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In cooperation with the
New Hampshire Department of Environmental Services,
Hazardous Waste and Remediation Bureau, and the
U.S. Environmental Protection Agency, Region 1,
Office of Site Remediation and Restoration

Results of a Monitoring Program of Continuous Water Levels, Specific Conductance, and Water Temperature at the OK Tool Facility of the Savage Municipal Well Superfund Site, Milford, New Hampshire

By Michael J. Brayton and Philip T. Harte

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
cubic foot (ft^3)	0.02832	cubic meter
gallon (gal)	3.785	liter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
million gallons per day (Mgal/d)	1.547	cubic liters per second
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	Slope	
foot per mile (ft/mi)	0.3048	meter per mile

Temperature in degrees Fahrenheit (^{o}F) can be converted to degrees Celsius (^{o}C) as follows:
$^{o}C = 5/9\ (^{o}F - 32)$.

Vertical Datum: In this report "NGVD-29" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Results of a Monitoring Program of Continuous Water Levels, Specific Conductance, and Water Temperature at the OK Tool Facility of the Savage Municipal Well Superfund Site, Milford, New Hampshire

By Michael J. Brayton *and* Philip T. Harte

Abstract

The Milford-Souhegan glacial drift aquifer (MSGD), in south-central New Hampshire, is an important source of industrial, commercial, and domestic water. The MSGD also was an important source of drinking water for the town of Milford until high levels of volatile organic compounds (VOCs) were found in the Savage and Keyes municipal supply wells in the early 1980s. A VOC plume covered the southwestern half of the MSGD aquifer and the site is now a U.S. Environmental Protection Agency Superfund site (called the Savage Municipal Well Superfund site). A primary source area of contaminants was the former OK Tool manufacturing facility, which disposed of solvents in the subsurface. The facility was closed in 1987 and buildings were removed in 1998. A containment barrier wall and a pump-and-treat remediation facility were constructed in 1998 to contain the highest concentrations of VOCs.

A network of monitoring sites was implemented by the U.S. Geological Survey (USGS) in 1994 to study transient hydrologic conditions in the aquifer. This network was modified in 1997 to assess the effects of remedial activities at the OK Tool portion of the Savage Municipal Well Superfund site. This report summarizes continuous and periodic manual measurements of water level, specific conductance, and water temperature for eight monitoring locations (including one river stream-gaging station and seven observations wells) during 3 water years (WY) (October 1, 1997, through September 30, 1999), before, during, and after remediation began. This report and study was done by the USGS, in cooperation with the New Hampshire Department of Environmental Services and the U.S. Environmental Protection Agency, Region 1.

River stage and riverbed water levels fluctuated 8 feet (ft) and ground-water levels fluctuated 5 to 7 ft. Continuous water-level data provided information on hydrologic events, such as the formation of an ice dam on the Souhegan River in January 1999, and a hurricane that produced a 6-ft rise in ground-water levels in September 1999.

The barrier wall proved effective in isolating ground water inside the barrier wall. Changes in ground-water levels inside the wall did not correlate with changes in ground-water levels outside the wall. Furthermore, a reduction inside the barrier wall in cumulative water-level rise, after wall construction, indicated a decrease in ground-water recharge.

Ground-water flow outside the barrier wall also was affected by remedial activities. River leakage from the Souhegan River increased northeast of the barrier wall as indicated by a wide range in ground-water temperatures caused by increases in river leakage to ground water.

Specific conductance of water in the riverbed well varied from 30 to 150 microseimens per centimeter at 25° Celsius (μS/cm), whereas river water varied from 50 to 120 μS/cm. Specific conductance of ground water varied from 60 to 2,400 μS/cm, depending on location. Elevated specific conductance in ground water (above background levels), an indicator of road-salt contamination, was detected in the southern part of the study area. Temporal changes in specific conductance are correlated with changes in hydraulic head at some of the monitoring wells. These changes in vertical stratification of ground water are shown by abrupt changes in specific conductance with depth.

River temperature varied from 0 to 26°C and ground-water temperature varied from 10 to 12°C for a well farthest from the river. Ground-water temperature inside the barrier wall after construction changed by as much as 2°C from previously observed annual cycles, in response to repeated extractions and injections from remedial wells.

INTRODUCTION

The Milford-Souhegan glacial-drift aquifer (MSGD), in south-central New Hampshire (fig. 1) is an important source of industrial, commercial, and domestic water. The MSGD also was an important source of drinking water for the town of Milford until high levels of volatile organic compounds (VOCs) were detected in the Savage and Keyes municipal-supply wells in the early 1980s. A VOC plume was found to cover the southwestern half of the MSGD aquifer and has been designated as a U.S. Environmental Protection Agency Superfund site, called the Savage Municipal Well Superfund site (fig. 2). A primary source area of contaminants was the OK Tool facility, a former tool manufacturing facility that disposed of solvents in the subsurface (HMM Associates, Inc., 1989). The Superfund site is divided into two operable units, the OK Tool facility (operable unit 1), and the remaining plume area (operable unit 2).

Although the tool facility was closed in 1987, and buildings demolished in the winter of 1998, lingering pockets of VOCs in the subsurface continue to contaminate ground water flowing through the area. In 1998, a fully penetrating, low permeability barrier (slurry) wall was constructed, which encapsulated the highest concentrations of VOCs (fig. 3). The slurry wall is made of bentonite “type” clayey material. Extraction and injection wells were installed inside and outside the barrier wall to remediate the contaminant plume through capture, treatment, and re-injection of waters. Active remedial pumping at the OK Tool facility began in March 1999.

Since 1994, the U.S. Geological Survey (USGS) has monitored the hydrologic conditions of this site. A network of automated monitoring sites was developed and implemented in 1994 as part of a 3-year pre-remedial study by the USGS, in cooperation with the U.S. Environmental Protection Agency (USEPA), to study transient hydrologic conditions in the aquifer (Harte and others, 1997). Over time, the emphasis on monitoring shifted to provide greater data resolution near the OK Tool facility (fig. 4) to better understand local contaminant transport. Monitoring wells initially were installed before the onset of remedial activities at the source area. Additional monitoring wells were installed in 1998 as part of this study to assess the effects of the remedial operations on ground-water flow outside of the barrier wall and to determine rates of recharge inside the barrier wall. This USGS study, is part of a larger study to understand and evaluate solute transport of VOCs in the Savage Well Superfund area, in cooperation with the New Hampshire Department of Environmental Services, Hazardous Waste and Remediation Bureau, and the USEPA, Region 1, Office of Site Remediation and Restoration.

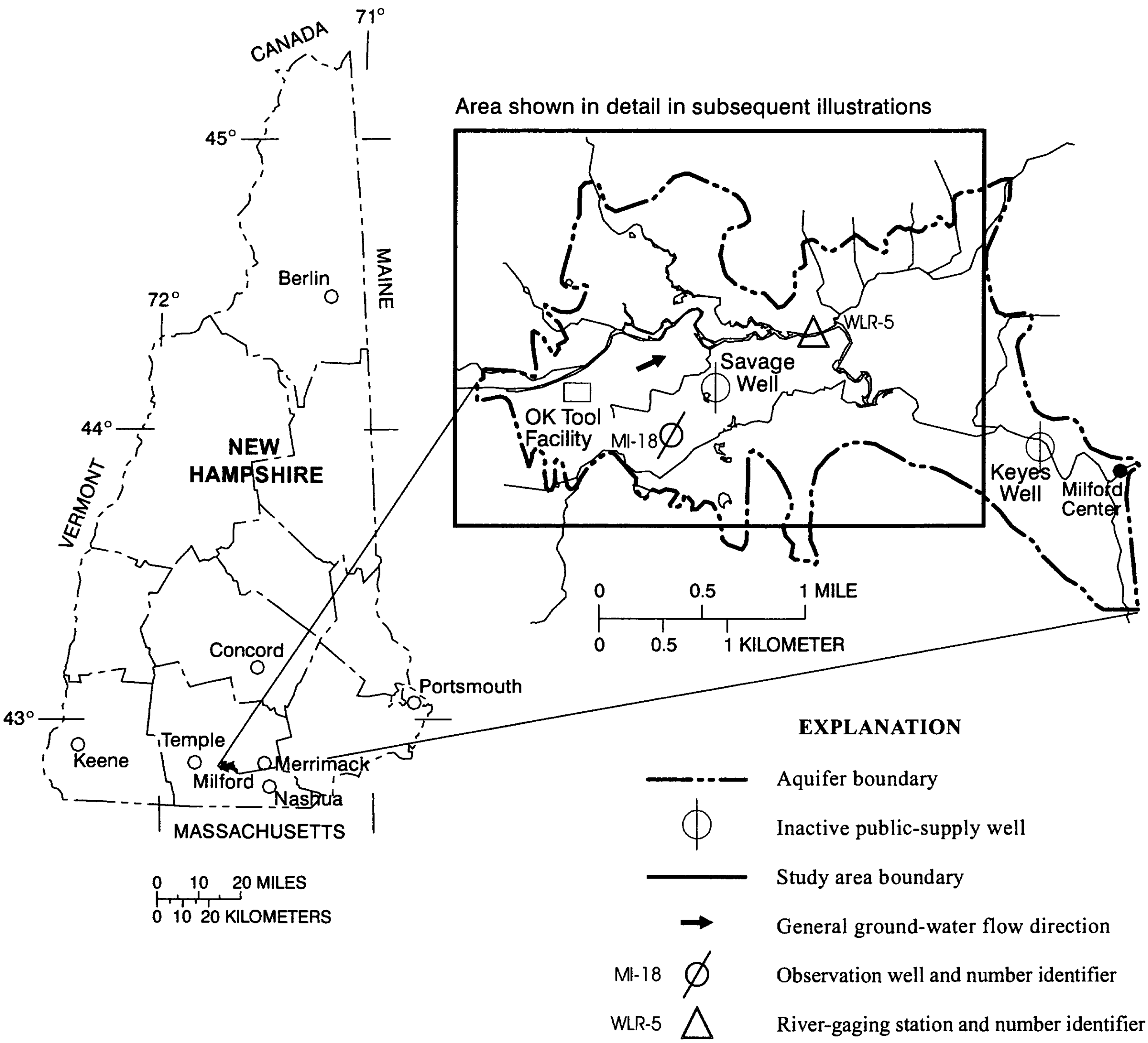


Figure 1. Location of the Milford-Souhegan glacial-drift aquifer, Milford, N.H.

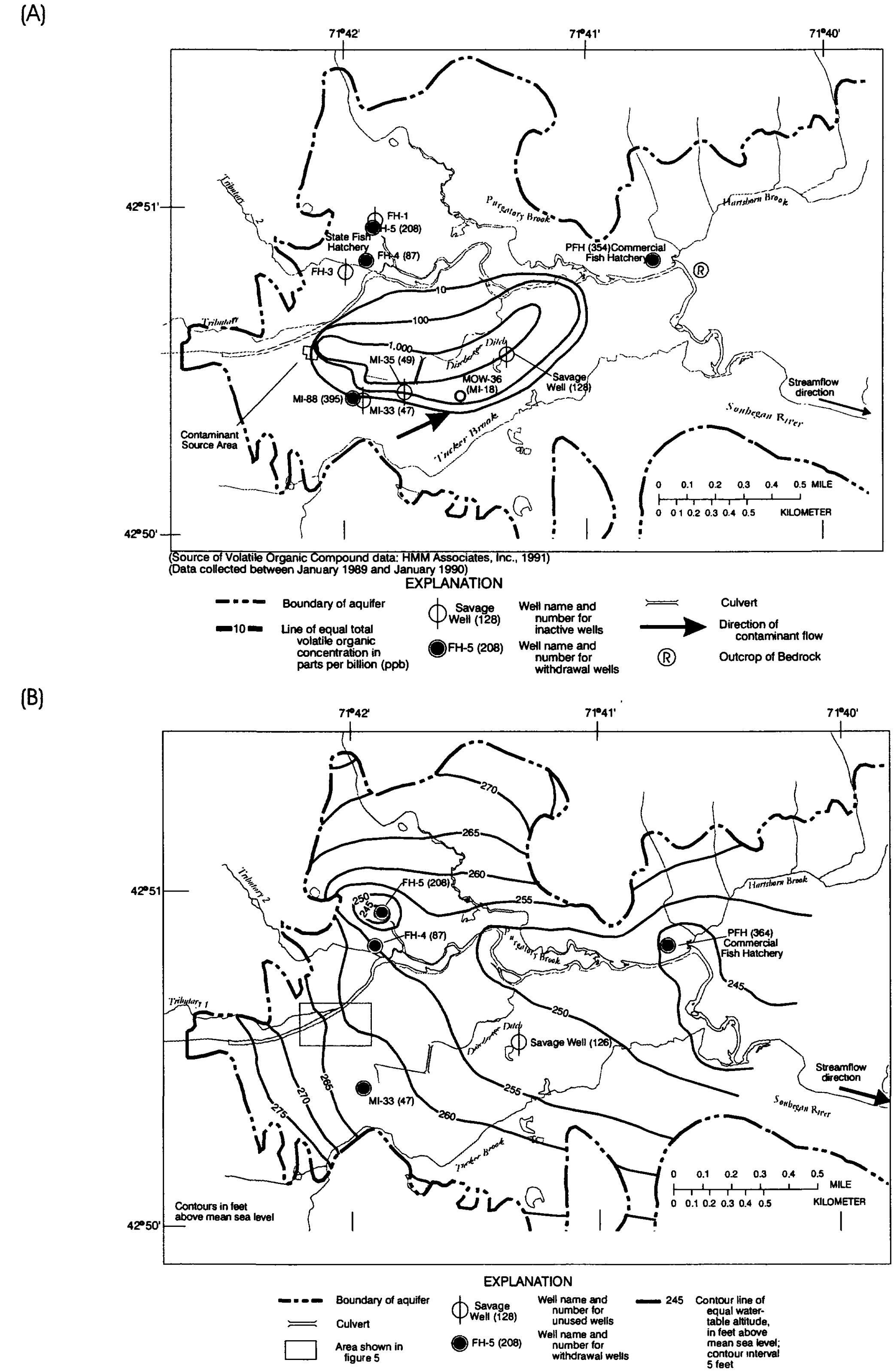


Figure 2. Extent of contaminant plume (shaded) of total volatile organic compounds in 1989 (A), and water-table contours in April 1994 (B), in the Milford-Souhegan glacial-drift aquifer, Milford, N.H.

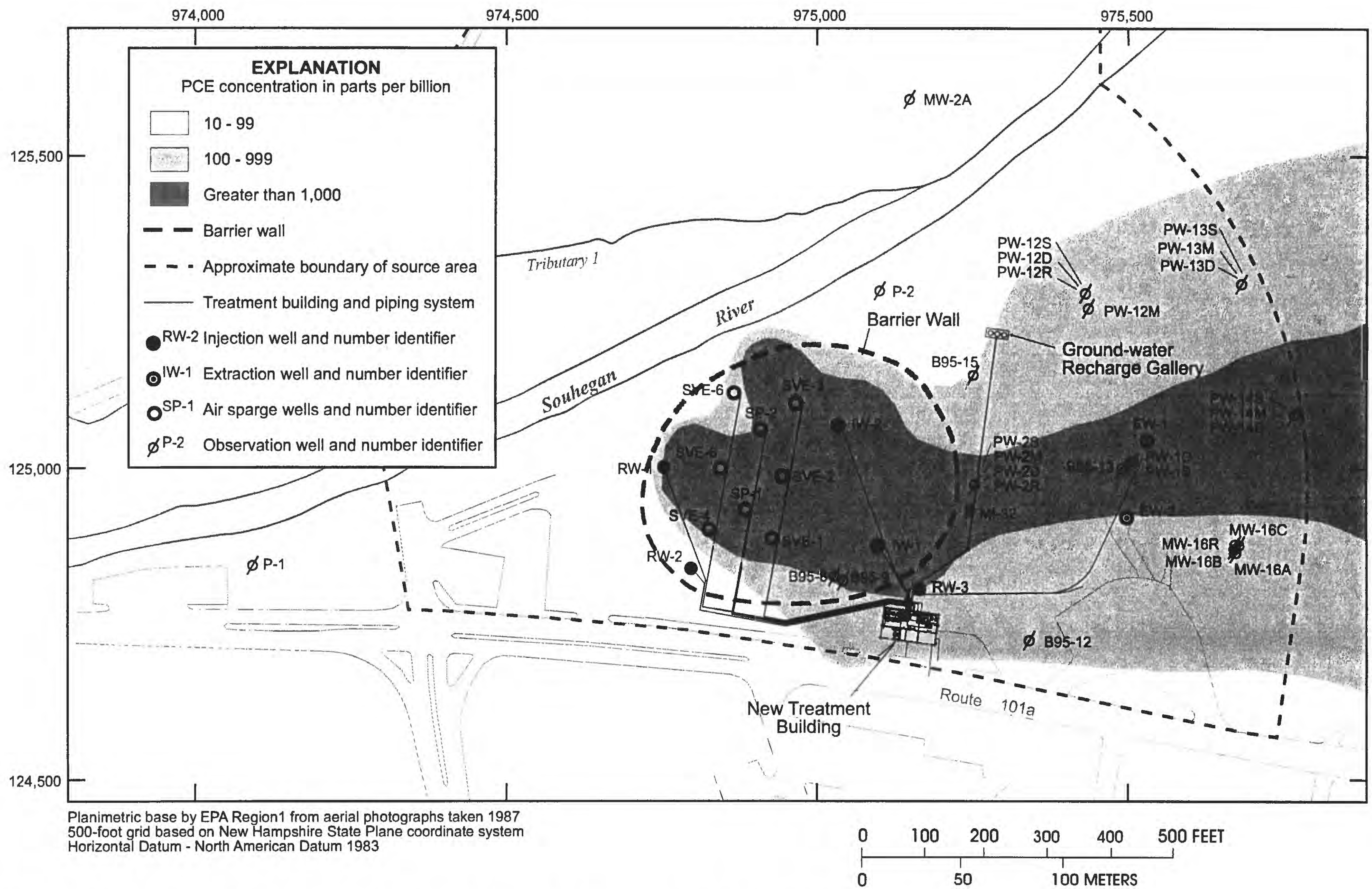
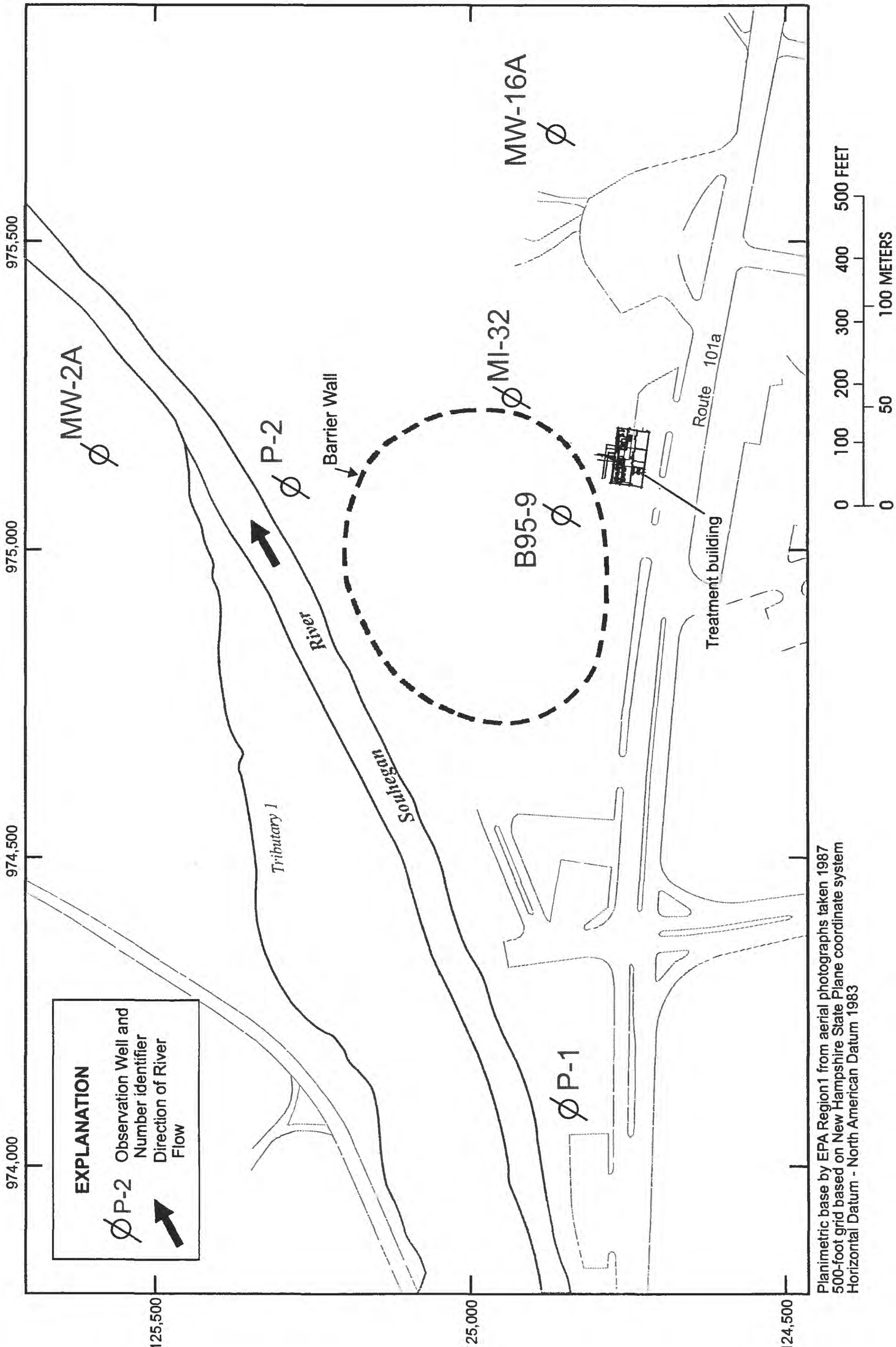


Figure 3. Location of the OK Tool portion of the Savage Municipal Well Superfund site, Milford, N.H.



Planimetric base by EPA Region1 from aerial photographs taken 1987
500-foot grid based on New Hampshire State Plane coordinate system
Horizontal Datum - North American Datum 1983

Figure 4. Automated monitoring sites at the OK Tool portion of the Savage Municipal Well Superfund site, Milford, N.H.

Purpose and Scope

This report describes the results of a study to assess changes in hydrologic conditions before, during, and after construction of a remedial system at the OK Tool facility of the Savage Municipal Well Superfund site. Data from the continuous monitoring network were used to evaluate changes in ground-water flow that may affect contaminant transport of VOCs. Continuous and periodic discrete data collected for water year (WY) 1997, 1998, and 1999 (October 1, 1996, through September 30, 1999) are summarized in this report. Data presented include continuous measurements of river stage at one river-gaging station and ground-water levels at seven observation wells. Data are presented in graphical form. Tabular data are available from the USGS New Hampshire/Vermont District Office upon request.

Description of Study Area

The study area encompasses a 3.3-mi^2 river valley aquifer called the MSGD aquifer in the Town of Milford, N.H. The aquifer is defined as the entire sequence of unsaturated and saturated alluvium, glacial drift, and other unconsolidated deposits overlying bedrock. Saturated thickness of the aquifer generally ranges from 0 to 60 ft, but approaches 100 ft in some locations on the eastern side of the study area. The aquifer is laterally bounded by till-covered bedrock uplands.

The Souhegan River valley slopes gently at 12 ft/mi, with land-surface elevations ranging from 230 to 280 ft above NGVD-29. The valley is drained by the Souhegan River and many small tributaries. The river-valley system is composed of unconsolidated sediments of alluvium and glacial drift. Surface drainage is to the east.

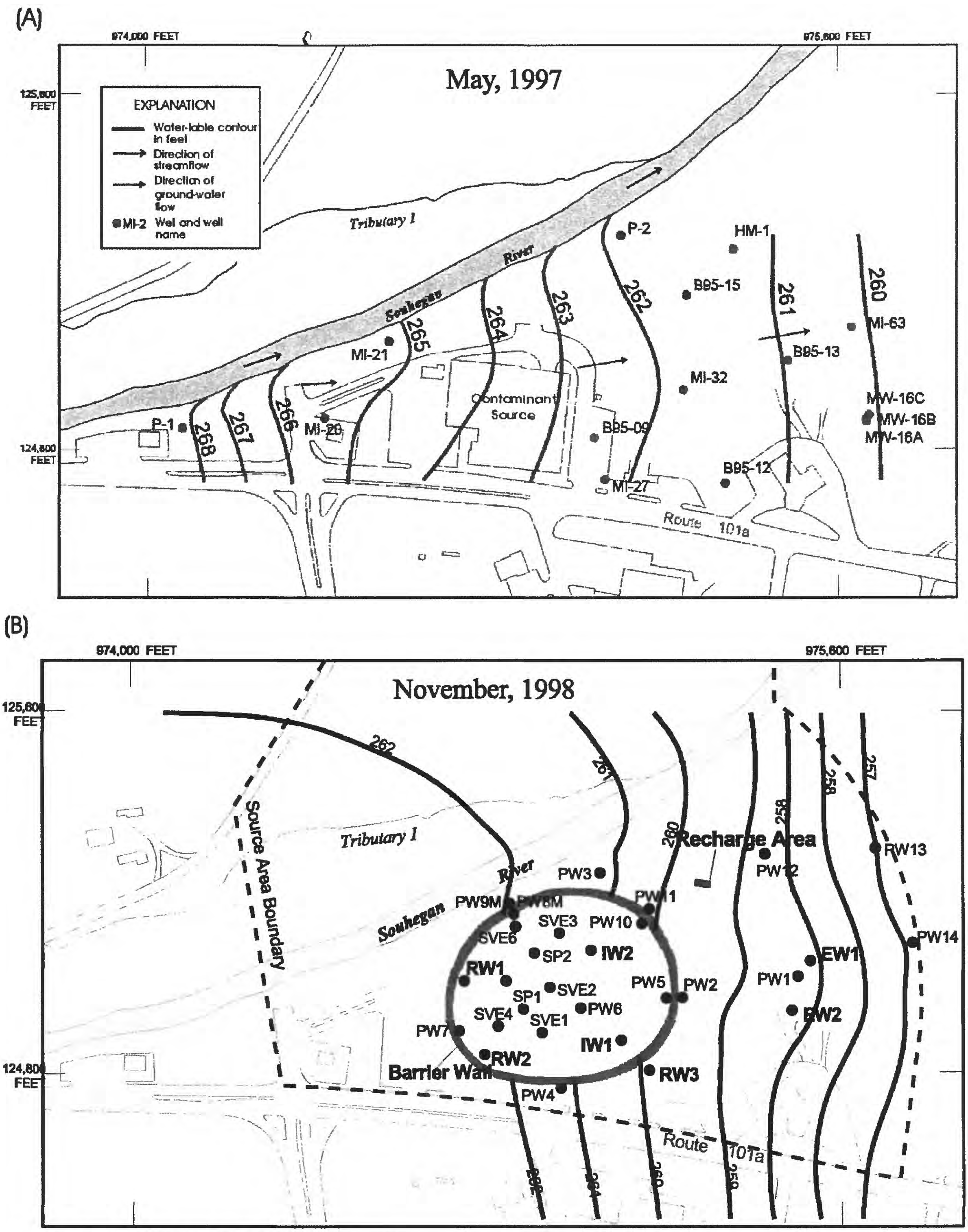
Land use varies from primarily industrial in the southwestern part of the study area, agricultural in the central and northwestern parts, and residential to commercial elsewhere. The contaminant plume is composed of tetrachloroethylene (PCE) and its daughter products. The plume underlies a 0.5-mi^2 area (fig. 2). Major sources of ground-water withdrawal include two wells operated by the New Hampshire State Fish Hatchery, and a well for an industrial and manufacturing complex (fig. 2).

Ground-water flow at the Superfund site primarily is to the northeast (figs. 2A and 2B). The OK Tool facility is at the head of the plume in the far western part of the aquifer. The local-flow system at the facility primarily is west to east (fig. 5).

The 64,000-ft^2 area remediation site at the OK Tool facility is in the western part of the MSGD and is bounded to the northwest by the Souhegan River. The river is an important source of recharge to the MSGD. Near the remediation site, the river loses about 4.5 ft^3/s of water to the aquifer along a reach from monitoring well P-1 to P-2 (fig. 4) (Harte and others, 1997). The construction of the barrier wall has focused river losses to the northeastern part of the facility (fig. 5B). The stratigraphy underlying the remedial site consists of sands and gravels interbedded with fine sands (Harte and others, 2001). A cobble layer occurs between 5-20 ft below the land surface. The bedrock slopes to the east and ranges in depth from 40 ft in the west to more than 80 ft in the east. A discontinuous till overlies the bedrock.

Acknowledgments

The study of the Savage Well Superfund site is a collaborative effort between Federal, State, and local governments, private companies and individuals. The authors wish to thank Richard Goehlert and Richard E. Willey of the USEPA, Region 1, Thomas Andrews and Wayne Ives of the New Hampshire Department of Environmental Services, and Joseph Newton of Camp, Dresser, and McKee, Inc., for their cooperation and support.



Planimetric base by EPA Region 1 from aerial photographs taken 1987
Remedial construction data from Camp, Dresser, and McKee Inc., 1999

Figure 5. Water-table surface for pre-remedial construction (May 1997) (A) and post-remedial construction (November 1998) (B).

MONITORING PROCEDURES

Monitoring of the plume included collecting hydrologic and other physical data. Measurements of river stage, riverbed water level, ground-water level, specific conductance, and water temperature were made every 15 min by electronic sensors wired to data loggers. Check measurements of these parameters also were made manually by separate devices approximately once a month to validate continuous readings. Manual measurements at additional sites were used to supplement spatial coverage of continuous measurement sites.

River stages, riverbed water levels, and ground-water levels are referenced to NGVD-29. Measurement points were surveyed to nearby USGS geodetic benchmarks by the USGS and private contractors. ***The datum conversion from NGVD-29 to North American Vertical Datum 1988 (NAVD-88) is -0.68 ft.***

Surface Water

Continuous monitoring of river data occurred at one river-gaging station (WLR-5, fig. 1). The design of this gage is shown in Harte and others (1997, fig. 6). The gage consists of a 2-in. diameter river pipe directly opened to the river and a large-diameter riverbed well opened to the riverbed. In general, the performance of the river pipe and riverbed well in measuring water properties was good except for some minor ice formation during the winter (affected data are noted on figures where appropriate).

Measurements of continuous river stage were made from the river pipe with a pressure transducer. This measurement system was discontinued in WY[1] 1998. Riverbed water levels were measured every 15 min. in the riverbed well with a potentiometer and attached float and weight. Concurrent measurements of river stage and riverbed water levels allow for an evaluation of hydraulic connection through the riverbed. The pressure transducer recorded height of the water column, in pounds per square inch (psi) above pressure intake of the transducer. The potentiometer recorded depth of water level, in feet below a known measurement point.

Continuous measurements of river stage, from the pressure transducer, were calibrated against periodic measurements of stage from a known datum point on top of the river pipe by measuring depth to water inside the river pipe. An outside reference gage was used periodically to verify that the depth to water from the river pipe was an accurate representation of river stage. Pressure-transducer readings were not adjusted in the field but checked using a linear relation between instantaneous readings of pressure, as measured in pounds per square inch, from the transducer and corresponding periodic manual measurements of river stage (table 1).

Continuous riverbed water levels from potentiometers were checked monthly for accuracy against manual measurements made with an electric water-level probe from a known datum point. If a discrepancy exceeded 0.05 ft between the instantaneous reading of the continuous sensor (potentiometer) and the manual measurement, continuous water levels were adjusted to match the manual water levels by adjusting the potentiometer offset. Corrections were made for the time during which the drift (error) occurred using a linear time-weighted equation to adjust continuous readings.

Specific conductance and temperature of river water and riverbed water were measured every 15 min. These parameters were measured by water-quality sensors, designed by the USGS Hydrologic Instrumentation Facility, Stennis Space Center, Miss., and connected to the same data loggers used to measure river stage and riverbed water levels. Air temperature was measured using thermistors connected to the data loggers.

Values of specific conductance and temperature were checked monthly against discrete measurements by comparing instantaneous readings from continuous sensors with discrete readings from separate water-quality sensors. The separate water-quality sensors periodically were calibrated against known standards to ensure correct readings. Specific-conductance calibration standards of 50 and 250 microseimens per centimeter at 25°C (µS/cm) were selected to calibrate separate sensors that bracketed ranges of waters observed in the field. River water was tested by lowering separate sensors directly into the river. Riverbed water was tested by lowering separate sensors directly into the stilling well.

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[1]Water year is a 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends.

Table 1. Information on accuracy of water level recording devices for automated monitoring sites, water years 1997-99, Milford, New Hampshire.

[--, no data; for equations: y = depth to water in feet from measurement point, x = pressure of water column in pounds per square inch (psi) above sensor; R-squared is the goodness of fit for the regression equation; average offset computed from summation of all offsets divided by number of check measurements]

Monitoring site (locations shown on fig. 4 or fig. 2a)	Type of water-level recording device	Regression equation	R-squared (coefficient of determination)	Average offset for potentiometers (in feet)
B95-9	Pressure transducer	y = -2.29x + 16.46	0.99	--
P-1	Potentiometer	--	--	0.113
P-2	Pressure transducer	y = -2.32x + 13.06	.99	--
MW-2A	Pressure transducer	y = -2.33x + 14.55	.99	--
MI-32	Pressure transducer	y = -2.31x + 15.83	.99	--
MW-16A	Pressure transducer	y = -2.06x + 17.27	.86	--
MI-18	Potentiometer	--	--	.001
WLR5(RIVER)	Pressure transducer	y = -2.23x +11.90	.96	--
WLR5-(BED)	Potentiometer	--	--	.086

Continuous values of specific conductance were not adjusted to match discrete readings unless the total value differed by 5 percent. Specific-conductance measurements are subjected to greater error than measurements of hydraulic head. If a field adjustment was made, a linear time-weighted correction was applied backward in time to the time of the previous check measurement (which would be the zero adjustment point). A long-term comparison of continuous specific-conductance values to discrete values was done to evaluate the relative reliability of continuous specific-conductance sensors. If check measurements differed from sensor measurements by more than 20 μS/cm for three consecutive check measurements, then continuous specific-conductance probes were removed, cleaned with soap, and replaced; this procedure typically corrected the problem. For this study, reported values of specific conductance have an accuracy of ±5 percent.

Continuous measurements of water temperature were not adjusted. Water-temperature data generally were more accurate than specific-conductance data. Data from air and water temperature sensors always differed from calibration check measurements by less than 5 percent. For this report, data are considered to be within ±1°C of true values.

Ground Water

Seven observation wells were continuously monitored—P-1, P-2, MW-2A, MW-16A, B95-9, MI-32 (fig. 4), and MI-18 (fig. 1, known as MOW-36 in Coakley and others, 1997). Monitoring wells P-1, P-2, MW-2A, and MI-18 were instrumented between May and September 1994 and remain in operation. Two additional wells, MI-32 and MW-16A, downgradient and immediately adjacent to the source area, were instrumented in December 1996 to provide additional background data before the start of remedial activities. The remaining monitoring well, B95-9, was in the immediate contaminant source area, and was instrumented in July 1997. Well construction and monitoring installation data are provided in table 2.

All observation wells are 2 in. in diameter, except MI-18, which is a 3-ft-diameter well. The instrumentation of small diameter 2-in. wells with multiple probes for measurement of hydrologic and other physical parameters involved the use of several small insert pipes to locate individual probes and access tubes for discrete measurements. The design of a continuous ground-water measurement site is shown by Harte and others (1997, fig. 8).

Table 2. Information on observation well and river-gaging station construction and instrumentation for automated monitoring sites, Milford, N.H.

[Altitude in feet above NGVD-29; depth in feet below land surface; --, not applicable; no., number; TPVC, top of polyvinyl chloride (PVC) pipe; MP, measuring point; SC, top of steel casing; POT, potentiometer; Ptrans, pressure transducer; well locations are shown in figures 2 and 4; CDM, Camp, Dresser, and McKee, Inc.; USGS, U.S. Geological Survey]

Well No.	Well name	Altitude of land surface	Source	Altitude of TPVC	Source	Altitude of MP	MP Description	TPVC to MP	SC to MP	Source	Notes
335	P-1	276.6	Meridian 1994	278.95	Meridian 1994	279.26	shelter floor	0.31	0.29	USGS 12/96	
336	P-2	268.6	HMM 1989	271.32	HMM 1989	271.79	shelter floor	.47	.3	USGS 12/96	
310	MW-2A	266.6	USGS 1988	269.32	USGS 1988	270.08	shelter floor	.76	.25	USGS 12/96	
233	MW-16A	267.5	USGS 1988	269.98	USGS 1989	270.39	shelter floor	.41	.21	USGS 12/96	installed 12/11/96
46	MI-32	270.2	USGS 1988	273.57	USGS 1990	273.88	shelter floor	.31	.88	USGS 12/96	installed 12/11/96
29	MI-18	262.7	Meridian 1994	--	--	264.34	top of wall	--	--	--	MOW-36, "dug" well
404	B95-9	270.3	CDM 1996	273.34	USGS 1997	273.34	TPVC	.	--	USGS 7/97	PVC extention added
393	WLR-5	--	--	--	--	254.27	shelter floor	--	--	--	
393	WLR-5 River	--	--	--	--	254.93	TPVC	--	--	--	

				Depth, in feet				Depth, in feet				
					to top of	to bottom		of pressure	sample	of conductivity		Water level
Well No.	Well name	X-coordinate	Y-coordinate	of well	screen	of screen	Source	transducer	tube	probe no. 1	probe no. 2	recording device
335	P-1	974,088.3	124,847.5	14.9	13.9	14.9	USGS 1997	--	10.45	14.9	--	POT
336	P-2	975,100.9	125,281.9	18	17	18	USGS 1997	9.81	16.81	17.81	--	H-310 Ptrans[1]
310	MW-2A	975,148.9	125,591.3	41	29	39	USGS 1997	7.6	20.1/31.5	17.7	31.5	H-310 Ptrans[2]
233	MW-16A	975,669.3	124,865.8	26.9	16.9	26.9	USGS 1997	13.95	16.55	23.65	--	Ptrans
46	MI-32	975,322.2	124,982.6	75	30	75	USGS 1997	12.17	23.07	26.47	--	Ptrans
29	[3]MI-18	977,625.4	123,963.1	12.8	--	--	USGS 11/97	--	--	--	--	POT
404	B95-9	975,039.8	124,825.6	20	10	20	CDM 1996	14.2	16.2	17.2	--	H-310 Ptrans
393	[3]WLR-5	980,644.9	126,283.6	11.8	--	--	USGS 11/97	--	--	11.8	--	POT
393	[3]WLR-5 River	980,644.9	126,283.6	11.5	--	--	USGS 11/97	11.1	--	11.5	--	H-310 Ptrans

[1] Changed water level recording device from POT to Ptrans 10/2/97.

[2] Depth of H-310 changed 1/29/98 (raised 4.0 feet).

[3] Depth of well below MP.

Continuous measurements of ground-water levels were made with potentiometers and attached floats and counterweights at P-1, P-2 (WY 1997 only), and MI-18. Pressure transducers were used at P-2 (WY 1998-99), B95-9, MI-32, MW-16A, and MW-2A. Procedures for calibration followed similar procedures as that for river stage and riverbed water levels. Linear-regression equations that are used to calibrate and convert pounds per square inch readings to depth to water appear in table 1. Continuous water levels were measured as depth below measurement point, in feet, for potentiometers and as pressure of water column above sensor for pressure transducers. Discrepancies between continuous and discrete measurements were up to 0.3 ft for potentiometers. Corrections to potentiometers were made in the field if discrepancies exceeded 0.05 ft by adjusting the potentiometer offset. Wherever field corrections were made, continuous readings were adjusted linearly over the time in which the deviation occurred. Adjustments to potentiometer readings were made less often in large-diameter (more than 6 in.) wells than in small-diameter wells (less than 4 in.). The average offset is an indicator of the reliability of the potentiometer and float and weight system to accurately measure water levels (table 1). The offset is computed by summing all discrepancies between continuous and discrete readings and dividing by the number of check measurements. At WLR-5 (BED) stilling well (1-ft-diameter well) and MI-18 (3-ft-diameter well), potentiometers had less of a discrepancy with check measurements (average offsets of 0.086 and 0.001 ft) than at P-1 (2-in.-diameter well; average offset of 0.113 ft), where it was more difficult to install down-hole specific conductance and temperature probes along with the floats from the potentiometers (table 1).

Performance of pressure transducers was evaluated based on their correlation with manual water-level readings by use of a linear regression equation to calibrate the pressure transducers. Manual water levels showed a strong correlation to pressure transducer readings at all ground-water monitoring wells, with R-squared readings above 0.96, except at MW-16A where there were apparently some hysteresis effects in the recording by the pressure transducer (R-squared 0.86) (table 1) following large rises and declines in water levels.

Specific conductance and temperature of ground waters were measured every 15 min at 6 wells: P-1, P-2, MW-2A, MI-32, MW-16A, and B95-9. These parameters were measured using the same type of sensors used at the river-gaging station (WLR-5, fig. 1). Discrete data were collected monthly at well MI-18. Specific conductance and temperature readings were checked monthly against discrete measurements for all wells. Water samples were extracted using a peristaltic pump to obtain discrete measurements of specific conductance and water temperature for comparison to continuous readings. Wells were pumped after measuring the static water level and between 15-min recordings of water level so as not to affect continuous measurement. Continuous values of specific conductance were not adjusted to match discrete readings unless the difference was greater than 5 percent of the value, in which case an adjustment was made similar to that used for the gaging station. Discrepancies between continuous and discrete values for water temperature ranged from 10 to 20 percent of continuous readings. These large discrepancies are present because the pumped water is subject to warming or cooling based on the air temperature when pumping. Water temperatures obtained by pumping are not considered to be as reliable as down-hole water-temperature measurements, unlike specific conductance which can be accurately measured from the pumped water sample. Thus, no adjustments were made to the water-temperature probe or water-temperature data for ground-water stations.

MONITORING RESULTS

Emphasis of the monitoring results is on illustrating and describing conditions during three periods: (1) pre-wall construction (October 1, 1996, to June 1998), (2) barrier wall construction (July 1998 through October 1998), and (3) post-wall construction (November 1998 to September 30, 1999). Remedial operations began with partial pumping (limited number of extraction and injection wells) in early March 1999. Pumping stopped in mid-April 1999, and full pumping (all extraction and injection wells) resumed in early May 1999. Monitoring results are provided as graphs in figures 6-23. The periods of the study are noted on the graphs where appropriate.

Effects of Remedial Activities

The OK Tool portion of the Savage Municipal Well Superfund site is a highly transient, large volume, and rapid ground-water-flow environment. The OK Tool facility is next to a recharge source, the Souhegan River, which is one of the primary reasons for these flow conditions. Ground-water levels and river stage are closely connected to each other and to natural stresses, such as precipitation. Since the construction of the remedial facility, anthropogenic factors, such as well construction or injection or extraction of water, at the site also affect ground-water levels.

Barrier-wall construction began in early July 1998, and was completed by October 21, 1998. Effects of the construction on the flow system at the OK Tool facility were minimal during July and August but were apparent when continuous water levels from monitoring well B95-9 inside the barrier wall were compared with water levels from adjacent wells (MI-32, P-2, and MW-2A) outside the wall (fig. 4). Water levels rose at well B95-9 from mid-September to early October, while the other wells showed a decline in water levels over the same period. This decline shows that B95-9 is isolated from the local-flow system (fig. 6).

The remedial facility began operating on March 1, 1999, using a combination of extraction and injection wells. Pumping-induced changes in water level can be seen inside the barrier wall at observation well B95-9 (fig. 7). Water levels declined when pumping began, and rose sharply when the pumping was halted in mid-April. Pumping rates for extraction wells IW-1and IW-2 inside the wall are large enough (25 gal/min) to negate the effects of precipitation in late March. When pumping at wells IW-1 and IW-2 resumed in May, however, the rate was slow enough (10 gal/min) that B95-9 showed a response to precipitation.

Water Levels, Specific Conductance, and Water Temperature for Individual Sites

Results of data collection for individual monitoring sites are presented as graphs and include water levels, specific conductance, and water temperature. Daily average values for each parameter are presented as a continuous data series unless otherwise indicated. Water-level, specific-conductance, and water-temperature data spanning WY 1997-99 were plotted for observation sites B95-9, MW-16A, P-1, MI-32, MW-2A, M-18, P-2, and river-gaging station WLR-5 (figs. 8-15). The start of data records and any loss of data are included on the graphs. A summary of maximum, minimum, and total range of daily averages over 3 years for each monitoring site is provided in table 3. Information on maximum, minimum, mean, and median values of each parameter for each water year at each monitoring location is provided in appendix 2. A description of the monitoring sites and a summary of the data-collection results are included in the following paragraphs.

B95-9: This observation well is located inside the barrier wall. The range of water-level fluctuations decreased from nearly 6 ft in WY 1998 to slightly greater than 4 ft in WY 1999 (fig. 8). A large recession occurred in late summer 1998. Overall, water levels declined from a high in summer 1998 to a low during April 1999. In summer 1999, effects of pumping and little precipitation can be seen as water levels declined more rapidly. Variable specific conductances are observed in WY 1997 and WY 1998. A large decrease (650 to 250 μS/cm) in specific conductance is coincident with the constructed barrier wall cutting off ground-water flow and associated input of road salt. Water-temperature fluctuations were small (3°C) before completion of the barrier wall, but increased to 6°C following wall completion. Greater fluctuations in ground-water temperatures likely were the result of ground-water withdrawal and reinjection.

MW-16A: This observation well is located downgradient of the barrier wall. The range of water-level fluctuation is about 5 ft annually (fig. 9). Maximum winter water levels are lower in WY 1999 than in the two previous water years. Specific conductance reached a maximum of 660 μS/cm in the fall of 1998, and slowly declined to an average of 480 μS/cm during WY 1999. Changes in water level had little effect on the specific conductance of the well indicating a long-term accumulation of road salt, which has remained present in and around the well at varying concentrations. Annual variations in water temperature are minimal (2°C). A sudden drop in water temperature in mid-April 1999 is related to pumping at extraction wells EW-1 and EW-2, which increased vertical ground-water flow and pulled cold water from near the surface.

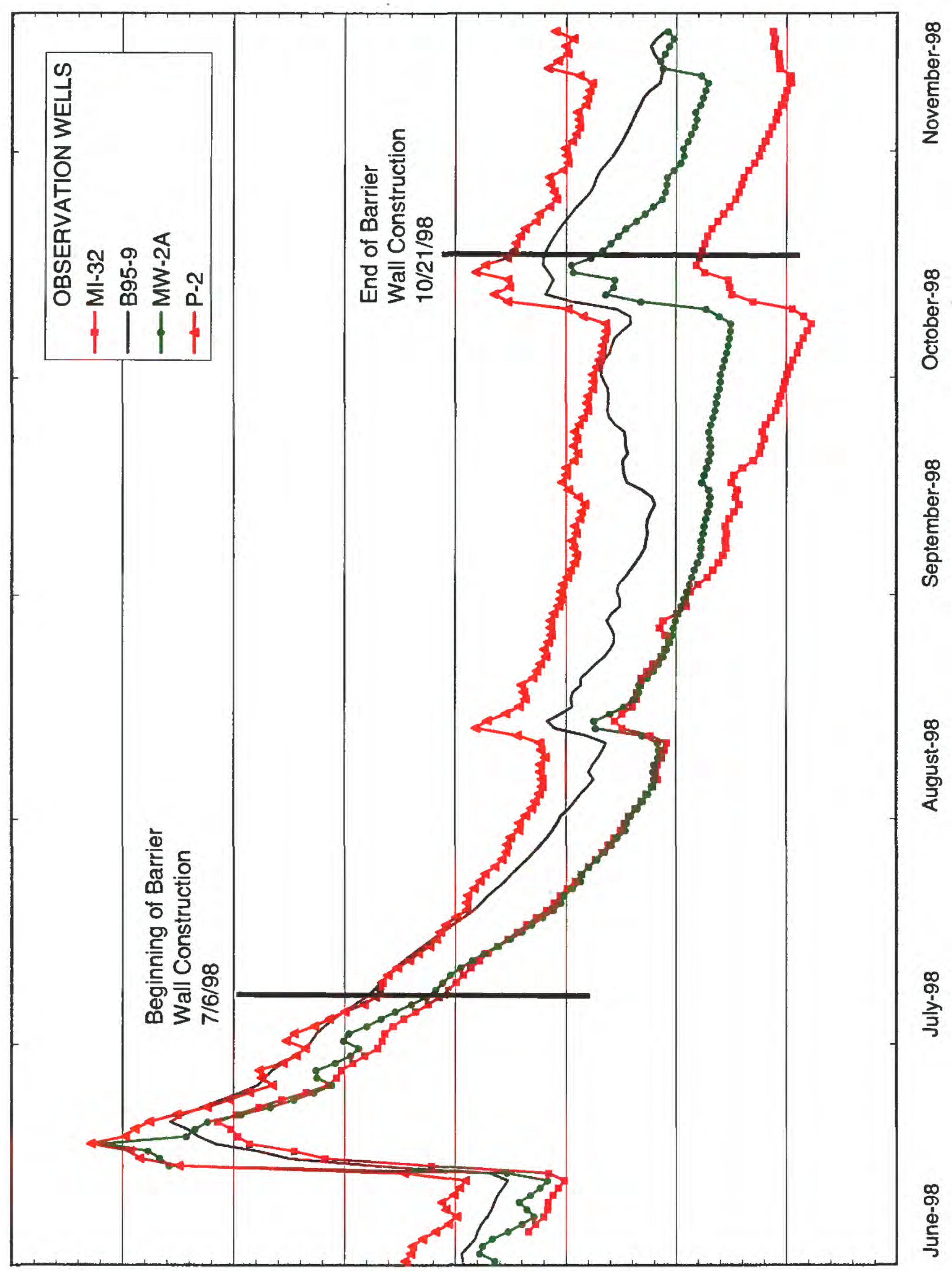
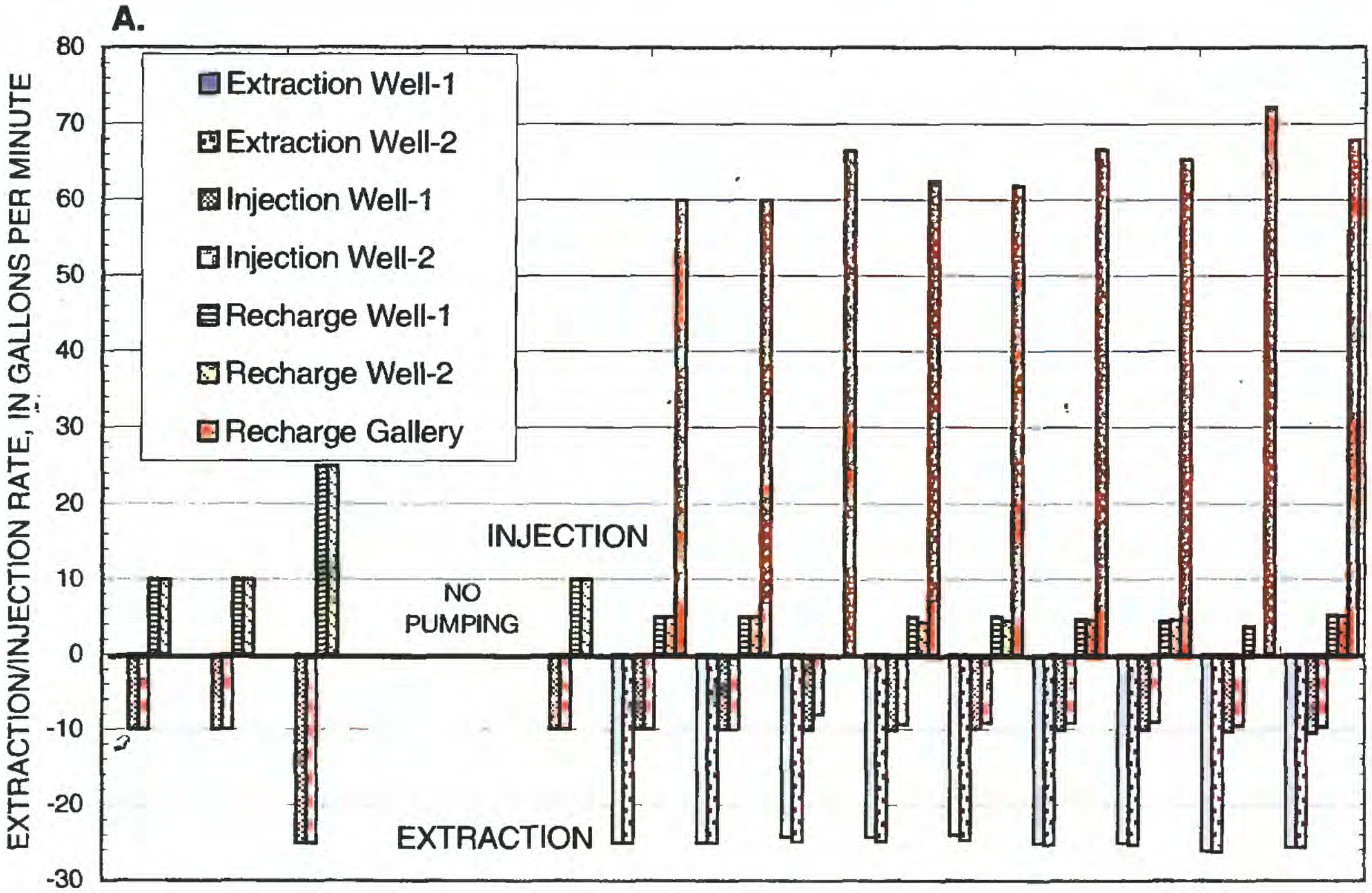


Figure 6. Altitude of ground-water levels at observation wells during barrier wall construction in Milford, N.H.



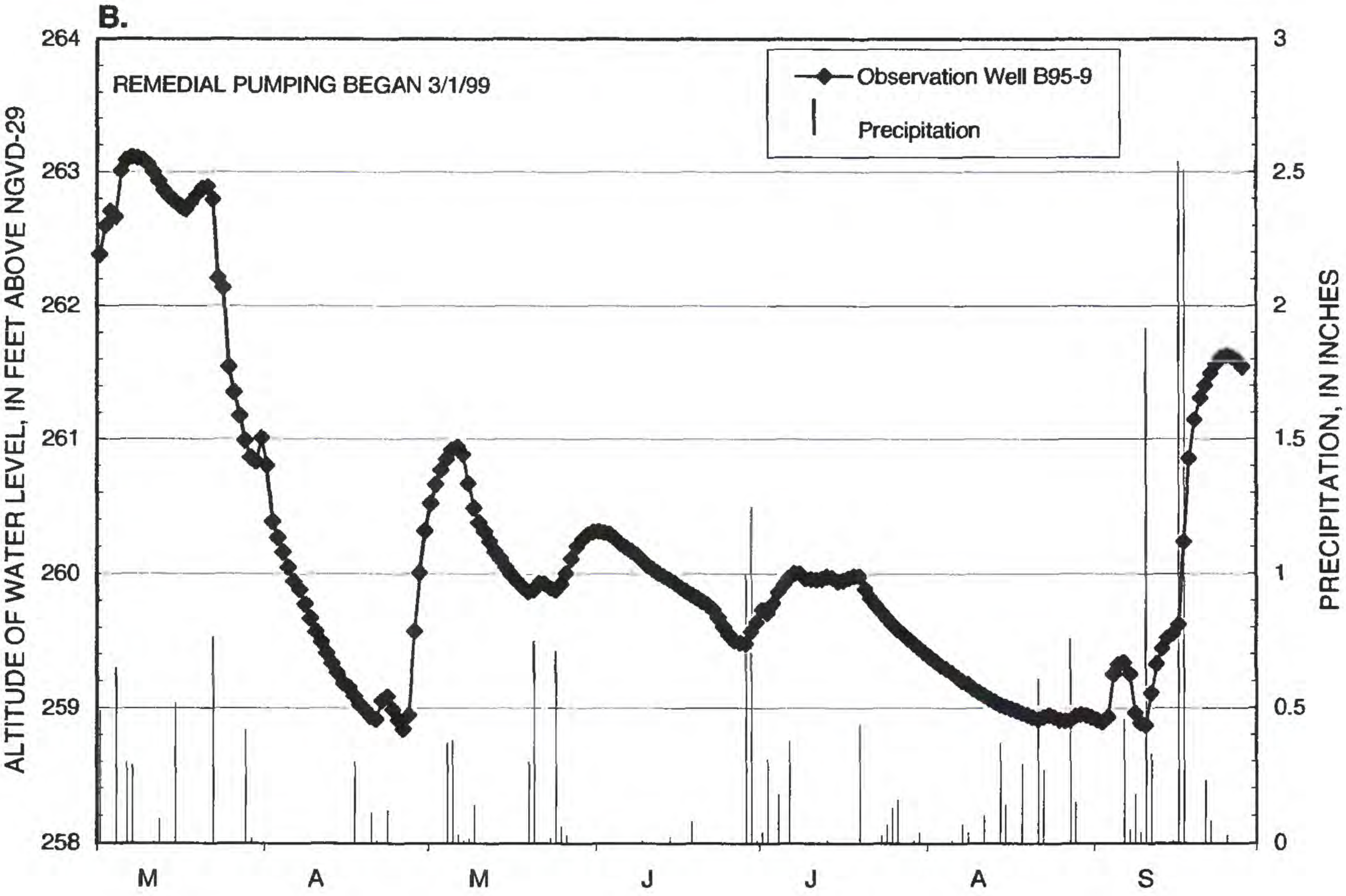


Figure 7. OK Tool facility pumping rates (A) and precipitation and water level at observation well B95-9, water year 1999 (B) in Milford, N.H.

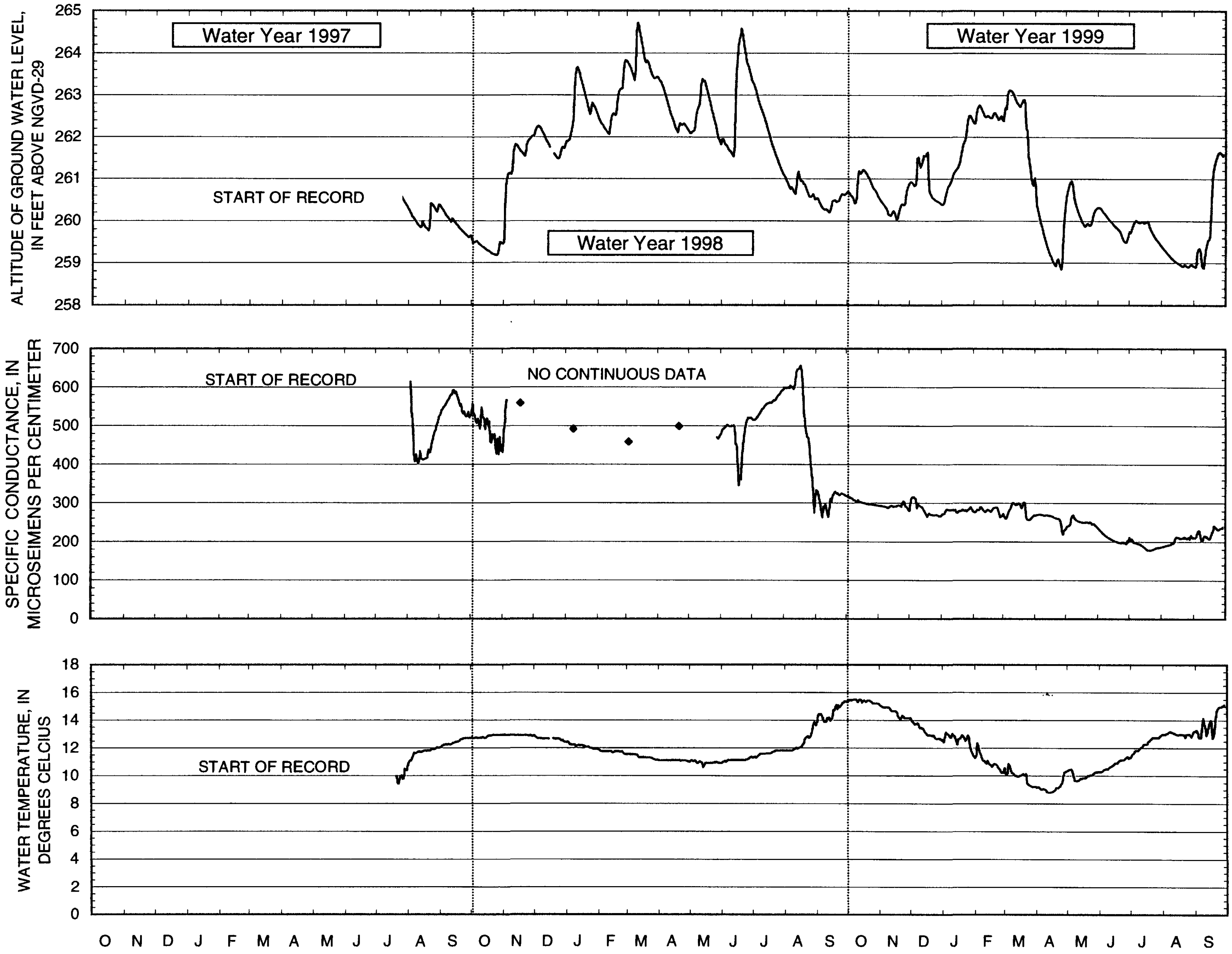


Figure 8. Altitude of ground-water level, specific conductance, and water temperature from observation well B95-9 in Milford, N.H., for water years 1997-99. (Location of wells shown on fig. 4)

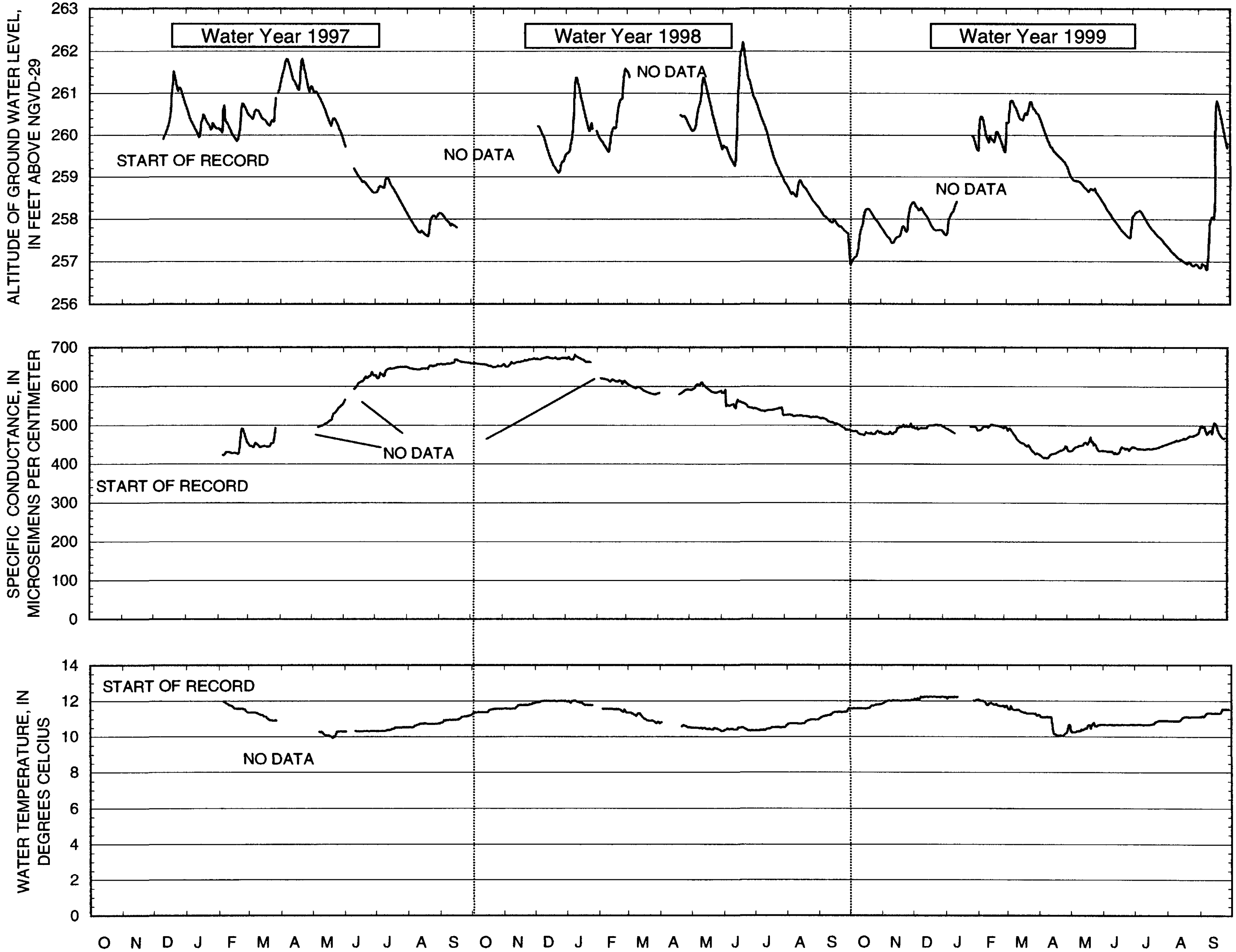


Figure 9. Altitude of ground-water level, specific conductance, and water temperature from observation well MW-16A in Milford, N.H., for water years 1997-99. (Location of wells shown on fig. 4)

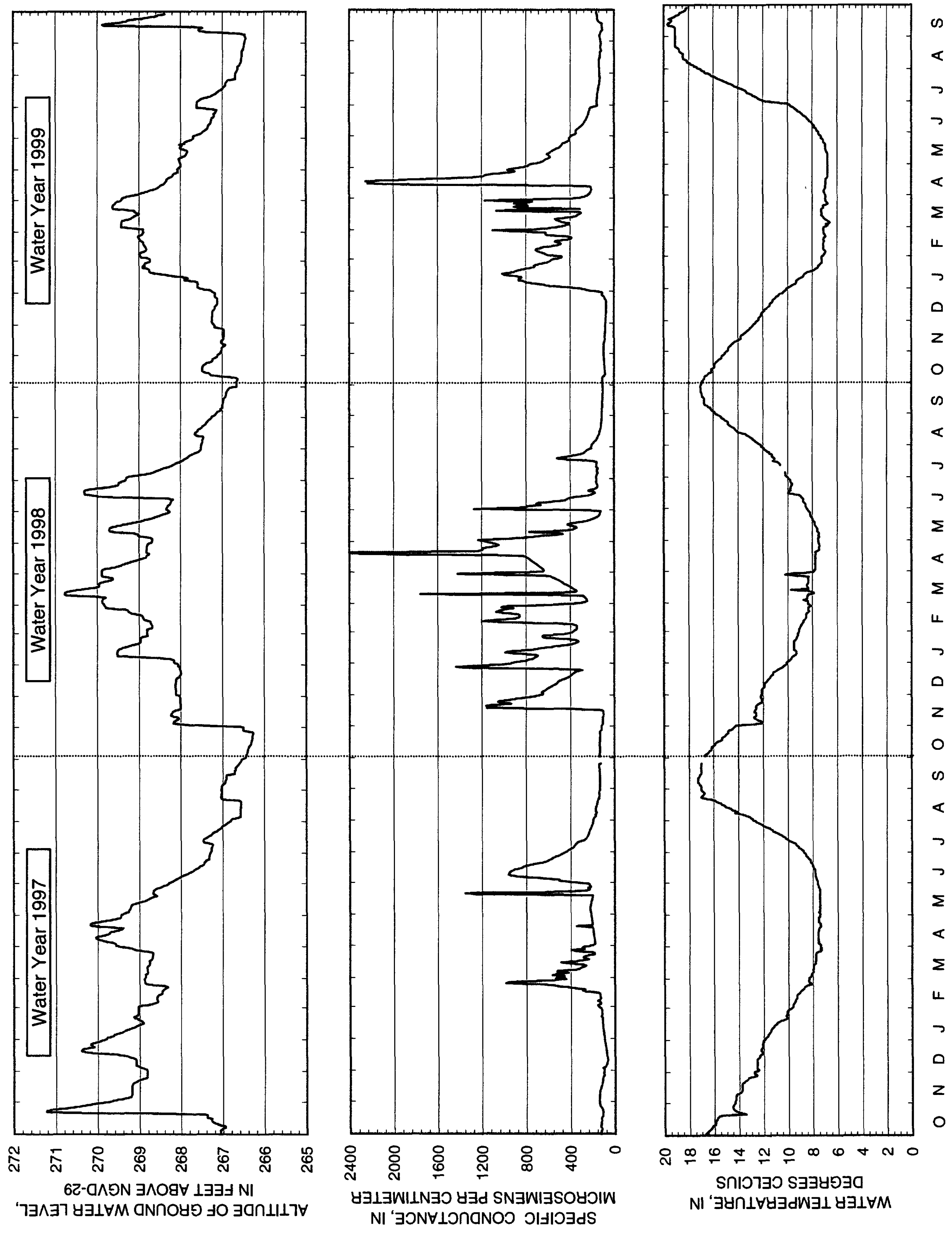


Figure 10. Altitude of ground-water level, specific conductance, and water temperature from observation well P-1 in Milford, N.H., for water years 1997-99. (Location of wells shown on fig. 4)

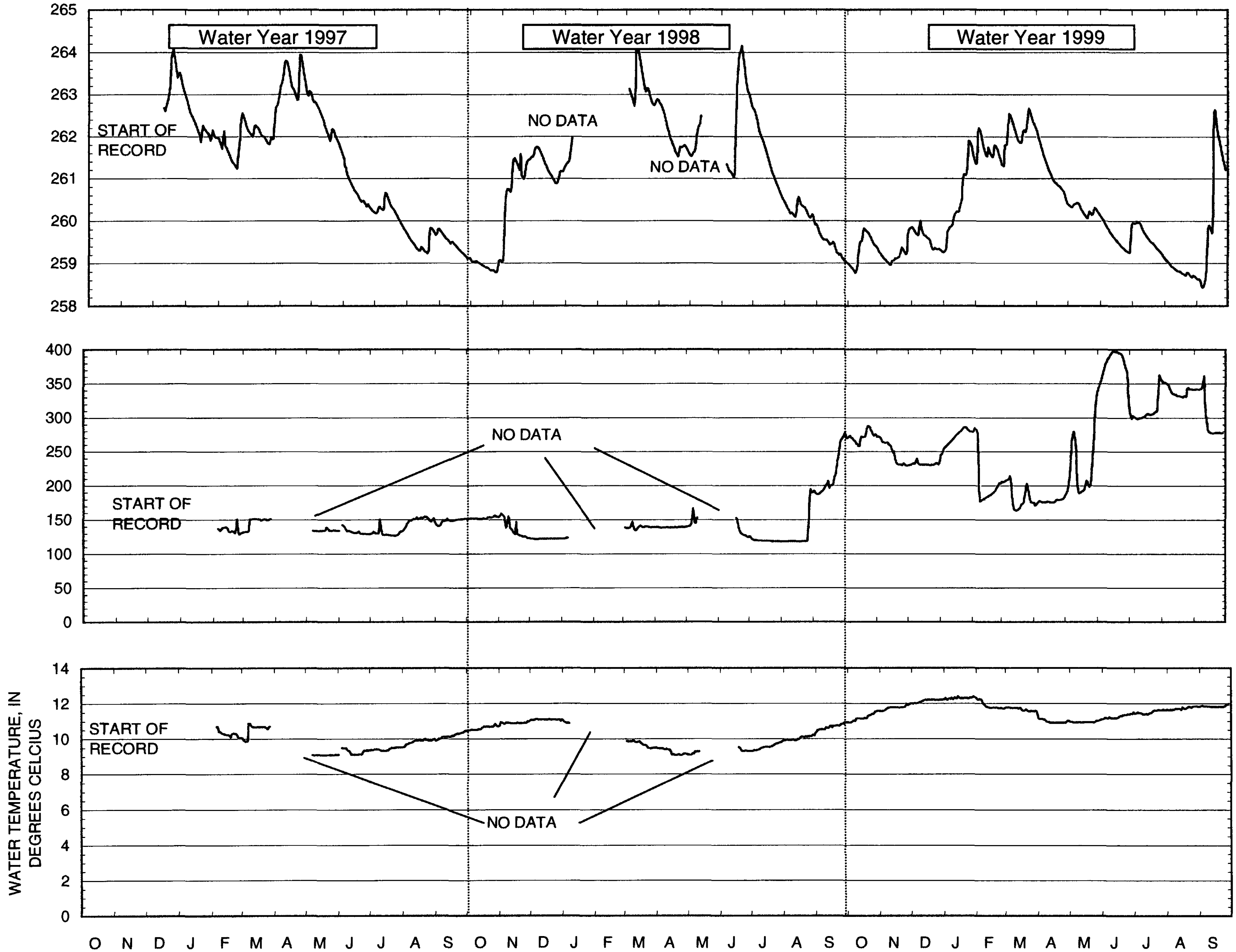


Figure 11. Altitude of ground-water level, specific conductance, and water temperature from observation well MI-32 in Milford, N.H., for water years 1997-99. (Location of wells shown on fig. 4)

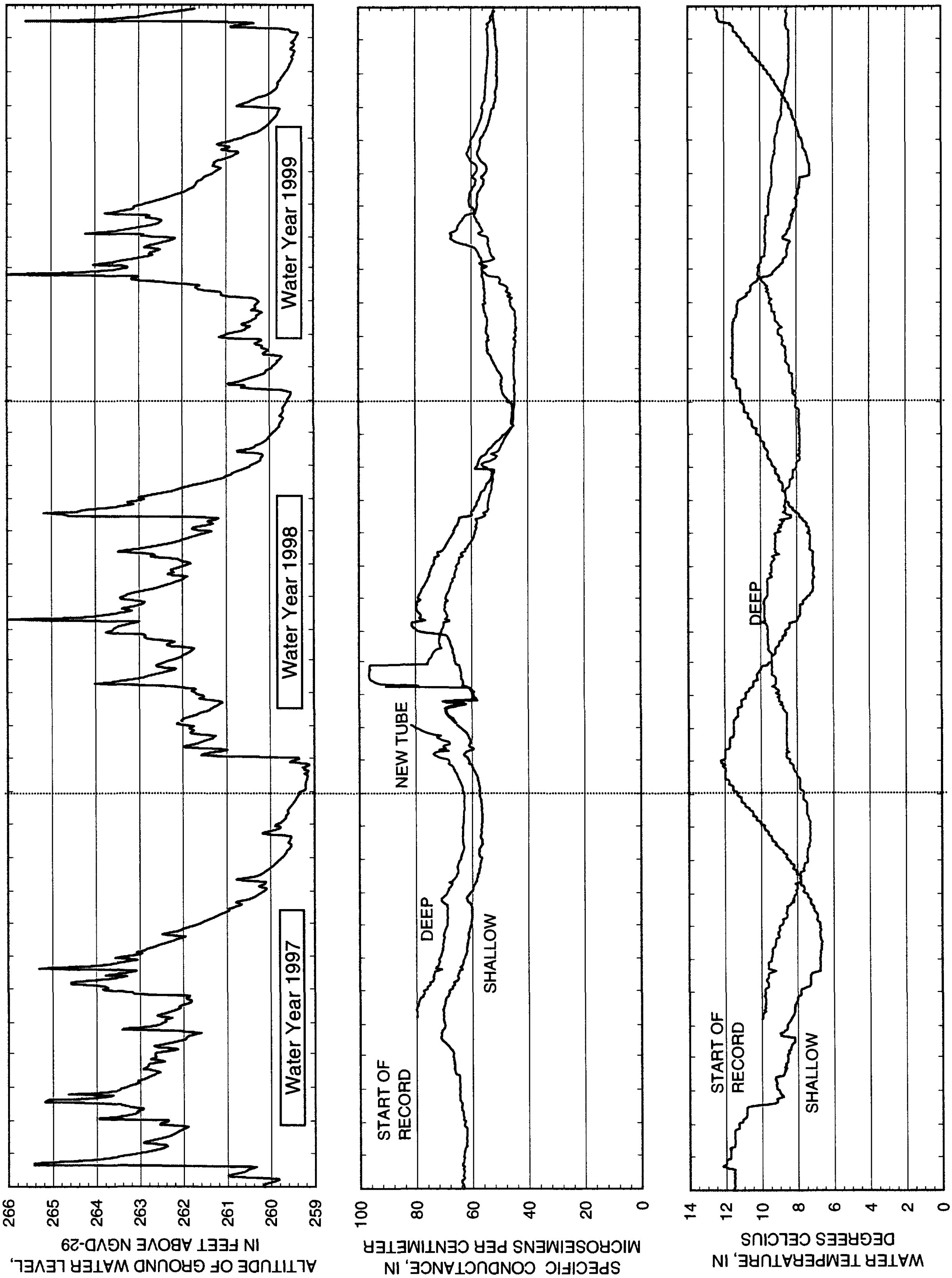


Figure 12. Altitude of ground-water level, specific conductance, and water temperature from observation well MW-2A in Milford, N.H., for water years 1997-99. (Location of wells shown on fig. 4)

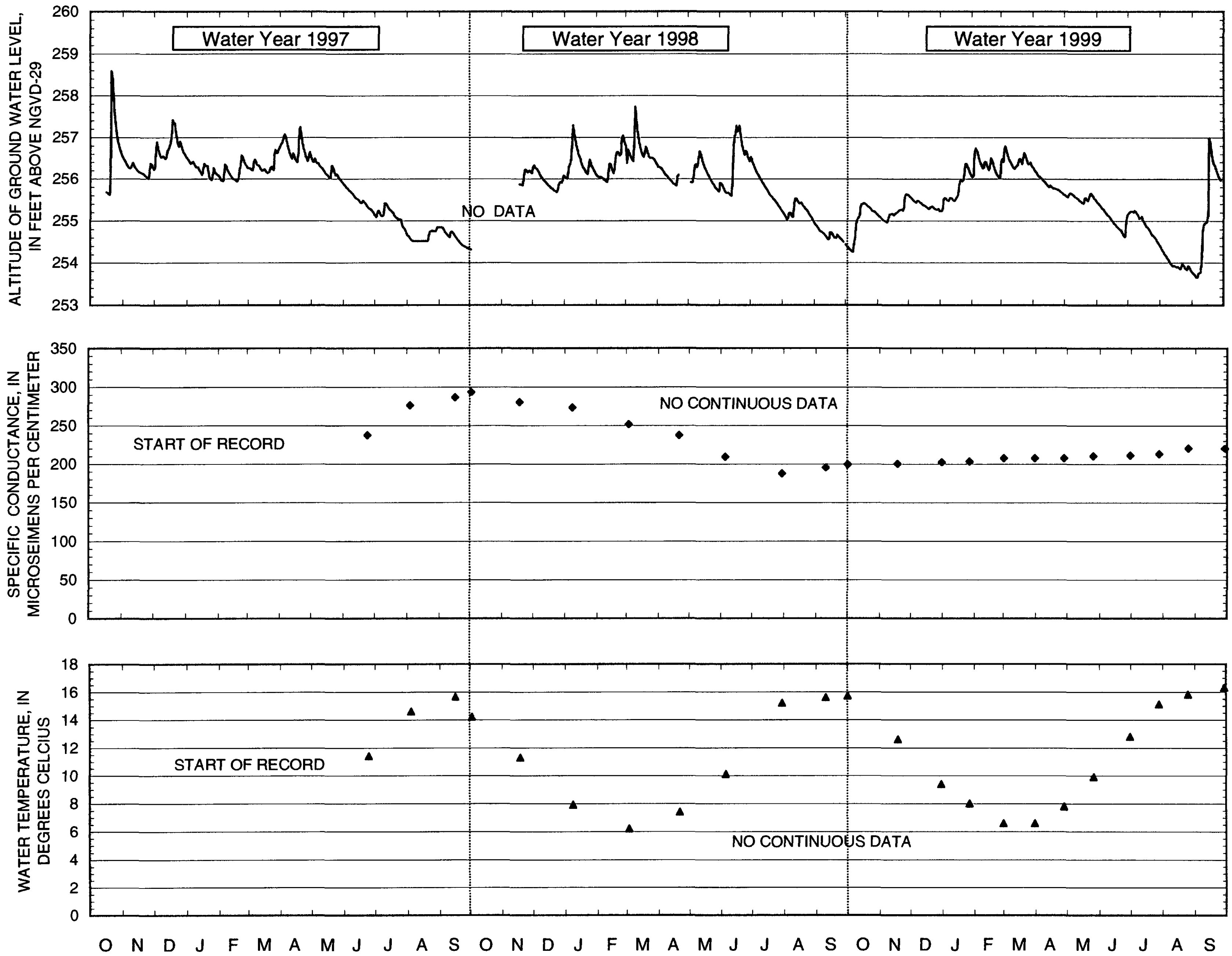


Figure 13. Altitude of ground-water level, specific conductance, and water temperature from observation well MI-18 in Milford, N.H., for water years 1997-99. (Location of wells shown on fig. 2a)

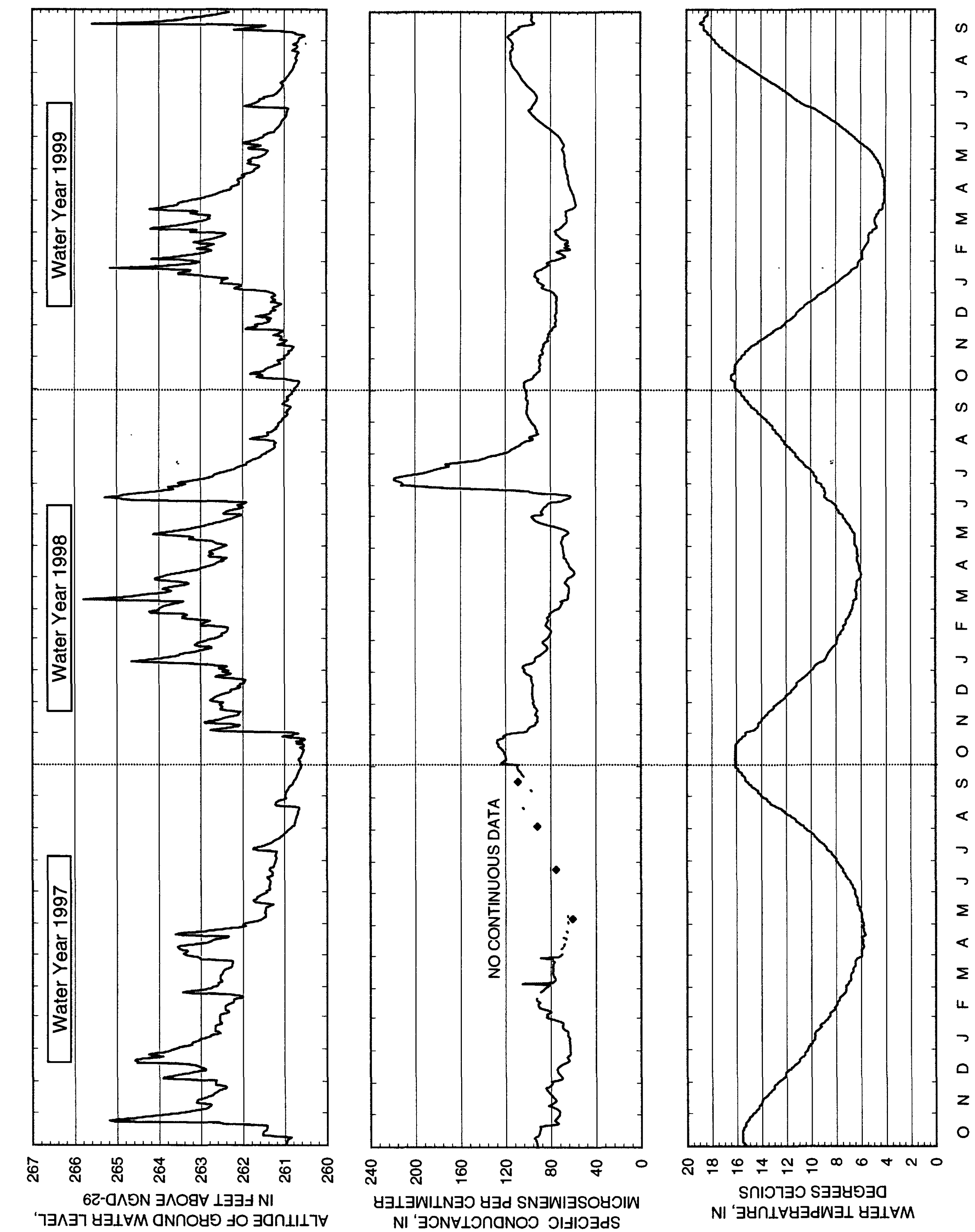


Figure 14. Altitude of ground-water level, specific conductance, and water temperature from observation well P-2 in Milford, N.H., for water years 1997-99. (Location of wells shown on fig. 4)

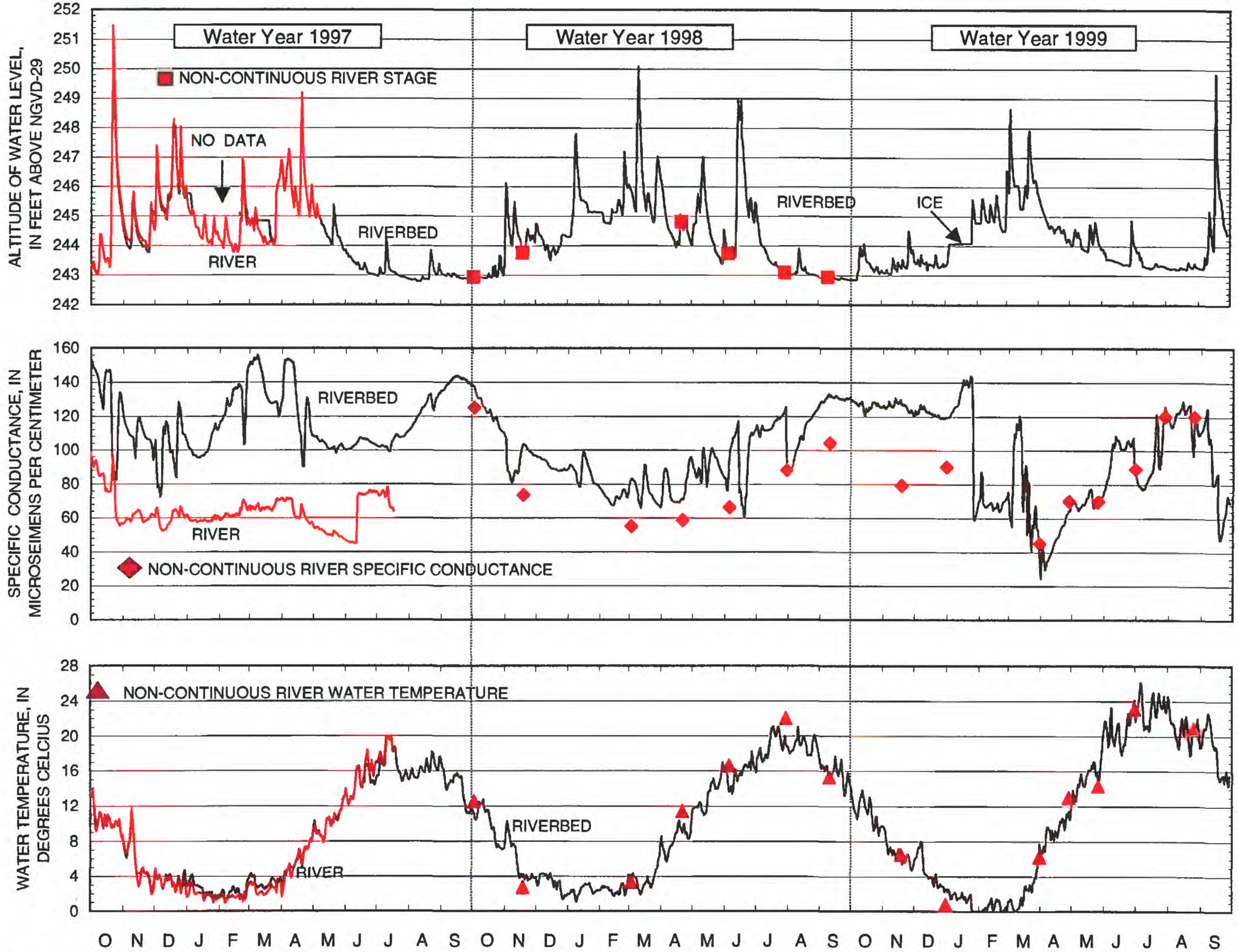


Figure 15. Altitude of riverbed-water level, specific conductance, and water temperature from river-gaging station WLR-5 in Milford, N.H., for water years 1997-99. (Location of wells shown on fig. 2a)

Table 3. Summary of ranges of water level, specific conductance, and water temperature for automated monitoring sites, water years 1997-99, Milford, N.H.

[All values from ranges of daily averages; °, degrees]

Monitoring site (location shown on fig. 2A or fig. 4)	Water level (in feet)			Specific conductance (microsiemens per centimeter at 25° Celsius)			Water temperature (° Celsius)		
	Range	Maximum	Minimum	Range	Maximum	Minimum	Range	Maximum	Minimum
B95-9	6	265	259	450	650	200	6	15	9
P-1	5	271.5	266.5	2,300	2,400	100	12	19	7
P-2	5	265.5	260.5	160	220	60	15	19	4
MW-2A	7	266	259	35	80	45	5	12	7
MW-2A(DEEP)	7	266	259	50	95	45	3	10	7
MI-32	6	264.5	258.5	270	400	130	3	12	9
MW-16A	5	262	257	260	680	420	2	12	10
MI-18	5	258.5	253.5	120	300	180	10	16	6
WLR5(RIVER)	8	251	243	80	120	40	24	24	0
WLR5(BED)	8	251	243	120	150	30	26	26	0

P-1: This observation well is upgradient of the barrier wall, adjacent to a highway and to the Souhegan River. The range of water-level fluctuation is about 4.5 ft annually (fig. 10). Recharge was low during winter 1999. The effect of road-salt application is visible at this well by the large spikes in specific conductance and as a result, specific conductance values are higher at this well than the other wells. Specific conductance is most variable during the "winter-weather" months of November through early May. There are no clear patterns other than seasonal trends that link water-level rise or decline with a rise or decline in specific conductance. Ground-water-temperature patterns are strongly affected by river water recharge to the aquifer. A drop in ground-water temperature in October 1997 is probably the result of increased river leakage to ground water during high river stage. It is unclear what caused the temperature fluctuation in March 1998.

MI-32: This well is immediately adjacent and downgradient to the barrier wall. The range of water-level fluctuations is approximately 5 ft annually (fig. 11). Water levels were low in winter 1999, similar to other sites, because of low recharge. There was an increase (more than 25 percent) in specific conductance during completion of the barrier wall in late summer 1998. There are two possible reasons for the elevated specific conductance, (1) leaching from the slurry at the wall or (2) alteration of ground-water flowpaths after wall construction that promotes flow from the south where road salt is applied. Specific conductance became highly variable beginning in WY 1999. An inverse correlation between specific conductance and water level was observed during WY 1999. The annual ground-water temperature range was small (2°C).

MW-2A: This well is on the north side of the Souhegan River (opposite side of river from the barrier wall). There was a strong effect of river water on ground water at this observation well. The range of water-level fluctuations exceeded 6 ft annually (fig. 12). A hurricane in September 1999 raised the water level 6 ft in one event. Two specific-conductance/water-temperature probes are installed at different depths (shallow probe and deep probe) and generally mimic each other with regard to specific conductance. The shallow probe was 11 ft above the top of the screen and 17.7 ft below land surface. The deep probe was positioned in the screen interval, 31.5 ft below land surface, and recorded more variations in specific conductance because of its positioning in the screened interval. Specific conductances were relatively low (less than 100 µS/cm) (less than the shallow or positioned one) from the effect of low specific conductance river water. This well was not affected by road salting. The water-temperature gradient reverses seasonally with reversals occurring in mid-January and at the end of June. Shallow water affected by cold air at the ground surface was colder than the deep water from mid-January to the end of June. The shallow probe showed a larger annual temperature range (5°C) than the deep probe (3°C). The deep probe was more insulated from changes in air temperature at the ground surface.

MI-18: This shallow, large diameter observation well is 1 mi east of the OK Tool facility and serves as a background index well. This well is a former domestic supply (dug) well and is now a long-term observation wells in the USGS ground-water-level network. Water-level fluctuations were moderate, about 4 ft annually (fig. 13). The lowest water level for the reporting period was in September 1999, preceding a hurricane. Specific conductance and temperature measurements were measured discretely. Overall, specific conductance was relatively constant, but trended lower in 1999, possibly the effect of less road salting. A range in water temperature of 10°C annually results from the shallow depth and the large water surface area of the dug well exposed to the air.

P-2: This observation well is between the barrier wall and the river. Water levels were highly affected by river stage (fig. 14), though a 5-ft range is typical of wells in this aquifer. Some specific conductance data were lost during a part of WY 1997 because of a malfunctioning (dirty) probe, which was replaced October 1, 1997. A large increase in specific conductance from mid-June to mid-August 1998 was coincident with construction of the barrier wall and probably is caused by leaching of slurry from the wall. Low water temperatures during winter 1999 indicated an increase in recharge of river water to the aquifer.

WLR-5: This river-gaging site is approximately 1.5 mi downstream of the OK Tool facility. There was a close correlation between riverbed water level and river stage during WY 1997 (fig. 15) as shown by the similarity in responses. Monitoring at the river well was discontinued at the end of WY 1997. Scouring of the riverbed during 1998 resulted in the riverbed stilling well essentially becoming a river well. From 1998 onward, water temperature and specific conductance for the river and the stilling well are nearly identical. A high water temperature in summer 1999 was the result of solar heating of shallow water at low flow.

Water Levels, Specific Conductance, and Water Temperature for All Sites

Results of data collection for all sites are presented as composite graphs, which include water level, specific conductance, and water temperature (figs. 16-18) for the period of record October 1, 1996, to September 30, 1999. Monitoring locations P-1 and WLR-5 are shown in the composite hydrographs with offsets of -6 ft and +11 ft, respectively. As a result, inferences regarding gradients cannot be made between these sites and other wells on the graphs. Maximum high water occurred in October 1996, March 1998, and September 1999 from daily rainfall events in excess of 2 in. Riverbed water levels fluctuated 8 ft (WLR-5), and ground-water levels fluctuated 5 to 7 ft (fig. 16). Wells MW-2A and P-2, located closest to the Souhegan River, showed large fluctuations (quick rises and rapid recessions). Recessions at these wells were large following a large rise; however, during a period of low ground-water levels, as in the summer of 1997, water levels at P-2 showed only a gradual decline because of recharge from river leakage. Prior to wall construction in June 1998 (fig. 17), ground-water levels at P-2 and MW-2A were higher than at other wells during recharge. After wall construction in the fall of 1998, water-level patterns at B95-9 differed from water-level patterns at other wells. Differences in ground-water levels in 1999 among wells B95-9, MI-32, P-2, and MW-2A were larger than in preceding years (fig. 18). These differences were the result of changes in the local-flow system that were caused by the barrier wall and were further increased in WY 1999 by lower than average rates of ground-water recharge.

Composite graphs of specific conductance are provided in figures 19-21. These graphs help identify water affected by road salting activities (see wells P-1, MW-16A and B95-9). Specific conductance of water in the stilling well at river-gaging station WLR-5 varied from 30 to 150 μS/cm, whereas river water varied from 50 to 120 μS/cm. Specific conductance of ground water varied from 60 to 2,400 μS/cm, depending on location. Prior to barrier wall construction, wells P-1, MW-16A, and B95-9 showed high specific conductance from road-salting activities (figs. 8-10). After construction of the barrier wall, well MI-32 showed high specific conductance, which may be attributed to dissolution of barrier wall materials and(or) road salt (fig. 21). Specific conductance of ground water at MI-32 and P-2 increased in mid to late summer of 1998 (fig. 20). This increase coincided with the construction of the barrier wall.

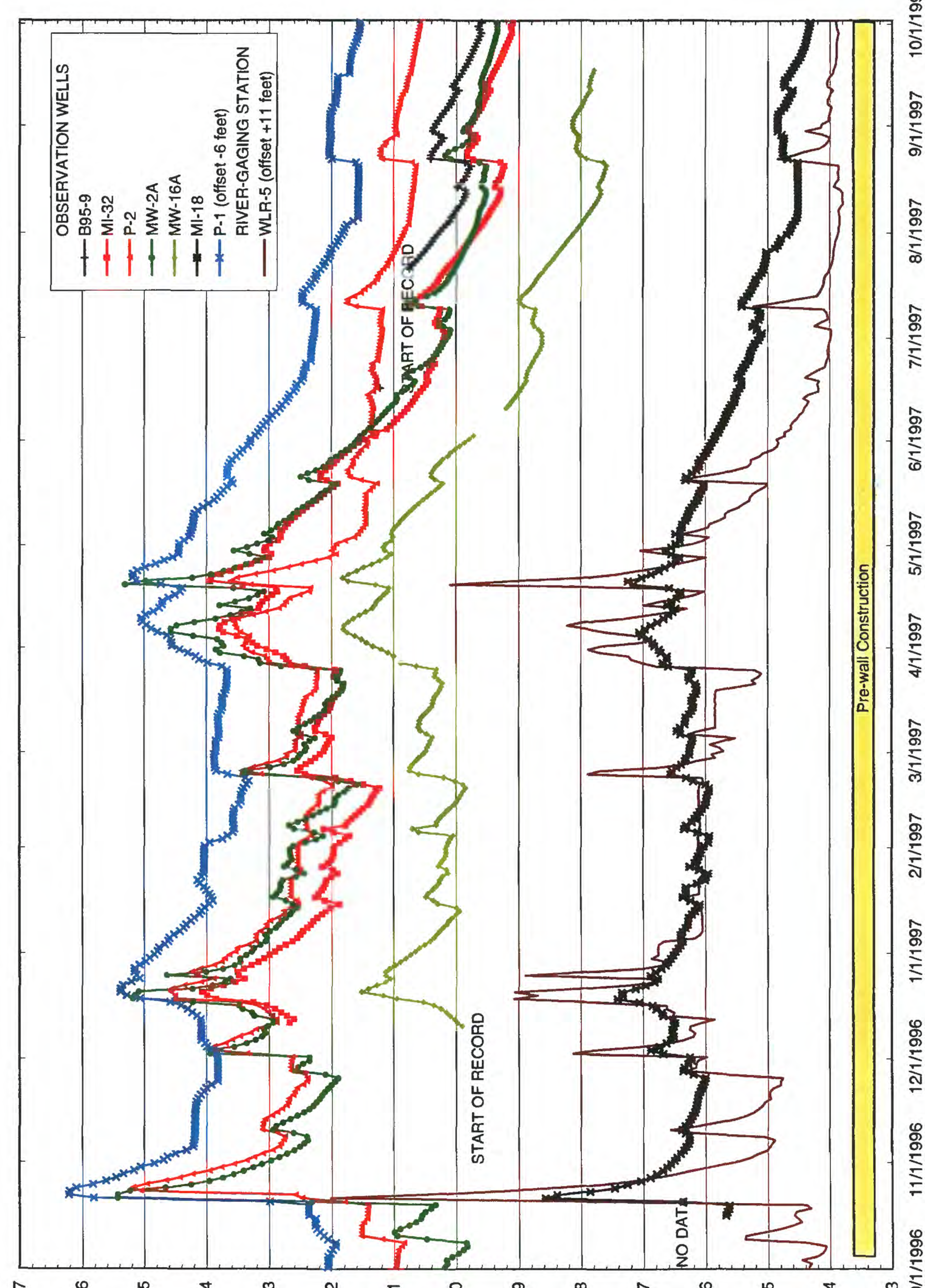


Figure 16. Altitude of water level for observation wells and a river-gaging station in Milford, N.H., for water year 1997 (WLR-5 is offset +11 feet; P-1 is offset -6 feet).

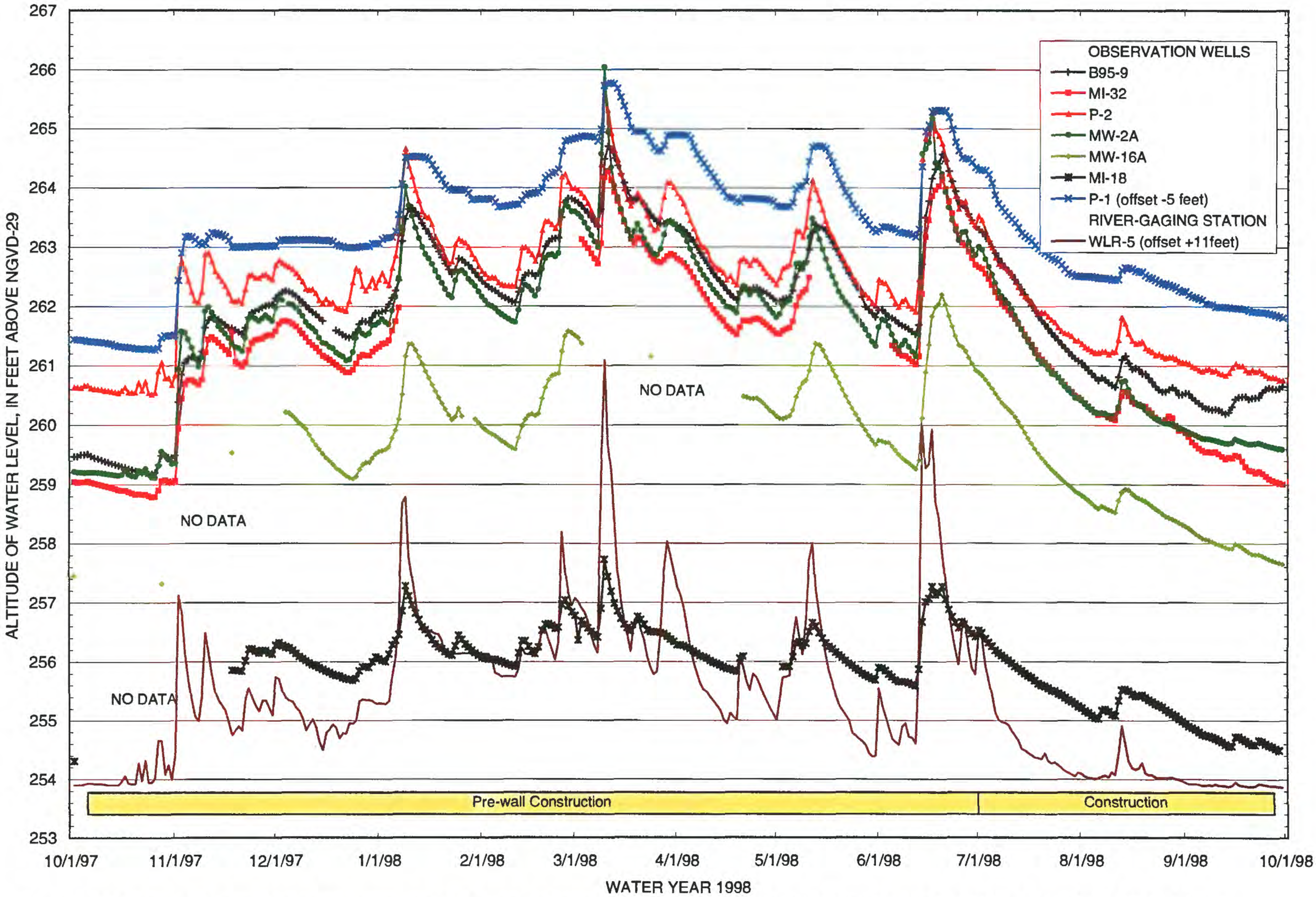


Figure 17. Altitude of water level for observation wells and a river-gaging station in Milford, N.H., for water year 1998 (WLR-5 is offset +11 feet; P-1 is offset -6 feet).

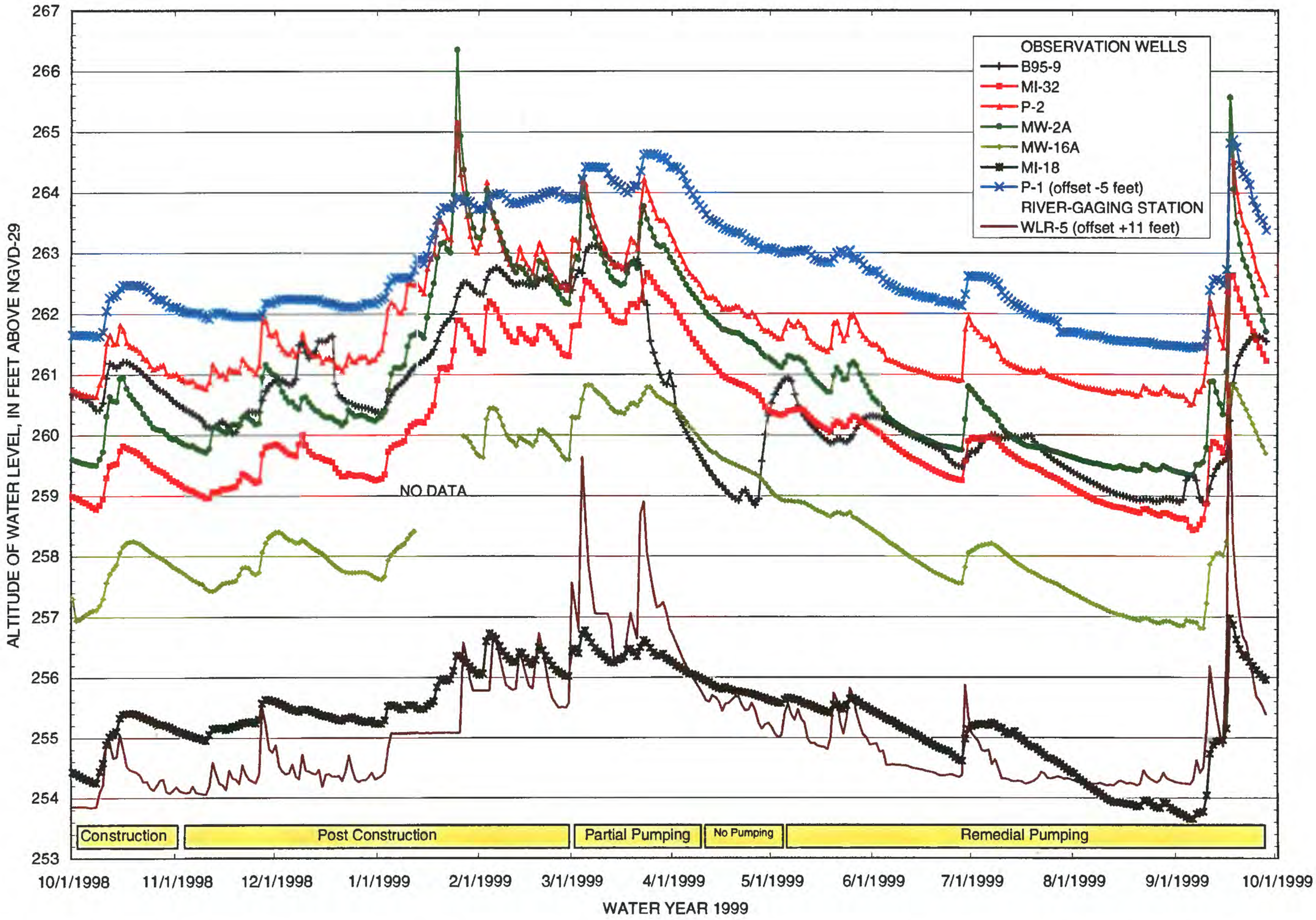


Figure 18. Altitude of water level for observation wells and a river-gaging station in Milford, N.H., for water year 1999 (WLR-5 is offset +11 feet; P-1 is offset -6 feet).

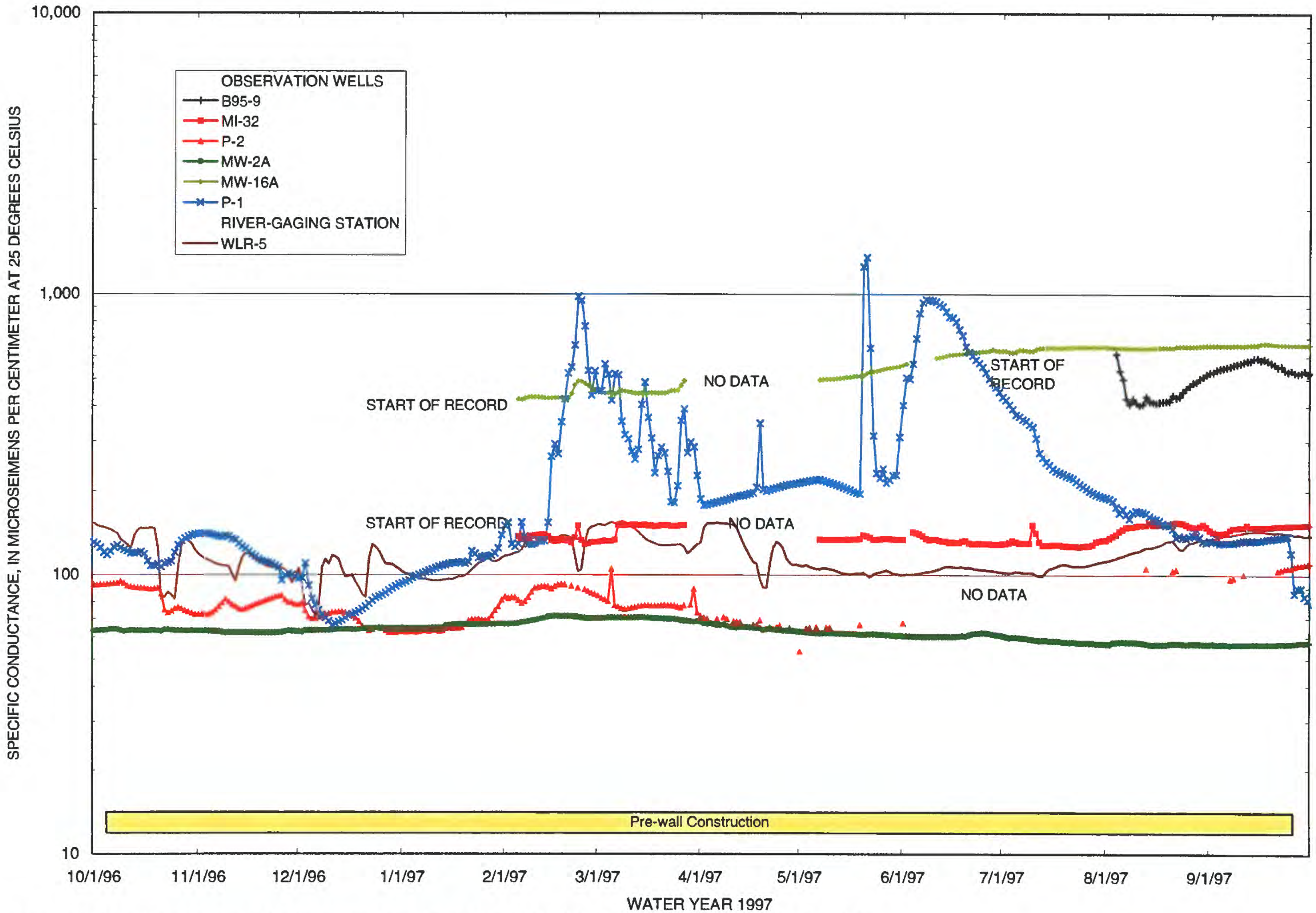


Figure 19. Specific conductance for observation wells and a river-gaging station in Milford, N.H., for water year 1997.

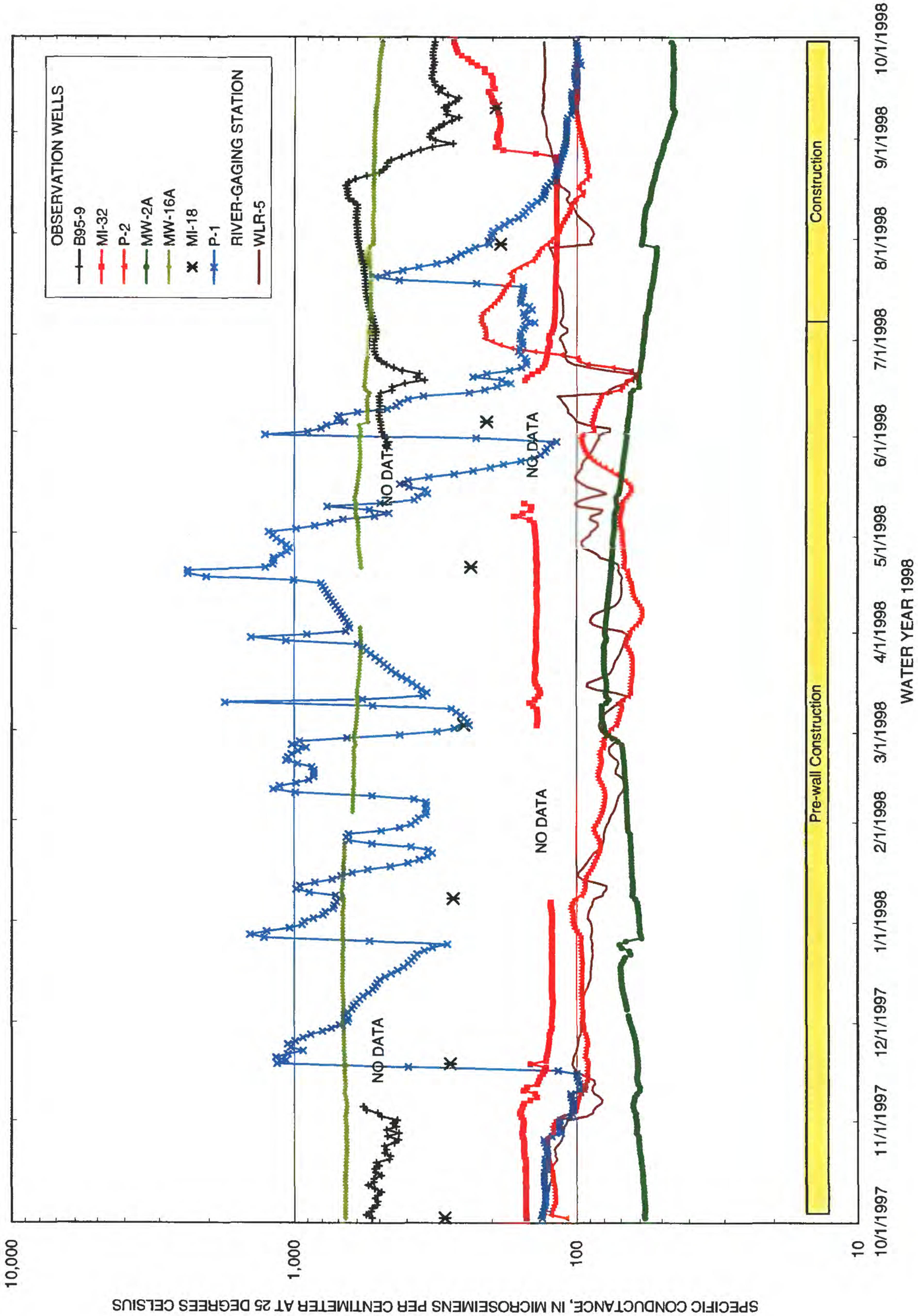


Figure 20. Specific conductance for observation wells and a river-gaging station in Milford, N.H., for water year 1998.

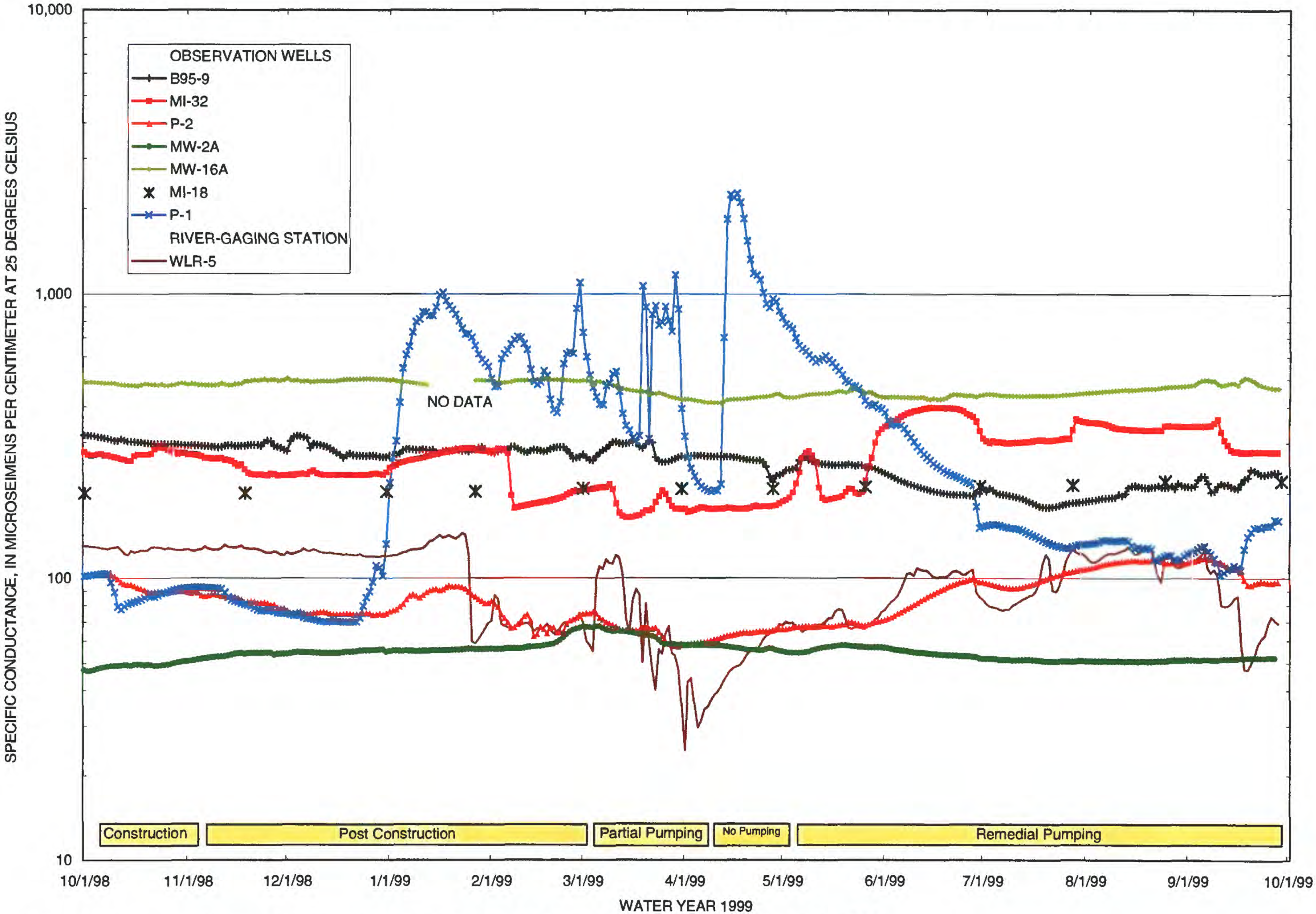


Figure 21. Specific conductance for observation wells and a river-gaging station in Milford, N.H., for water year 1999.

Composite graphs of water-temperature data illustrate the effects of site location and well and probe depth on the variability of water temperature (figs. 22-24). Water temperature is affected by the depth of the water temperature reading (probe depth) because of the effect of thermal conduction from the air. Temperatures of water from all observation wells fluctuated annually (figs. 22-24). Water temperature ranged from 0 to 26°C at WLR-5 at the river, and for wells highly affected by the river (P-1 and P-2), to 10-12°C at wells farther from the river (MW-16A). Water temperature at well B95-9, prior to barrier wall construction, showed a relatively small fluctuation for a shallow well (less than 40 ft below land surface) and probe depth because the well is located farther from the river than P-1 and P-2. Deep ground water showed less fluctuations and increased lag time between minimum and maximum air temperature and affected minimum and maximum water temperatures (for example, the lag at MW-2A (deep probe)) than shallow ground water. Low river stages and ground-water levels in late summer 1999 resulted in the highest water temperatures for the monitoring period at locations P-1, P-2, and WLR-5 (fig. 24).

One of the primary benefits of continuous automated data collection is to provide information on hydrologic conditions that are not discernible with discrete monitoring. Continuous readings provide information on water-level responses to hydrologic events such as precipitation infiltration, ground-water discharge, rapid river-stage changes, ice jams, overland flow, ground-water withdrawals, and other stresses. A comparison of manual and continuous measurements from April 25 to August 4, 1999, at observation well MI-32, demonstrated how water-level responses are more accurately shown by a continuous record (fig. 25), such as the water-level recession and subsequent rapid rise from May 26 to June 30. Discrete manual water-level measurements on May 26 and June 30 reflected the overall net water level change; however, information was not provided for the intervening recession and rise. Understanding these detailed changes in hydrologic conditions is important for sites where changes in water levels may affect water chemistry, remedial operations, or chemical-contaminant sampling strategies. For example, the specific conductance at observation well MI-32 showed an inverse relation between water level and specific conductance for May 26 to June 30. This relation indicates vertical stratification of ground-water flow. At high water levels, the ground-water-flow system allows lower specific conductance water to be intercepted by the probe than at low water levels.

Ice jammed the upper reach of the Souhegan River, adjacent to the OK Tool facility, in late January 1999. Continuous ground-water levels recorded at observation wells P-2 and MW-2A recorded the magnitude of this event. Field observations by personnel at the site identified the formation of an ice dam 50 ft downstream of observation well P-2. Wells P-2 and MW-2A are adjacent to the river and had a rapid water-level rise and decline over 5 days during January 24-28, 1999 (fig. 26). There was a 2-ft rise in water level at well P-2 and a 3.5-ft rise in water level at MW-2A. The concurrent rise in water level at MI-32 was 1 ft. There was precipitation infiltration on January 23 and 24; however, the magnitude of water-level rise in observation wells P-2 and MW-2A was 2 to 3 times the response expected from precipitation only, which indicates that additional water was supplied by the partially impounded river. In addition, similar precipitation events before and after the ice jam do not result in similar rises in water level. A 1/2-ft rise in water level was observed at B95-9 inside the barrier wall, but this small rise likely was a result of precipitation only.

Estimates of Recharge and Leakage

Daily average ground-water-level rises were correlated to daily precipitation from October 2 to December 31 for a pre-wall period in 1997 and a post-wall period in 1998 to determine the effects of remedial activities on recharge to the aquifer. Remedial activities included construction of the barrier wall and alteration of the land surface inside the barrier wall by the addition of fill material, which contains a mixture of fine-grained material. The effect of the fill material on decreasing recharge from infiltration of precipitation was unknown prior to this study. The period analyzed during fall and early winter was chosen because recharge was high and evapotranspiration was low. The two periods evaluated are referred to in this section as Fall-97 and Fall-98. The cumulative daily precipitation during WY 1998 (Fall-97) was 11.2 in., about 2.5 in. greater than the cumulative daily precipitation of 9.47 in. during WY 1999 (Fall-98).

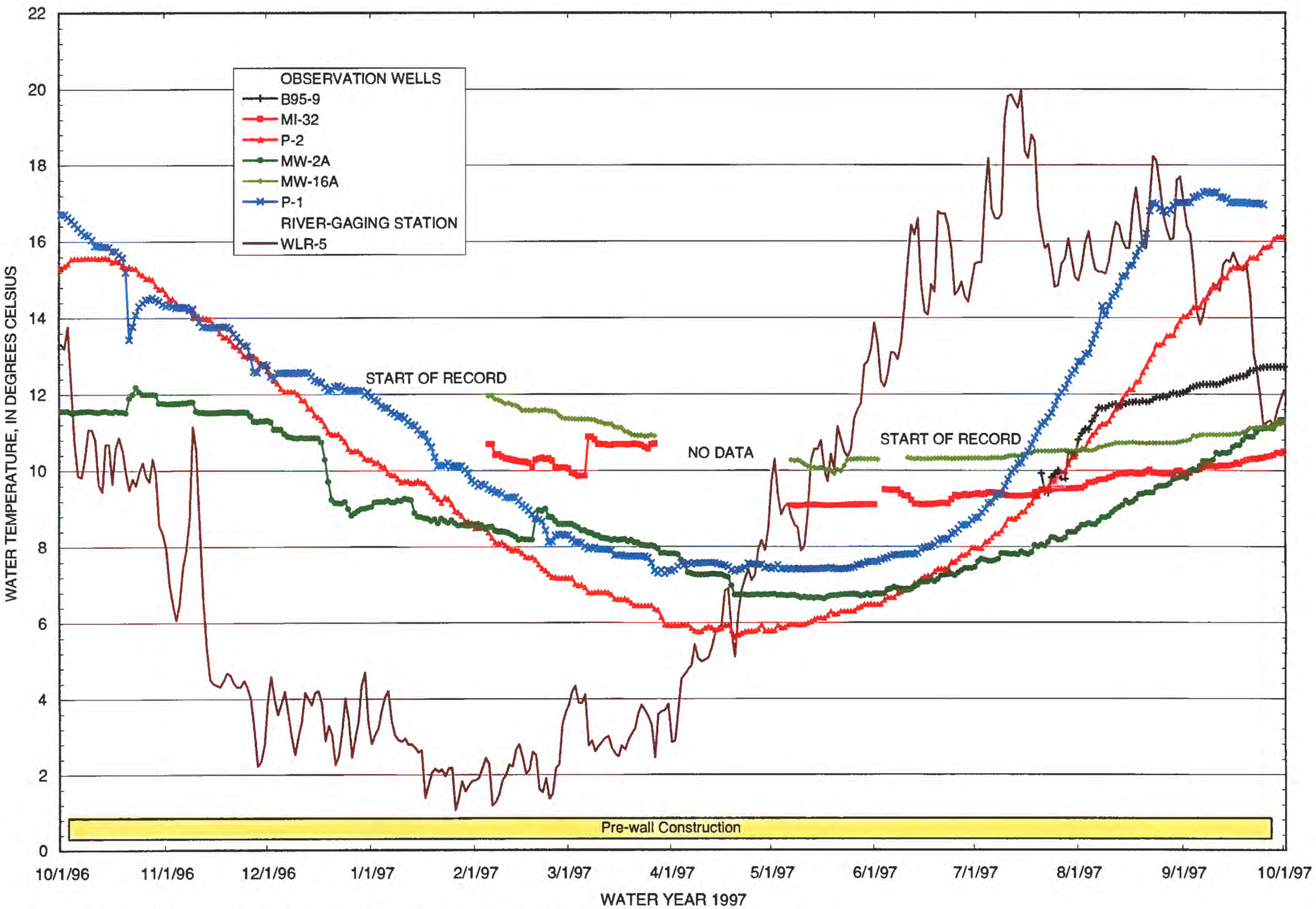


Figure 22. Water temperature for observation wells and a river-gaging station in Milford, N.H., for water year 1997.

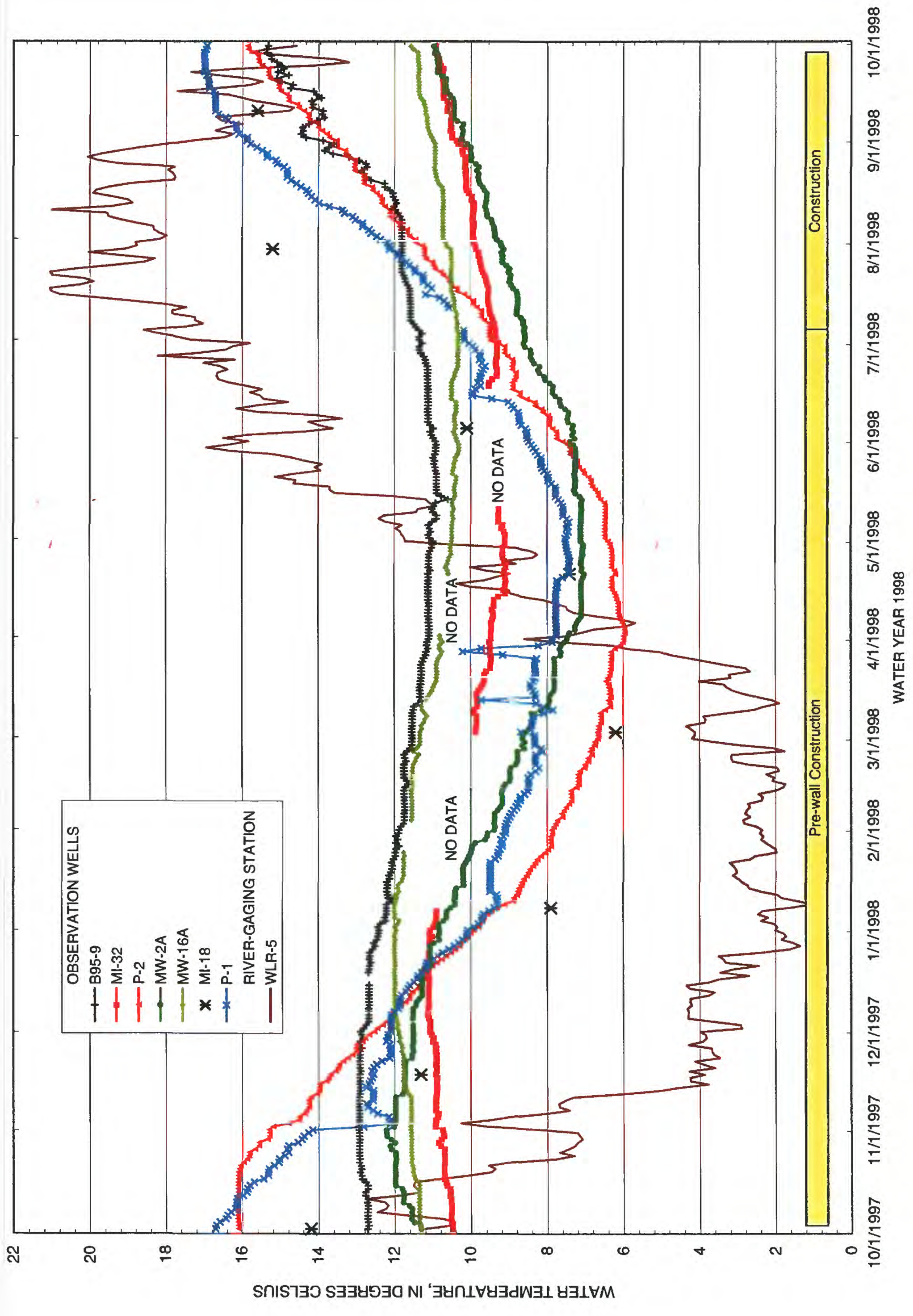


Figure 23. Water temperature for observation wells and a river-gaging station in Milford, N.H., for water year 1998.

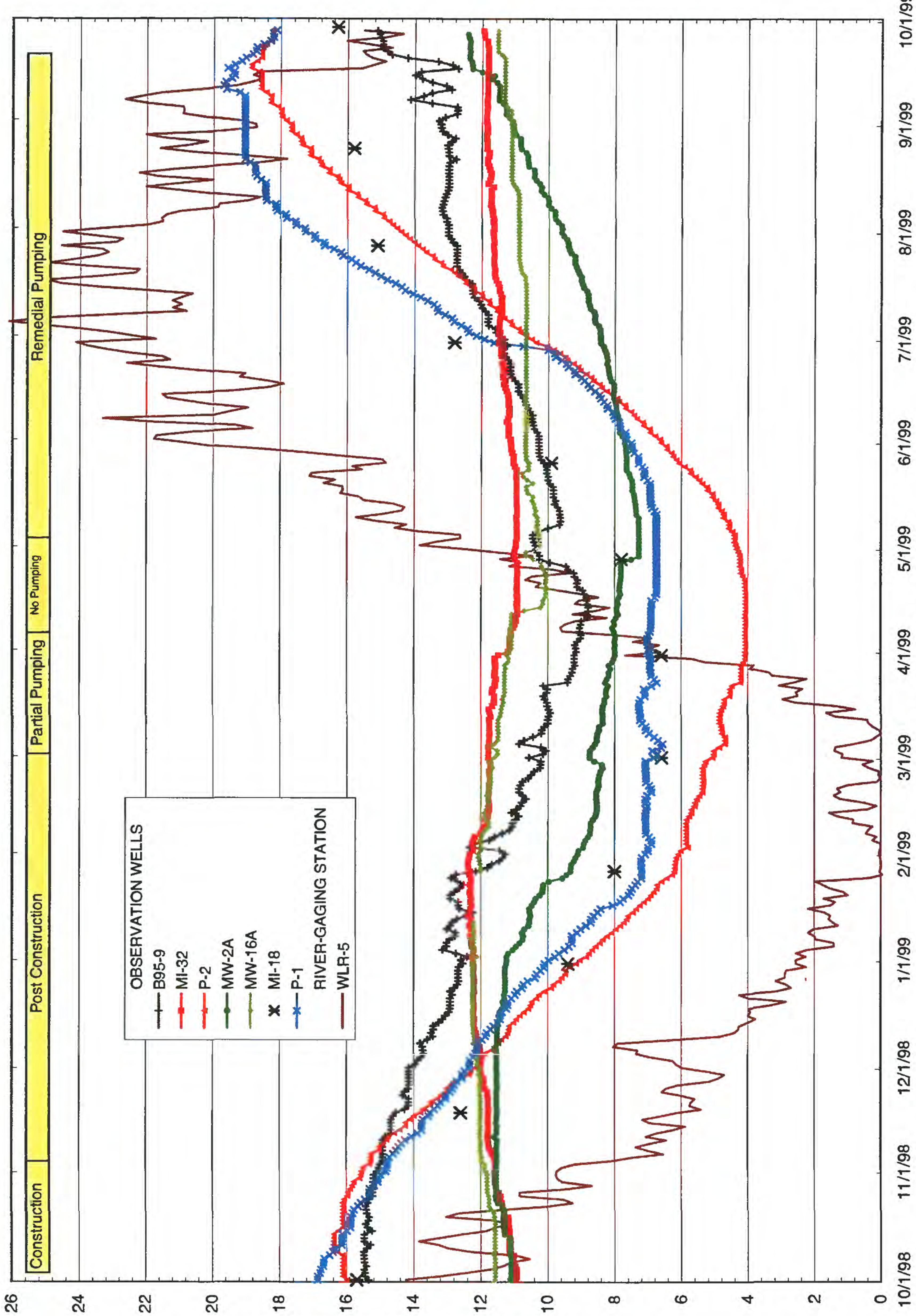


Figure 24. Water temperature for observation wells and a river-gaging station in Milford, N.H., for water year 1999.

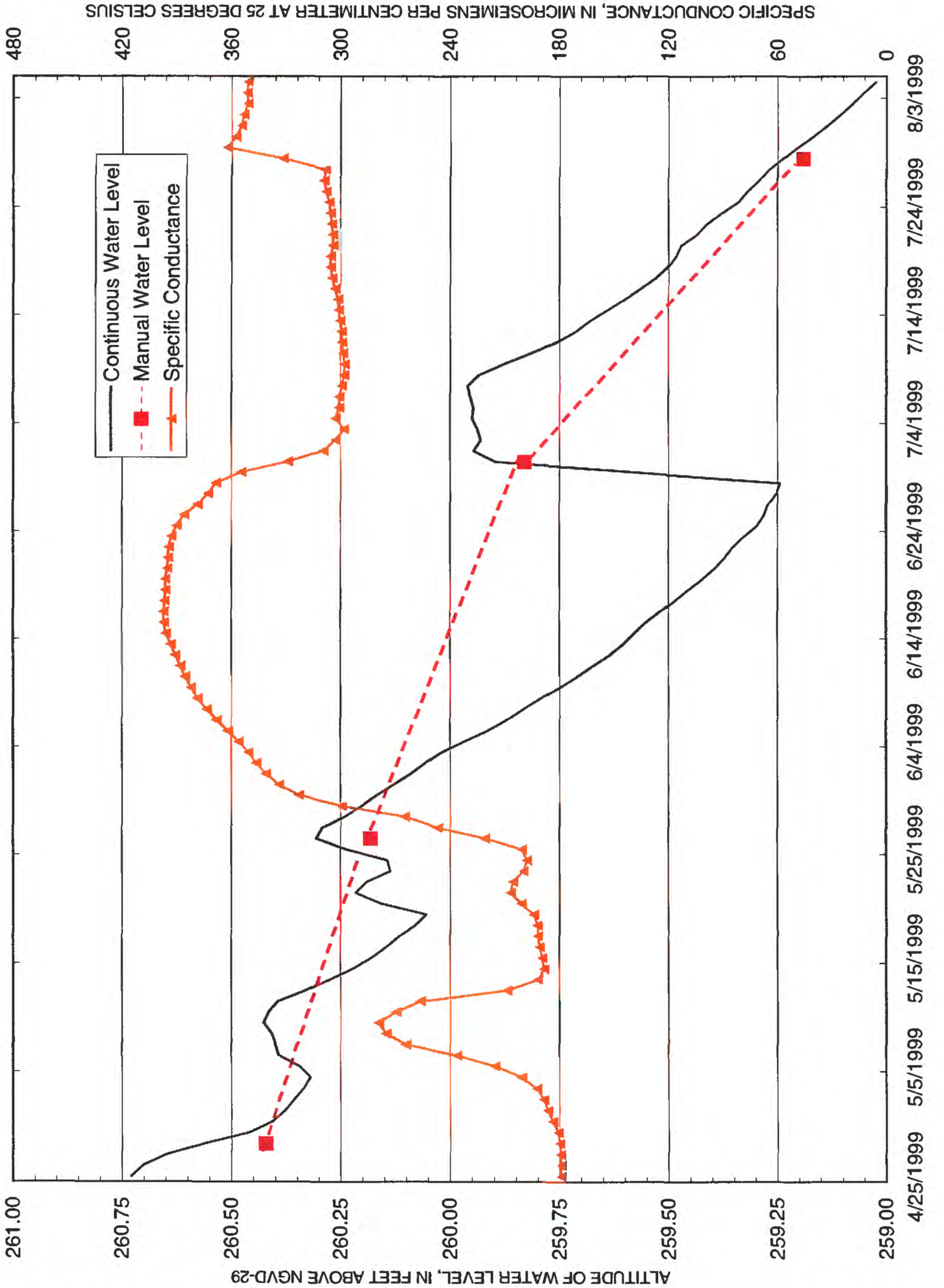


Figure 25. Relation of manual and continuous water levels to specific conductance for observation well MI-32, in Milford, N.H.

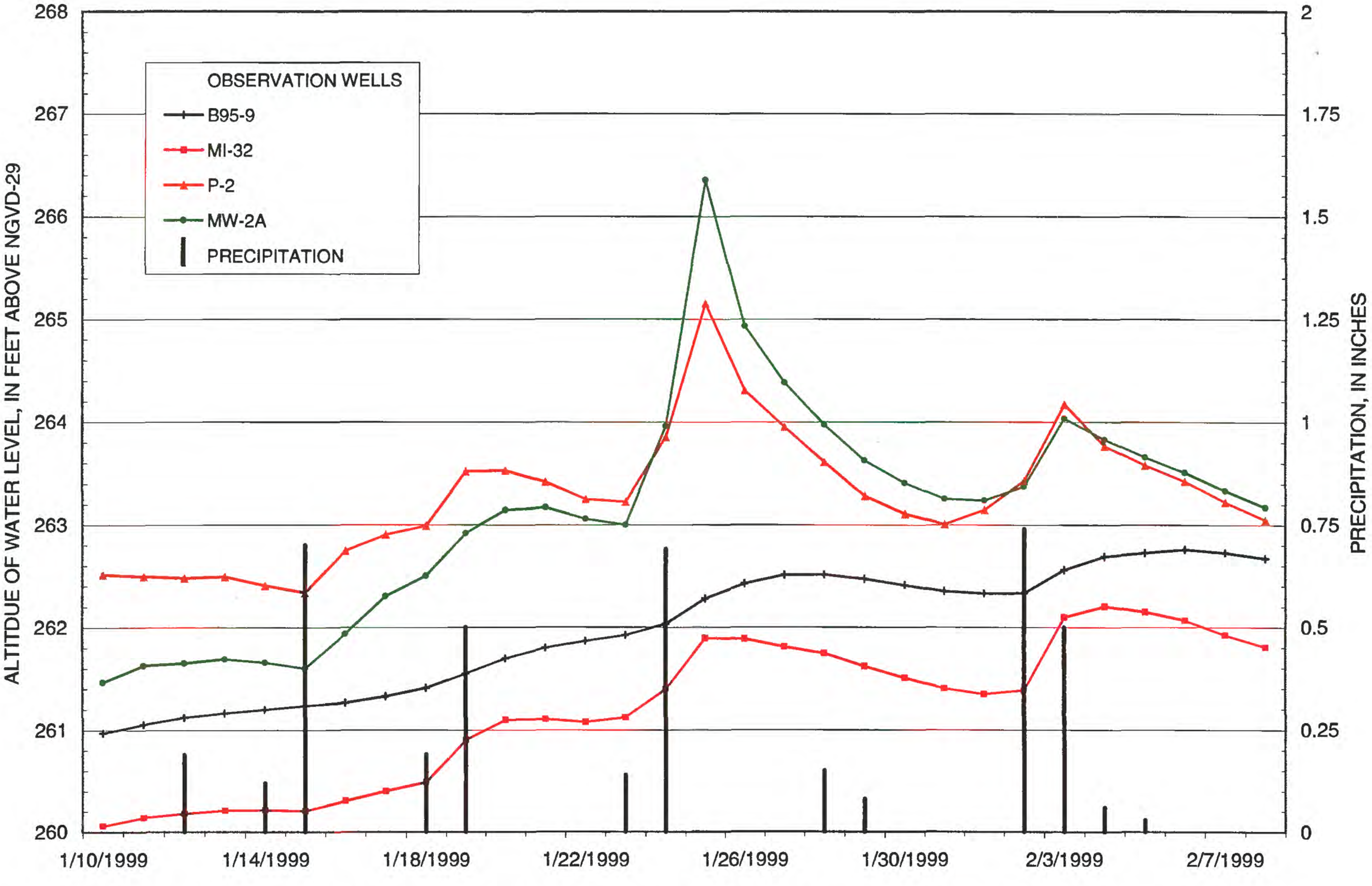


Figure 26. Ground-water level response to ice-dam formation on the Souhegan River near observation wells P-2 and MW-2A, in Milford, N.H.

The technique used to tabulate the response of daily water-level rise to daily precipitation was performed by (1) computing the daily water level rise as the difference between the preceding daily mean water level to the current daily water level, (2) ignoring antecedent conditions or trends in water levels, (3) assuming precipitation was uniform across the study area and that only infiltration and subsequent recharge varied spatially, and (4) plotting daily rises and daily precipitation. Ignoring antecedent conditions or trends potentially is problematic because it may underestimate recharge; however, the technique equally is applied to the two periods (pre- and post-wall), allowing for a fair assessment of changes in ground-water-level rises associated with daily precipitation events. Another problem in assessing the relation of daily water-level rises to daily precipitation include the effects of river leakage on water-level rises, which introduces some spatial bias in the analysis because observations of ground-water levels in the aquifer are spatially related to river stage rises (Harte and others, 1997). Wells located closest to the Souhegan River, for example, P-2 and MW-2A, responded to river-stage rises much more than wells B95-9, MI-32, and others.

The slope of least-squares regression lines indicates the degree that the rise of ground-water levels correlates with precipitation, and is a measure of recharge efficiency. Recharge efficiency, as used in this report, refers to the percent of precipitation that infiltrates and recharges the aquifer. Steep slopes indicate high recharge efficiency from precipitation. The coefficient of determination (R^2) is a measure of goodness of fit of the least-squares regression to the data and is equal to the square of the correlation coefficient (r). These statistics, along with the cumulative rise of water levels for Fall-97 and Fall-98, are summarized in table 4.

Daily average ground-water-level rises were poorly correlated with daily precipitation (fig. 27) for all wells, especially during Fall-98. All coefficients of determination were less than 0.4. The poor correlation is evident by various large daily water-level rises that are associated with minimal precipitation for that day. Also, some water levels decreased on days with measurable precipitation. These patterns demonstrate the effect of antecedent conditions on water levels. Nevertheless, the method of tabulating water-level rises provided recharge patterns for pre- and post-wall periods because it was uniformly applied to both periods.

The coefficient of determination ranges from 0.22 (at MI-18) to 0.33 (at B95-9 and MW-2A) for the Fall-97. The slopes of the regression lines range from 0.34 (at MW-2A) to 0.07 (at MI-18). Well B95-9 had the second steepest regression line slope of 0.2 during the Fall-97. The coefficients of determination and slopes all decreased during Fall-98, indicating a natural reduction in recharge during Fall-98 from Fall-97. Well B95-9 had the second largest decrease in slope from Fall-97 to Fall-98.

Table 4. Summary of daily average ground-water-level rises in response to daily precipitation for October 2 to December 31, 1997 (Fall-97) and 1998 (Fall-98), Milford, N.H.

[Slope is linear slope from least-squares regression line between daily precipitation and corresponding daily water-level rise; R-squared is goodness of fit for the linear regression equation; -- no data; well locations are shown in figure 4]

Well No.	[1]Percent difference in cumulative water-level rise	Pre-wall			Post-wall		
		Fall-97 (before remedial construction)			Fall-98 (after remedial construction)		
		Slope	R-squared (Coefficient of determination)	Cumulative weter-level rise (in feet)	Slope	R-squared (Coefficient of determination)	Cumulative water-level rise (in feet)
B95-9	78	0.20	0.31	2.23	0.06	0.03	0.50
MI-32	29	.18	.24	2.11	.07	-.08	1.49
P-2	21	.39	.42	3.39	.14	-.07	2.67
MW-2A	37	.34	.31	3.26	.09	-.07	2.05
MW-16A	--	--	--	--	.06	-.01	1.02

[1]Equation =100* 1-(x2/x1).

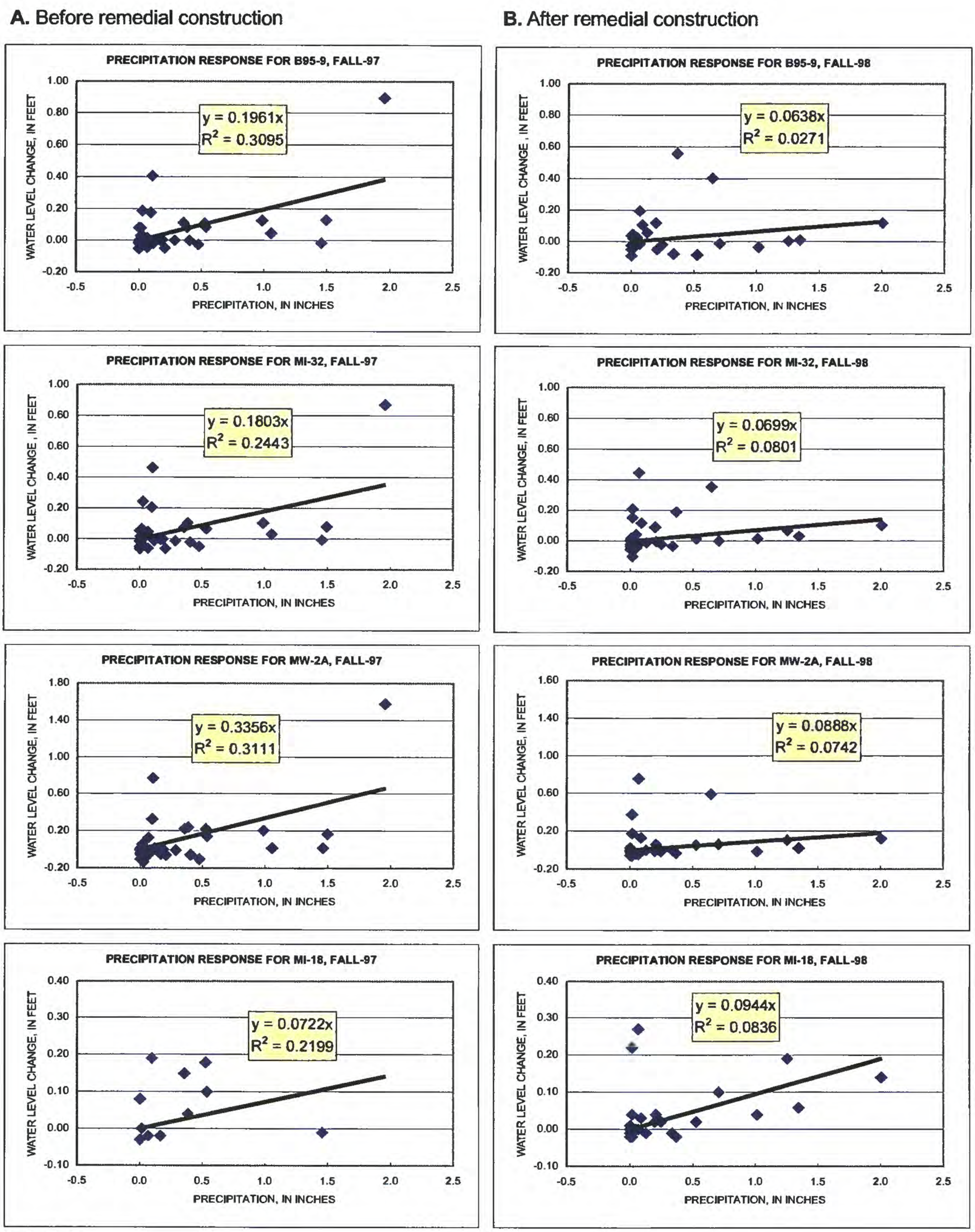


Figure 27. Relation of precipitation response for selected observation wells (A) before and (B) after remedial construction from October 2 to December 31, 1997 (Fall-97) and 1998 (Fall-98), in Milford, N.H. [R^2 is the coefficient of determination, or goodness of fit, for the linear regression of water level with precipitation; location of wells shown on figs. 2a and 4].

Recharge efficiency as measured by cumulative water-level rises (summation of the daily water-level rises) also was less for all wells in Fall-98 than in Fall-97 and likely was a consequence of differences in the timing and magnitude of precipitation between Fall-98 and Fall-97 (Fall-98 had 1.72 in. less precipitation than Fall-97). Well B95-9 had the largest decrease in recharge efficiency from Fall-97 to Fall-98. The relative percent difference between cumulative water-level rises for Fall-97 and Fall-98 is 78 percent at well B95-9 and is more than twice the percent at well MW-2A. These data indicate that the remedial construction of the barrier wall, which encapsulates B95-9, decreased recharge to the well inside the wall. Although the changes between the slopes of daily water-level rises associated with daily precipitation from Fall-97 to Fall-98 were greater for well MW2A than for well B95-9, the decline in cumulative water-level rises probably is a better indicator of recharge changes (such as a decrease in recharge inside the wall) than a change in slope of daily water-level rises to daily precipitation. Thus, based on the decline of cumulative water-level rises, the largest decreased in recharge was in B95-9. The decrease in recharge at well B95-9 inside the wall, however, may be partially affected by a decrease in river leakage because of the isolation of the flow systems inside and outside the wall. The effects of river stage fluctuation and leakage on water levels at B95-9 is discussed latter in this section.

Daily average water levels from October 2 to December 31 were compared for pre-wall (1997) and post-wall (1998) periods. Water-level data from three wells, P-2, MI-32 and MW-2A, were compared to water-level data from well B95-9 to assess the similarity of response to ambient hydrologic conditions (fig. 28). Direct individual comparison of water levels between well B95-9 and each of the three wells by use of simple linear regression shows that the barrier wall reduced the hydrologic connection inside the wall to the outside aquifer. Although the three comparison wells differed in their screened intervals and distances from the river, water-level responses at B95-9 were similar to P-2, MI-32, and MW-2A for pre-wall conditions. Coefficients of determination (R^2) of water levels between wells ranged from 0.91 to 0.99 for pre-wall conditions (fig. 28). The pattern of water levels in B95-9 for pre-wall conditions was most similar to observation well MI-32. These two wells were along a similar flow path, which became truncated by the completion of the barrier wall. Pre-wall coefficients are lower between water levels at B95-9 and wells P-2 and MW-2A than between B95-9 and MI-32. These low coefficients reflect the effect of the river on water levels at wells P-2 and MW-2A because the wells are next to the river. In contrast, the post-wall water-level response of B95-9 dramatically changed (fig. 28). Post-wall coefficients ranged from 0.27 to 0.57 between B95-9 and the other wells.

The recharge analysis shows that recharge decreased more in the fall of 1998 than in the fall of 1997 at all wells. Well B95-9, however, showed an overall cumulative decline in water-level rises that is attributed to a reduction in infiltration recharge from the fill material. Water levels in B95-9 responded differently to recharge than the other wells because of the barrier wall and recharge from infiltration of precipitation through the fill material.

To assess the effect that fluctuations in river stage have on fluctuations in ground-water levels, daily precipitation data were used to identify periods when river-stage fluctuations (specifically increased stage) were measured with no corresponding precipitation event. Any river-stage fluctuations during these periods probably reflect streamflow changes (regulation) from dams upstream. A minimum no-precipitation period of 3 days was used to insure that delayed infiltration from precipitation would not affect ground-water levels. Alternatively, ground-water level rises during this time would be an indicator that ground-water levels in a well are affected by the river. Assessing ground-water level changes during these conditions provides insight into the analyses on ground-water levels and precipitation by identifying wells with water levels that are strongly correlated with river stage, and allows for the computation of hydraulic properties of the stream and aquifer.

Two short periods in the fall were selected for assessing the effect of river-stage fluctuations: a pre-wall period, from October 19 to 24, 1997, and a post-wall period, from October 23-29, 1998. During the pre-wall period, river stage increased by as much as 0.39 ft. During the post-wall period, river stage increased approximately 0.05 ft, followed by an immediate 0.15 ft decrease caused by streamflow regulations upstream.

River-stage fluctuations were tabulated and used in an analytical model (Barlow and Moench, 1998) of stream-aquifer interactions. Computed ground-water-level fluctuations from the model output then were compared to observed ground-water levels for all monitored wells.

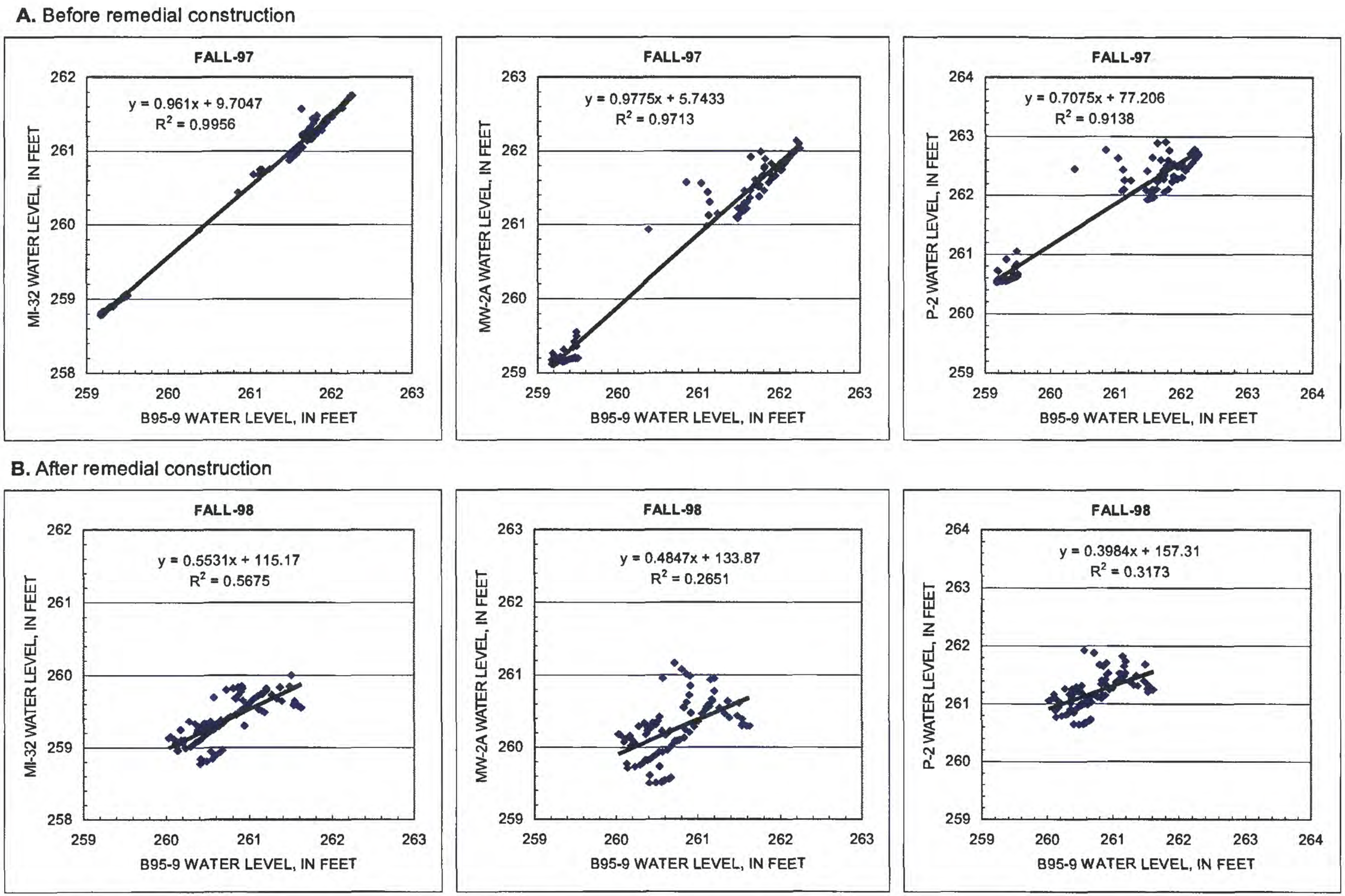


Figure 28. Relation of water levels at observation well B95-9 with other wells (A) before and (B) after remedial construction from October 2 to December 31, 1997 (Fall-97) and 1998 (Fall-98), Milford, N.H. [R^2 is the coefficient of determination, or goodness of fit, for the linear regression of water level; location of wells shown on fig. 4].

The analytical model uses a convolution solution to solve for ground-water levels, and for river leakage between the stream and aquifer that results from river-stage changes. The following conditions and assumptions apply to the use of the model:

1. A fully penetrating river,
2. The aquifer is unconfined,
3. A homogeneous and isotropic system,
4. Flow is essentially two-dimensional in a cross-sectional mode,
5. Wells partially penetrate the aquifer,
6. A finite river reach; a river reach length of 1,000 ft was used for this analysis, which is equivalent to the distance of the Souhegan River through the OK Tool facility, and
7. Aquifer width was assumed infinite (not an issue for unconfined conditions, which tend to attenuate flood waves).

Graphs of computed and observed ground-water level changes caused by river-stage fluctuations are shown in figure 29 for pre- and post-wall periods. Both graphs show computed values of ground-water levels above an arbitrary zero datum, as lines from DAY0 to DAY5 for pre-wall analysis and DAY0 to DAY6 for post-wall analysis. Because the x-axis represents horizontal distance, the graphed water-level lines are essentially head profiles through the aquifer. Observed data are shown as points (denoted as ODAYO-ODAY6 in fig. 29). The range of variations in observed data are given as vertical lines. Therefore, a match between computed and observed water levels are indicated in figure 29 when vertical lines intersect the computed lines. The point of intersection indicates computed water levels are similar to observed water levels.

Values of stream and aquifer properties, which were used in the previously described model, were taken from results described in Harte and others (1997). Values used include a horizontal hydraulic conductivity of the aquifer of 450 ft/d, a vertical hydraulic conductivity of the streambed of 6 ft/d, a streambed thickness of 3 ft, and a ratio of vertical to horizontal hydraulic conductivity in the upper part of the aquifer of 1:1 (the upper part of the aquifer consists of a coarse cobble layer at the OK Tool facility).

Simulated results indicate that the dissipation of ground-water levels in the aquifer, associated with the river-stage fluctuation, is about 0.06 ft in 200 ft or 0.0003 ft/ft. This means that for an instantaneous 1-ft rise in river stage, ground-water levels should rise 0.97 ft at a distance of 100 ft from the stream, 0.85 ft at 500 ft, and 0.7 ft at 1,000 ft.

For the pre-wall period, the observed water-level data show ranges of fluctuations at well P-2 and at well MW-2A comparable to computed fluctuations. In contrast, observed water levels in wells B95-9 and MI-32 did not respond to river-stage fluctuations indicating some of the following possibilities:

1. That the stage-dissipation constant is too low, suggesting that a decrease in hydraulic conductivity in the aquifer is warranted,
2. The assigned streambed leakance value is too high or the assumption of a fully penetrating stream overexaggerates leakage to the aquifer,
3. Water levels at these wells are affected by other processes during this period,
4. River-stage rise is too small to accurately evaluate properties at these distances from the river, and(or)
5. Geologic heterogeneity is affecting the water-level responses in the aquifer.

For the post-wall period, all observed water levels except at well P-2 did not match computed levels. Most of the computed water levels (fig. 29) showed an overall negative response to the post-wall river stage event because the small river stage increase of 0.05 ft (DAY1) was followed by a decrease of 0.15 ft (DAY2). The weakest match between computed and observed water levels is at well B95-9.

Further testing of aquifer horizontal hydraulic conductivity examined the dissipation of ground-water levels resulting from river-stage fluctuations. Ground-water-levels were computed for the pre-wall period and then compiled at a common distance from the stream to simplify the analysis (a distance of 775 ft was used). At 775 ft, decreasing the aquifer hydraulic conductivity from 450 to 150 ft/d decreases the computed rise in water levels from 0.07 to 0.044 ft. Compared to the observed range at B95-9, computed results still inadequately represent observed fluctuations. Therefore, it appears likely that processes other than river-stage change were affecting observed ground-water levels.

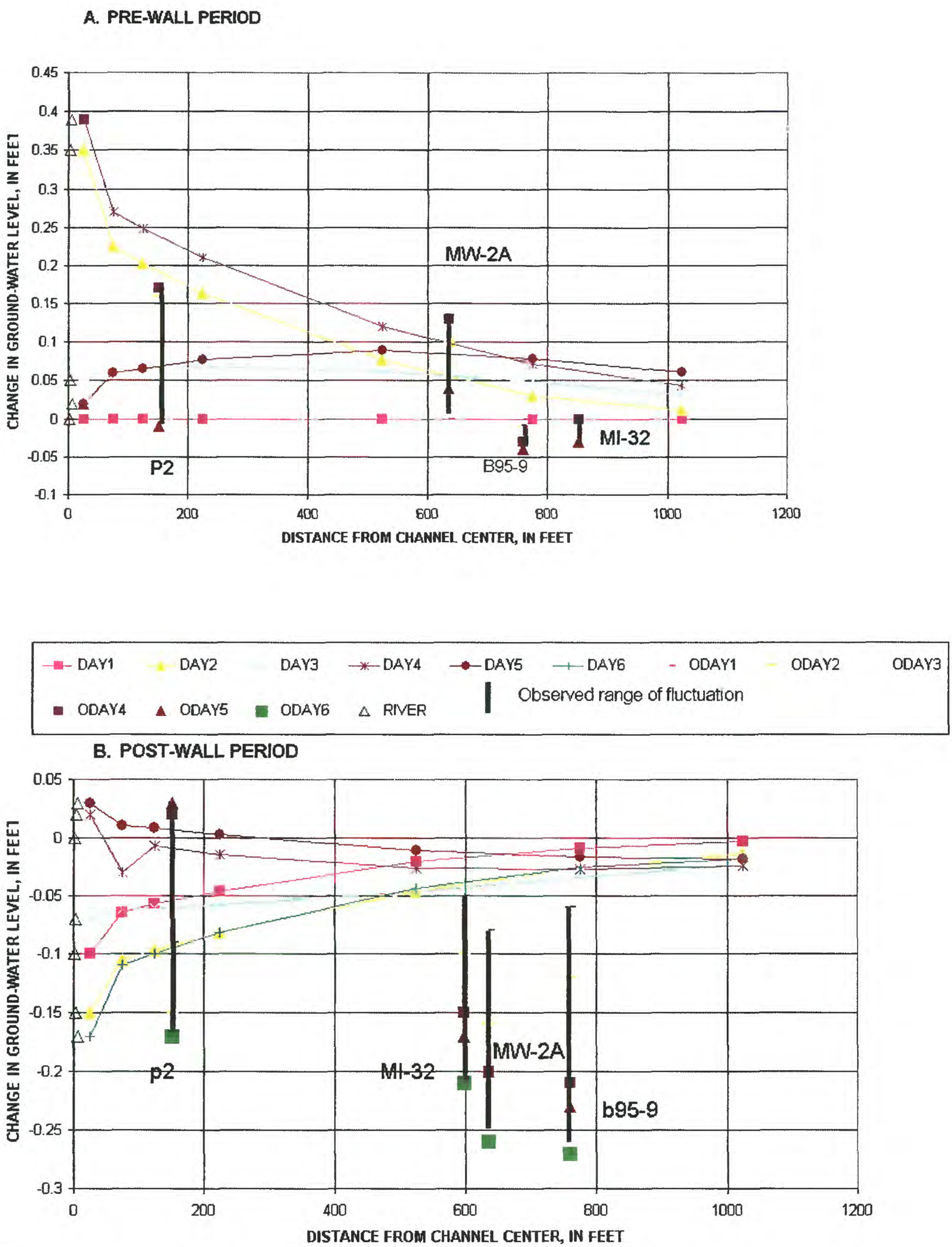


Figure 29. Computed and observed changes in ground-water level in response to changes in river stage (A) pre- and (B) post-wall barrier construction, Milford, N.H. [DAY0-DAY6 is model-computed ground-water level for day1 to day6 since river stage change; ODAY1-ODAY6 is observed ground-water level for day 1 to day 6 since river stage change].

Computed river leakage from the pre-wall simulated event ranged from an instantaneous rate of -14 to -30 ft^3/s (average leakages of -2.33 to -5 ft^3/s) over the simulated period for the simulated 1,000-ft reach of river. These rates are consistent with measured river leakage for the site (Harte and others, 1997). The assigned relative riverbed leakance[2] changed the pattern of the computed leakage to the aquifer. As the assigned leakance decreased (increase in river connectivity), the daily variation in computed leakage increased. In particular, the decline in river stage on day 4 (profile DAY4 in fig. 29) caused large flow reversals and discharge of ground water to the river. When the assigned leakance increased (decrease in river connectivity), the amount of flow reversal on DAY4 was small (not shown).

The river-leakage analysis shows that the observed water levels at well P-2 compared favorably with the computed water levels from the analytical model (Barlow and Moench, 1998). Thus, the model-assigned aquifer and stream properties appear adequate for the area by well P-2. The analysis demonstrates the interconnection of water levels at well P-2 with river stage. Computed water levels in wells farther away from the river did not favorably compare with observed water levels, probably because ground-water levels are marginally affected by a change in river stage (0.39 ft) at distances exceeding 600 ft from the river. Computed water levels changed by less than 0.1 ft (25 percent of the river stage change) at a distance of 600 ft from the river. Undoubtedly, other processes such as barometric changes, heterogeneity in the aquifer, and remedial activities (post-wall period only) will more likely affect water levels at distances exceeding 600 ft from the river than the perturbation of river stage changes through the aquifer. The analysis of river stage and ground-water levels showed that water levels at some wells are poorly correlated to small river stage changes, particularly well B95-9. Therefore, these results support the conclusion that a decrease in infiltration recharge is the primary factor in reducing rises in ground-water levels at B95-9 (located inside the wall), because changes in river stage are small at this well.

SUMMARY AND CONCLUSIONS

The Savage Municipal Well Superfund site contains a large volatile organic compound (VOC) plume and covers the southwestern half of a glacial-drift aquifer. The OK Tool facility has been identified as a primary source area of VOCs. This report summarizes analysis of 3 years of water levels, specific conductance, and water temperature data collection from October 1, 1996, to September 30, 1999, at the OK Tool facility of the Savage Municipal Well Superfund site in Milford, N.H. Data collected include ground-water levels, riverbed water levels, river stage, specific conductance, and water temperature. These data were collected as part of a monitoring effort by the U.S. Geological Survey in cooperation with the New Hampshire Department of Environmental Services, and the U.S. Environmental Protection Agency, Region 1, to assess changes in the local-flow system before, during, and after construction of a barrier wall at the site.

The barrier wall, built in 1998, was effective during the study in isolating ground water inside the wall from water outside the wall. Before wall construction, water levels at observation well B95-9 (inside the wall) were similar to water levels at wells outside the wall. After wall construction, water levels at B95-9 did not correlate with water levels at wells outside the wall. Specific-conductance values also changed. The volume of water associated with road salting flowing to the well decreased, causing the variability and magnitude of specific conductance at well B95-9 also to decrease.

The amount of recharge inside the barrier wall decreased since barrier wall construction because of the addition of a top cap composed of fine-grained sediments. The cumulative water-level rises during the fall of water year 1999 (after wall construction) decreased the most at well B95-9 from the preceding fall of water year 1998 than the decline observed at other wells outside the barrier.

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[2]The relative riverbed leakance is computed as follows: Kx * d/Ks where Kx is the horizontal hydraulic conductivity of the aquifer, d is the width of the streambank material, Ks is the hydraulic conductivity of the streambank material in the direction perpendicular to streamflow (DeSimone and Barlow, 1999, p. 6). Therefore, for a constant Kx*d, and increase in Ks results in a lower relative riverbed leakance term.

Ground-water flow outside the barrier wall also was affected by remedial activities. River leakage from the Souhegan River near well P-2 increased, causing a large volume of ground-water flow through this area. Low water temperatures in well P-2 during the winter after wall construction supports this conclusion.

Vertical stratification of ground water was identified by specific-conductance fluctuations in response to changes in water level at wells MI-32 and P-1. At well P-1, road salting during winter months caused large increases in specific conductance. At well MI-32, declines in ground-water levels sometimes were marked by increases in specific conductance indicating possible stratification of ground-water flow with depth.

Fluctuations of water temperature at well B95-9 after barrier wall construction, and subsequent ground-water extractions and injections from remedial wells, show the effect of remedial activities. These fluctuations may provide additional insight into effectiveness of remedial pumping to capture shallow contaminants.

Continuous monitoring throughout the study area validated the connection between river leakages and aquifer hydraulic properties. The response of ground-water levels to river-stage fluctuations at wells near the river shows river connectivity is high and reported hydraulic properties from earlier studies are reasonable estimates. Previously estimated hydraulic properties included a horizontal hydraulic conductivity of 450 ft/d for the shallow aquifer and riverbed hydraulic conductivity of 6 ft/d.

The data-collection network established for remediation of the site helped evaluate hydrologic changes during pre-wall, wall construction, and completed-wall phases of the monitoring period. Continued monitoring would allow for further evaluation of barrier wall effectiveness, remedial pumping effectiveness, and post-wall recharge conditions. Recharge was relatively low in water year 1999; a wetter year may affect hydrologic processes in ways not yet identified. Furthermore, the identification of elevated specific conductance waters (above background levels) from road-salting may prove useful in helping to delineate sources of water to wells, particularly the remedial extraction wells located outside the barrier.

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APPENDIX

Appendix 1. Measuring point, well screen data, and geology for selected wells in the OK Tool study area, Milford, N.H.

[All data are in feet; altitude in feet above NGVD-29; Aquifer code: S&G = sand and gravel; f-c= fine to coarse; G&S = gravel and sand; rk=bedrock; --, no data available; TPVC, top of polyvinylchloride pipe; TSC, top of steel casing; shelter, monitoring shelter; Tconc, top of concrete; TINRSC, top of inner steel casing]

Well name (see fig. 4)	Well No.	Easting	Northing	Site type	Altitude of land surface	Altitude of measuring point	Description of measuring point	Top of opening below land surface	Bottom of opening below land surface	Depth to bedrock below land surface	Screen material
B95-09	404	975039.81	124825.60	Observation well	270.31	273.34	TPVC	10.0	20.0	--	S&G
B95-12	407	975343.81	124724.70	Observation well	269.45	272.01	TPVC	55.0	60.0	76	G&S
B95-13	408	975490.62	125002.0	Observation well	267.01	266.26	TPVC	60.0	65.0	90.5	S&G
B95-15	409	975254.0	125149.40	Observation well	269.61	267.90	TPVC	85.0	95.0	96.5	G&S
EW-1	565	975535.23	125046.05	Extraction well	266.88	265.09	TSC	63.55	93.55	--	S&G
EW-2	566	975492.89	124936.25	Extraction well	267.05	265.81	TSC	51.22	81.22	81.5	S&G
IW-1	567	975105.37	124871.14	Extraction well	272.4	269.91	TSC	78.32	108.32	108.3	Sand
IW-2	568	975037.83	125068.37	Extraction well	277.03	268.44	TSC	78.32	108.32	--	S&G
MI-32	46	975247.2	124933.7	Observation well	270.2	273.57	TPVC	30.0	75.0	95	S&G
MW-2A	310	975148.9	125591.3	Observation well	266.6	270.08	Shelter	29.0	39.0	--	S&G
MW-16A	233	975671.2	124863.1	Observation well	267.5	270.39	Shelter	16.9	26.9	--	S&G
MW-16B	321	975671.0	124868.6	Observation well	267.6	269.85	TPVC	39.6	49.6	--	Sand, f-c
MW-16C	344	975678.1	124877.1	Observation well	267.4	269.70	TPVC	73.2	83.2	87.5	S&G
MW-16R	345	975670.8	124875.2	Observation well	266.5	268.92	TSC	88.0	138.0	87.5	Rock
P-1	335	974088.3	124847.5	Observation well	276.6	279.26	Shelter	13.9	14.9	--	S&G
P-2	336	975100.9	125281.9	Observation well	268.6	271.32	Shelter	17.0	18.0	--	S&G
PW-1D	531	975507.1	125010.99	Observation well	266.88	266.76	TPVC	84.48	94.48	94	Till/rock
PW-2R	535	975254.74	124973.56	Observation well	268.92	273.21	TPVC	113.9	133.93	102	Rock
PW-3S	536	975059.0	125239.0	Observation well	269.83	272.39	TPVC	19.76	29.76	--	S&G
PW-3D	537	975059.1	125239.1	Observation well	269.84	272.38	TPVC	84.85	94.85	94.5	S&G
PW-4M	538	974970.0	124767.0	Observation well	271.81	274.87	TPVC	31.87	41.87	--	S&G
PW-4D	539	974970.1	124767.0	Observation well	272.01	274.49	TPVC	62.0	72.0	70	S&G/rock
PW-6S	543	975016.0	124942.0	Observation well	276.65	279.12	TPVC	23.63	33.63	--	S&G
PW-6M	544	975016.1	124942.1	Observation well	276.37	278.96	TPVC	40.39	50.39	--	S&G
PW-6D	545	975016.2	124942.2	Observation well	276.98	279.01	TPVC	87.6	97.6	94	S&G/rock
PW-6R	546	975016.3	124942.3	Observation well	276.32	278.58	TPVC	101.04	111.04	95	Rock
PW-8M	549	974856.2	125140.4	Observation well	273.34	275.95	TPVC	31.37	41.37	--	S&G
PW-10M	551	975152.0	125127.0	Observation well	273.98	276.34	TPVC	50.15	60.15	--	S&G
PW-10D	552	975152.1	125127.1	Observation well	273.80	276.41	TPVC	94.71	104.71	--	S&G
PW-12S	555	975432.0	125281.0	Observation well	265.73	276.75	TPVC	18.1	28.1	--	S&G
PW-12M	556	975437.17	125255.65	Observation well	265.81	268.06	TPVC	57.8	68.0	--	S&G
PW-12D	557	975432.20	125281.20	Observation well	265.69	267.68	TPVC	87.0	97.0	--	Sand
PW-12R	558	975432.30	125281.30	Observation well	265.66	267.78	TPVC	113.9	134.0	100	Rock

Appendix 1. Measuring point, well screen data, and geology for selected wells in the OK Tool study area, Milford, N.H.--Continued

Well name (see fig. 4)	Well No.	Easting	Northing	Site type	Altitude of land surface	Altitude of measuring point	Description of measuring point	Top of opening below land surface	Bottom of opening below land surface	Depth to bedrock below land surface	Screen material
PW-13S	559	975682.00	125294.00	Observation well	267.68	269.75	TPVC	20.3	30.3	--	S&G
PW-13M	560	975682.10	125294.10	Observation well	267.86	269.95	TPVC	59.8	70.0	--	S&G
PW-13D	561	975682.20	125294.20	Observation well	267.55	269.58	TPVC	94.3	104.35	103	Gravel/rk
PW-14S	562	975765.00	125085.00	Observation well	266.76	268.77	TPVC	20.03	30.03	--	S&G
PW-14M	563	975765.10	125085.10	Observation well	266.76	268.89	TPVC	60.0	70.0	--	Sand,c-f
PW-14D	564	975765.20	125085.20	Observation well	266.77	268.94	TPVC	102.71	112.71	111.5	Sand,c-f/rk
RW-1	569	974751.80	125000.52	Injection well	273.67	267.19	TSC	31.65	41.65	--	Gravel
RW-2	570	974799.44	124838.74	Injection well	273.38	267.15	TSC	22.04	32.04	--	S&G
RW-3	571	975168.45	124805.82	Injection well	269.96	268.79	TSC	18.45	28.45	--	Gravel
SP-1	572	974885.08	124935.83	Air sparge well	274.45	266.58	TSC	60.66	65.66	66.8	Sand
SP-2	573	974910.85	125063.90	Air sparge well	275.34	266.57	TSC	59.71	64.71	--	Sand
SVE-1	574	974927.14	124888.11	Airwell	274.99	--	--	8.37	23.36	--	--
SVE-2	575	974946.49	124988.03	Airwell	276.25	--	--	9.41	24.41	--	--
SVE-3	576	974966.91	125106.60	Airwell	273.38	--	--	12.34	27.34	--	--
SVE-4	577	974828.74	124901.85	Airwell	274.02	--	--	12.66	27.66	--	--
SVE-5	578	974846.81	125001.08	Airwell	274.76	--	--	7.87	23.87	--	--
SVE-6	579	974870.28	125128.88	Airwell	273.7	--	--	12.39	27.39	--	--
SavageWell	128	978473.2	124848.0	Extraction well	261.00	--	--	35.0	45.0	--	--
Keyes	126	986875.0	123316.5	Extraction well	240.10	--	--	50.0	60.0	--	--
MI-18	29	977625.4	123963.1	Observation well	262.70	264.34	Tconc	--	--	--	--
WLR-5	393	980644.9	126283.6	Streambed observation well	--	254.28	Shelter	--	--	--	--
MI-33	47	975651.3	124011.3	Observation well	268.00	265.90	Well cover	50.0	60.0	--	S&G
FH-14	87	975867.0	126592.8	Extraction well	262.20	263.53	Bolt	32.0	42.0	--	--
FH-5	208	975988.3	127199.9	Extraction well	268.00	267.89	TINRSC	50.0	65.0	--	--
PFHprodwell	354	981195.6	126601.6	Extraction well	249.20	251.68	--	30.0	40.0	--	--

Appendix 2. Summary statistics for altitude of water level, specific conductance, and water temperature for automated monitoring sites, water years 1997-99, Milford, N.H.

[--, no data; water levels are in feet; specific conductance is measured in microsiemens per centimeter; water temperature is measured in degrees celsius; MAX, maximum; MIN, minimum; MED, median]

Site (in figs. 2a and 4)		Water level			Specific conductance			Water temperature		
	Water year	1997	1998	1999	1997	1998	1999	1997	1998	1999
B95-9	MAX	--	264.70	263.11	--	654.60	317.00	--	15.36	15.48
	MIN	--	259.18	258.84	--	262.80	177.70	--	10.60	8.78
	MEAN	--	261.95	260.59	--	474.88	253.79	--	12.10	12.14
	MED	--	262.08	260.39	--	498.60	266.50	--	11.80	12.63
P-1	MAX	271.22	270.77	269.88	1349.98	2381.45	2251.00	17.29	17.00	19.69
	MIN	266.54	266.26	266.43	65.88	96.10	69.85	7.29	7.39	6.57
	MEAN	268.40	268.37	267.75	237.56	449.87	358.00	11.17	11.04	11.48
	MED	268.72	268.26	267.47	158.80	342.57	159.80	10.64	9.95	10.21
MI-32	MAX	264.07	264.28	262.66	154.20	272.60	397.00	10.87	11.10	12.38
	MIN	259.09	258.78	258.43	126.20	117.40	163.40	9.06	9.07	10.90
	MEAN	261.42	261.13	260.17	139.19	142.21	262.58	9.79	10.16	11.59
	MED	261.87	261.24	259.83	135.80	137.90	266.70	9.88	10.12	11.65
P-2	MAX	265.18	265.78	265.59	109.60	218.20	117.70	16.11	16.12	18.87
	MIN	260.59	260.51	260.51	53.21	58.52	57.18	5.62	5.94	4.07
	MEAN	262.10	262.42	261.81	78.24	97.76	84.27	9.99	10.20	10.23
	MED	262.21	262.47	261.51	77.00	93.53	82.90	9.43	9.54	9.58
MW-2A (shallow)	MAX	265.43	266.04	266.35	71.20	81.20	67.54	12.17	12.21	12.40
	MIN	259.33	259.11	259.33	56.19	44.87	46.82	6.62	7.01	7.26
	MEAN	261.80	261.65	261.04	62.68	63.27	54.58	8.96	9.44	9.63
	MED	262.15	261.79	260.61	62.92	63.10	54.42	8.58	9.37	9.33
MW-2A (deep)	MAX	--	--	--	80.00	96.40	61.50	9.98	9.90	10.12
	MIN	--	--	--	62.57	44.53	43.80	7.26	7.63	8.01
	MEAN	--	--	--	68.82	63.70	52.77	8.49	8.77	9.02
	MED	--	--	--	68.82	64.97	54.07	8.54	8.67	9.01
MI-18	MAX	258.58	257.73	256.98	286.00	293.00	220.00	15.66	15.60	16.30
	MIN	254.31	254.31	253.65	237.00	187.00	199.00	11.40	6.20	6.60
	MEAN	255.90	255.96	255.37	266.33	240.63	208.25	13.89	10.99	11.38
	MED	256.14	256.04	255.40	276.00	244.00	207.00	14.60	10.70	11.25
MW-16A	MAX	261.81	262.20	260.82	667.80	679.90	505.50	11.95	12.00	12.23
	MIN	257.58	257.32	256.81	420.70	487.70	414.10	9.91	10.31	10.04
	MEAN	259.77	259.74	258.52	572.83	596.12	465.16	10.75	11.13	11.29
	MED	260.18	259.80	258.16	624.95	593.90	471.70	10.71	11.22	11.30
WLR-5 (river)	MAX	251.46	244.81	--	96.70	125.00	120.00	19.93	22.00	23.90
	MIN	243.02	242.93	--	44.94	55.00	45.00	.94	2.70	.8
	MEAN	245.12	243.55	--	63.18	81.39	85.38	6.99	11.97	13.58
	MED	244.89	243.41	--	61.36	73.20	84.00	4.66	12.50	13.65
WLR-5 (riverbed)	MAX	251.01	250.08	249.84	155.70	137.2	143.60	19.97	21.05	26.09
	MIN	242.78	242.86	242.84	71.90	60.404	24.56	1.06	1.03	-.06
	MEAN	244.42	244.12	243.83	117.63	96.549	96.08	8.85	9.9055	11.17
	MED	244.15	244.26	243.80	112.50	91.881	103.70	8.53	9.345	10.35