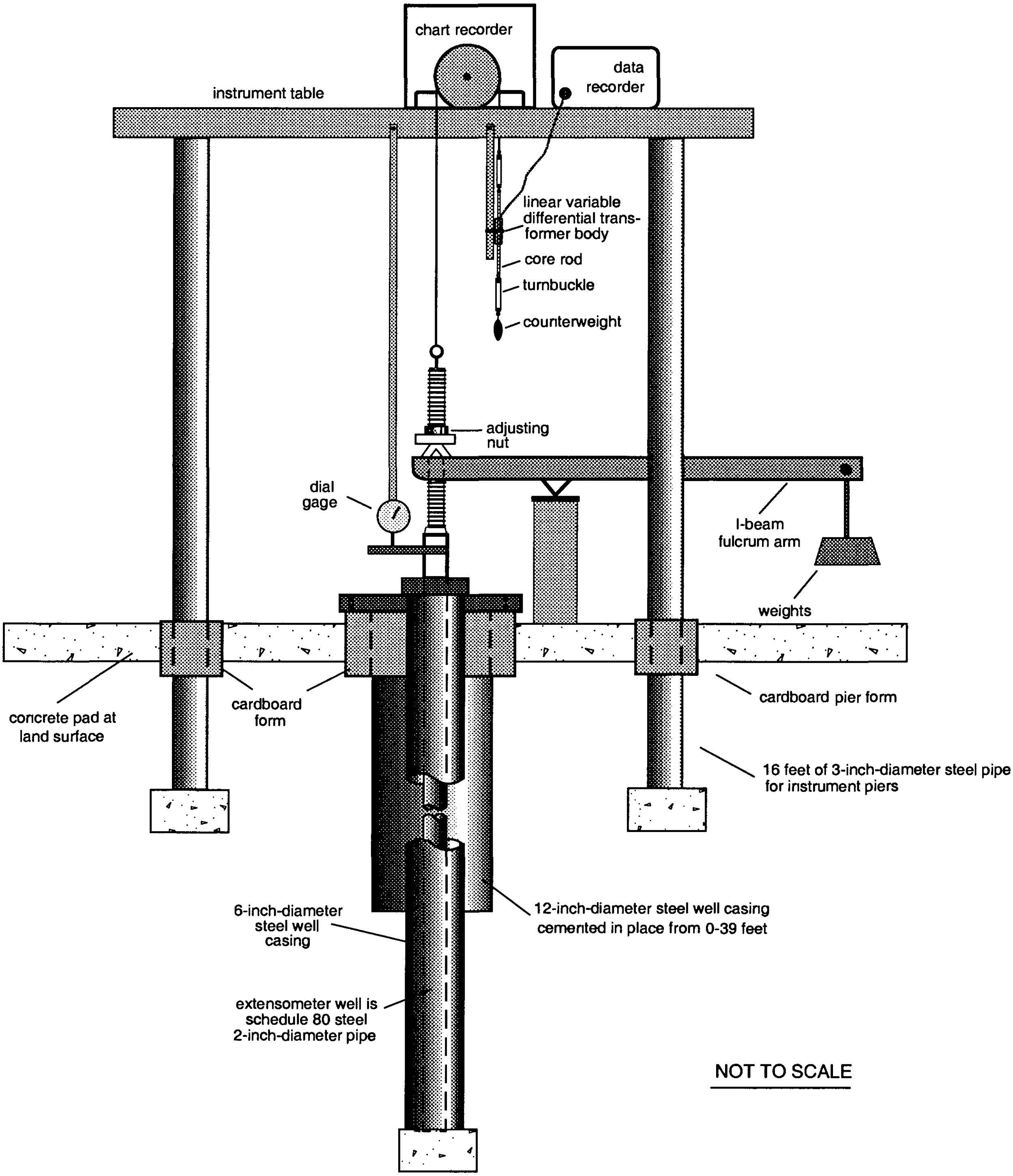

Figure 2. Diagram of typical vertical extensometer.

BACON ISLAND

DEEP HOLE (Borehole total depth = 445 feet)

(NOT TO SCALE)

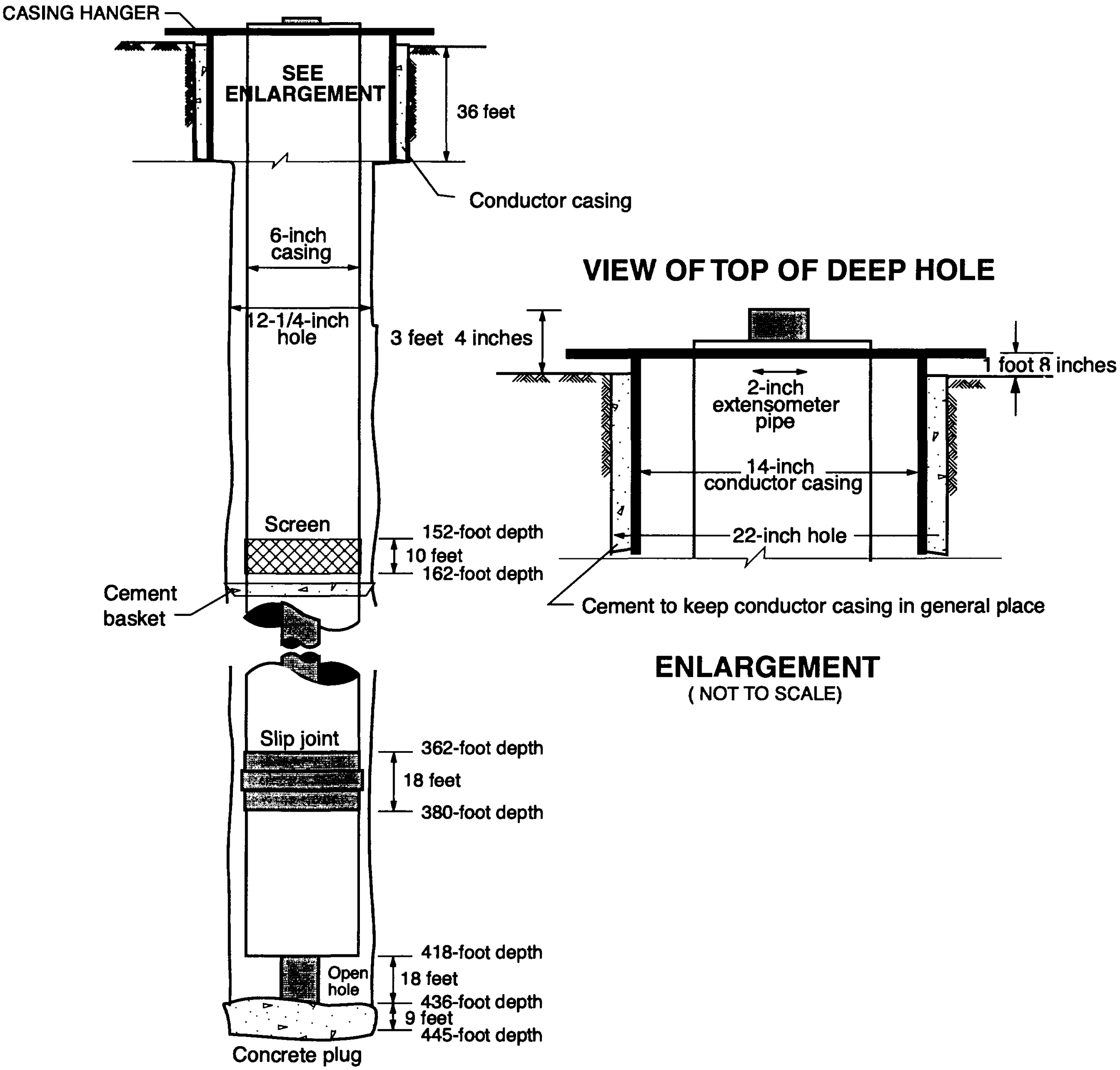

Figure 3. Bacon Island extensometer and piezometer construction.

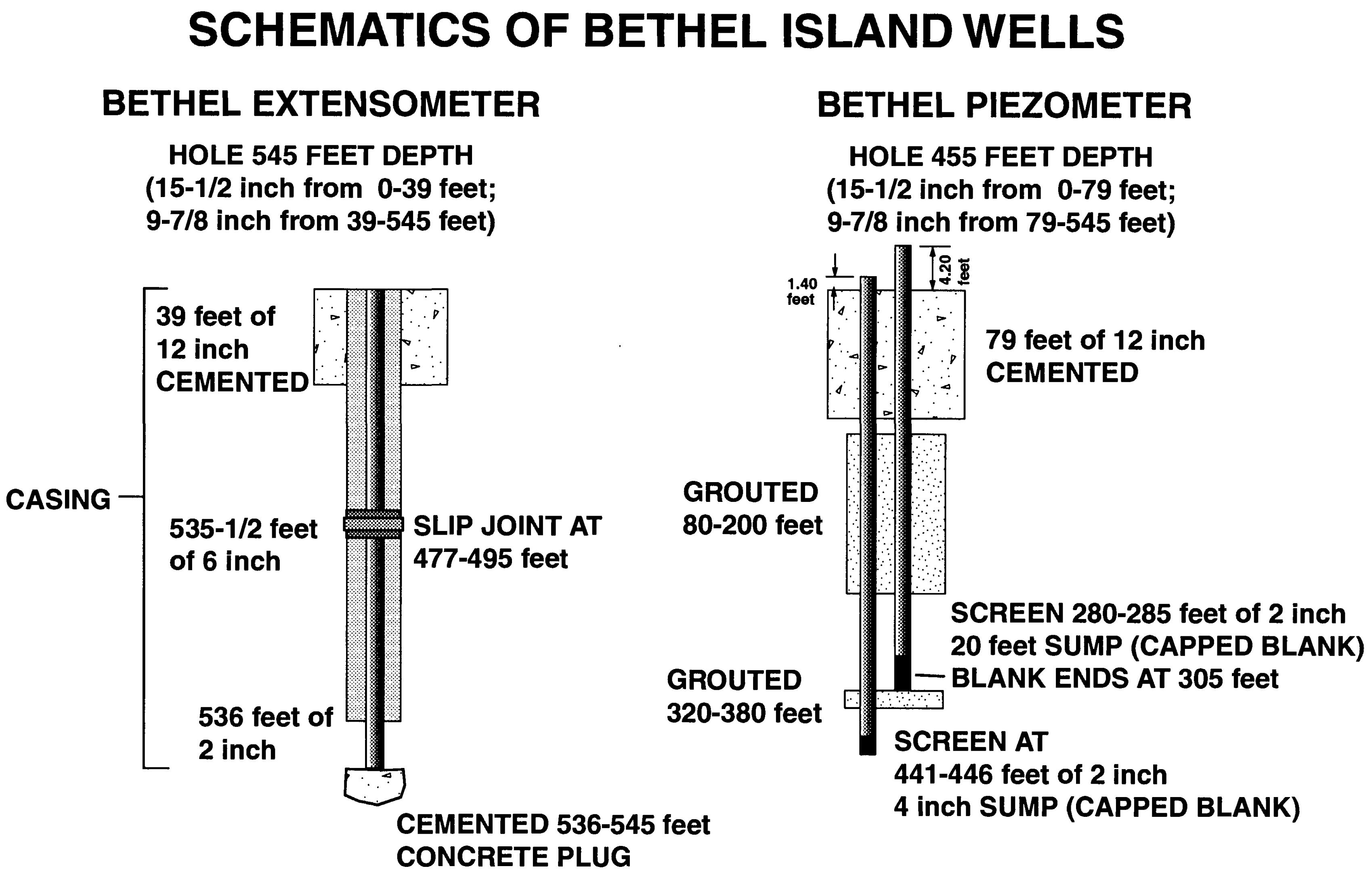

Figure 4. Bethel Island extensometer and piezometer construction.

DATA MEASUREMENT AND COLLECTION METHODS

Initially, compaction was measured using Leopold and Stevens type-F analog drum recorders, and water levels, as depth below land surface, were measured monthly with a steel tape in accordance with standard U.S. Geological Survey (USGS) field procedures (U.S. Geological Survey, 1977). Then, digital data loggers, linear variable differential transformers (LVDT's), and Druck vented submersible pressure transducers were installed at Bacon Island on December 15, 1988, and at Bethel Island on September 15, 1989, after which hourly compaction and water-level measurements were recorded using digital data loggers. Compaction was measured relative to an arbitrary datum and data are not referenced to the National Geodetic Vertical Datum of 1929.

Both extensometers were fitted with micrometer dial gages that were read and recorded monthly. Regression analysis of the dial gage versus LVDT values resulted in a coefficient of determination of 96 percent for Bethel Island, even though the gage started to corrode and became temporarily inoperable. The coefficient of determination was more than 98 percent for Bacon Island.

Data from the digital data logger were retrieved from the sites on a monthly schedule and uploaded to the USGS's Automated Data Processing System (ADAPS), located in Sacramento, California. Linear interpolation of corrections of digital data for transducer drift were computed using steel tape water-level measurements. Compaction chart recordings are not currently being processed, but are kept as backup data.

EXTENSOMETER, WATER-LEVEL, AND LITHOLOGIC DATA

Mean daily compaction and monthly manual water levels (depth to water) for Bacon and Bethel Islands are shown in figures 5 and 6. Compaction from autumn 1987 (the annual low) to spring 1993 (the annual high) was about 0.0060 and 0.0050 ft at Bacon and Bethel Islands, respectively. Although the extensometer records show seasonal rebound, cumulative compaction was 0.009 ft at the Bacon Island site from September 1987 to August 1993 and 0.008 ft at the Bethel Island site from August 1988 to August 1993. For these periods, the rates of compaction (where ground-water levels were about equal) were 0.0015 and 0.0016 ft/yr at Bacon and Bethel Islands, respectively.

At Bacon and Bethel Islands, the depth from land surface to ground water was less than 6.0 ft. The well on Bethel Island experienced flowing conditions during part of the winters of 1989, 1990, 1992, and 1993. The annual maximum depths to ground water occurred during the dry spring months (February to April), when pumping was greatest, and the annual minimum depth to water occurred during the wet autumn months (October to December).

The lithologic logs of the boreholes are shown in table 1. Included in the table is site construction information and land-surface datum.

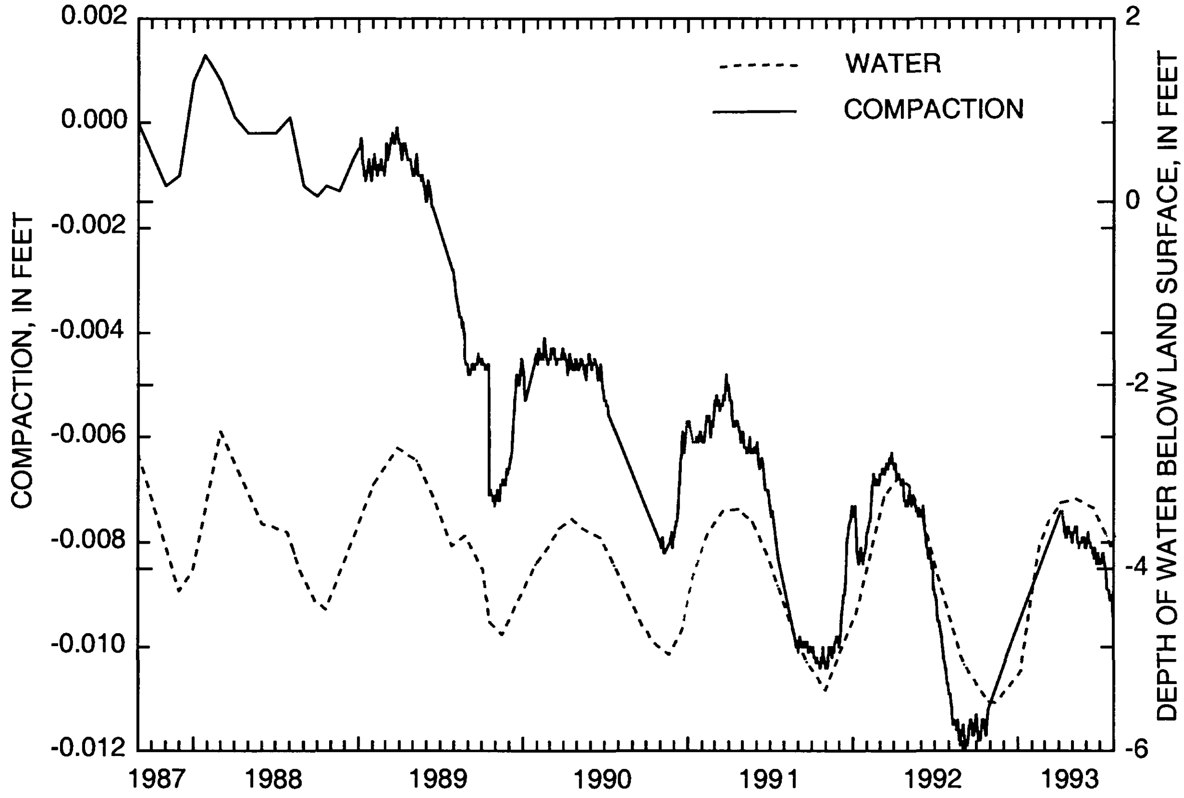

Figure 5. Extensometer record of compaction and depth to water from September 1987 to August 1993 for the Bacon Island site.

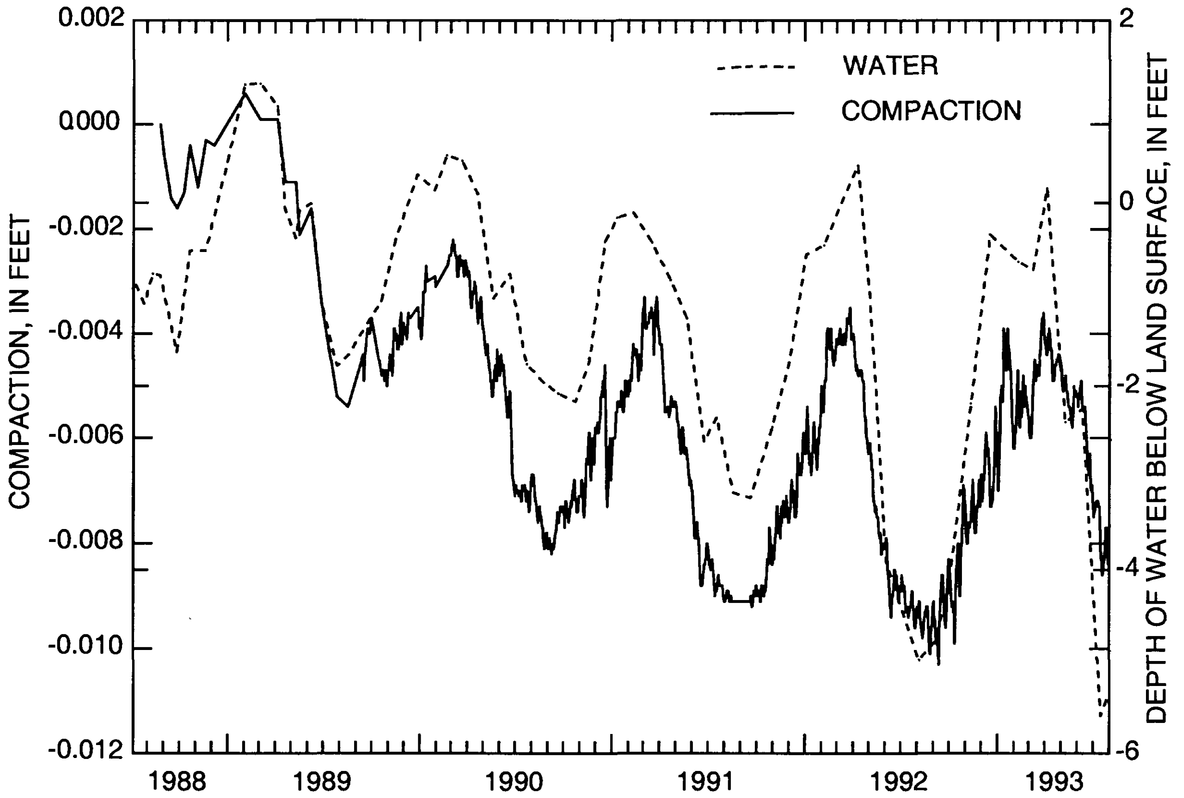

Figure 6. Extensometer record of compaction and depth to water from August 1988 to August 1993 for the Bethel Island site.

Table 1. Lithologic logs of boreholes

[Depth in feet below sea level. NGVD, National Geodetic Vertical Datum; ft, foot; in., inch]

Bacon Island, monitoring wells 2N/4E-31R002 and 2N/4E-31R003

Because of the close proximity, the deepest borehole was used to compile the following log.
Extensometer well 2N/4E-31R002: Altitude of land surface, –7.5 ft (NGVD of 1929). Drilled by a U.S. Geological Survey hydraulic rotary rig, November 22, 1986. Well casing 2-in. diameter steel. Total depth 436 ft. Total borehole depth 445 ft.

Piezometer well 2N/4E-31R003: Altitude of land surface, –7.5 ft (NGVD of 1929). Drilled by a U.S. Geological Survey hydraulic rotary rig, November 22, 1986. Well casing 6-in. diameter steel. Total depth 418 ft. Screened interval 152 to 162 ft. Depth was measured on September 15, 1992, to be 114.23 ft below land surface.

Depth		Description
From	To	
0	5	Peat, dark brown to black; 90 to 100 percent organic content, 0 to 10 percent mineral material
5	7	Peat, brown; 80 to 90 percent organic, 10 to 20 percent mineral material
7	9	Peat, dusky yellow brown; 80 to 90 percent organic, 10 to 20 percent mineral material
9	12.5	Peat, brownish black; 70 to 80 percent organic, 20 to 30 percent mineral material
12.5	14	Clay, medium dark gray; 80 percent mineral material, 20 percent organic
14	27	Clay, medium gray; fine sand; 95 percent mineral material, 5 percent organic
27	60	Clay, medium bluish gray; fine to medium sand
60	70	Clay, dark yellowish brown; fine sand
70	75	Clay, medium bluish gray; medium sand
75	78	Sand, medium to coarse, rounded quartz grains
78	80	Clay, medium bluish gray; trace of sand
80	110	Clay, greenish gray to medium bluish gray
110	118	Clay, medium bluish gray; fine sand
118	120	Sand, medium; some mica flakes
120	130	Clay, medium dark gray to dark greenish gray
130	142	Clay, dark greenish gray; fine to medium sand; mica flakes
142	160	Sand, medium to coarse; some clay, medium yellowish brown
160	200	Sand, medium to coarse; trace of clay, olive gray
200	250	Clay, olive gray to dark greenish gray; fine to medium sand; trace of silt
250	260	Sand, coarse; trace of clay, moderate yellowish brown
260	270	No sample
270	280	Clay, olive gray; medium sand
280	290	Clay, dark greenish gray to medium bluish gray; medium to coarse sand
290	310	Sand, coarse; some clay, greenish black to dark greenish gray
310	320	Sand, dusky brown
320	330	Clay, dark gray with streaks of olive gray; fine sand and silt
330	340	Sand, medium to coarse; some clay, dusky brown to medium dark gray
340	350	Sand, fine to medium; some silty clay, medium dark gray
350	360	Clay, moderate yellowish brown; medium to coarse sand
360	370	Clay, dark greenish gray to medium gray; trace very fine sand

Table 1. Lithologic logs of boreholes—Continued

Bacon Island, monitoring wells 2N/4E-31R002 and 2N/4E-31R003—Continued

Depth		Description
From	To	
370	380	Clay, brownish gray; medium sand
380	400	Clay, dark yellowish orange to dark greenish gray to medium dark gray; trace cobbles
400	410	Sand, coarse; some clay, dusky yellowish brown
410	420	Clay, medium dark gray; some coarse sand
420	428	Clay
428	433	Clay; some sand
433	435.5	Clay
435.5	438	Clay; some sand
438	445	Sand

Bethel Island, monitoring wells 2N/3E-10H001 and 2N/3E-10H005

Because of the close proximity, the deepest test hole was used to compile the following log.
Extensometer well 2N/3E-10H001: Altitude of land surface, −10.1 ft (NGVD of 1929). Drilled by a U.S. Geological Survey hydraulic rotary rig, February 21, 1988. Well casing 2-in. diameter steel. Total depth 539 ft. Total borehole depth 545 ft.

Piezometer well 2N/3E-10H005: Altitude of land surface, −10.1 ft (NGVD of 1929). Drilled by a U.S. Geological Survey hydraulic rotary rig, February 25, 1988. Well casing 6-in. diameter steel. Screened interval 441 to 446 ft.

Depth		Description
From	To	
0	38	Sand, medium fine, 90 percent quartz, well rounded; 10 percent mineral material
38	40	Clay, brown
40	50	Sand, very fine
50	52	Clay
52	60	Sand, coarse
60	80	Sand, mixed with gravel, coarsening downward sequence
80	85	Gravel, increasingly mixed with clay
85	90	Clay, gray, pliable
90	100	Clay, gray; minor sand
100	110	Clay, light brown; minor sand
110	120	Clay, brown mixed with gravel; minor sand
120	130	Clay, brown
130	140	Clay, dark gray-green; sand; some organic matter (twigs)
140	150	Clay, medium gray; minor sand
150	160	Clay, brown
160	170	Clay, dark gray
170	180	Clay, gray; gravel
180	190	Clay; minor sand
190	200	Clay, tan; minor sand
200	220	Clay, gray

Table 1. Lithologic logs of boreholes—Continued

Depth		Description
From	To	
Bethel Island, monitoring wells 2N/3E-10H001 and 2N/3E-10H005—Continued		
220	250	Clay, gray; minor sand
250	270	Sand, fine, with small clay clods
270	275	Sand, fine
275	290	Gravel, coarse, of granodiorite origin; fine sand
290	300	Gravel, dark color, poorly sorted, fine sand
300	335	Gravel, dark color, poorly sorted
335	360	Clay; coarse gravel
360	372	Sand, coarse black; minor clay, lots of silt
372	380	Clay; minor sand
380	397	Clay, gritty; minor sand
397	400	Clay, gritty; major sand
400	410	Clay, gritty
410	430	Sand, fine; gritty clay
430	437.5	Clay, gray, hard, gritty
437.5	455	Sand, coarse, poorly sorted black with lots of silt
455	495	Clay, tan, gritty
495	505	No sample
505	525	Clay, tan, gritty
525	530	Clay, gray, pliable
530	540	Clay, tan, hard
540	545	Clay, tan, silty, pliable

SUMMARY

Subsidence in the Sacramento–San Joaquin Delta is primarily caused by oxidation of drained peat soils. This report presents compaction, water-level, and lithologic data collected at two extensometer sites. These data will be used to determine the effects of ground-water withdrawal on subsidence. Compaction was measured between instrument tables referenced to steel pipes cemented about 40 ft below land surface (well below the peat layer) and concrete plugs at 436 and 536 ft on Bacon and Bethel Islands, respectively. Ground-water levels were measured in wells with screened intervals of 152 to 162 ft and 441 to 446 ft below land surface on Bacon and Bethel Islands, respectively. The rate of compaction at Bacon Island was 0.0015 ft/yr. Bethel Island showed a compaction rate of 0.0016 ft/yr. Cumulative compaction at the Bacon Island site from September 1987 to August 1993 was about 0.009 ft. Cumulative compaction at the Bethel Island site from August 1988 to August 1993 was about 0.008 ft.

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