GE Corporate Environmental Programs

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October 22, 1997

Douglas Tomchuk
Remedial Project Manager
U.S. Environmental Protection Agency
290 Broadway
New York, NY 10007

Re: Groundwater Flux - Thompson Island Pool

Dear Mr. Tomchuk:

In the Preliminary Model Calibration report prepared on your behalf by TAMS and Limno-Tech (October, 1996), groundwater movement through the sediments into the overlying water in Thompson Island Pool (TIP) was proposed as a potential mechanism for PCB movement from the sediments. This analysis was based upon assumed conditions not site specific information. Given the potential importance of this mechanism, GE undertook a field study to determine the actual amount of groundwater movement through these sediments. GE requested EPA's participation in this study. EPA declined to participate and did not supply any comments on the proposed work.

Enclosed is a report, documenting the results of the investigation prepared by HSI-GeoTrans, entitled: Investigation of Groundwater Seepage in the Upper Hudson River (October, 1997). The measured groundwater seepage rates are typically an order of magnitude less than that assumed by EPA. In addition, the seepage investigation documented that groundwater discharge into the pool does not always occur over the entire length of the TIP as was assumed by EPA. Based on this information, groundwater upward through the sediments is not a significant mechanism for the transport of PCBs from the sediments to the water column within the TIP. As a result, we recommend that this mechanism not be included in the model being developed on behalf of EPA for PCB movement in the upper Hudson River . We would appreciate the opportunity to review with you and your team, this important data as well the other data we have collected in the TIP.

If you have any questions, let me know. Please place a copy of this letter and the enclosed report into the Site Administrative Record.

Very truly yours,

John G. Haggard/ss

John G. Haggard
Technical Program Manager

JGH/ss

Enclosure

cc: Al D'Bernardo, TAMS
Vic Bierman, Limno-Tech
Steve Hammond, NYS DEC
William Ports, NYS DEC
William McCabe, US EPA

bcc: Mel Schweiger, GE-CEP
Mike Elder, GE-CEP
Jack Guswa, (GeoTrans)
Angus Macbeth, Sidley & Austin
John Connolly, HydroQual

INVESTIGATION OF GROUNDWATER SEEPAGE IN THE UPPER HUDSON RIVER

HSI
GEOTRANS

OCTOBER 16, 1997

312614

Investigation of Groundwater Seepage

in the Upper Hudson River

Prepared for:

General Electric Company

Prepared by:

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HSI GEOTRANS Project No. N082-003

October 16, 1997

HSI GEOTRANS

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1 INTRODUCTION

This report has been prepared by HSI GeoTrans, in association with HydroQual Inc. and O'Brien & Gere Engineers, Inc. on behalf of the General Electric Company (General Electric). This report presents results of the groundwater seepage investigation described in the February 1997 Sampling and Analysis Plan (SAP) entitled "Investigation of Groundwater Seepage in the Thompson Island Pool Section of the Upper Hudson River" (HydroQual, 1997). The study was conducted, in part, to evaluate the U.S. Environmental Protection Agency (U.S. EPA) postulated hypothesis that upward advective transport of groundwater through contaminated sediments can result in a significant source of PCBs to the Thompson Island Pool (TIP) water column.

1.1 BACKGROUND

A low flow PCB concentration in excess of that attributable to sediment diffusive mechanisms has been detected in the Thompson Island Pool (TIP) section of the upper Hudson River since approximately 1991 (HydroQual, 1995). In recent modeling studies, the U.S. EPA has hypothesized that this increased concentration may represent an increased PCB mass load in the river that may be attributed, at least in part, to advective transport of groundwater through contaminated sediment and into the water column of the TIP (U.S. EPA, 1996). The U.S. EPA modeling study hypothesized that an average groundwater discharge flux of 1.3 $L/m^2/hr$ over the area of the TIP (2.35×10^6 m^2) may contribute to the anamolous PCB load detected in the TIP. The estimates prepared by the U.S. EPA were based on literature values for hydraulic conductivity and land surface topography for the regional hydraulic gradient.

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1.2 Objectives

The principal objective of the groundwater seepage investigation was to test the hypothesis that groundwater flux could cause the anomolous TIP PCB loadings through direct measurement of groundwater seepage. The specific objectives of the study included:

- evaluate proposed seepage meter and piezometer construction designs,
- determine the most effective installation, monitoring, and sampling procedures, and
- obtain data on seepage rates and groundwater hydraulic parameters within the TIP.

1.3 Approach

The groundwater seepage investigation occurred between May 28, and August 19, 1997 at six locations within the upper Hudson River. Five of these locations were within Hudson River Reach 8 (TIP) and one within Hudson River Reach 6. Phase I consisted of the installation and feasibility testing of two instruments:

- seepage meters were installed in the river bed at six locations within the upper Hudson River to facilitate measurement of the rate of groundwater flux into the river or the rate of surface water flux out of the river, and
- piezometers were installed in the river sediments adjacent to seepage meters to allow monitoring of the local vertical hydraulic gradient. Selected piezometers were equipped with data loggers to allow regular monitoring of variations in vertical hydraulic gradients following the spring high-flow period.

Phase II consisted of continued monitoring of local vertical hydraulic gradients through the 1997 summer period at sampling locations equipped with data loggers.

2 METHODOLOGY

Piezometers and seepage meters were installed by personnel from HydroQual, O'Brien & Gere Engineers and HSI GeoTrans at five sites (S-1 through S-5) within the TIP and at one site downstream of the TIP (S-6) between May 28 and June 5, 1997 (Figure 2-1). The piezometers and seepage meters at each site were installed about five feet from each other in river water depths of one to three feet. Each site was located adjacent to the river bank, except site S-5 which was located adjacent to the eastern shore of Griffin Island within the TIP. The two seepage meters at each location are identified as upstream or downstream, or east or west, depending on their relative location in the river. A schematic of a monitoring site is shown in Figure 2-2. Each monitoring location was accessed by boat.

2.1 SITE SELECTION

Groundwater seepage within the TIP may be influenced by a number of factors, including sediment type, local topography and groundwater elevations, and by spatial differences in pool elevation upstream of the dams. Six sites, five within Hudson River Reach 8 (TIP) and one within Hudson River Reach 6, covering approximately eight miles of the upper Hudson River, were selected to facilitate the evaluation of spatial variations in groundwater seepage rates. Site selection was based on historic sediment PCB concentrations, sediment texture, shoreline accessibility, and other field logistics.

Site S-1 is located in the H-7 area (1976 NYSDEC Hot Spot 5), adjacent to a shore deposit of dredge spoils and within an area historically associated with elevated PCB concentrations. Site S-2 is located near an eastern shore dredge spoil site, where SideScan Sonar interpretation of the river bed indicated coarse sediments. Site S-3 was selected based on river bed sediment textures and results of water column monitoring which found elevated PCB concentrations within this region of the river (HydroQual, 1996). Fine-grained sediment and high sediment PCB concentrations have also been observed in this region near Hot Spot 8.

Site S-4 is located within Hot Spot 14 and Site S-5, the downstream TIP location, is near the southern tip of Griffin Island. Site S-6 is located downstream of Thompson Island Dam, near Lock 6 on the eastern shore of the river, within sediments historically associated with elevated PCB concentrations (1976 NYSDEC Hot Spot 28). Figure 2-1 shows the location of each of the study sites, and provides a description of typical sediment depth profiles extracted from historical sediment coring information.

2.2 GROUNDWATER SEEPAGE METERS

Measurement of seepage rates between groundwater and the river was conducted using groundwater seepage meters. The seepage meters consisted of a 12-quart cylindrical stainless steel vessel equipped with two 1/4-inch Teflon bulkhead fittings (Figure 2-2). A valve attached with 1/4-inch Teflon tubing to one of the fittings permitted the release of accumulated gasses from within the seepage meter. A sampling bag was attached to the other fitting for seepage rate monitoring. Each seepage meter monitored an area of 0.076 m^2 (0.815 ft^2).

The seepage meters were installed in the Hudson River by pushing their sides six to ten inches into the river bed. The tops of the meters were completely submerged below the water surface and the meters were tilted slightly so that the air release valve was at the high point to allow gas to escape. Seepage flux was measured by attaching a sampling bag, pre-filled with 0.5 to 1.0 L of water, to the bulkhead fitting for a measured length of time, removing it, then measuring the final volume of water in the bag with a graduated cylinder. For data collected after June 5, 1997 the sampling bags were weighed before and after installation to determine the volume change.

2.3 PIEZOMETERS

Piezometers were used to monitor groundwater levels beneath the river bed at each of the six sites (Figure 2-2). Groundwater piezometers S-1, S-3, S-4 and S-6 are constructed of a five foot length of two-inch diameter stainless steel riser pipe and a two foot length of two-inch diameter ten slot (0.010 inch) screen. Groundwater piezometer S-2 has two five-foot lengths of riser pipe, and groundwater piezometer S-5 has three feet of 20 slot (0.020 inch) screen. The screened sections were attached to the riser pipe with a stainless steel threaded coupling sealed with Teflon tape. To aid installation, the ends of each piezometer were equipped with a steel drive point and a driving cap. A sledge hammer was used to drive each piezometer into the river bed until the top of the screen was at least one foot below the sediment/water interface. Following installation, water was bailed from each piezometer to remove sediment that may have accumulated during installation. Piezometer completion information is summarized in Table 2-1.

Water levels in the river were monitored using either a one-inch diameter PVC stilling well or a second piezometer screened within the river water column. A stilling well, consisting of a length of PVC pipe, was attached with electrical tape to the outside of the groundwater piezometers at monitoring locations S-2, S-3 and S-5 to facilitate river water level monitoring. At locations containing data loggers (S-1, S-4 and S-6), a second stainless steel piezometer, with a three foot length of screen was installed. These piezometers were installed in the manner described above for the groundwater piezometers, except that the top of the screen was left exposed to the river.

Temporal changes in hydraulic gradients between the groundwater and the river were monitored at 15 minute intervals using electronic water level data loggers at locations S-1, S-4 and S-6. TROLL dataloggers, manufactured by In-Situ, Inc., were installed in both the surface water and groundwater piezometers at these locations. The TROLL is fully contained in each piezometer and secured with a sealing well cap and Master lock. Each TROLL was programed to record water level data at 15 minute intervals. Depth to water at these monitoring locations, as well as at locations S-2, S-3 and S-5, were measured with an electronic water level meter relative to an arbitrary local datum set on the shore adjacent to the piezometer and established using a surveyors level.

Table 2-1. Piezometer Construction Details

Monitoring Location	Date Installed	Arbitrary Measuring Point Elevation	Depth to River/ Sediment Interface (ft bmp)	Screen Depth Relative to Top of Stainless Steel Riser Pipe		Screen Depth Relative to River/Sediment Interface		Installed Total Depth (ft bmp)	Installed Total Depth (ft Below River/Sediment Interface)
				Top	Bottom	Top*	Bottom		
S-1 Groundwater	28 May 1997	101.96	3.7	5.3	7.3	1.6	3.6	7.8	4.1
S-1 River	28 May 1997	103.81	5.7	5.3	8.3	-0.4	2.6	8.8	3.2
S-2 Groundwater	28 May 1997	102.04	4.8	10.4	12.4	5.6	7.6	13.9	9.1
S-3 Groundwater	28 May 1997	100.93	3.2	5.3	7.3	2.1	4.1	7.8	4.7
S-4 Groundwater	28 May 1997	102.04	4.1	5.3	7.3	1.2	3.2	7.8	3.7
S-4 River	28 May 1997	104.10	6.2	5.3	8.3	-0.9	2.1	8.8	2.6
S-5 Groundwater	5 June 1997	102.13	3.9	5.4	8.4	1.5	4.5	8.9	5.0
S-6 Groundwater	29 May 1997	101.44	3.4	5.3	7.3	1.9	3.9	7.8	4.4
S-6 River	29 May 1997	103.43	5.3	5.3	8.3	-0.1	2.9	8.8	3.4

Notes:

1. All depths are expressed in feet.
2. "ft bmp" designates feet below measuring point (i.e., feet below the top of the stainless steel riser pipe.)
3. "*" A negative value indicates top of screen is above river/sediment interface.
4. Arbitrary measuring point elevation is based on an assumed river elevation of 100 feet plus the length of the stainless steel riser pipe stickup at the time of setup.

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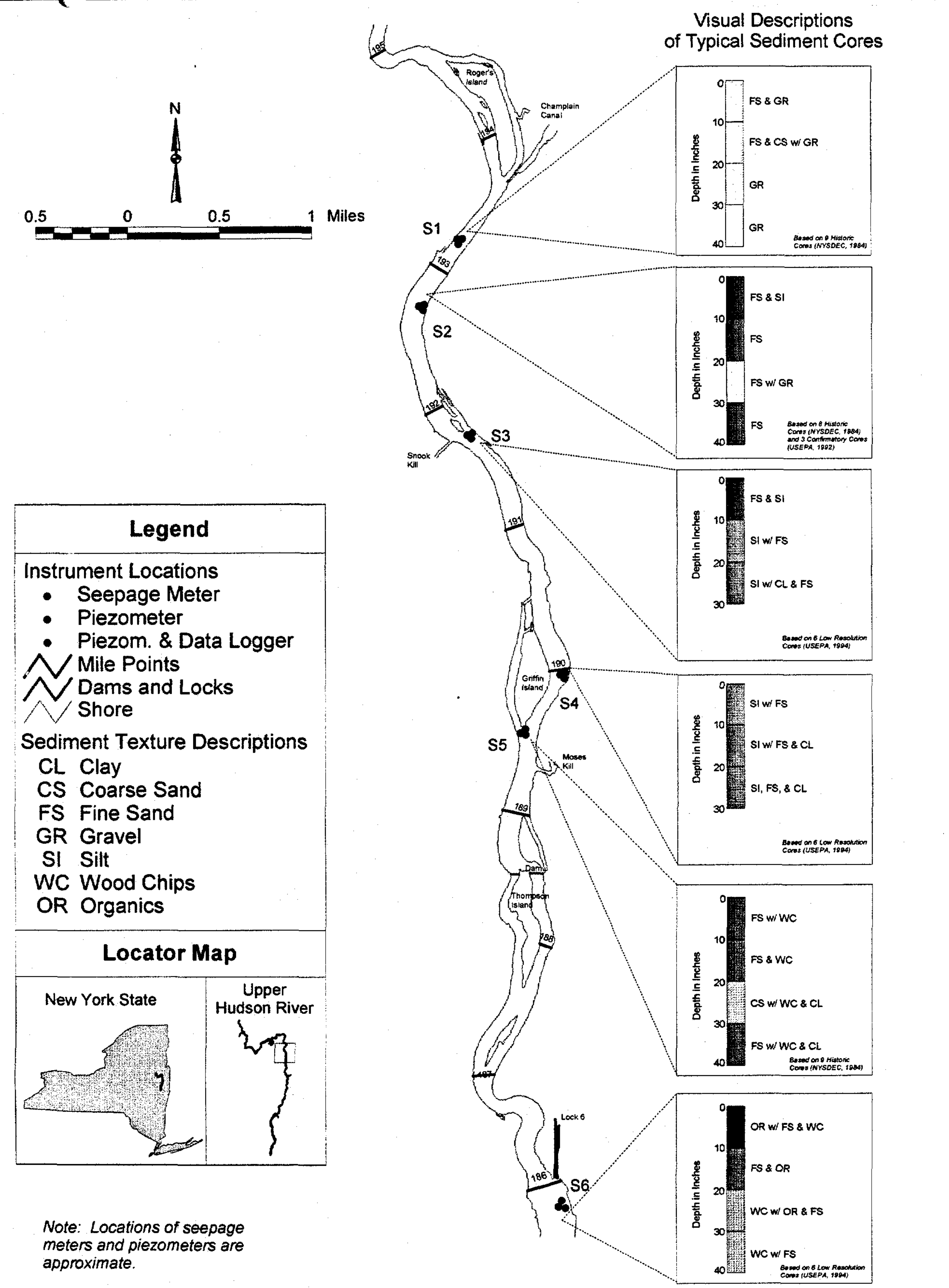

Figure 2-1. Groundwater Seepage Monitoring Stations and Sediment Core Visual Descriptions

HydroQual, Inc. September, 1997

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DATE: SEPTEMBER 17, 1997

I:\DIV52\PROJECTS\612.226\DWG\FIG2-2

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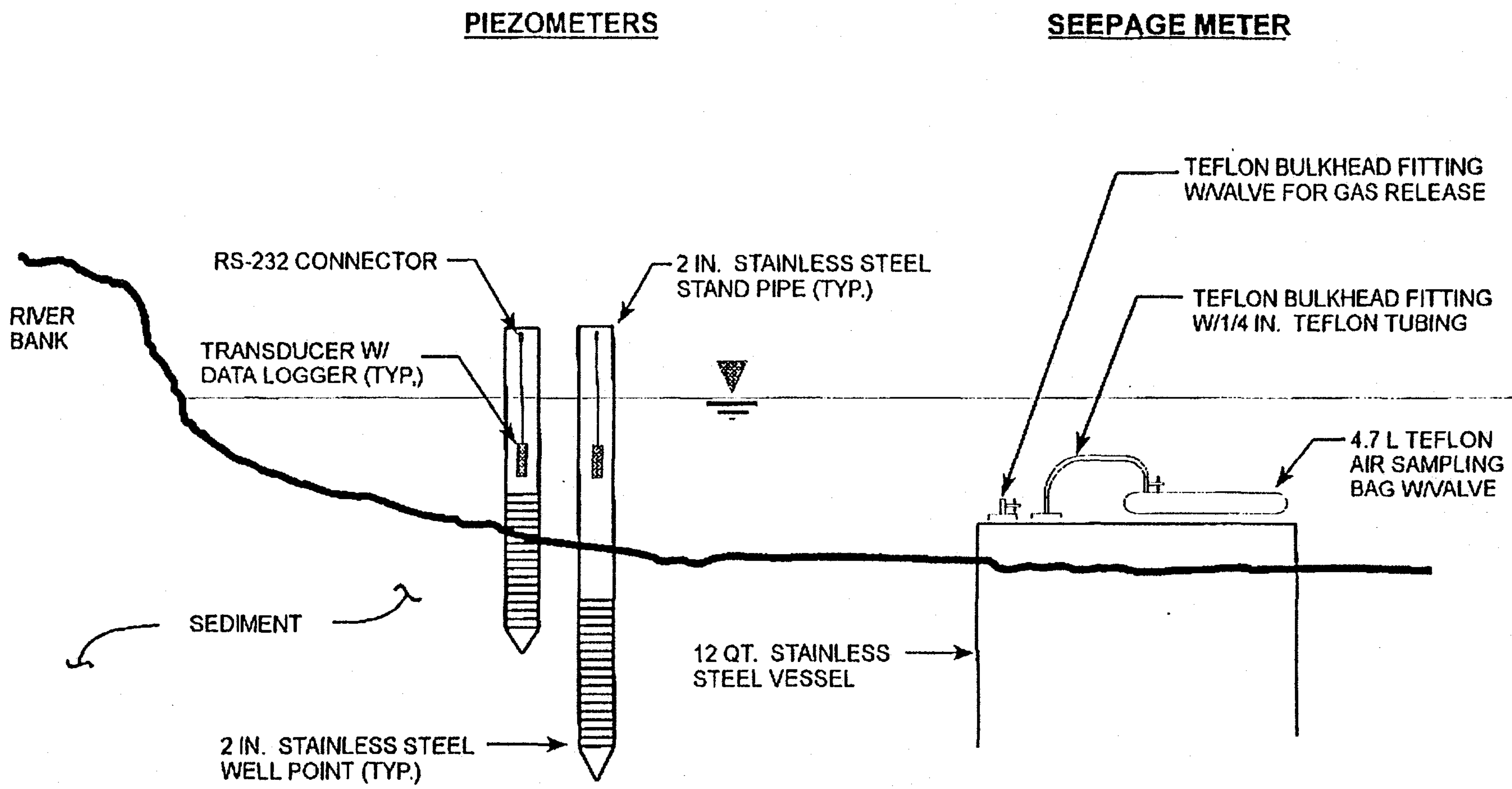

GENERAL ELECTRIC COMPANY
HUDSON RIVER PROJECT

TYPICAL PIEZOMETER/SEEPAGE METER INSTALLATION

NOT TO SCALE

O'BRIEN & GERE ENGINEERS INC.

FIGURE 2-2

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3 RESULTS AND DISCUSSION

Between May 28 and August 19, 1997, between three and five seepage rate measurements were made at the six monitoring locations. Between five and seven times, hand water level measurements of the river and groundwater piezometers were also made at these locations. (Tables 3-1 through 3-3). In addition, data loggers recorded river and groundwater levels at 15 minute intervals between May 29 and August 19, 1997 at monitoring locations S-1, S-4 and S-6 (Figures 3-1 through 3-9).

3.1 GENERAL OBSERVATIONS

In general, seepage measurements, hand measured water levels, and data logger water levels produced consistent information with regard to groundwater seepage in the upper Hudson River (Figures 3-1 through 3-12, Tables 3-1 through 3-3). That is, the water levels and seepage rates both indicate water movement in the same direction. A positive hydraulic gradient and a positive seepage rate both indicate groundwater seepage to the river. A negative hydraulic gradient and a negative seepage rate both indicate seepage from the river to groundwater. There were occasions, however, when vertical hydraulic gradients and seepage measurements were inconsistent. In addition, there were occasions when the two seepage meters at the same monitoring site measured water movement in opposite directions. These observations suggest that there was some uncertainty in the seepage data, possibly related to rapidly fluctuating river levels or seepage measurements at or near the detection limit of the meters. Nonetheless, the general consistency in the measurements and their predictable relationship with time and space, as discussed below, indicates that these measurements can be used to provide reasonable estimates of groundwater seepage.

3.2 Temporal Fluctuations

Data collected during the groundwater seepage investigation indicate that vertical hydraulic gradients and seepage rates vary temporally within the upper Hudson River. The short term fluctuations in the vertical hydraulic gradients illustrated by the data logger data from sites S-1, S-4 and S-6 (Figures 3-10 through 3-12) indicate that frequent water level measurements are required to understand the nature of the groundwater-surface water interaction in the upper Hudson River. The infrequent hand measurements from the other sites (S-2, S-3 and S-5) are not sufficient to get a complete picture of the temporal variability of the groundwater-surface water interaction. The data logger data from sites S-1, S-4 and S-6 show that the vertical hydraulic gradients fluctuate continuously. The vertical hydraulic gradient at site S-1 remained positive over the entire monitoring period, but its magnitude varied considerably over the course of a day. At sites S-4 and S-6, not only the magnitude of the gradient varied, but the direction was reversed over the course of a day.

The long term temporal variability in the vertical hydraulic gradient is best illustrated by the data logger data for location S-1 (Figures 3-10 through 3-12). The average vertical hydraulic gradient at site S-1 was 0.016 from the end of May until about June 4, 1997. On June 5, 1997 the vertical gradient increased to about 0.115, where it remained through about June 13, 1997. The increase in vertical hydraulic gradient coincided with a significant drop in the river water level. As illustrated on Figure 3-1, the predominant stage of the river piezometer at site S-1 dropped two to three feet between June 5 and June 10, 1997. From about June 14 through August 19, 1997, the vertical hydraulic gradient at S-1 fluctuated daily, remaining positive, with an average of 0.031.

The vertical hydraulic gradients measured at sites S-4 and S-6 exhibit a similar, but less dramatic pattern to that observed at S-1. The average vertical hydraulic gradient at S-4 was -0.002 from the end of May until June 4, 1997, then increased to about 0.007 through June 13, 1997. The gradient then decreased to an average of -0.038 through August 19,

1997. The average vertical hydraulic gradient at S-6 was 0.003 from the end of May through June 13, 1997 then decreased to an average of -0.008 through August 19, 1997.

The seepage data exhibits a similar long term temporal pattern to that described above for the vertical hydraulic gradient data. Figure 3-13 shows that the seepage flux decreased over the monitoring period. At the end of May, most of the seepage rates were positive (river gain), while by June 18, 1997, most of the rates had become negative (river loss). Short term temporal patterns in the seepage data were not observed since each measurement occurred over many hours to a few days.

3.3 SPATIAL PATTERNS

Data collected during the groundwater seepage investigation indicates that vertical hydraulic gradients and seepage rates also vary spatially within the upper Hudson River. The largest positive vertical hydraulic gradients, indicating seepage into the river, were measured at Site S-1, at the upstream end of the TIP. The average vertical hydraulic gradient at S-1, between May 28, and August 19, 1997, was 0.042. The gradients determined from the hand water level measurements indicate that the magnitude of the positive vertical hydraulic gradient decreases in the downstream direction within TIP, and was negative, indicating seepage out of the river, at sites S-3, S-4, and S-5 for much of the monitoring period. The average vertical hydraulic gradient at S-4 for the monitoring period was -0.030. Vertical hydraulic gradients measured at site S-6, just downstream of the Thompson Island Dam, were near zero, with an average of -0.006.

The seepage data exhibits a similar spatial pattern to that described above for the vertical hydraulic gradient data. Figure 3-14, a plot of the seepage flux versus river mile location, shows that the seepage flux decreases from the upstream end to the downstream end of the TIP. This distribution of seepage flux conforms to the typical hydraulic conditions exhibited upstream of a dam. That is, the rate of groundwater seepage into a pool behind a dam decreases as one approaches the dam, and eventually becomes negative, causing water to flow under or around the dam.

3.4 COMPARISON TO U.S. EPA HYPOTHESIZED FLUX RATE

The vertical hydraulic gradient data, seepage flux data and hydraulic conductivity data collected during Phase I of the groundwater seepage investigation were compared to the parameter estimates used by the U.S. EPA for their groundwater seepage hypothesis (U.S. EPA, 1996). The critical parameters were hydraulic gradient, hydraulic conductivity, and cross-sectional area. The U.S. EPA assumed a uniform hydraulic gradient of 0.02 over the full area of the TIP. The U.S. EPA estimate was based on topographic slopes adjacent to the river. It is not clear why horizontal topographic slope was used to estimate vertical hydraulic gradient. The vertical hydraulic gradients measured between May 28 and June 19, 1997 within TIP were highly variable and ranged from a negative gradient of -0.284 (river loss) to a positive gradient of 0.238 (river gain). The measured vertical hydraulic gradient was found to vary both spatially and temporally. Only the upstream end of the TIP had positive gradients and the large positive gradients were of a short duration, from about June 5 through June 13, 1997 (Figures 3-10 through 3-12).

The U.S. EPA assumed an estimated hydraulic conductivity of about 28 ft/day. The estimated hydraulic conductivities calculated using the field data, range from nearly zero to 4.14 ft/day. Vertical hydraulic conductivities of the river bed sediments were estimated using the seepage fluxes and vertical hydraulic gradients measured at each site. Darcy's law states that the volumetric flux rare is directly proportional to the hydraulic conductivity and the hydraulic gradient. Table 3-4 shows the estimated hydraulic conductivity associated with each seepage measurement, while Table 3-5 summarizes the range of estimated hydraulic conductivities for each monitoring site. Though the data are somewhat sparse, there seems to be correlation between the type of sediment at each location and the estimated hydraulic conductivity. This suggests that, as expected, the seepage rate within TIP will be dependent, in part, on sediment type.

The U.S. EPA has also assumed that groundwater seepage into the TIP occurred over the entire area of the TIP. Data collected during this seepage investigation indicates that it is not appropriate to assume that groundwater is seeping in the river over the entire area of the TIP. As previously discussed, the river was losing water to groundwater over much of the length of the TIP.

Using the assumed values for the three parameters, the U.S. EPA hypothesized an average seepage flux into the river of 1.3 $L/m^2/hr$ for the entire area of the TIP (2.53E7 ft^2). Measured seepage fluxes ranged from -0.248 to 0.505 $L/m^2/hr$, but were generally an order of magnitude below these estimates. As with the vertical hydraulic gradients, the measured seepage fluxes were found to vary both spatially and temporally within the TIP. Only the upstream portion of the TIP had positive seepage fluxes (Figure 3-14) and the magnitude of the fluxes decreased in the downstream direction, becoming negative, indicating loss from the river. Positive seepage fluxes were found to decrease temporally as well (Figure 3-13). The highest gains to the river were measured in late-May and early-June. By mid-June, the majority of the seepage fluxes were near zero, or were negative, indicating loss from the river.

Table 3-1. Groundwater Seepage Rates 5/28/97-6/5/97

MONITORING LOCATION	START TIME	END TIME	START VOLUME (ML)	END VOLUME (ML)	SEEPAGE RATE (L/M^2/HR)*
S-1 Upstream	5/28/97 12:30	5/29/97 16:46	1000	NA	NA
S-1 Downstream	5/28/97 12:50	5/29/97 16:46	1000	1805	0.381
S-2 Upstream	5/28/97 14:18	5/29/97 16:08	1000	1400	0.205
S-2 Downstream	5/28/97 14:18	5/29/97 16:08	1000	1615	0.314
S-3 Upstream	5/28/97 15:20	5/29/97 15:22	1000	1000	0.000
S-3 Downstream	5/28/97 15:20	5/29/97 15:22	1000	610	-0.214
S-4 Upstream	5/28/97 16:54	5/29/97 13:37	1000	890	-0.070
S-4 Downstream	5/28/97 16:54	5/29/97 13:37	1000	1010	0.006
S-5 Upstream	NA	NA	NA	NA	NA
S-5 Downstream	NA	NA	NA	NA	NA
S-6 East	NA	NA	NA	NA	NA
S-6 West	NA	NA	NA	NA	NA
S-1 Upstream	5/29/97 17:07	5/30/97 12:45	1000	NA	NA
S-1 Downstream	5/29/97 17:07	5/30/97 12:45	1000	1750	0.505
S-2 Upstream	5/29/97 16:31	5/30/97 12:25	1000	1560	0.372
S-2 Downstream	5/29/97 16:31	5/30/97 12:25	1000	1470	0.312
S-3 Upstream	5/29/97 15:49	5/30/97 12:00	1000	1130	0.085
S-3 Downstream	5/29/97 15:49	5/30/97 12:00	1000	1750	0.491
S-4 Upstream	5/29/97 14:28	5/30/97 10:55	1000	NA	NA
S-4 Downstream	5/29/97 14:28	5/30/97 10:55	1000	1050	0.032
S-5 Upstream	NA	NA	NA	NA	NA
S-5 Downstream	NA	NA	NA	NA	NA
S-6 East	5/29/97 11:16	5/30/97 9:10	1000	1320	0.193
S-6 West	5/29/97 11:16	5/30/97 9:10	1000	1220	0.133
S-1 Upstream	6/3/97 19:15	6/5/97 15:10	1000	980	-0.01 **
S-1 Downstream	6/3/97 19:15	6/5/97 15:15	1000	1000	0.00 **
S-2 Upstream	6/3/97 18:52	6/5/97 15:55	1000	1000	0.00 **
S-2 Downstream	6/3/97 18:52	6/5/97 16:00	1000	1530	0.155
S-3 Upstream	6/3/97 18:02	6/5/97 12:00	1000	1210	0.066
S-3 Downstream	6/3/97 18:02	6/5/97 12:05	1000	1900	0.283
S-4 Upstream	6/3/97 17:32	6/5/97 11:32	1000	NA	NA
S-4 Downstream	6/3/97 17:32	6/5/97 11:37	1000	1000	0.000
S-5 Upstream	6/3/97 17:00	6/5/97 11:00	1000	640	-0.113
S-5 Downstream	6/3/97 17:00	6/5/97 11:05	1000	470	-0.166
S-6 East	NA	NA	NA	NA	NA
S-6 West	NA	NA	NA	NA	NA

Notes:

1. "NA" Designates not applicable.
2. "*" Positive seepage rate indicates a gain to the river.
3. "**" Tedlar bag used for this measurement.

Table 3-2. Groundwater Seepage Rates 6/16/97-6/19/97

MONITORING LOCATION	START TIME	END TIME	START WEIGHT (GRAMS)	END WEIGHT (GRAMS)	SEEPAGE RATE (L/M^2/HR)*
S-1 Upstream	6/16/97 20:42	6/18/97 17:25	605.7	1022.3	0.123
S-1 Downstream	6/16/97 20:42	6/18/97 17:25	617.4	342.4	-0.081
S-2 Upstream	6/16/97 20:24	6/18/97 17:10	606.8	486.5	-0.035
S-2 Downstream	6/16/97 20:24	6/18/97 17:10	614.0	503.1	-0.033
S-3 Upstream	6/16/97 20:10	6/18/97 16:55	610.2	542.1	-0.020
S-3 Downstream	6/16/97 20:10	6/18/97 16:55	612.0	628.3	0.005
S-4 Upstream	6/16/97 19:38	6/18/97 15:35	615.6	215.0	-0.120
S-4 Downstream	6/16/97 19:38	6/18/97 15:35	614.2	603.6	-0.003
S-5 Upstream	6/16/97 19:23	6/18/97 15:15	604.6	153.8	-0.136
S-5 Downstream	6/16/97 19:23	6/18/97 15:15	611.8	183.7	-0.129
S-6 East	6/16/97 18:45	6/18/97 10:00	500.0	70.0	-0.145
S-6 West	6/16/97 18:45	6/18/97 10:00	500.0	70.0	-0.145
S-1 Upstream	6/18/97 17:30	6/19/97 15:30	1022.3	1143.0	0.072
S-1 Downstream	6/18/97 17:30	6/19/97 15:30	342.4	389.0	0.028
S-2 Upstream	6/18/97 17:15	6/19/97 15:18	486.5	512.0	0.015
S-2 Downstream	6/18/97 17:15	6/19/97 15:18	503.1	447.5	-0.033
S-3 Upstream	6/18/97 17:00	6/19/97 14:14	542.1	548.0	0.004
S-3 Downstream	6/18/97 17:00	6/19/97 14:14	628.3	637.0	0.005
S-4 Upstream	6/18/97 16:07	6/19/97 13:40	648.0	682.5	0.021
S-4 Downstream	6/18/97 16:07	6/19/97 13:40	592.2	537.5	-0.034
S-5 Upstream	6/18/97 15:25	6/19/97 13:22	662.5	371.5	-0.175
S-5 Downstream	6/18/97 15:25	6/19/97 13:22	684.0	510.0	-0.105
S-6 East	6/18/97 10:45	6/19/97 11:06	634.9	401.0	-0.127
S-6 West	6/18/97 10:45	6/19/97 11:06	631.0	174.5	-0.248

Notes:

"*" Positive seepage rate indicates a gain to the river.

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Table 3-3. Vertical Hydraulic Gradients

Monitoring Location	29-May-97		30-May-97		5-Jun-97		16-Jun-97		18-Jun-97		19-Jun-97		19-Aug-97	
	Water Level Elevation	Vertical Hydraulic Gradient	Water Level Elevation	Vertical Hydraulic Gradient	Water Level Elevation	Vertical Hydraulic Gradient	Water Level Elevation	Vertical Hydraulic Gradient	Water Level Elevation	Vertical Hydraulic Gradient	Water Level Elevation	Vertical Hydraulic Gradient	Water Level Elevation	Vertical Hydraulic Gradient
S-1 Groundwater	100.08	0.033	100.26	0.024	100.02	0.037	99.74	0.016	100.08	0.024	100.08	0.020	99.61	0.029
S-1 River	100.00		100.20		99.93		99.70		100.02		100.03		99.54	
S-2 Groundwater	100.19	0.029	100.01	0.024	99.81	0.008	99.52	0.011	99.78	-0.002	99.80	0.003	99.38	0.008
S-2 River	100.00		99.85		99.76		99.45		99.79		99.78		99.33	
S-3 Groundwater	100.06	0.019	99.83	0.006	99.62	0.013	99.40	-0.003	99.70	-0.006	99.61	-0.016	99.28	-0.010
S-3 River	100.00		99.81		99.58		99.41		99.72		99.66		99.31	
S-4 Groundwater	100.06	0.074	99.69	-0.005	99.69	0.056	99.24	-0.051	99.33	-0.139	99.42	-0.093	99.36	0.056
S-4 River	99.90		99.70		99.57		99.35		99.63		99.62		99.24	
S-5 Groundwater	NA	NA	NA	NA	99.95	-0.013	99.76	0.000	99.98	0.000	99.97	-0.007	99.64	0.010
S-5 River	NA	NA	NA	NA	99.99		99.76		99.98		99.99		99.61	
S-6 Groundwater	100.30	0.124	99.93	0.047	99.91	0.030	99.66	0.003	99.73	0.013	99.86	0.013	99.53	-0.017
S-6 River	99.93		99.79		99.82		99.65		99.69		99.82		99.58	

Notes:

1. "NA" Designates not applicable
2. All elevations are based on the assigned measuring point elevation.

Table 3-4. Estimated hydraulic conductivity

Monitoring Location	Start Time	End Time	Seepage Rate (L/M^2/HR)	Vertical Hydraulic Gradient	Estimated K (FT/DAY)
S-1 Upstream	5/28/97 12:30	5/29/97 16:46	NA	0.033	NA
S-1 Downstream	5/28/97 12:50	5/29/97 16:46	0.381	0.033	0.92
S-1 Upstream	5/29/97 17:07	5/30/97 12:45	NA	0.029	NA
S-1 Downstream	5/29/97 17:07	5/30/97 12:45	0.505	0.029	1.39
S-1 Upstream	6/3/97 19:15	6/5/97 15:10	-0.01 **	0.037	NA
S-1 Downstream	6/3/97 19:15	6/5/97 15:15	0.00 **	0.037	NA
S-1 Upstream	6/16/97 20:42	6/18/97 17:25	0.123	0.020	0.47
S-1 Downstream	6/16/97 20:42	6/18/97 17:25	-0.081	0.020	OG
S-1 Upstream	6/18/97 17:30	6/19/97 15:30	0.072	0.022	0.25
S-1 Downstream	6/18/97 17:30	6/19/97 15:30	0.028	0.022	0.10
S-2 Upstream	5/28/97 14:18	5/29/97 16:08	0.205	0.029	0.56
S-2 Downstream	5/28/97 14:18	5/29/97 16:08	0.314	0.029	0.86
S-2 Upstream	5/29/97 16:31	5/30/97 12:25	0.372	0.027	1.10
S-2 Downstream	5/29/97 16:31	5/30/97 12:25	0.312	0.027	0.93
S-2 Upstream	6/3/97 18:52	6/5/97 15:55	0.00 **	0.008	NA
S-2 Downstream	6/3/97 18:52	6/5/97 16:00	0.155	0.008	1.61
S-2 Upstream	6/16/97 20:24	6/18/97 17:10	-0.035	0.005	OG
S-2 Downstream	6/16/97 20:24	6/18/97 17:10	-0.033	0.005	OG
S-2 Upstream	6/18/97 17:15	6/19/97 15:18	0.015	0.001	1.59
S-2 Downstream	6/18/97 17:15	6/19/97 15:18	-0.033	0.001	OG
S-3 Upstream	5/28/97 15:20	5/29/97 15:22	0.000	0.019	0.00
S-3 Downstream	5/28/97 15:20	5/29/97 15:22	-0.214	0.019	OG
S-3 Upstream	5/29/97 15:49	5/30/97 12:00	0.085	0.013	0.52
S-3 Downstream	5/29/97 15:49	5/30/97 12:00	0.491	0.013	3.00
S-3 Upstream	6/3/97 18:02	6/5/97 12:00	0.066	0.013	0.40
S-3 Downstream	6/3/97 18:02	6/5/97 12:05	0.283	0.013	1.73
S-3 Upstream	6/16/97 20:10	6/18/97 16:55	-0.020	-0.005	0.33
S-3 Downstream	6/16/97 20:10	6/18/97 16:55	0.005	-0.005	OG
S-3 Upstream	6/18/97 17:00	6/19/97 14:14	0.004	-0.011	OG
S-3 Downstream	6/18/97 17:00	6/19/97 14:14	0.005	-0.011	OG

Table 3-4. (Continued)

MONITORING LOCATION	START TIME	END TIME	SEEPAGE RATE (L/M^2/HR)	VERTICAL HYDRAULIC GRADIENT	ESTIMATED K (FT/DAY)
S-4 Upstream	5/28/97 16:54	5/29/97 13:37	-0.070	0.074	OG
S-4 Downstream	5/28/97 16:54	5/29/97 13:37	0.006	0.074	0.01
S-4 Upstream	5/29/97 14:28	5/30/97 10:55	NA	0.035	NA
S-4 Downstream	5/29/97 14:28	5/30/97 10:55	0.032	0.035	0.07
S-4 Upstream	6/3/97 17:32	6/5/97 11:32	NA	0.056	NA
S-4 Downstream	6/3/97 17:32	6/5/97 11:37	0.000	0.056	0.00
S-4 Upstream	6/16/97 19:38	6/18/97 15:35	-0.120	-0.095	0.10
S-4 Downstream	6/16/97 19:38	6/18/97 15:35	-0.003	-0.095	0.00
S-4 Upstream	6/18/97 16:07	6/19/97 13:40	0.021	-0.116	OG
S-4 Downstream	6/18/97 16:07	6/19/97 13:40	-0.034	-0.116	0.02
S-5 Upstream	NA	NA	NA	NA	NA
S-5 Downstream	NA	NA	NA	NA	NA
S-5 Upstream	NA	NA	NA	NA	NA
S-5 Downstream	NA	NA	NA	NA	NA
S-5 Upstream	6/3/97 17:00	6/5/97 11:00	-0.113	-0.013	0.67
S-5 Downstream	6/3/97 17:00	6/5/97 11:05	-0.166	-0.013	0.98
S-5 Upstream	6/16/97 19:23	6/18/97 15:15	-0.136	0.000	OG
S-5 Downstream	6/16/97 19:23	6/18/97 15:15	-0.129	0.000	OG
S-5 Upstream	6/18/97 15:25	6/19/97 13:22	-0.175	-0.003	4.14
S-5 Downstream	6/18/97 15:25	6/19/97 13:22	-0.105	-0.003	2.47
S-6 East	NA	NA	NA	NA	NA
S-6 West	NA	NA	NA	NA	NA
S-6 East	5/29/97 11:16	5/30/97 9:10	0.193	0.085	0.18
S-6 West	5/29/97 11:16	5/30/97 9:10	0.133	0.085	0.12
S-6 East	NA	NA	NA	0.030	NA
S-6 West	NA	NA	NA	0.030	NA
S-6 East	6/16/97 18:45	6/18/97 10:00	-0.145	0.008	OG
S-6 West	6/16/97 18:45	6/18/97 10:00	-0.145	0.008	OG
S-6 East	6/18/97 10:45	6/19/97 11:06	-0.127	0.013	OG
S-6 West	6/18/97 10:45	6/19/97 11:06	-0.248	0.013	OG

Notes:
"NA" Designates not applicable.
"OG" Designates seepage and hydraulic gradient in opposite directions.
"**" Tedlar bag used for this measurement.

Table 3-5. Estimated hydraulic conductivity summary

Monitoring Location	Predominant Sediment Texture *	Minimum	Maximum	Average
S-1	Fine Sand and Gravel	0.10	1.39	0.63
S-2	Fine Sand	0.56	1.61	1.11
S-3	Fine Sand and Silt	0.00	3.00	1.00
S-4	Silt, Fine Sand, and Clay	0.00	0.10	0.03
S-5	Fine Sand, Wood Chips	0.67	4.14	2.07
S-6	Fine Sand, Wood Chips, Organics	0.12	0.18	0.15

Note:
* = See Figure 2-1 for details.

Figure 3-1. Hydrograph for piezometer pair S-1, 5/29/97 - 6/28/97

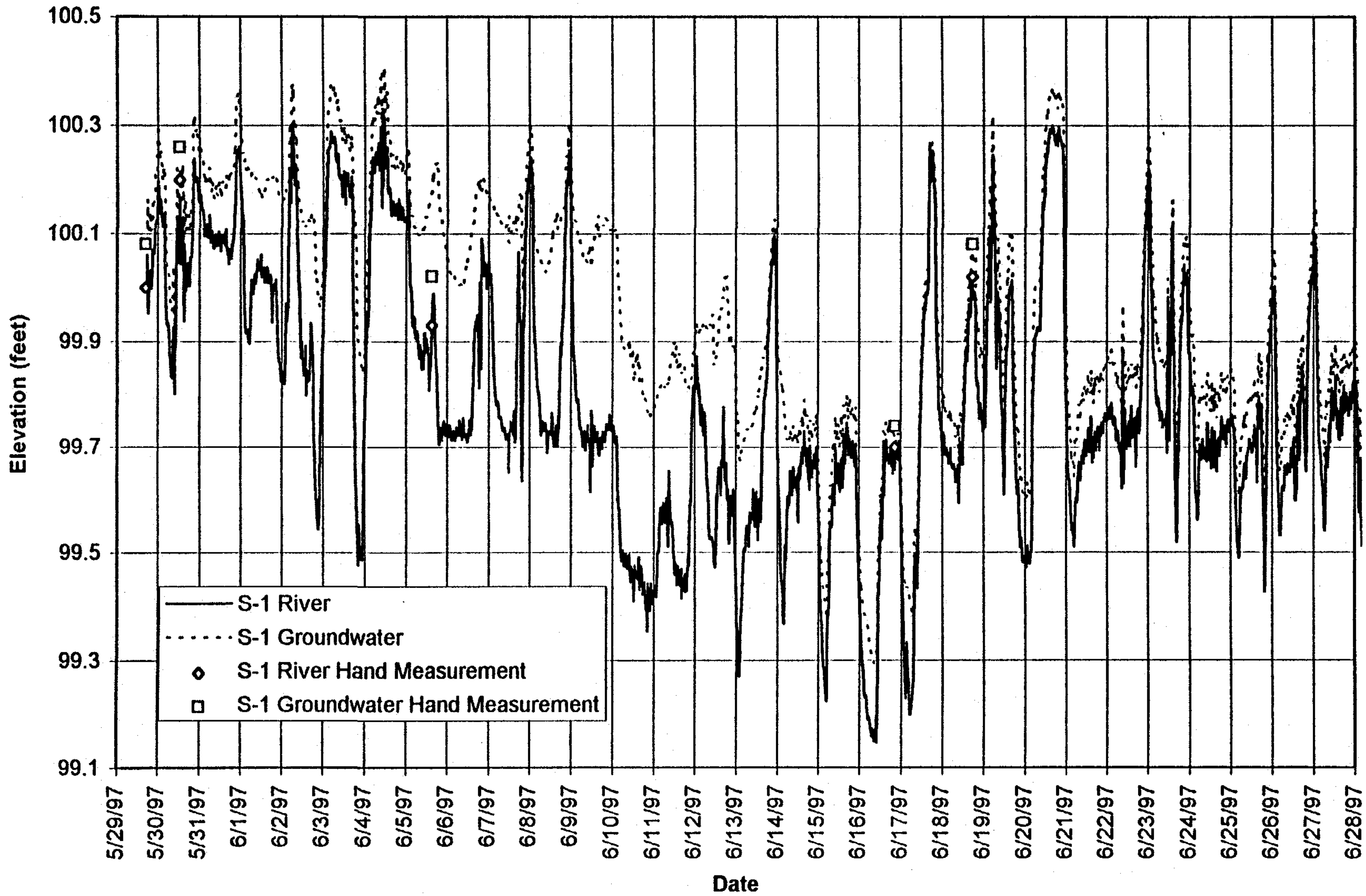

Figure 3-2 Hydrograph for piezometer pair S-1, 6/28/97 - 7/28/97

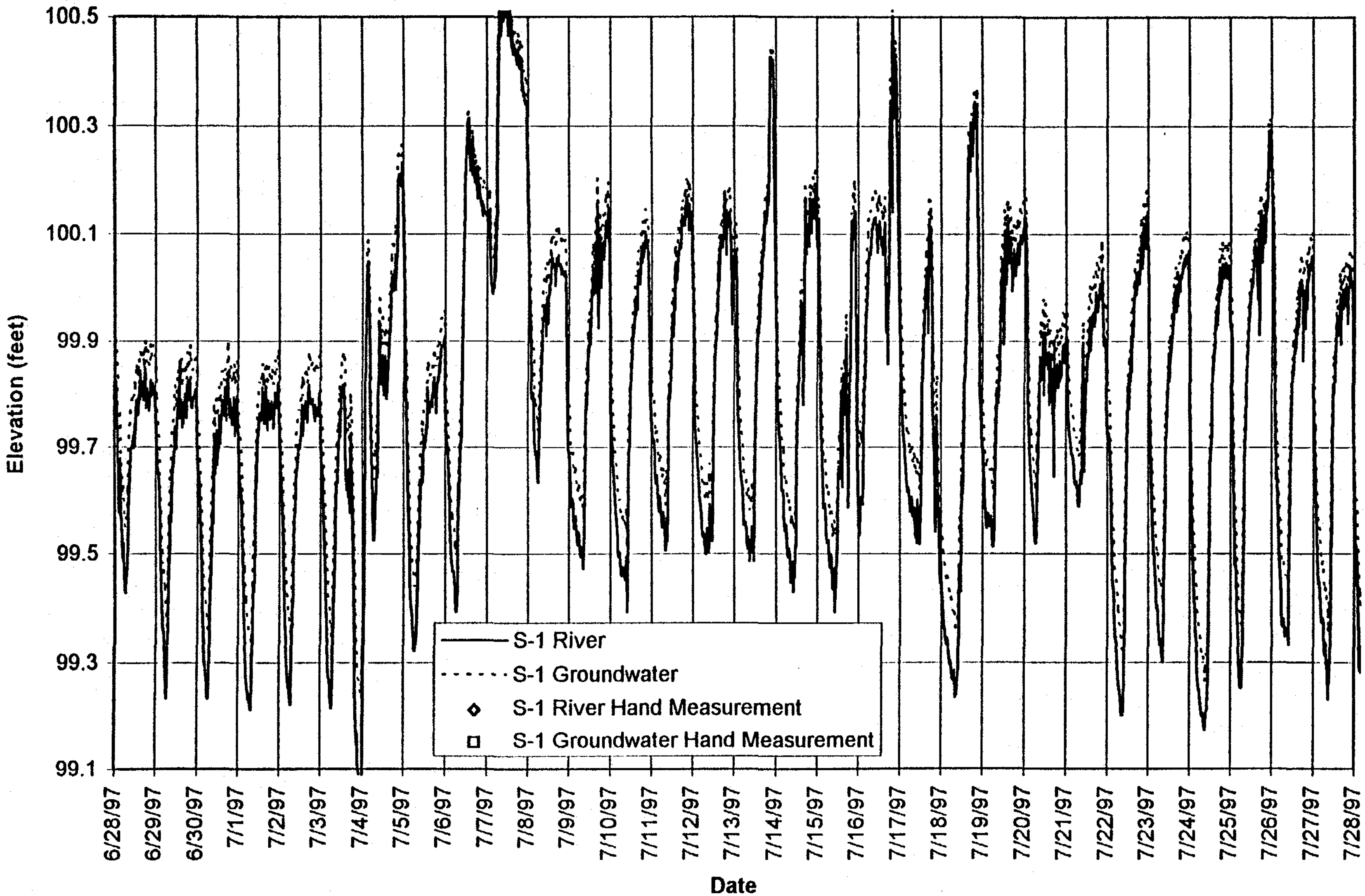

Figure 3-3 Hydrograph for piezometer pair S-1, 7/28/97 - 8/20/97

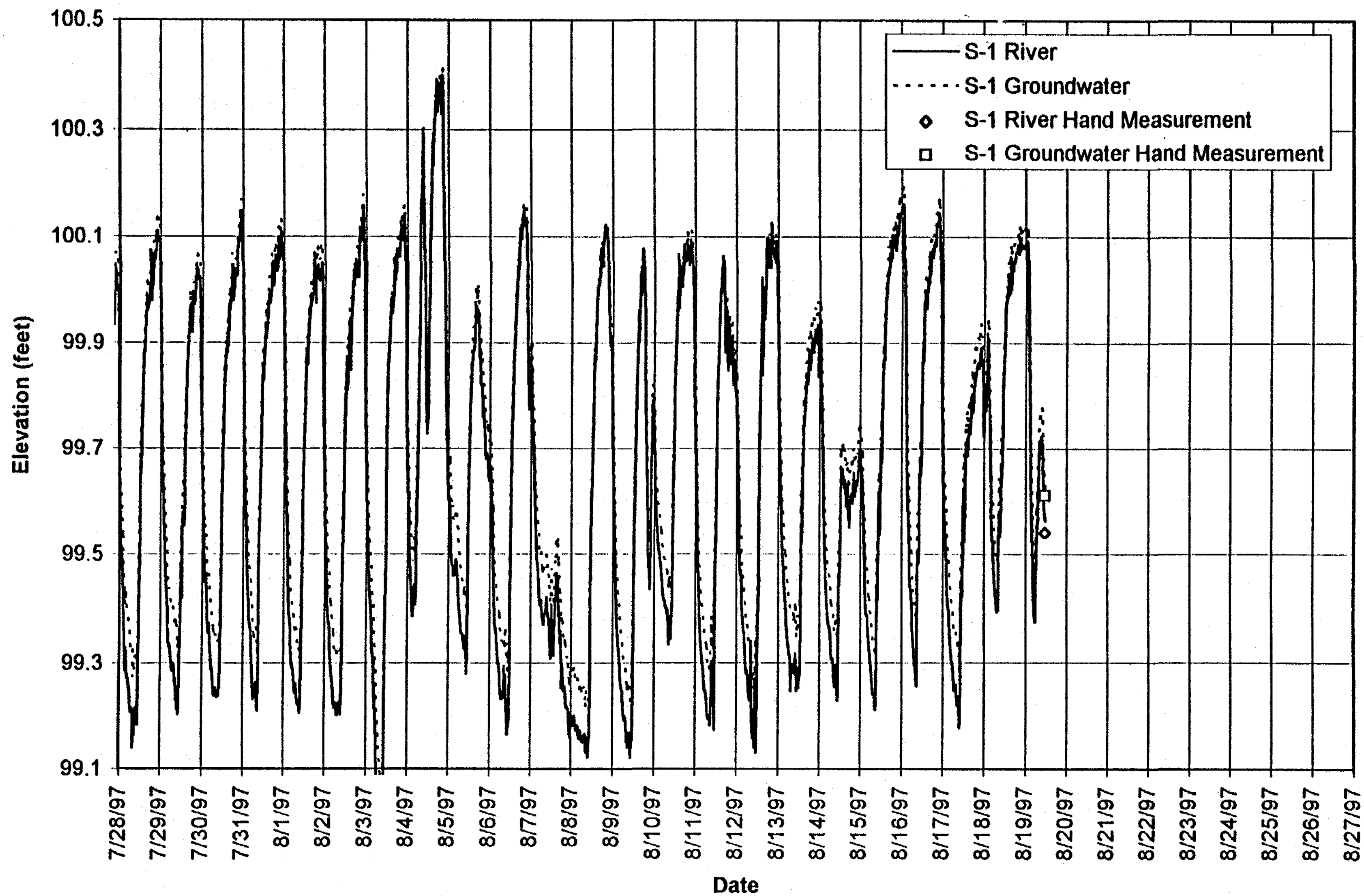

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Figure 3-4 Hydrograph for piezometer pair S-4, 5/29/97 - 6/28/97

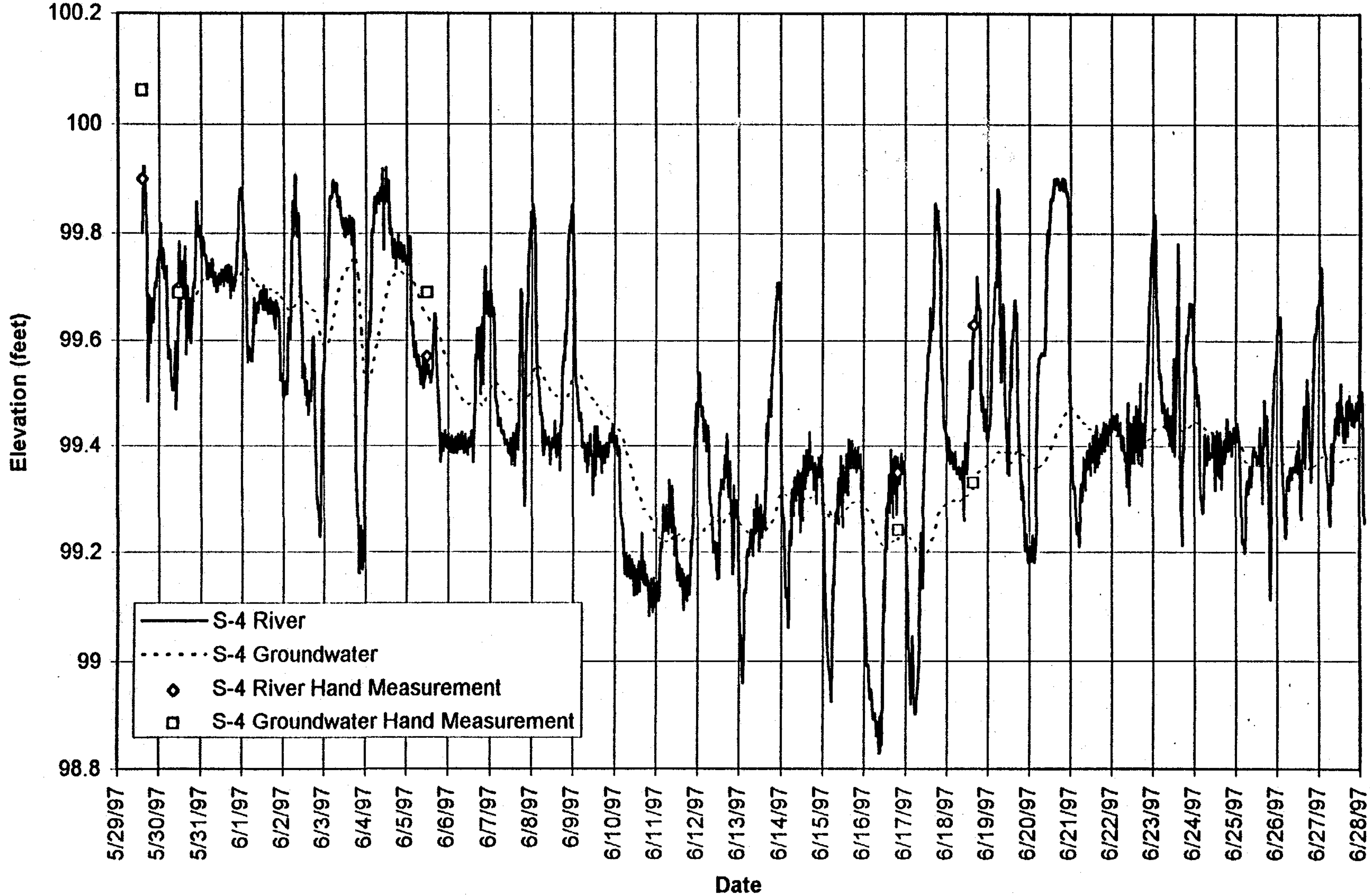

Figure 3-5 Hydrograph for piezometer pair S-4, 6/28/97 - 7/28/97

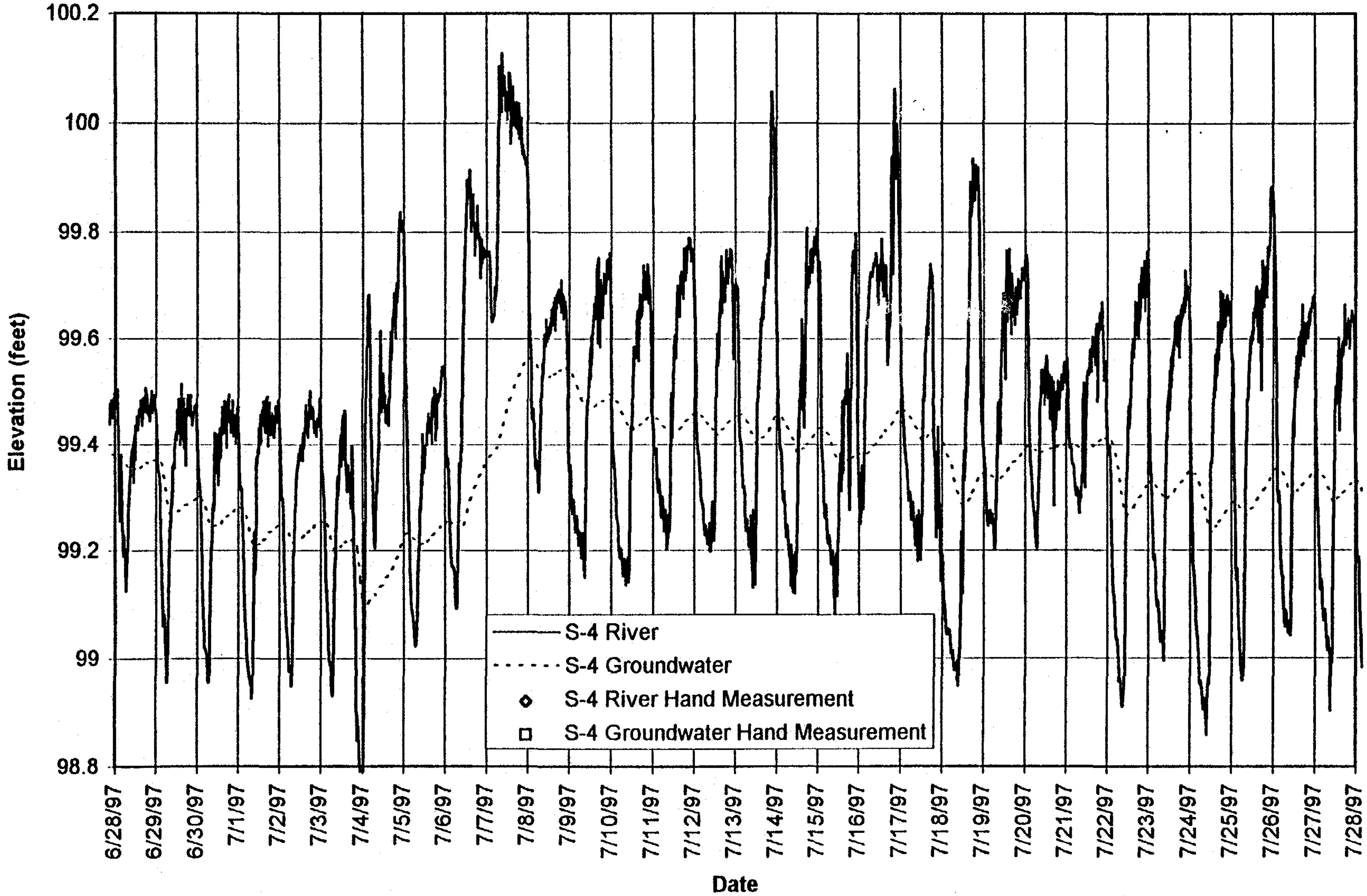

Figure 3-6 Hydrograph for piezometer pair S-4, 7/28/97 - 8/20/97

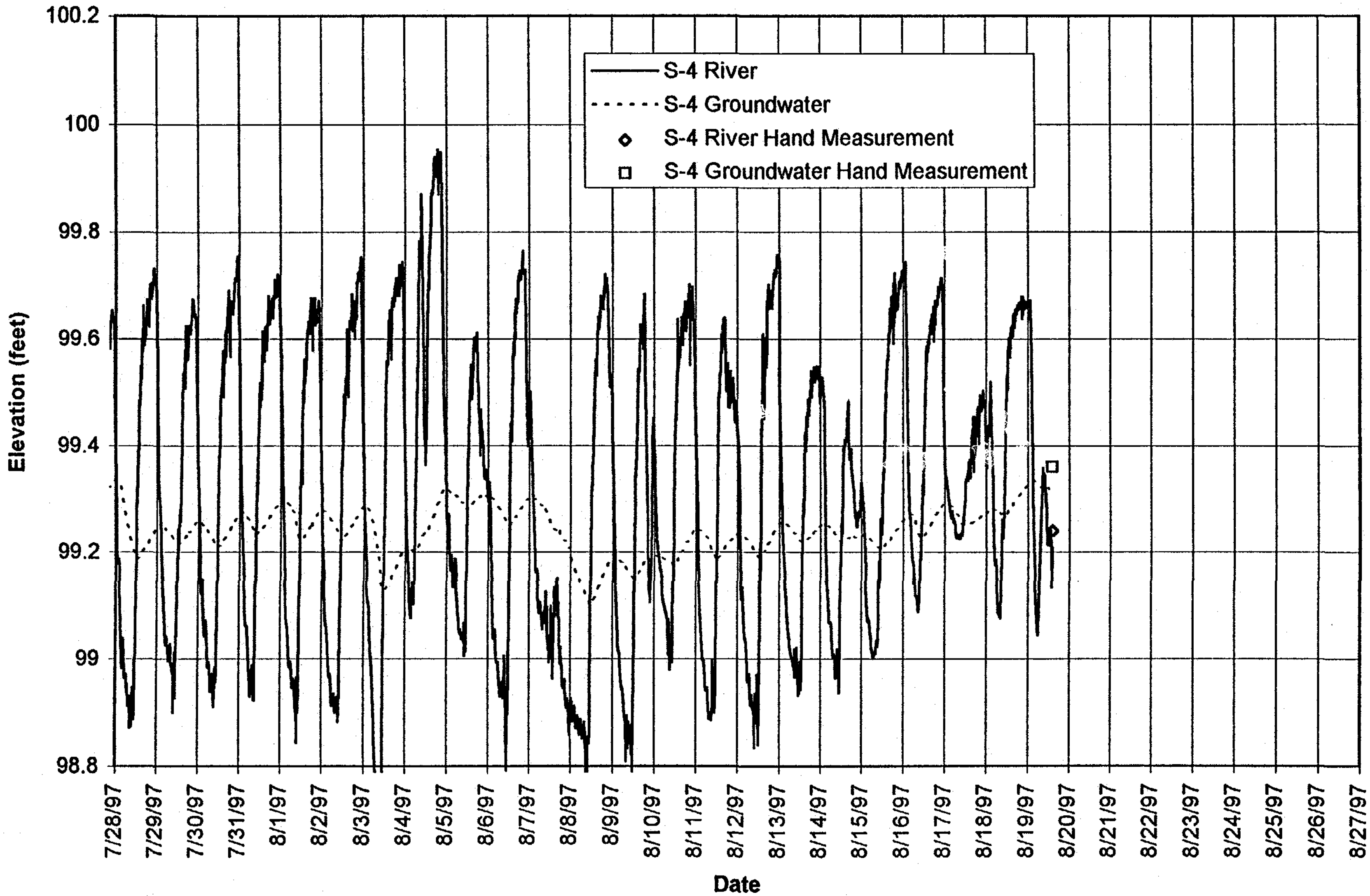

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Figure 3-7 Hydrograph for piezometer pair S-6, 5/29/97 - 6/28/97

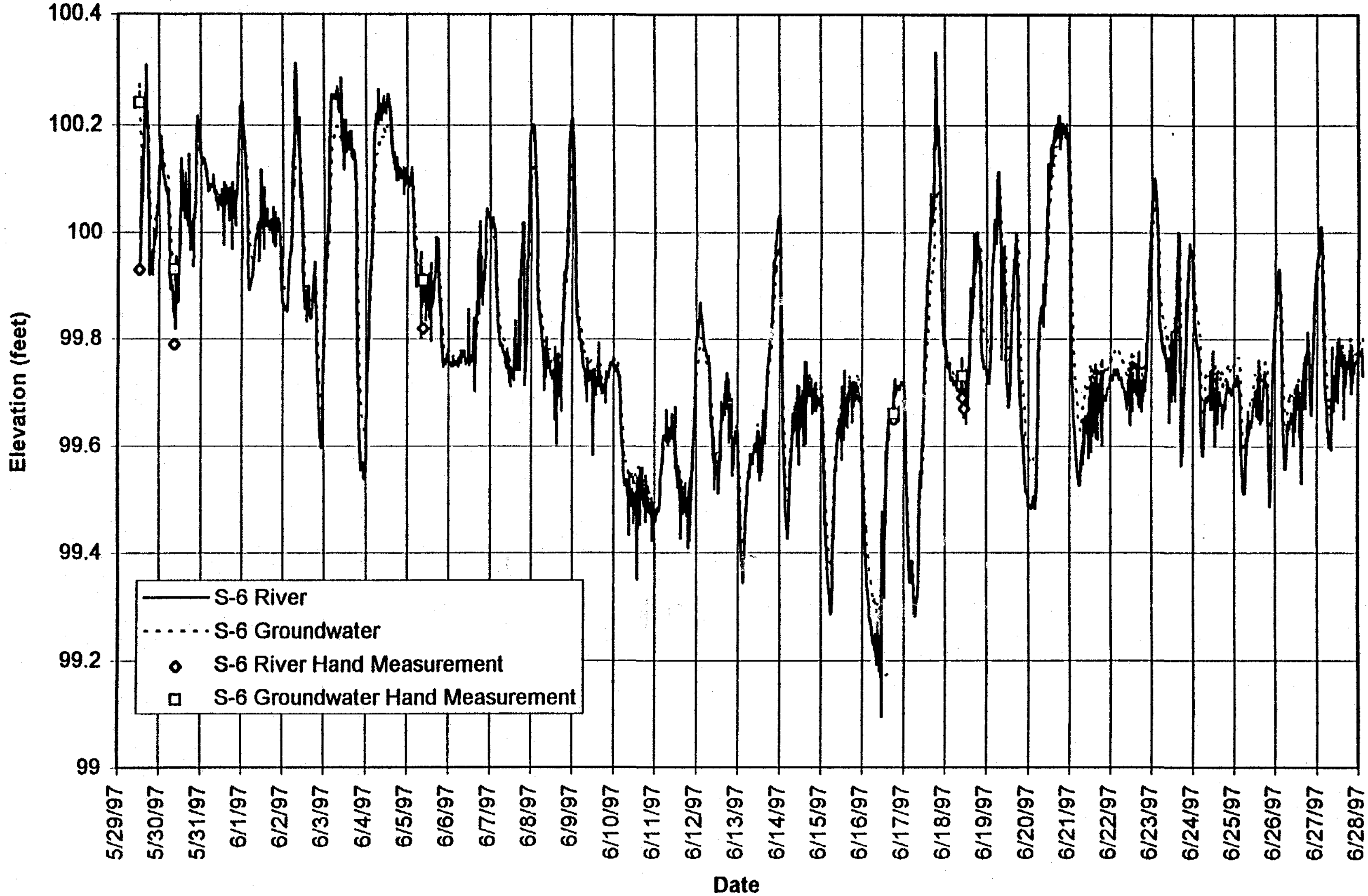

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Figure 3-8 Hydrograph for piezometer pair S-6, 6/28/97 - 7/28/97

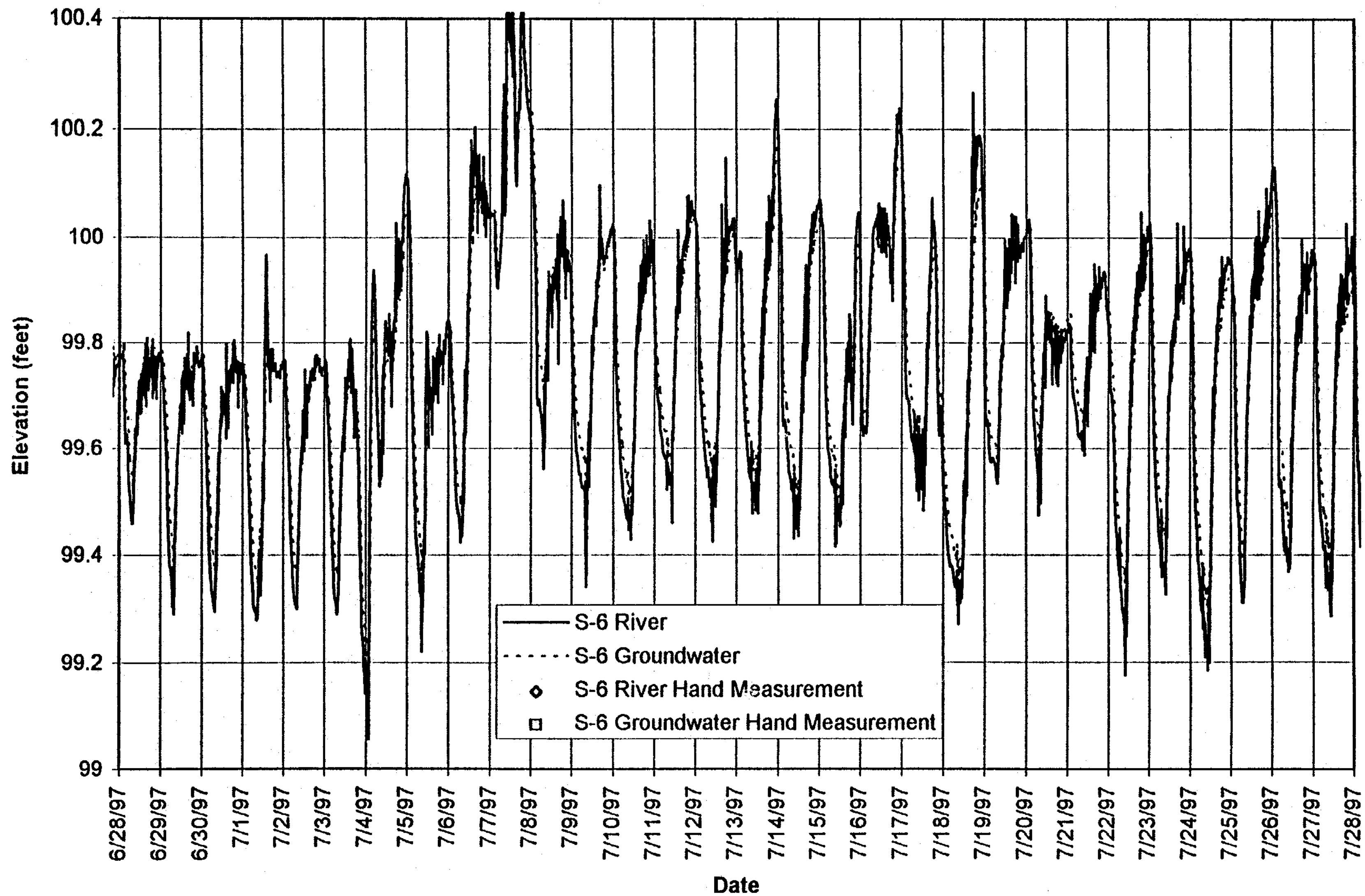

Figure 3-9 Hydrograph for piezometer pair S-6, 7/28/97 - 8/20/97

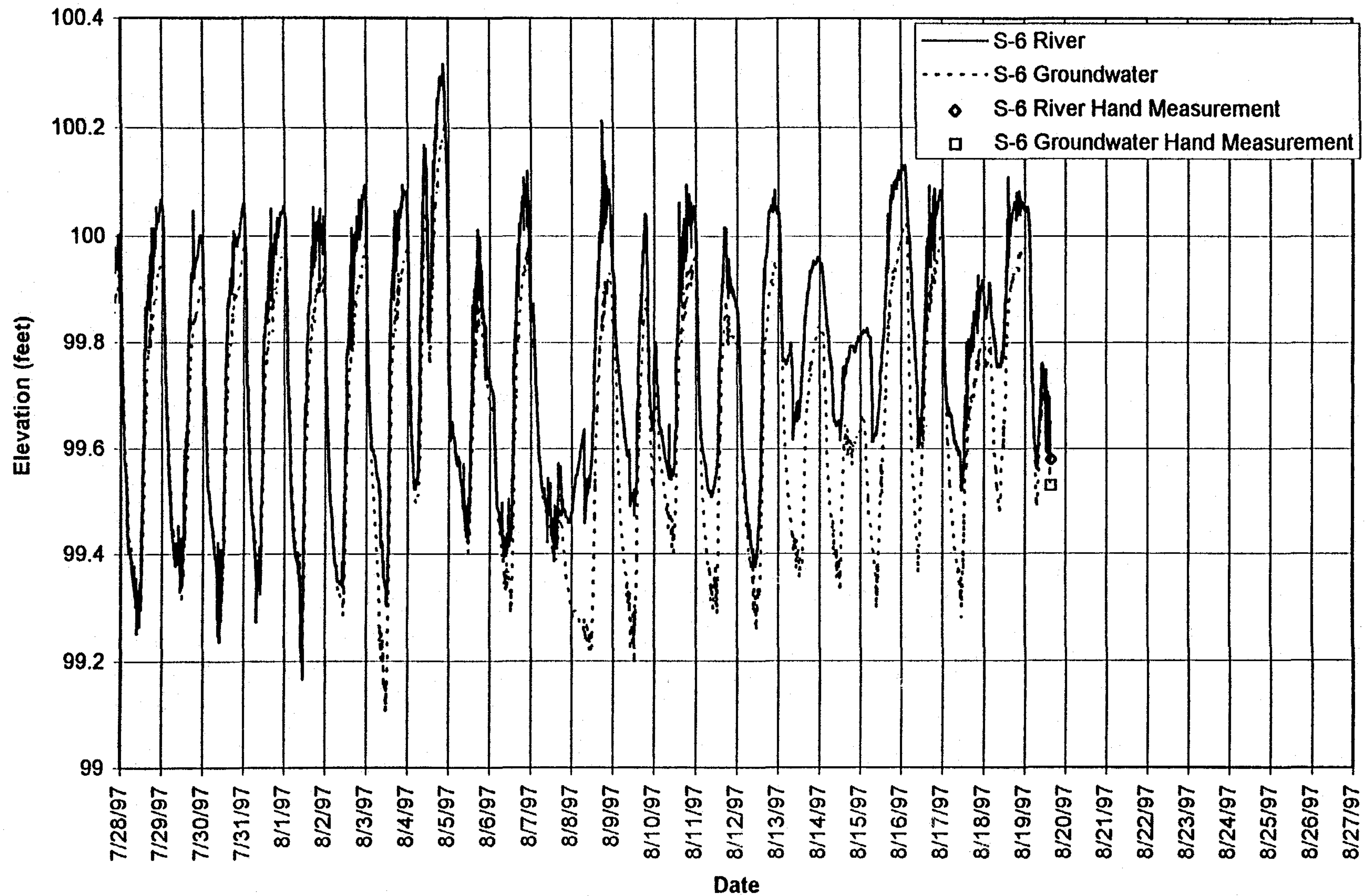

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Figure 3-10 Vertical hydraulic gradients, 5/29/97 - 6/28/97

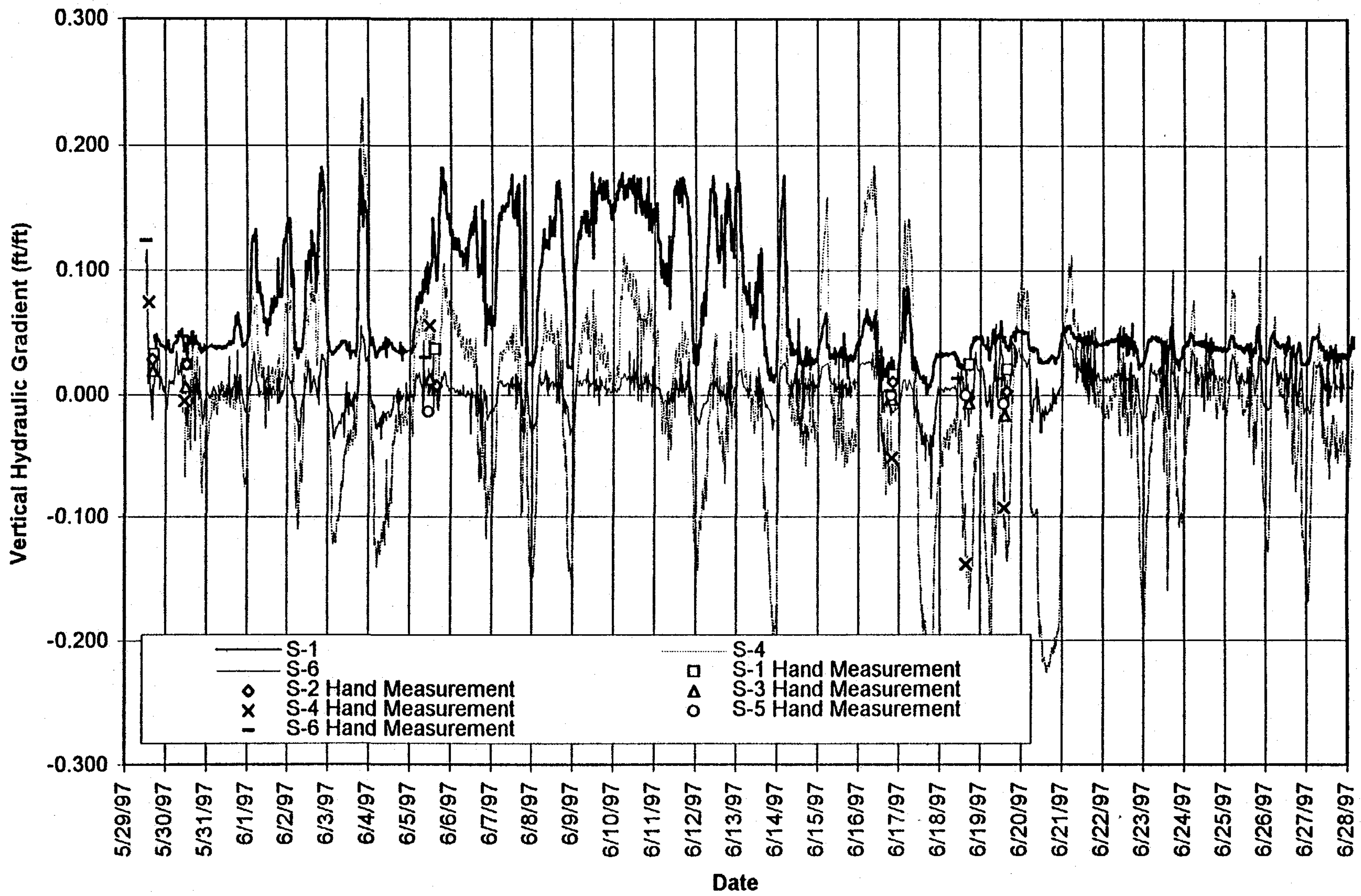

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Figure 3-11 Vertical hydraulic gradients, 6/28/97 - 7/28/97

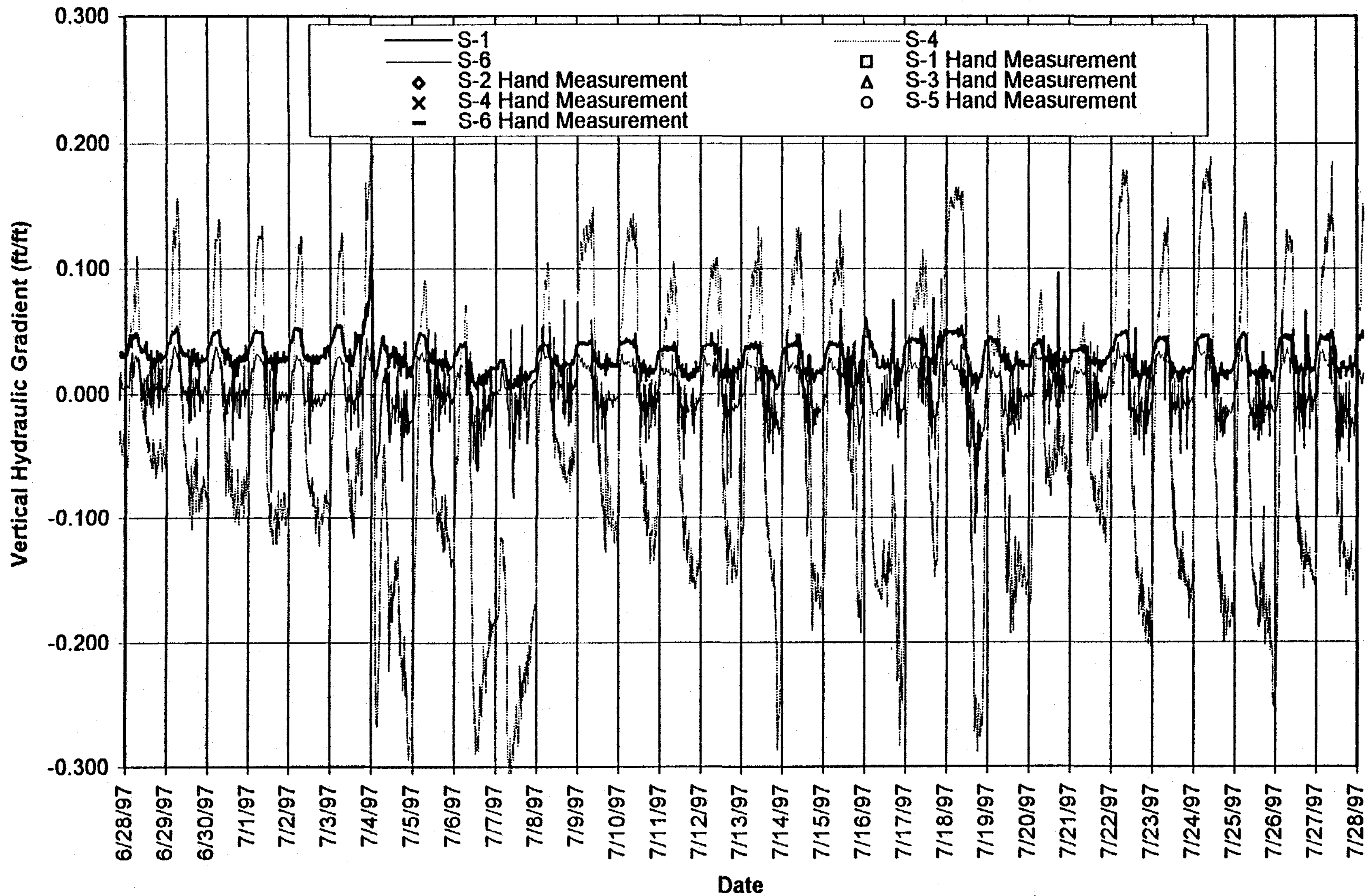

Figure 3-12 Vertical hydraulic gradients, 7/28/97 - 8/20/97

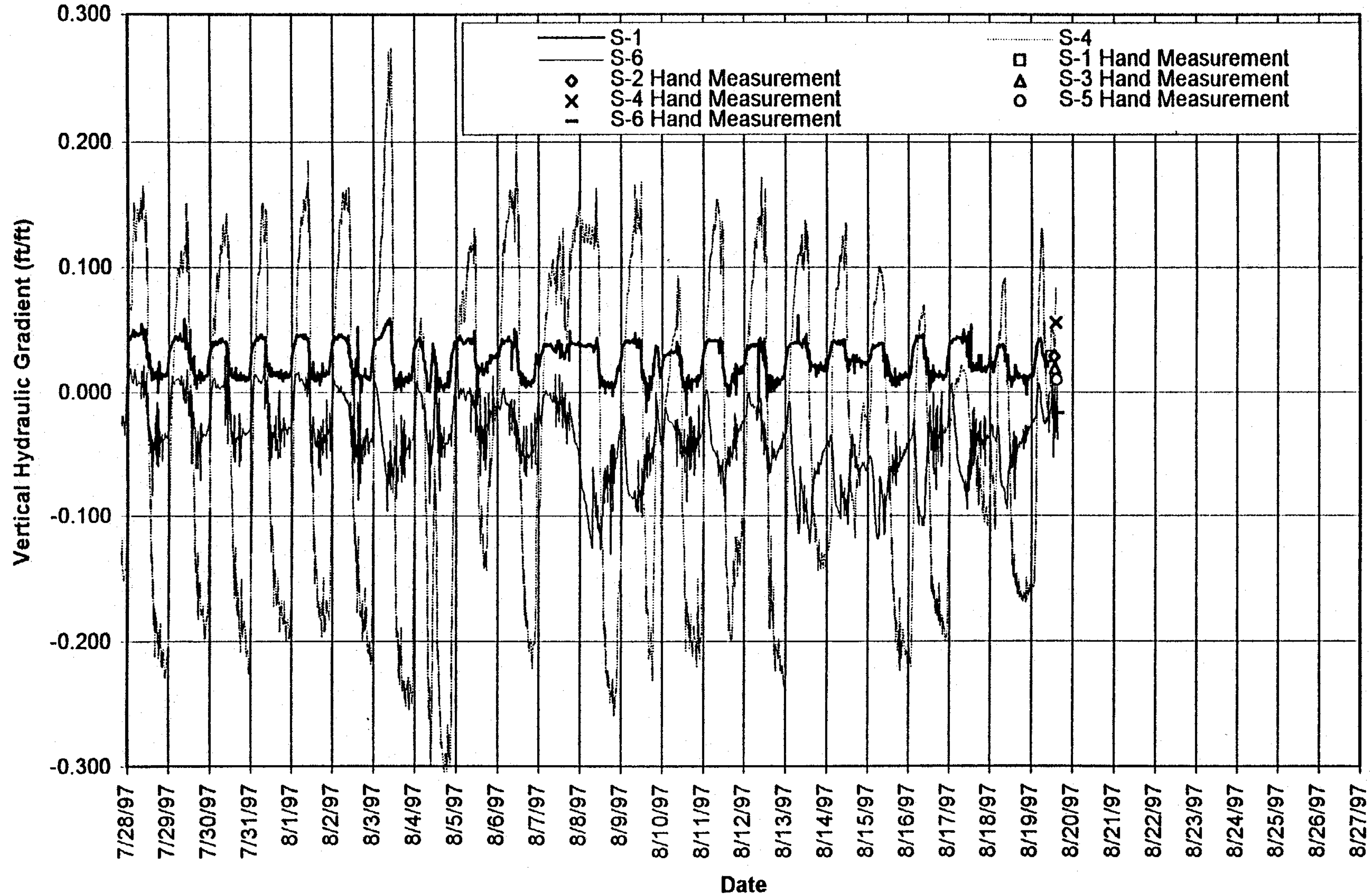

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Figure 3-13 Temporal trends in seepage flux

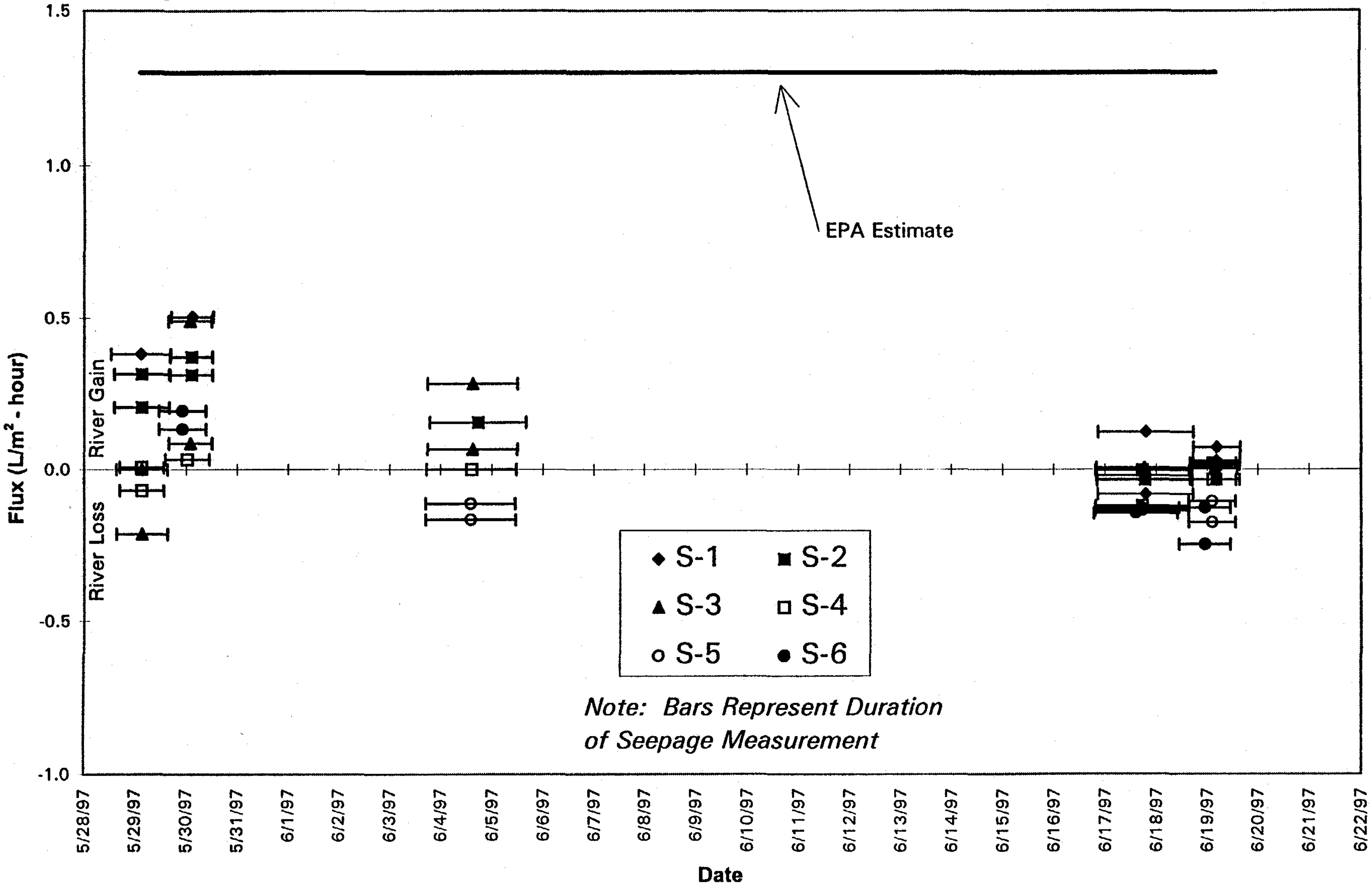
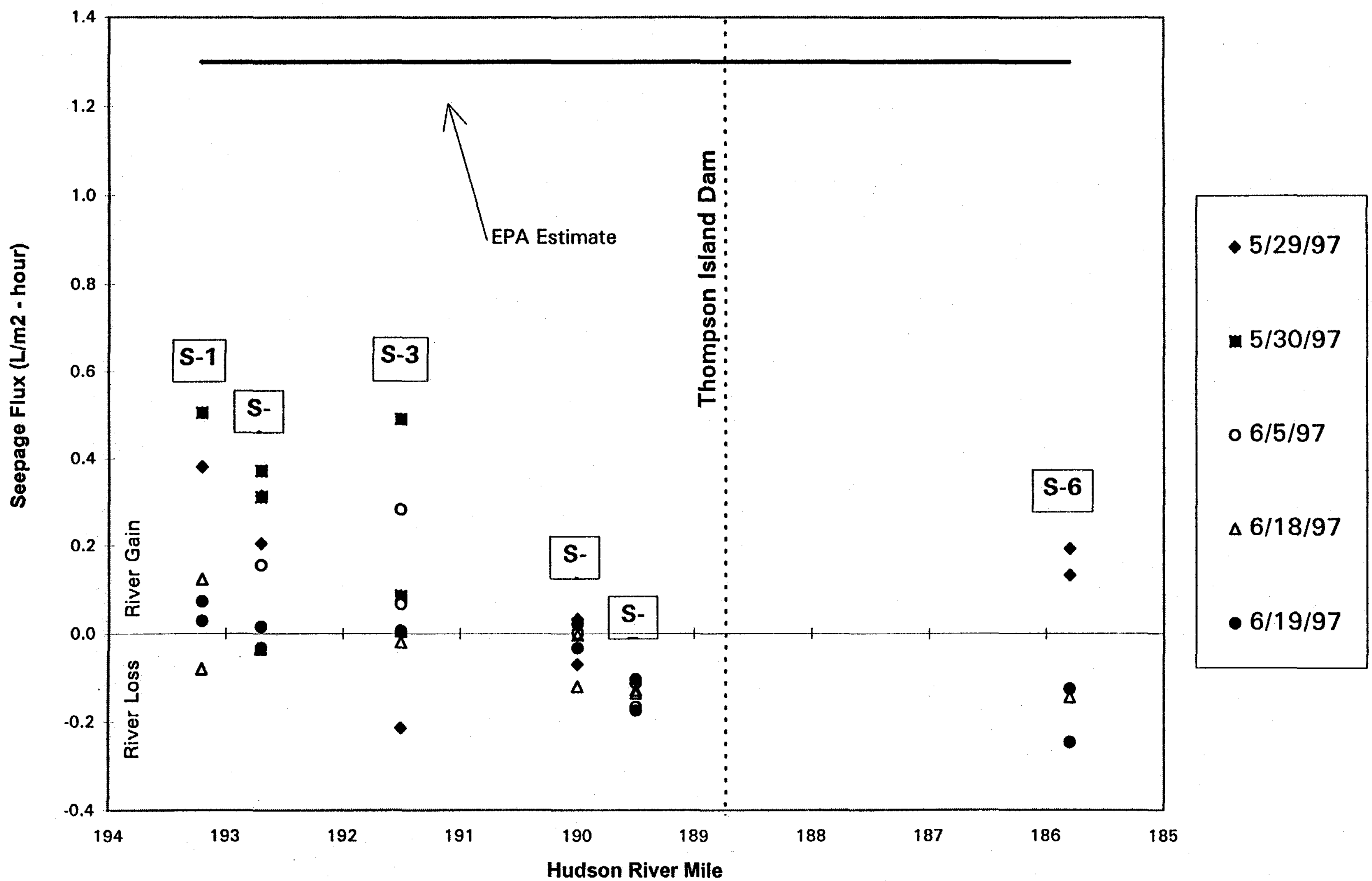


Figure 3-14 Spatial trends in seepage flux



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4 CONCLUSIONS

The following conclusions can be drawn from the groundwater seepage investigation:

- Measured seepage rates were generally consistent with measured hydraulic gradients.
- Groundwater seepage into the TIP is not uniform across the TIP.
- Spatial and temporal patterns in vertical hydraulic gradients and groundwater/surface water seepage were consistent with a dammed river reach subject to seasonal flow variations.
- Measured seepage rates decreased spatially from the upstream end of the TIP to the downstream end and decreased temporally during the study from May 28 through June 19, 1997.
- Rates of groundwater seepage into the TIP ranged from 0.004 to 0.505 $L/m^2/hr$, with an average rate of 0.166 $L/m^2/hr$.
- Most of the groundwater seepage into the TIP was measured at the upstream of the TIP, at monitoring locations S-1, S-2, and S-3.
- Rates of river loss to groundwater within the TIP ranged from -0.003 to -0.214, with an average rate of -0.092.
- Most of the river loss to groundwater was measured at the downstream end of the TIP, at monitoring locations S-4 and S-5.
- Measured seepage rates were inconsistent with values estimated by the U.S. EPA. Measured values were typically an order of magnitude less than that estimated by the U.S. EPA.
- Based on the data collected as part of this study, groundwater is an insignificant mechanism for the transport of PCBs from the sediments to the water column of the TIP.

- The data collected during the groundwater seepage investigation clearly show that the seepage rates vary within the TIP and that actual data, site conditions and variability need to be explicitly considered in any groundwater seepage theories.

5 REFERENCES

HydroQual, 1997. Sampling & Analysis Plan: Investigation of Groundwater Seepage in the Thompson Island Pool Section of the Upper Hudson River. HydroQual, February 1997.

HydroQual, 1996. Sampling and Analysis Plan: Thompson Island Pool Transect Study. HydroQual, September, 1996.

U.S. EPA, 1996. Phase 2 Report - Review Copy. Further Site Characterization and Analysis. Preliminary Model Calibration Report. Hudson River PCBs Reassessment RI/FS. U.S. EPA, October 1996.