Water-Level Fluctuations, Water Temperatures, and Tilts in Sandbars –6.5R, 43.1L, and 172.3L, Grand Canyon, Arizona, 1990–93

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS

Multiply	By	To obtain
millimeter (mm)	0.03937	inch
meter (m)	3.281	foot
cubic meter per second (m^3/s)	35.31	cubic foot per second
kilopascal (kPa)	0.1450	pound per square inch

Temperatures are given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8(°C) + 32$$

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By Michael C. Carpenter, Jason A. Crosswhite, *and* Robert L. Carruth

Abstract

Rill erosion, slumping, and fissuring develop on seepage faces of many sandbars along the Colorado River in the Grand Canyon at low river stage. Three sandbars were instrumented with sensors for continual monitoring of stage, pore pressure, ground-water temperature, and tilt to determine the relation between ground-water flow and sandbar deformation. Data were collected from October 1990 to July 1993 at sandbar –6.5R, which had 17 pore-pressure sensors, one stage sensor, and 19 temperature sensors. Data were collected from April 1991 to March 1993 at sandbar 43.1L, which had 15 pore-pressure sensors, one stage sensor, 29 temperature sensors, and eight tilt sensors. Data were collected from April 1991 to March 1993 at sandbar 172.3L, which had 15 pore-pressure sensors, one stage sensor, 29 temperature sensors, and 10 tilt sensors. Attenuation of water-level fluctuation from the zone of fluctuating river stage to the back of the sandbars ranged from 70 percent at sandbar –6.5R to 40 percent for sandbars 43.1L and 172.3L. Shallow tilt occurred at sandbar 43.1L from July 7 to August 10, 1991. Tilt occurred at sandbar 172.3L on May 7–8, June 18–19, and September 1–2, 1991; July 3 and 31, 1992; January 12, 14, 20–21, and 31, 1993; and February 21 and 24, 1993.

INTRODUCTION

Discharge from Glen Canyon Dam on the Colorado River can fluctuate from less than 85 to more than 850 m^3/s on a daily basis. Corresponding stage fluctuations at downstream sandbars can exceed 3.4 m. Rill erosion, slumping, and fissuring occur on seepage faces of many sandbars at low river stage.

The study was designed to document the processes of seepage erosion, slumping, and fissuring and to establish relations among material properties of sandbar sediments, threshold of hydraulic gradient for rill erosion, and effective stresses causing slumping. During the study, three sandbars were instrumented (fig. 1), and data were collected for intended studies of variably saturated ground-water flow, deformation, and heat flow. The purpose of this report is to provide data for the three sandbars. The report includes pore-pressure, water-temperature, river-stage, and tilt data from the three sandbars from 1990 to 1993.

Acknowledgments

Brian L. Cluer, William L. Werrell, Richard R. Inglis, Larry J. Martin, and David L. Sharrow (National Park Service) and William Vernieu (Bureau of Reclamation) assisted in installing piezometers. The Glen Canyon Environmental Studies Office of the Bureau of Reclamation provided raft-trip support.

METHODS AND QUALITY CONTROL

Three sandbars were instrumented with sensors for continual monitoring of stage, pore pressure, temperature, and tilt to determine relations between ground-water flow and sandbar deformation. Deep, intermediate, and shallow pairs

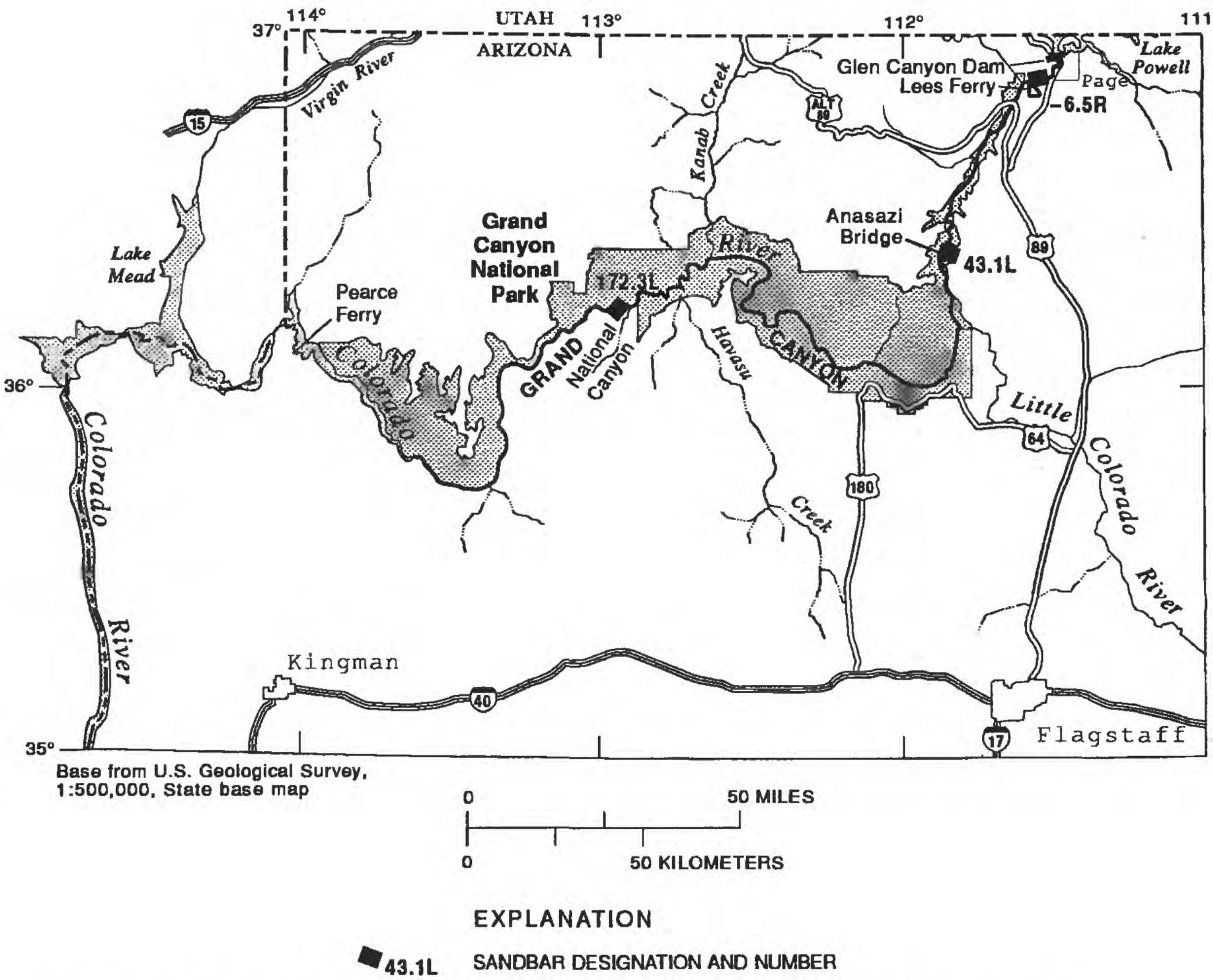

Figure 1. Location of sandbars –6.5R, 43.1L, and 172.3 L. (Source: Carpenter and others, 1995.)

of pore-pressure and temperature sensors were installed at each sandbar in a vertical plane orthogonal to the river's edge. The clusters were spaced a few meters apart in the zone of fluctuating river stage to determine the vertical component of ground-water flow in the deforming sandbar face. The clusters were spaced more than 10 m apart in the middle and back of the sandbar. Seven tilt sensors were arrayed both parallel with and orthogonal to the river's edge in the deforming sandbar face. Two vertical clusters of tensiometers at three depths also were set in the sandbar. A pressure sensor and temperature sensor were installed at the sand-water interface below the zone of fluctuating river stage to function as a stage sensor.

The instrumentation plan was modified for each sandbar. Sandbar –6.5R had no tilt sensors and no tensiometers. At sandbar 43.1L, tensiometers were installed beneath vegetated and unvegetated soil. At sandbar 172.3L, tensiometers were in a medium sand and a lower bench of silty, very fine sand.

Piezometers were placed in the sandbars using a jetting and driving technique. Water was pumped from the river down a 13-millimeter-diameter polyvinyl-chloride (PVC) pipe for jetting inside and near the bottom of 50-millimeter-diameter PVC flush-thread pipe. A 1-meter section of flush-thread pipe was fitted with a coupling on the outside near the bottom to make a driver. A fence-post-type hammer with a hole in the top to fit over the pipe but not over the coupling was used to drive the string of flush-thread pipe by hammering on the coupling with the 1-meter section as the top section of the string. Maximum depth reached was 10 m. A Motorola MPX2200AS 0 to 200 kPa absolute-pressure sensor was attached to the tip of a 13-millimeter PVC pipe that was fitted with a fine nylon screen about 75 mm long and lowered into the 50-millimeter casing. The 50-millimeter casing was then pulled from around the piezometer. In vertical nests of piezometers, each piezometer was set in its own jetted hole, which eliminated the possibility of pressure contamination from lower in the drill hole. Because the pressure sensors were absolute devices, additional pressure sensors were used as barometers to remove the effect of atmospheric-pressure fluctuations. Because of the importance of the pressure correction, each site had three barometers for redundancy. Resolution of the pressure sensors in the datalogging system was 3 mm of water-level fluctuation. The temperature sensors were Campbell Scientific 107B thermistors that were inserted to the bottom of the 13-millimeter PVC pipes adjacent to the pressure sensors. Resolution of the temperature sensors is less than 0.01°C, but specified absolute accuracy is ±0.2°C. Observed performance is ±0.5°C before correction for field-calibration checks. Data were recorded on Campbell Scientific CR10 dataloggers with multiplexers and storage modules. Sampling interval varied from 20 minutes to 1 hour. Data were filtered to 1-hour intervals for this report. Excitation voltage to pressure sensors was provided by switched regulated circuits with a voltage stability of ±0.01 percent. The electronic equipment was buried in a sealed metal box containing desiccant.

The pressure sensors were calibrated at three temperatures and five pressures in a Dewar flask in an isothermal bath. Pressure sensors were calibrated and field checked using a Paroscientific model 760 Portable Pressure Standard with a range of 0–690 kPa absolute and accuracy of ±0.01 percent. The primary temperature standard was a certified Ever Ready thermometer with an accuracy of ±0.03°C. The secondary standard for field checks of the 107B thermistors was a Doric digital thermometer with a YSI 401 thermistor. Accuracy of the secondary standard tested against the primary standard was ±0.1°C. The tilt sensors were calibrated using an accurately cut 10° angle for three-point calibration at +10°, 0°, and −10° from an arbitrary near-horizontal plane. In the field, temperature sensors were placed with all pressure sensors and most tilt sensors. Pressure sensors used for water levels were field checked by measuring depth to water in the 13-millimeter pipes for all sensors that were accessible at the time of a site visit. Submerged pressure sensors, including stage sensors, were checked using surveyed river stage at known times. Accessible temperature sensors were checked at two temperatures by pulling them out of the 13-millimeter pipes and putting the sensors in a thermos bottle with the secondary standard.

WATER-LEVEL FLUCTUATIONS, WATER TEMPERATURES, AND TILTS

Water levels are reported as head with respect to an arbitrarily surveyed datum. In each cross section (fig. 2), river stages for discharges of 140 m^3/s and 850 m^3/s are shown as a frame of reference for water levels in the sandbars and river-stage fluctuations. Considering drift, adjustments for drift, subtraction of barometric pressure, and surveying errors, the absolute accuracy of water levels is estimated to be ±20 mm. The water-level data are provided with a resolution of about 3 mm because differences between nearby pressure sensors in a period of days or a few weeks provide information on local changes in head gradients and seepage stresses. The tensiometers, which were at sandbars 43.1L and 172.3L only, exhibited several problems including cavitation of the porous cup, flooding of the boxes containing the pressure sensors, and erosion. Data from the tensiometers, therefore, are not included in this report. In each of the three sandbars, the barometer that exhibited the least drift was used for the barometric subtraction and is included in the data files for that sandbar.

Water temperatures were measured in the piezometers adjacent to the pressure sensors, beside the tilt sensors, and separately at selected depths in each sandbar. Considering field calibrations and repeated calibration checks on accessible sensors, the accuracy of temperature measurements is estimated to be ±0.2°C. Temperature data are provided with a resolution of 0.01°C to provide

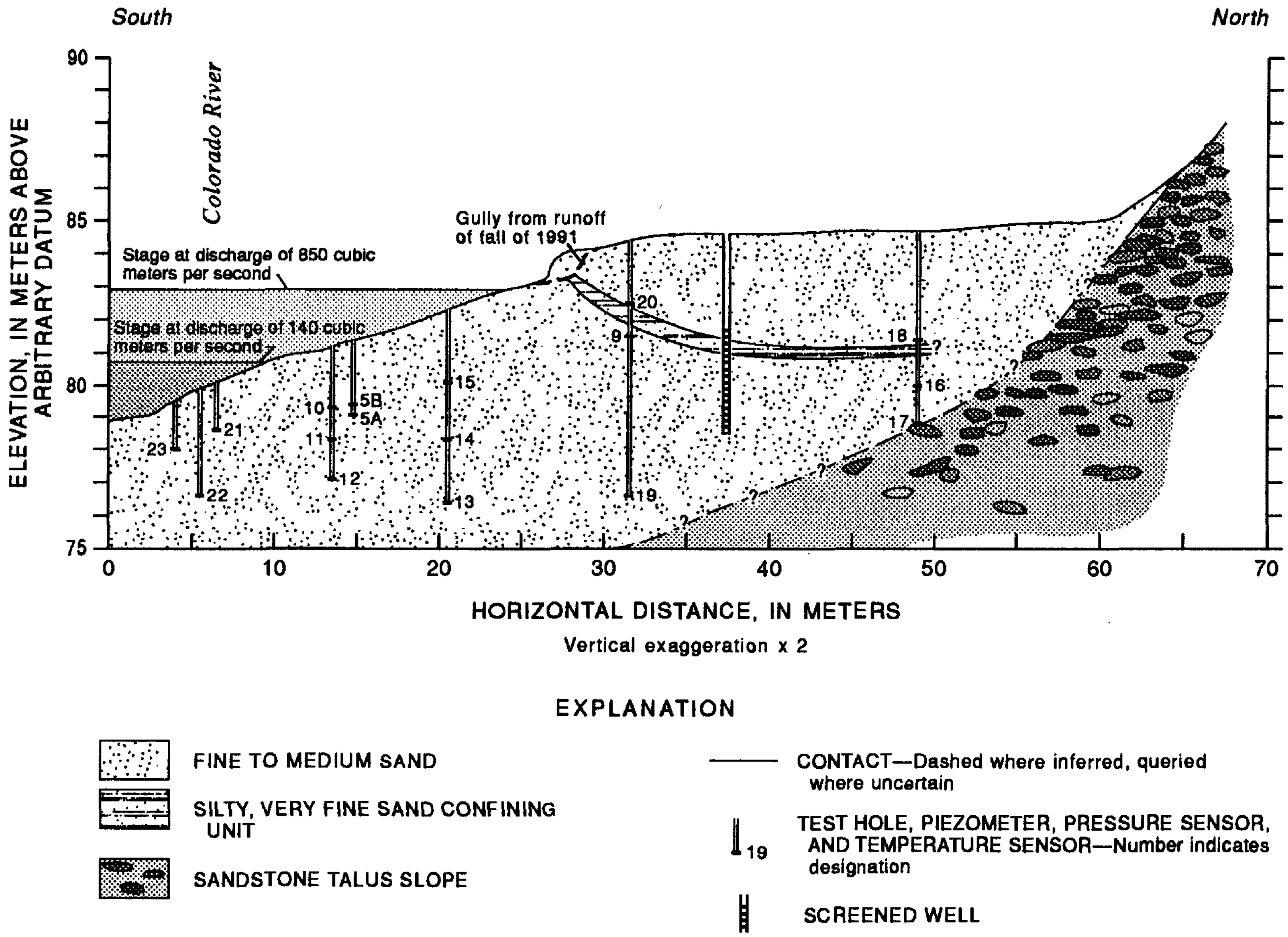

Figure 2. Geologic section and location of sensors at sandbar –6.5R, upstream from Lees Ferry. (Source: Carpenter and others, 1995.)

information associated with daily and seasonal temperature fluctuations.

Tilt is a change in inclination of a zone or a shear strain in a vertical plane. The sign and axis conventions used in this report are: the positive x axis is orthogonal to and points toward the river, and tilt of the x axis is positive when the sensor rotates counterclockwise when viewed from upstream on the left bank; the positive y axis is parallel with the river and points downstream, and tilt of the y axis is positive when the sensor rotates counterclockwise when viewed from the river looking toward the sandbar on the left bank. Positive tilt may also be thought of as upward, and negative tilt as downward when viewed along the axis. In a medium that can be treated as two-dimensional (reflecting plane strain), all deformation will occur in the plane defined by the x axis and the vertical (or z) axis, that is, orthogonal to the river. A sensor located within a slump block or rotational failure will exhibit positive x tilt. A sensor located within a zone undergoing creep or within a zone on the riverward side of a fissure during early stages of a process similar to glacial calving will exhibit negative x tilt. The tilt sensors exhibited a noise level of about ±0.05°. Absolute accuracy of the tilt sensors is about ±0.2°. Applying a moving-average time-series technique reveals minor long-period tilts in some sensors. Tilt data are provided with a resolution of 0.01° to provide information on the subtle tilting processes.

Location of Data

The user can access the data for this report on the internet using a file-transfer protocol (ftp) at dg0daztcn.wr.usgs.gov (130.118.172.65) in the directory /pub/GrandCanyon/GroundWater by logging in as anonymous with the user's internet E-Mail address as the password. The data are in compressed binary files. A binary executable file, compress.exe, can be transferred to DOS-based machines using ftp for decompressing the data files. The ASCII file, compress.man, can be transferred as well and explains the use of compress.exe. A read.me file has the tables that describe the data files and a table of Julian days. The decompressed data are ASCII flat files with a single space separating columns. Time is given as Julian day; hours and minutes are shown as a decimal fraction.

Sandbar –6.5R

Sandbar –6.5R (fig. 2) is 6.5 river miles upstream from Lees Ferry on the right river bank. This sandbar had a gentle slope in the zone of fluctuating river stage and exhibited a seepage face with rill erosion but did not exhibit slumping and fissuring during the study. In October 1990, 17 pore-pressure sensors, 3 barometric sensors, and 18 temperature sensors were installed. The stage sensor was added in December 1990, and a temperature sensor at the stage sensor was added in May 1992. The stage sensor and its accompanying temperature sensor were installed in boulders about 100 m downstream from sandbar –6.5R. Data were collected at sandbar –6.5R from October 23, 1990, until July 13, 1993. Representative plots of water-level and temperature fluctuations (figs. 3–4) from July to September 1991 show significantly larger fluctuations in the sandbar in the zone of fluctuating river stage than in the shoreward part of the sandbar. The lateral attenuation of water-level fluctuations over 35 m was 70 percent.

Table 1 lists sensor-data files, and table 2 identifies the columns in the sensor-data files for sandbar –6.5R. Sensor locations are shown in figure 2, and notes for specific sensors are in table 3.

Sandbar 43.1L

Sandbar 43.1L (fig. 5) is 43.1 river miles downstream from Lees Ferry on the left river bank. This sandbar had a narrow, deep return channel (Schmidt and Graf, 1990, p. 5), and the zone of fluctuating river stage was a steeply sloping face that exhibited rill erosion, slumping, and

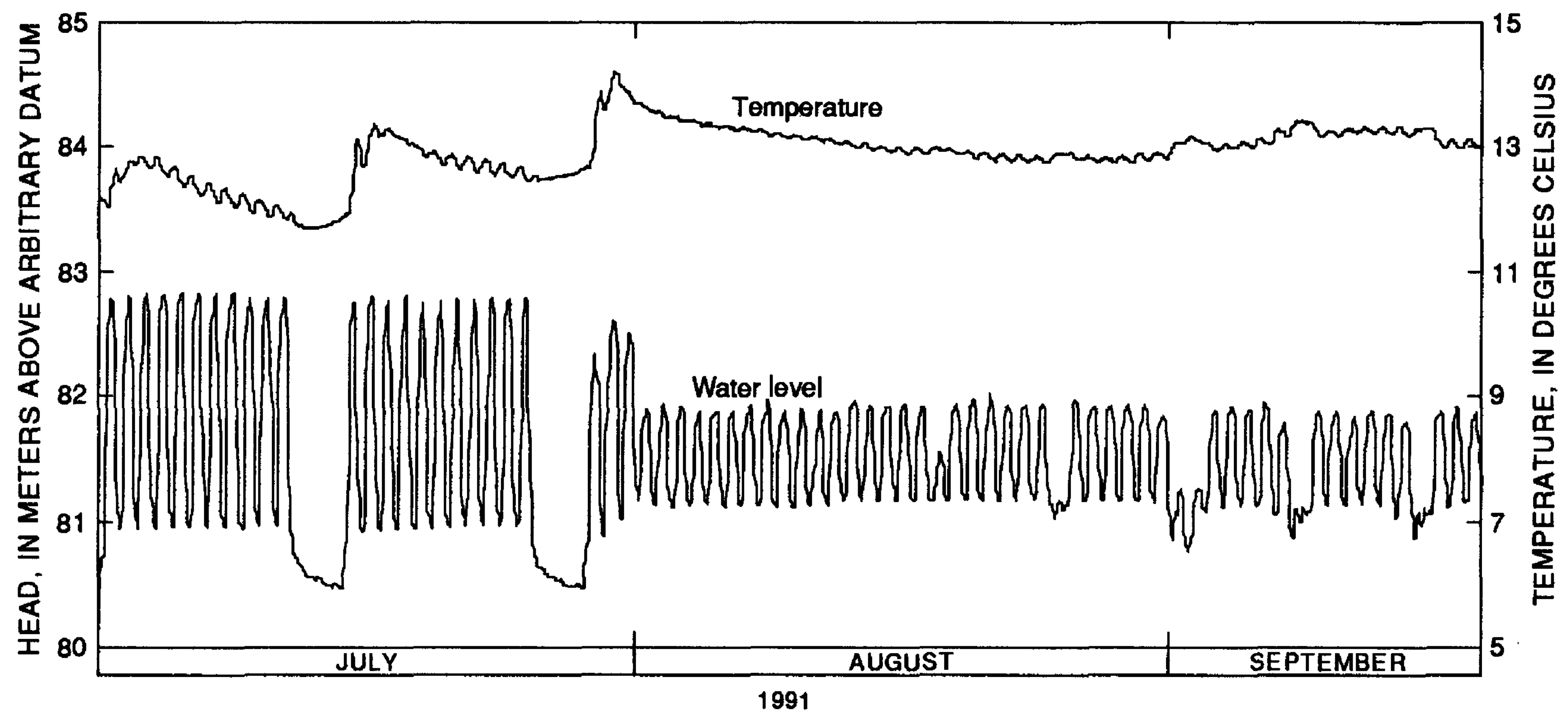

Figure 3. Water-level and water-temperature fluctuations at sensor 10, sandbar –6.5R, upstream from Lees Ferry, July 1 through September 18, 1991.

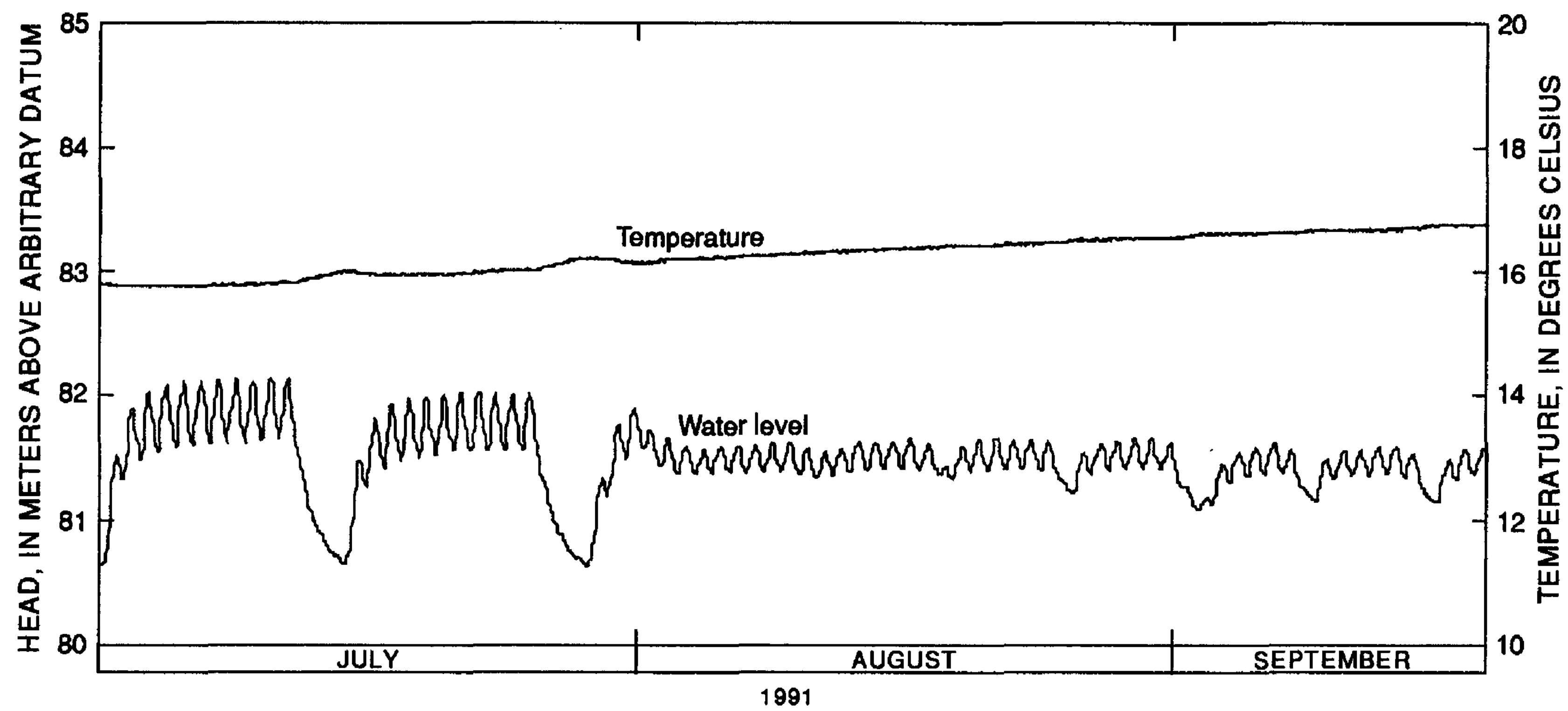

Figure 4. Water-level and water-temperature fluctuations at sensor 16, sandbar −6.5R, upstream from Lees Ferry, July 1 through September 18, 1991.

Table 1. Sensor-data files for sandbar −6.5R, upstream from Lees Ferry

[File name: Letter, Z, indicates that the file is a compressed file and must be uncompressed before the file can be used. Julian day: Hours and minutes are shown as decimal fraction]

File name	Starting dates and times			Ending dates and times		
	Julian day	Time	Date	Julian day	Time	Date
m690d.Z	296.5417	1300	10–23–90	365.9583	2300	12–31–90
m691a.Z	1.0000	0000	1–01–91	120.9583	2300	4–30–91
m691c.Z	182.0000	0000	7–01–91	310.5417	1300	11–06–91
m692a.Z	5.5833	1400	1–05–92	181.9583	2300	6–29–92
m692c.Z	182.0000	0000	6–30–92	366.9583	2300	12–31–92
m693a.Z	1.0000	0000	1–01–93	194.6250	1500	7–13–93

fissuring. In April 1991, 15 pore-pressure sensors, 6 tensiometers, 3 barometric sensors, 1 stage sensor, 29 temperature sensors, and 6 tilt sensors were installed at sandbar 43.1L. In June 1992, two additional tilt sensors were added. Data were collected at sandbar 43.1L from April 8, 1991, until March 12, 1993. Representative plots of water-level and temperature fluctuations from July to September 1991 (figs. 6–7) show larger fluctuations in water level in the zone of fluctuating river stage than in the shoreward part of the sandbar. Temperature fluctuations, however, were greater in the shoreward part of the sandbar than in the zone of fluctuating river stage. Attenuation of water-level fluctuations from sensor P46 to sensor P42 over 30 m was 40 percent. Shallow

Table 2. Format of sensor-data files for sandbar –6.5R, upstream from Lees Ferry

[Type of sensor: B, barometer; P, piezometer; S, stage, T, temperature. Name of sensor: The letter and following number is the name of the sensor. Field width: First number is the total number of characters in the field; the number to the right of the decimal represents the number of decimal places within the field. See figure 2 for sensor locations]

Column	Type and name of sensor	Column field width	Column	Type and name of sensor	Column field width	Column	Type and name of sensor	Column field width	Column	Type and name of sensor	Column field width
1	Julian day	8.4	11	P16	7.3	21	S	7.3	31	T18	7.2
2	Time	5.0	12	P17	7.3	22	T9	7.2	32	T19	7.2
3	B2	6.3	13	P18	7.3	23	T10	7.2	33	T20	7.2
4	P9	7.3	14	P19	7.3	24	T11	7.2	34	T21	7.2
5	P10	7.3	15	P20	7.3	25	T12	7.2	35	T22	7.2
6	P11	7.3	16	P21	7.3	26	T13	7.2	36	T23	7.2
7	P12	7.3	17	P22	7.3	27	T14	7.2	37	T5A	7.2
8	P13	7.3	18	P23	7.3	28	T15	7.2	38	T5B	7.2
9	P14	7.3	19	P5A	7.3	29	T16	7.2	39	[2]T17B	7.2
10	P15	7.3	20	P5B	7.3	30	[1]T17	7.2	40	TS	7.2

[1]0.1-meter depth.
[2]Temperature sensor at location of piezometer.

tilting involving tilt sensor I18 occurred from July 7, 1991, to August 10, 1991 (fig. 8).

Table 4 lists sensor-data files, and table 5 identifies columns in the sensor-data files for sandbar 43.1L. Sensor locations are shown in figure 5, and notes for specific sensors are in table 6.

Sandbar 172.3L

Sandbar 172.3L (fig. 9) is 172.3 river miles downstream from Lees Ferry on the left river bank. This sandbar had a steeply sloping face in the zone of fluctuating river stage and exhibited rill erosion, slumping, and fissuring. In April 1991, 15 pore-pressure sensors, 6 tensiometers, 3 barometric sensors, 1 stage sensor, 29 temperature sensors, and 7 tilt sensors were installed at sandbar 172.3L. In June 1992, three additional tilt sensors were added. Data were collected at sandbar 172.3L from April 19, 1991, until March 12, 1993. Representative plots of water-level and temperature fluctuations from July to September 1991 (figs. 10–12) show larger fluctuations in water level in the zone of fluctuating river stage than in the shoreward part of the sandbar. Daily temperature fluctuations were slightly greater in the zone of fluctuating river stage than in the shoreward part of the sandbar. Unusually large daily temperature fluctuations occurred at sensor P62 at the base of the sandbar (fig. 11). Attenuation of water-level fluctuations from sensor P56 to sensor P64 over 23 m was 40 percent. Tilt occurred in the exposed part of the sandbar during May 7–8, June 18–19, and September 1–2, 1991, and January 14, 1993 (fig. 12). Tilt occurred in submerged sediment in the eddy (Schmidt and Graf,

Table 3. Sensor–record notes for sandbar –6.5R, upstream from Lees Ferry

[Type of sensor: P, piezometer, S, stage; T, temperature; TS, temperature sensor at the stage sensor. Name of sensor: The letter and following number is the name of the sensor. Julian day: Hours and minutes are shown as decimal fraction]

Type and name of sensor	Julian day	Time	Date	Remarks
All sensors	296.5417	1300	10–23–90	Record started.
	57.5417	1300	2–26–91	Gap.
	73.8750	2100	3–14–91	Record resumed.
	120.9583	2300	4–30–91	Gap.
	182.0000	0000	7–01–91	Record resumed.
	310.5417	1300	11–06–91	Gap.
	5.5833	1400	1–01–92	Record resumed.
	194.6250	1500	7–13–93	Record ended.
All piezometers	356.9583	2300	12–21–92	Gap; degraded relay contacts in multiplexer.
	1.0000	0000	1–01–93	Record resumed.
	40.0000	0000	2–09–93	Record ended; multiplexer contacts.
P5A, P10, P12, P14, P16, P18, P20, P22			1990	Short gaps caused by degraded relay contacts in multiplexer.
P5A	191.0000	0000	7–10–91	Liquefaction or sensor malfunction.
	215.0417	0100	8–03–91	Record resumed.
	366.9583	2300	12–31–92	Record ended; multiplexer contacts.
P5B				Sensor acted as tensiometer by following water level below altitude of sensor.
P15	182.0000	0000	7–01–91	Sensor failed; had acted as tensiometer.
P18				Mostly dry; acted as tensiometer.
P20				Always dry.
P23	182.0000	0000	7–01–91	Liquefaction or sensor drift.
	177.0417	0100	6–25–92	Record resumed.
	286.7083	1700	10–12–92	Record ended; liquefaction or sensor drift.
S	335.0000	0000	12–01–90	Record started.
	365.9583	2300	12–31–90	Submerged cable cut by beaver.
	32.0417	0100	2–01–91	Record resumed.
	120.9583	2300	4–30–91	Record ends; cable cut by beaver.
T15	182.0000	0000	6–30–92	Sensor failed.
T17B	310.5417	1300	11–01–91	Cable cut.
	5.5833	1400	1–05–92	Cable repaired.
T21	44.1250	0300	2–13–91	Sensor failed.
TS	182.0000	0000	6–30–92	Record started.
	286.8333	2000	10–12–92	Cable cut by beaver.

Table 4. Sensor-data files for sandbar 43.1L, opposite Anasazi Bridge

File name: First character of all files is a lowercase L. Letter, Z, indicates that the file is a compressed file and must be uncompressed before the file can be used. Julian day: Hours and minutes are shown as decimal fraction]

File name	Starting dates and times			Ending dates and times		
	Julian day	Time	Date	Julian day	Time	Date
l491b.Z	98.7917	1900	4–08–91	180.9583	2300	6–29–91
l491c.Z	181.0000	0000	6–30–91	273.3750	0900	9–30–91
l491d.Z	273.4167	1000	9–30–91	365.9583	2300	12–31–91
l492a.Z	1.0000	0000	1–01–92	89.9583	2300	3–29–92
l492b.Z	90.0000	0000	3–30–92	181.9583	2300	6–29–92
l492c.Z	182.0000	0000	6–30–92	274.9583	2300	9–30–92
l492d.Z	275.0000	0000	10–01–92	366.9583	2300	12–31–92
l493a.Z	1.0000	0000	1–01–93	71.5000	1200	3–12–93

Table 5. Format of sensor-data files for sandbar 43.1L, opposite Anasazi Bridge

[Type of sensor: B, barometer; S, stage; P, piezometer; TVB, temperature sensor at the vegetation box; T, temperature; TBB, temperature sensor at the bare box; TB, temperature sensor at a barometer; TI, temperature sensor at a tilt sensor; TS, temperature sensor at the stage sensor; I, tilt sensor. Name of sensor: The letter and following number is the name of the sensor. X, *x* axis on tilt sensor; Y, *y* axis on tilt sensor. Field width: First number is the total number of characters in the field; the number to the right of the decimal represents the number of decimal places within the field. See figure 5 for sensor locations]

Column	Type and name of sensor	Column field width	Column	Type and name of sensor	Column field width	Column	Type and name of sensor	Column field width	Column	Type and name of sensor	Column field width
1	Julian day	8.4	17	P48	8.3	32	T40	7.2	47	TS	7.2
2	Time	5.0	18	P49	8.3	33	T41	7.2	48	I54X	7.2
3	B2	6.3	19	TVB	7.2	34	T42	7.2	49	I54Y	7.2
4	S	8.3	20	[1]T0.25	7.2	35	T43	7.2	50	I48X	7.2
5	P41	8.3	21	[2]T2.50	7.2	36	TI54	7.2	51	I48Y	7.2
6	P42	8.3	22	[3]T1.25	7.2	37	TBB	7.2	52	I18X	7.2
7	P43	8.3	23	[4]T0.50	7.2	38	T47	7.2	53	I18Y	7.2
8	P35	8.3	24	T35	7.2	39	T48	7.2	54	I45X	7.2
9	P37	8.3	25	T36	7.2	40	T49	7.2	55	I45Y	7.2
10	P44	8.3	26	T37	7.2	41	TB	7.2	56	I61X	7.2
11	P45	8.3	27	T39	7.2	42	TI48	7.2	57	I61Y	7.2
12	P46	8.3	28	T44	7.2	43	TI45	7.2	58	I17X	7.2
13	P38	8.3	29	T45	7.2	44	TI17	7.2	59	I17Y	7.2
14	P39	8.3	30	T46	7.2	45	TI18	7.2	60	I62X	7.2
15	P40	8.3	31	T38	7.2	46	TI42	7.2	61	I62Y	7.2
16	P47	8.3									

[1]Temperatnre sensor at 0.25-meter depth.
[2]Temperature sensor at 2.50-meter depth
[3]Temperature sensor at 1.25-meter depth.
[4]Temperature sensor at 0.50-meter depth

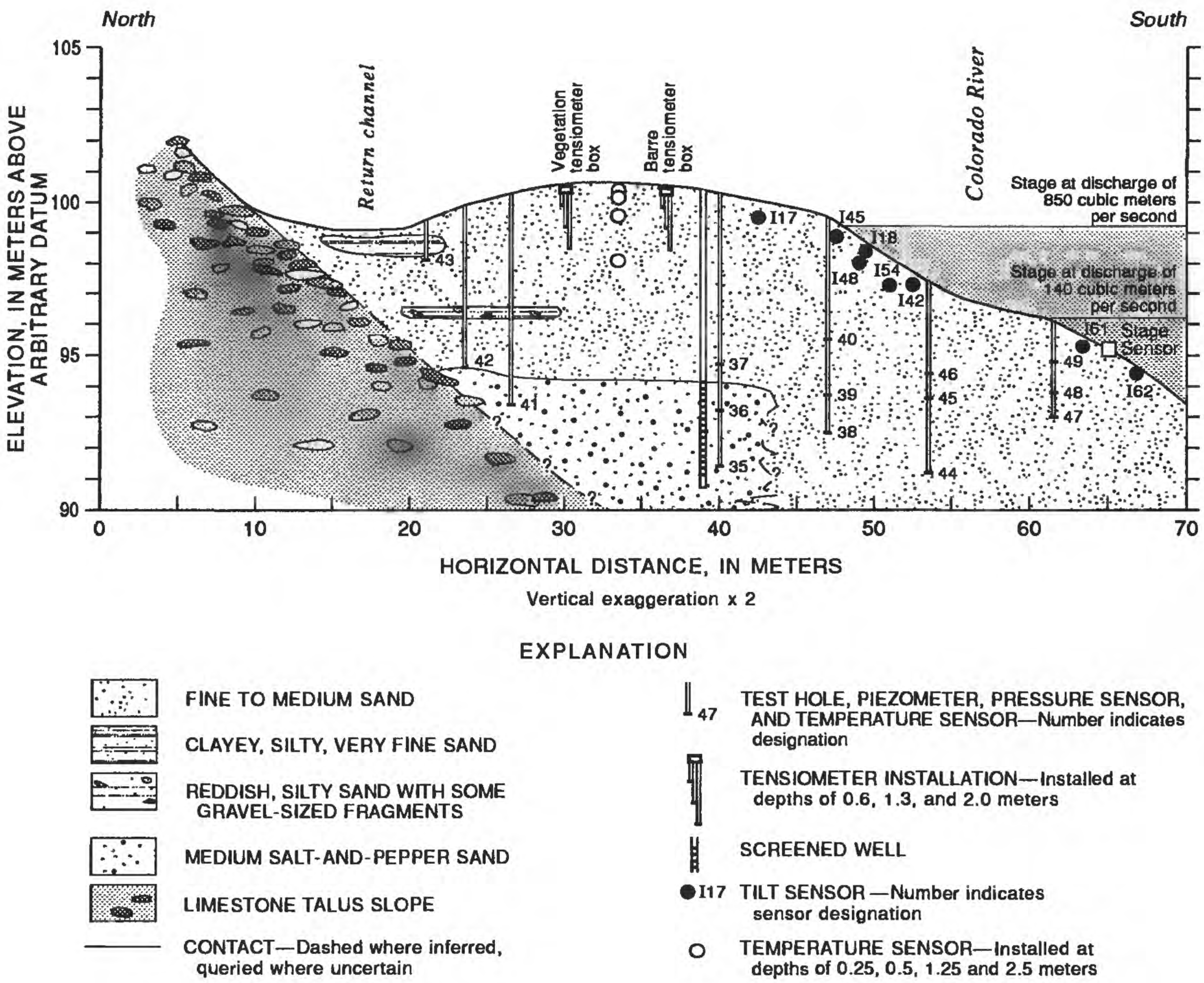

Figure 5. Geologic section and location of sensors at sandbar 43.1L, opposite Anasazi Bridge. (Source: Carpenter and others, 1995.)

1990, p. 5) during July 3 and 31, 1992; January 12, 20–21, and 31, 1993; and February 21 and 24, 1993.

Table 7 lists sensor-data files, and table 8 identifies the columns in the sensor-data files for sandbar 172.3L. Sensor locations are shown in figure 9, and notes for specific sensors are in table 9.

SUMMARY

Three sandbars along the Colorado River in Grand Canyon were instrumented with sensors for continual monitoring of stage, pore pressure, ground-water temperature, and tilt to determine the relation between ground-water flow and sandbar deformation. Typically, in a sandbar, five vertical clusters of deep, intermediate, and shallow pairs of pore-pressure and temperature sensors were installed in a vertical plane orthogonal to the river's edge.

Data were collected from October 1990 to July 1993 at sandbar –6.5R, which had 17 pore-pressure sensors, 1 stage sensor, and 19 temperature sensors. Data were collected from April 1991 to March 1993 at sandbar 43.1L, which had 15 pore-pressure sensors, 1 stage sensor, 29 temperature sensors, and 8 tilt sensors. Data were collected from April 1991 to March 1993 at sandbar 172.3L, which had

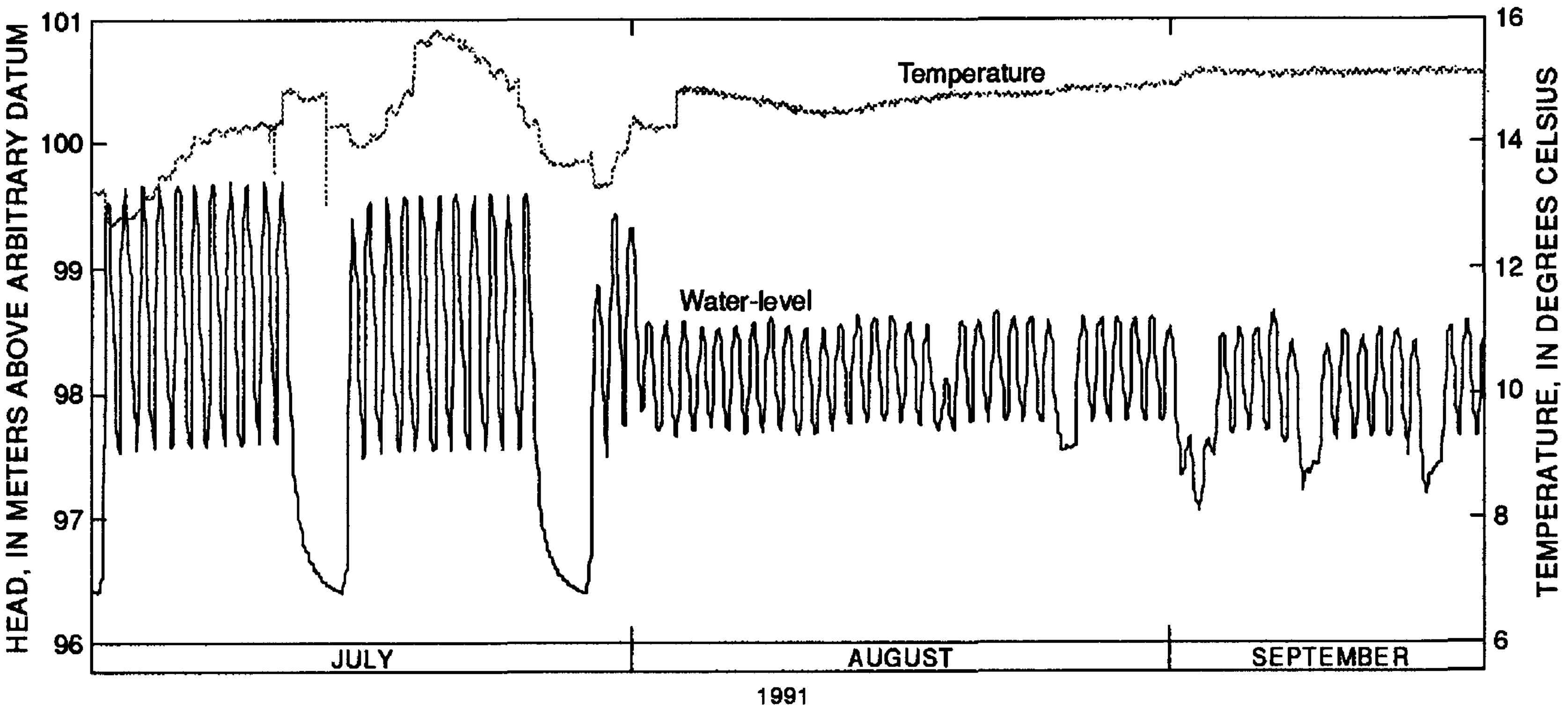

Figure 6. Water-level and water-temperature fluctuations at sensor 46, sandbar 43.1L, opposite Anasazi Bridge, July 1 through September 18, 1991.

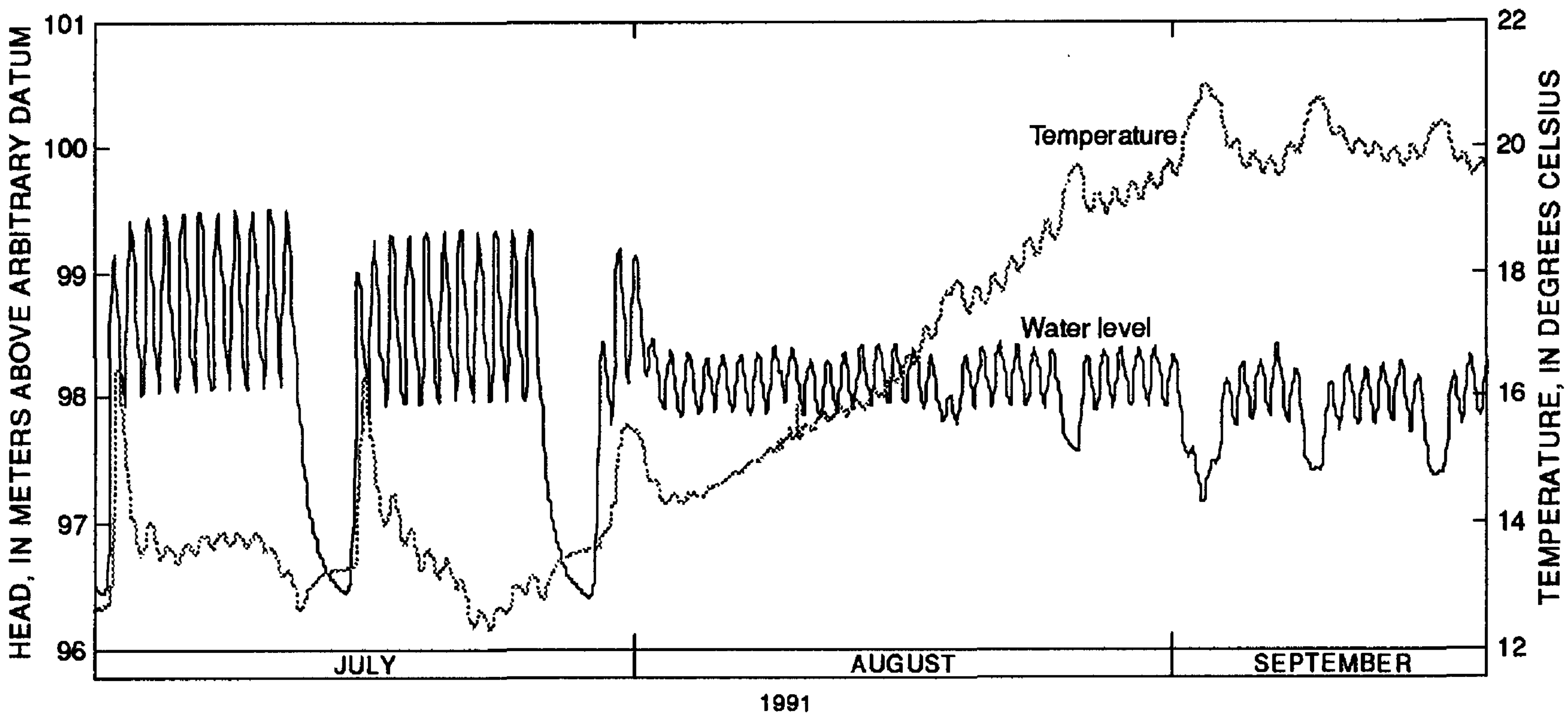

Figure 7. Water-level and water-temperature fluctuations at sensor 42, sandbar 43.1L, opposite Anasazi Bridge, July 1 through September 18, 1991.

15 pore-pressure sensors, 1 stage sensor, 29 temperature sensors, and 10 tilt sensors. Attenuation of water-level fluctuations from the zone of fluctuating river stage to the back of the sandbars ranged from 70 percent at sandbar –6.5R to 40 percent for sandbars 43.1L and 172.3L. Shallow tilt occurred at sandbar 43.1L from July 7 to August 10, 1991. Tilt occurred at sandbar 172.3L on May 7–8, June 18–19, and September 1–2, 1991; July 3 and 31, 1992; January 12, 14, 20–21, and 31, 1993; and February 21 and 24, 1993.

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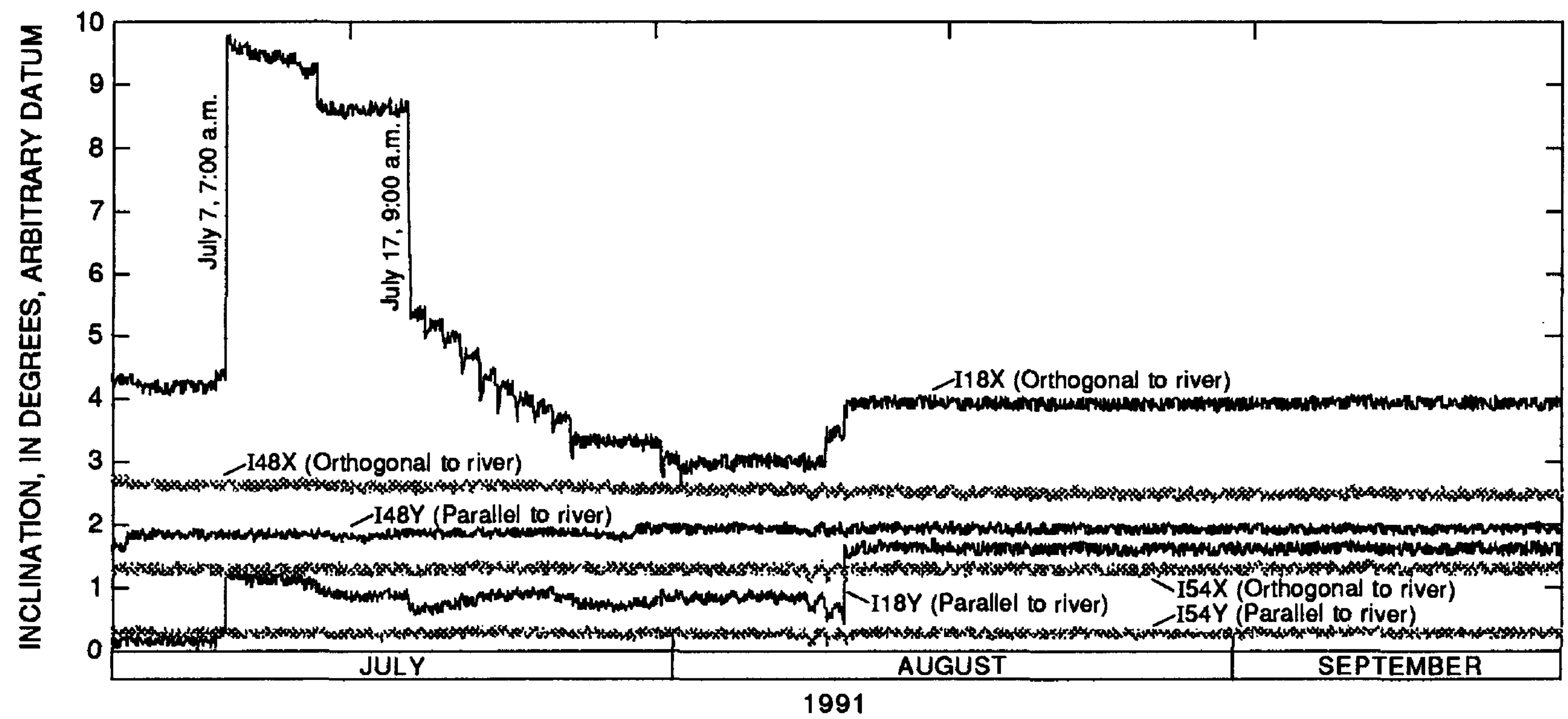

Figure 8. Tilt for sensors I18, I48, and I54 at sandbar 43.1L, opposite Anasazi Bridge, July 1 through September 18, 1991.

Table 6. Sensor–record notes for sandbar 43.1L, opposite Anasazi Bridge

[Type of sensor: I, tilt sensor; P, piezometer; S, stage; TB, temperature sensor at a barometer; T, temperature; TBB, temperature sensor at the bare box. Name of sensor: The letter and following number is the name of the sensor. Julian day: Hours and minutes are shown as decimal fraction]

Type and name of sensor	Julian day	Time	Date	Remarks
All sensors	98.7917	1900	4–08–91	Record started.
	130.6250	1500	5–10–91	Gap; error in setting storage module.
	159.8333	2000	6–08–91	Record resumed.
	71.5000	1200	3–12–93	Record ended.
I17	48.0000	0000	2–17–92	Sensor noise increased.
I18	188.3333	0800	7–07–91	Tilt started.
	193.3750	0900	7–12–91	Additional tilt.
	198.3750	0900	7–17–91	Additional tilt.
	222.5000	1200	8–10–91	Tilt ended.
I61, I62	153.6667	1600	6–01–92	Record started.
P39	246.5833	1400	9–03–91	Sensor failed.
P43				Acted as tensiometer when water level declined below sensor plane.
P47	113.0000	0000	4–23–91	Sensor failed.
P49	251.1667	0400	9–08–91	Sensor scoured 0.56 meters.
S	173.0000	0000	6–22–91	Sensor scoured; did not restabilize.
TB	112.0000	0000	4–22–91	Sensor failed.
[1]T1.25	258.0000	0000	9–15–91	Sensor failed.
[2]T0.25 [3]T0.50 [4]T2.50 TBB	283.7083	1700	10–09–92	Sensors vandalized.

[1]Temperature sensor at 1.25–meter depth.
[2]Temperature sensor at 0.25–meter depth
[3]Temperature sensor at 0.50–meter depth.
[4]Temperature sensor at 2.50–meter depth

Table 7. Sensor–data files for sandbar 172.3L, downstream from the mouth of National Canyon

[File name: First character of all files is a lowercase L. Letter, Z, indicates that the file is a compressed file and must be uncompressed before the file can be used. Julian day: Hours and minutes are shown as decimal fraction]

File name	Starting dates and times			Ending dates and times		
	Julian day	Time	Date	Julian day	Time	Date
*l*191b.Z	109.5000	1200	4–19–91	181.9583	2300	6–30–91
*l*191c.Z	182.0000	0000	7–01–91	258.9583	2300	9–15–91
*l*191d.Z	259.0000	0000	9–16–91	365.9583	2300	12–31–91
*l*192a.Z	1.0000	0000	1–01–92	89.9583	2300	3–29–92
*l*192b.Z	90.0000	0000	3–30–92	181.9583	2300	6–29–92
*l*192c.Z	182.0000	0000	6–30–92	274.9583	2300	9–30–92
*l*192d.Z	275.0000	0000	10–01–92	366.9583	2300	12–31–92
*l*193a.Z	1.0000	0000	1–01–93	71.4167	1000	3–12–93

Table 8. Format of sensor-data files for sandbar 172.3L, downstream from the mouth of National Canyon

[Type of sensor: B, barometer; P, piezometer; TS, temperature sensor at the stage sensor; T, temperature; TI, temperature sensor at a tilt sensor; TB, temperature sensor at a barometer; TU, temperature sensor at the upper box; TL, temperature sensor at the lower box; I, tilt sensor. Name of sensor: The letter and following number is the name of the sensor. X, *x* axis on tilt sensor; Y, *y* axis on tilt sensor. Field width: First number is the total number of characters in the field; the number to the right of the decimal represents the number of decimal places within the field. See figure 9 for sensor locations]

Column	Type and name of sensor	Column field width	Column	Type and name of sensor	Column field width	Column	Type and name of sensor	Column field width	Column	Type and name of sensor	Column field width
1	Julian day	8.4	16	P61	7.3	31	T59	7.2	46	I11X	7.2
2	Time	5.0	17	TS	7.2	32	T66	7.2	47	I11Y	7.2
3	B2	6.3	18	T69	7.2	33	T67	7.2	48	I41X; I66X	7.2
4	Stage	7.3	19	T68	7.2	34	T60	7.2	49	I41Y; I66Y	7.2
5	P56	7.3	20	TI46	7.2	35	T61	7.2	50	I46X	7.2
6	P60	7.3	21	TI53	7.2	36	T65	7.2	51	I46Y	7.2
7	P64	7.3	22	TI47	7.2	37	T64	7.2	52	I47X	7.2
8	P65	7.3	23	TI49	7.2	38	T63	7.2	53	I47Y	7.2
9	P62	7.3	24	TI41	7.2	39	T62	7.2	54	I49X; I69X	7.2
10	P68	7.3	25	TI11	7.2	40	TB	7.2	55	I49Y; I69Y	7.2
11	P69	7.3	26	TI50	7.2	41	TU	7.2	56	I50X	7.2
12	P63	7.3	27	T55	7.2	42	TL	7.2	57	I50Y	7.2
13	P55	7.3	28	T56	7.2	43	[1]TL2.0	7.2	58	I53X; I70X	7.2
14	P67	7.3	29	T57	7.2	44	[2]TL1.3	7.2	59	I53Y; I70Y	7.2
15	P57	7.3	30	T58	7.2	45	[3]TL0.6	7.2			

[1] Temperature sensor at 2.0-meter depth.
[2] Temperature sensor at 1.30-meter depth.
[3] Temperature sensor at 0.6-meter depth.

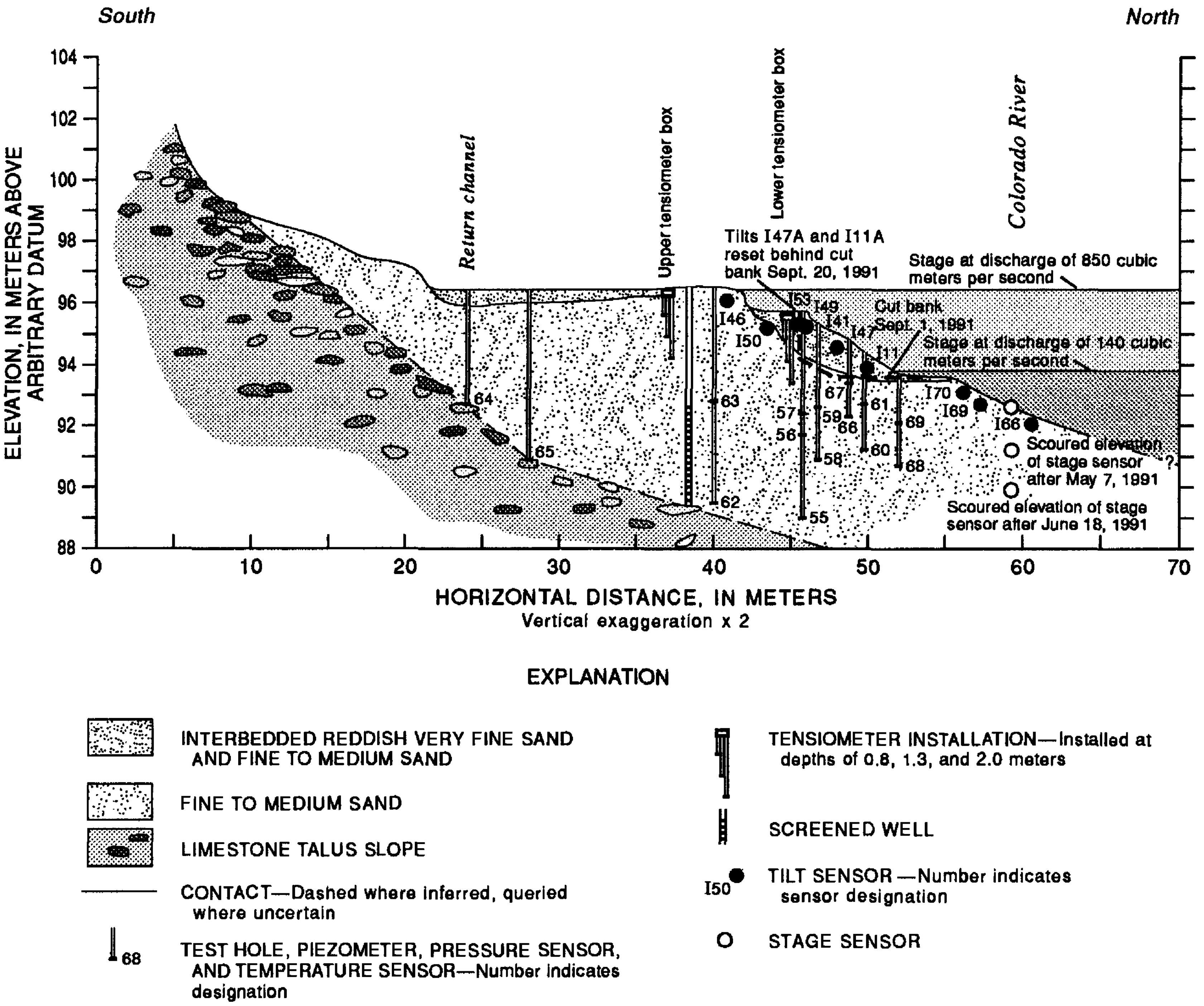

Figure 9. Geologic section and location of sensors at sandbar 172.3L, downstream from the mouth of National Canyon. (Source: Carpenter and others, 1995.)

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Cluer, B.L., Carpenter, M.C., Martin, L.J., Wondzell, M.A., Dexter, L.R., and Manone, M.A., 1993,

Table 9. Sensor–record notes for sandbar 172.3L, downstream from the mouth of National Canyon

[Type of sensor: I, tilt sensor; P, piezometer; S, stage; TL, temperature sensor at the lower box; T, temperature; TS, temperature sensor at the stage sensor. Name of sensor: The letter and following number is the name of the sensor. Julian day: Hours and minutes are shown as decimal fraction]

Type and name of sensor	Julian day	Time	Date	Remarks
All sensors	109.5000	1200	4–19–91	Record started.
	263.5417	1300	9–20–91	Gap, secondary storage module failed.
	293.1667	0400	10–20–91	Record resumed
	71.4167	1000	3–12–93	Record ended
I11	169.9167	2200	6–18–91	Tilted off scale.
	227.5417	1300	8–15–91	Reset.
	244.7083	1700	9–01–91	Tilted off scale.
	293.1667	0400	10–19–91	Relocated; reset.
I11X	14.3750	0900	1–14–93	Tilted off scale.
I11Y	14.5417	1300	1–14–93	Tilted off scale.
I41	127		5–07–91	Minor tilt.
	170		6–19–91	Tilt.
	244.7917	1900	9–01–91	Tilted off scale; record ended.
I46	170		6–19–91	Minor tilt.
I47X	170.375	0900	6–19–91	Tilted off scale.
I47Y	170.4167	1000	6–19–91	Tilted off scale.
I47	227.5833	1400	8–15–91	Reset.
I47X	244.7500	1800	9–01–91	Tilted off scale.
I47Y	244.7917	1900	9–01–91	Tilted off scale.
I47	293.1667	0400	10–19–91	Relocated; reset.
I49	128		5–08–91	Minor tilt.
	170		6–19–91	Minor tilt.
	227.5417	1300	8–15–91	Reset.
I49X	245.1250	0300	9–02–91	Tilted off scale; record ended.
I49Y	245.3750	0900	9–02–91	Tilted off scale; record ended.
I53X	166.9583	2300	6–16–91	Sensor tilted off scale or leaked; record ended.
I53Y	167.1667	0400	6–17–91	Sensor tilted off scale or leaked; record ended.
I66	161.4583	1100	6–09–92	Record started.
	185.0000	0000	7–03–92	Tilt.
	213.2917	0700	7–31–92	Tilt.
	55.7500	1800	2–24–93	Tilt.
I69Y	161.4583	1100	6–09–92	Record started.
	185.0000	0000	7–03–92	Tilt.
	213.3333	0800	7–31–92	Tilt.
	12.3750	0900	1–12–93	Tilt.
	20.0417	0100	1–20–93	Tilt.
	31.0417	0100	1–31–93	Tilt.
	52.2083	0500	2–21–93	Tilt.
	55.7500	1800	2–24–93	Tilt.
I70Y	161.4583	1100	6–09–92	Record started.
	185.5417	1300	7–03–92	Tilt.
	213.2917	0700	7–31–92	Tilt.
	12.3750	0900	1–12–93	Tilt.
	20.0417	0100	1–20–93	Tilt
	21		1–21–93	Stabilizing
	31.0417	0100	1–31–93	Tilt.

Table 9. Sensor–record notes for sandbar 172.3L, downstream from the mouth of National Canyon—Continued

Type and name of sensor	Julian day	Time	Date	Remarks
I70Y	52.2083	0500	2–21–93	Tilt.
	55.7500	1800	2–24–93	Tilt.
P57	166.8333	2000	6–15–91	Sensor failed.
P63	167.2917	0700	6–16–91	Sensor failed.
P64	62.0000	0000	3–02–92	Sensor failed.
P67	226.6667	1600	8–14–91	Sensor failed; record ended.
P68	227.6667	1600	8–15–91	Gap.
	238.2500	0600	8–26–91	Record resumed.
	305.7917	1900	10–31–92	Sensor failed.
P69	168.7917	1900	6–17–91	Sensor scoured downward 0.50 meters.
S	127.7500	1800	5–07–91	Sensor scoured downward 1.31 meters.
	168.7917	1900	6–17–91	Sensor scoured downward 1.81 meters.
	303.8750	2100	10–30–91	Gap.
	1.0000	0000	1–01–92	Record resumed.
TL	13.7917	1900	1–13–93	Sensor failed.
[1]TL1.3	22.6250	1500	1–22–93	Sensor failed.
[2]TL2.0	169.8333	2000	6–18–91	Sensor malfunction.
	1.0000	0000	1–01–92	Record resumed.
T60	20.4583	1100	1–20–93	Sensor failed.
T69	226.6250	1500	8–14–91	Sensor failed.
TS	251.6667	1600	9–08–91	Sensor failed.

[1]Temperature sensor set at 1.30-meter depth.
[2]Temperature sensor set at 2.00-meter depth.

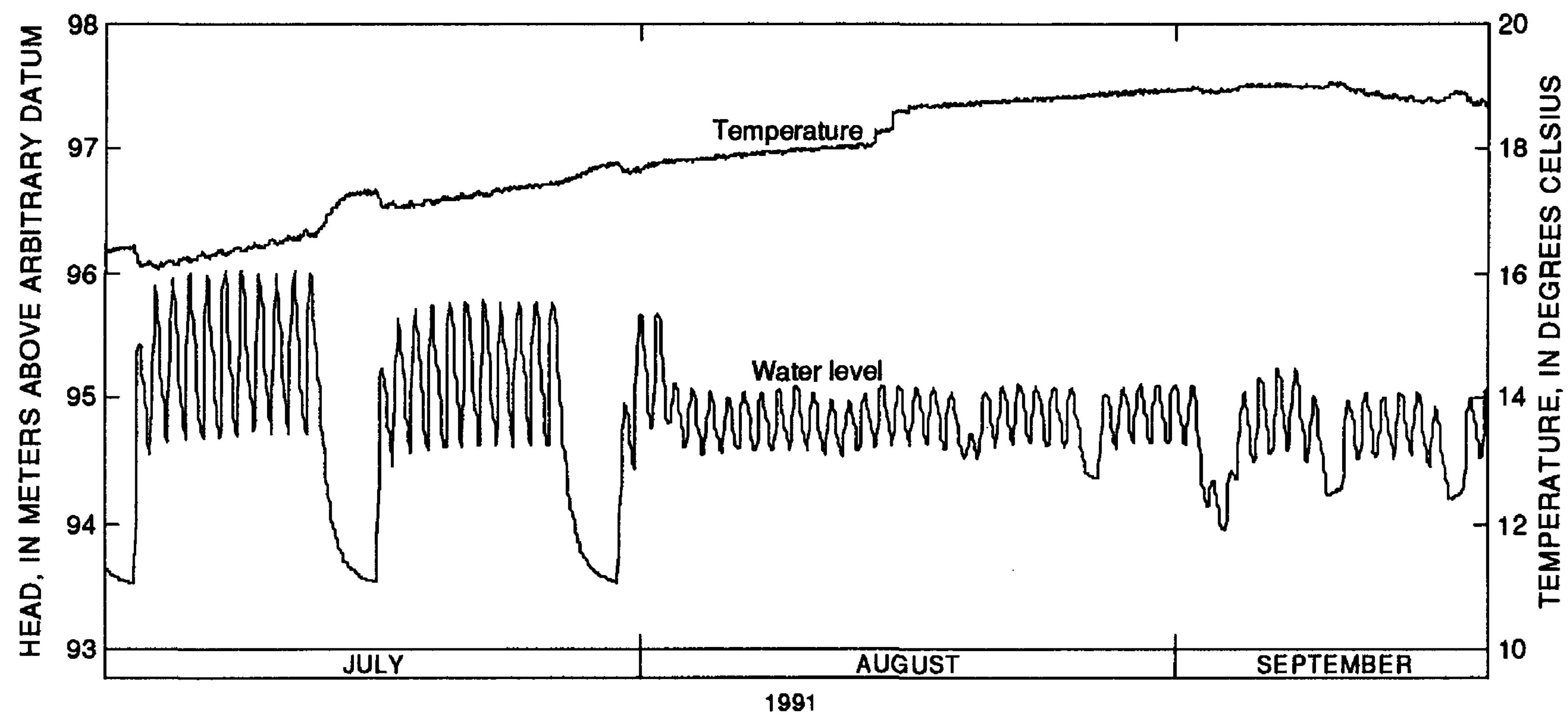

Figure 10. Water-level and water-temperature fluctuations at sensor 56, sandbar 172.3L, downstream from the mouth of National Canyon, July 1 through September 18, 1991.

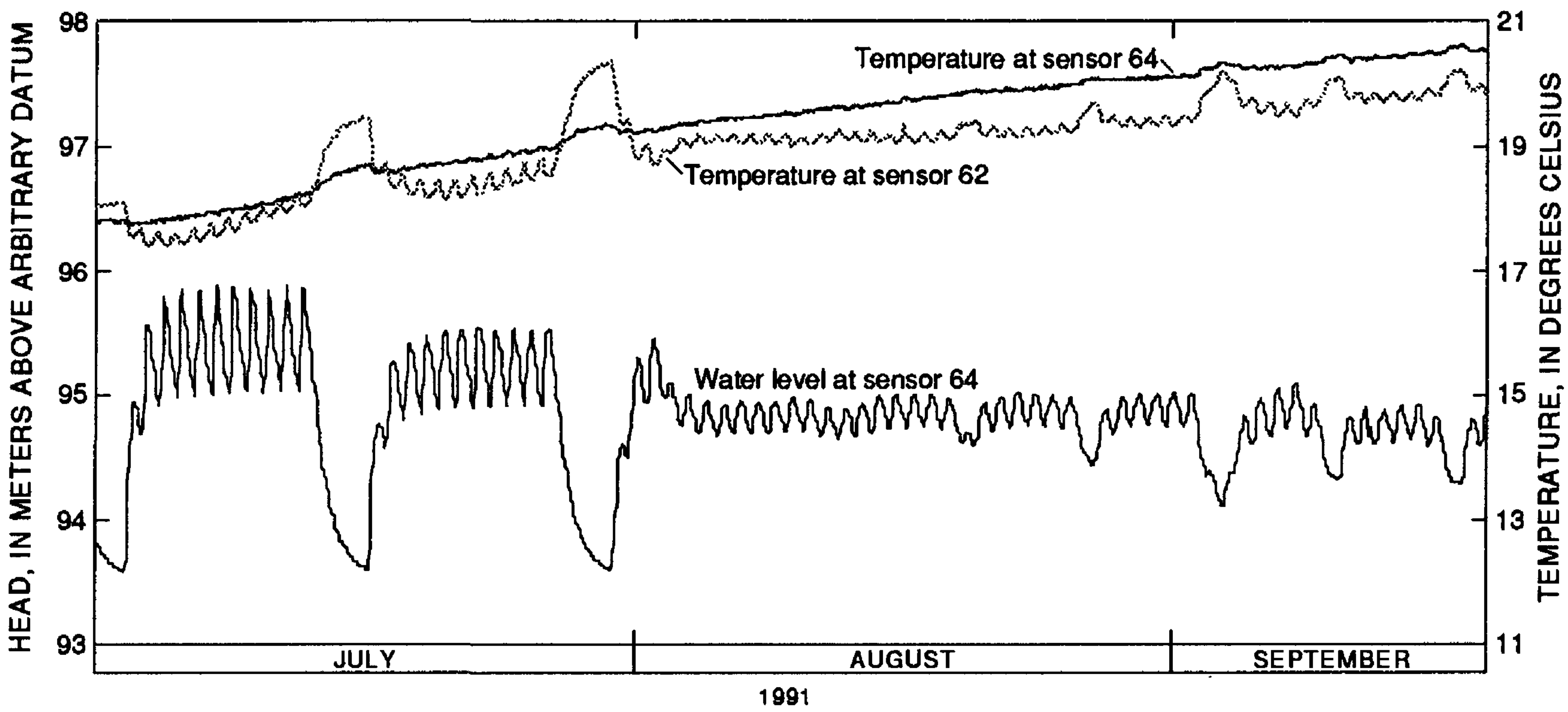

Figure 11. Water-level and water-temperature fluctuations at sensor 64 and water-temperature fluctuations at sensor 62, sandbar 172.3L, downstream from the mouth of National Canyon, July 1 through September 18, 1991.

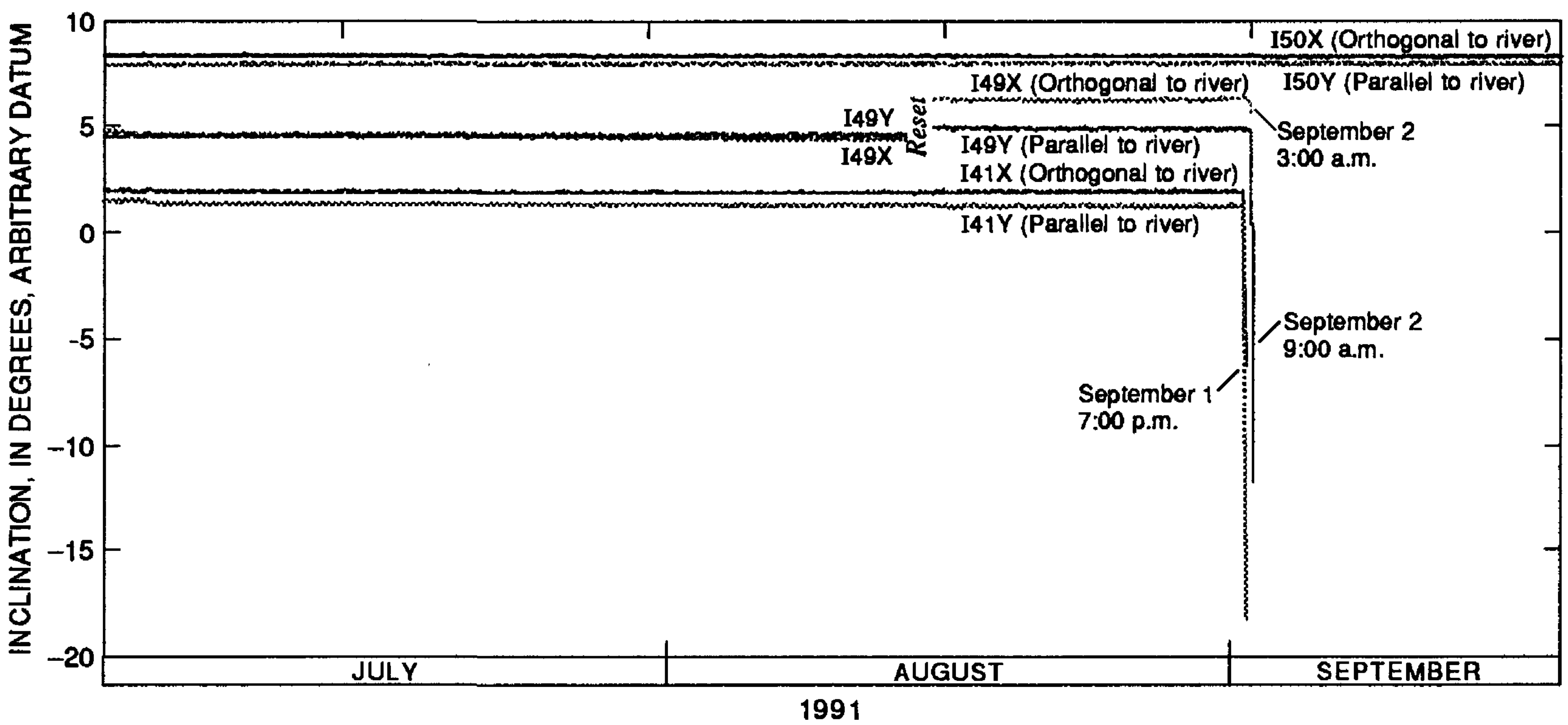

Figure 12. Tilt for sensors I41, I49, and I50 at sandbar 172.3L, downstream from the mouth of National Canyon, July 1 through September 18, 1991.

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