PLATTE RIVER WETLAND HYDROLOGY STUDY

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EXECUTIVE SUMMARY

While the importance of wetlands for native plants and wildlife has been recognized, the hydrology that maintains these areas is poorly understood. To address this knowledge gap the Project Team began a study in 1988 to examine the seasonal relationships between wet meadow groundwater elevations and river stage, precipitation, evapotranspiration, and adjacent irrigation. Three study sites along the Platte River between Lexington and Grand Island, Nebraska, were selected for the study. This research was initially funded by U.S. Fish and Wildlife Service, with continuation funding provided by the U.S. Bureau of Reclamation and parts of the analysis funded by the Nebraska Game and Parks Commission.

To accomplish our analysis we: 1) Described the continuous hydrologic and soil temperatures; 2) Developed box-plot groundwater and river-stage hydrographs; 3) Developed depth-to-groundwater and river stage duration curves; 4) Determined the relationship between river stage and river flow; 5) Presented cross-valley groundwater-level transects; 6) Developed groundwater-level contours for each site; 7) Developed depth-to-groundwater maps for a representative area at each site; 8) Described the apparent effective rooting depth for plants affecting the water table level; 9) Examined the effect of adjacent groundwater withdrawal for irrigation; and 10) Separated the influence of river stage, precipitation, and evapotranspiration on wet-meadow groundwater levels.

Continuous hydrologic and soil temperatures were plotted by water year to show the 'real-time' relationships. Box-plot hydrographs and depth-to-groundwater duration curves were generated from the continuous daily mean groundwater depths and river stage. The box-plot hydrographs summarize the variation within and between months, while the duration curves are cumulative frequency distributions that show the percent of time a particular depth or stage was equaled or above that level for the period specified. Linear regression was used to determine the relationship between the river stage at a site and the river flow at an adjacent USGS gaging station. Groundwater levels for dates selected to represent the lowest and highest periodic measurements, and a median level for spring and summer, were used for the cross-valley transects, groundwater-level contours at each site, and the depth-to-groundwater maps for selected areas at each site. The effective plant rooting depth was determined by plotting the observed evapotranspiration from the water table versus the depth to the water table. Continuous plots of groundwater, precipitation, and periods of pumping for adjacent irrigation were examined for possible groundwater fluctuations caused by pumping. Correlation analysis was used to separate the effects of river stage, precipitation, and evapotranspiration on the groundwater level.

The continuous data and the box-plot hydrographs showed that the median groundwater levels typically peaked by March, and then declined through September. Recharge began in October and varied between a gradual recharge over the winter for the drier wells, to a relatively rapid recharge following plant senescence in the fall at the wetter sites. The duration curves showed that the water table was within 0.5 ft of the surface 0%, <1%, and 56-95% of the time for Elm Creek, Rowe Sanctuary, and for the two wettest wells at Crane Meadows, respectively, for February through April. Reasonably good relationships were developed between the river stage and river flow for Rowe Sanctuary and Crane Meadows, but the relationship was poor at Elm Creek because the river only enters the Elm Creek channel at high flow. Interpretation of the groundwater profile next to Rowe Sanctuary and Crane Meadows was confounded because the cross-valley transects were not oriented perpendicular to the Platte River. The Elm Creek transect was almost perpendicular to the River, however, and there was a steep gradient toward the River from the south and a moderate gradient toward the River from the north. Groundwater contours at each site showed a predominant gradient down-valley, but precipitation directed this gradient toward the River at each site and evapotranspiration apparently directed this gradient toward the center of the island at Crane Meadows. The depth-to-groundwater maps showed that Elm Creek had the deepest groundwater levels, Rowe Sanctuary had intermediate groundwater levels, and Crane Meadows had the highest groundwater levels. Up to 77% of the representative area at Crane Meadows had groundwater levels within 1 ft or above the surface for the median spring level. The effective rooting depth for plants located in the wettest areas of Crane Meadows was about 3 ft below the surface, and 5 to 6 ft below the surface for the drier areas. Groundwater withdrawals for adjacent irrigation had little or no direct affect on the groundwater levels at the three study sites. This was probably because most irrigation wells were at least a half mile from the nearest groundwater-level recorder. River stage, precipitation, and evapotranspiration were nearly always highly correlated with the groundwater level, with river stage usually the most highly correlated.

The conclusions from this study are:

1. River stage is most often the dominant influence on the groundwater level.

2. Precipitation is usually the next most dominant influence on groundwater levels.

3. Evapotranspiration from the water table does not become important until May, and is usually insignificant again by late September.

4. Groundwater withdrawals for adjacent irrigation has little or no direct affect on the groundwater levels at the three study sites. The cumulative effect on the study-site groundwater levels from groundwater withdrawals throughout the Platte River Valley was not evaluated, however.

5. Plants in the wettest areas of Crane Meadows appear able to remove water directly from the water table up to about 3 ft below the surface. The water table seldom drops below 3 ft in these areas. Plants in the drier areas of Crane Meadows appear able to remove water directly from the water table up to 5-6 ft below the surface. The water table in these drier areas seldom drops below this limit.

6. Crane Meadows has more area with shallower groundwater levels than either Rowe Sanctuary or Elm Creek.

7. Median groundwater levels typically peak by March and then gradually declined through September. Recharge begins in October and varies between a gradual recharge over the winter at the drier sites, to a relatively rapid recharge at the wetter sites following plant senescence.

8. The groundwater gradient is primarily down-valley at each site. Large precipitation events, however, direct this gradient toward the River at each site and evapotranspiration apparently directs this gradient toward the center of the island at Crane Meadows during the summer.

9. The groundwater gradient adjacent to the Platte River at Elm Creek is relatively steep toward the River from the south, and relatively moderate toward the River from the north. Interpretation of the groundwater gradient next to Rowe Sanctuary and Crane Meadows is confounded because the cross-valley transects are not oriented perpendicular to the Platte River.

10. The relationship between river stage and river flow at Rowe Sanctuary and Crane Meadows was good, but the Elm Creek relationship was poor because the river channel for the Elm Creek gage was fed primarily by a groundwater drain.

11. Depth-to-groundwater duration curves are useful for determining maximum and minimum levels, as well as the percent of time a particular level was equaled or maintained above that level. If this duration information was combined with the response of selected plant species to produce depth-to-groundwater suitability curves, then it may be possible to predict plant response to future water management practices along the Platte River.

ACKNOWLEDGEMENTS

Initial funding for this study was provided by the U.S. Fish and Wildlife Service, with continuation funding provided by the U.S. Bureau of Reclamation. The Nebraska Game and Parks Commission also contributed funds for parts of the analysis. The cooperation and use of the wet-meadow study sites from the Platte River Whooping Crane Habitat Maintenance Trust and the National Audubon Society was greatly appreciated. Thanks to Larry Dolan, the first Project Scientist, for designing and installing the hydrologic sampling network, including most of the groundwater wells at each site. Assistance in the field from Paul Currier, Marie Strom, Ross Metcalf, and Bill Dunn helped make the long hours enjoyable (often under harsh conditions), and provided invaluable additional data for the analysis. Finally, thanks to the irrigators who took their valuable time to record their pumping times and provide these records for our analysis of the effects of adjacent groundwater withdrawals at each site.

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INTRODUCTION

The Platte River in central Nebraska is located within the main corridor of the Central Flyway and is an important staging area for migratory waterfowl, sandhill cranes, and whooping cranes. The wet meadows along the River provide important feeding and resting areas that do not exist on the surrounding upland and agricultural fields. Although the importance of wetlands has been recognized, the hydrology of these areas is poorly understood (LaBaugh 1986, Kusler and Kentula 1990). River stage (water-surface elevation), precipitation, evapotranspiration, and adjacent cropland irrigation are examples of hydrologic components that may influence the condition of wet meadows. As the demand for agricultural and municipal water increases, there is speculation that surface-water diversions and groundwater withdrawals may adversely affect the hydrology of the Platte River's wet meadows. Future wetland management decisions, therefore, will require a thorough understanding of their hydrology.

To address these concerns the Project Team began a study in 1988 to examine the hydrology of wet meadows along the Platte River at three study sites between Lexington and Grand Island, Nebraska (Figures 1 and 2). Our specific objectives were to examine the seasonal relationships between wet meadow groundwater elevations and river stage, precipitation, evapotranspiration, and adjacent irrigation. Based on our initial findings (Wesche et al. 1990), the study was expanded in 1990 and additional hydrologic data were collected through September of 1992. Before our study, continuous hydrologic data were inadequate for the wet meadows along the Platte River in central Nebraska. Several investigators examined point data, but only Hurr (1983) and our present study collected continuous, time-series data. Since the interaction between hydrologic components is complex, long-term data are necessary to improve our understanding of wetland hydrology. Hurr (1983) obtained continuous data for seven months from one site (Crane Meadows, Figure 2). Our

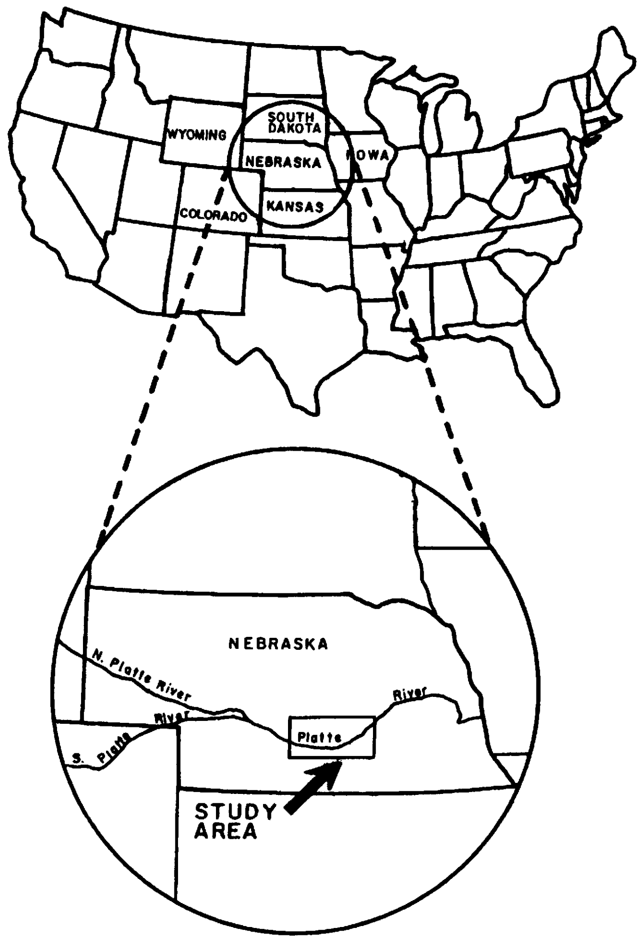


Figure 1. Map of the Platte River study area.

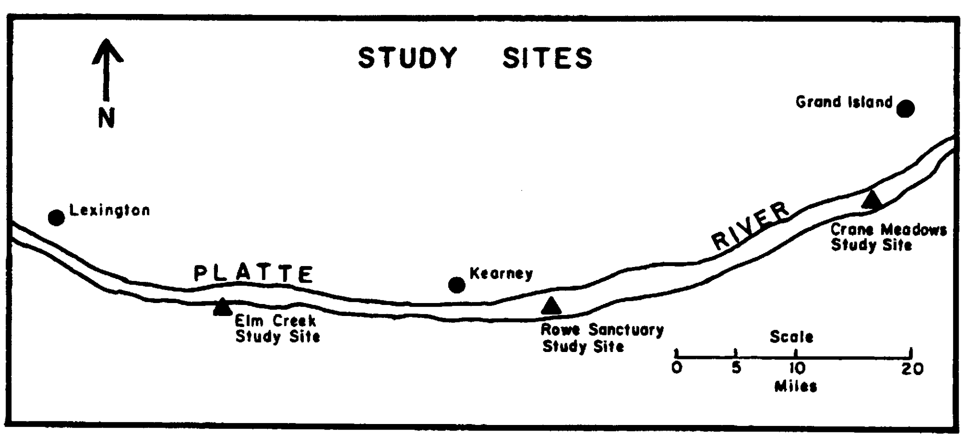


Figure 2. Map of the three study site locations.

report was based on 4¼ years (July 1988 through September 1992) of continuous data from three sites (Figure 2).

DESCRIPTION OF THE STUDY AREA

Bio-Geography

The Platte River drains approximately 90,000 mi^2 from the states of Nebraska, Colorado, and Wyoming. This drainage system is composed of three major segments: the North Platte River, the South Platte River, and the main stem of the Platte River (Figure 1). The main stem of the Platte River begins at North Platte, Nebraska, where the North and South Platte Rivers join. From this point, the River flows in an easterly direction across the plains of Nebraska to its confluence with the Missouri River near Plattsmouth, Nebraska. Between North Platte and Columbus, Nebraska, the River forms a wide bend to the south. This wide bend is often called the "Big Bend" section of the River, and is considered a critical area for wildlife. Throughout this section, the Platte River forms a wide, braided channel with numerous islands. Our three study sites were located within this section between the cities of Lexington and Grand Island, Nebraska (Figure 2).

The wet meadows along the Platte River typically occur in low-lying areas within the Platte River valley. The Platte River valley within the study area is approximately 7 to 15 miles wide. Although much of the land is presently under cultivation, the remaining wet meadows are generally used as pastureland for livestock and contain plant species that are absent in the adjacent uplands.

Hydrology

The Platte River flows in response to surface water inputs from numerous tributaries, surrounding groundwater fluctuations, and to storage and withdrawals from upstream reservoirs. Before flow regulation, much of this flow originated from melting snowpacks in the higher elevations of Wyoming and Colorado during the spring. This snow melt, together with spring rainfall, recharges the alluvial aquifers and causes the hydrograph to peak in May and June. Following this springtime peak, streamflow decreases significantly during the summer. In the fall, streamflow again increases to a relatively uniform level until the following spring (Bentall and Others 1975).

Present-day streamflows, however, have been significantly modified by water development activities within the basin. This hydrologic change has caused shifts in the low and high levels of flow, and a flattening of the flow duration curve (Kircher and Karlinger 1981). These changes have also caused a significant decrease in the channel cross-sectional area of the Platte River over the past 40 years, and an increase in island area (Kircher and Karlinger 1981).

Groundwater levels within the study area are influenced by both the movement of subsurface water down the Platte River valley, and the influence of regional groundwater movements. The principal aquifer within the Platte River valley is formed by Pleistocene sands and gravels (Schreurs and Rainwater 1956). The general direction of regional groundwater movement is from northwest to southeast (Lugn and Wenzel 1938). Within the Platte River valley, however, the direction of groundwater movement is almost parallel to the direction of streamflow (Schreurs and Rainwater 1956). The mean groundwater gradient is from 6 to 7 feet per mile, closely conforming to the average gradient of the Platte River (Schreurs and Rainwater 1956). The water table within the Platte River valley is generally shallow, and in the wet meadows the water table is usually at or near the ground surface. Groundwater elevations are generally highest in the spring and lowest in the summer (Hurr 1983).

METHODS

Study Site Selection

Three study sites were established in representative wet meadows along the Platte River between Lexington and Grand Island, Nebraska in May of 1988 (Figure 2). Two sites were located on large islands between river channels, while the third site was located next to the south bank. Study sites were selected in agreement with the U.S. Fish and Wildlife Service, Platte River Whooping Crane Habitat Maintenance Trust, U.S. Bureau of Reclamation, and the National Audubon Society. Topographic maps were used to identify potential wet meadow sites, and the suitability of these sites was verified in the field. These sites were chosen to represent a variety of topographic, drainage, and vegetation types; all considered important sandhill crane, whooping crane, and other migratory bird habitat.

Instrumentation Common to All Sites

Study site instrumentation began in July of 1988 and was completed in August of 1988, except as noted below. Monitoring continued through September of 1992. Each site had a weather station, a cross-valley well transect, a well grid, and one or more river-stage gaging stations, (Figures 3, 4, and 5). Weather stations were used to measure precipitation and determine the length of the growing season. Each station was equipped with a minimum of one Belfort weighing bucket rain gage, and a thermograph for measuring the air and soil temperatures at 4 and 40 inches. The Crane Meadows site has an expanded weather station for estimating evapotranspiration. Instrumentation for this site included a hygrothermograph (for relative humidity), a pyroheliograph (for solar radiation), a barograph (for barometric pressure), a totalizing anemometer (for wind travel), and a Class A evaporation pan.

Groundwater levels were monitored with a cross-valley transect and a grid of wells. The cross-valley transects provided a two dimensional view of the surrounding groundwater

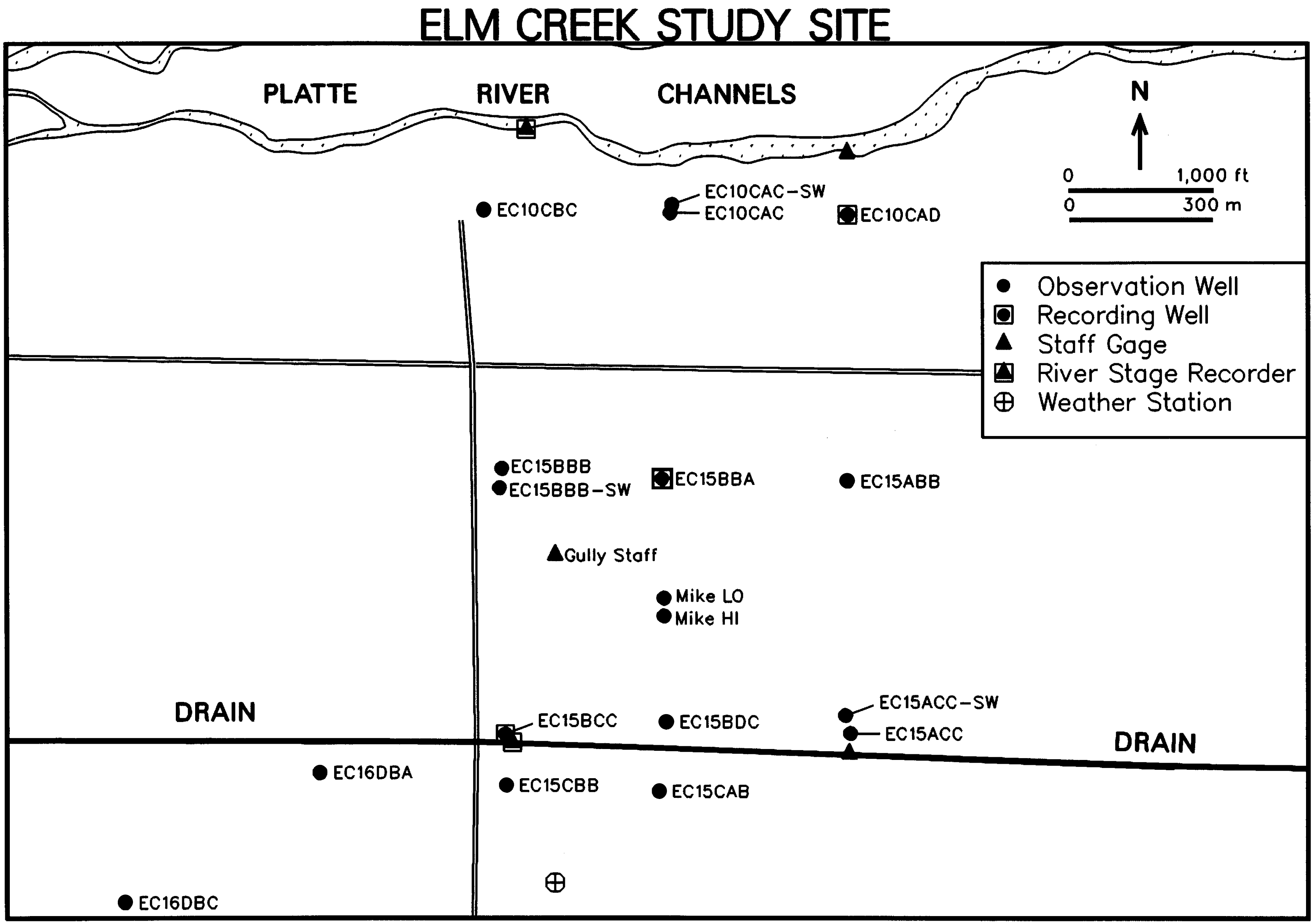


Figure 3. Map of the Elm Creek study site.

ROWE SANCTUARY STUDY SITE

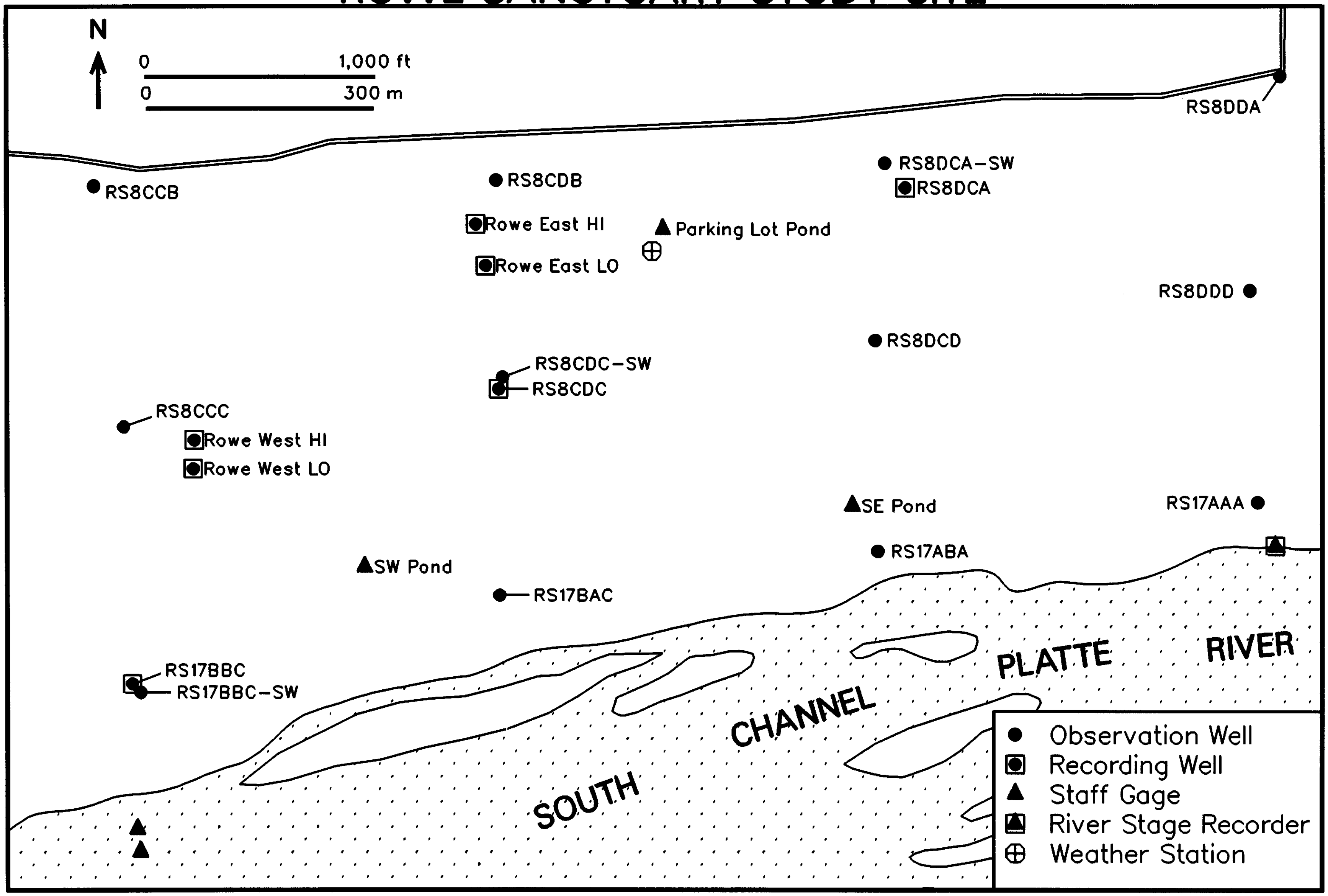


Figure 4. Map of the Rowe Sanctuary study site.

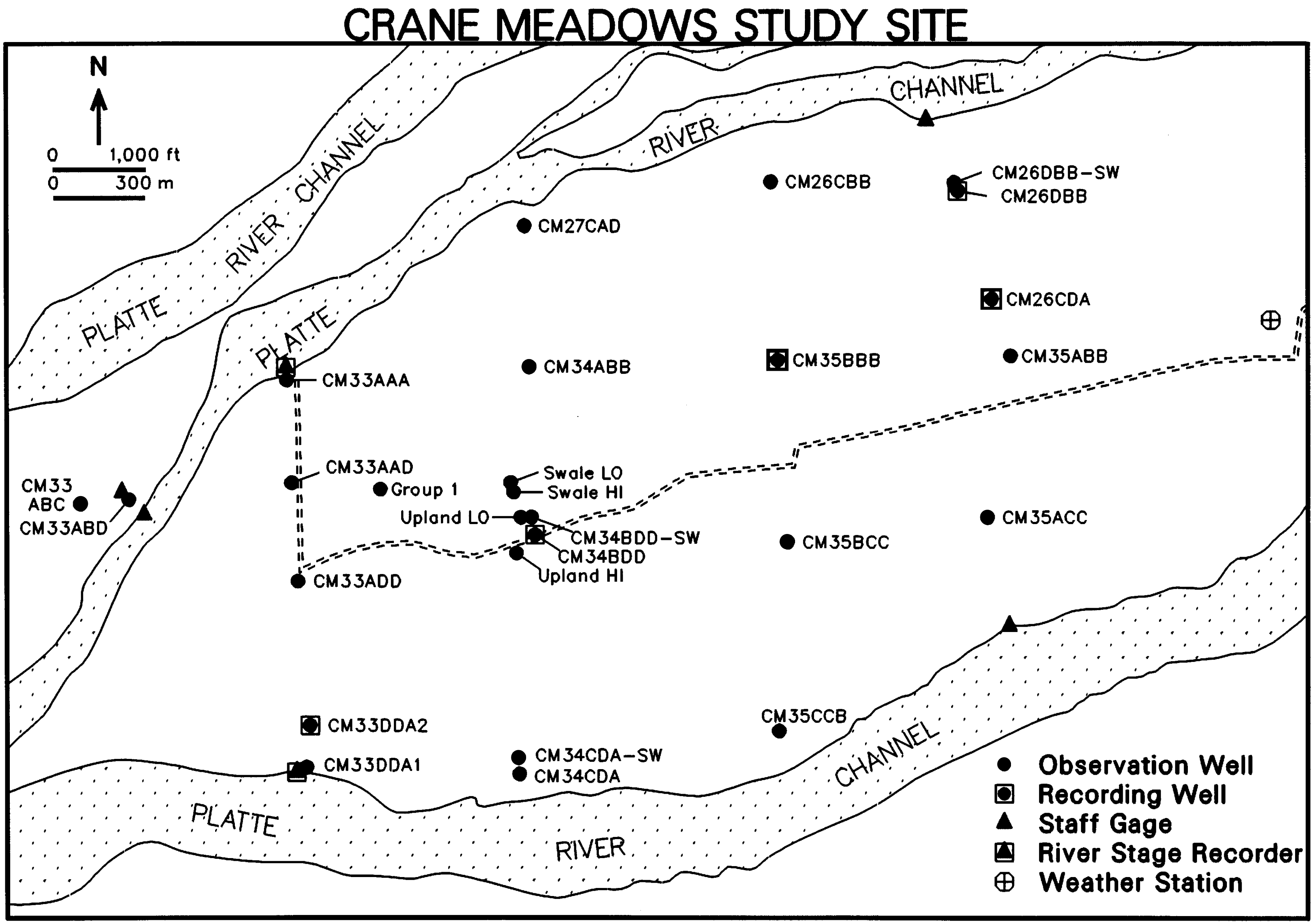


Figure 5. Map of the Crane Meadows study site.

levels, while the well grids provided a three-dimensional view of the groundwater levels at each site. Three of the grid wells at each site were equipped with Stevens Type F recorders for continuously monitoring groundwater levels since the start of the study. Two additional wells were equipped with recorders at the Crane Meadows site in 1990 (CM35BBB in May, and CM26CDA in mid September). The National Audubon Society also maintained four additional recorders (Rowe West LO and HI, and Rowe East LO and HI) at the Rowe Sanctuary, but their continuous data were not included in our analysis. The remainder of the cross-valley transect wells and the grid wells were measured at least once a month, with supplemental weekly measurements taken by the National Audubon Society. The cross-valley transect wells were installed by the U.S. Bureau of Reclamation and were cased with 1¼ inch pipe (iron or PVC). Most wells in the grids were new, although some previously existing wells were also used. New wells were constructed of 2 inch, schedule 40 PVC pipe with the lower 3 feet perforated. In 1990, the U.S. Bureau of Reclamation tied the coordinates of the grid wells into the 10,000-foot grid of the Nebraska coordinate system, south zone. Surface profiles were surveyed for the Rowe Sanctuary and Crane Meadows cross-valley transects. Elm Creek's surface profile was surveyed within the study area, and distances between wells outside the study area were estimated from 1:24,000 topographic maps. All transect and grid wells were surveyed to elevations above mean sea level.

River stage was monitored at each site with a continuous Stevens Type F recorder. The Elm Creek site had an additional recorder installed at the west end of the groundwater drain in June of 1990, and an additional river-stage recorder was installed on the northwest corner of Crane Meadows in June of 1990. A stilling well was used at each gage to reduce fluctuations caused by wave action. Additional staff gages were installed to monitor surface water elevations surrounding each site. Staff gage readings were taken when the well grids were sampled. All gaging stations and staff gages were surveyed to elevations above mean sea level.

Pumping from adjacent irrigation wells (within 1 mile) was also monitored. Irrigators were requested to provide their pumping times and approximate flows. These data were collected after the growing season and examined for relationships between pumping and groundwater levels.

Study Site Descriptions and Instrumentation

Elm Creek Site

The Elm Creek site (Figure 3) was on the south bank of the Platte River approximately 5 miles west of the Elm Creek exit on Interstate 80. This site is owned and managed by the Platte River Whooping Crane Habitat Maintenance Trust. Elm Creek was the "driest" of the three sites, and was characterized by a widely spaced drainage pattern with few depressions where the land surface intersected the water table. The southwestern portion of the site, however, had a wet pothole area with seasonal standing water. This standing water was maintained primarily by groundwater flowing from the south toward the river, and was isolated from the river by a groundwater drainage canal. Groundwater drainage canals are used in the area surrounding the study site to make croplands more accessible by lowering the water table. The site was managed for wildlife habitat, and was hayed once a year through 1989. Beginning in 1990, the site was seasonally grazed by cattle.

The well grid was composed of 16 observation wells located east of the north-south county road. Wells EC16DBA and EC16DBC were used to evaluate groundwater elevations in a pothole-type meadow. The three side wells (EC10CAC-SW, EC15BBB-SW, and EC15ACC-SW), and Mike LO and Mike HI were installed for a study by the National Audubon Society, but these data were also used for our analysis. All wells were drilled to a depth of 10 feet with a Giddings Rig, except Mike LO and Mike HI which were installed by the National Audubon Society by pounding an open-ended, non-perforated 20 ft pipe approximately 16 ft into the ground.

The cross-valley transect extended an additional 3.4 miles beyond the study site to the south, and 2.5 miles north of the northern most river channel (Figure 6). The transect wells were installed by the U.S. Bureau of Reclamation, and were constructed of 1¼ inch schedule 40 PVC pipe. The wells ranged from 20 to 50 ft deep, and had the lower 5 feet perforated.

The river stage gaging station was near the northwestern corner of the study site on a very small channel of the Platte River. Surface water from the Platte River entered this channel only at high flows. At lower flows the channel was fed primarily by a groundwater drainage canal that entered the channel near its inlet, about 1.3 miles west of the study site (Figure 6). Staff gages were also established within the study site at the east end of this small channel, and at the east and west ends of the groundwater drain. These staff gages helped determine the surface water elevations surrounding the site. The Gully Staff was installed in an old, dry channel, but surface water was seldom observed in this channel.

Rowe Sanctuary Site

The second study site (Figure 4) was at the Lillian Annette Rowe Sanctuary, approximately 10 miles north of Minden, Nebraska. The Sanctuary is owned and managed by the National Audubon Society for the protection of wildlife and native plant species. The site was composed primarily of seasonally flooded native prairie, and was located on the south side of a large island between two channels of the Platte River. Controlled burning and haying were used to manage the Sanctuary.

The well grid had 19 observation wells. The three side wells (RS8DCA-SW, RS8CDC-SW, and RS17BBC-SW), and the four Rowe West and East wells were installed for a study by the National Audubon Society. These data were also used for our grid analysis, although the continuously recorded data were not used. All wells were drilled to a depth of 10 feet with a Giddings Rig, except the two Rowe West and two Rowe East wells which were installed by the National Audubon Society by pounding an open-ended, non-perforated 20 ft pipe approximately 16 ft into the ground. The cross-valley transect wells (Figure 7), including the northeastern well of the grid, were installed by the U.S. Bureau of Reclamation. Transect

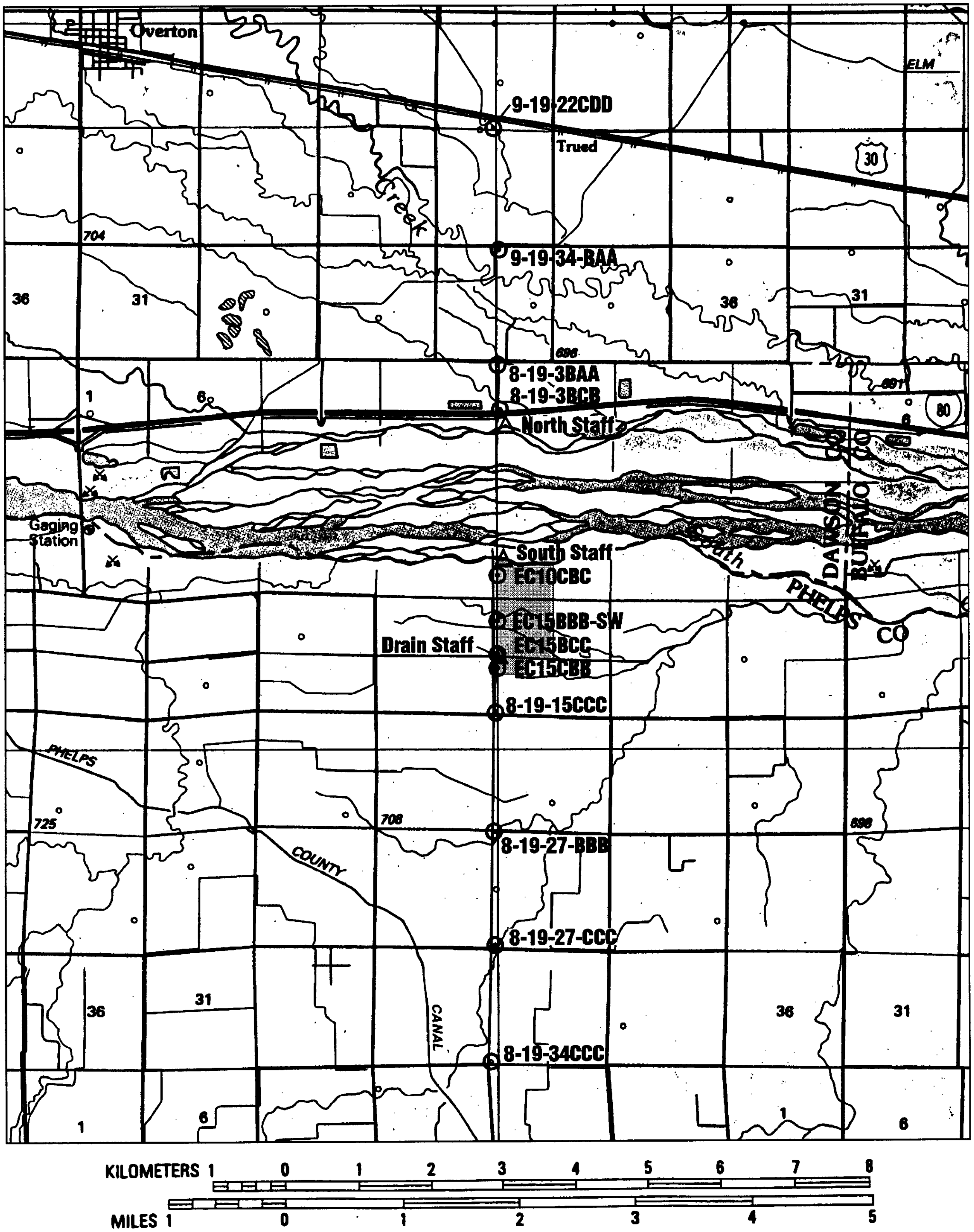


Figure 6. Map of the Elm Creek cross-valley transect. The shaded area includes the study site with the well grid. Base map from the U.S. Geological Survey (1985b).

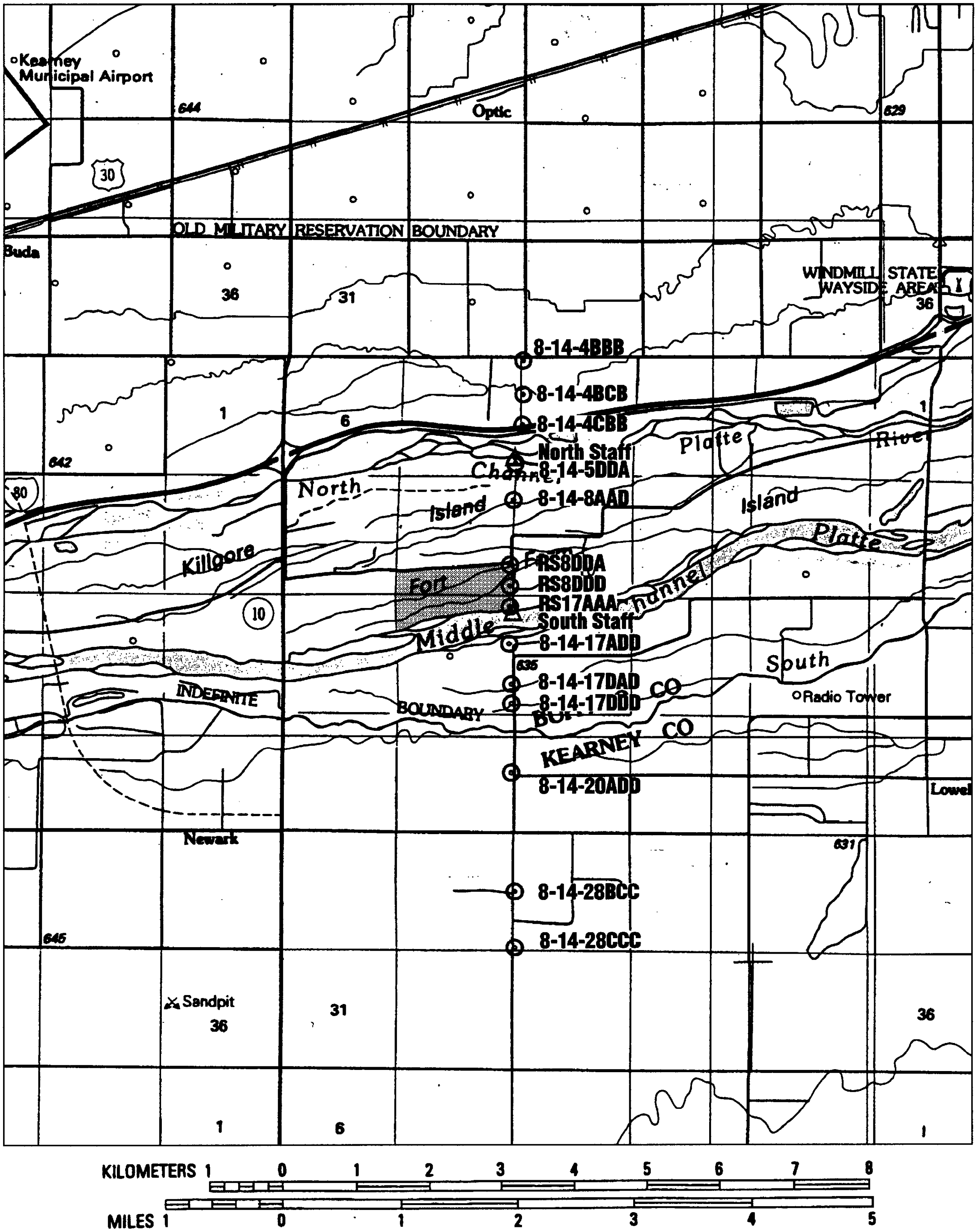


Figure 7. Map of the Rowe Sanctuary cross-valley transect. The shaded area includes the study site with the well grid. Base map from the U.S. Geological Survey (1985a).

wells extended 1.8 miles north and 2.9 miles south of the study site, and were constructed of 1¼ inch iron pipe.

The river stage gaging station was near the southeastern corner of the study site on the South Channel of the Platte River (Figure 4). Additional staff gages were established by the National Audubon Society to help define the surface water slope of the channel, and to monitor surface water levels in three shallow stock ponds on the Sanctuary.

Crane Meadows Site

The Crane Meadows site (Figure 5) was approximately 6 miles south of Grand Island, Nebraska on a large island in the Platte River. The site was located on the Mormon Island Crane Meadows Wildlife Refuge, which is owned and managed by the Platte River Whooping Crane Habitat Maintenance Trust. This was the wettest of the three sites, and was characterized by a large proportion of low, seasonally flooded wet meadows, with some higher dry meadows, and a tree-lined fringe on the natural levees bordering the river. The refuge is managed for both migratory and resident wildlife. Land management practices included grazing, burning, and haying.

The well grid had 25 observation wells. Two additional wells (CM33ABC and CM33ABD) were established on an island directly northwest of the main study site to evaluate the groundwater relationships for this type of drainage pattern. The three side wells (CM26DBB-SW, CM34BDD-SW, and CM34CDA-SW), and the four Swale and Upland wells were installed for a study by the National Audubon Society, but these data were also used for our analysis. Five piezometer wells in Group 1 were installed for a study by Hurr (1983). Four of these wells were still intact, and were monitored on a monthly basis from April 1991 through the end of the study to investigate vertical groundwater movements. The shallowest piezometer was also included in the grid analysis. Wells along the western side of the grid composed a portion of the cross-valley transect. The cross-valley transect extended 1.6 miles north and 2.2 miles south of the study site (Figure 8). Transect wells were installed by the U.S. Geological Survey (Hurr 1983), and were from 25 to 100 feet deep. All new grid wells

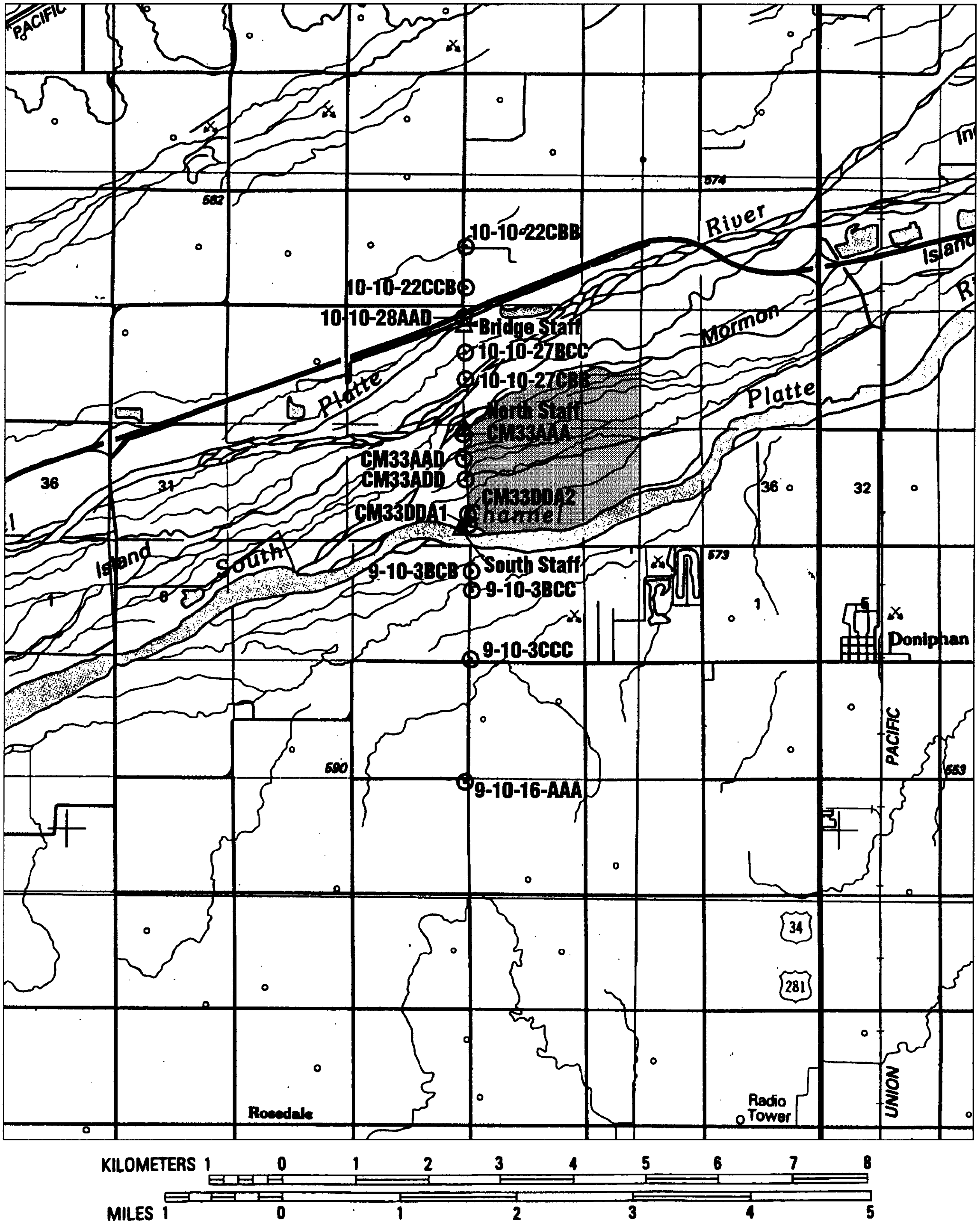


Figure 8. Map of the Crane Meadows cross-valley transect. The shaded area includes the study site with the well grid. Base map from the U.S. Geological Survey (1985a).

were drilled with a Giddings Rig or a hand auger, and were from 7 to 12 feet deep, except the four Swale and Upland wells which were installed by the National Audubon Society by pounding an open-ended, non-perforated 20 ft pipe approximately 16 ft into the ground.

The river stage gaging station was located near the southwestern corner of the study site on the South Channel of the Platte River. An additional river stage gaging station was installed on the channel in the northwest corner of the site in June 1990 to monitor potential differences between the two channels. Two additional staff gages were also located near the other two corners of the study site to help define the surface water slope surrounding the site.

Data Analysis

Data were entered into a micro computer using standard data management programs to simplify data transfer between agencies. Data were also transferred to the University of Wyoming's VAX mainframe computer for manipulation, plotting, and statistical analysis. Continuous groundwater and river-stage data were entered as mean daily values. Data for all other wells and staff gages were entered as point data. Precipitation and pan evaporation were entered as daily totals. Relative humidity, solar radiation, and barometric pressure were entered as mean daily values. Soil and air temperatures were entered as daily maximum, minimum, and mean values. Wind travel data were entered as average daily values computed from the monthly total wind travel. Groundwater withdrawals for irrigation were entered as daily on/off data for each well during the irrigation season. Due to the substantial quantity of continuous data obtained, the raw data will not be included in this report. The data, however, can be obtained by request from the Principal Investigators through the U.S. Bureau of Reclamation at Mills, Wyoming.

Groundwater and River Stage Hydrographs

Box-and-whisker plots (Ott 1988, SAS Institute Inc. 1990a) were used to summarize the groundwater and river stage hydrographs. Observations were summarized by month to allow examination of the water level variation within months as well as between months.

Groundwater depths were calculated by subtracting the groundwater elevation from the surface elevation. River stage was presented as an elevation above mean sea level. Boxes were constructed to represent the median (connected by a line through each month), the middle 50% of the observations (the box), the lower 10 to 25% and the upper 75 to 90% of the observations (the whiskers), and the lower 0 to 10% and upper 90 to 100% of the observations (individual data points). For box-and-whisker plots based on continuous observations (i.e., wells and gages with recorders), each box shows the percent of time during the month that a water level was maintained or above (similar to the duration curves). Periodic observations were used for wells and gages without recorders (Appendix A), but the data must be interpreted as the percentage of *observations* instead of the percentage of *time*.

Depth-to-Groundwater and River Stage Duration Curves

Depth to groundwater and river stage duration curves were generated from the continuous daily mean groundwater depths and river stage. These curves are cumulative frequency distribution curves that show the percent of time that a particular depth or stage was equaled or above that level for the period specified. Values are typically expressed as a duration followed by a depth or stage. For example, D_{90} = -3.25 ft means that 90% of the time the water level was at or above 3.25 ft below the surface. The duration curves were calculated using procedures similar to those used to calculate a typical flow duration curve for streamflow analysis (Searcy 1959). Duration curves are useful for predicting the availability and variability of sustained levels, but they do not represent the actual sequence of observed events (Viessman et al. 1977).

PROC FREQ (SAS Institute Inc. 1985a) was used to generate the duration data and PROC GPLOT (SAS Institute Inc. 1990b) was used to graph the data. Graphical data were based upon 0.01 ft size classes for more accurate representations.

River Stage and River Flow Relationships

The river flow (Q) for a given river stage at each site was estimated by using a simple power function:

$$Q = a(\text{Stage})^b \quad \textbf{(1)}$$

where a and b were empirically derived. By taking the Log_{10} of both sides of the equation, the equation can be put into a form where a and b can be estimated by linear regression:

$$\text{Log}_{10}Q = a + b\text{Log}_{10}(\text{Stage}) \quad \textbf{(2)}$$

Equation 2 was modified slightly by subtracting a constant from the stage to reduce the range of stage values compared to the mean stage (e.g., instead of using the elevation above sea level for the stage, the stage was adjusted by subtracting a constant such as 1,899 ft). Mean daily river stage values for each site were then regressed with the mean daily discharge (flow) for the USGS river gaging station near each site. The USGS gage near Overton, NE (06768000) was 3.6 miles upstream from the Elm Creek gage; the USGS gage near Kearney, NE (06770200) was 9 miles upstream from the Rowe Sanctuary gage; and the USGS gage near Grand Island, NE (06770500) was 11 miles down stream from the Crane Meadows gage. All data for the period-of-record at each site were used, except the estimated flows for the USGS gage and a few estimated river stages at each site. Data estimated by correlation with other gages were routinely used to provide a continuous record when the data were missing due to equipment malfunction or for other reasons (e.g., frozen river). The accuracy of estimated data is seldom as good as actual data, however, and the USGS considers their missing data poor. The time lag between the site and USGS gage was minimized by using the mean daily flow and stage. When the flow changed rapidly near the end of the day, however, the time lag caused the relationship between the mean daily flow and stage to deviate from normal. Days with an obvious time lag, therefore, were also excluded. Ninety-five percent confidence belts for predicting Q from a given stage were calculated using equation 16.27 from Zarr (1974).

PROC REG (SAS Institute Inc. 1985b) was used to calculate the regression equation, and statistics from PROC REG and PROC MEANS (SAS Institute Inc. 1985a) were used to calculate the 95% confidence belts. The data were plotted using PROC GPLOT (SAS Institute Inc. 1990b).

Cross-Valley Transects

Groundwater levels for selected dates were combined with surface profile data to produce a two-dimensional view of the groundwater levels next to each site. Dates were selected to represent the lowest and highest observed periodic measurements, and a median groundwater profile for the spring and summer seasons. The median profiles were selected to represent as close as possible a day when D_{50} depths were observed at the continuously monitored wells at each site. Surface profiles outside the study areas were "smoothed" by plotting only the surface elevations at the well, instead of plotting the complete surface profile. The complete surface profile included too much variation to show with the scale used for the graphs. The graphs are oriented so that the observer is looking down valley, and the vertical scale is exaggerated to emphasize the groundwater levels. River stage is shown for a specific date, which may or may not correspond to the river stage at other times when the groundwater elevations are presented.

Groundwater-Level Contours

Groundwater contour maps were generated for selected dates to produce a "three-dimensional" view of the groundwater level at each site. Dates were selected to represent the lowest and highest observed periodic measurements, and a median groundwater level for the spring and summer seasons. The median levels were selected to represent, as close as possible, a day when D_{50} depths were observed at the continuously monitored wells. Contours were generated by forming a regular matrix of equally spaced elevations from the groundwater well grid. PROC G3GRID (SAS Institute Inc. 1990b) was used to generate this regular matrix of groundwater elevations. The contours were then superimposed over additional geographic information for each site using the FORTRAN subroutines provided by DISSPLA (Computer Associates International Inc. 1987). Surface water elevations between each river-stage gage were estimated by linear interpolation at 100 or 200 ft intervals. Interpolation between wells was also used where a river channel or the well spacing did not provide an adequate hydrologic boundary to form realistic contours near the edge of each site.

Depth-to-Groundwater Maps

Depth-to-groundwater maps for a representative area of each site were determined by subtracting the groundwater-contour elevations from the surface-topographic elevations. Each representative area was bounded by four wells, and the groundwater-contour elevations were produced from the same data and dates as the groundwater contour maps. Surface-topographic information was obtained from detailed topographic surveys conducted within each area using standard engineering techniques. The detail of these surveys was not always adequate to produce uniform topographic information, but the level of detail was sufficient to produce better depth-to-groundwater maps than would have been produced using available topographic maps. PROC G3GRID (SAS Institute Inc. 1990b) was used to generate a uniform matrix of groundwater and surface elevations, and PROC GCONTOUR (SAS Institute Inc. 1990b) was used to graph the data.

Evapotranspiration and the Effective Plant Rooting Depth

The effective plant rooting depth was determined by plotting the percent of potential evapotranspiration (observed $\div$ potential $\times$ 100) versus the depth-to-water table for each observation. White (1932) used a similar method to describe the effects of evaporation on the water table by depth. The Committee on Irrigation Water Requirements of the Irrigation and Drainage Division of the ASCE (1990) defines:

1) **evaporation** as the physical process by which a liquid or solid is transformed to the gaseous state.

2) **transpiration** as the process by which water in plants is transferred as water vapor to the atmosphere.

3) **evapotranspiration** (ET) as the combined processes by which water is transferred from the earth surface to the atmosphere (evaporation plus transpiration).

4) **potential evapotranspiration** (PET) as the rate at which water if available would be removed from wet soil and plant surfaces.

Water withdrawn from the water table by evapotranspiration (ET_{WT}), plus water withdrawn from the unsaturated soil profile by evapotranspiration (ET_{US}), equals the total or actual ET. The actual ET is almost always less than the potential evapotranspiration.

Potential evapotranspiration was estimated by using both the Turc's method and the FAO-24 pan method. The Turc's method was rated second over 20 different methods for humid locations (Committee on Irrigation Water Requirements of the Irrigation and Drainage Division of the ASCE 1990). The FAO-24 pan method was rated 17th, but it was the highest rated pan evaporation method. When the Turc's method is expressed on a daily basis in $mm \cdot d^{-1}$ of evaporated water the equation is:

$$PET = 0.013 \frac{T}{(T + 15)} (R_s + 50) \left[1 + \frac{(50 - RH)}{70} \right] \tag{3}$$

where T is the average temperature in °C, R_s is the solar radiation in $cal \cdot cm^{-2} \cdot d^{-1}$, and RH is the relative humidity for values $<50\%$ or set equal to 50% for RH values $\geq 50\%$. For our analysis T was converted to °F and PET was converted to inches per day.

The equation for the FAO-24 pan method is:

$$PET = k_p \cdot E_{pan} \tag{4}$$

where E_{pan} is the daily pan evaporation in inches, and the pan coefficient k_p is calculated from the following formula when the upwind area had green vegetation:

$$k_p = 0.108 - 0.000331 \cdot U_2 + 0.0422 \cdot \ln(Fetch) + 0.1434 \cdot \ln(RH_{mean}) - 0.000631 \cdot [\ln(Fetch)]^2 \cdot [\ln(RH_{mean})] \tag{5}$$

The limits for equation 5 are:

$30 \leq RH_{mean} \leq 84\%$

$84 \leq U_2 \leq 700\ km \cdot d^{-1}$, where U_2 = wind at 2 m above soil

$1 \leq Fetch \leq 1000\ m$

The above limits were set to their respective limit if the value exceeded its bounds.

Evapotranspiration from the water table was estimated with a method described by Gerla (1992). This method uses the daily cycle of water table drawdown and recoveries caused by ET and groundwater flow to obtain an estimate of the ET_{WT} rate (q_{ET}), and the ground- and soil-water flow rate near the well (q_{GW}). The following matrix equation describes this relationship:

$$\begin{bmatrix} q_{ET} \\ q_{GW} \end{bmatrix} = \begin{bmatrix} m_{ET} - \{i_{ET}/(t_{ET}\cdot(\phi-\Theta))\} \\ m_{RC} - \{i_{RC}/(t_{RC}\cdot(\phi-\Theta))\} \end{bmatrix} \cdot \begin{bmatrix} -1/(\phi-\Theta) & 1/(\phi-\Theta) \\ t_{ET}/(t_{RC}\cdot(\phi-\Theta)) & 1/(\phi-\Theta) \end{bmatrix}^{-1} \qquad \textbf{(6)}$$

where

m_{ET} = rate of groundwater-level recession from ET

m_{RC} = rate of groundwater-level recovery from ET

i_{ET} = total infiltration that occurs during the ET portion of the daily cycle

i_{RC} = total infiltration that occurs during the recovery portion of the daily cycle

t_{ET} = length of time during which ET occurs

t_{RC} = length of time during which recovery occurs

$(\phi-\Theta)$ = air-filled porosity of the soil immediately above the water table

The total ET_{WT} in inches per day can be calculated from the q_{ET} rate by multiplying q_{ET} times the duration of ET for the day (t_{ET}). Most of these terms (m_{ET}, m_{RC}, t_{ET} and t_{RC}) can be measured directly from the groundwater-level recording chart. The infiltration terms (i_{ET} and i_{RC}) and the air-filled porosity [$(\phi-\Theta)$] must be estimated, however. Infiltration is usually negligible, except for periods of precipitation. Without a more precise measurement, Gerla (1992) suggests using the total precipitation for the period as an estimate for infiltration. This assumes little or no runoff and that interception by plant foliage is negligible. Both assumptions are probably valid for the sandy Platte River soils and for the larger precipitation events, which tend to make runoff and interception insignificant compared to infiltration. Gerla (1992) also suggests dividing the infiltration (i.e., precipitation) by the change in groundwater level to obtain a rough estimate for $(\phi-\Theta)$. This technique seemed to work well most of the time for our study, but usually produced widely different values from one event to another. Most of these differences can probably be attributed to runoff from saturated or frozen soil, 'excessive losses' to the dewatered soil above the capillary fringe, or the spatial distribution of precipitation between the gage and the well. To reduce this variability between events, a mean value was used for each well based on all estimates of $(\phi\text{-}\Theta) \leq 0.10$. The upper limit of 0.10 was chosen because this value represents the lower limit of the specific yield for a sandy soil (Driscoll 1986). The specific yield is the quantity of water that a unit volume of unconfined aquifer gives up by gravity, and can also be thought of as the maximum amount of total porosity that can be filled with air when the soil is drained by gravity (i.e., air-filled porosity).

Evapotranspiration data were stored and processed within Lotus spreadsheets (Lotus Development Corporation 1990), and were plotted using PROC GPLOT (SAS Institute Inc. 1990b).

<u>Groundwater Withdrawal for Irrigation</u>

The effect of pumping water from adjacent irrigation wells (within 1 mile) on the groundwater at each study site was evaluated by examining the response of the study-site wells equipped with recorders during pumping. Since groundwater levels were summarized as daily means, the pumping data were also summarized on a daily basis as either off or on. If a pump was on during any portion of the day (midnight to midnight), then the pump was recorded as being on for that day. The groundwater response was evaluated by examining simultaneous plots of groundwater, precipitation, and pumping periods for each irrigation well.

<u>Separation of River Stage, Precipitation and Evapotranspiration</u>

Correlation analysis was used to separate the effects of river stage, precipitation, and evapotranspiration on the groundwater level. The analysis was based on mean daily values for river stage and groundwater levels, an antecedent precipitation index (API), and total daily potential evapotranspiration. Potential evapotranspiration was included only in the Crane Meadows analysis, since it was the only site with a weather station equipped to collect data for estimating PET. Turc's method, described in the previous section, was used to estimate PET. An antecedent precipitation index was used to simulate the groundwater recession following each event. Although the water table peaked within hours after a precipitation event, it usually took several days for the water table to return to its previous level when no other inputs were involved. This groundwater recession appeared to fit an exponential decay curve described by the following equation (Viessman et al. 1977):

$$API_t = K(API_{t-1}) + P_t \tag{7}$$

where

API_t = antecedent precipitation index for the current time period

API_{t-1} = antecedent precipitation index from the previous time period (assumed = 0 at the start)

K = recession constant, empirically derived

P_t = total precipitation for the current time period

The recession constant K is normally reported in the range of 0.85 to 0.98 for modeling soil moisture, with higher values approaching an additive effect for precipitation. For modeling the water table recession at Crane Meadows, however, a value of 0.60 provided the best fit to the data. Increasing K from 0.5 to 0.9 increased the correlation with the groundwater level, but it also increased the correlation with the river stage. One notable exception to this observation was for the month of April, when increasing K seemed to dramatically increase the correlation with the groundwater level while also decreasing the correlation with the river stage. Different values of K were tried for each month, but a fixed value of 0.60 consistently improved the correlation with the groundwater level while minimizing the increased correlation with the river stage. Since 0.60 fit the data best and provided the best balance between correlations, a fixed value of 0.60 was used for all analysis.

River stage and groundwater levels were rescaled by subtracting a constant to reduce their range compared to their mean, (e.g., instead of using the elevation above sea level, the elevation was adjusted by subtracting a constant such as 1,800 ft). PROC CORR (SAS Institute Inc. 1985a) was used to calculate the correlations.

Missing Data Estimation

Missing data for precipitation, mean daily groundwater elevations, and river stage were estimated to provide a complete record of continuous hydrologic data and to calculate the duration curves. Missing precipitation data were estimated using data from the National Weather Service's Grand Island station and Overton 3 W station, and the High Plains Climate Center at the University of Nebraska-Lincoln's automated weather stations located near Gibbon and Lexington, Nebraska. The Grand Island weather station was 12¼ miles north-northeast of the Crane Meadows weather station. The Overton 3 W station was approximately 9 miles northwest of the Elm Creek weather station. The Gibbon automated weather station was 2 miles north of the Rowe Sanctuary weather station. The Lexington automated weather station was approximately 18 miles northwest of the Elm Creek weather station.

Missing mean daily groundwater and river stage data were estimated by eye or by linear regression with other locations. In most cases estimation by eye was considered superior to estimation by regression, because the estimator could take into account 'clues' left on the chart by the pen trace, as well as precipitation inputs and the groundwater response to similar conditions in the past. When a regression was used, it was based on other continuous recorders at the site. River stage was estimated using gage heights or discharge from the U.S. Geological Survey gaging stations near Grand Island (06770500) for Crane Meadows, near Kearney (06770200) for Rowe Sanctuary, and near Overton (06768000) for Elm Creek.

Missing climatological data (other than precipitation) were not estimated. These data were supplemental to most analyses, so it was not critical to have a continuous record. One exception was when PET could not be estimated using Turc's method. In this case, the estimate for PET using the FAO-24 pan method was substituted for Turc's estimate. In most cases, however, the observation (day) was excluded from an analysis when a required value was missing.

Supplemental Data

Some limited supplemental data were also collected during the study. Since these data supplement the study, they will not be included in this report. These data include surface and groundwater electrical conductivity, surface water and groundwater temperatures, dye tracing, and barometric pressure. Electrical conductivity data were collected periodically until April of 1989 when the meter malfunctioned. Surface water and groundwater temperatures were collected on a monthly basis for the duration of the study. Preliminary tests with fluorescent dye suggested that it would be difficult to trace the direction of groundwater flow, so fluorescent dye tests were discontinued. Todd (1980) states that barometric pressure affects confined aquifers, but has little or no affect on unconfined aquifers. Since the study-site wells were all located in the unconfined alluvium of the Platte River Valley, we did not test for groundwater fluctuations caused by changes in barometric pressure. Barometric pressure may have influenced water levels when the ground was frozen (similar to a confining layer), but there were usually other more important factors to consider during this period (e.g., frozen wells).

RESULTS AND DISCUSSION

Observed versus Long-term Precipitation and River Flows

Departures from the normal precipitation at Grand Island, Nebraska, suggest that precipitation during the study period (July 1988 through September 1992) was mostly above normal during the summers (June though September), and precipitation for the remaining months of the study had roughly equal numbers of above and below normal months. There were 14 months of above normal precipitation and 5 months of below normal precipitation during the summer months of the study. Monthly precipitation for the remaining months tended to be below normal during the first half of the study (October 1988 through May 1990, excluding summers), and above normal for the second half of the study (October 1990 through September 1992, excluding summers). Although the non-summer months tended to be drier during the first half of the study, the number of months with below normal precipitation (17 months) was almost equal to the number of months with normal or above normal precipitation (15 months). Monthly departures from normal ranged from 2.55 inches below normal for April 1989, to 4.49 inches above normal for June 1990.

The percent of mean monthly discharge near Overton (Table 2) and near Grand Island (Table 3), Nebraska, show that Platte River discharge during the 52-month study period was mostly below normal. The mean monthly discharges were based on data since Lake McConaughy began storing water in 1942. Only six months were at or above average at the Overton gage, and only nine months were at or above normal at the Grand Island gage. Monthly mean discharge at the Overton gage ranged from 17 to 119% of average (June 1990 and August 1988, respectively), and at the Grand Island gage the monthly mean discharge ranged from 13 to 182% of average (July 1991 and September 1989, respectively). Months with above average discharge tended to be isolated, except for July and August 1988 (both gages) and for July through September 1989 at the Grand Island gage.

Table 1. Normal monthly precipitation (in) at Grand Island, Nebraska, and the departure from normal for 1988 through 1992 (after National Oceanic and Atmospheric Administration 1988ab, 1989-1992).

		Departure From Normal				
Month	Normal[1]	1988	1989	1990	1991	1992
January	0.52	0.61	0.19	-0.15	0.00	0.88
February	0.81	-0.48	-0.17	-0.36	-0.75	0.55
March	1.55	-1.45	-1.14	1.45	0.24	1.40
April	2.64	-0.23	-2.55	-2.18	0.09	-1.88
May	3.70	-1.93	-1.80	0.45	2.57	-0.12
June	3.72	0.67	1.14	4.49	1.53	1.59
July	2.71	1.22	-0.51	0.93	3.03	1.96
August	2.59	0.20	0.67	0.57	-1.25	2.61
September	2.51	0.75	3.98	-1.79	-1.72	-1.49
October	1.09	-1.08	-0.15	-0.19	0.52	M[2]
November	0.80	-0.10	-0.77	0.02	0.91	0.28
December	0.67	-0.40	-0.27	0.09	1.44	M[2]
Annual	23.31	-2.22	-1.38	3.33	6.61	M[2,3]

1. Based on the 1951-80 period of record.
2. Ten or more missing daily values.
3. Annual precipitation for 1992 was at least 4.02 inches above normal.

Table 2. Mean monthly discharge (cfs) near Overton, Nebraska (USGS gage 06768000), and the percent of mean monthly discharge for water years 1988 through 1992 (data from Boohar et al. 1989-1993).

		Percent of Monthly Mean				
Month	Mean[1] Discharge	1988	1989	1990	1991	1992
October	1334	140	80	56	51	40
November	1419	144	58	53	60	65
December	1538	146	77	57	49	67
January	1616	135	96	80	63	75
February	1939	168	90	72	74	76
March	2129	121	100	75	55	110
April	1953	100	35	99	39	59
May	2300	94	19	53	56	19
June	2360	21	30	17	38	21
July	982	108	58	26	35	76
August	629	119	93	117	64	100
September	1116	91	89	47	48	38
Annual	1606	112	65	61	52	59

1. Based on water years 1942-92.

Table 3. Mean monthly discharge (cfs) near Grand Island, Nebraska (USGS gage 06770500), and the percent of mean monthly discharge for water years 1988 through 1992 (data from Boohar et al. 1989-1993).

Month	Mean[1] Discharge	Percent of Monthly Mean				
		1988	1989	1990	1991	1992
October	1189	142	85	76	41	28
November	1292	151	70	71	63	67
December	1343	128	91	54	53	71
January	1448	127	108	135	54	91
February	2032	165	83	82	76	76
March	2384	105	84	85	51	96
April	2066	93	36	91	34	61
May	2310	90	18	75	56	16
June	2364	22	41	29	59	24
July	1023	109	118	14	13	76
August	458	171	124	126	37	100
September	861	99	182	32	30	43
Annual	1560	108	74	72	50	59

1. Based on water years 1942-92.

Continuous Hydrologic and Soil Temperature Data

Continuous river stage, groundwater level, precipitation, and soil temperature data for Elm Creek, Rowe Sanctuary, and Crane Meadows for the 1992 water year are presented in Figures 9, 10, and 11 (additional water years are in Appendix B). Groundwater elevations differed between wells because the wells were located diagonally across each site (Figures 3, 4, 5), rather than along an elevational gradient. In general, the groundwater elevations mirrored the changes in river stage at all three sites. This was especially apparent during the fall season when precipitation was minor. Precipitation, however, modified this relationship between river stage and groundwater levels by temporarily elevating the groundwater level above the level that would be expected by a change in river stage alone. The larger precipitation events temporarily elevated the water table over three feet, with residual effects lasting up to two weeks. The closer the water table was to the surface before precipitation, the closer precipitation brought the water table to, or above, the surface.

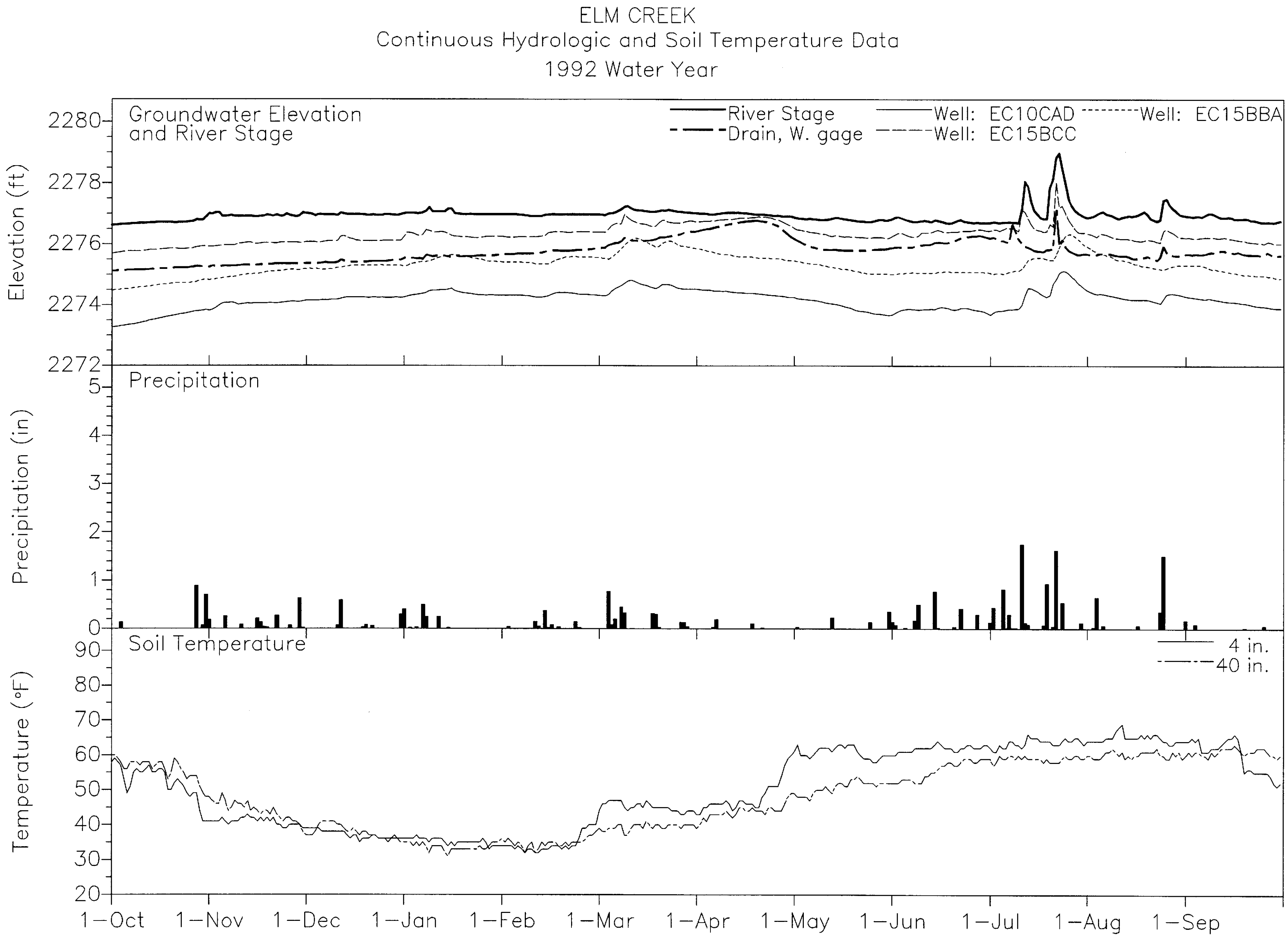


Figure 9. Elm Creek continuous hydrologic, and soil temperature data for water year 1992.

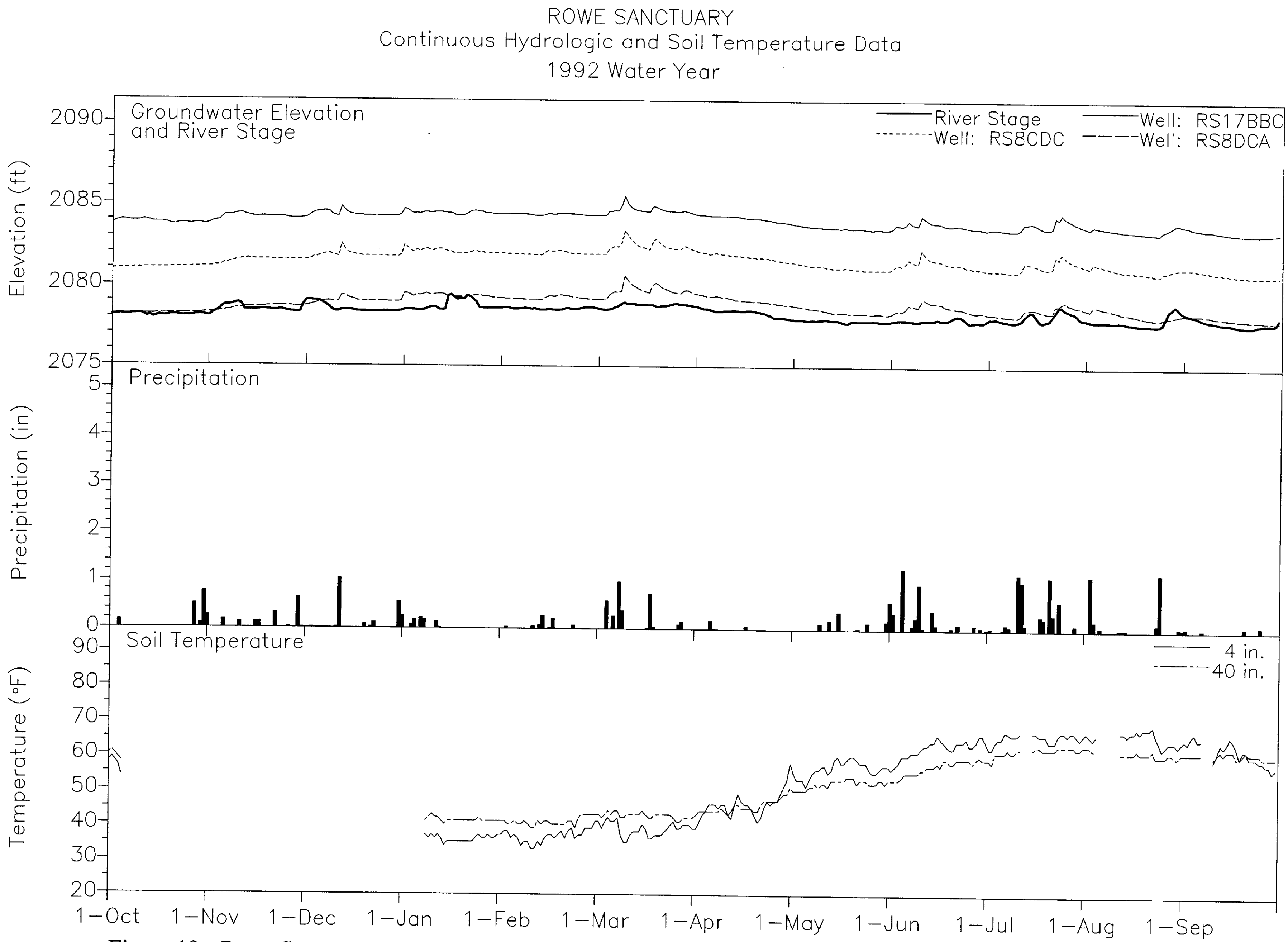


Figure 10. Rowe Sanctuary continuous hydrologic, and soil temperature data for water year 1992.

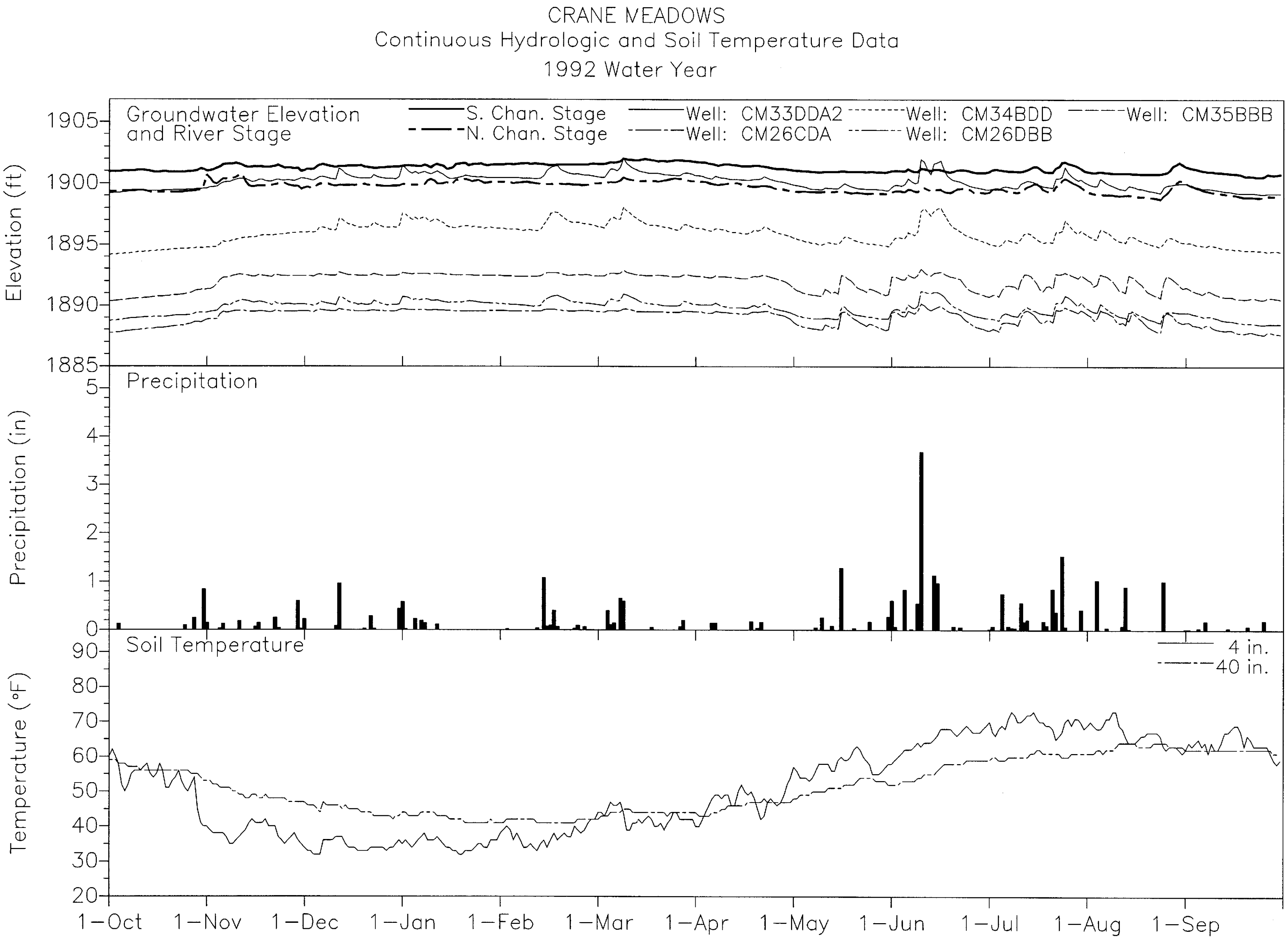


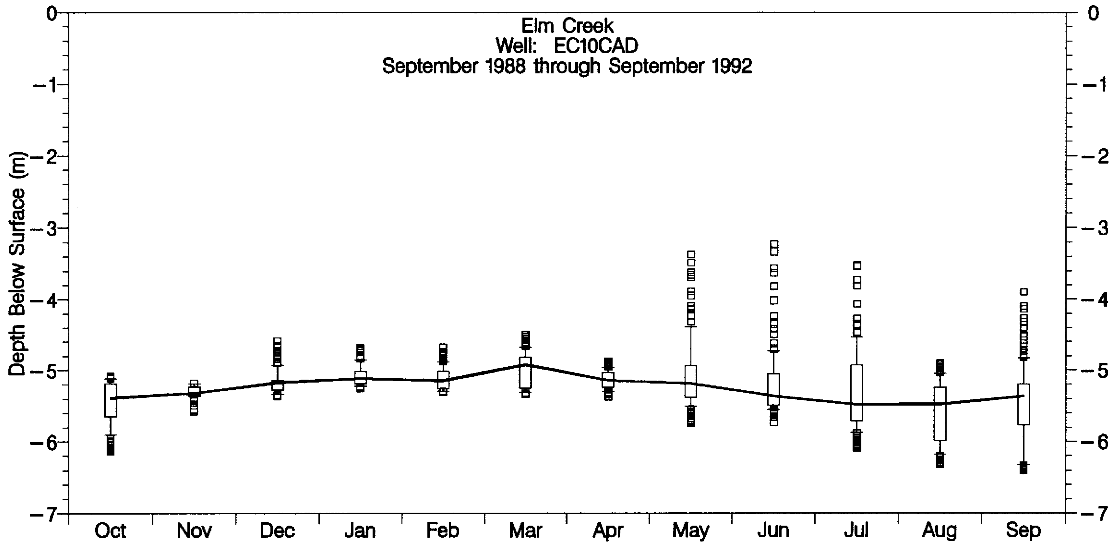
Figure 11. Crane Meadows continuous hydrologic, and soil temperature data for water year 1992.

The soil temperature thermographs at Rowe Sanctuary and Elm Creek were located in wetlands representative for their sites, while the soil temperature thermograph at Crane Meadows was located on the first terrace (approximately 5 ft) above the wet sedge meadows representative of this site. Crane Meadows, however, had the most complete record for soil temperature (Figure 11 and Appendix B). Both Elm Creek and Rowe Sanctuary had mice contaminate the chart drives during cold spells, and the 40 inch probe at Rowe Sanctuary was cut September 23, 1989, when the field was hayed. Four-inch soil temperatures were generally warmer than 40 inch soil temperatures, except from about October through March when the 40 inch soil was warmer. The 40 inch soil temperature fluctuations were generally more moderate than the 4 inch soil temperatures. The maximum mean daily 4 inch soil temperature was 83°F at Elm Creek on 1 June 1988, and the minimum mean daily 4 inch soil temperature was 21°F at Crane Meadows on 5-6 January 1989. The maximum mean daily 40 inch soil temperature was 74°F Rowe Sanctuary on 1 June 1988, and the minimum mean daily 40 inch soil temperature was 28°F at Elm Creek on 9 March 1989.

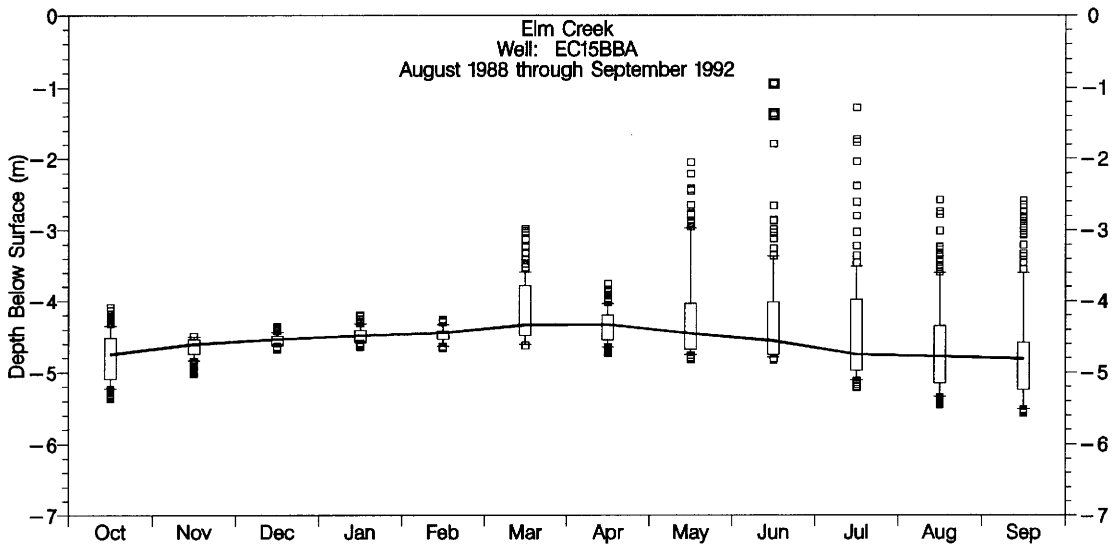
Groundwater and River Stage Hydrographs

The depth-to-groundwater and river-stage hydrographs for wells and gages with recorders at Elm Creek, Rowe Sanctuary, and Crane Meadows are presented in Figures 12, 13, and 14. Median groundwater levels typically peaked by March, and then declined through September. Recharge began in October and varied between a gradual recharge over the winter at the drier sites (Figures 13a-c and 14a-c), to a relatively rapid recharge following plant senescence in the fall at the wetter sites (Figures 14d-e). Although the peak median groundwater level typically occurred in March, some peak daily mean values were higher during the summer than during the spring (Figures 12a-c, 13a-c, and 14b-e). These peak mean daily groundwater levels were caused by intense summer thunder storms, with the groundwater usually returning to its previous level within two weeks if there were no additional precipitation events. River stage showed less variation than groundwater levels, and the

(a)



(b)



(c)

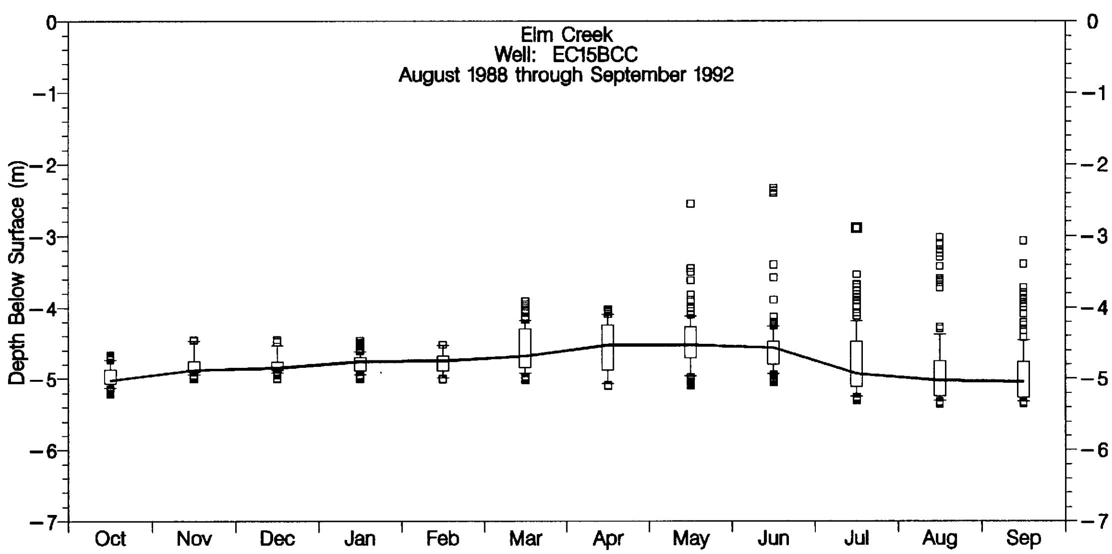
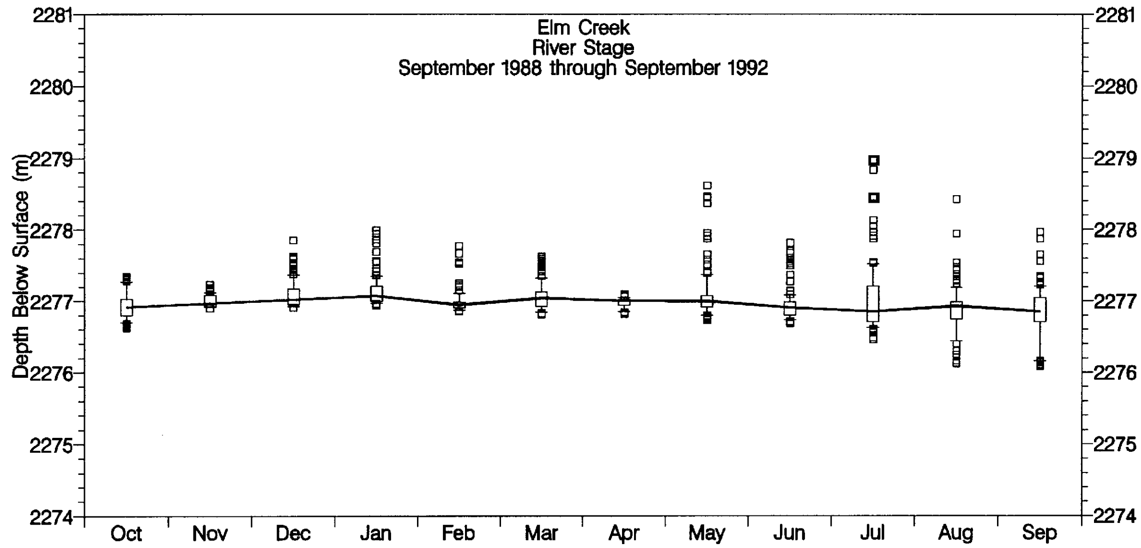


Figure 12. Elm Creek depth-to-groundwater and river-stage hydrographs for wells and gages with recorders, showing the variation within each month. (Continued next page)

(d)



(e)

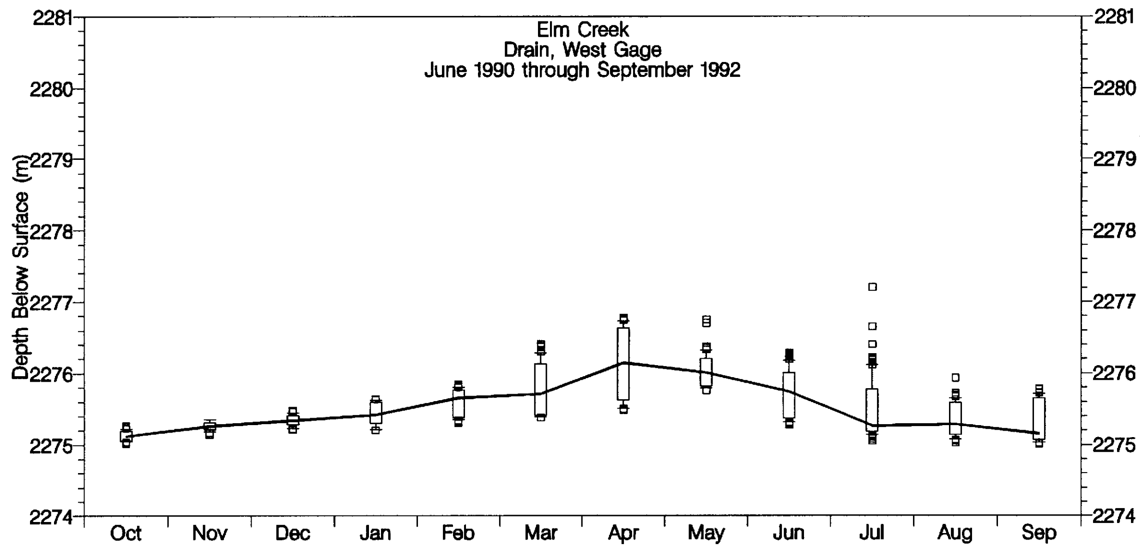


Figure 12 (continued). Mean daily values for each month were summarized with box-and-whisker plots that show the median (connected by a line through each month), the middle 50% of the observations (the box), the lower 10 to 25% and the upper 75 to 90% of the observations (the whiskers), and the lower 0 to 10% and upper 90 to 100% of the observations (individual data points).

(a)

(b)

(c)

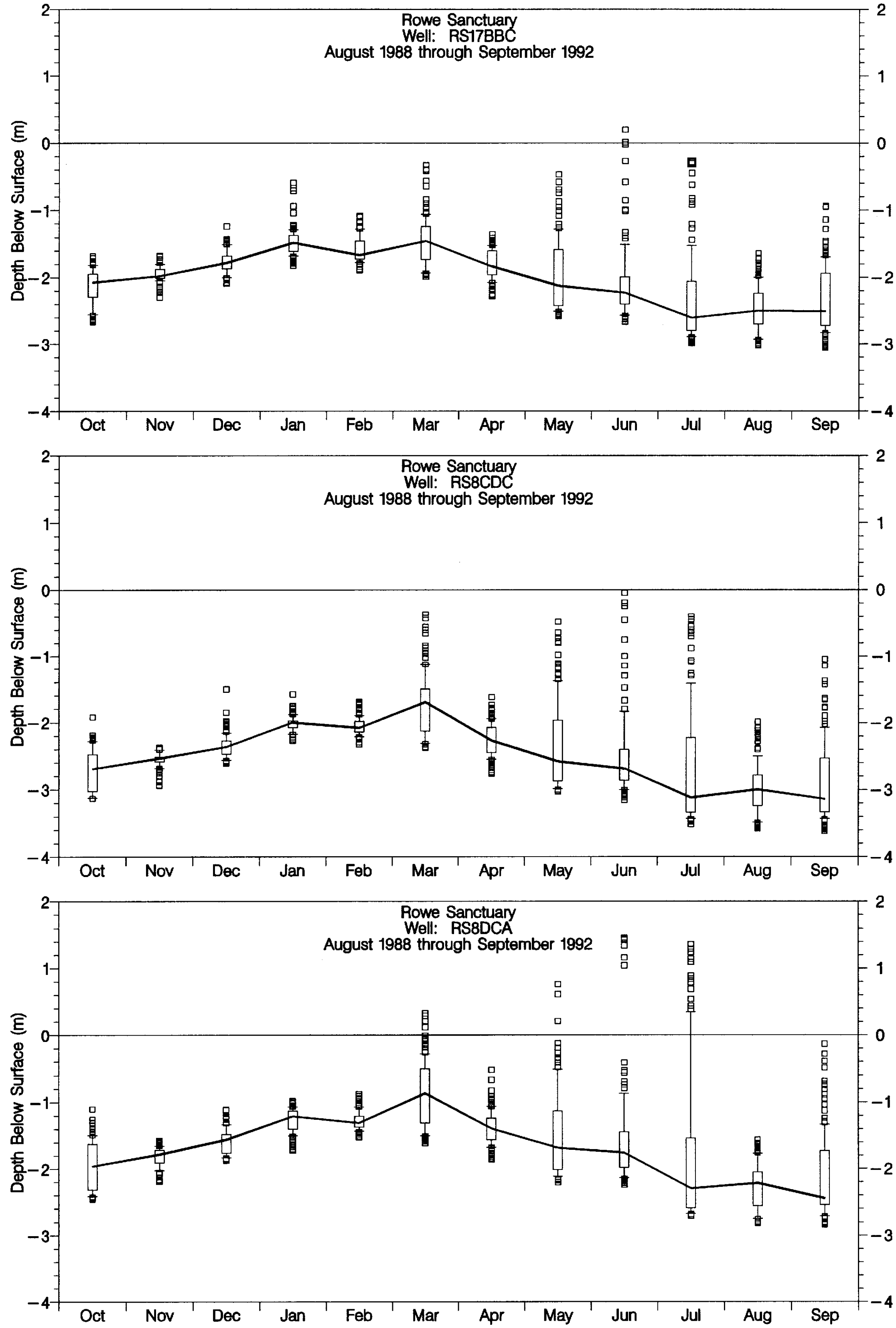


Figure 13. Rowe Sanctuary depth-to-groundwater and river-stage hydrographs for wells and gages with recorders, showing the variation within each month. (Continued next page)

(d)

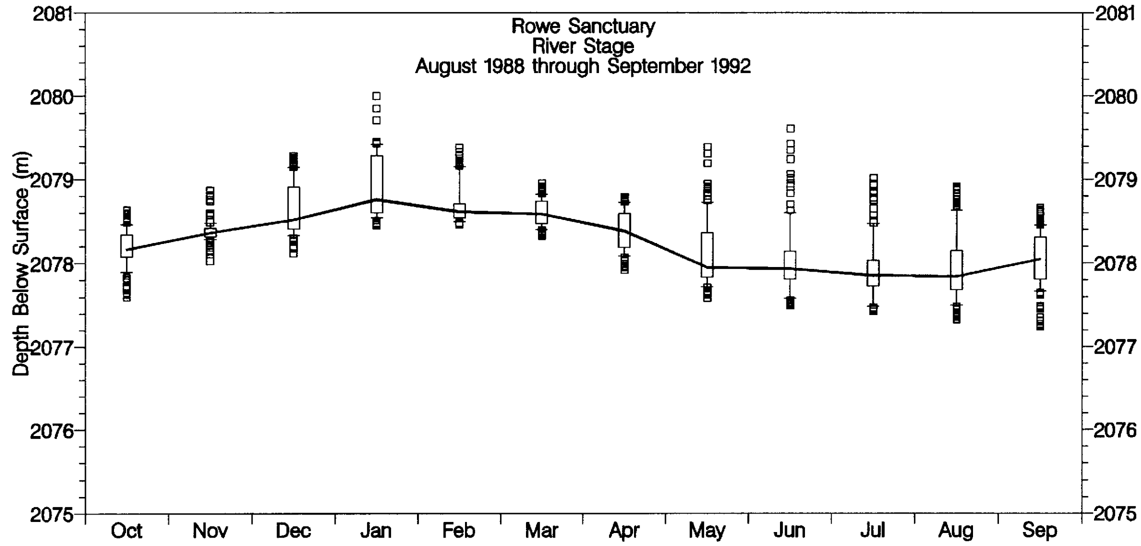


Figure 13 (continued). Mean daily values for each month were summarized with box-and-whisker plots that show the median (connected by a line through each month), the middle 50% of the observations (the box), the lower 10 to 25% and the upper 75 to 90% of the observations (the whiskers), and the lower 0 to 10% and upper 90 to 100% of the observations (individual data points).

(a)

(b)

(c)

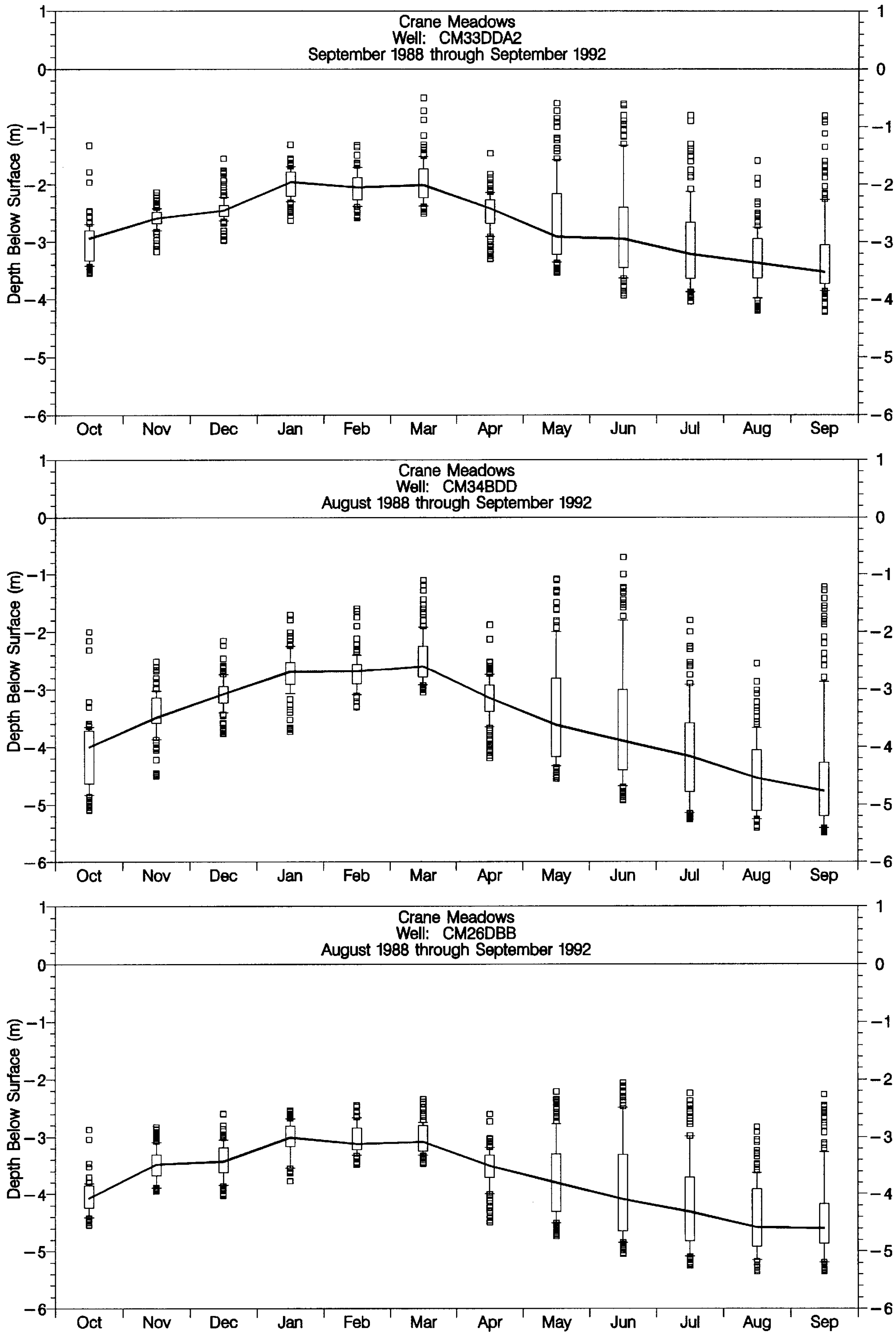
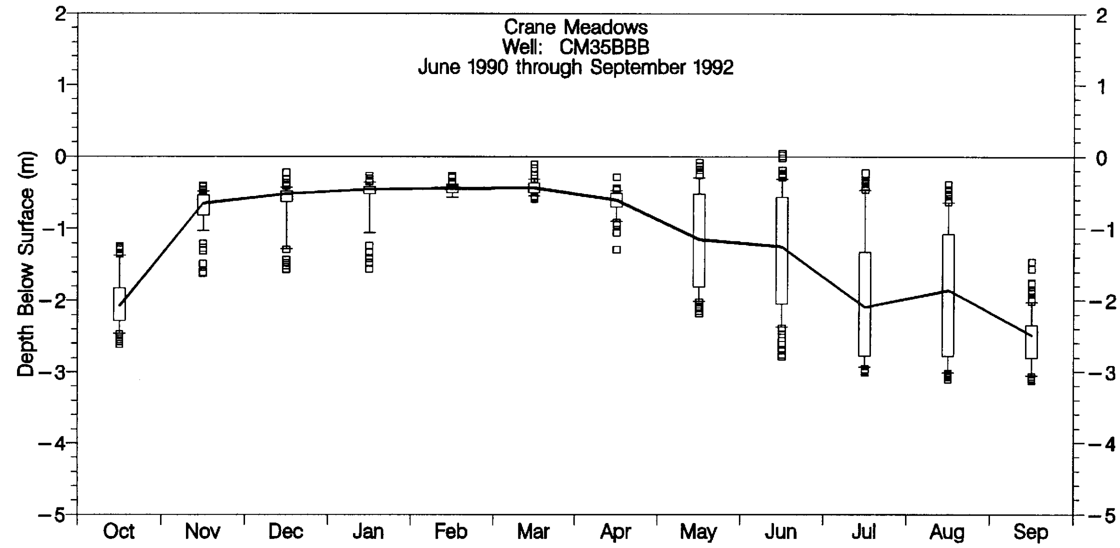
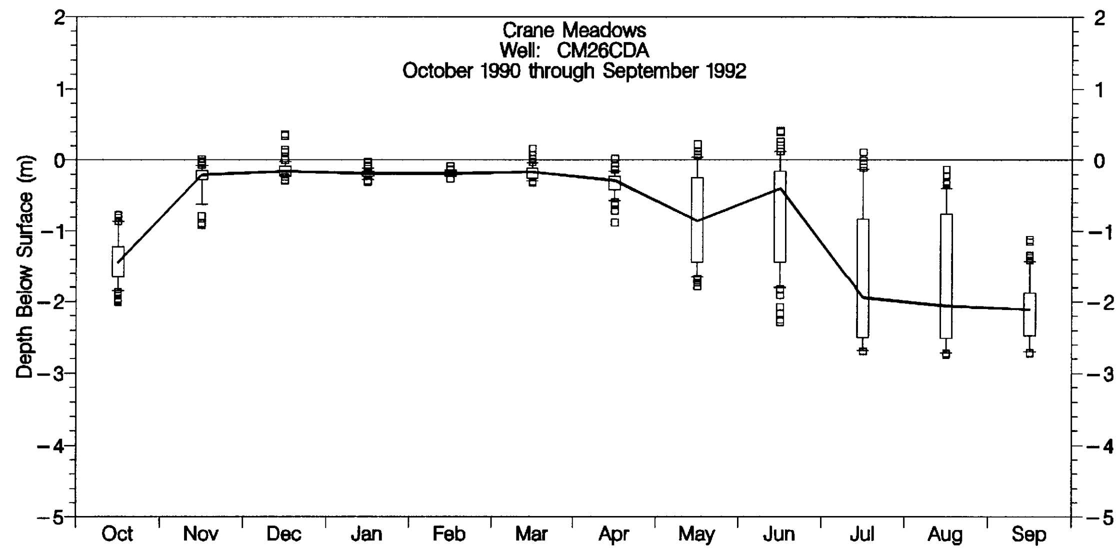


Figure 14. Crane Meadows depth-to-groundwater and river-stage hydrographs for wells and gages with recorders, showing the variation within each month. (Continued next page)

(d)



(e)



(f)

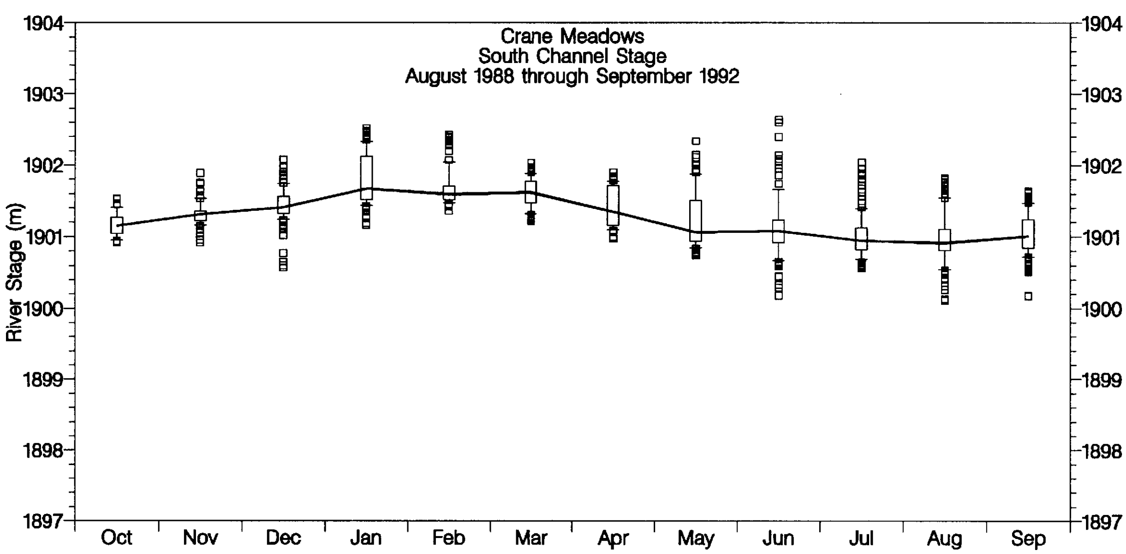


Figure 14 (continued). Mean daily values for each month were summarized with box-and-whisker plots that show the median (connected by a line (Continued next page)

(g)

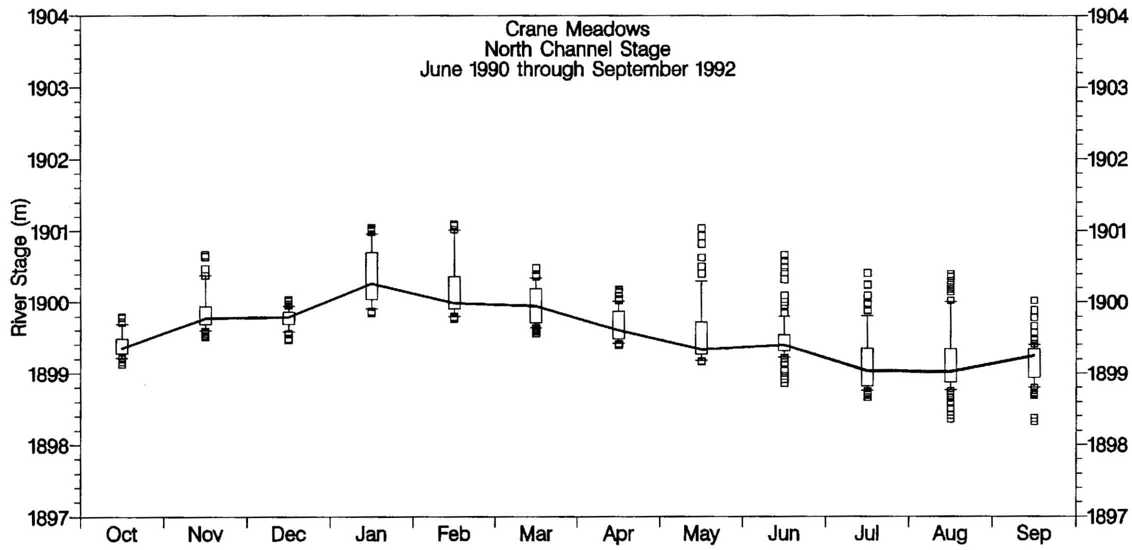


Figure 14 (continued). through each month), the middle 50% of the observations (the box), the lower 10 to 25% and the upper 75 to 90% of the observations (the whiskers), and the lower 0 to 10% and upper 90 to 100% of the observations (individual data points).

median stage typically peaked in January rather than March. This lack of variation in river stage was especially noticeable at the Elm Creek site (Figure 12d), where surface water from the Platte River only entered this channel at higher flows.

Median groundwater levels at Elm Creek (Figure 12a-c) varied less than 0.56 ft during the year, while the median groundwater levels at Rowe Sanctuary and Crane Meadows varied from 1.42 to 2.16 ft during the year. This lack of variation suggests that the groundwater drainage network in the Elm Creek area may be restricting groundwater recharge above a specific level at each well. Higher groundwater levels at Elm Creek were possible, since the response to intense precipitation during the summer was similar to the other two sites. The small Platte River channel next to the Elm Creek site occasionally had no surface water during part of July, August, and September (Figure 12d, based on an approximate river bed elevation of 2276.5 ft). The channel was dry less than 10% of the time in July, and was dry from 10 to 25% of the time during August and September. Peak median water levels in the Elm Creek drain occurred in April (Figure 12e), and then declined throughout the growing season. Since the Phelps County Canal (Figure 6) typically conveyed water from May through September, it appears that the groundwater drain at the Elm Creek site receives very little, if any, groundwater from this canal. This apparent lack of influence from the Phelps County Canal is interesting, since a water-table contour map for the spring of 1979 (Nebraska Department of Environmental Control 1980) shows a gradient from southwest to northeast in the area between the Phelps County Canal and the Elm Creek site.

The shape of the median hydrographs for the wells at Rowe Sanctuary (Figures 13a-c) and the drier wells at Crane Meadows (Figure 14a-c) were relatively similar, although the Crane Meadows wells tended to have water levels about 1 to 2 ft deeper than the Rowe Sanctuary Wells. The two wettest wells with recorders at Crane Meadows (Figure 14d-e) had median hydrographs shaped differently than the drier wells at Crane Meadows or the other two sites. Median groundwater levels at these two wells were within the 0.5 ft of the surface for 3 to 7 months per year from November through June, and within 1.0 ft of the surface for 6 to

8 months per year from November through June. Although the groundwater level was 1 to 2 ft higher at these two wells during the growing season compared to the drier wells, it may be possible that the plant communities at these two wells were defined by the 6 to 8 months of median groundwater levels within 1.0 ft of the surface rather than the growing season groundwater levels. The hydrographs at Rowe Sanctuary (Figure 13a-c) support this idea since they are relatively similar to the two wetter wells at Crane Meadows during the growing season, yet the plant communities at the Crane Meadows wells are more water tolerant than the plant communities at the Rowe Sanctuary wells.

Depth-to-Groundwater and River Stage Duration Curves

Depth-to-groundwater and river stage duration curves for Elm Creek, Rowe Sanctuary, and Crane Meadows are presented in Figures 15 through 17. Groundwater levels were adjusted to depths below the surface on the left axis, while river stage is shown as an elevation above sea level on the right axis. Duration curves are cumulative frequency distributions that show the percent of time a specific depth or stage was equaled or above that level. These curves do not represent the actual sequence of events, but they are especially useful for identifying maximum and minimum levels, as well as the frequency a particular level was equaled or maintained above that level. The curves should also be useful for differentiating between plant communities with different hydrology. For example wells CM26CDA and CM35BBB were in much wetter plant communities than the other three wells at Crane Meadows (Figures 17). The major drawback for this type of analysis, however, is that it requires intensive sampling to determine daily means for the period of record. The longer the period of record, the more representative the curves will be.

Elm Creek was the driest of the three study sites. No wells equipped with recorders had their mean daily water level above the surface during the 1989-92 water years (Figure 15a), and the mean daily groundwater depths were never above 0.5 ft below the surface. The highest mean daily groundwater level at Elm Creek during this period was

(a)
(b)
(c)

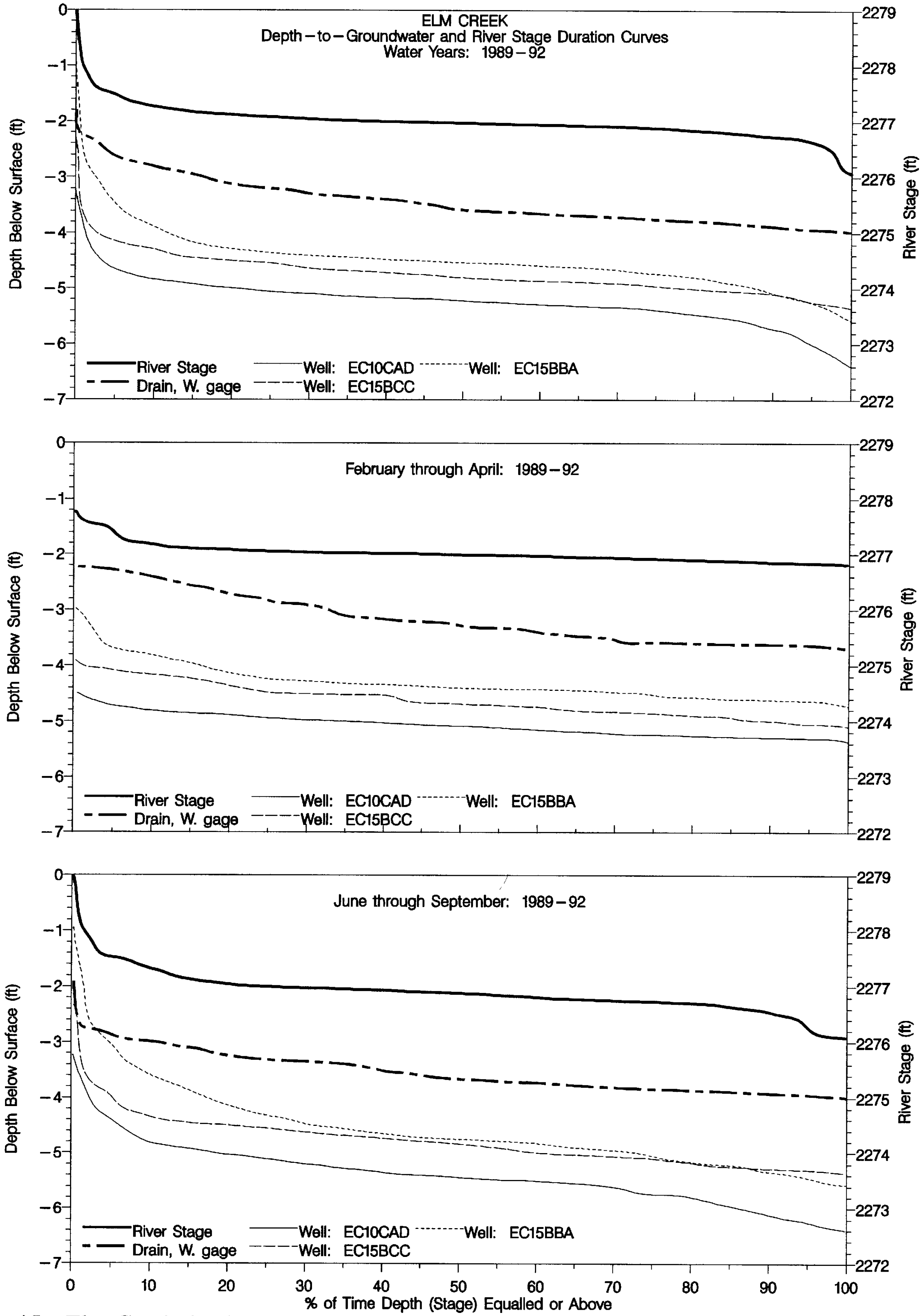


Figure 15. Elm Creek depth-to-groundwater and river stage duration curves for the period specified. See text for explanation.

(a)

(b)

(c)

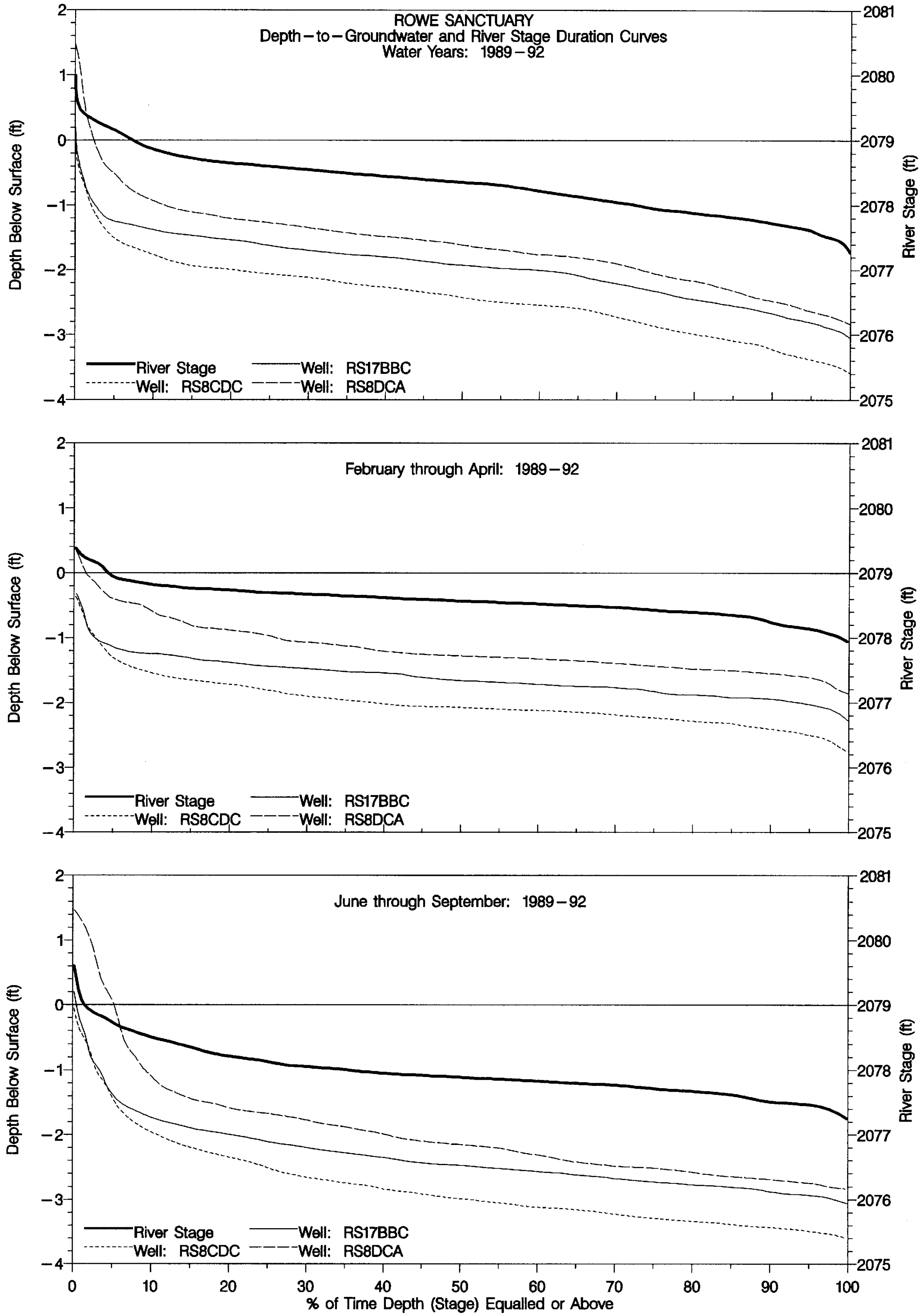


Figure 16. Rowe Sanctuary depth-to-groundwater and river stage duration curves for the period specified. See text for explanation.

(a)
(b)
(c)

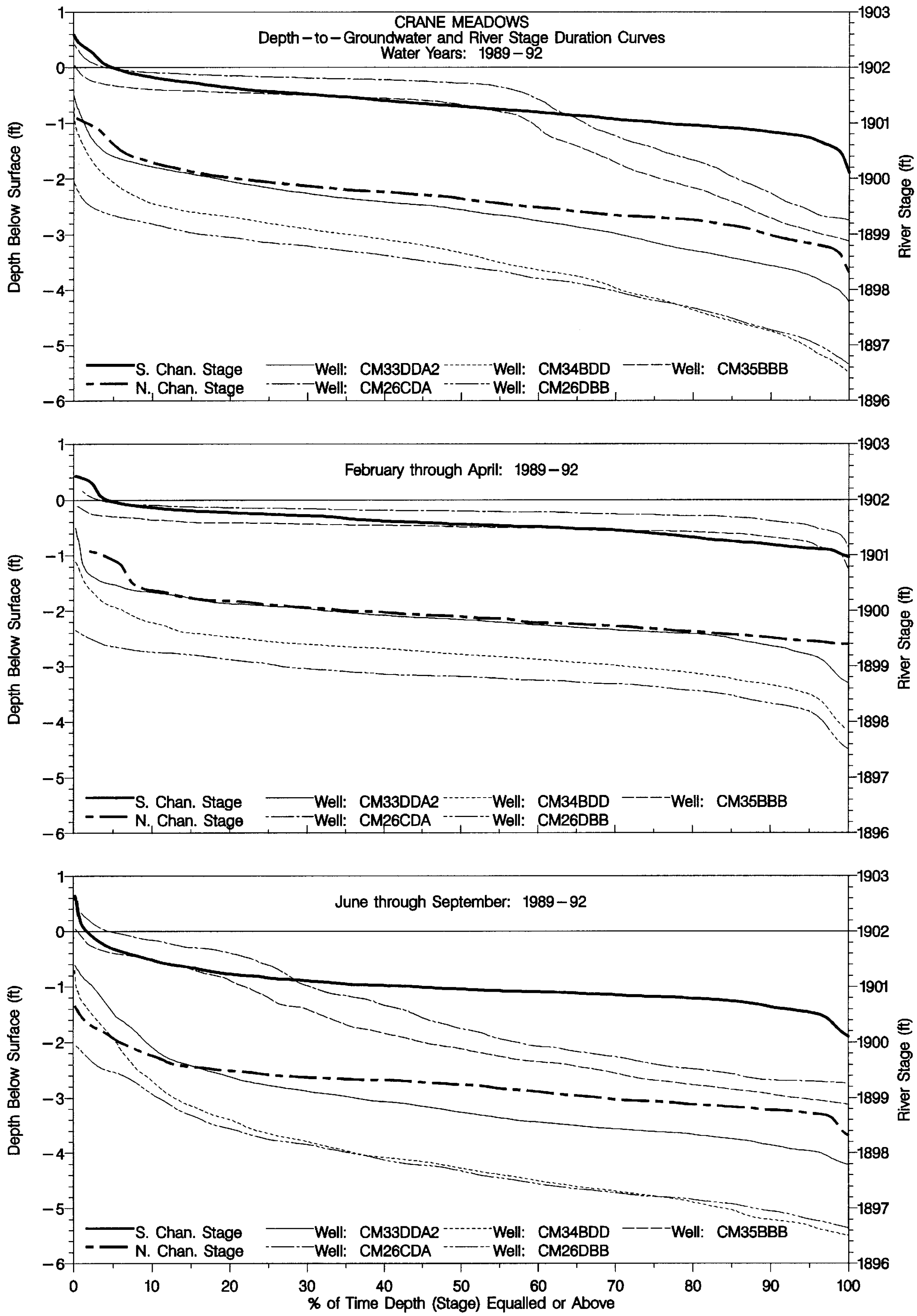


Figure 17. Crane Meadows depth-to-groundwater and river stage duration curves for the period specified. See text for explanation.

-0.94 ft (well EC15BBA), and the deepest mean daily groundwater level was -6.40 ft (well EC10CAD). Predictably the June through September groundwater levels were deeper than the February through April groundwater levels for 50 and 90% of the time (D_{50} and D_{90}). The 0 to 5% of the time ($D_{<5}$) groundwater levels for June through September were closer to the surface than for February through June, however. These short periods of elevated groundwater were caused by intense summer thunderstorms and can also be seen on the hydrographs for this period (Figures 9 and 12). The most change in the $D_{<5}$ range occurred in the well farthest from either the river or the drain (well EC15BBA). Mean daily river stage ranged from 2276.08 to 2278.97 ft above mean sea level for the 1989-92 water years (Figure 15a). The groundwater drain recorder was installed by June 1990, so the time periods for this gage include the 1990-92 for June through September period, and the 1991-92 water years and February through April period. Mean daily stage for the drain ranged from 2275.02 to 2277.20 ft for the 1991-92 water years, and had a more linear shape to its duration curve than the river stage or the three wells. Streams (or drains) fed primarily by groundwater typically have more constant flows than streams fed by other sources. The small Platte River channel at Elm Creek was also fed by a groundwater drain, and it appears that the Platte River stage was high enough to enter this channel only about 10% of the time. About 10% of the time the small Platte River channel next to the Elm Creek site had no surface water during June through September (Figure 15c, based on an approximate river bed elevation of 2276.5 ft). From the hydrograph for this period (Figure 12d), it appears that these periods of no flow occurred with increasing frequency from July though September.

Rowe Sanctuary (Figure 16) had the highest mean daily level of standing water (1.46 ft) observed for any well equipped with a recorder during the study. The natural drainage for this well (RS8DCA) was blocked by a low road embankment, however, so this relatively deep standing water may not be natural for this location. In general, however, the groundwater levels observed at Rowe Sanctuary were intermediate between the drier site at Elm Creek and the wettest sites at Crane Meadows. Mean daily water levels were above the surface for two of the three wells (Figure 16a), and occurred more often during the summer (up to 5%, Figure 16c) than in the spring (up to 1%, Figure 16b). From June through September the mean daily groundwater levels were within 0.5 ft of the surface for less than 2% of the time for the two wells with a natural drainage pattern (RS17BBC and RS8CDC, Figure 16c), while from February through April groundwater levels were within 0.5 ft of the surface for less than 1% of the time (Figure 16b). The maximum mean daily groundwater depth for the three wells was -3.61 ft (well RS8CDC), and the minimum depth was 1.46 ft (i.e., 1.46 ft above the surface for well RS8DCA). June through September mean daily groundwater levels were about one foot deeper than the February through April groundwater levels for all groundwater durations greater than about D_{10}. Like Elm Creek, the shorter duration groundwater levels ($D_{<5}$) were primarily caused by intense summer thunderstorms. Mean daily river stage at Rowe Sanctuary ranged from 2077.24 to 2080.00 ft above mean sea level for the 1989-92 water years (Figure 16).

Crane Meadows (Figure 17) had recorders on two wells in the wettest area of the study, and on wells in sites similar to Elm Creek and Rowe Sanctuary. Recorders were installed on the two wettest wells by June (well CM35BBB) and October (well CM26CDA) of 1990, so the time periods for these wells include the 1990-92 (well CM35BBB) or 1991-92 (well CM26CDA) time for June through September, and the 1991-92 water years and the February through April period (both wells). The North Channel stage recorder was also installed after the study began (by June 1990), and included the same time periods as well CM35BBB. Mean daily water levels were above the surface for two of the five wells (Figure 17a), and occurred more often during the summer (up to 4.5%, Figure 17c) than in the spring (up to 3.4%, Figure 17b). In contrast to Elm Creek and Rowe Sanctuary, the two wettest wells at Crane Meadows had mean daily groundwater levels within 0.5 ft of the surface more often from February through April (56 to 95%) than from June through September (10 to 23%). These two wells also had hydrographs similar to the hydrographs for the wells in Group 1 (Figure 5, Figure 14d-e, and Figure 71a-d). Group 1 was located in an area where the endangered prairie white-fringed orchid (*Platanthera praeclara* Sheviak and Bowles) has been observed. Mean daily groundwater depths were never above 0.5 ft below the surface for the other three wells equipped with continuous recorders. The maximum mean daily groundwater depth for the two wettest wells was -3.12 ft (well CM35BBB) and the minimum depth was 0.41 ft (i.e., 0.41 ft above the surface for well CM26CDA), while the maximum mean daily groundwater depth for the three drier wells was -5.49 ft (well CM34BDD) and the minimum mean daily groundwater depth was -0.50 ft (well CM33DDA2). June through September mean daily groundwater levels were about 1.5 ft deeper than the February through April groundwater levels for all groundwater durations greater than about D_{50}. Like Elm Creek and Rowe Sanctuary, the shorter duration groundwater levels ($D_{<5}$) were primarily caused by intense summer thunderstorms, but the short-term elevated water levels are more easily distinguished on the hydrographs (Figure 14) rather than on the duration curves (Figure 17c). Mean daily river stage for the South Channel ranged from 1900.11 to 1902.64 ft above mean sea level for the 1989-92 water years (Figure 17a). The North Channel stage mirrored the South Channel stage, but was about 1.5 ft lower in elevation. Most of this difference in elevation between the North and South Channel stage is because the North Channel gage was located down valley from the South Channel gage (Figure 5).

River Stage and River Flow Relationships

River stage (elevation) and river flow (discharge $\equiv$ Q) relationships for Elm Creek, Rowe Sanctuary, and Crane Meadows are presented in Figures 18 through 20. These 'stage-discharge' relationships can be used to estimate the river flow for a specific river stage at each site. We used river stage instead of river flow for our analyses, because groundwater levels are more precisely defined by the stage of the river. These figures, therefore, provide a way to relate river stage to river flow.

All three regression models were highly significant as well as their parameters ($p \leq 0.0001$). The coefficient of determination for Elm Creek ($r^2 = 0.37$), however, was

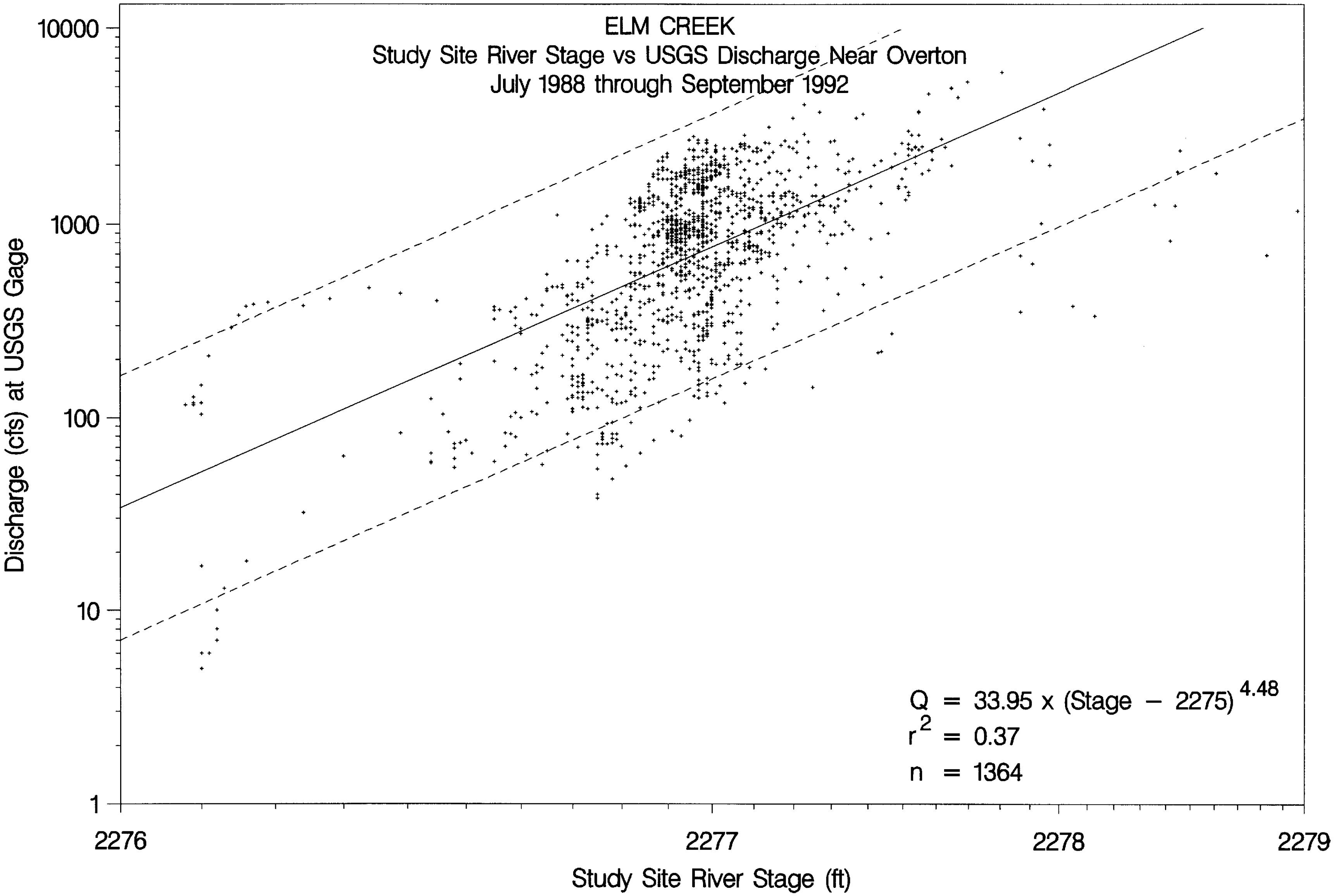


Figure 18. Elm Creek stage-discharge relationship with the USGS gage near Overton, NE.

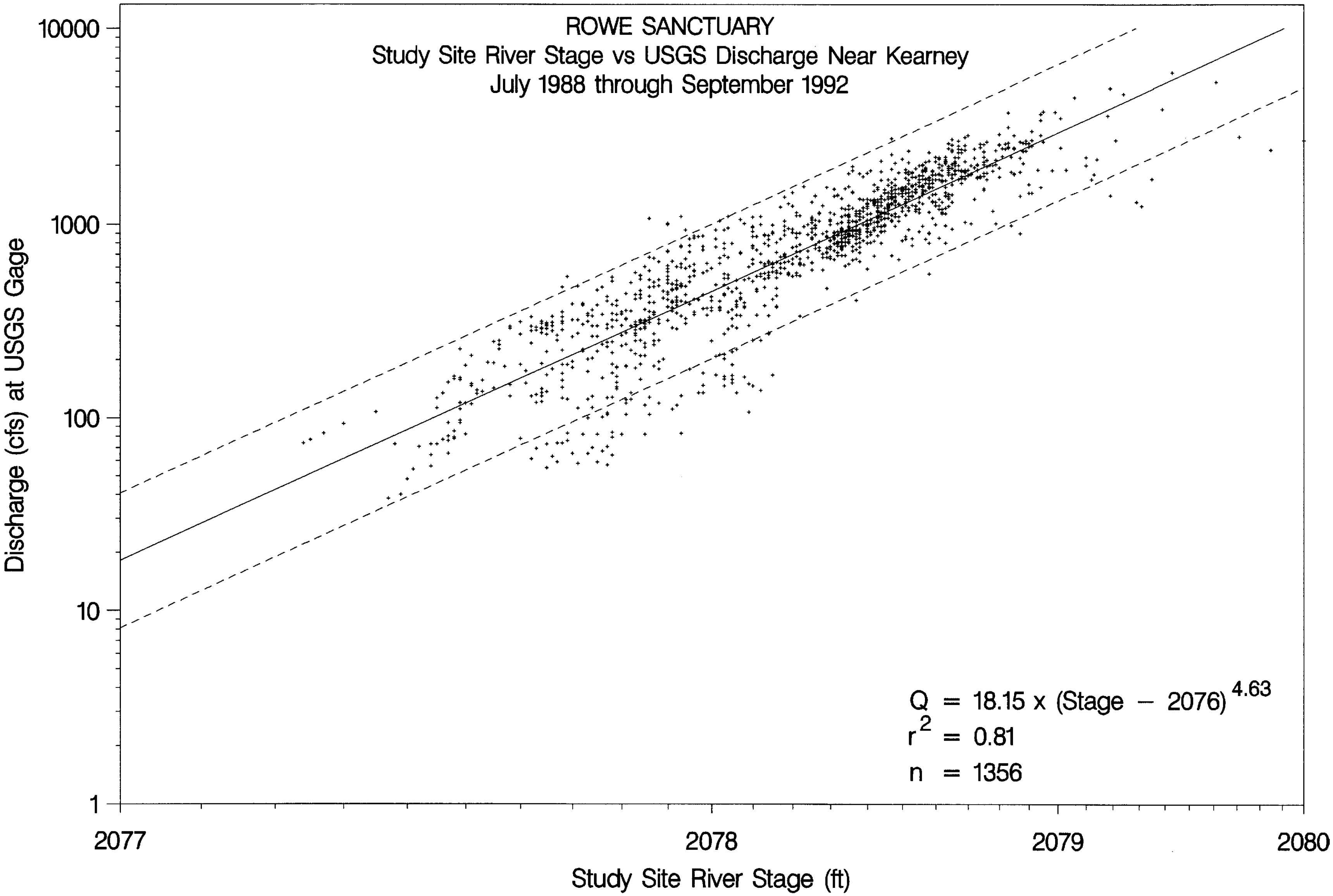


Figure 19. Rowe Sanctuary stage-discharge relationship with the USGS gage near Kearney, NE.

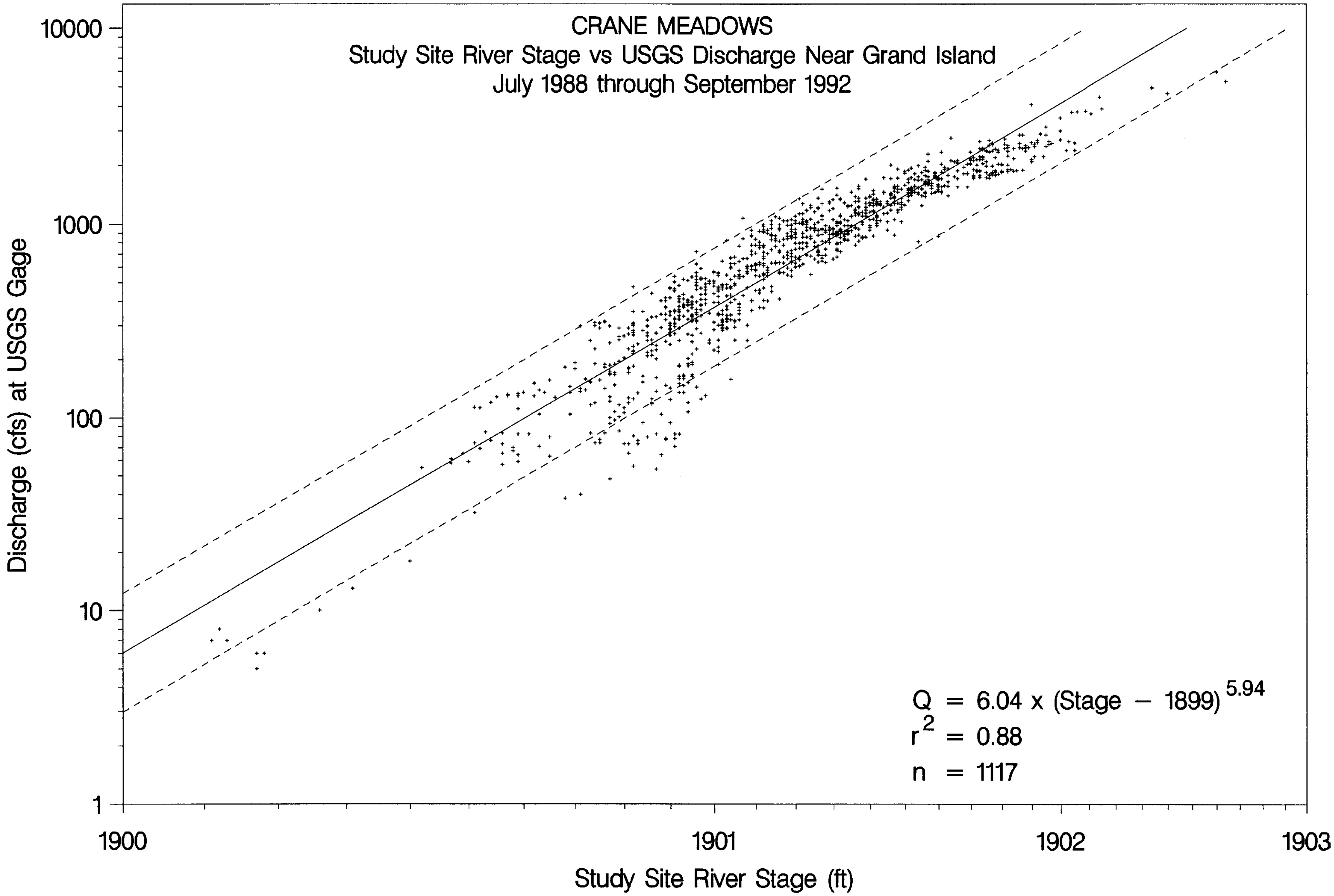


Figure 20. Crane Meadows stage-discharge relationship between the south channel gage at Crane Meadows and the USGS gage near Grand Island, NE.

rather poor. The coefficient of determination is used to estimate the amount of variation explained by the regression equation, with a value of 0 explaining very little and a value of 1 explaining nearly all the variation. Values for r^2 typically range from 0.95 to 0.99 for most stage-discharge relationships where there is a stable streambed. Considering the unstable nature of the sandy Platte River bed and that the river stage was measured several miles (9 to 11 mi) from where the discharge was measured, the relationships for Rowe Sanctuary (r^2 = 0.81) and Crane Meadows (r^2 = 0.88) were considered reasonably good. The 95% confidence belts are probably too conservative for most environmental predictions, but they do provide a good indication of the range of values. Confidence belts based on lower levels (e.g., 80%) would produce narrower belts about the regression line.

The poor relationship between the river stage at Elm Creek and the USGS gage near Overton (Figure 18) was not unexpected, since the river channel for the Elm Creek gage was fed primarily by a groundwater drain. Water from the Platte River entered this channel only at high flows. The Platte River flow necessary to enter this Elm Creek channel does not appear consistent, however, since there was no distinct break in the distribution of data (Figure 18).

Cross-Valley Transects

Cross-valley transects for each study site are presented in Figures 21 through 23. Figures 21a, 22a, and 23a depict groundwater levels within the vicinity of each site for selected dates, while Figures 21b, 22b, and 23b highlight the transect at each site for these groundwater levels. Note that these figures are oriented so that the observer is looking down valley, and that the transects run from north to south along section lines (Figures 6 through 8). Since these transects are not perpendicular to the river, the north side of each transect appears lower in elevation than the south side. The transects at Rowe Sanctuary (Figure 22) and Crane Meadows (Figure 23) are particularly affected by this orientation, since the river bends more at these two sites than at Elm Creek. When comparing groundwater gradients with the River, this orientation must be considered. Groundwater gradients should be judged in relation to the

(a)

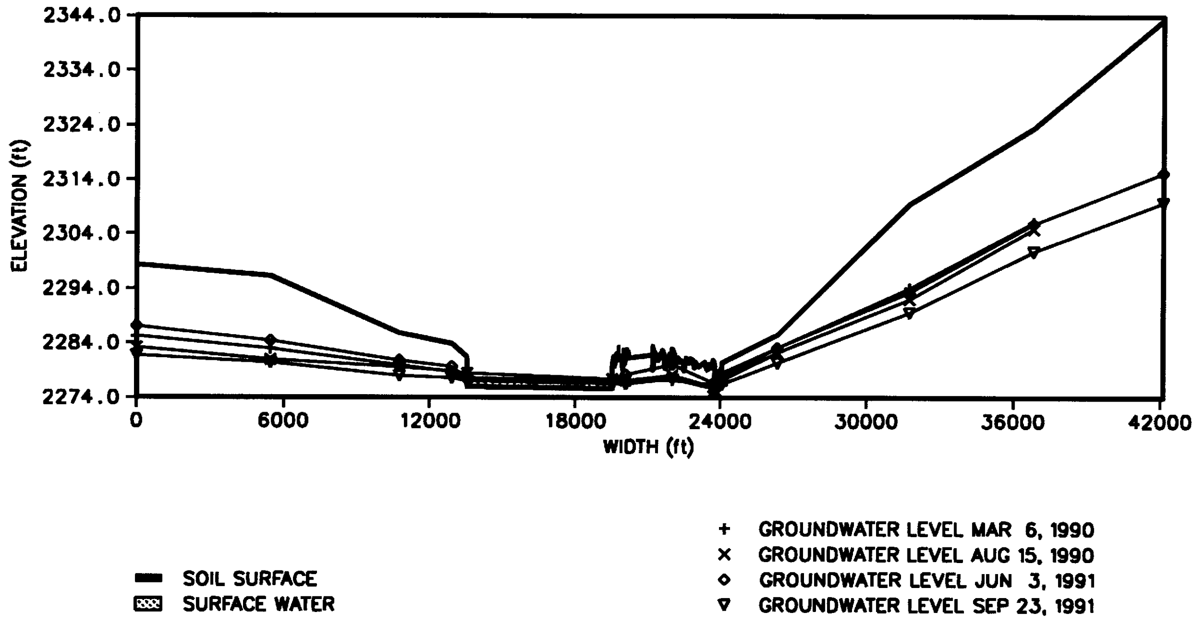


Figure 21. The Elm Creek cross-valley transect with selected groundwater profiles, showing the entire transect (a) and highlighting the transect at the study area (b). (Continued)

(b)

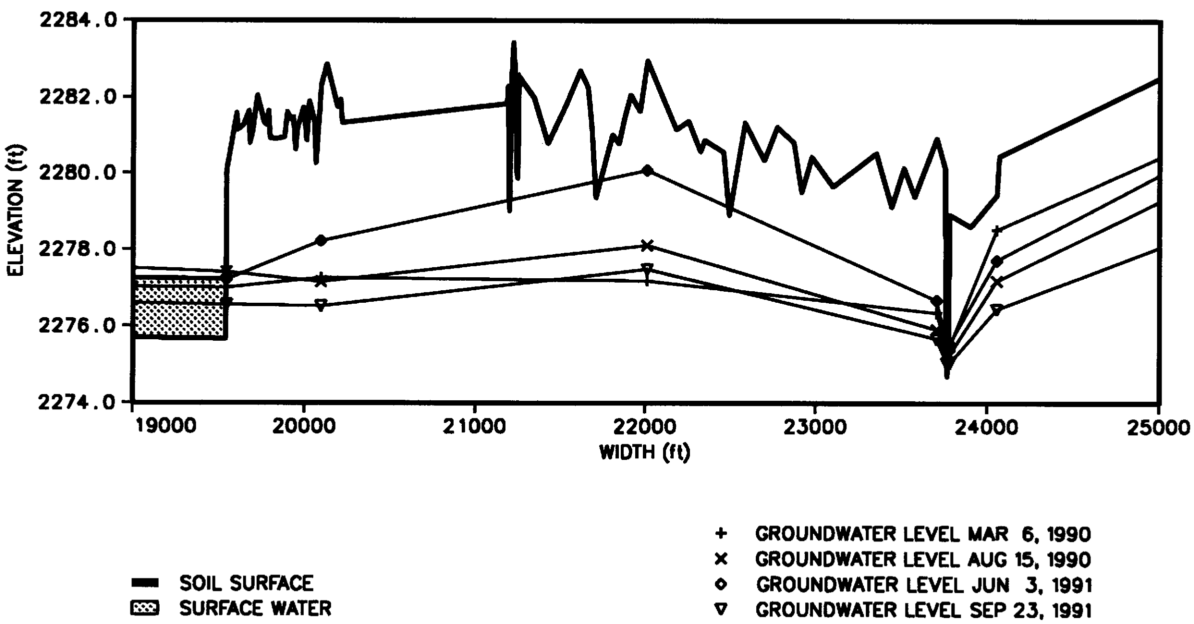


Figure 21 (continued). Dates were selected to represent typical groundwater profiles next to the Elm Creek site when the lowest (September 23, 1991) and highest (June 3, 1991) periodic measurements were observed at the site, and a median (approximately D_{50}) groundwater profile for the spring (March 6, 1990) and summer (August 15, 1990) seasons. Note the location of the groundwater drain at 23,770 ft.

(a)

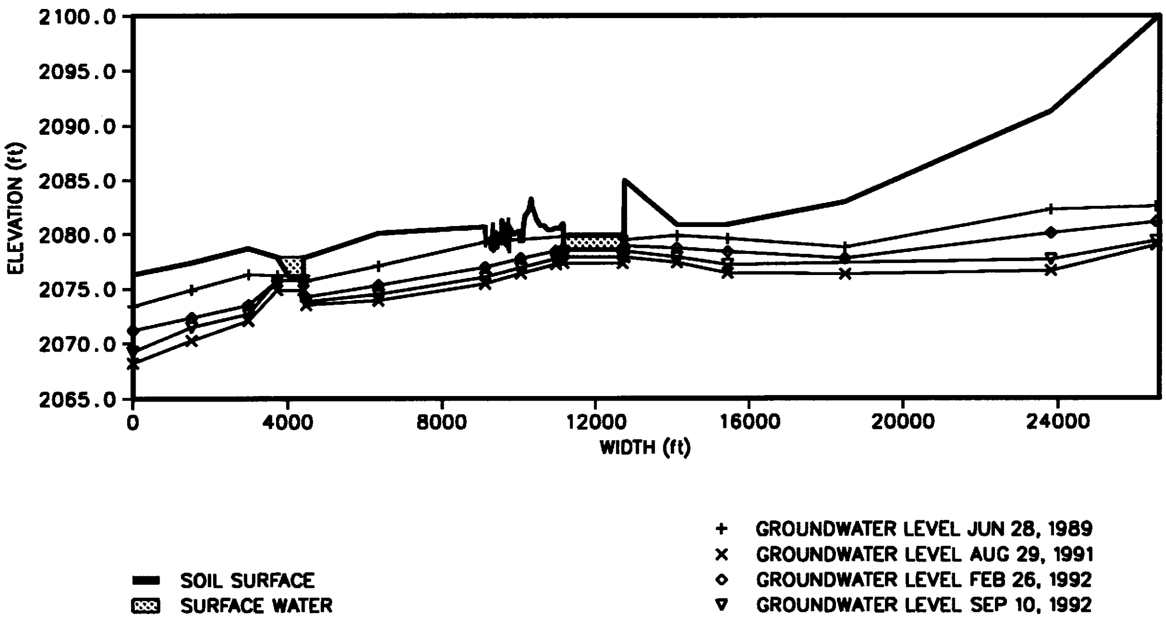


Figure 22. The Rowe Sanctuary cross-valley transect with selected groundwater profiles, showing the entire transect (a) and highlighting the transect at the study area (b). (Continued)

(b)

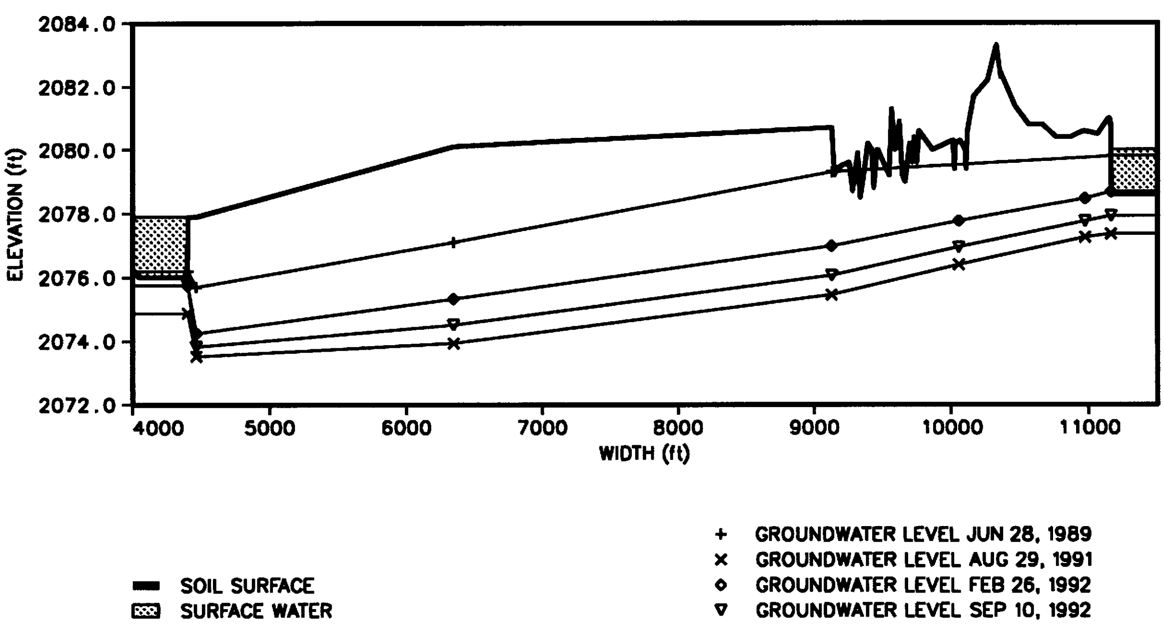


Figure 22 (continued). Dates were selected to represent typical groundwater profiles next to the Rowe Sanctuary site when the lowest (August 29, 1991) and highest (June 28, 1989) periodic measurements were observed at the site, and a median (approximately D_{50}) groundwater profile for the spring (February 26, 1992) and summer (September 10,1992) seasons.

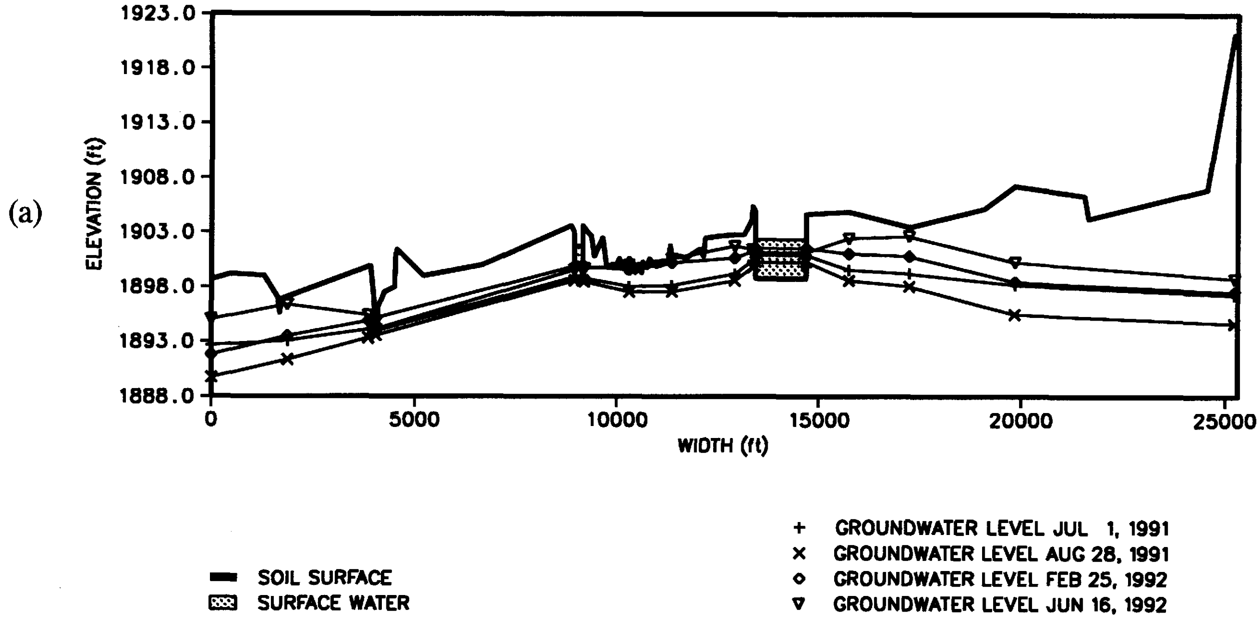


Figure 23. The Crane Meadows cross-valley transect with selected groundwater profiles, showing the entire transect (a) and highlighting the transect at the study area (b). (Continued)

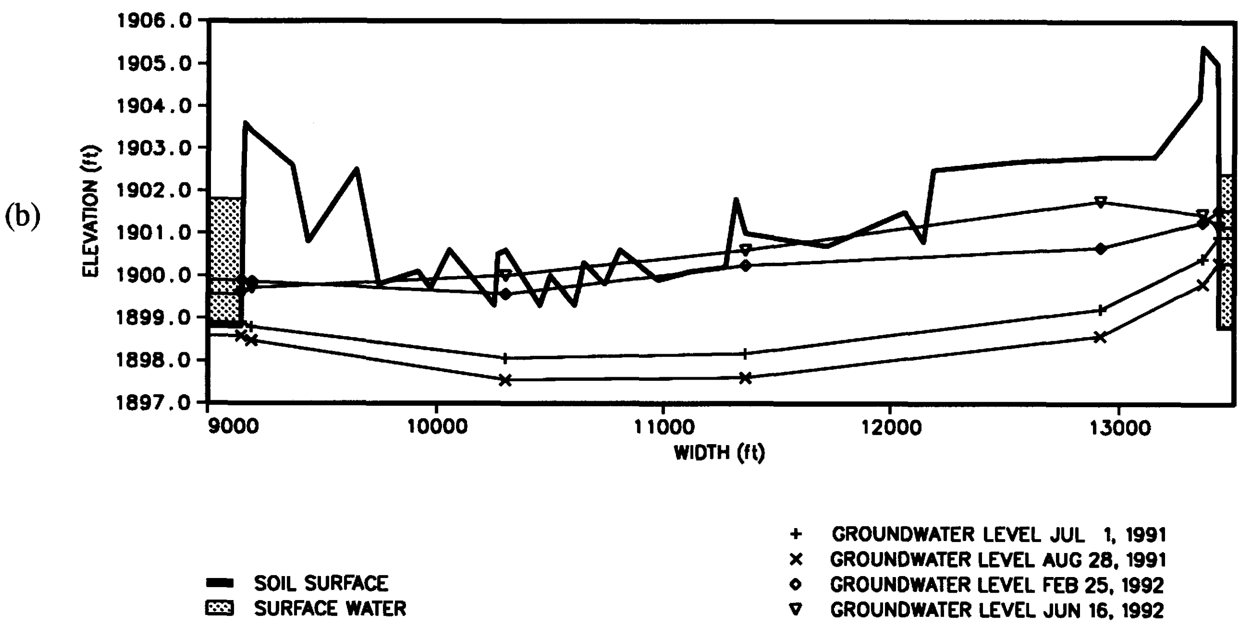


Figure 23 (continued). Dates were selected to represent typical groundwater profiles next to the Crane Meadows site when the lowest (August 28, 1991) and highest (June 16, 1992) periodic measurements were observed at the site, and a median (approximately D_{50}) groundwater profile for the spring (February 25, 1992) and summer (July 1, 1991) seasons.

surface profile, rather than in absolute elevations. The groundwater profiles within the vicinity of the Elm Creek site show a steep gradient toward the River from the south, and a moderate gradient toward the river from the north (Figure 21). The Elm Creek transect was nearly perpendicular to the Platte River (Figure 6), so these profiles more accurately depict the groundwater gradient near the Elm Creek site than the gradients at Rowe Sanctuary or Crane Meadows. Within the Elm Creek study site three swales apparently intercept the peak water table, and the groundwater drain (at 23,770 ft) intercepts the water table for all levels observed (Figure 21b). Peak groundwater levels flow from the center of the study site toward either the groundwater drain or the River, and also follow this pattern for most other groundwater levels. The groundwater contours in the next section, however, suggests that the groundwater flows from the River toward the groundwater drain for most of the year, except following intense precipitation events that produce the peak groundwater levels. A surveying error, corrected for this report, showed a relatively flat groundwater gradient between the Platte River and the groundwater drain (Wesche et al. 1990).

The groundwater profiles within the vicinity of the Rowe Sanctuary site are difficult to interpret (Figure 22), since the cross-valley transect was not perpendicular to the River. It does appear, however, that there may be a fairly flat gradient on either side of the River if the difference between the surface profile and the groundwater profile is used to at least partially offset the effects of a slanted transect. There was a groundwater drain next to well 8-14-20ADD (18,491 ft) that may have intercepted some of the groundwater flowing from the south for at least the higher groundwater levels. Peak groundwater levels were apparently intercepted by several swales within the study site, but most of the time the water table was at least a foot below the deepest swales.

The groundwater profiles within the vicinity of the Crane Meadows site are also difficult to interpret (Figure 23), since the cross-valley transect was not perpendicular to the River. It does appear, however, that there is a gradient flowing from the River toward the south, and possibly the north, when the difference between the surface profile and the groundwater profile is used to at least partially offset the effects of a slanted transect. The water table contours south of the Platte River near the Crane Meadows site also indicate a gradient flowing away from the River (Nebraska Department of Environmental Control 1980). Several swales within the study area apparently intercepted the peak and median spring groundwater levels (Figure 23b), while the rest of the year the water table was about one to two feet below the deepest swales. The summertime groundwater profiles show a gradient from the Platte River channels toward the center of the island, suggesting that some factor (such as evapotranspiration or loss to a deeper aquifer) may be depressing the water table below the level that would be expected. This depression in the center of Crane Meadows during the summer can also be seen on the groundwater contours presented in the next section.

Groundwater was intercepted by the Wild Rose slough throughout the year (Figure 24). A staff gage was installed in the slough and the Platte River channel to establish a transect between these points through well CM33ABD. Since the bottom of the Wild Rose slough is approximately 0.8 ft below the bed of the Platte River Channel at this location, there was a consistent groundwater gradient from the channel toward the slough. Note also that the water level in the slough varied less than the water level in the Platte River channel, which is characteristic of many groundwater-fed streams. Another characteristic of groundwater-fed streams that the Wild Rose slough shares, is that the water temperature is moderated by the water flowing from the ground. This was particularly noticeable in the winter because the Wild Rose slough seldom, if ever, froze.

Hydrographs for selected transect wells at Elm Creek, Rowe Sanctuary, and Crane Meadows are presented in Figures 25 through 27. Wells are labeled in the legend so that they are listed from north to south along the transect. The hydrographs show that water levels near the Platte River tend to fluctuate around a constant mean, while the groundwater levels away from the River appear to be declining with time. This decline is especially apparent south of the River at all three sites (e.g., wells 8-19-27BBB, 8-19-27CCC, and 8-19-34CCC at Elm Creek), and to a lesser extent for wells located north of the River at Rowe Sanctuary (well

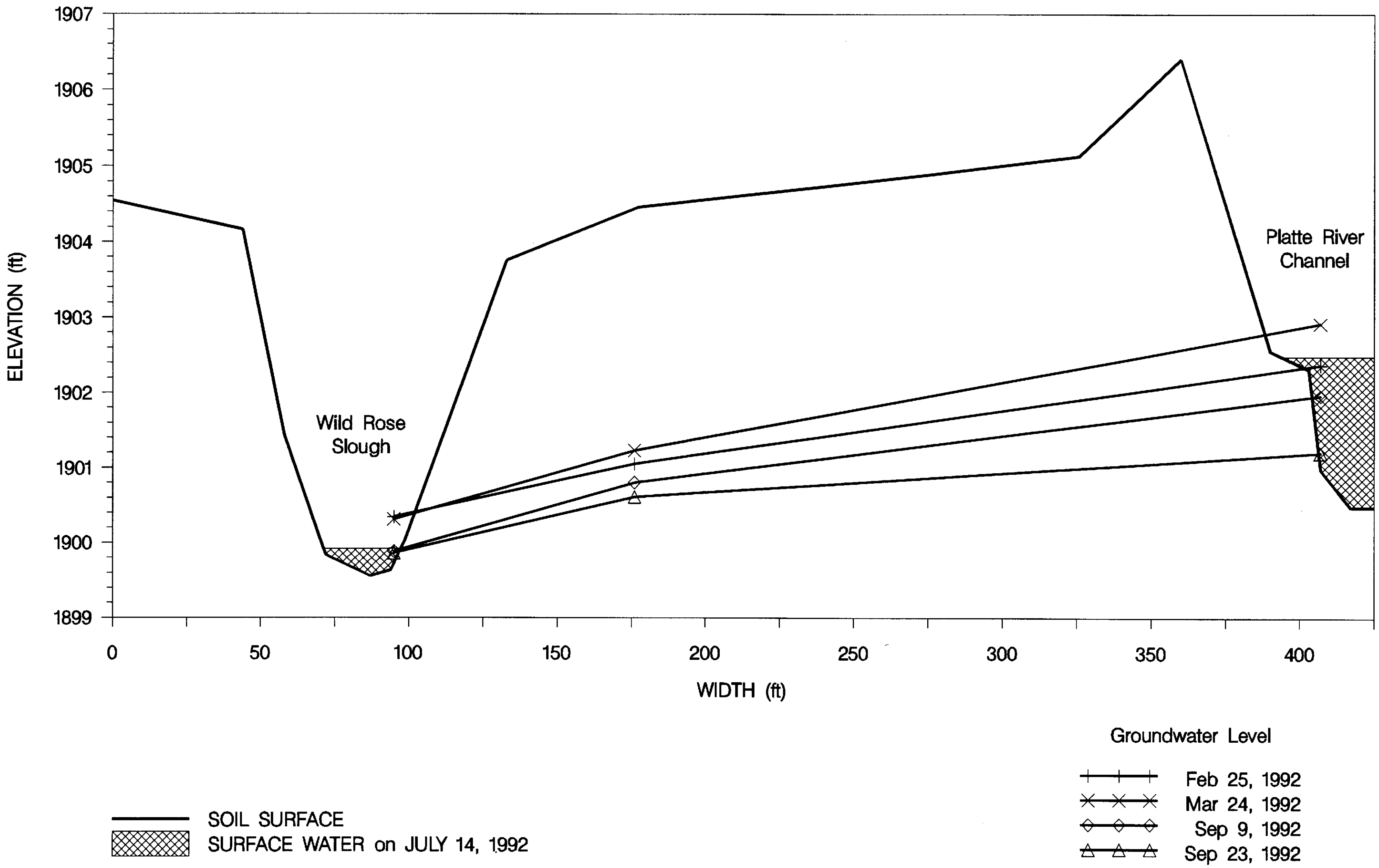


Figure 24. A cross-section profile, looking downstream, at the Wild Rose slough, well CM33ABD, and a Platte River channel. Dates were selected to represent the lowest (September 23, 1992) and highest (March 24, 1992) periodic measurements in 1992, and a typical median (approximately D_{50}) groundwater profile for the spring (February 25, 1992) and summer (September 9, 1992) seasons at Crane Meadows.

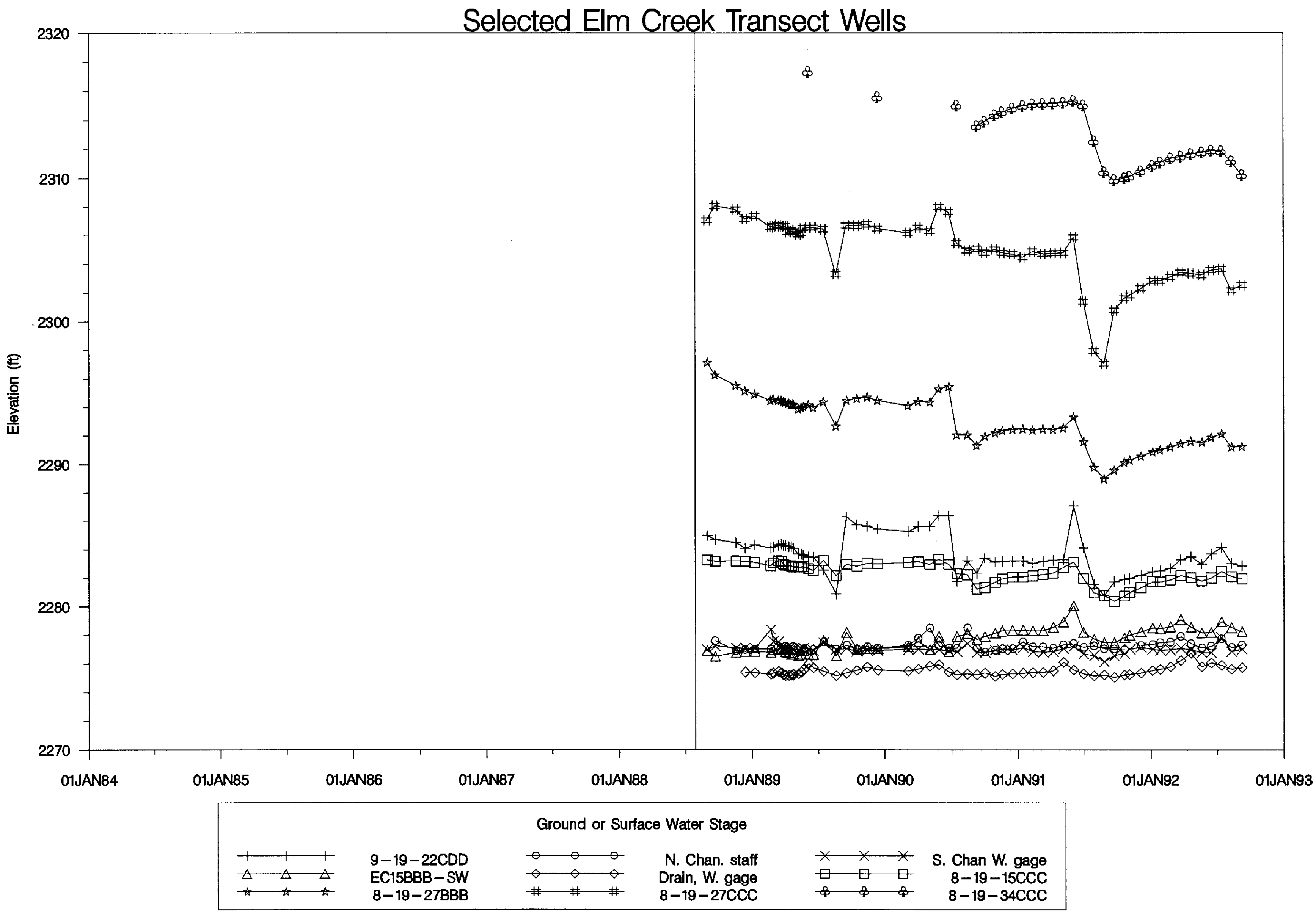


Figure 25. Hydrographs for selected Elm Creek transect wells for the period of record. Data for the Platte River Wetland Hydrology Study at Elm Creek was first collected on 28 July 1988 (vertical line).

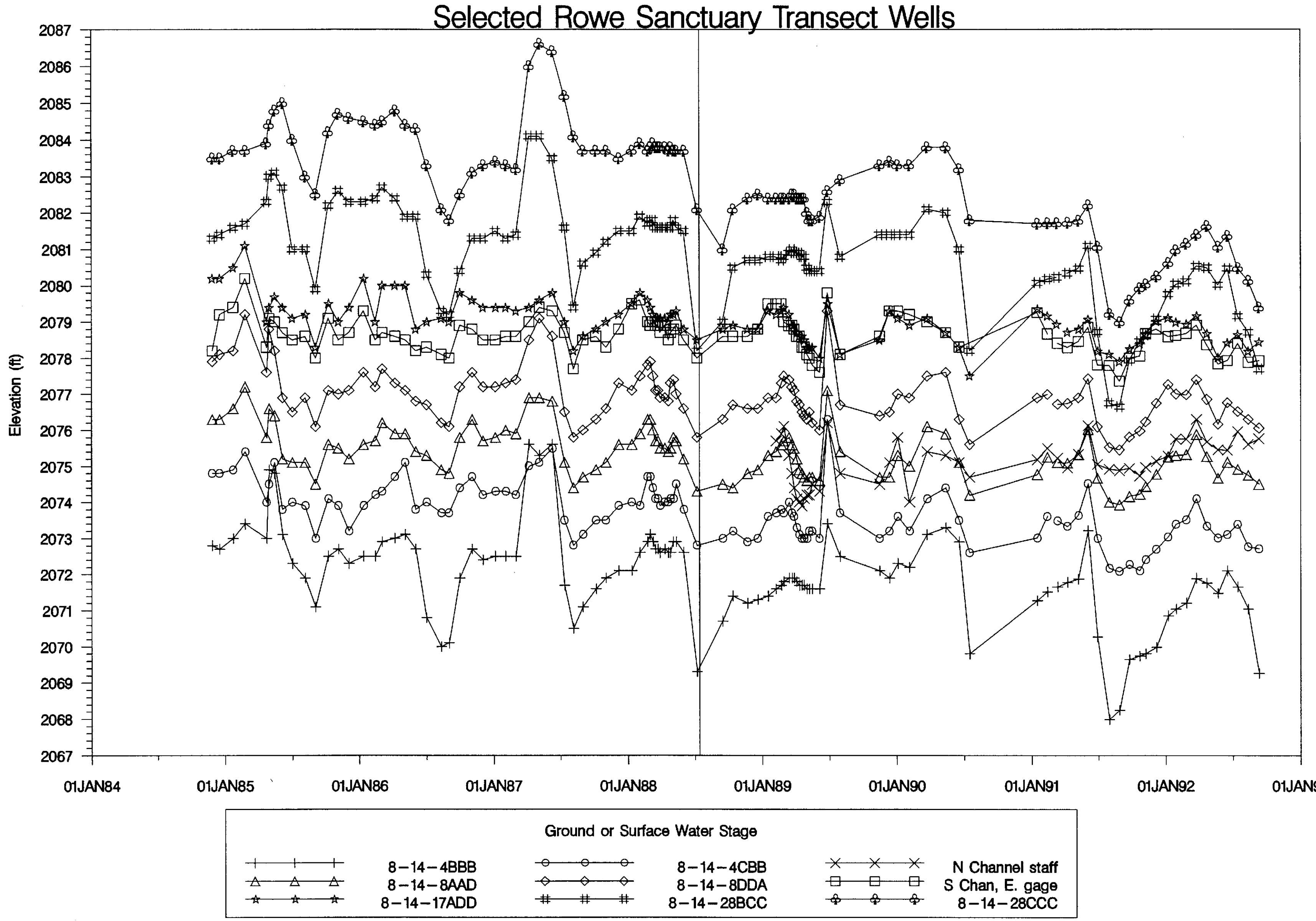


Figure 26. Hydrographs for selected Rowe Sanctuary transect wells for the period of record. Data for the Platte River Wetland Hydrology Study at Rowe Sanctuary was first collected on 13 July 1988 (vertical line).

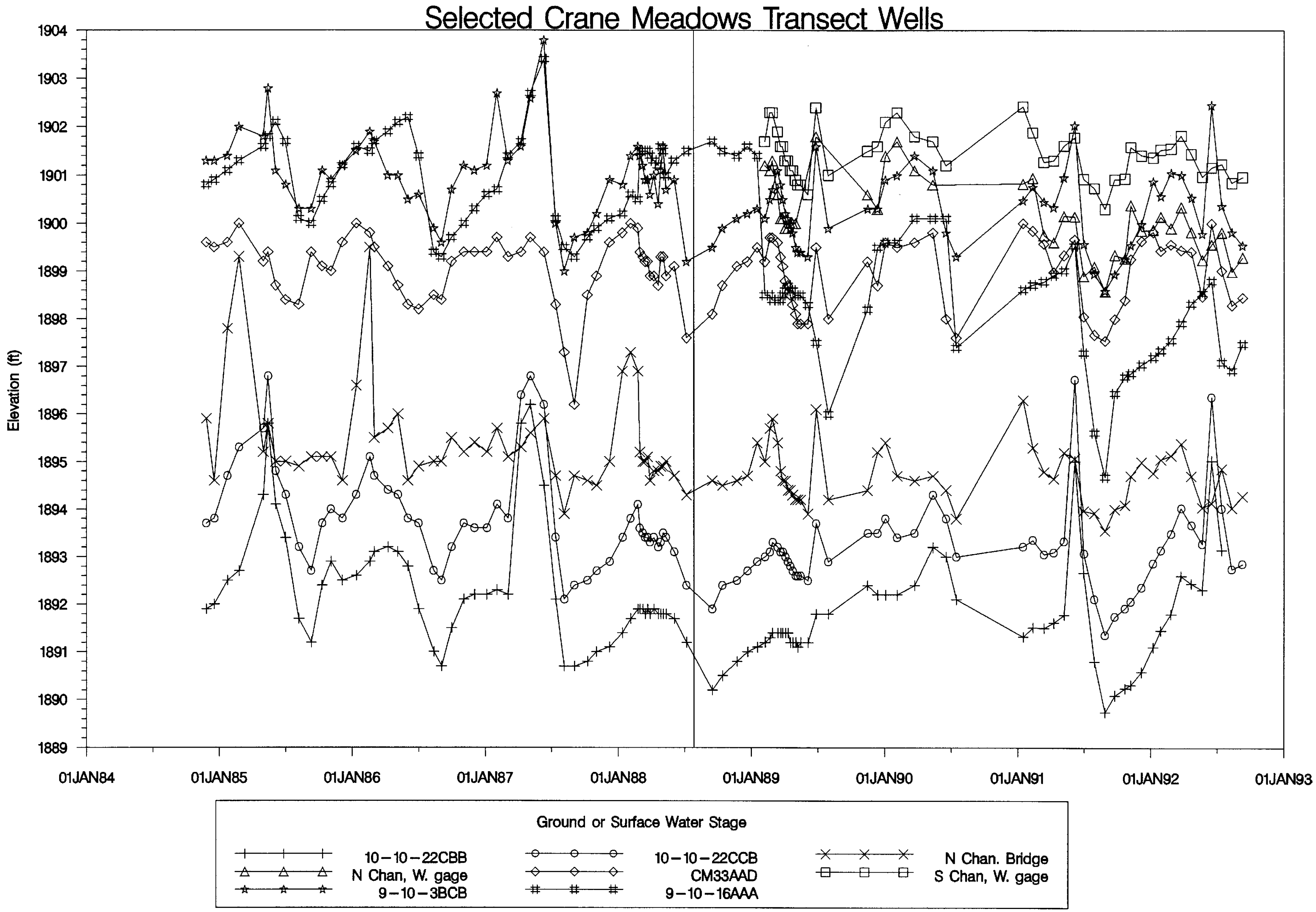


Figure 27. Hydrographs for selected Crane Meadows transect wells for the period of record. Data for the Platte River Wetland Hydrology Study at Crane Meadows was first collected on 27 July 1988 (vertical line).

8-14-4BBB) and Crane Meadows (well 9-10-16AAA). A detailed analysis of this decline was beyond the scope of our study, but it appears that the Platte River was maintaining groundwater levels within its immediate influence, while the surrounding aquifer was declining. Well 9-19-22CDD at Elm Creek had an additional response worth noting. The water table at this well was elevated above the normal winter levels during the winter of 1989-90 following an unusual amount (5.28 in) of precipitation from 21 August 89 to 19 September 1989 (Figure 25).

Groundwater-Level Contours

Groundwater-level contour maps eliminate the orientation problem that occurred in the previous section with two-dimensional cross-valley transects. When possible, the same date shown for the lowest, highest, and median spring and summer cross-valley transect groundwater levels was also used for the groundwater-level contours. When a date differed, it was because the date chosen for the groundwater-level contours had more wells measured in the well grid, or there was a more even distribution between depth-to-groundwater level durations for the well grid. Although the dates may have differed for the specified groundwater level at a site, the contour shape and position was always similar among dates for the specified groundwater level.

The contour maps for Elm Creek showing dates representing the lowest and highest observed periodic measurements, and approximating a median water level for the spring and summer seasons are presented in (Figures 28 through 31). Except for high water levels (e.g., Figure 29), the general direction for the groundwater gradient at Elm Creek was down valley and slightly toward the groundwater drain (Figures 28, 30, and 31). This suggests that the drain intercepts groundwater from the Platte River as well as groundwater from south of the drain. Note that a surveying error, corrected for this report, initially showed the general direction for the groundwater gradient at Elm Creek to be down-valley with little or no component toward the groundwater drain (Wesche et al. 1990). High groundwater levels at

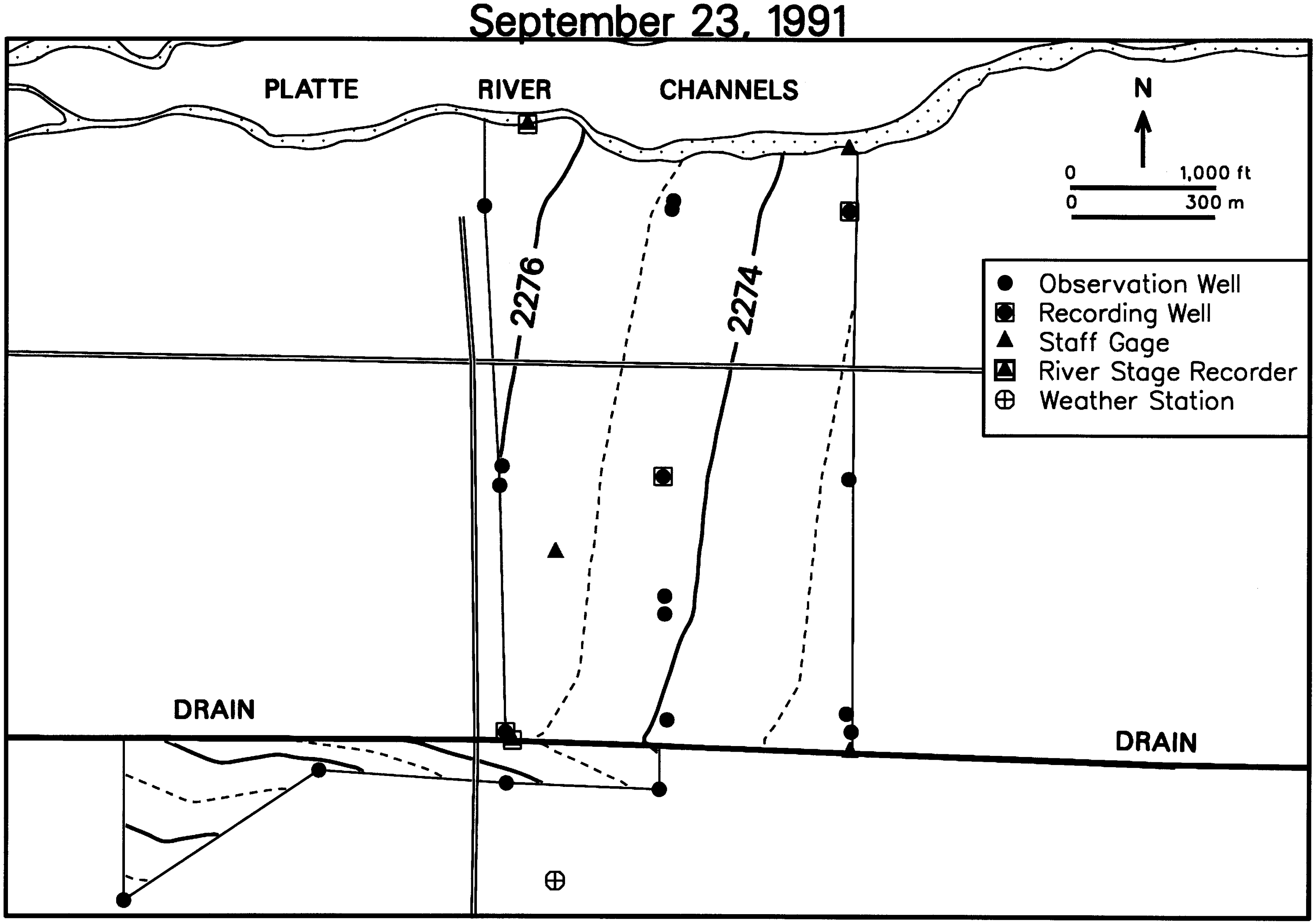


Figure 28. Elm Creek groundwater-level contours (ft) for the day when the lowest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: EC10CAD=D_{97}, EC15BBA=D_{98}, EC15BCC=D_{93}, South Channel=D_{95}, and Groundwater Drain=D_{96}.

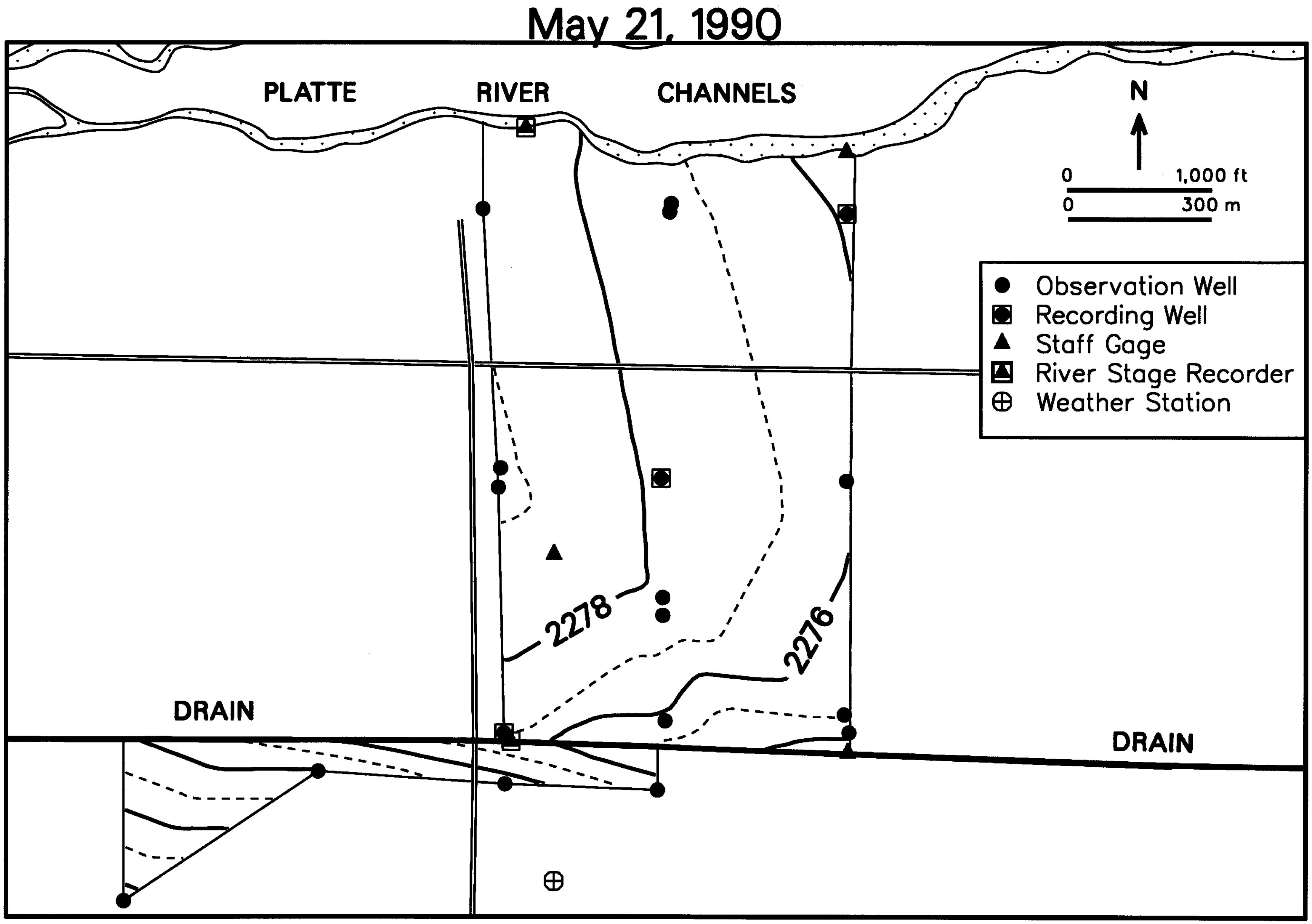


Figure 29. Elm Creek groundwater-level contours (ft) for the day when the highest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: EC10CAD=$D_{<1}$, EC15BBA=D_1, EC15BCC=D_1, South Channel=$D_{<1}$, and Groundwater Drain=D_4.

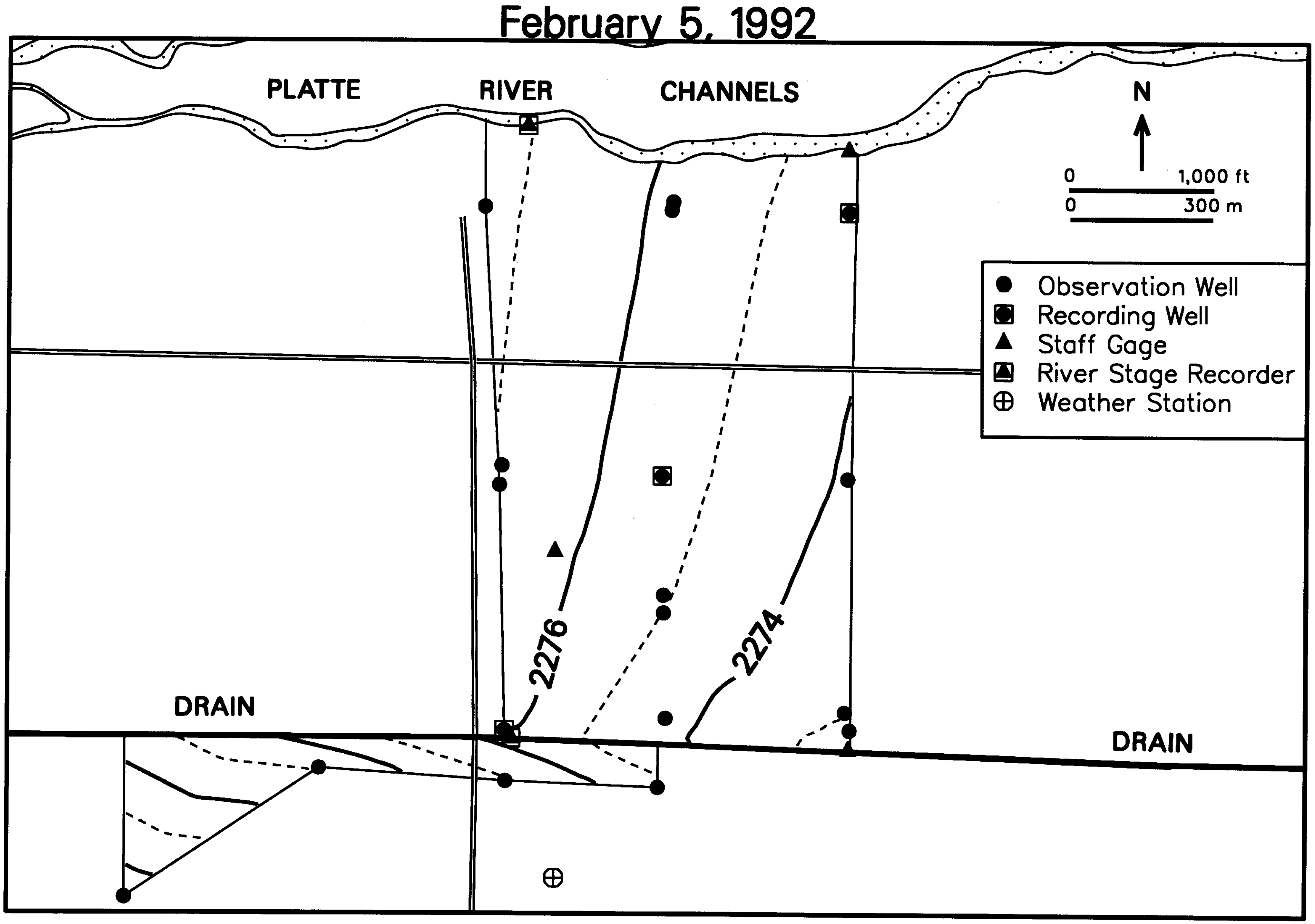


Figure 30. Elm Creek groundwater-level contours (ft) for a day approximating a median water level from February though April. Depth-to-groundwater durations for the wells and gages with recorders were: EC10CAD=D_{47}, EC15BBA=D_{64}, EC15BCC=D_{50}, South Channel=D_{28}, and Groundwater Drain=D_{55}.

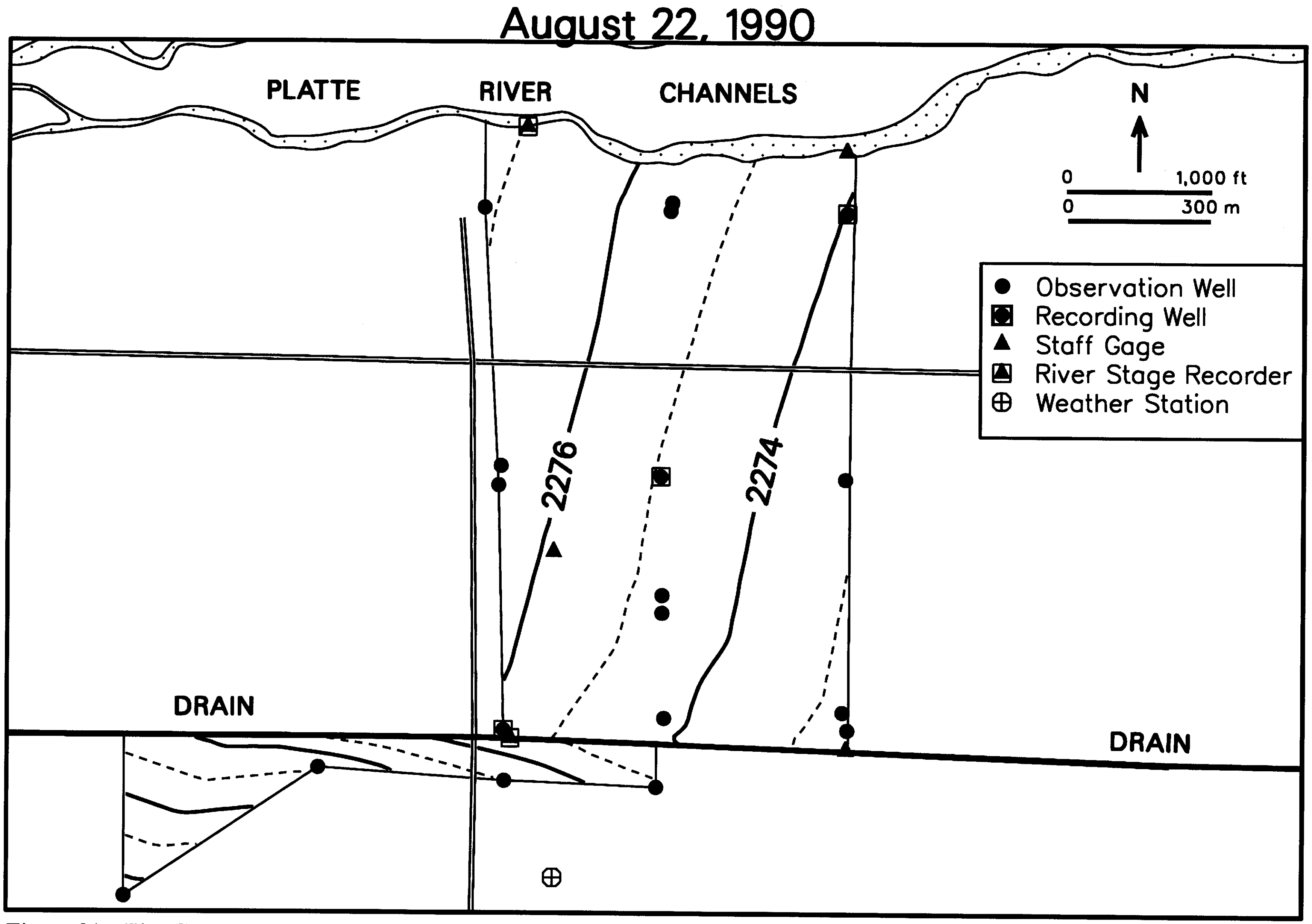


Figure 31. Elm Creek groundwater-level contours (ft) for a day approximating a median water level from June through September. Depth-to-groundwater durations for the wells and gages with recorders were: EC10CAD=D_{45}, EC15BBA=D_{57}, EC15BCC=D_{50}, South Channel=D_{37}, and Groundwater Drain=D_{32}.

August 29, 1991

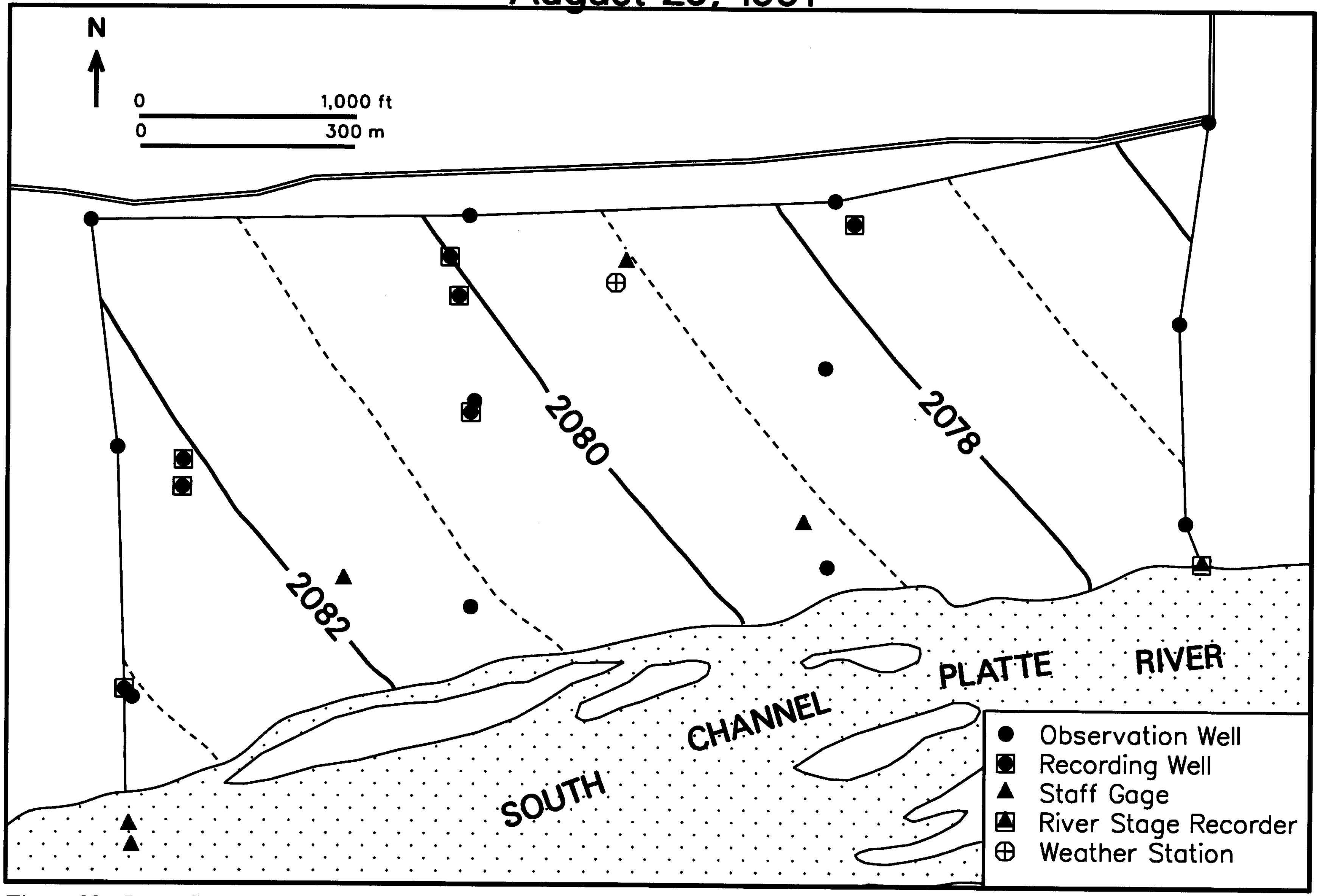


Figure 32. Rowe Sanctuary groundwater-level contours (ft) for the day when the lowest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: RS8CDC=D_{99}, RS8DCA=D_{99}, RS17BBC=D_{99}, and River Stage=D_{99}.

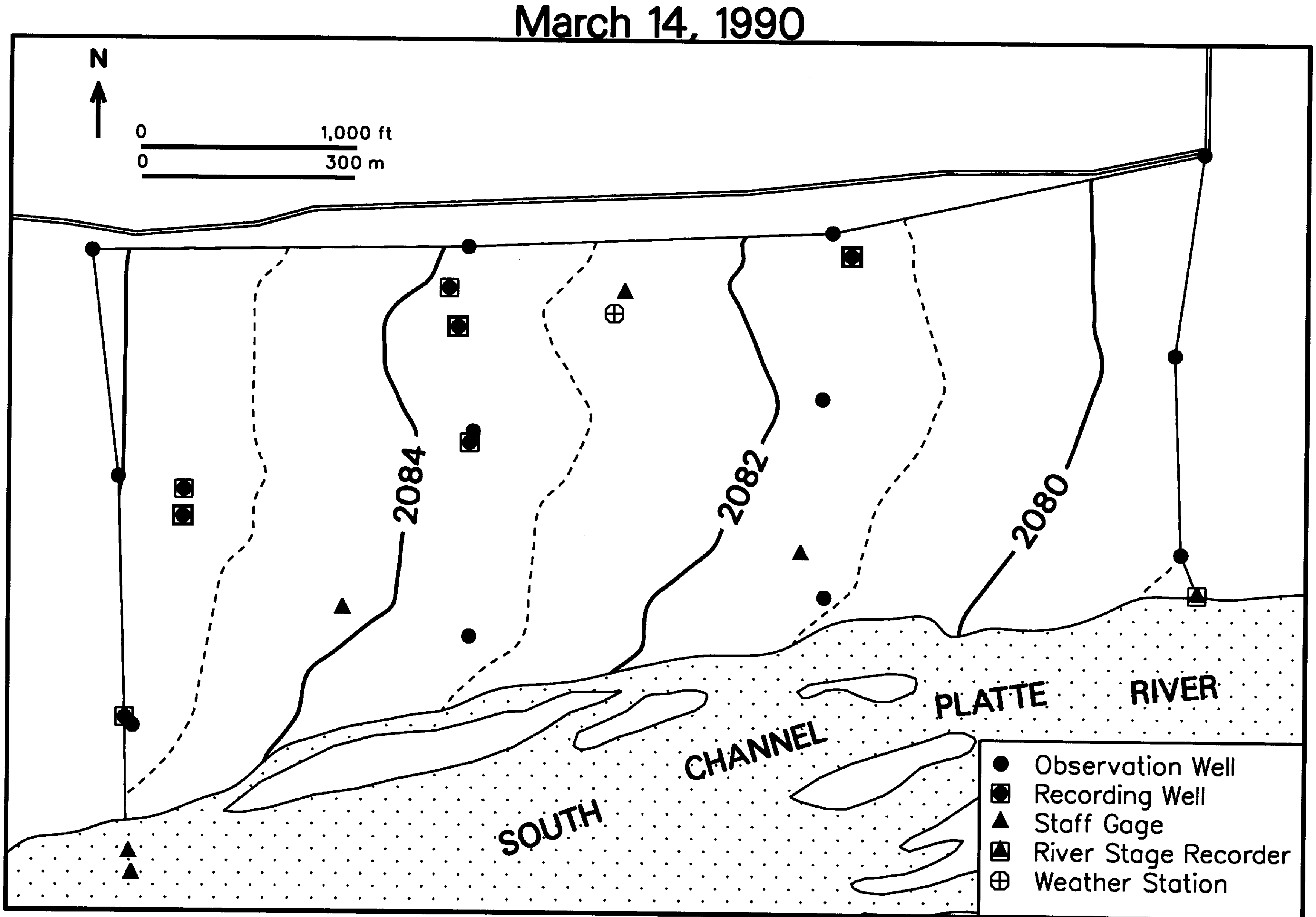


Figure 33. Rowe Sanctuary groundwater-level contours (ft) for the day when the highest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: RS8CDC=D_1, RS8DCA=D_1, RS17BBC=D_1, and River Stage=D_{24}.

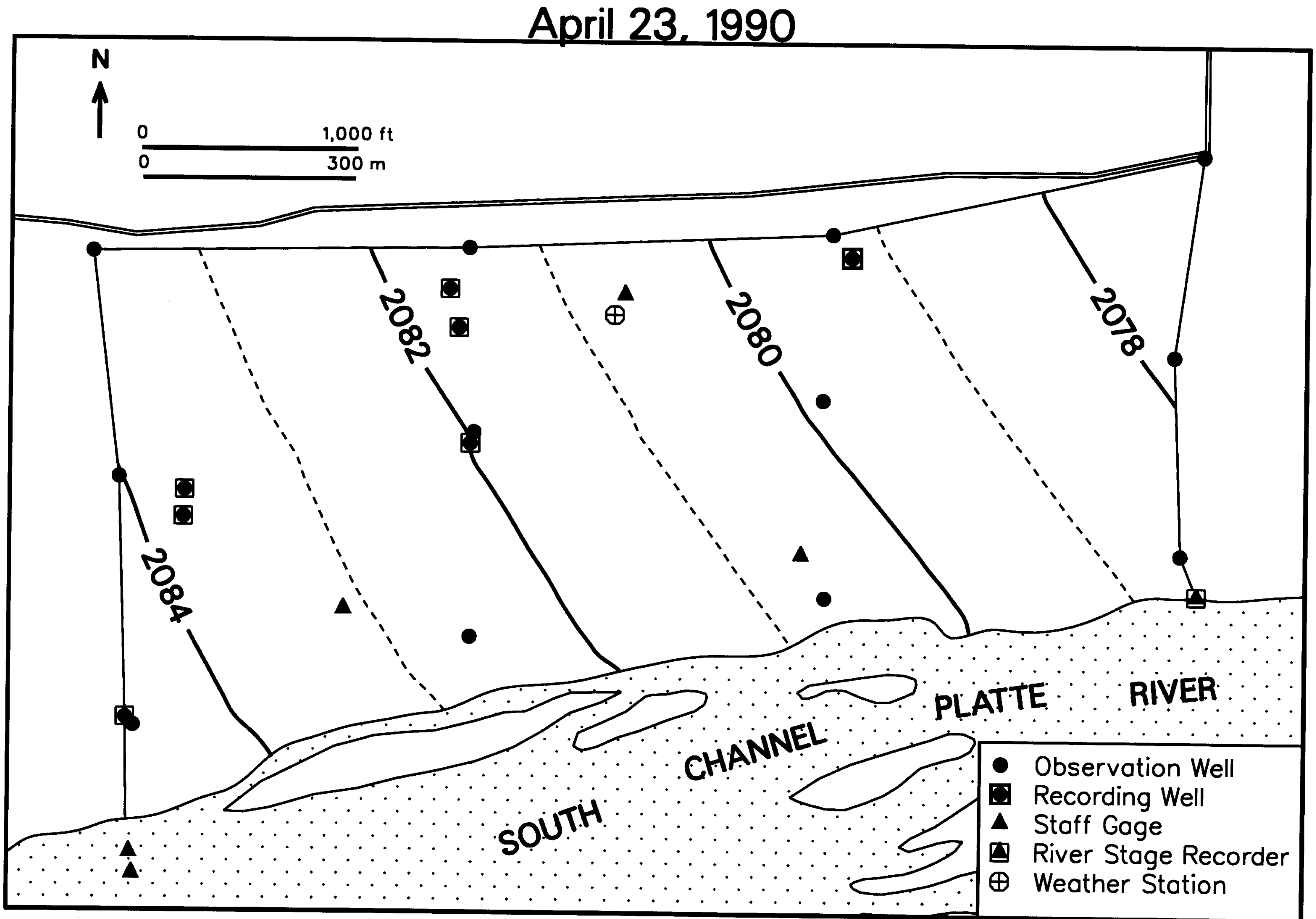


Figure 34. Rowe Sanctuary groundwater-level contours (ft) for a day approximating a median water level from February though April. Depth-to-groundwater durations for the wells and gages with recorders were: RS8CDC=D_{49}, RS8DCA=D_{44}, RS17BBC=D_{46}, and River Stage=D_{26}.

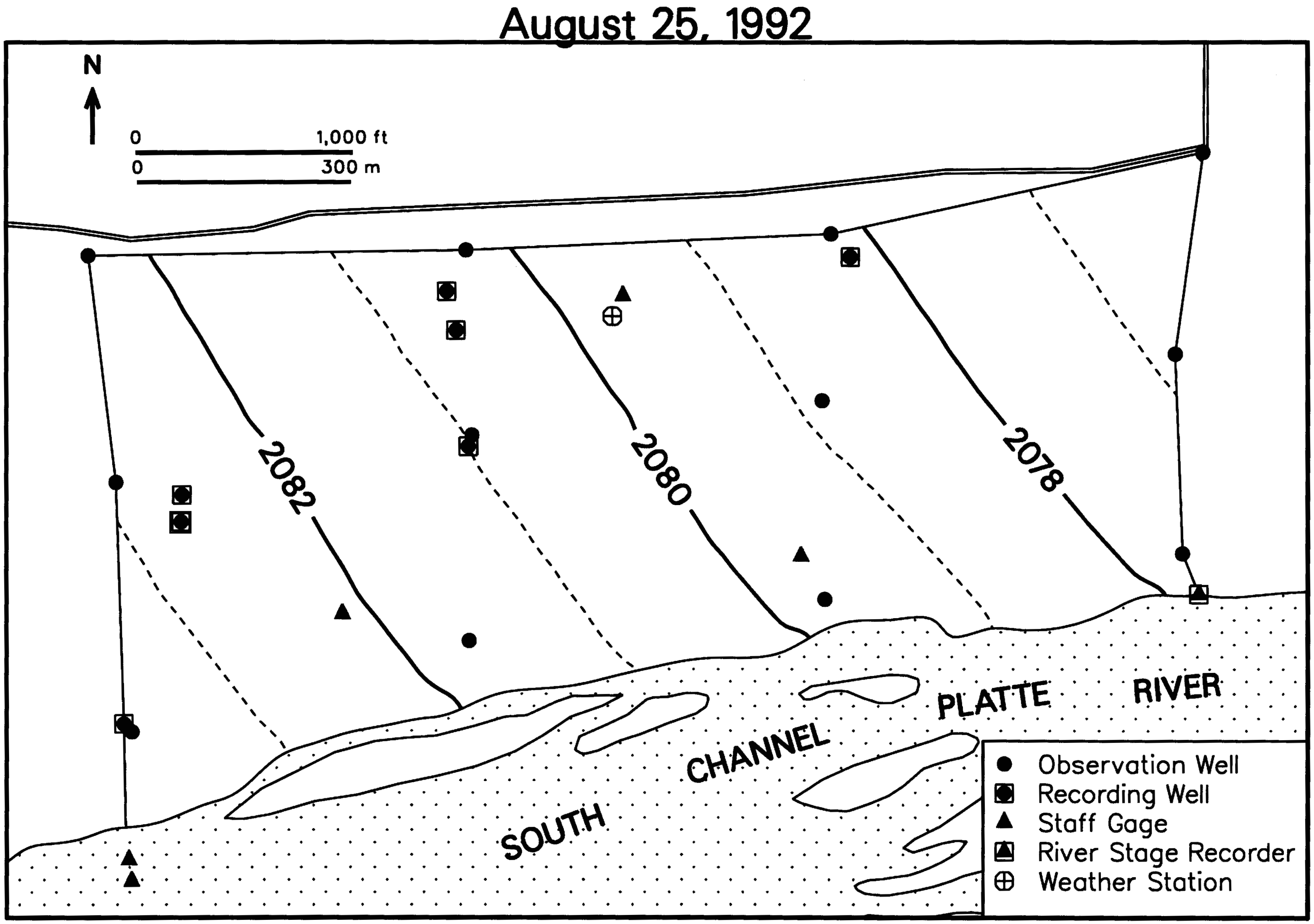


Figure 35. Rowe Sanctuary groundwater-level contours (ft) for a day approximating a median water level from June through September. Depth-to-groundwater durations for the wells and gages with recorders were: RS8CDC=D_{52}, RS8DCA=D_{53}, RS17BBC=D_{51}, and River Stage=D_{56}.

Elm Creek typically followed large precipitation events (e.g., 2.08 in from 18-21 May 1990), and the groundwater gradient typically formed from near the center of the site toward either the Platte River or the groundwater drain (Figure 29). The limited groundwater level information from south of the groundwater drain, suggests that there is a fairly steep gradient toward the drain from the south. This can also be seen in the cross-valley transects (Figures 21).

The Rowe Sanctuary contour maps show that the general direction for the groundwater gradient at this site was down-valley and slightly toward the center of the island (Figures 32, 34, and 35), except at high water levels (Figure 33). The high groundwater levels at Rowe Sanctuary typically followed large precipitation events (e.g., 1.56 in on 13 March 1990) and the gradient was generally down-valley, but also toward the River (Figure 33). Even at high groundwater levels, however, it appears that some groundwater may be flowing toward the center of the island. Figure 33 suggests that the gradient turns toward the center of the island about 1,000 ft from the Platte River bank, at least for the east half of the site. Additional wells north of the study site may have confirmed this possibility, but with only the slanted transect wells located north of the site it would be difficult to show that groundwater flows toward the center of the island at high water levels also.

In contrast to Elm Creek and Rowe Sanctuary, the Crane Meadows site encompassed a relatively large area on a reasonably large island. The general direction for the groundwater gradient at Crane Meadows was down-valley (Figures 36 through 39). At low and median groundwater levels during the summer, the general down-valley gradient also turned slightly toward the center of the island (Figures 36 and 39). This gradient toward the center of the island was caused by a groundwater depression under the island that can also be seen in the cross-valley transects (Figure 23b). Rowe Sanctuary is also on an island similar to Crane Meadows and may have had a similar depression, but additional wells north of the study site would be required to detect this. The groundwater depression during the summer was probably caused by evapotranspiration rather than groundwater inception by the many small

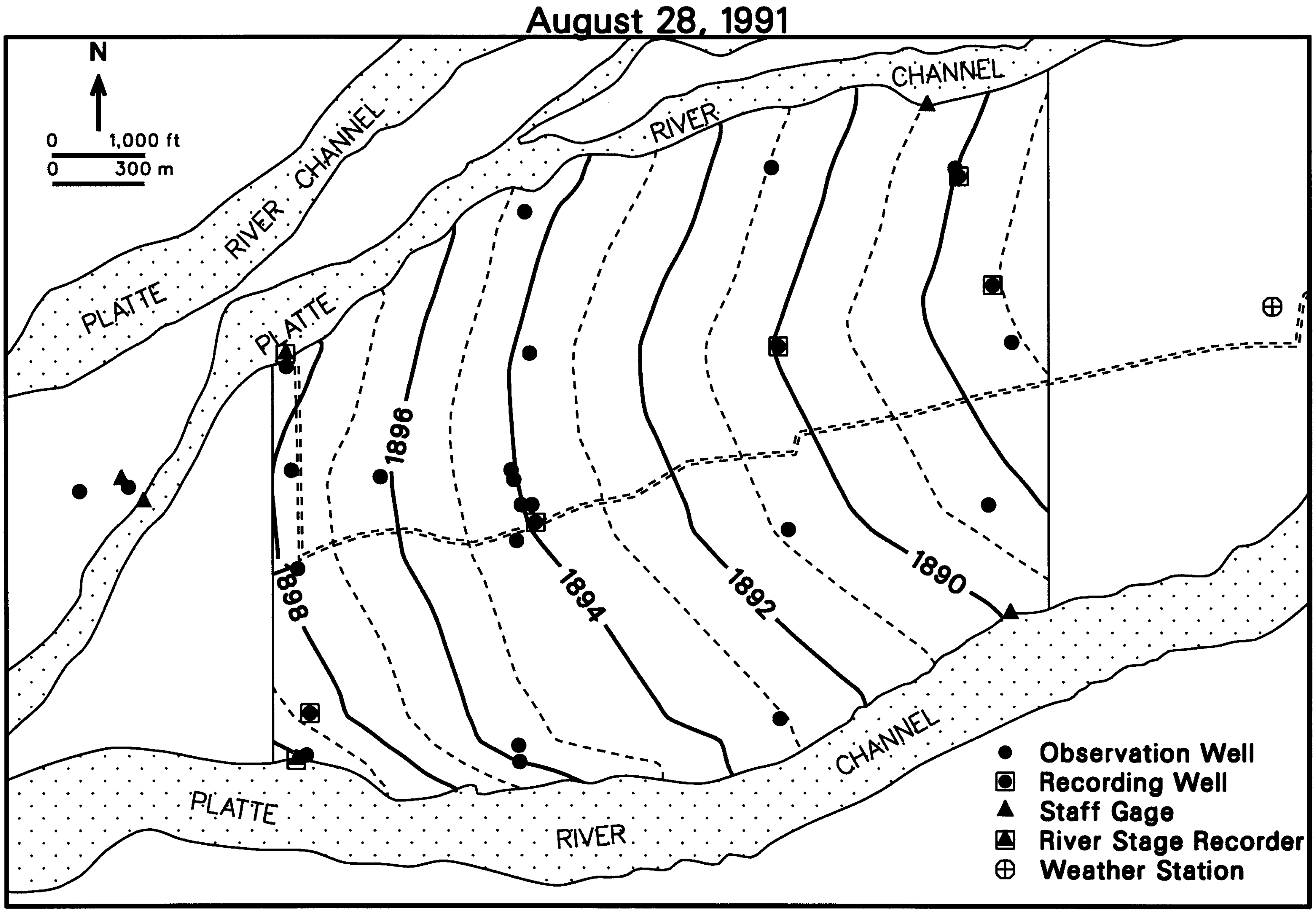


Figure 36. Crane Meadows groundwater-level contours (ft) for the day when the lowest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: CM26CDA=D_{100}, CM26DBB=D_{100}, CM33DDA2=D_{99}, CM34BDD=D_{98}, CM35BBB=D_{98}, South Channel Stage=D_{99}.

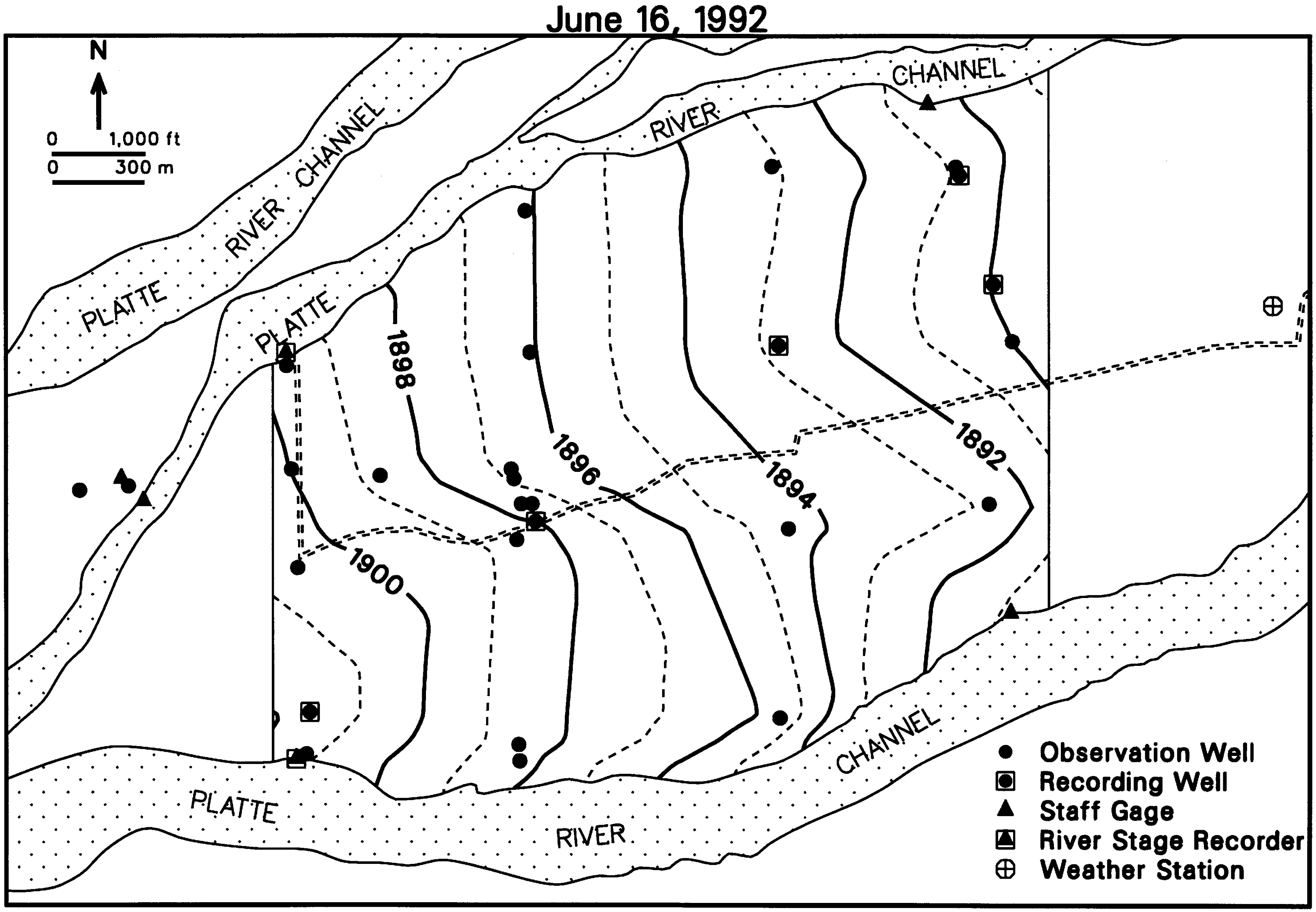


Figure 37. Crane Meadows groundwater-level contours (ft) for the day when the highest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: CM26CDA=D_2, CM26DBB=D_1, CM33DDA2=D_1, CM34BDD=D_1, CM35BBB=D_2, South Channel Stage=D_{65}.

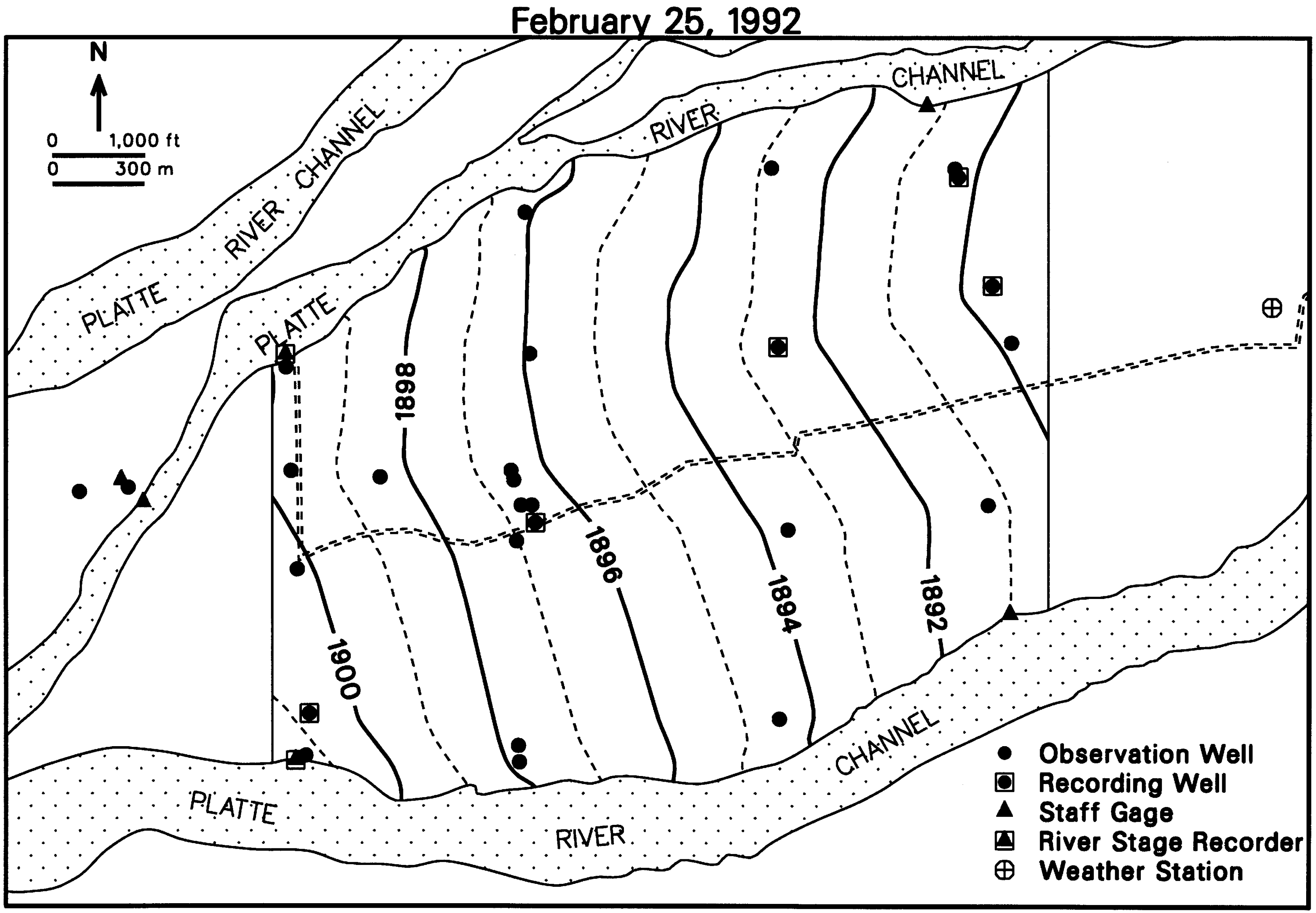


Figure 38. Crane Meadows groundwater-level contours (ft) for a day approximating a median water level from February though April. Depth-to-groundwater durations for the wells and gages with recorders were: CM26CDA=D_{50}, CM26DBB=D_{30}, CM33DDA2=D_{38}, CM34BDD=D_{24}, CM35BBB=D_{50}, South Channel Stage=D_{53}.

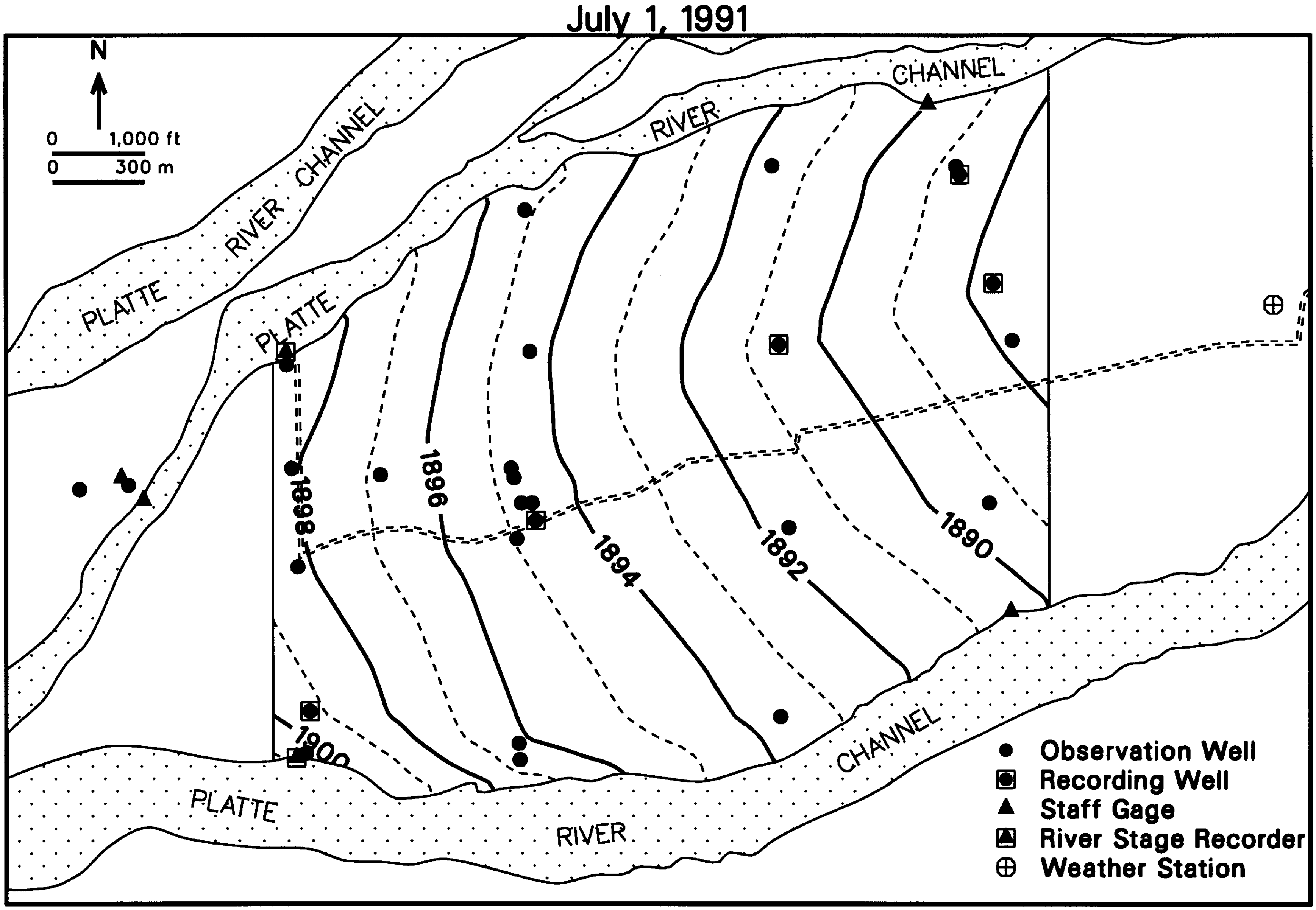


Figure 39. Crane Meadows groundwater-level contours (ft) for a day approximating a median water level from June through September. Depth-to-groundwater durations for the wells and gages with recorders were: CM26CDA=D_{28}, CM26DBB=D_{61}, CM33DDA2=D_{50}, CM34BDD=D_{63}, CM35BBB=D_{50}, South Channel Stage=D_{56}.

swales in the center of Crane Meadows, because the groundwater level was typically below the swales during the summer (Figure 23). In addition, the water levels observed before plant growth suggests that the gradient across the island was relatively flat when evapotranspiration was minimal (Figure 38). There was a localized gradient toward the center of the island that began north of the access road at high water levels (Figure 38), but this area was the lowest part of the island and the groundwater was probably intercepted and discharged as surface flow by the many small swales (Figure 23b). The only time a gradient was observed from the island toward the River was following large precipitation events (e.g., 2.10 in from 14-15 June 1992). Even when a gradient did occur from the island toward the River, it typically only occurred within about the first 1,000 ft from the Platte River bank (Figure 37). The vast majority of the island still had a gradient toward the center of the island, suggesting that groundwater was also flowing toward the swales in the center of the island and being discharged as surface water. A gradient limited to within about 1,000 ft of the Platte River bank for groundwater flowing toward the River was also observed at Rowe Sanctuary (Figure 33).

Besides inputs from precipitation and the Platte River at Crane Meadows, there was also groundwater moving upward within the aquifer as shown by the Group 1 piezometer nest (Figure 40). Hurr (1983) monitored these wells for 7 months in 1980 and observed less than a 0.2 ft difference between the shallowest and deepest wells, with the shallowest well having the higher water level. This would suggest water moving downward within the aquifer. After monitoring Group 1 for 18 months, however, we observed a gradient suggesting downward movement only once (24 September 1991) and that may have been a miss measurement since the gradient was not consistent from the shallowest to the deepest well. All the other measurements showed a hydraulic head greater for the deeper wells, suggesting that groundwater was moving upward within the aquifer nearly year round. This upward movement, however, was apparently insufficient to offset evapotranspiration since the groundwater contours show that groundwater was flowing from the River toward the center of

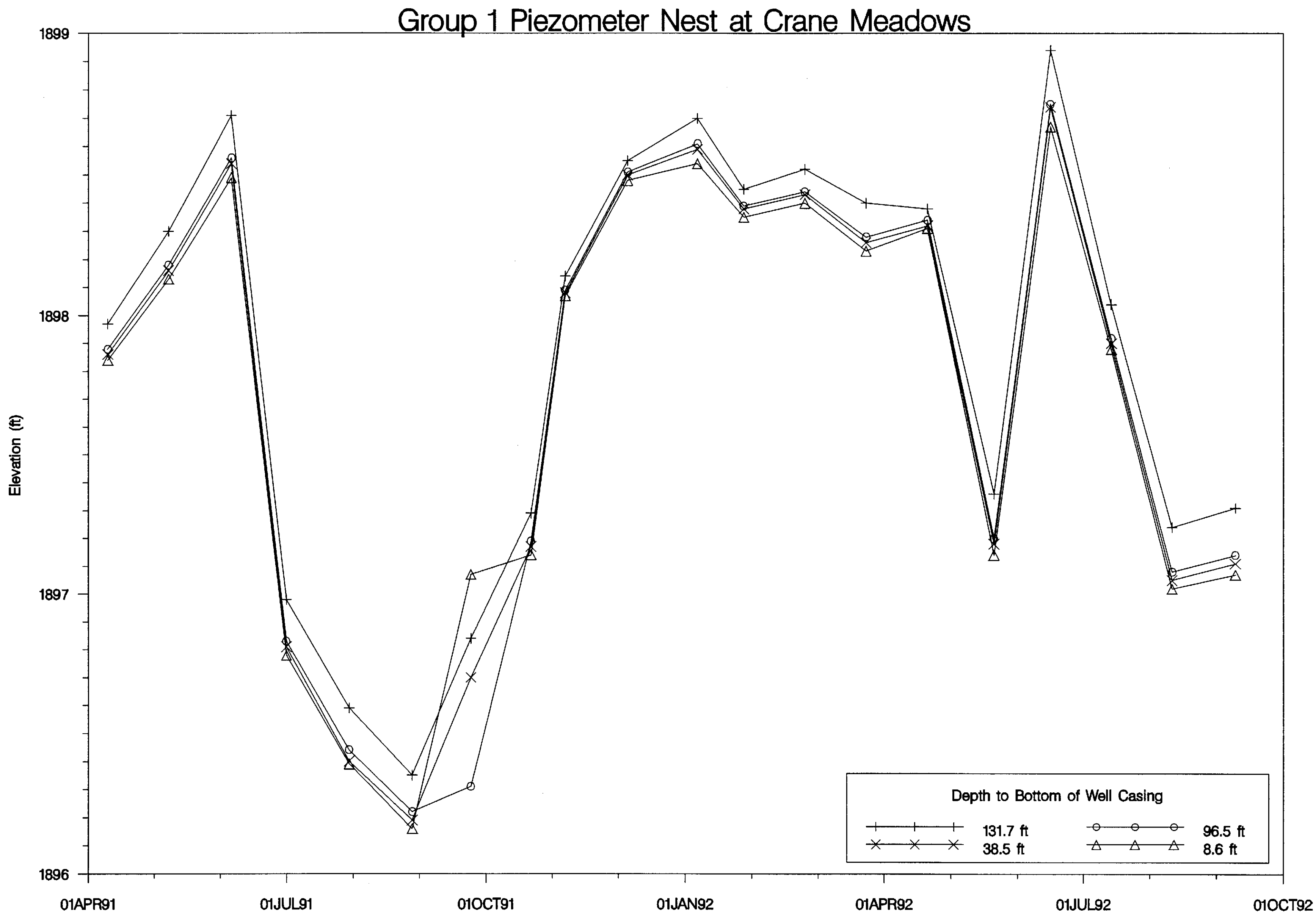


Figure 40. Hydrographs for the Group 1 piezometer nest at Crane Meadows, showing the difference between hydraulic heads at selected depths within the aquifer. These wells were installed for a study by Hurr (1983), and the exact depths open to the aquifer were unknown. Well depths shown were measured from the top of the well to the bottom of the casing. The ground surface was approximately 1898.70 ft.

the island for most of the growing season.

Depth-to-Groundwater Maps

Depth-to-groundwater maps for a representative area at each site were developed for the same dates as the groundwater-level contour maps. These dates represent the lowest, highest, and median spring and summer groundwater depths observed at each site. A representative area for each site was chosen, because the detailed topographic surveys used to produce these maps required a considerable amount of field time. Even with the smaller area, the number of survey points (Appendix C) was not always adequate to produce uniform topographic information. The most noticeable feature resulting from an insufficient number of survey points was that many of the swales appeared as disconnected depressions instead of as a continuous drainage network. The level of detail obtained from these topographic surveys was still sufficient to produce better depth-to-groundwater maps than would have been produced using available topographic maps. Until a more detailed survey of the topography of each site becomes available, therefore, the following depth-to-groundwater maps should provide a good indication of the general groundwater depths within each area for the period specified.

Most of Elm Creek had deeper groundwater levels than the other two sites (Table 4, and Figures 41 through 44). Only about 1% of the area bounded by wells EC15BBA, EC15BDC, EC15BCC, and EC15BBB had surface water, and that was only at the highest groundwater levels (Figure 42). Although Elm Creek had deeper groundwater, most of the area (about 93%) never had groundwater deeper than 6 ft below the surface (Figure 41). The median springtime groundwater depth for most of the representative area (about 86%) was between 3 to 5 ft below the surface (Figure 43), while the median groundwater depth during the summer tended to be about one foot deeper (Table 4, and Figure 44).

Most of Rowe Sanctuary had intermediate groundwater levels compared to the other two sites (Table 4, and Figures 45 through 48). There was always surface water in the SE Pond for the area bounded by wells RS8DCD, RS17ABA, RS17BAC, and RS8CDC, but

Table 4. Proportion of each representative area within the depth-to-groundwater (ft) ranges shown in Figures 41 through 52. T = trace (0 < T < 0.5%).

	Proportion of Each Representative Area within the Depth-to-groundwater Range			
Depth-to-Groundwater	Lowest Day	Highest Day	Median Spring	Median Summer
Elm Creek				
>0	0	1	0	0
0 to -1	0	9	0	0
-1 to -2	0	38	T	0
-2 to -3	T	39	6	2
-3 to -4	10	11	36	21
-4 to -5	46	2	50	55
-5 to -6	37	0	8	20
<-6	7	0	T	2
Rowe Sanctuary				
>0	T	4	T	T
0 to -1	T	46	T	T
-1 to -2	T	37	31	T
-2 to -3	8	12	58	33
-3 to -4	68	1	11	56
-4 to -5	23	0	T	11
-5 to -6	1	0	0	T
<-6	0	0	0	0
Crane Meadows				
>0	0	46	24	0
0 to -1	0	40	53	T
-1 to -2	6	11	17	38
-2 to -3	55	2	5	45
-3 to -4	30	1	1	14
-4 to -5	8	T	T	2
-5 to -6	1	0	0	1
<-6	T	0	0	T

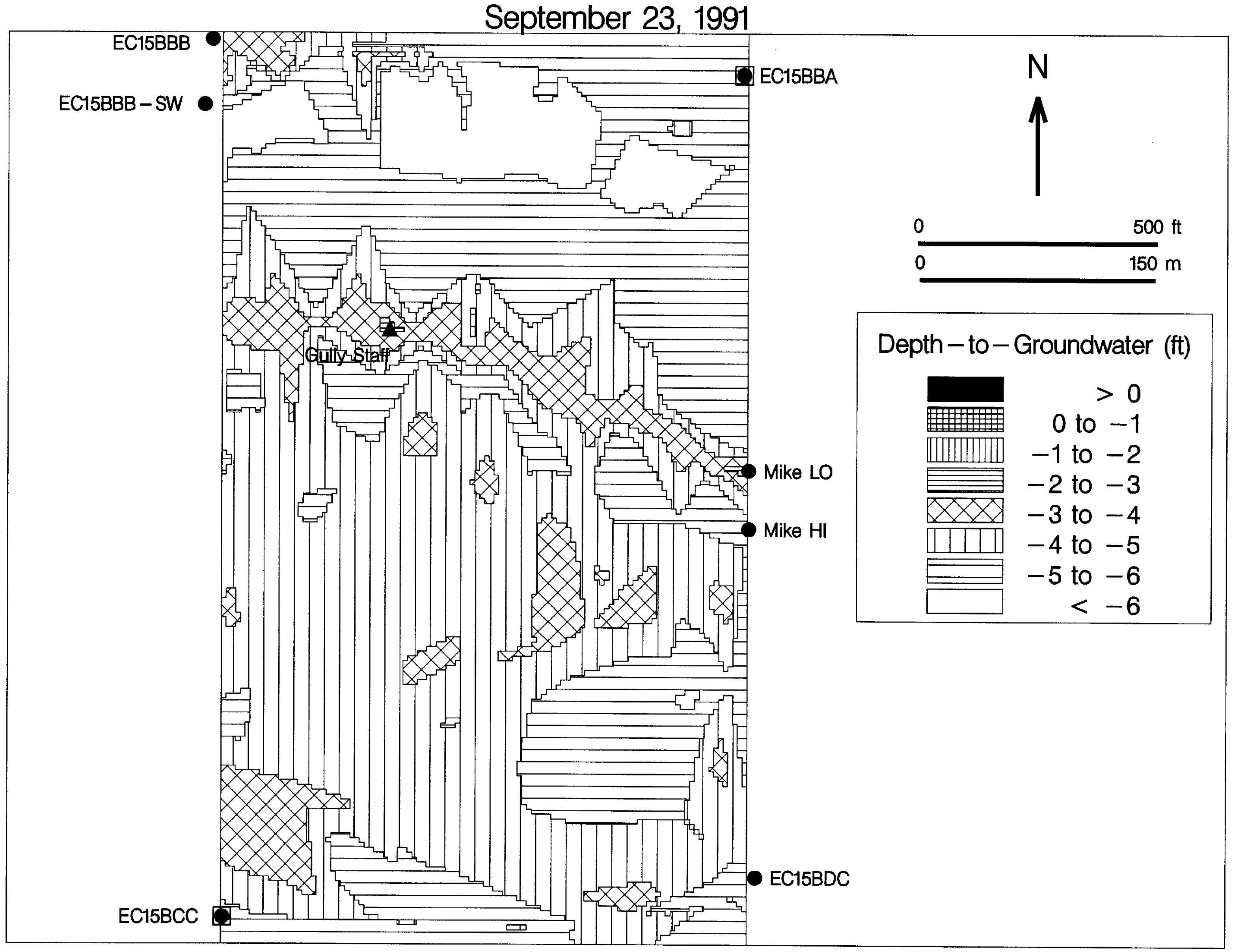


Figure 41. Depth-to-groundwater (ft) for a representative area at Elm Creek on the day when the lowest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: EC10CAD=D_{97}, EC15BBA=D_{98}, EC15BCC=D_{93}, South Channel=D_{95}, and Groundwater Drain=D_{96}.

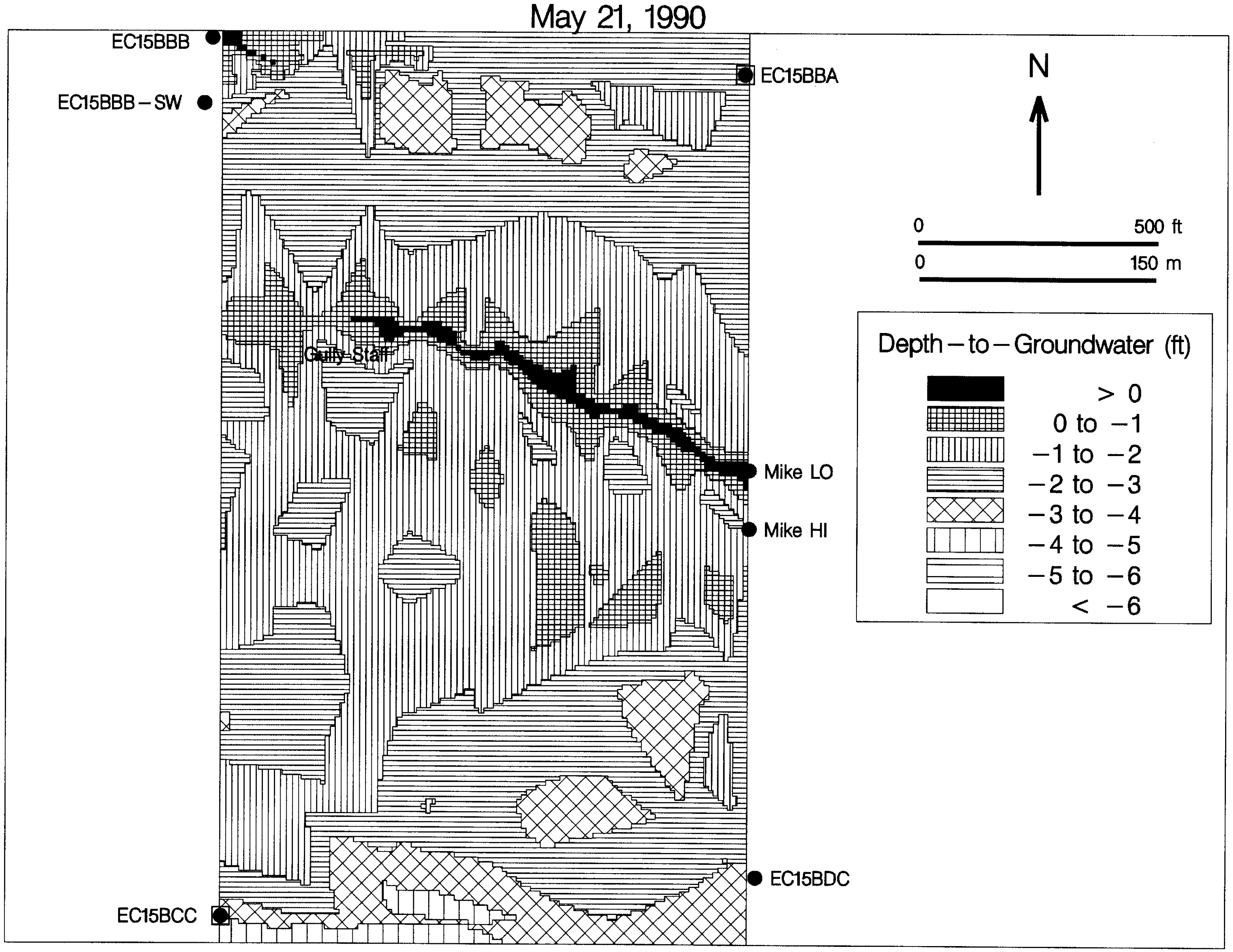


Figure 42. Depth-to-groundwater (ft) for a representative area at Elm Creek on the day when the highest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: EC10CAD=$D_{<1}$, EC15BBA=D_1, EC15BCC=D_1, South Channel=$D_{<1}$, and Groundwater Drain=D_4.

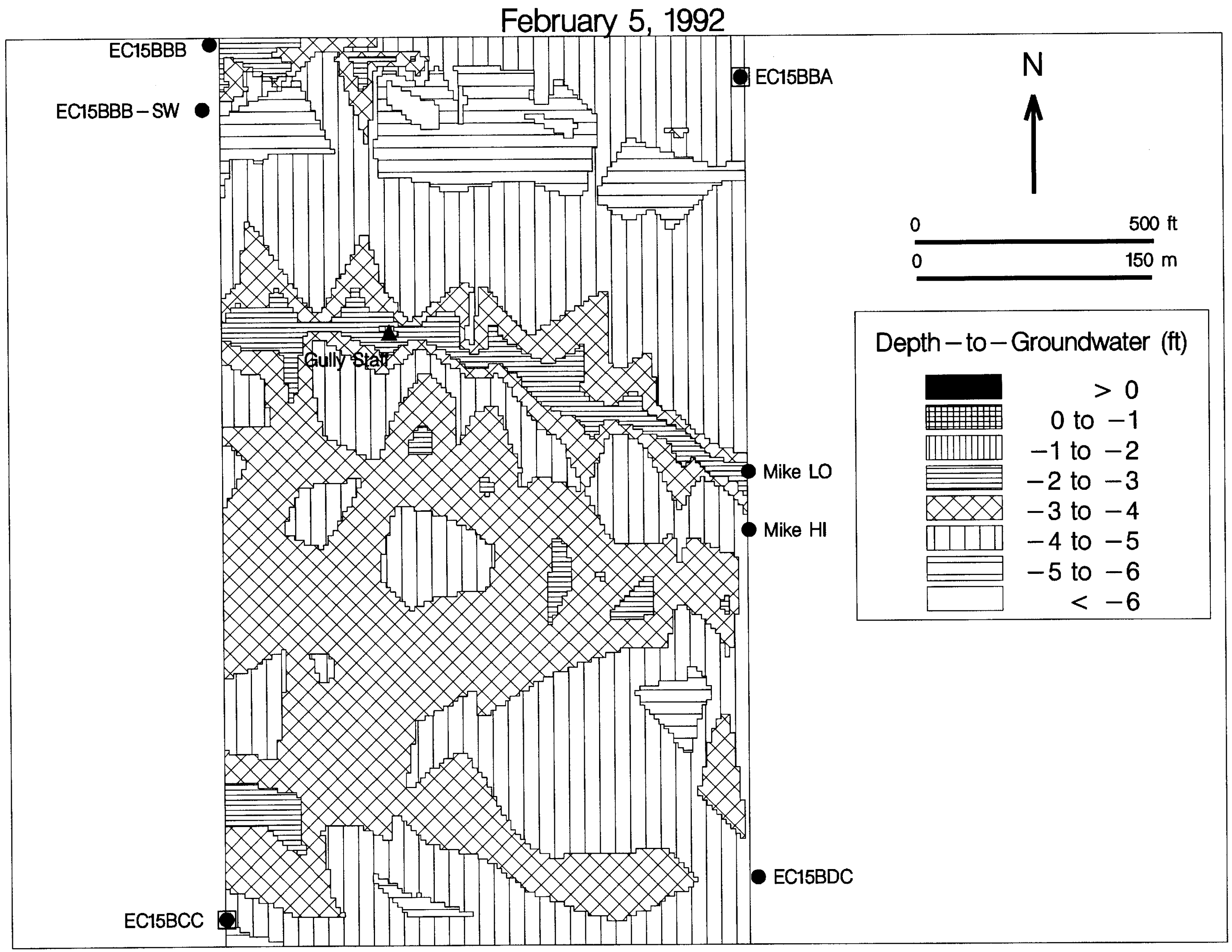


Figure 43. Depth-to-groundwater (ft) for a representative area at Elm Creek on a day approximating a median water level for February though April. Depth-to-groundwater durations for the wells and gages with recorders were: EC10CAD=D_{47}, EC15BBA=D_{64}, EC15BCC=D_{50}, South Channel=D_{28}, and Groundwater Drain=D_{55}.

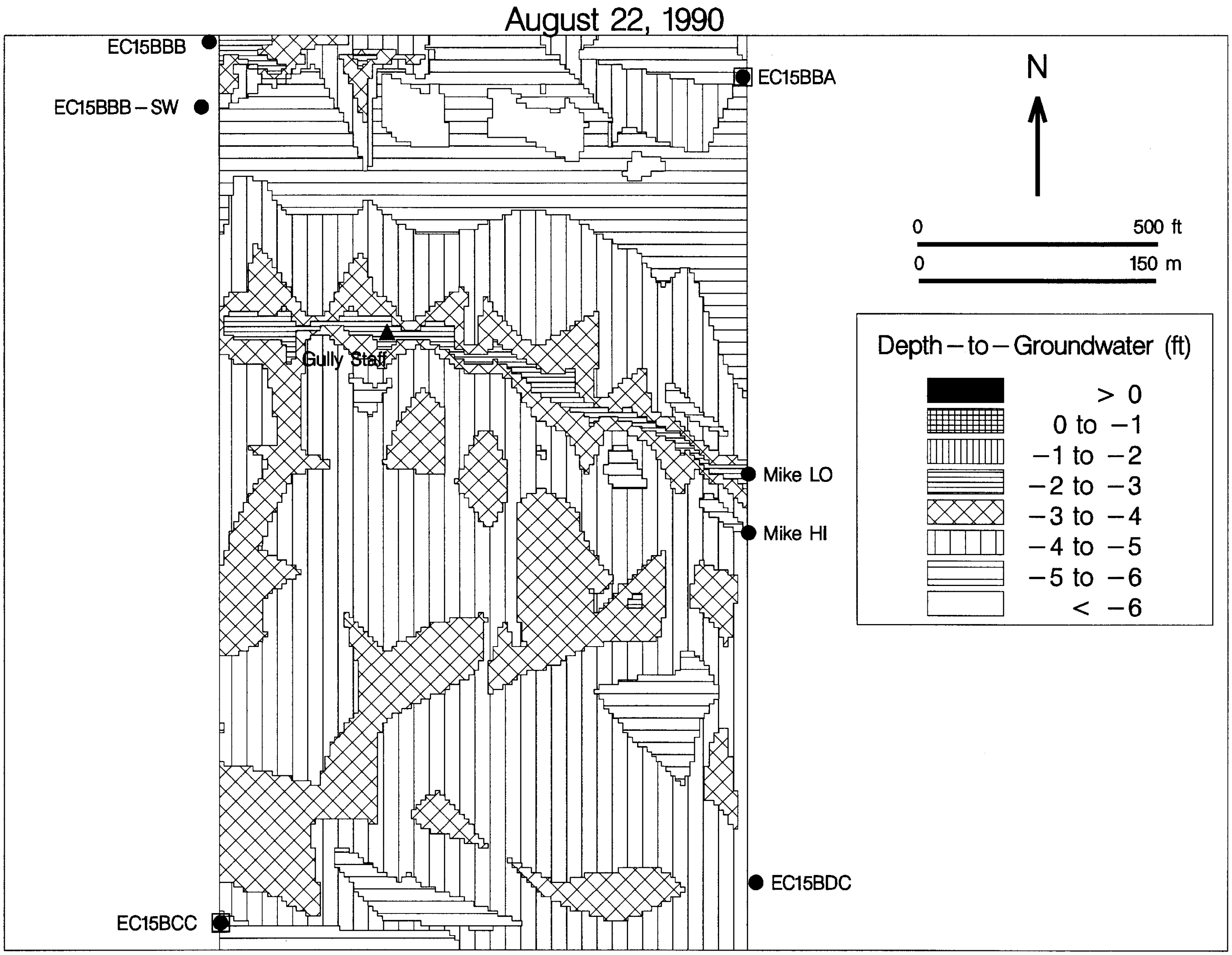


Figure 44. Depth-to-groundwater (ft) for a representative area at Elm Creek on a day approximating a median water level for June through September. Depth-to-groundwater durations for the wells and gages with recorders were: EC10CAD=D_{45}, EC15BBA=D_{57}, EC15BCC=D_{50}, South Channel=D_{37}, and Groundwater Drain=D_{32}.

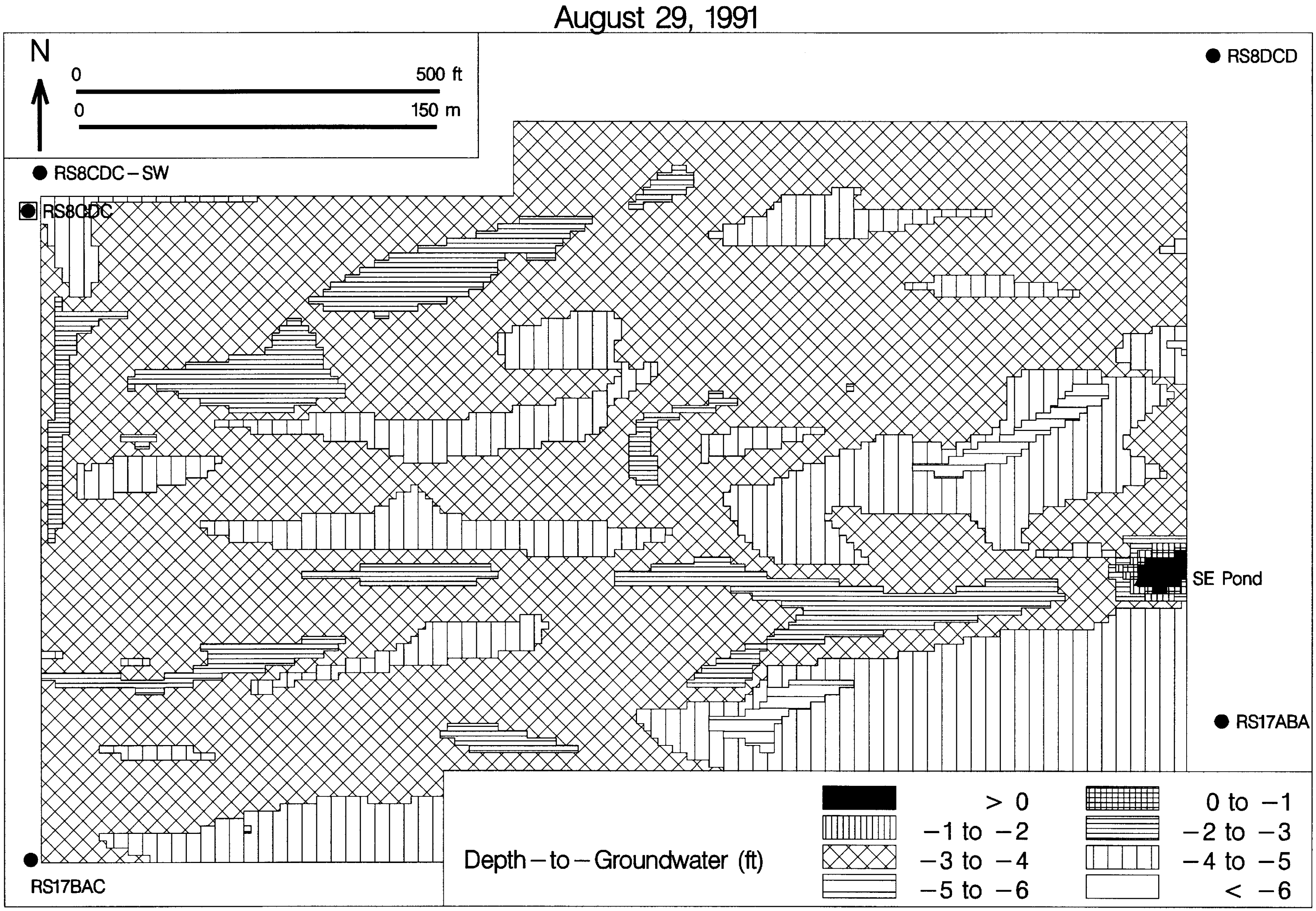


Figure 45. Depth-to-groundwater (ft) for a representative area at Rowe Sanctuary on the day when the lowest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: RS8CDC=D_{99}, RS8DCA=D_{99}, RS17BBC=D_{99}, and River Stage=D_{99}.

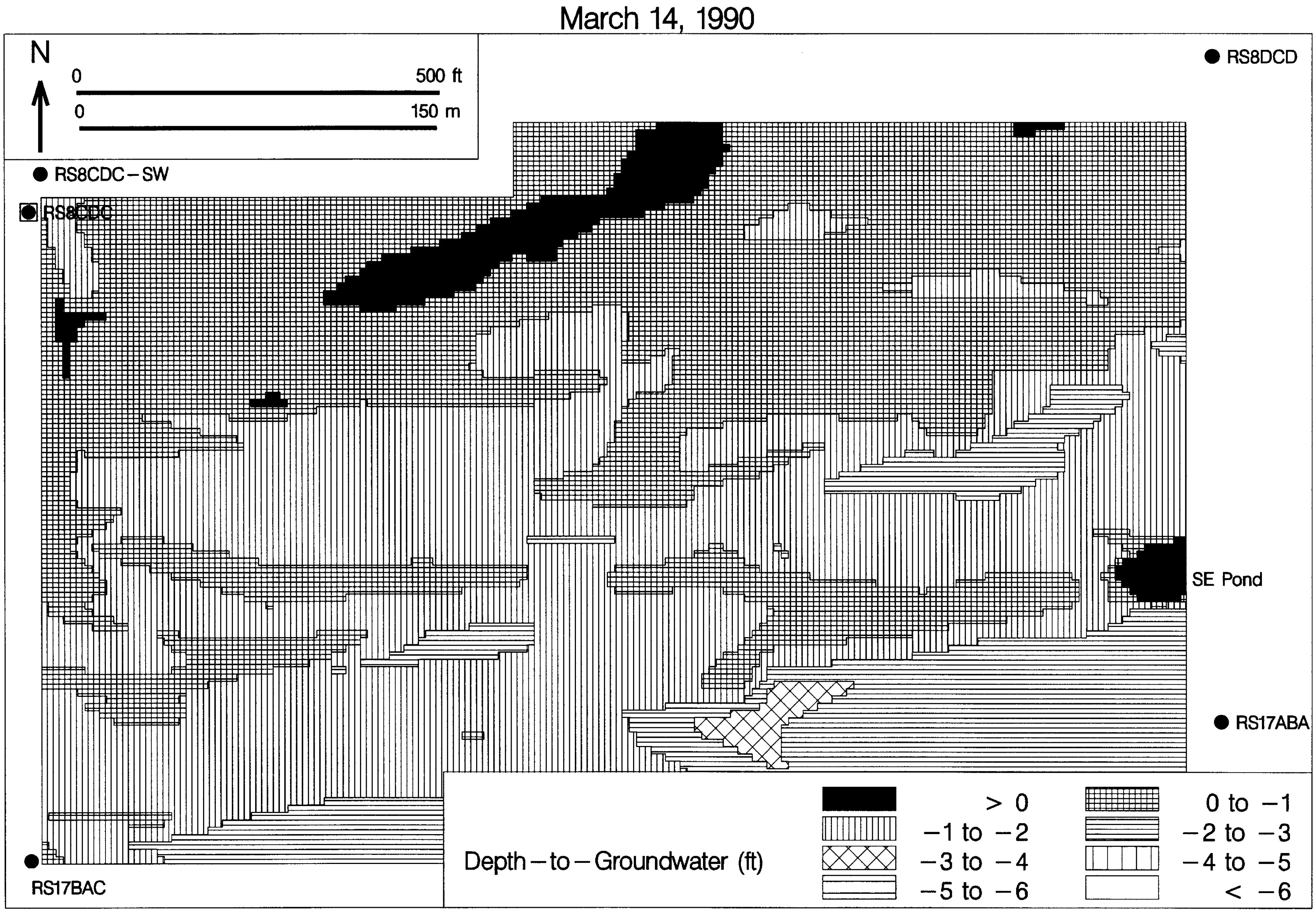


Figure 46. Depth-to-groundwater (ft) for a representative area at Rowe Sanctuary on the day when the highest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: RS8CDC=D_1, RS8DCA=D_1, RS17BBC=D_1, and River Stage=D_{24}.

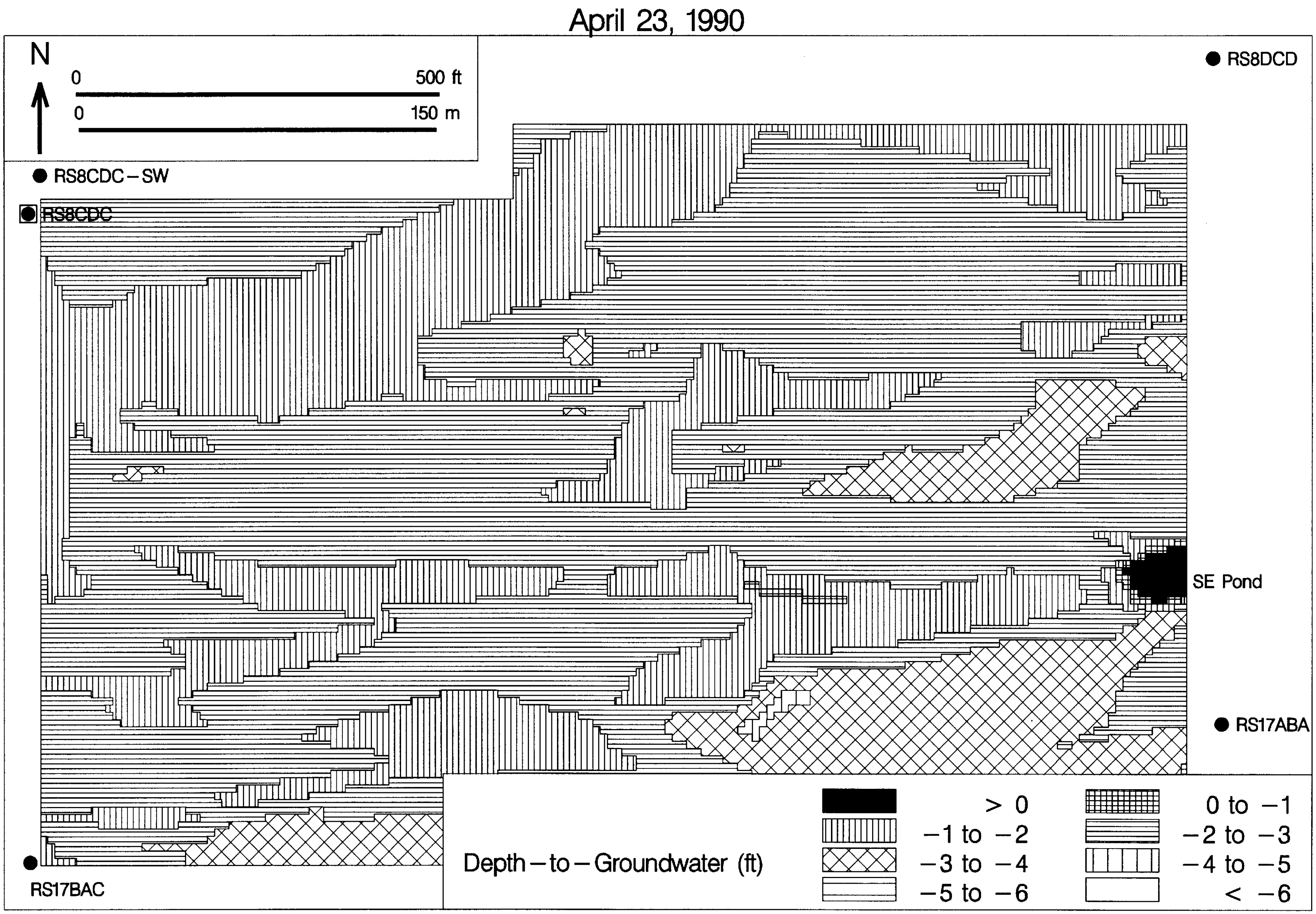


Figure 47. Depth-to-groundwater (ft) for a representative area at Rowe Sanctuary on a day approximating a median water level for February through April. Depth-to-groundwater durations for the wells and gages with recorders were: RS8CDC=D_{49}, RS8DCA=D_{44}, RS17BBC=D_{46}, and River Stage=D_{26}.

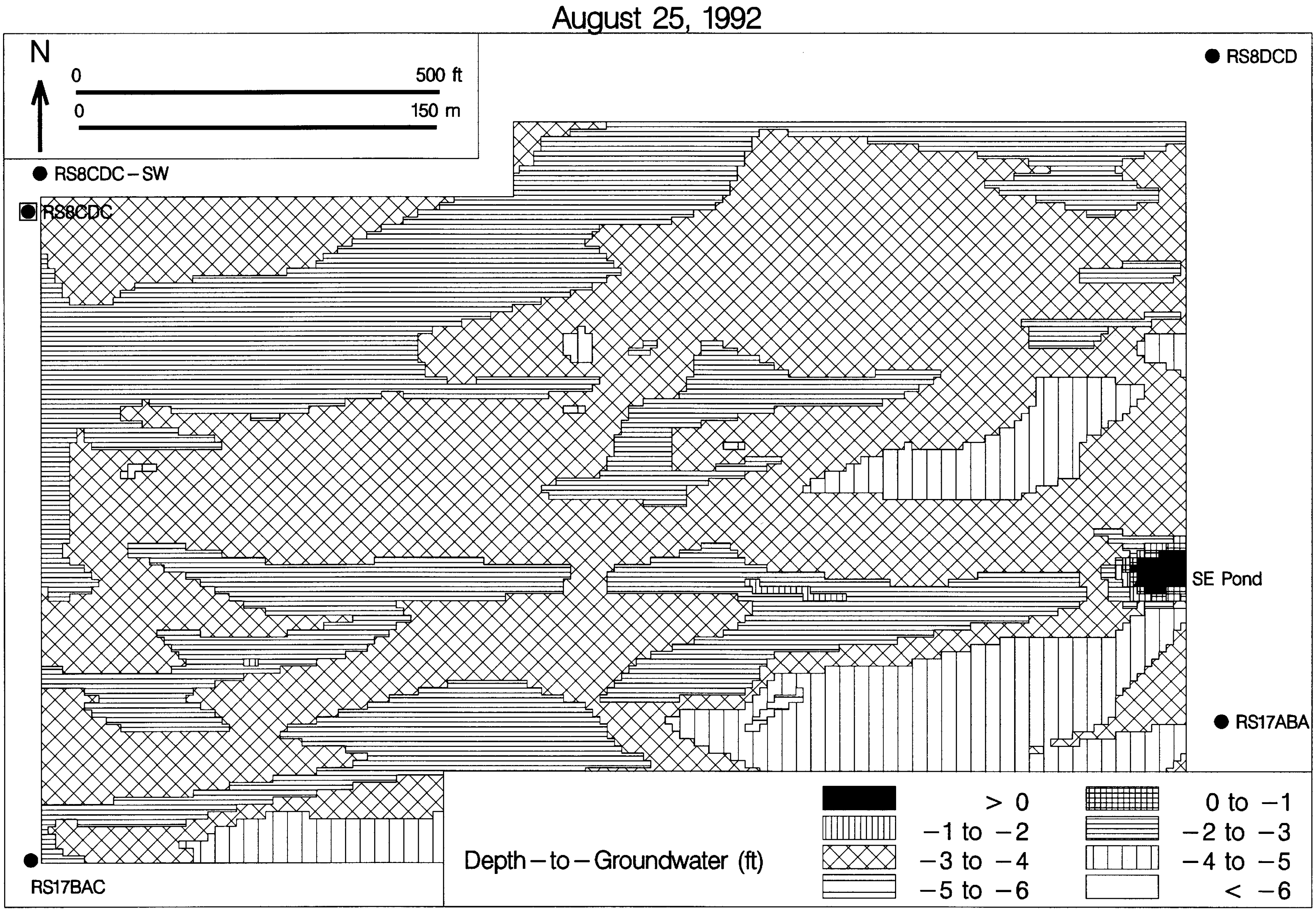


Figure 48. Depth-to-groundwater (ft) for a representative area at Rowe Sanctuary on a day approximating a median water level for June through September. Depth-to-groundwater durations for the wells and gages with recorders were: RS8CDC=D_{52}, RS8DCA=D_{53}, RS17BBC=D_{51}, and River Stage=D_{56}.

surface water was only observed in the wet meadows at the highest groundwater levels (Figure 46). Groundwater depths were never deeper than 6 ft below the surface in the representative area (Figure 45), and only a small area (about 1% or less) had groundwater depths deeper than 5 ft below the surface for the deepest or median-summer groundwater levels (Figures 45 and 48). Most of the representative area had a median spring groundwater depth between 1 to 3 ft below the surface (about 89% of the area in Figure 47), while the median groundwater depth during the summer was about a foot deeper (2 to 4 ft below the surface for about 89% of the area in Figure 48).

Most of Crane Meadows had higher groundwater levels than the other two sites (Table 4, and Figures 49 through 52). Surface water occurred over much of the area bounded by wells CM26DBB-SW, CM35ABB, CM35BBB, and CM26CBB during both the highest groundwater levels (about 46% of the area in Figure 50) and the median spring groundwater levels (about 24% of the area in Figure 51). Most of the area ($\geq$99%) had groundwater within 5 ft of the surface, but a few remnant sandbars in the northern quarter of the area had groundwater deeper than 6 ft below the surface for both the lowest observed levels and the median summer groundwater levels (Figures 49 and 52). About 77% of the area during the spring had a median groundwater level within 1 ft or above the surface (Figure 51), while the median groundwater level during the summer was about 1 to 2 ft deeper (1 to 3 ft below the surface for about 83% of the area in Figure 52).

Effective Plant Rooting Depth

In wetlands where the water table is close to the surface, evapotranspiration (ET) may remove water from both the unsaturated soil profile (ET_{US}) and directly from the water table (ET_{WT}). Groundwater removed by ET is expressed as a diurnal fluctuation in the water table. During the day the water table drops as water is removed. At night the water table may recover if groundwater flows into the area while ET is minimal. The water table recovery may range from nearly complete to no recovery at all. This phenomenon was observed

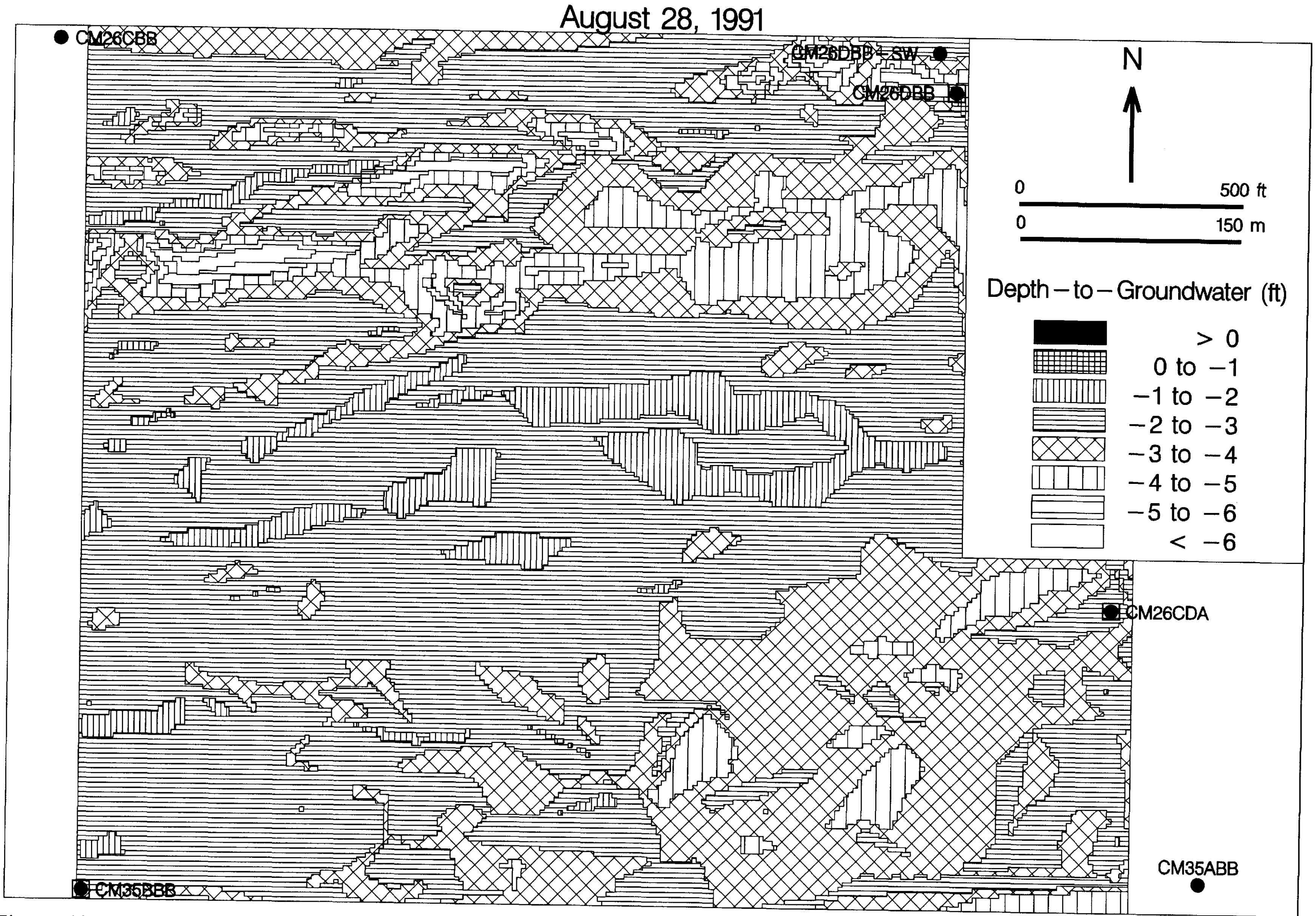


Figure 49. Depth-to-groundwater (ft) for a representative area at Crane Meadows on the day when the lowest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: CM26CDA=D_{100}, CM26DBB=D_{100}, CM33DDA2=D_{99}, CM34BDD=D_{98}, CM35BBB=D_{98}, South Channel Stage=D_{99}.

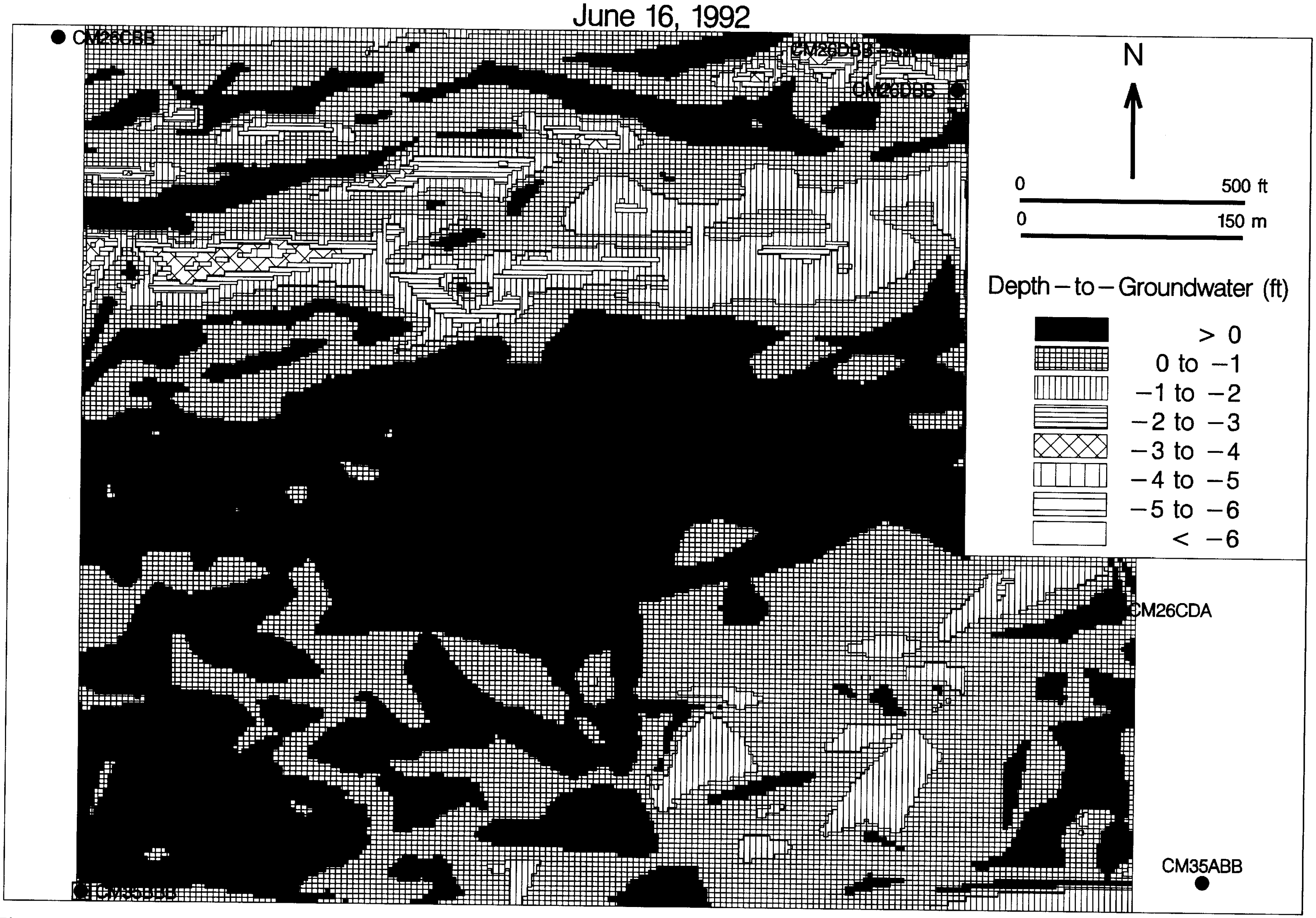


Figure 50. Depth-to-groundwater (ft) for a representative area at Crane Meadows on the day when the highest periodic measurement was observed. Depth-to-groundwater durations for the wells and gages with recorders were: CM26CDA=D_2, CM26DBB=D_1, CM33DDA2=D_1, CM34BDD=D_1, CM35BBB=D_2, South Channel Stage=D_{65}.

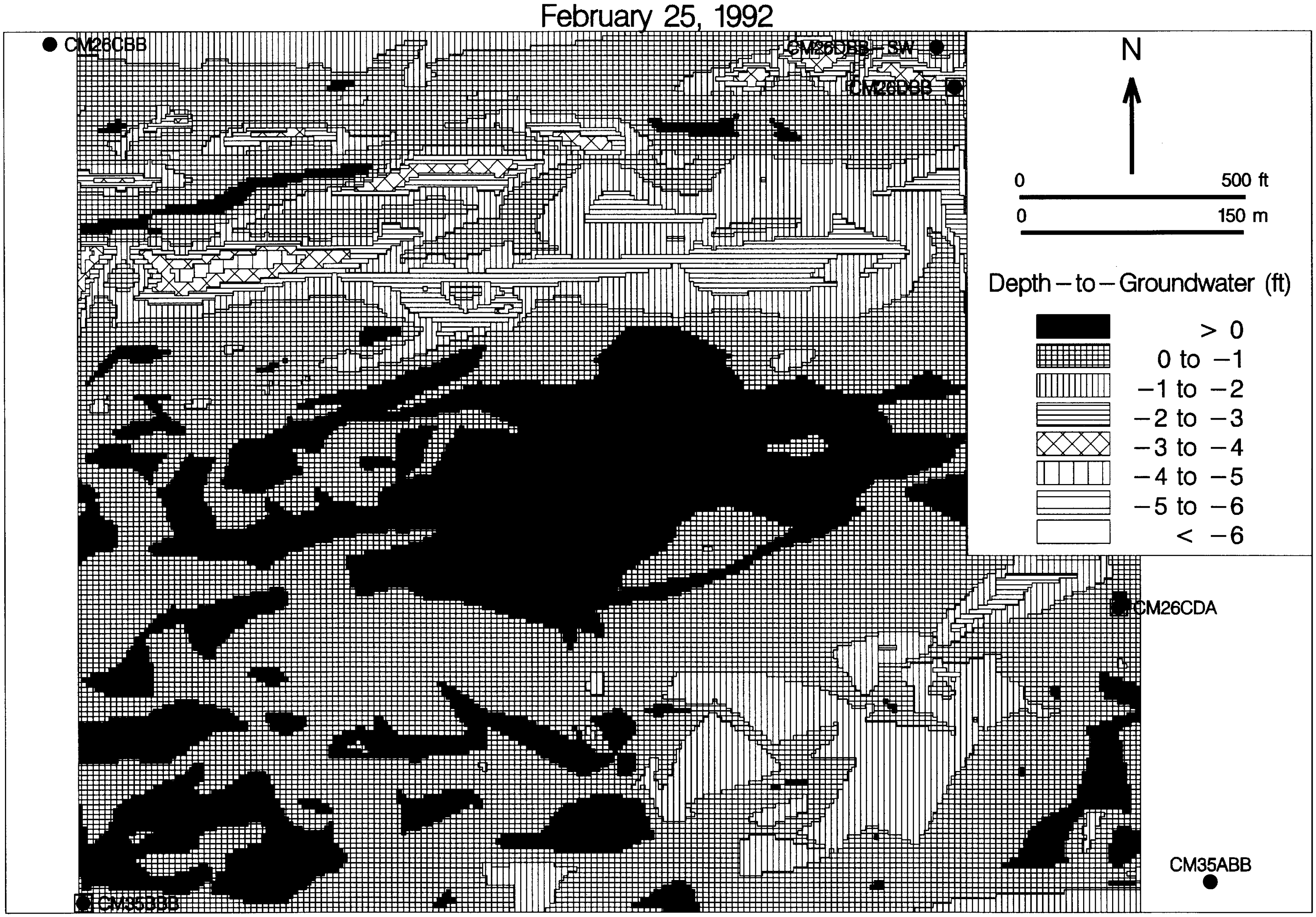


Figure 51. Depth-to-groundwater (ft) for a representative area at Crane Meadows on a day approximating a median water level for February though April. Depth-to-groundwater durations for the wells and gages with recorders were: CM26CDA=D_{50}, CM26DBB=D_{30}, CM33DDA2=D_{38}, CM34BDD=D_{24}, CM35BBB=D_{50}, South Channel Stage=D_{53}.

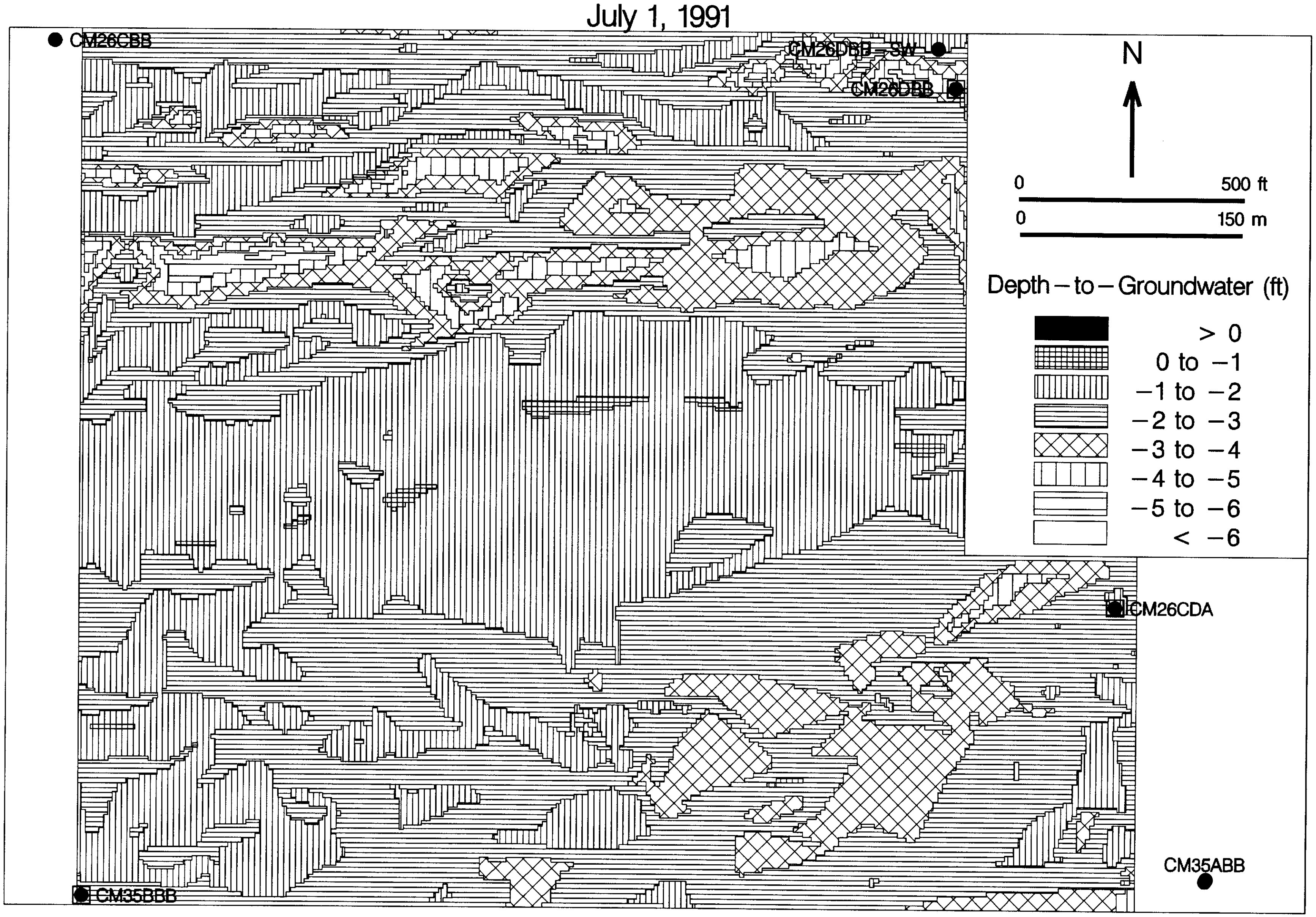


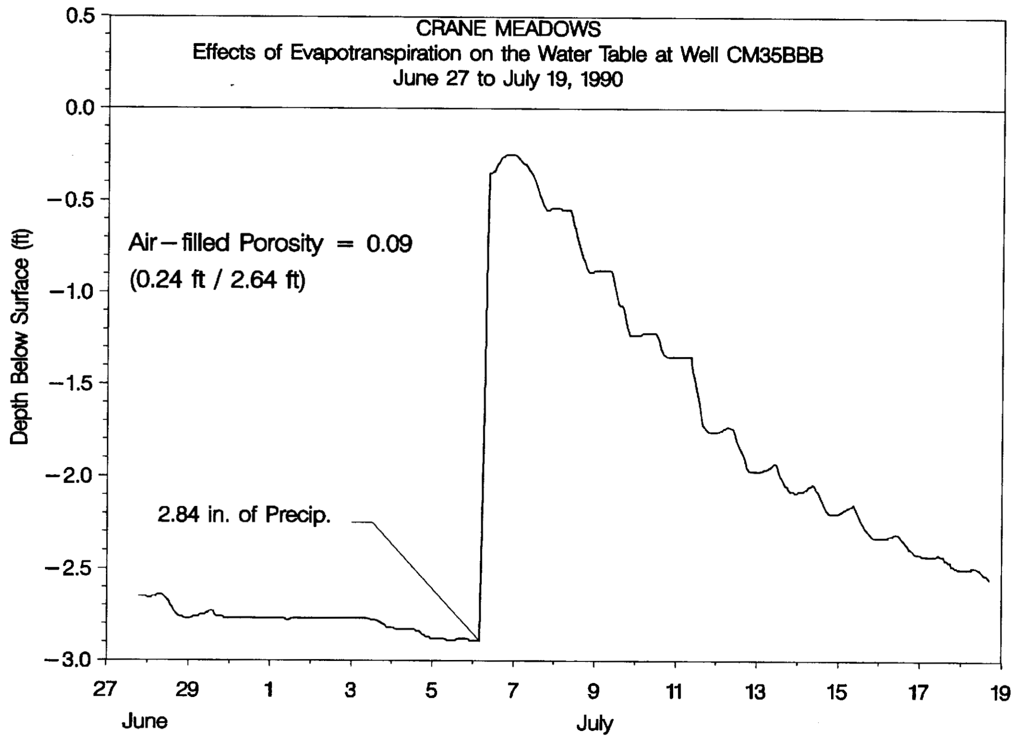
Figure 52. Depth-to-groundwater (ft) for a representative area at Crane Meadows on a day approximating a median water level for June through September. Depth-to-groundwater durations for the wells and gages with recorders were: CM26CDA=D_{28}, CM26DBB=D_{61}, CM33DDA2=D_{50}, CM34BDD=D_{63}, CM35BBB=D_{50}, South Channel Stage=D_{56}.

repeatedly throughout the growing season at the three sites.

Figure 53a shows a typical response to precipitation and evapotranspiration for a well located where the water table was close to the surface. From 27 June through 5 July the water table was apparently below the effective rooting zone, because there were no diurnal water table fluctuations. Precipitation on 6 July raised the water table 2.64 ft. For the next 12 days or so, the daily cycle of ET_{WT} lowered the water table to the point where roots were no longer able to effectively remove water from the water table. As the water table dropped, the plants probably became more dependent on the unsaturated water (ET_{US}) stored in the soil profile from precipitation or from when the water table was higher. Note also that when the water table was above -1.5 ft there was no recharge at night (8-11 July), suggesting that the river was neither supplying nor receiving groundwater from this location and that the plants were primarily responsible for lowering the water table. Once the water table dropped below about -1.5 ft recharge occurred at night (12-19 July), suggesting that groundwater was flowing to the well.

When the plants became dormant and ET was minimal, the diurnal water-table fluctuations did not occur (Figure 53b). Evapotranspiration began to influence the groundwater level in late March or early April, and became an important influence by May (Figure 54). The influence of ET_{WT} was greatly reduced again by late September. The last observable ET_{WT} in 1990 for this well was 14 September (Figure 54c), and the adjacent vegetation was mostly brown by 3 October 1990. The last ET_{WT} observed for any well with a recorder in 1990 was during the first week of October (Figure 54d). When ET_{WT} was minimal, the water table tended to remain elevated following precipitation (Figure 53b). The water table also tended to rise in the fall following the cessation of ET_{WT} without a corresponding change in river stage. For example from 28 September through 16 October 1990 the river stage was nearly constant (1901.02 to 1901.06 ft), but the water table at CM35BBB rose. This may indicate that ET_{WT} was depressing the water table in the center of Crane Meadows, preventing recharge until ET_{WT} decreased in the fall. Diurnal water-table

(a)



(b)

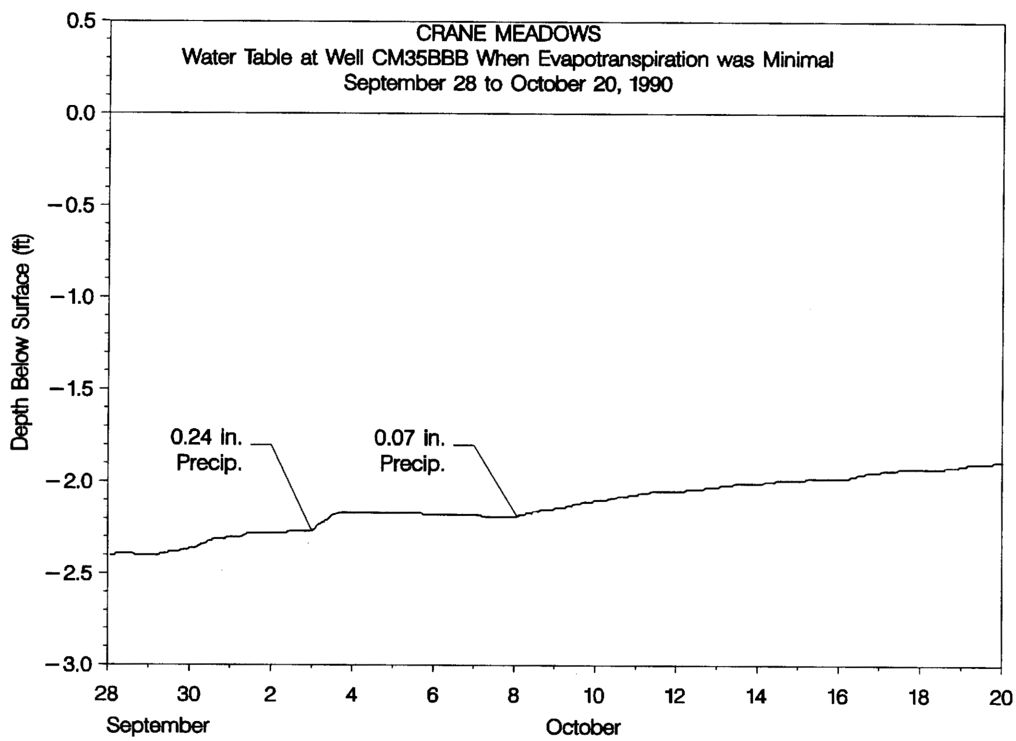


Figure 53. A typical response to precipitation and evapotranspiration (ET_{WT}) for well CM35BBB. ET_{WT} was active during the growing season (a), and was minimal during the rest of the year (b).

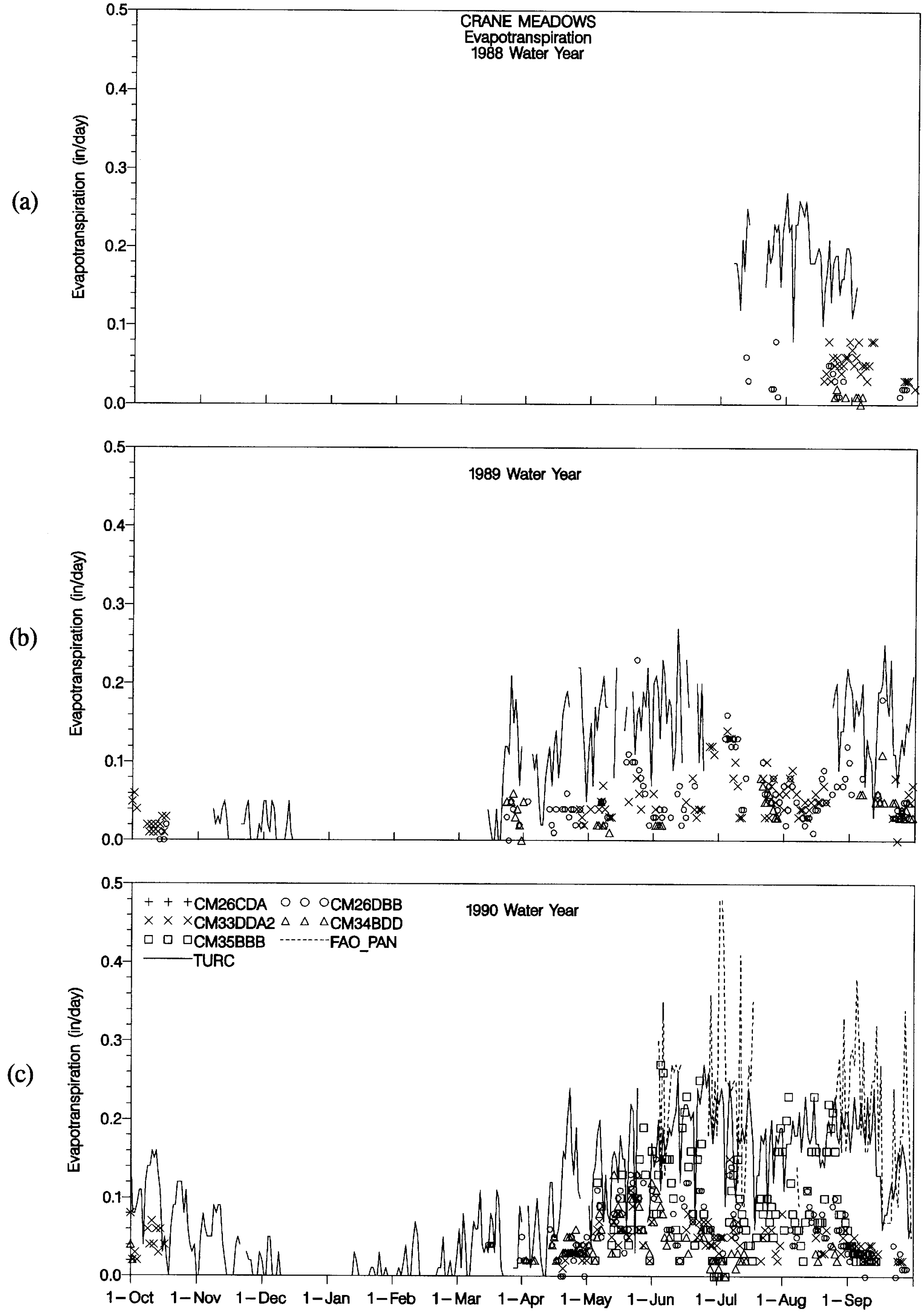
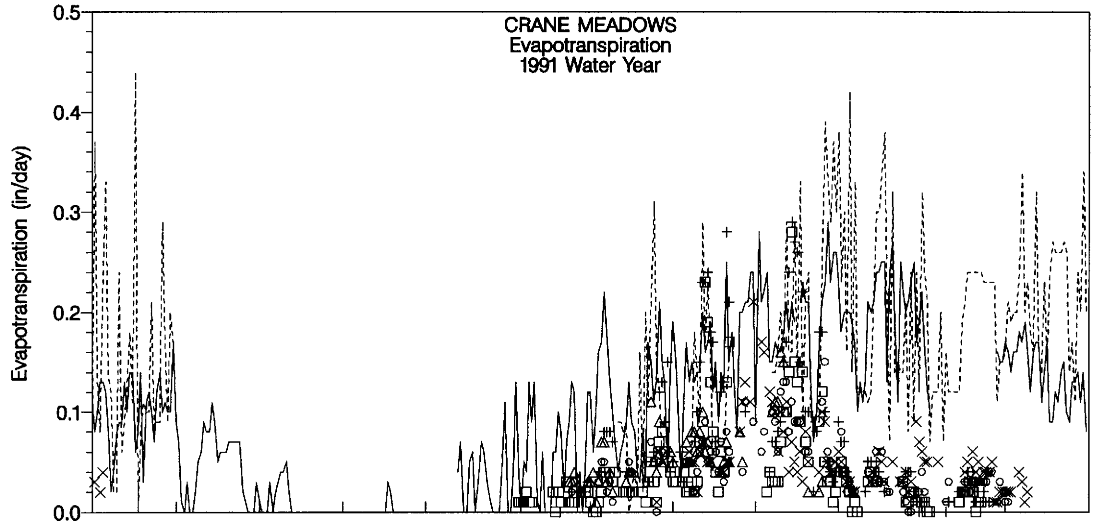


Figure 54. Evapotranspiration (in/day) for Crane Meadows by water year from 1988 through 1992. (Continued next page)

(d)



(e)

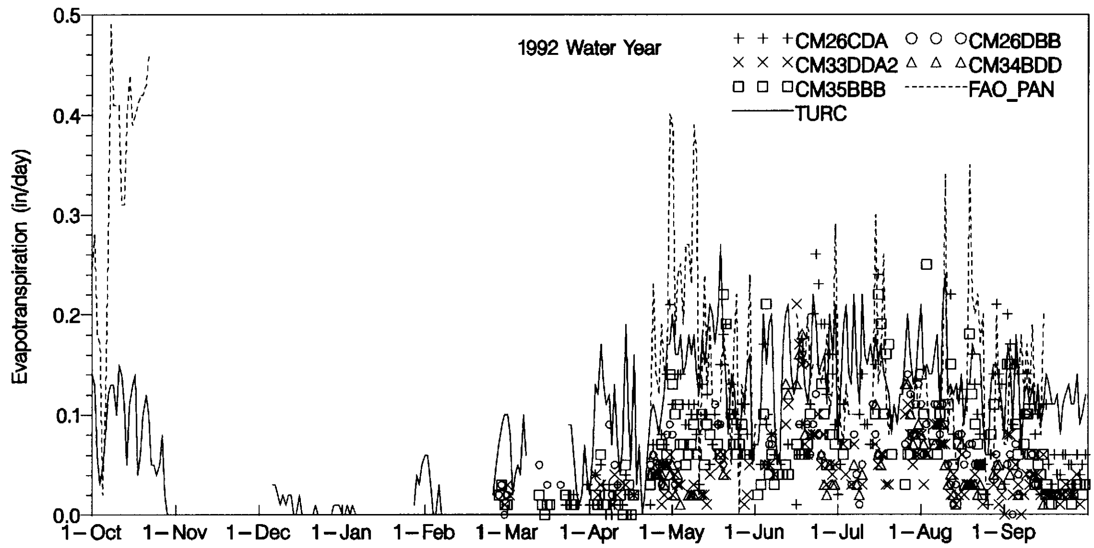


Figure 54 (continued). Evapotranspiration from the water table (ET_{WT}) is shown for wells CM26CDA, CM26DBB, CM33DDA2, CM34BDD, and CM35BBB. Well CM35BBB began May 1990, and well CM26CDA began September 1990. The potential evapotranspiration (PET) based on Turc's method is shown for all non-missing days, and all non-missing days during the growing season for the FAO-24 pan method are shown beginning in 1990.

cycles caused by the river stage responding to power peaking also occurred. This was especially evident at Rowe Sanctuary, but usually occurred during the dormant season or the cycles were out of phase with the typical ET_{WT} cycle.

Since ET_{WT} declined as the water table dropped, it appeared possible to determine the effective plant rooting depth by finding the depth at which ET_{WT} became insignificant. ET_{WT} also varied by season (Figure 54), so ET_{WT} was adjusted for seasonal variation by dividing ET_{WT} by the potential evapotranspiration (PET). The adjusted data were then plotted by depth for each observation to produce Figures 55 through 59. A best-fit curve was drawn by hand through the data to help identify the ET_{WT} trend. The percent of PET exceeded 100% for three wells (Figures 55, 56 and 58). This may be because PET was not adjusted for a well watered reference crop such as alfalfa (Committee on Irrigation Water Requirements of the Irrigation and Drainage Division of the ASCE 1990), or the value selected for the air-filled porosity (ϕ-Θ) was too high. In either case, the axis for the percent of PET can be interpreted as a relative scale without regard for the precise value. Only the wells from Crane Meadows were examined, since it was the only site equipped with instrumentation for estimating PET.

The effective plant rooting depth for the two wells located where the water table was normally close to the surface (CM26CDA and CM35BBB) appeared to be about -3.0 ft (Figures 55 and 56). No ET_{WT} was observed below -3.1 ft. ET_{WT} reached a maximum at about -1.2 to -1.0 ft, then declined again as the water table approached the surface. The decline in ET_{WT} when the water table was above -1.0 ft may indicate that these plants were inhibited by a high water table. The water table was only above -1.0 ft for about 22-30% of the time for June through September 1990(91)-92 (Figure 17c), so maybe these plants were able to tolerate high water levels rather than maximize their water use. By tolerating high water levels these plants probably had an advantage over species not native to the wet meadows. Without this advantage, the native species might be replaced by other species. About 43-56% of the time the water table for June through September 1990(91)-92 was below -2.0 ft (Figure 17c), indicating that these plants may also be dependent upon water stored in

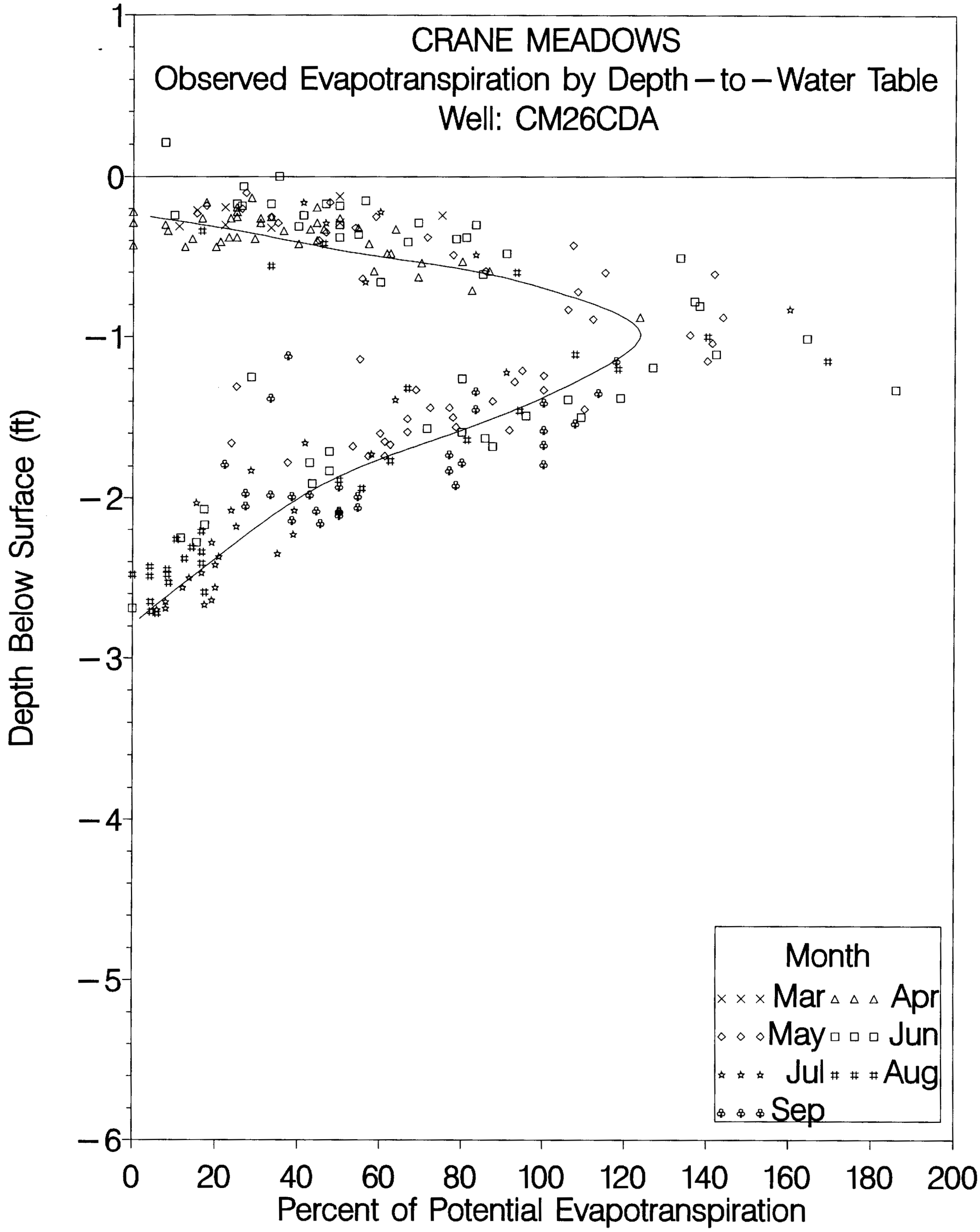


Figure 55. Evapotranspiration from the water table (ET_{WT}) at Crane Meadows well CM26CDA, expressed as a percentage of ET_{WT} to the potential evapotranspiration (PET), and as a function of depth below the surface. The air-filled porosity (ϕ-Θ) selected for this well was 0.057.

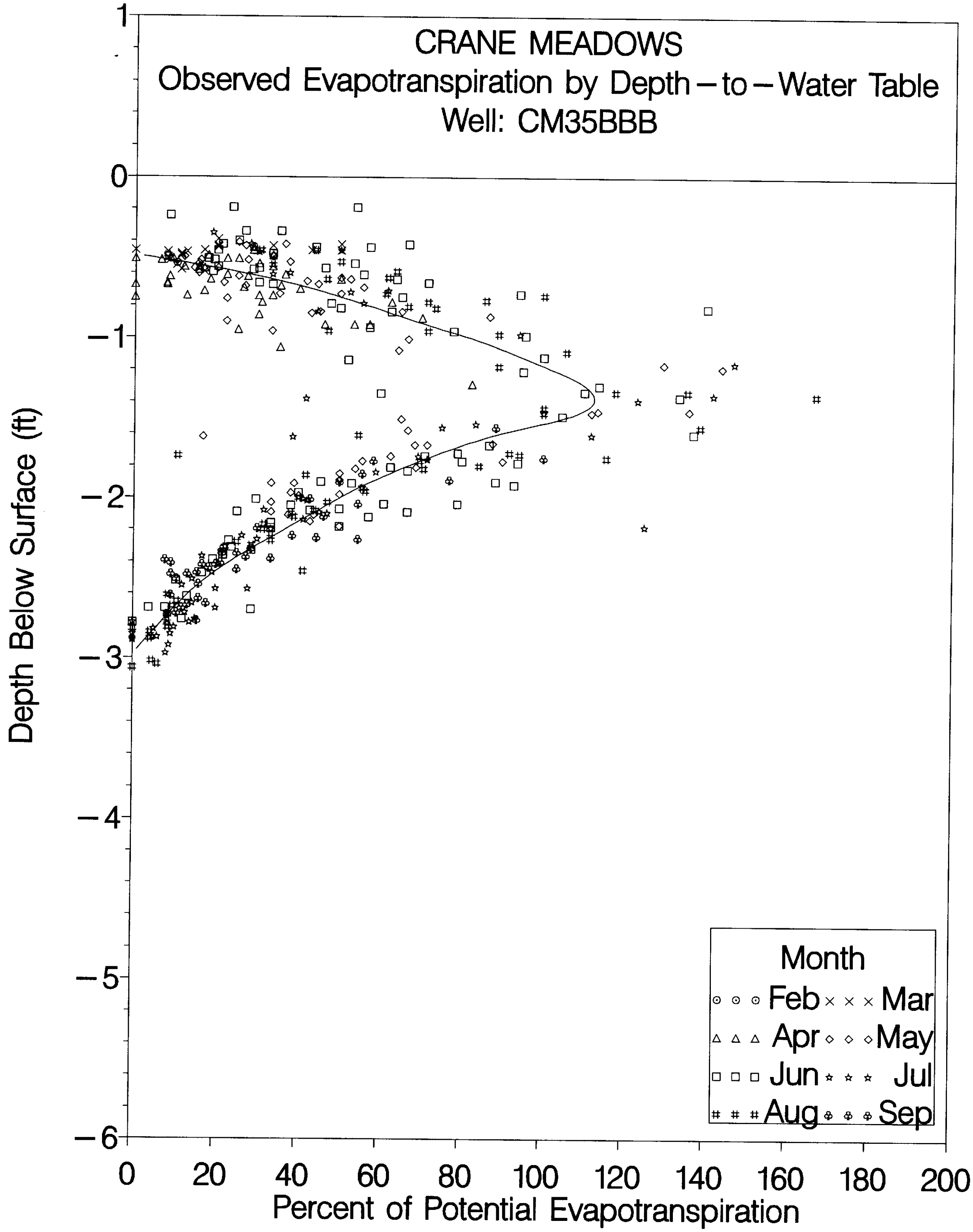


Figure 56. Evapotranspiration from the water table (ET_{WT}) at Crane Meadows well CM35BBB, expressed as a percentage of ET_{WT} to the potential evapotranspiration (PET), and as a function of depth below the surface. The air-filled porosity (ϕ-Θ) selected for this well was 0.053.

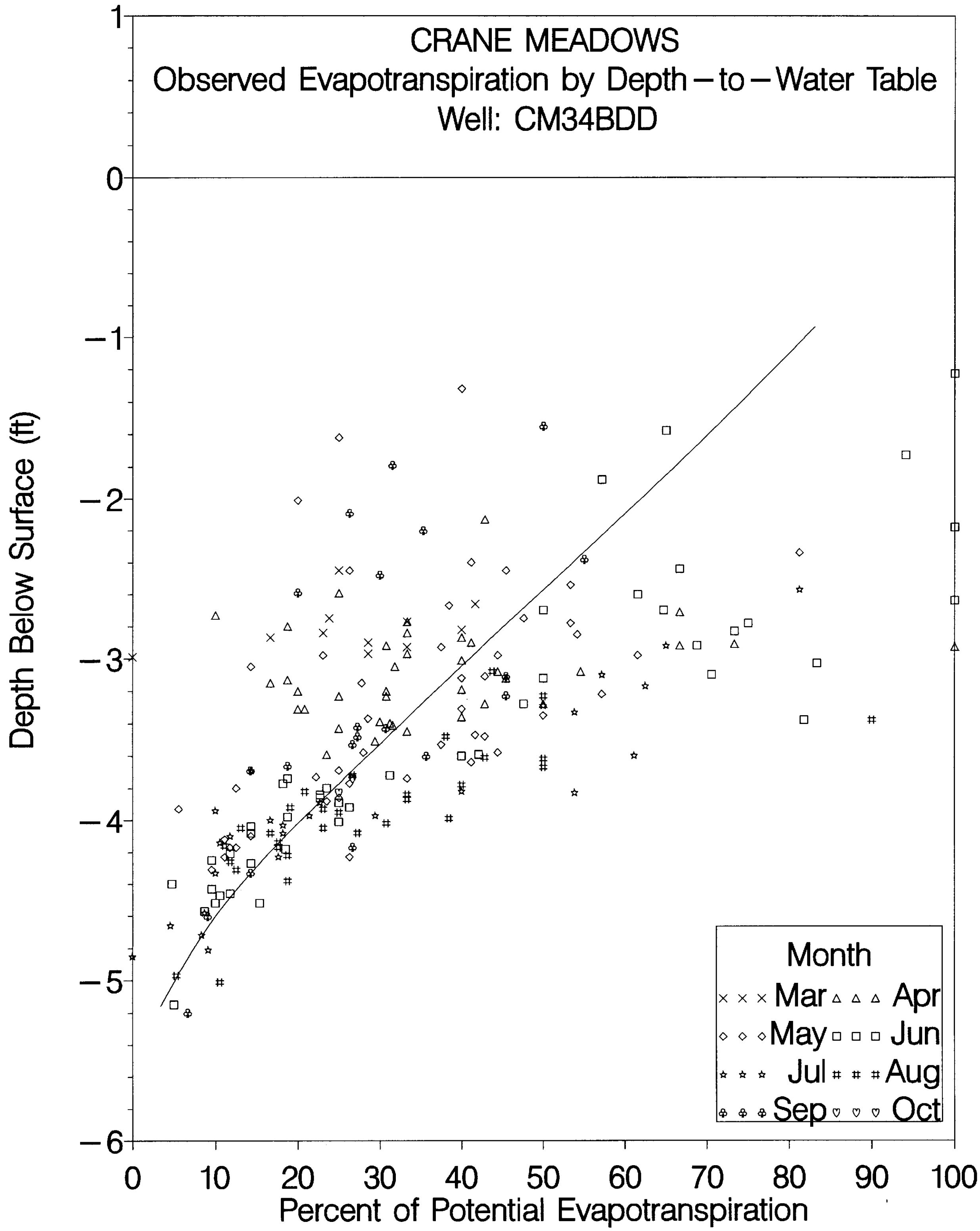


Figure 57. Evapotranspiration from the water table (ET_{WT}) at Crane Meadows well CM34BDD, expressed as a percentage of ET_{WT} to the potential evapotranspiration (PET), and as a function of depth below the surface. The air-filled porosity (ϕ-Θ) selected for this well was 0.058.

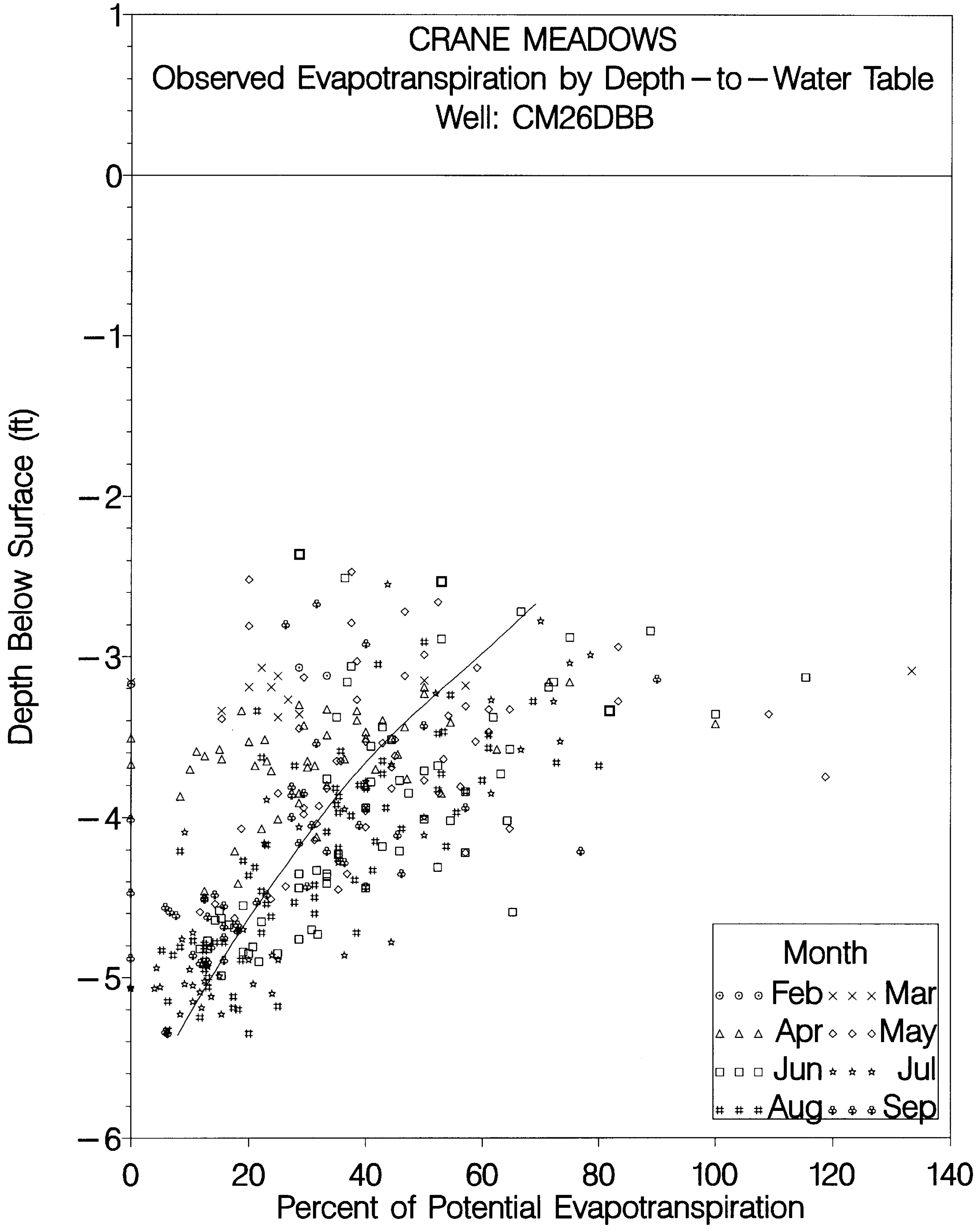


Figure 58. Evapotranspiration from the water table (ET_{WT}) at Crane Meadows well CM26DBB, expressed as a percentage of ET_{WT} to the potential evapotranspiration (PET), and as a function of depth below the surface. The air-filled porosity (ϕ-Θ) selected for this well was 0.071.

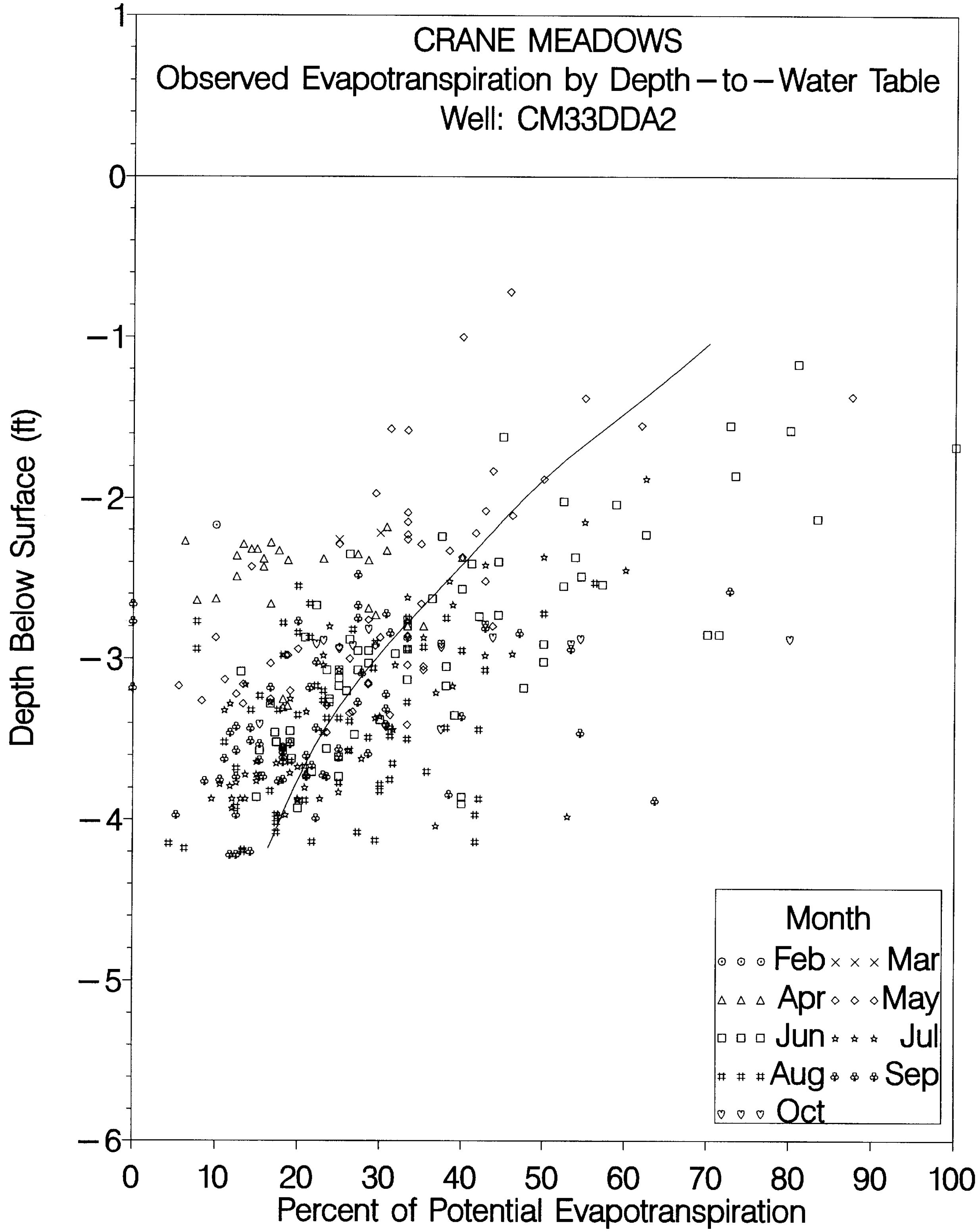


Figure 59. Evapotranspiration from the water table (ET_{WT}) at Crane Meadows well CM33DDA2, expressed as a percentage of ET_{WT} to the potential evapotranspiration (PET), and as a function of depth below the surface. The air-filled porosity (ϕ-Θ) selected for this well was 0.070.

the soil profile besides water from the water table. These plants may require a shallow water table for their long-term survival, however, since the water table was never below -3.2 ft for June through September 1990(91)-92 (Figure 17c).

The other three wells (Figures 57, 58 and 59) seldom, if ever, had the water table above -1.0 ft for June through September 1989-92 (Figure 17c), so it was impossible to detect any potential inhibitory effects from an elevated water table. The water table was above -2.0 ft less than 10% of the time for June through September 1989-92 (Figure 17c), so it was also impossible to determine an optimum depth for ET_{WT}, since ET_{WT} was still increasing above this depth. It does, however, appear that the effective rooting depth for the plants surrounding these wells was between -5.0 and -6.0 ft. The plants surrounding well CM33DDA2 appeared to have an effective rooting depth at about -4.0 ft (Figure 59), but this well was close the river and the water table never dropped below -4.3 ft for June through September 1989-92 (Figure 17c). The ET_{WT} trend was similar to CM34BDD and CM26DBB, however, so the effective rooting depth was also probably similar.

Groundwater Withdrawal for Irrigation

Adjacent groundwater withdrawal for irrigation had little or no direct affect on the groundwater levels at all three sites (Figures 60 through 62, see Appendix D for additional years). This does not mean, however, that the cumulative effects from groundwater withdrawals for irrigation in the Platte River Valley did not have an affect on the groundwater levels at the study sites. Evaluating the effect of valley-wide groundwater withdrawals was beyond the scope of our study. This portion of our study was only intended to determine the effects that adjacent groundwater withdrawals might have on the study site groundwater levels. If adjacent groundwater withdrawals had an affect, then the groundwater levels at each site would have shown temporary water-level fluctuations as individual wells were turned on and off. This pattern of water level fluctuations did not occur (Figures 60 through 62). The groundwater levels, were however, responsive to precipitation events.

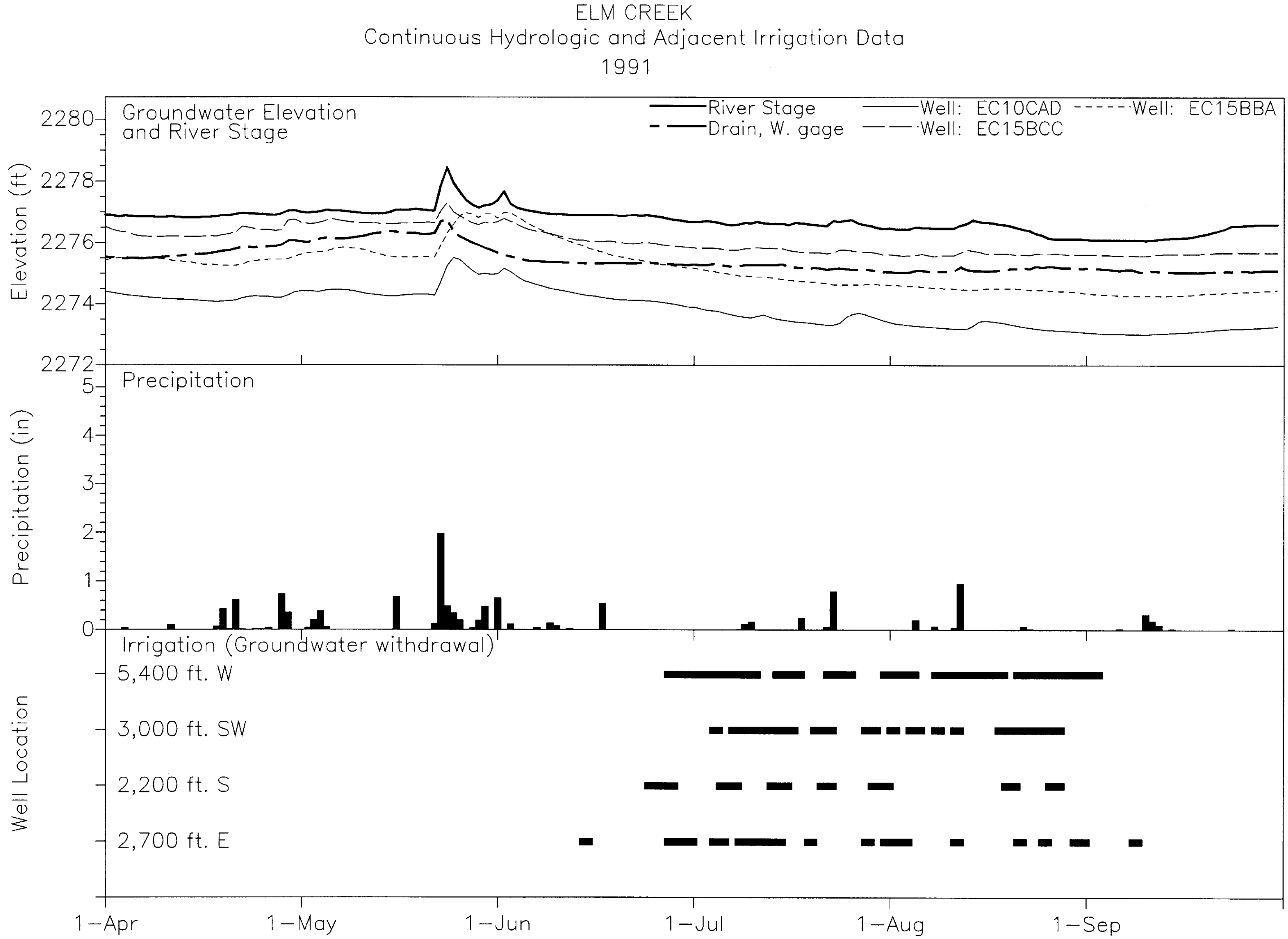


Figure 60. Elm Creek groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1991. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

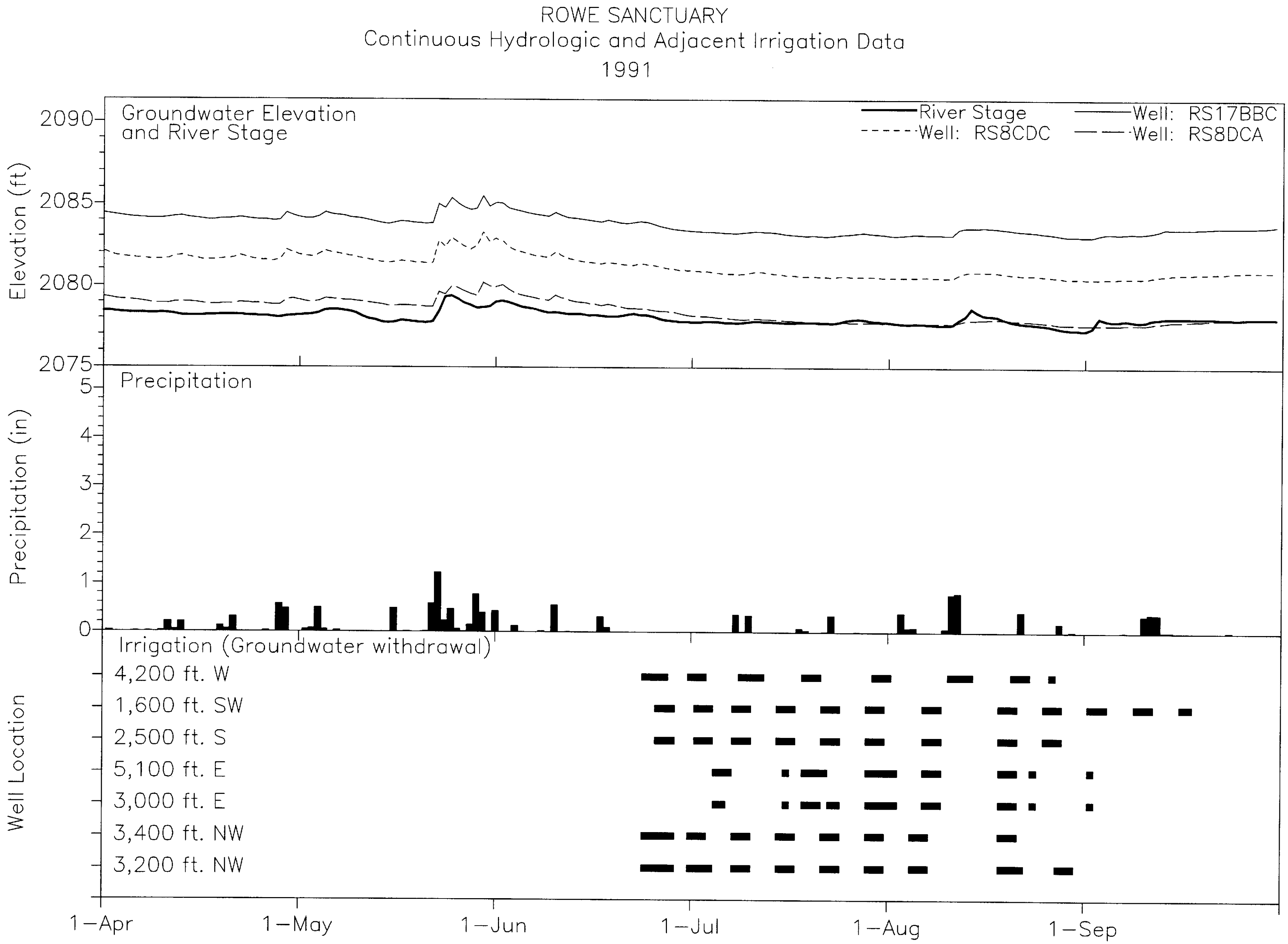


Figure 61. Rowe Sanctuary groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1991. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

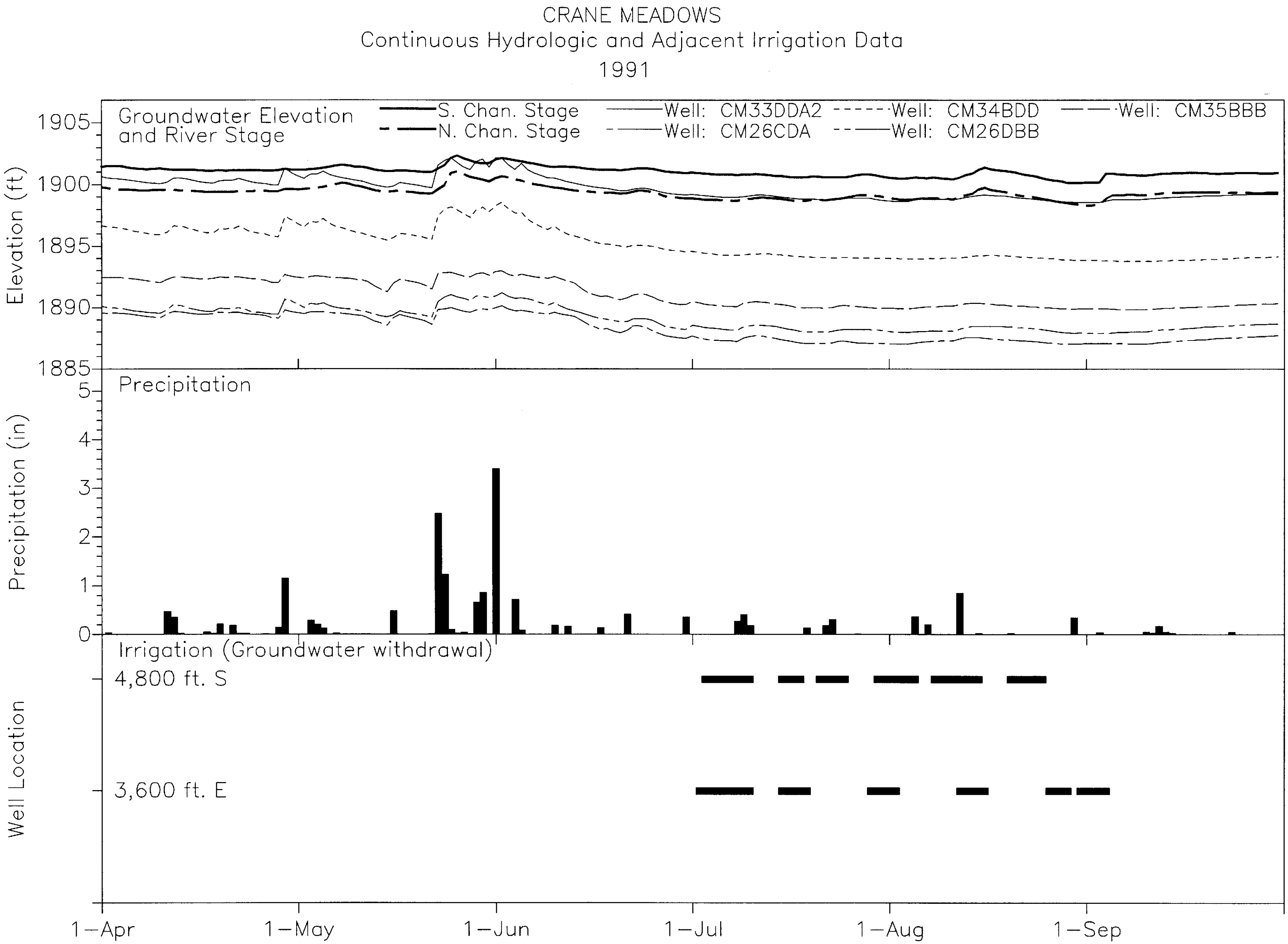


Figure 62. Crane Meadows groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1991. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

The distance between the study-site wells and the irrigation wells was probably the most important factor that minimized the effect of adjacent groundwater withdrawals. Most irrigation wells were at least a half mile from the nearest groundwater-level recorder. In a permeable unconfined aquifer, such as the Platte River alluvium, the cone of depression from an irrigation well has a wide radius, but the cone is shallow with flat sides (Driscoll 1986). So even though the radius of influence from irrigation wells in permeable soils can be fairly wide, Driscoll (1986, p. 209) has an example with a radius of 40,000 ft, the drawdown rapidly becomes insignificant with increasing distance from the well. For the Wet Meadow Hydrology study sites, the distance between observation wells (i.e., wells with recorders) and irrigation wells was sufficient to make the influence from adjacent groundwater withdrawals undetectable. We did, however, observe drawdowns caused by nearby irrigation wells in a few cross-valley transect wells, but these drawdowns do not appear in the figures for this report (i.e., Figures 21 through 27). For example, cross-valley transect well 9-10-3CCC (Figure 8) was located within 25 ft of an irrigation well, and cross-valley transect well 8-14-4BCB (Figure 7) was an irrigation well that was also used as an observation well.

Separation of River Stage, Precipitation and Evapotranspiration

Correlation of daily values was used to separate the influence of river stage, precipitation, and evapotranspiration on the groundwater level at each site. Short-term values (e.g., daily means and totals) tend to emphasize highly responsive relationships, while long-term values (e.g., monthly means and totals) tend to emphasize the dominant relationships. Correlations (r) for Elm Creek and Rowe Sanctuary are presented in Tables 5 through 8. Data were available for potential evapotranspiration (PET) at Crane Meadows and are presented with the correlations in Tables 9 and 10. Tables 5, 7, and 9 present the correlations for the period-of-record and seasonal correlations for Elm Creek, Rowe Sanctuary, and Crane Meadows respectively. The seasonal correlations include the February through June period, and correlations for this period separated into a season for minimal PET (February through

Table 5. Period-of-record and seasonal correlations (r) between daily values for groundwater level, river stage and precipitation for three wells and the groundwater drain at Elm Creek. Wells are listed in order of increasing distance from the River. The probability (p) that $r \neq 0$, and the sample size (n) are shown in parentheses. Highlighted correlations are significantly correlated ($p \leq 0.05$) with the groundwater level at the well, but not correlated with each other ($p > 0.05$).

Well	River Stage r (p / n)	Antecedent Precipitation r (p / n)
PERIOD OF RECORD:		
EC10CAD	**0.78** (<.001/1505)	0.24 (<.001/1514)
EC15BBA	**0.56** (<.001/1505)	0.22 (<.001/1528)
EC15BCC	**0.47** (<.001/1505)	0.43 (<.001/1528)
DRAIN	**0.33** (<.001/ 853)	0.24 (<.001/ 853)
FEBRUARY THROUGH JUNE:		
EC10CAD	**0.78** (<.001/601)	0.34 (<.001/601)
EC15BBA	**0.55** (<.001/601)	0.28 (<.001/601)
EC15BCC	0.40 (<.001/601)	**0.44** (<.001/601)
DRAIN	**0.34** (<.001/331)	0.16 (0.003/331)
FEBRUARY THROUGH APRIL:		
EC10CAD	**0.64** (<.001/357)	**0.14** (0.010/357)
EC15BBA	**0.21** (<.001/357)	**0.14** (0.007/357)
EC15BCC	-0.05 (0.349/357)	**0.30** (<.001/357)
DRAIN	**0.69** (<.001/179)	0.00 (0.989/179)
MAY THROUGH JUNE:		
EC10CAD	**0.83** (<.001/244)	0.43 (<.001/244)
EC15BBA	**0.69** (<.001/244)	0.30 (<.001/244)
EC15BCC	**0.68** (<.001/244)	0.49 (<.001/244)
DRAIN	0.24 (0.003/152)	**0.36** (<.001/152)
JULY THROUGH SEPTEMBER:		
EC10CAD	**0.82** (<.001/412)	0.28 (<.001/421)
EC15BBA	**0.64** (<.001/412)	0.20 (<.001/435)
EC15BCC	**0.70** (<.001/412)	0.52 (<.001/435)
DRAIN	**0.60** (<.001/276)	0.44 (<.001/276)
OCTOBER THROUGH NOVEMBER:		
EC10CAD	**0.85** (<.001/244)	-0.10 (0.124/244)
EC15BBA	**0.60** (<.001/244)	**-0.20** (0.002/244)
EC15BCC	0.06 (0.374/244)	**-0.16** (0.012/244)
DRAIN	**0.30** (<.001/122)	**0.19** (0.036/122)
DECEMBER THROUGH JANUARY:		
EC10CAD	**0.66** (<.001/248)	0.06 (0.338/248)
EC15BBA	**-0.19** (0.002/248)	0.00 (0.943/248)
EC15BCC	**-0.47** (<.001/248)	**0.20** (0.001/248)
DRAIN	**-0.50** (<.001/124)	**0.27** (0.002/124)

Table 6. Monthly correlation (r) between daily values for groundwater level, river stage and precipitation for three wells and the groundwater drain at Elm Creek. Wells are listed in order of increasing distance from the River. The probability (p) that $r \neq 0$, and the sample size (n) are shown in parentheses. Highlighted correlations are significantly correlated ($p \leq 0.05$) with the groundwater level at the well, but not correlated with each other ($p > 0.05$).

Well	River Stage r	River Stage (p / n)	Antecedent Precipitation r	Antecedent Precipitation (p / n)
JANUARY:				
EC10CAD	**0.47**	(<.001/124)	0.16	(0.067/124)
EC15BBA	**-0.56**	(<.001/124)	0.06	(0.514/124)
EC15BCC	**-0.60**	(<.001/124)	**0.34**	(<.001/124)
DRAIN	**-0.69**	(<.001/ 62)	0.24	(0.064/ 62)
FEBRUARY:				
EC10CAD	**0.70**	(<.001/113)	0.07	(0.477/113)
EC15BBA	0.18	(0.062/113)	0.06	(0.561/113)
EC15BCC	**-0.26**	(0.005/113)	0.14	(0.147/113)
DRAIN	**0.82**	(<.001/ 57)	0.25	(0.057/ 57)
MARCH:				
EC10CAD	**0.65**	(<.001/124)	0.07	(0.458/124)
EC15BBA	0.18	(0.051/124)	0.07	(0.420/124)
EC15BCC	-0.01	(0.923/124)	**0.42**	(<.001/124)
DRAIN	**0.92**	(<.001/ 62)	0.06	(0.634/ 62)
APRIL:				
EC10CAD	**0.21**	(0.020/120)	-0.08	(0.394/120)
EC15BBA	0.07	(0.448/120)	-0.09	(0.329/120)
EC15BCC	-0.16	(0.077/120)	0.11	(0.223/120)
DRAIN	**0.82**	(<.001/ 60)	-0.21	(0.110/ 60)
MAY:				
EC10CAD	**0.84**	(<.001/124)	0.52	(<.001/124)
EC15BBA	**0.70**	(<.001/124)	0.39	(<.001/124)
EC15BCC	**0.72**	(<.001/124)	0.47	(<.001/124)
DRAIN	**0.70**	(<.001/ 62)	0.57	(<.001/ 62)
JUNE:				
EC10CAD	**0.86**	(<.001/120)	0.37	(<.001/120)
EC15BBA	**0.77**	(<.001/120)	0.24	(0.007/120)
EC15BCC	**0.72**	(<.001/120)	0.50	(<.001/120)
DRAIN	**-0.37**	(<.001/ 90)	0.22	(0.037/ 90)
JULY:				
EC10CAD	**0.77**	(<.001/124)	0.38	(<.001/124)
EC15BBA	**0.62**	(<.001/124)	0.22	(0.011/130)
EC15BCC	**0.79**	(<.001/124)	0.51	(<.001/130)
DRAIN	**0.54**	(<.001/ 93)	0.69	(<.001/ 93)
AUGUST:				
EC10CAD	**0.77**	(<.001/138)	0.21	(0.010/147)
EC15BBA	**0.53**	(<.001/138)	0.22	(0.007/155)
EC15BCC	**0.71**	(<.001/138)	0.62	(<.001/155)
DRAIN	**0.66**	(<.001/ 93)	0.25	(0.014/ 93)

Table 6 (continued).

Well	River Stage r	River Stage (p / n)	Antecedent Precipitation r	Antecedent Precipitation (p / n)
SEPTEMBER:				
EC10CAD	**0.89**	(<.001/150)	0.24	(0.003/150)
EC15BBA	**0.71**	(<.001/150)	0.13	(0.105/150)
EC15BCC	**0.61**	(<.001/150)	0.34	(0.001/150)
DRAIN	**0.62**	(<.001/ 90)	-0.16	(0.128/ 90)
OCTOBER:				
EC10CAD	**0.88**	(<.001/124)	-0.08	(0.383/124)
EC15BBA	**0.64**	(<.001/124)	-0.12	(0.202/124)
EC15BCC	0.12	(0.181/124)	-0.03	(0.735/124)
DRAIN	**-0.49**	(<.001/ 62)	0.21	(0.104/ 62)
NOVEMBER:				
EC10CAD	**0.67**	(<.001/120)	**-0.37**	(<.001/120)
EC15BBA	**0.23**	(0.011/120)	**-0.55**	(<.001/120)
EC15BCC	**-0.40**	(<.001/120)	**-0.39**	(<.001/120)
DRAIN	**-0.42**	(<.001/ 60)	0.09	(0.515/ 60)
DECEMBER:				
EC10CAD	**0.84**	(<.001/124)	-0.15	(0.091/124)
EC15BBA	**0.21**	(0.017/124)	**-0.27**	(0.003/124)
EC15BCC	**-0.36**	(<.001/124)	0.01	(0.882/124)
DRAIN	**-0.60**	(<.001/ 62)	**0.34**	(0.007/ 62)

Table 7. Period-of-record and seasonal correlations (r) between daily values for groundwater level, river stage and precipitation for three wells at Rowe Sanctuary. Wells are listed in order of increasing distance from the River. The probability (p) that $r \neq 0$, and the sample size (n) are shown in parentheses. Highlighted correlations are significantly correlated ($p \leq 0.05$) with the groundwater level at the well, but not correlated with each other ($p > 0.05$).

Well	River Stage r (p / n)	Antecedent Precipitation r (p / n)
PERIOD OF RECORD:		
RS17BBC	**0.81** (<.001/1537)	**0.28** (<.001/1537)
RS8CDC	**0.70** (<.001/1536)	**0.32** (<.001/1536)
RS8DCA	**0.61** (<.001/1539)	**0.34** (<.001/1539)
FEBRUARY THROUGH JUNE:		
RS17BBC	**0.83** (<.001/601)	**0.37** (<.001/601)
RS8CDC	**0.76** (<.001/601)	**0.37** (<.001/601)
RS8DCA	**0.70** (<.001/601)	**0.43** (<.001/601)
FEBRUARY THROUGH APRIL:		
RS17BBC	**0.62** (<.001/357)	**0.42** (<.001/357)
RS8CDC	**0.53** (<.001/357)	**0.53** (<.001/357)
RS8DCA	**0.47** (<.001/357)	**0.47** (<.001/357)
MAY THROUGH JUNE:		
RS17BBC	**0.86** (<.001/244)	0.66 (<.001/244)
RS8CDC	**0.82** (<.001/244)	0.60 (<.001/244)
RS8DCA	**0.79** (<.001/244)	0.61 (<.001/244)
JULY THROUGH SEPTEMBER:		
RS17BBC	**0.78** (<.001/444)	0.58 (<.001/444)
RS8CDC	**0.61** (<.001/443)	0.54 (<.001/443)
RS8DCA	**0.53** (<.001/446)	0.50 (<.001/446)
OCTOBER THROUGH NOVEMBER:		
RS17BBC	**0.87** (<.001/244)	0.02 (<.778/244)
RS8CDC	**0.73** (<.001/244)	-0.04 (<.529/244)
RS8DCA	**0.67** (<.001/244)	-0.07 (<.310/244)
DECEMBER THROUGH JANUARY:		
RS17BBC	**0.46** (<.001/248)	0.06 (<.330/248)
RS8CDC	**0.38** (<.001/248)	0.29 (<.001/248)
RS8DCA	**0.16** (<.014/248)	0.19 (<.003/244)

Table 8. Monthly correlation (r) between daily values for groundwater level, river stage and precipitation for three wells at Rowe Sanctuary. Wells are listed in order of increasing distance from the River. The probability (p) that $r \neq 0$, and the sample size (n) are shown in parentheses. Highlighted correlations are significantly correlated ($p \leq 0.05$) with the groundwater level at the well, but not correlated with each other ($p > 0.05$).

Well	River Stage r (p / n)	Antecedent Precipitation r (p / n)
JANUARY:		
RS17BBC	0.01 (0.900/124)	0.01 (0.872/124)
RS8CDC	0.00 (0.998/124)	**0.51** (<.001/124)
RS8DCA	**-0.49** (<.001/124)	0.30 (<.001/124)
FEBRUARY:		
RS17BBC	**0.24** (0.009/113)	0.17 (0.066/113)
RS8CDC	0.17 (0.071/113)	**0.48** (<.001/113)
RS8DCA	-0.12 (0.210/113)	**0.53** (<.001/113)
MARCH:		
RS17BBC	**0.60** (<.001/124)	0.47 (<.001/124)
RS8CDC	**0.61** (<.001/124)	0.52 (<.001/124)
RS8DCA	**0.68** (<.001/124)	0.43 (<.001/124)
APRIL:		
RS17BBC	**0.91** (<.001/120)	0.08 (0.382/120)
RS8CDC	**0.81** (<.001/120)	**0.20** (0.028/120)
RS8DCA	**0.79** (<.001/120)	0.08 (0.414/120)
MAY:		
RS17BBC	**0.85** (<.001/124)	0.74 (<.001/124)
RS8CDC	**0.77** (<.001/124)	0.74 (<.001/124)
RS8DCA	**0.71** (<.001/124)	0.67 (<.001/124)
JUNE:		
RS17BBC	**0.88** (<.001/120)	0.72 (<.001/120)
RS8CDC	**0.86** (<.001/120)	0.65 (<.001/120)
RS8DCA	**0.85** (<.001/120)	0.64 (<.001/120)
JULY:		
RS17BBC	**0.78** (<.001/139)	0.68 (<.001/139)
RS8CDC	**0.66** (<.001/138)	0.62 (<.001/138)
RS8DCA	**0.60** (<.001/141)	0.54 (<.001/141)
AUGUST:		
RS17BBC	**0.80** (<.001/155)	0.25 (0.002/155)
RS8CDC	**0.50** (<.001/155)	0.20 (0.011/155)
RS8DCA	**0.43** (<.001/155)	0.14 (0.084/155)
SEPTEMBER:		
RS17BBC	**0.87** (<.001/150)	0.58 (<.001/150)
RS8CDC	**0.77** (<.001/150)	0.54 (<.001/150)
RS8DCA	**0.73** (<.001/150)	0.49 (<.001/150)
OCTOBER:		
RS17BBC	**0.89** (<.001/124)	-0.02 (0.833/124)
RS8CDC	**0.79** (<.001/124)	-0.01 (0.902/124)
RS8DCA	**0.80** (<.001/124)	-0.03 (0.705/124)

Table 8 (continued).

Well	River Stage	Antecedent Precipitation
	r (p / n)	r (p / n)
NOVEMBER:		
RS17BBC	**0.63** (<.001/120)	-0.09 (0.312/120)
RS8CDC	**0.20** (0.031/120)	**-0.32** (<.001/120)
RS8DCA	-0.02 (0.829/120)	**-0.29** (0.001/120)
DECEMBER:		
RS17BBC	**0.69** (<.001/124)	0.17 (0.059/124)
RS8CDC	0.24 (0.007/124)	**0.44** (<.001/124)
RS8DCA	0.22 (0.013/124)	**0.25** (0.005/124)

Table 9. Period-of-record and seasonal correlations (r) between daily values for groundwater level and river stage, precipitation, and evapotranspiration for five wells at Crane Meadows. Wells are listed in order of increasing distance from the River. The probability (p) that r ≠ 0, and the sample size (n) are shown in parentheses. Highlighted correlations are significantly correlated ($p \leq 0.05$) with the groundwater level at the well, but not correlated with each other ($p > 0.05$).

Well	River Stage		Antecedent Precipitation		Potential Evapotranspiration	
	r	(p / n)	r	(p / n)	r	(p / n)
PERIOD OF RECORD:						
CM33DDA2	**0.80**	(<.001/1512)	**0.29**	(<.001/1512)	-0.46	(<.001/1106)
CM26DBB	**0.74**	(<.001/1542)	**0.25**	(<.001/1542)	-0.50	(<.001/1130)
CM26CDA	**0.71**	(<.001/ 747)	**0.24**	(<.001/ 747)	-0.48	(<.001/ 612)
CM35BBB	**0.70**	(<.001/ 881)	**0.27**	(<.001/ 881)	-0.44	(<.001/ 742)
CM34BDD	**0.69**	(<.001/1547)	**0.23**	(<.001/1547)	-0.46	(<.001/1135)
FEBRUARY THROUGH JUNE:						
CM33DDA2	**0.81**	(<.001/601)	0.40	(<.001/601)	-0.41	(<.001/482)
CM26DBB	**0.76**	(<.001/601)	0.34	(<.001/601)	-0.45	(<.001/482)
CM26CDA	**0.56**	(<.001/301)	0.33	(<.001/301)	-0.43	(<.001/258)
CM35BBB	**0.59**	(<.001/359)	0.30	(<.001/359)	-0.49	(<.001/312)
CM34BDD	**0.73**	(<.001/601)	0.37	(<.001/601)	-0.40	(<.001/482)
FEBRUARY THROUGH APRIL:						
CM33DDA2	**0.68**	(<.001/357)	**0.47**	(<.001/357)	-0.48	(<.001/260)
CM26DBB	**0.59**	(<.001/357)	**0.39**	(<.001/357)	-0.51	(<.001/260)
CM26CDA	0.20	(0.007/179)	0.40	(<.001/179)	**-0.50**	(<.001/136)
CM35BBB	0.36	(<.001/179)	0.46	(<.001/179)	**-0.52**	(<.001/136)
CM34BDD	**0.48**	(<.001/357)	**0.51**	(<.001/357)	-0.44	(<.001/260)
MAY THROUGH JUNE:						
CM33DDA2	**0.81**	(<.001/244)	0.65	(<.001/244)	**-0.13**	(0.049/222)
CM26DBB	**0.76**	(<.001/244)	0.62	(<.001/244)	**-0.17**	(0.012/222)
CM26CDA	0.59	(<.001/122)	**0.62**	(<.001/122)	-0.14	(0.117/122)
CM35BBB	**0.60**	(<.001/180)	0.55	(<.001/180)	**-0.27**	(<.001/176)
CM34BDD	**0.74**	(<.001/244)	0.61	(<.001/244)	-0.12	(0.075/222)
JULY THROUGH SEPTEMBER:						
CM33DDA2	**0.71**	(<.001/419)	0.55	(<.001/419)	**-0.17**	(0.002/338)
CM26DBB	**0.60**	(<.001/449)	0.50	(<.001/449)	**-0.18**	(<.001/362)
CM26CDA	**0.64**	(<.001/200)	0.53	(<.001/200)	**-0.25**	(<.001/200)
CM35BBB	**0.59**	(<.001/276)	0.54	(<.001/276)	**-0.13**	(0.034/276)
CM34BDD	**0.51**	(<.001/454)	0.45	(<.001/454)	**-0.16**	(0.002/367)
OCTOBER THROUGH NOVEMBER:						
CM33DDA2	**0.61**	(<.001/244)	**0.26**	(<.001/244)	-0.45	(<.001/176)
CM26DBB	**0.61**	(<.001/244)	**0.32**	(<.001/244)	-0.53	(<.001/176)
CM26CDA	**0.82**	(<.001/122)	**0.22**	(0.017/122)	-0.43	(<.001/ 95)
CM35BBB	**0.83**	(<.001/122)	**0.22**	(0.015/122)	-0.42	(<.001/ 95)
CM34BDD	**0.54**	(<.001/244)	**0.15**	(0.018/244)	-0.45	(<.001/176)
DECEMBER THROUGH JANUARY:						
CM33DDA2	**0.58**	(<.001/248)	0.26	(<.001/248)	-0.15	(0.114/110)
CM26DBB	**0.37**	(<.001/248)	0.32	(<.001/248)	-0.09	(0.361/110)
CM26CDA	-0.07	(0.456/124)	0.17	(0.055/124)	0.08	(0.572/ 59)
CM35BBB	-0.05	(0.562/124)	**0.28**	(0.002/124)	-0.02	(0.870/ 59)
CM34BDD	0.18	(0.005/248)	**0.38**	(<.001/248)	-0.16	(0.105/110)

Table 10. Monthly correlation (r) between daily values for groundwater level and river stage, precipitation, and evapotranspiration for five wells at Crane Meadows. Wells are listed in order of increasing distance from the River. The probability (p) that $r \neq 0$, and the sample size (n) are shown in parentheses. Highlighted correlations are significantly correlated ($p \leq 0.05$) with the groundwater level at the well, but not correlated with each other ($p > 0.05$).

Well	River Stage		Antecedent Precipitation		Potential Evapotranspiration	
	r	(p / n)	r	(p / n)	r	(p / n)
JANUARY:						
CM33DDA2	**0.36**	(<.001/124)	0.34	(<.001/124)	**-0.35**	(0.038/36)
CM26DBB	0.25	(0.005/124)	**0.34**	(<.001/124)	0.00	(0.999/36)
CM26CDA	-0.33	(0.010/ 62)	**0.60**	(<.001/ 62)	**-0.57**	(0.034/14)
CM35BBB	**-0.28**	(0.029/ 62)	0.22	(0.088/ 62)	**-0.68**	(0.008/14)
CM34BDD	-0.18	(0.048/124)	**0.49**	(<.001/124)	-0.31	(0.063/36)
FEBRUARY:						
CM33DDA2	**0.50**	(<.001/113)	**0.33**	(<.001/113)	-0.07	(0.607/58)
CM26DBB	**0.41**	(<.001/113)	**0.36**	(<.001/113)	**0.27**	(0.043/58)
CM26CDA	**0.32**	(0.014/ 57)	**0.59**	(<.001/ 57)	-0.11	(0.571/29)
CM35BBB	0.18	(0.180/ 57)	**0.59**	(<.001/ 57)	0.19	(0.332/29)
CM34BDD	**0.20**	(0.036/113)	**0.46**	(<.001/113)	**0.35**	(0.008/58)
MARCH:						
CM33DDA2	**0.63**	(<.001/124)	**0.62**	(<.001/124)	-0.33	(0.002/93)
CM26DBB	**0.45**	(<.001/124)	**0.48**	(<.001/124)	-0.32	(0.002/93)
CM26CDA	**-0.53**	(<.001/ 62)	**0.41**	(<.001/ 62)	-0.30	(0.041/47)
CM35BBB	-0.05	(0.682/ 62)	**0.79**	(<.001/ 62)	-0.43	(0.003/47)
CM34BDD	**0.43**	(<.001/124)	**0.57**	(<.001/124)	-0.24	(0.019/93)
APRIL:						
CM33DDA2	**0.71**	(<.001/120)	**0.47**	(<.001/120)	-0.31	(<.001/109)
CM26DBB	**0.50**	(<.001/120)	**0.54**	(<.001/120)	-0.37	(<.001/109)
CM26CDA	0.16	(0.209/ 60)	**0.57**	(<.001/ 60)	-0.36	(0.005/ 60)
CM35BBB	0.25	(0.056/ 60)	**0.51**	(<.001/ 60)	-0.36	(0.005/ 60)
CM34BDD	**0.41**	(<.001/120)	**0.58**	(<.001/120)	-0.34	(<.001/109)
MAY:						
CM33DDA2	**0.86**	(<.001/124)	0.64	(<.001/124)	-0.04	(0.701/112)
CM26DBB	**0.82**	(<.001/124)	0.63	(<.001/124)	-0.03	(0.766/112)
CM26CDA	**0.75**	(<.001/ 62)	0.62	(<.001/ 62)	0.12	(0.360/ 62)
CM35BBB	**0.75**	(<.001/ 90)	0.57	(<.001/ 90)	-0.02	(0.891/ 86)
CM34BDD	**0.81**	(<.001/124)	0.61	(<.001/124)	-0.01	(0.876/112)
JUNE:						
CM33DDA2	**0.77**	(<.001/120)	0.71	(<.001/120)	-0.16	(0.101/110)
CM26DBB	**0.71**	(<.001/120)	0.65	(<.001/120)	**-0.22**	(0.022/110)
CM26CDA	0.44	(<.001/ 60)	**0.62**	(<.001/ 60)	-0.35	(0.006/ 60)
CM35BBB	0.46	(<.001/ 90)	**0.61**	(<.001/ 90)	-0.38	(<.001/ 90)
CM34BDD	**0.69**	(<.001/120)	0.67	(<.001/120)	-0.15	(0.119/110)
JULY:						
CM33DDA2	**0.88**	(<.001/124)	0.52	(<.001/124)	**-0.35**	(<.001/ 93)
CM26DBB	**0.60**	(<.001/144)	0.48	(<.001/144)	**-0.39**	(<.001/107)
CM26CDA	**0.88**	(<.001/ 62)	0.62	(<.001/ 62)	**-0.49**	(<.001/ 62)
CM35BBB	**0.79**	(<.001/ 93)	0.57	(<.001/ 93)	**-0.37**	(<.001/ 93)
CM34BDD	**0.55**	(<.001/149)	0.46	(<.001/149)	**-0.38**	(<.001/112)

Table 10 (continued).

Well	River Stage		Antecedent Precipitation		Potential Evapotranspiration	
	r	(p / n)	r	(p / n)	r	(p / n)
AUGUST:						
CM33DDA2	**0.56**	(<.001/145)	**0.43**	(<.001/145)	-0.18	(0.046/122)
CM26DBB	**0.45**	(<.001/155)	**0.44**	(<.001/155)	-0.20	(0.022/132)
CM26CDA	**0.52**	(<.001/ 62)	**0.39**	(0.002/ 62)	-0.35	(0.006/ 62)
CM35BBB	**0.54**	(<.001/ 93)	**0.44**	(<.001/ 93)	-0.23	(0.024/ 93)
CM34BDD	**0.31**	(<.001/155)	**0.31**	(<.001/155)	-0.28	(0.001/132)
SEPTEMBER:						
CM33DDA2	**0.76**	(<.001/150)	0.63	(<.001/150)	-0.04	(0.681/123)
CM26DBB	**0.75**	(<.001/150)	0.56	(<.001/150)	0.01	(0.951/123)
CM26CDA	**0.57**	(<.001/ 76)	-0.03	(0.827/ 76)	**-0.35**	(0.002/ 76)
CM35BBB	**0.42**	(<.001/ 90)	0.01	(0.949/ 90)	**-0.25**	(0.020/ 90)
CM34BDD	**0.65**	(<.001/150)	0.50	(<.001/150)	0.05	(0.555/123)
OCTOBER:						
CM33DDA2	**0.67**	(<.001/124)	**0.47**	(<.001/124)	-0.11	(0.273/ 93)
CM26DBB	**0.62**	(<.001/124)	**0.55**	(<.001/124)	-0.25	(0.015/ 93)
CM26CDA	**0.73**	(<.001/ 62)	**0.26**	(0.037/ 62)	-0.05	(0.683/ 62)
CM35BBB	**0.77**	(<.001/ 62)	0.24	(0.058/ 62)	-0.03	(0.840/ 62)
CM34BDD	**0.67**	(<.001/124)	**0.38**	(<.001/124)	-0.09	(0.382/ 93)
NOVEMBER:						
CM33DDA2	0.12	(0.182/120)	-0.15	(0.094/120)	-0.03	(0.785/ 83)
CM26DBB	**0.32**	(0.004/120)	**0.19**	(0.042/120)	0.08	(0.451/ 83)
CM26CDA	**0.39**	(0.002/ 60)	-0.22	(0.098/ 60)	0.18	(0.326/ 33)
CM35BBB	**0.39**	(0.002/ 60)	-0.14	(0.287/ 60)	0.12	(0.488/ 33)
CM34BDD	-0.08	(0.376/120)	**-0.31**	(<.001/120)	-0.01	(0.940/ 83)
DECEMBER:						
CM33DDA2	**0.34**	(<.001/124)	**0.42**	(<.001/124)	0.01	(0.950/ 74)
CM26DBB	-0.09	(0.326/124)	**0.47**	(<.001/124)	-0.04	(0.725/ 74)
CM26CDA	**0.56**	(<.001/ 62)	-0.02	(0.867/ 62)	0.26	(0.090/ 45)
CM35BBB	-0.08	(0.561/ 62)	**0.35**	(0.005/ 62)	0.10	(0.513/ 45)
CM34BDD	0.03	(0.767/124)	**0.41**	(<.001/124)	-0.03	(0.829/ 74)

April) and a season for active PET (May through June). Correlations for each month are presented in Tables 6, 8, and 10 for Elm Creek, Rowe Sanctuary, and Crane Meadows respectively. Parameters (river stage, precipitation, or PET) that were correlated with the water level at each well, but not correlated with each other, are highlighted in the Tables. Correlated parameters duplicate the variation they explain for the water level at each well, so they provide little additional information that could be used for predicting groundwater levels.

River stage, precipitation, and PET were nearly always highly correlated (p typically <0.001) with the groundwater level at each well; with river stage usually the most highly correlated. When the river stage was not correlated, precipitation was usually the most highly correlated parameter with the groundwater level. Evapotranspiration (ET_{WT}) was most active from late March through September (Figure 54), so PET outside this period (e.g., February through April and October through January in Tables 9 and 10) was probably reflecting the influence of some unknown parameter; not evapotranspiration.

Although river stage was usually the most highly correlated parameter, its correlation with the groundwater level typically decreased with distance from the river (Tables 5 through 10). The two wettest wells in the center of Crane Meadows (CM26CDA and CM35BBB in Tables 9 and 10) were highly correlated with river stage for the period-of-record, but were usually more highly correlated with precipitation or PET on a monthly basis from February through April. The correlation with river stage at these two wells was probably diminished because the water table was near or above the surface over 90% of the time during this period (Figure 17b). Elevating the water table further probably resulted in groundwater interception and subsequent runoff into the adjacent sloughs; thus diminishing the correlation with river stage.

The negative correlation between river stage and CM26CDA (March in Table 10) appears to be related to a difference between years instead of a relationship between river stage and groundwater level. March 1991 had higher water levels at CM26CDA and lower river stages than March 1992, while within each year there was no distinct negative relationship. A similar situation probably was responsible for the negative correlation for well CM35BBB in January (Table 10). Negative correlations between antecedent precipitation and fall groundwater levels (e.g., November in Tables 6, 8 and 10) were caused by an artifact of the antecedent precipitation index. Antecedent precipitation produces a response that decreases with time. This response usually fits the groundwater decline following the initial increase caused by precipitation, but during the fall the water table gradually rises as the groundwater is recharged. Thus, the rising water table and declining antecedent precipitation index produced a negative correlation.

SUMMARY AND CONCLUSIONS

Wet meadow groundwater elevations along the Platte River in south central Nebraska are influenced by a combination of river stage, precipitation, and evapotranspiration. River stage was most often the dominant factor. The influence of river stage decreases with increasing distance from the river, and decreases when the stage is sufficient to maintain the groundwater water level at or above the surface (e.g., wells CM26CDA and CM35BBB). When the water level is at or above the surface, raising the river stage has little influence because the surface water tends to flow away from the area. Although raising the river stage has little influence once the groundwater reaches the surface, lowering the stage will lower the groundwater once it has dropped below the surface.

After river stage, precipitation is usually the next most dominant influence on groundwater levels. An isolated precipitation event can temporarily elevate the water table over three feet, with residual effects lasting up to two weeks. The closer the water table is to the surface before the precipitation, the closer the precipitation will bring the water table to the surface. If the water table reaches the surface, then standing water and overland flow may occur.

Evapotranspiration begins to influence the groundwater level in late March or early April, and becomes an important factor by May. The influence of evapotranspiration is usually greatly reduced again by late September. Plants surrounding the wells in the wettest part of Crane Meadows appear able to remove water from below the water table up to about three feet below the surface. The water table in this area seldom drops below three feet, so it appears these plants may be dependent upon the water table for their long-term survival. These plants also appear able to tolerate a water table within one foot of the surface, even though their groundwater use dramatically declines when the water table is above one foot. This may be an important advantage, since most plants cannot tolerate saturated soils for extended periods. Removing this advantage (i.e., reducing the time with a high water table) could result in the displacement of native wetland species with other species. The plants surrounding the drier wells at Crane Meadows appear able to remove water from below the water table up to five to six feet below the surface. The water table in these areas seldom drops below this limit, so these plants may also be using the water table throughout much of the growing season. Evapotranspiration may also be depressing the water table in the center of Crane Meadows during the summer, because the water table typically begins to rise following the cessation of evapotranspiration without a corresponding rise in river stage.

Groundwater withdrawals for adjacent irrigation have little or no direct affect on the groundwater levels at the three study sites. The distance between the study-site wells and the irrigation wells was probably the most important factor that minimized the effect of adjacent groundwater withdrawals. Most irrigation wells were at least a half mile from the nearest groundwater-level recorder. Drawdowns were observed at a few cross-valley transect wells, but these observation wells were located less than 100 ft from an irrigation well. Although adjacent withdrawals for irrigation have minimal effect on the study-site groundwater levels, the cumulative effect from groundwater withdrawals throughout the Platte River Valley on the study-site groundwater levels was not evaluated. Evaluating the effect of valley-wide groundwater withdrawals was beyond the scope of our study.

Interpretation of the groundwater profile next to each site is confounded at Rowe Sanctuary and Crane Meadows because the cross-valley transects are not oriented perpendicular to the Platte River. This makes the groundwater on the "downstream" side of the transect appear lower than the "upstream" side of the transect. The Elm Creek transect is almost perpendicular to the Platte River, however, so this effect is minimized at this site. Groundwater next to the Elm Creek site has a steep gradient toward the River from the south, and a moderate gradient toward the River from the north. Rowe Sanctuary appears to have a fairly flat gradient on either side of the River, while Crane Meadows appears to have a gradient from the River toward the south and possibly to the north.

Within each study site a grid of groundwater observation wells was used to eliminate the orientation problem of a single transect by developing groundwater-level contours. Except at high water levels, the general direction of the groundwater gradient at Elm Creek is down-valley and slightly toward the groundwater drain. This suggests that the drain intercepts groundwater from the Platte River as well as groundwater from south of the drain. At Rowe Sanctuary the general direction of the groundwater gradient is down-valley and slightly toward the center of the island, except at high water levels. The high groundwater levels at Rowe Sanctuary typically follow large precipitation events, causing the gradient to be generally down-valley as well as toward the River. Crane Meadows also has a gradient toward the River following large precipitation events, but the gradient typically only occurs within about the first 1,000 ft from the Platte River bank. The vast majority of the island still has a gradient toward the center of the island at high groundwater levels, suggesting that most of the groundwater is flowing toward the swales in the center of the island and being discharged as surface water. The general direction of the groundwater gradient at Crane Meadows, however, is typically down-valley. At low and median groundwater levels during the summer, the general down-valley gradient also turns slightly toward the center of the island. This groundwater depression during the summer is probably caused by evapotranspiration rather than groundwater inception by the swales in the center of the island, because the groundwater is typically below the swales during the summer.

Until a more detailed survey of the topography of each site becomes available, the depth-to-groundwater maps should provide a good indication of the general groundwater depths at each study site. Elm Creek had deeper groundwater levels than the other two sites. Only about 1% of the representative area had surface water, and that was only at the highest groundwater levels. Rowe Sanctuary had intermediate groundwater levels compared to the other two sites. Crane Meadows had higher groundwater levels than the other two sites. Surface water at Crane Meadows occurred over much of the representative area during both the highest groundwater levels (46% of the area) and the median spring groundwater levels

(24% of the area).

Box-and-whisker plots simplified the interpretation of the depth-to-groundwater hydrographs by showing the groundwater-level variation within and between months for multiple periods (e.g., years). These box-plot hydrographs are only valid, however, when there is no long-term trend in the data. If there is a trend, such as a decline in groundwater level due to groundwater mining, then the traditional time-line hydrograph would be more appropriate. Wet meadow groundwater levels along the Platte River showed no consistent trend during the study period, although there may be a decline in the groundwater levels adjacent to each site (e.g., Figures 25 through 27). Median groundwater levels at the study sites typically peak by March, and then declined through September. Recharge begins in October and varies between a gradual recharge over the winter at the drier sites, to a relatively rapid recharge following plant senescence in the fall at the wetter sites. Although peak median groundwater levels typically occur in March, some peak daily mean values may be higher during the summer than during the spring. These peak mean daily groundwater levels are caused by intense summer thunderstorms, and the groundwater usually returns to its previous level within two weeks.

The depth-to-groundwater duration curves are a useful tool for determining maximum and minimum levels, as well as the percent of time a particular level was equaled or maintained above that level. These curves should also be useful in differentiating between plant communities with different hydrology. Henszey et al. (1994) combined depth-to-groundwater durations with the response of selected plant species to produce depth-to-groundwater suitability curves. The depth-to-groundwater suitability curves were adapted from the Habitat Suitability Index (HSI) models used by the U.S. Fish and Wildlife Service (Bovee 1986). Suitability curves include the water-level duration information required by current and proposed government regulations for delineating wetlands (U.S. Army Corps of Engineers 1987, Federal Interagency Committee for Wetland Delineation 1989, General Services Administration 1991), and are especially useful for predicting plant response to different groundwater-level regimes. This type of information would be very useful for evaluating the effects of future water management practices on wet-meadow plant communities along the Platte River.

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APPENDIX A

DEPTH-TO-GROUNDWATER AND RIVER-STAGE HYDROGRAPHS FOR WELLS AND GAGES WITHOUT RECORDERS

Box-and-whisker plots were used to construct a median hydrograph for each well or gage. The boxes were constructed to represent the median (connected by a line through each month), the middle 50% of the observations (the box), the lower 10 to 25% and the upper 75 to 90% of the observations (the whiskers), and the lower 0 to 10% and upper 90 to 100% of the observations (individual data points). In contrast to the box-plot hydrographs presented in the text, these hydrographs were constructed from periodic measurements, instead of from continuous data. Each box, therefore, shows the percent of *observations* (not percent of *time*) during the month that a water level was maintained or above. The number of observations for each box (month) is shown below the deepest observation.

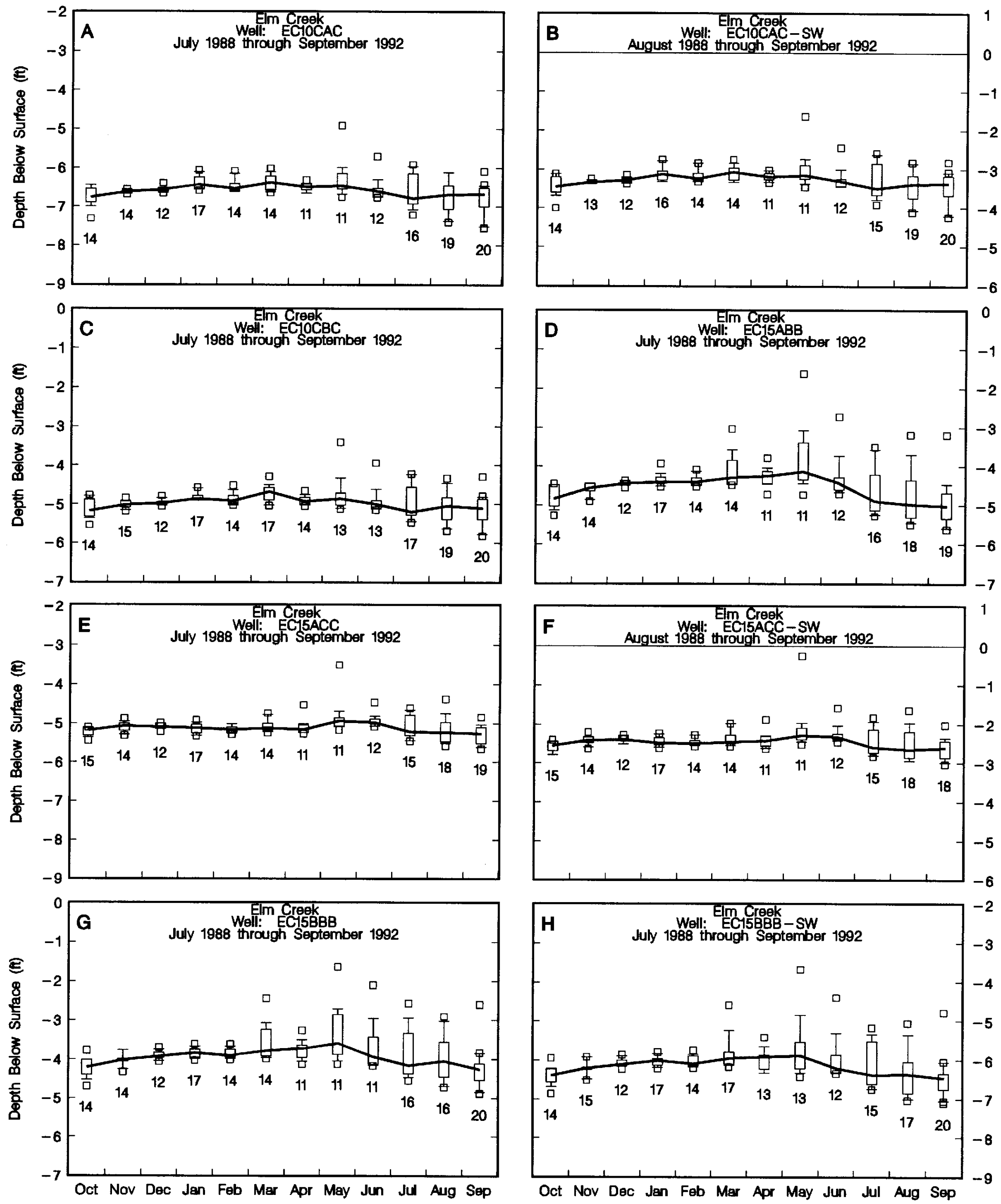

Figure 63. Elm Creek depth-to-groundwater and river-stage hydrographs for wells and gages without recorders, showing the variation within each month.

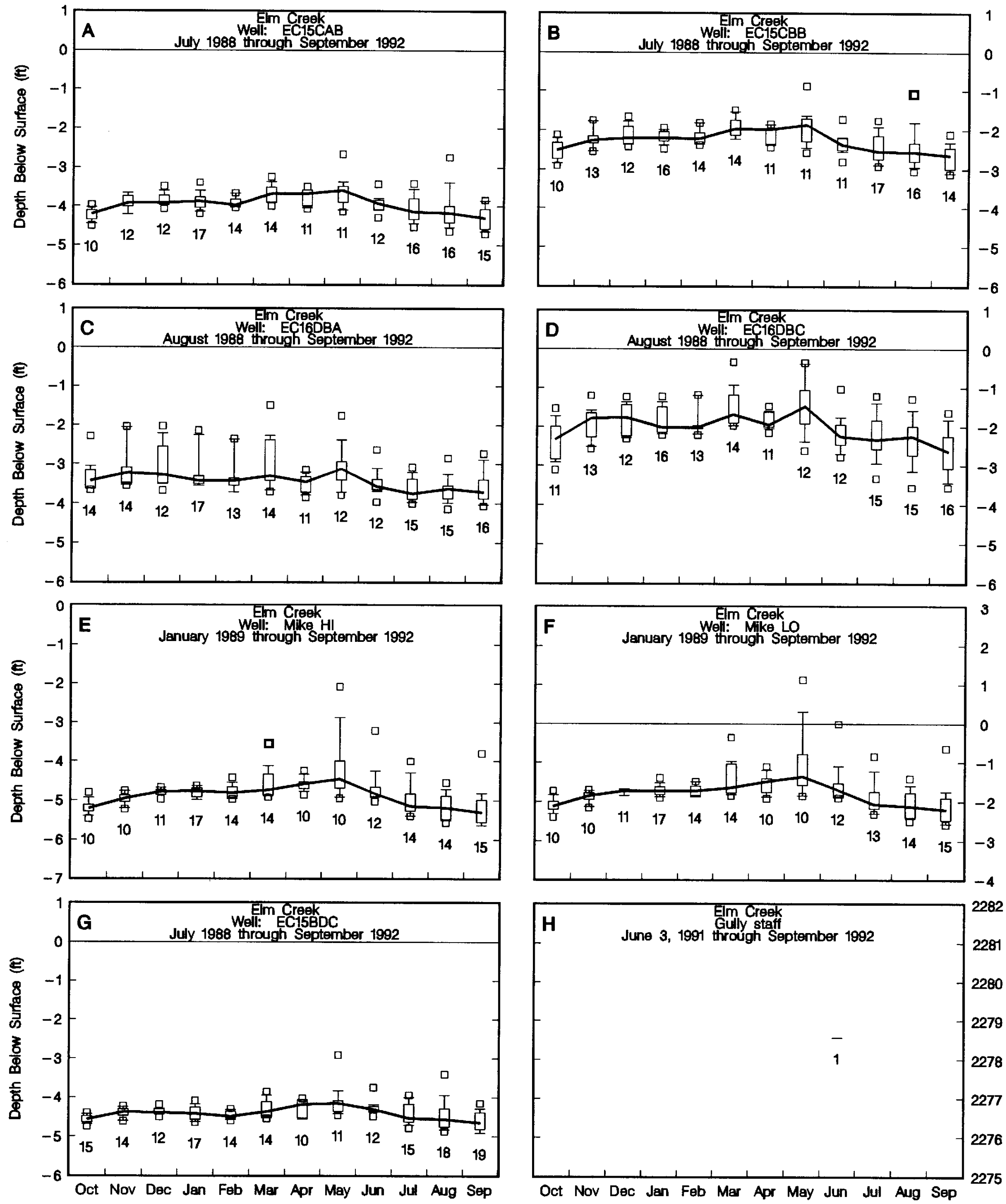

Figure 64. Elm Creek depth-to-groundwater and river-stage hydrographs for wells and gages without recorders, showing the variation within each month.

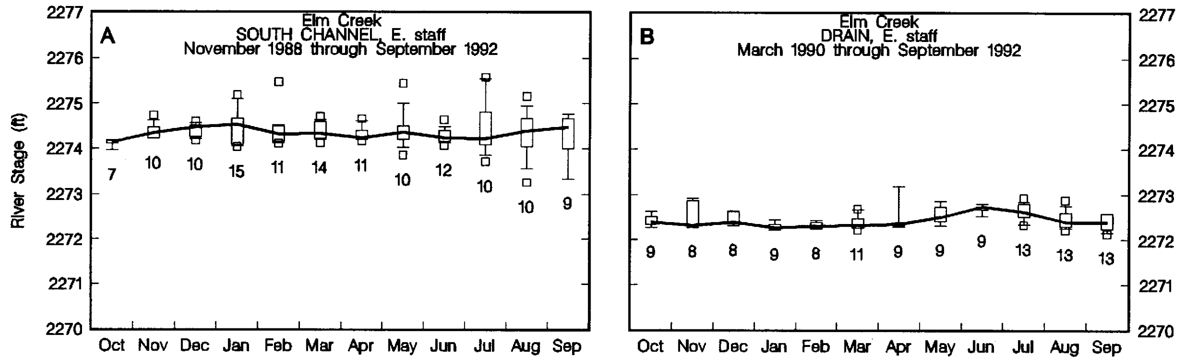

Figure 65. Elm Creek depth-to-groundwater and river-stage hydrographs for wells and gages without recorders, showing the variation within each month.

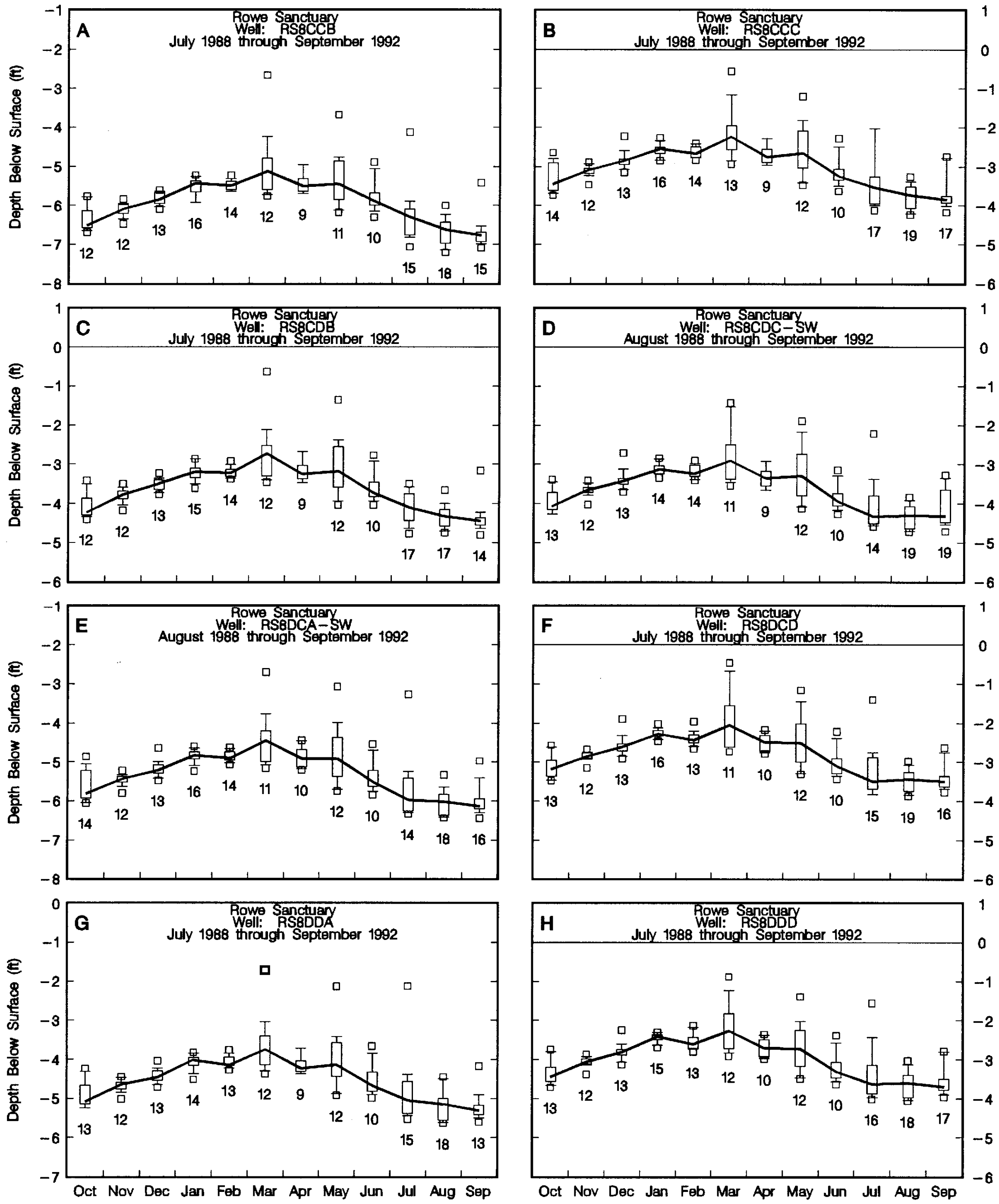

Figure 66. Rowe Sanctuary depth-to-groundwater and river-stage hydrographs for wells and gages without recorders, showing the variation within each month.

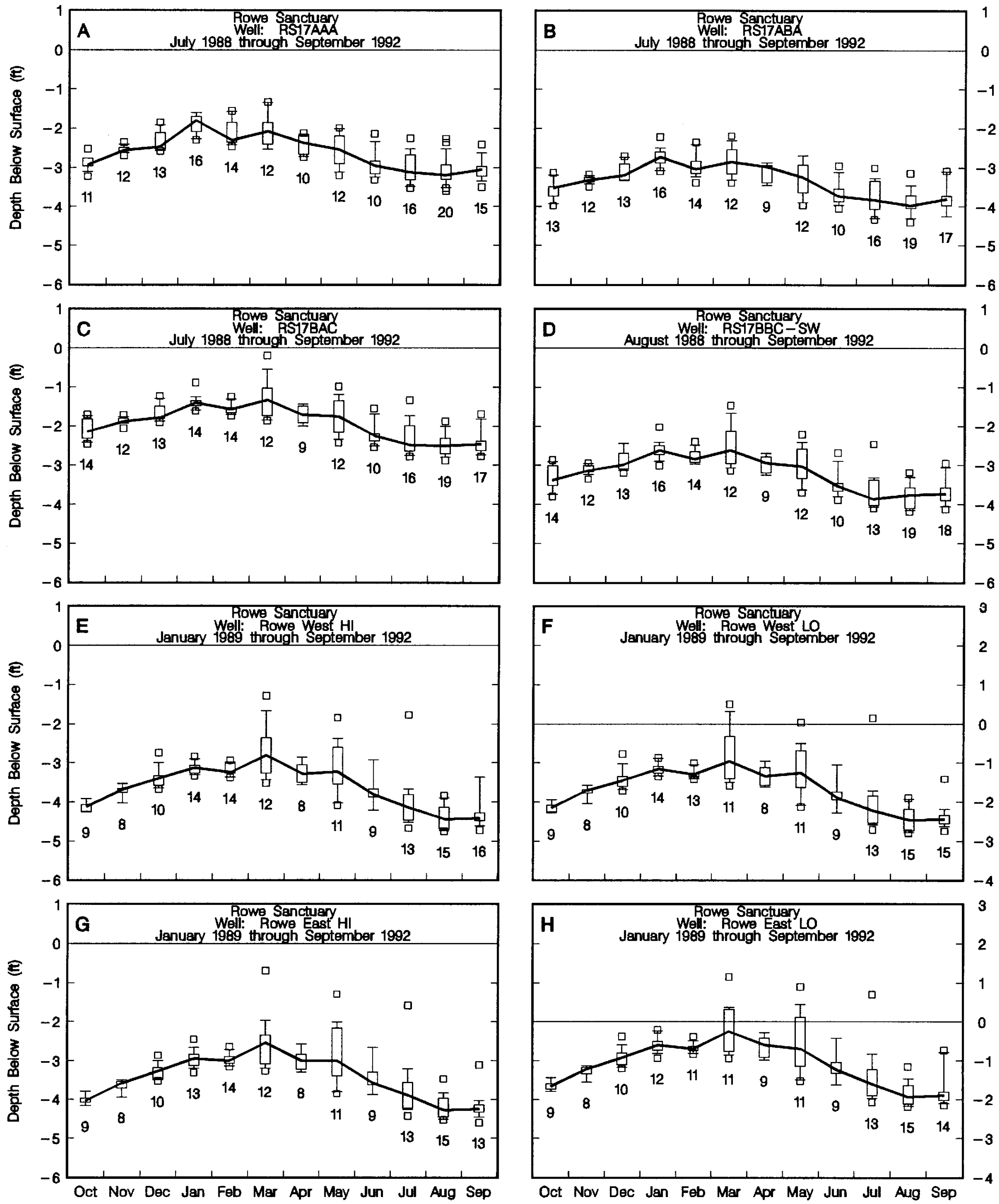

Figure 67. Rowe Sanctuary depth-to-groundwater and river-stage hydrographs for wells and gages without recorders, showing the variation within each month.

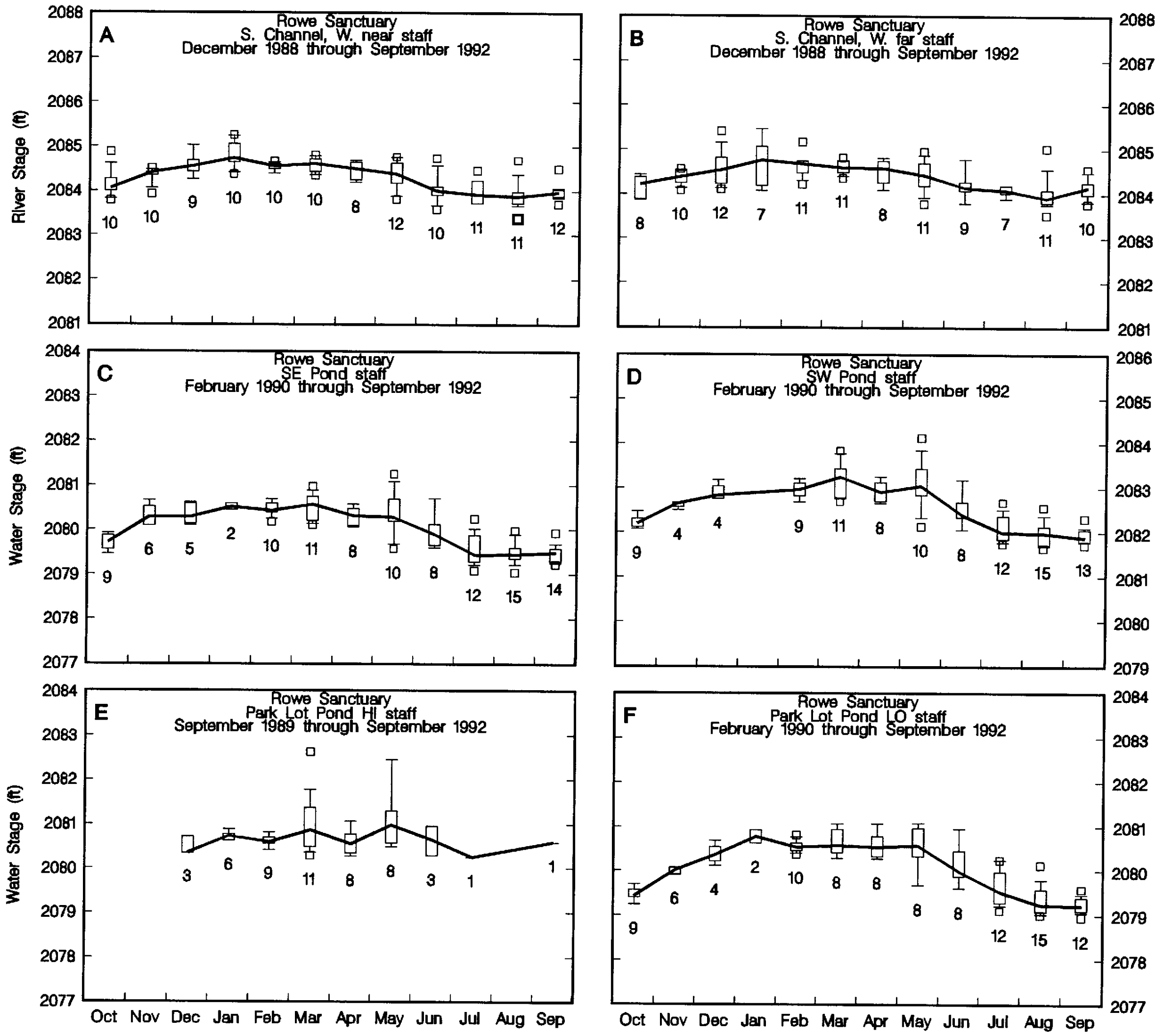

Figure 68. Rowe Sanctuary depth-to-groundwater and river-stage hydrographs for wells and gages without recorders, showing the variation within each month.

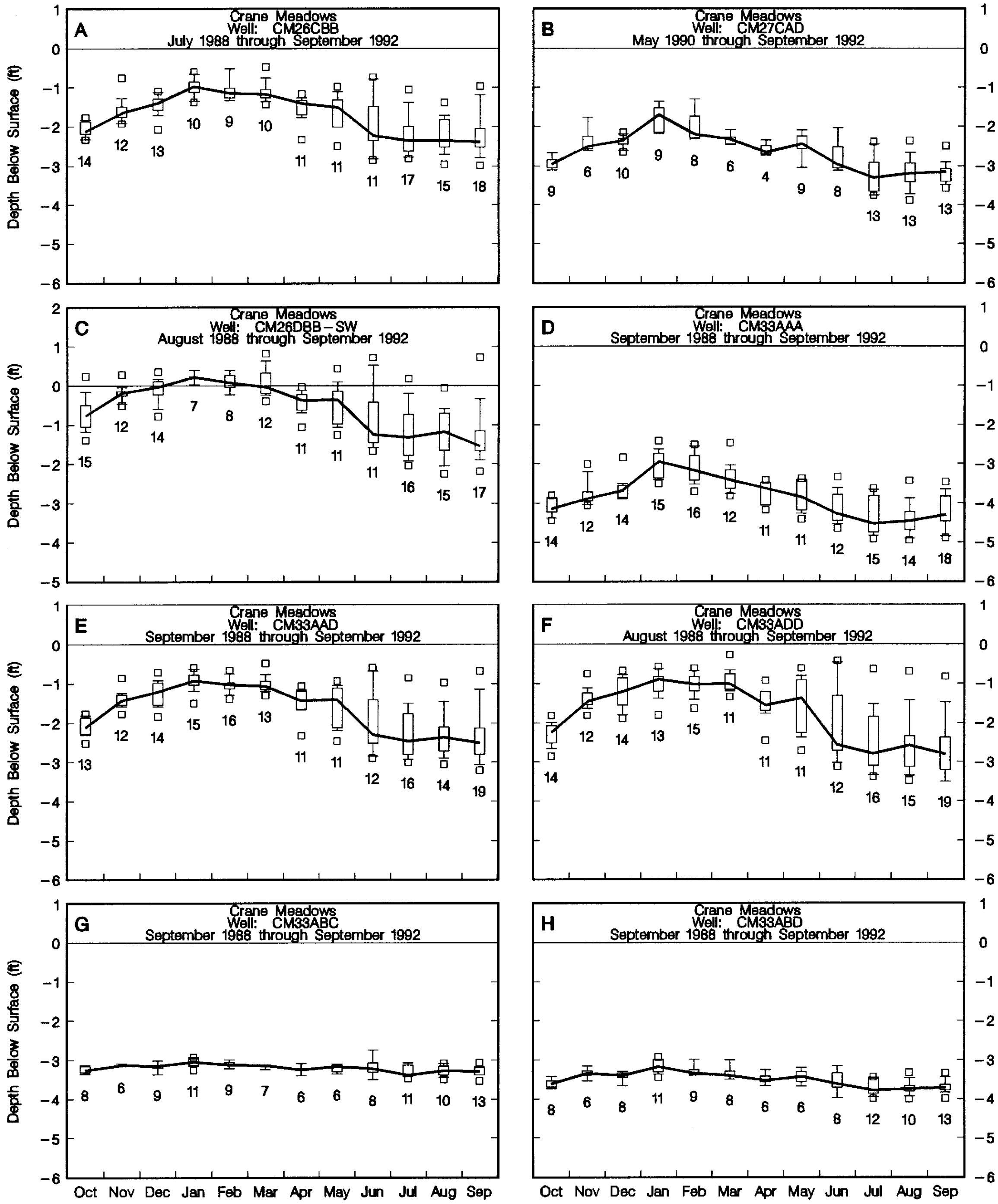

Figure 69. Crane Meadows depth-to-groundwater and river-stage hydrographs for wells and gages without recorders, showing the variation within each month.

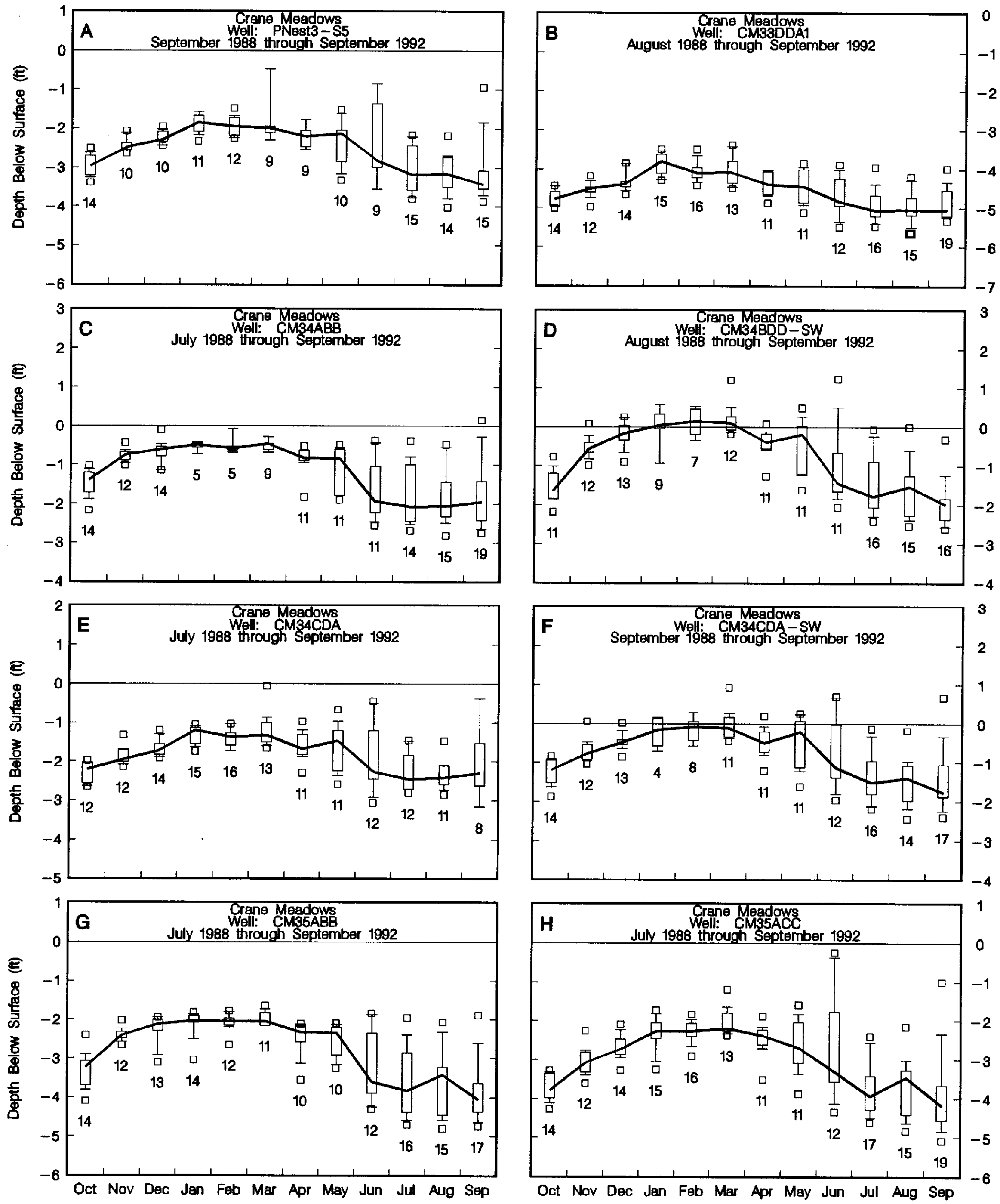

Figure 70. Crane Meadows depth-to-groundwater and river-stage hydrographs for wells and gages without recorders, showing the variation within each month.

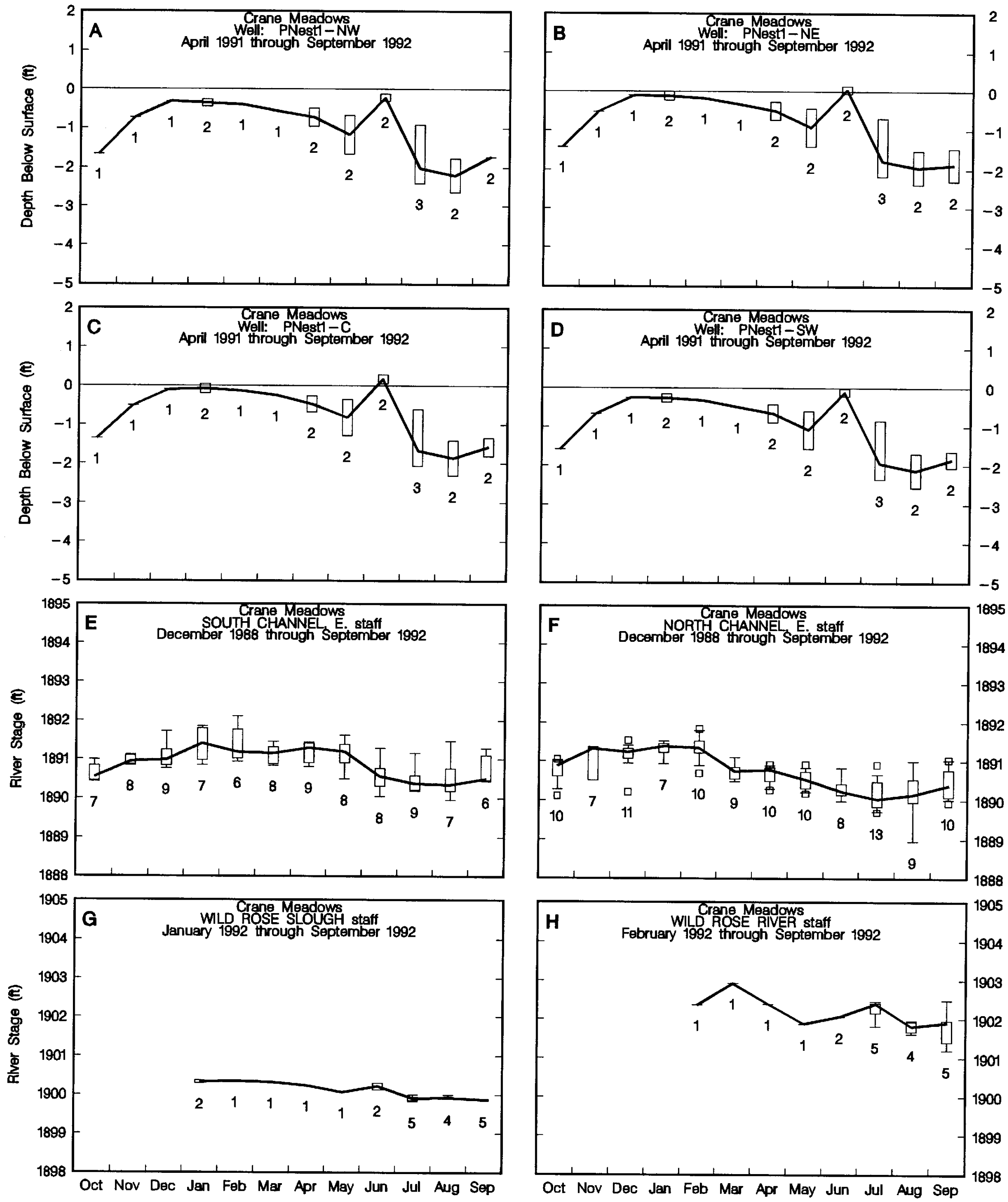

Figure 71. Crane Meadows depth-to-groundwater and river-stage hydrographs for wells and gages without recorders, showing the variation within each month.

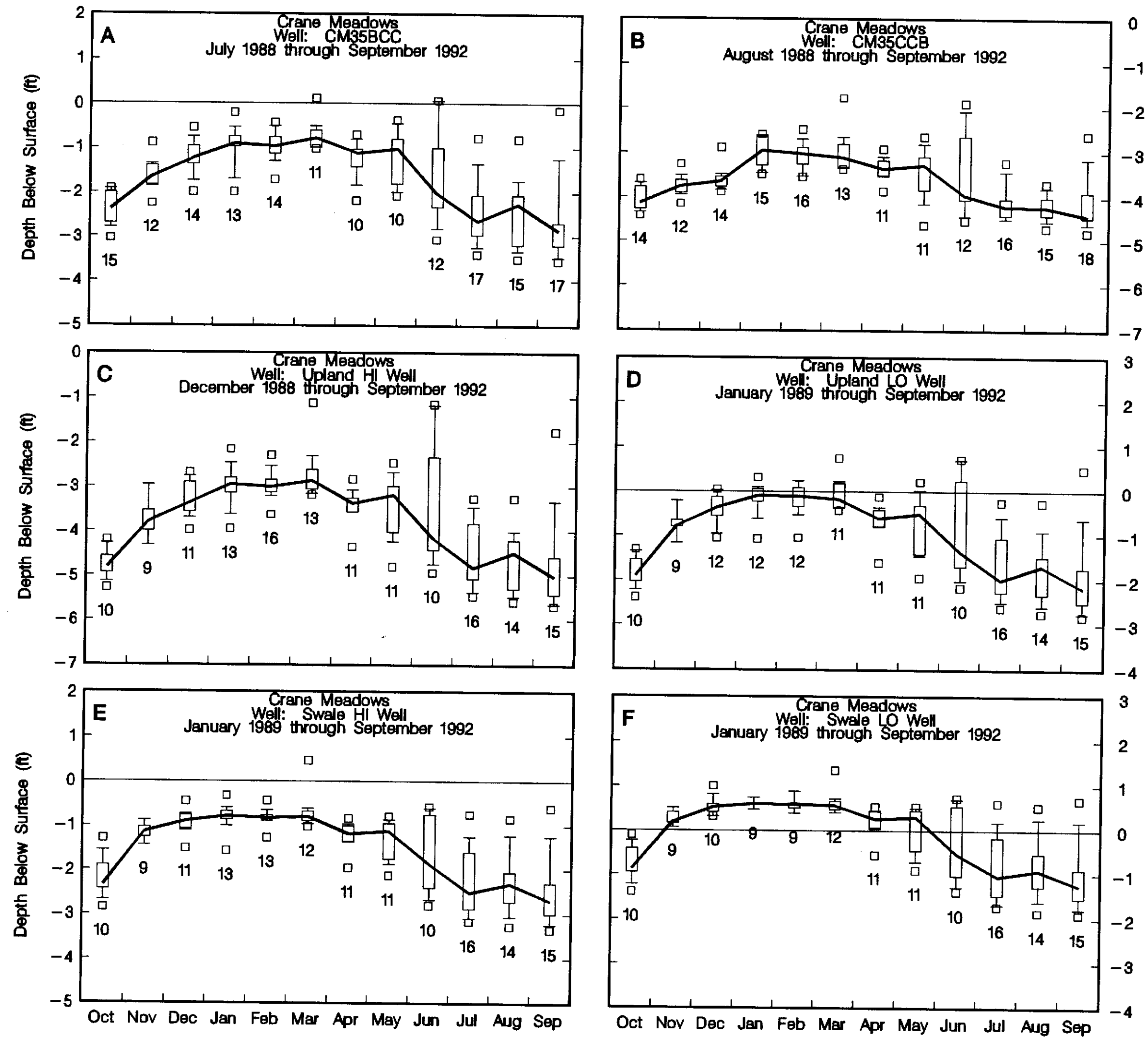

Figure 72. Crane Meadows depth-to-groundwater and river-stage hydrographs for wells and gages without recorders, showing the variation within each month.

APPENDIX B

ADDITIONAL CONTINUOUS HYDROLOGIC AND SOIL TEMPERATURE DATA

Continuous river stage, groundwater level, precipitation, and soil temperature data for Elm Creek, Rowe Sanctuary, and Crane Meadows for water years other than 1992 are presented in the following figures.

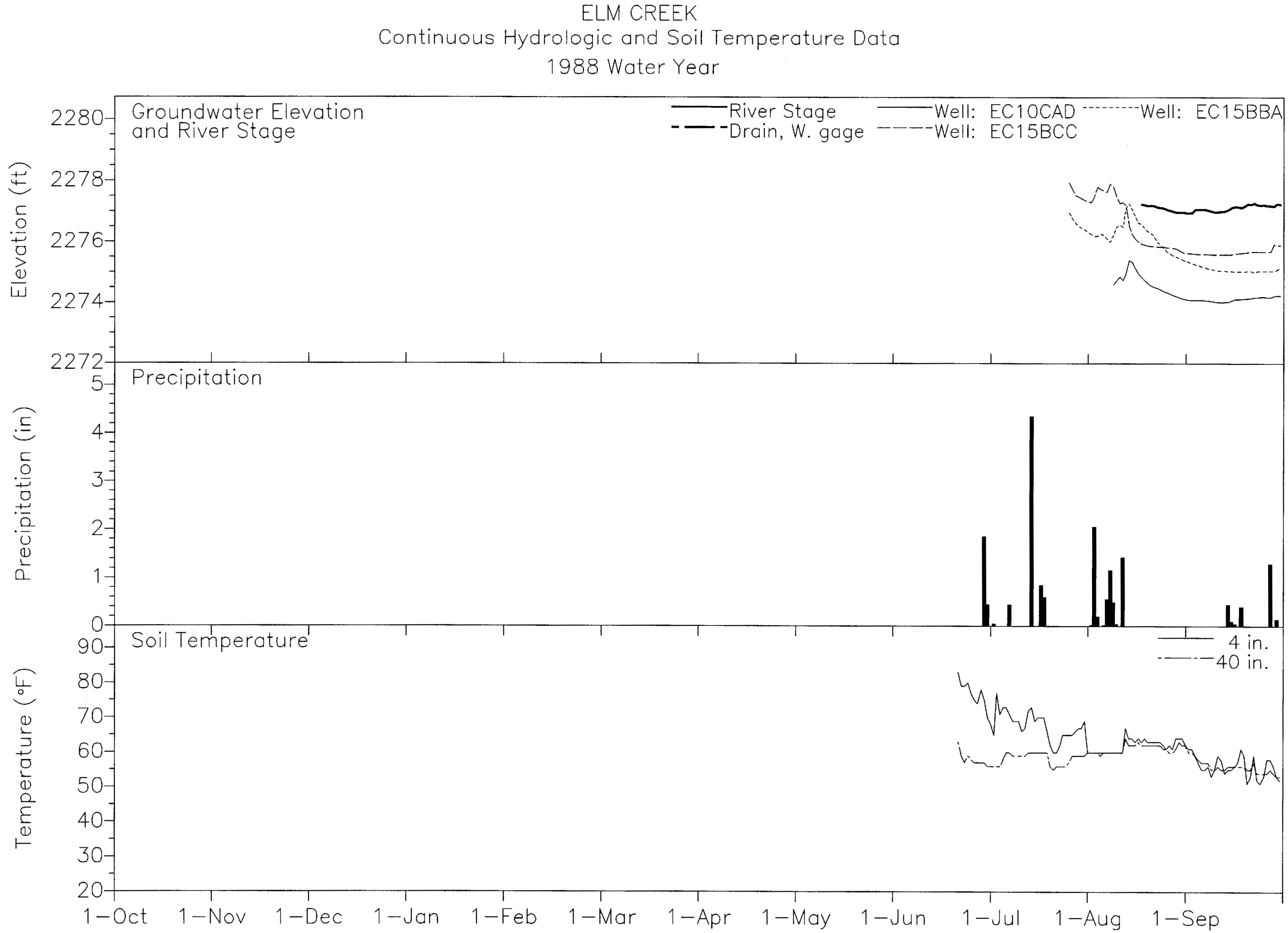

Figure 73a. Elm Creek continuous hydrologic, and soil temperature data for water year 1988.

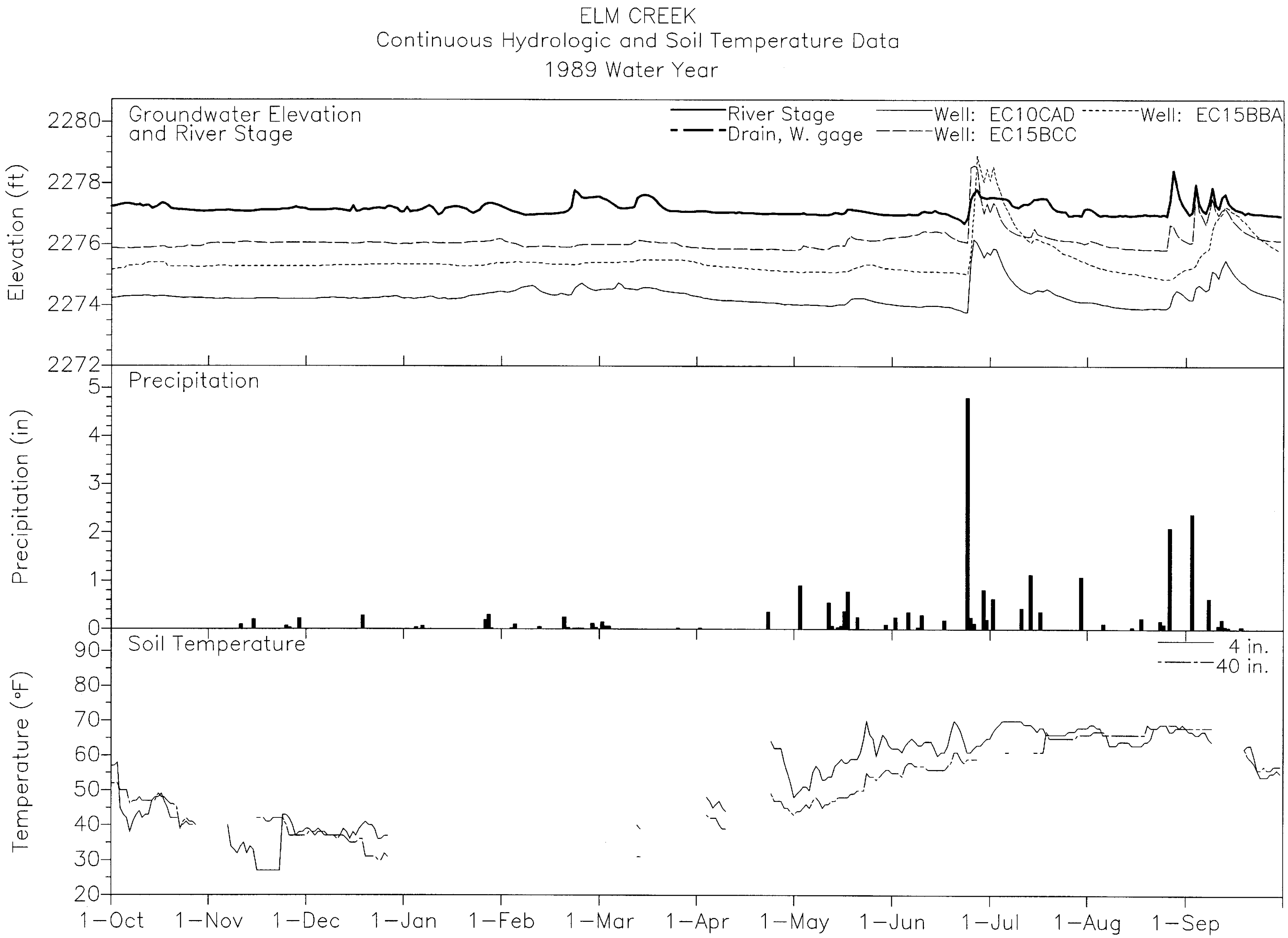

Figure 73b. Elm Creek continuous hydrologic, and soil temperature data for water year 1989.

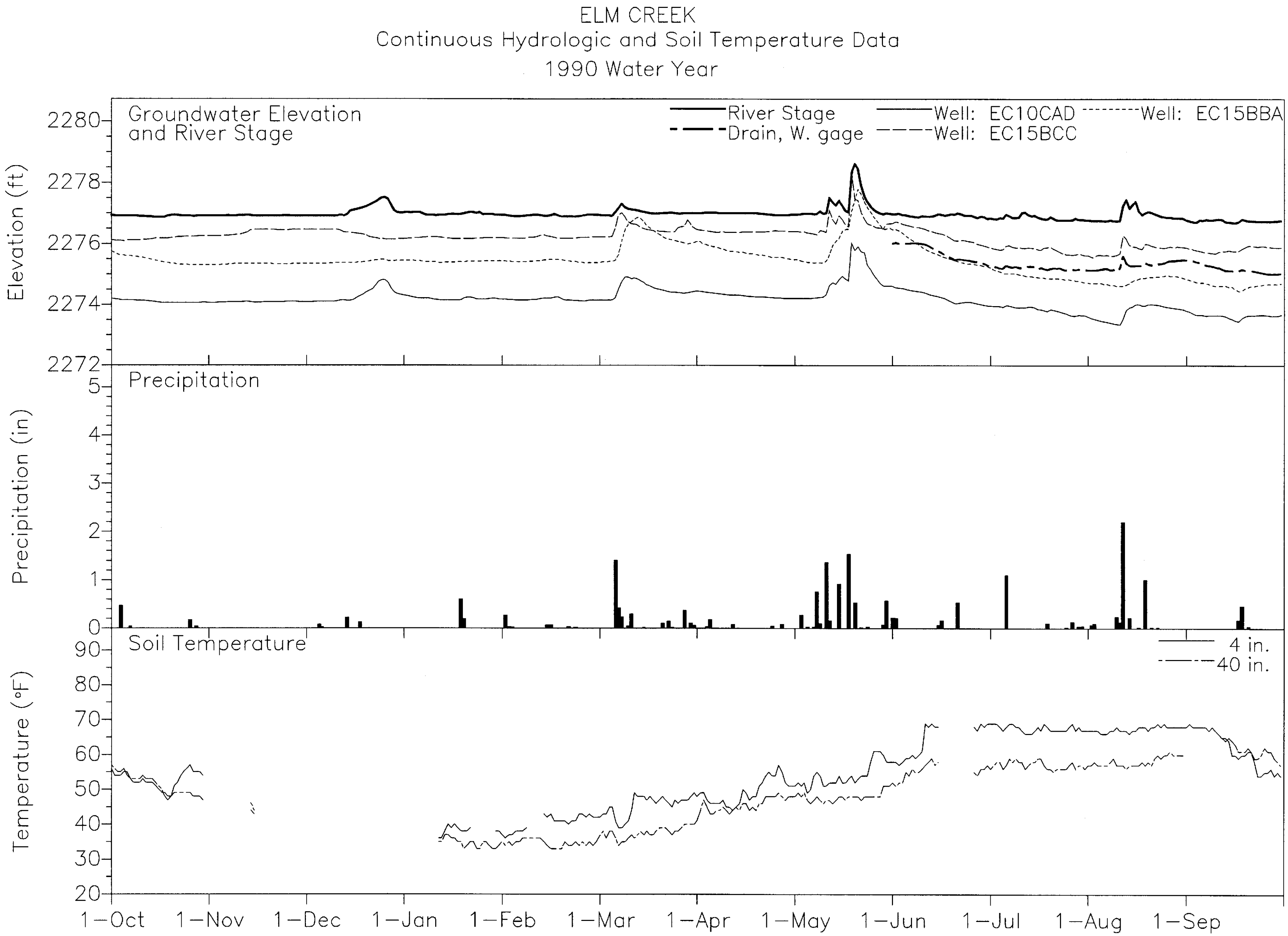

Figure 73c. Elm Creek continuous hydrologic, and soil temperature data for water year 1990.

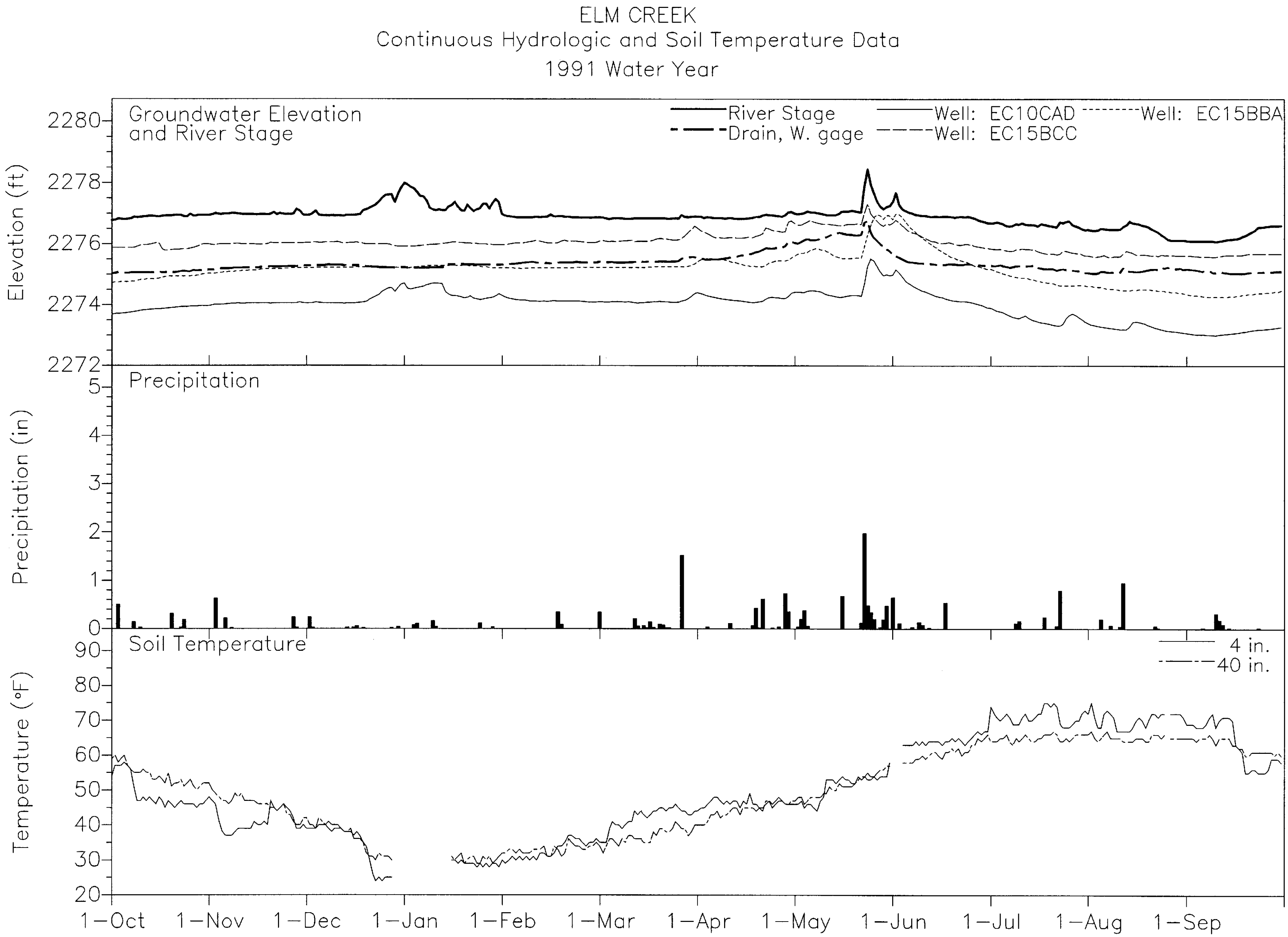

Figure 73d. Elm Creek continuous hydrologic, and soil temperature data for water year 1991.

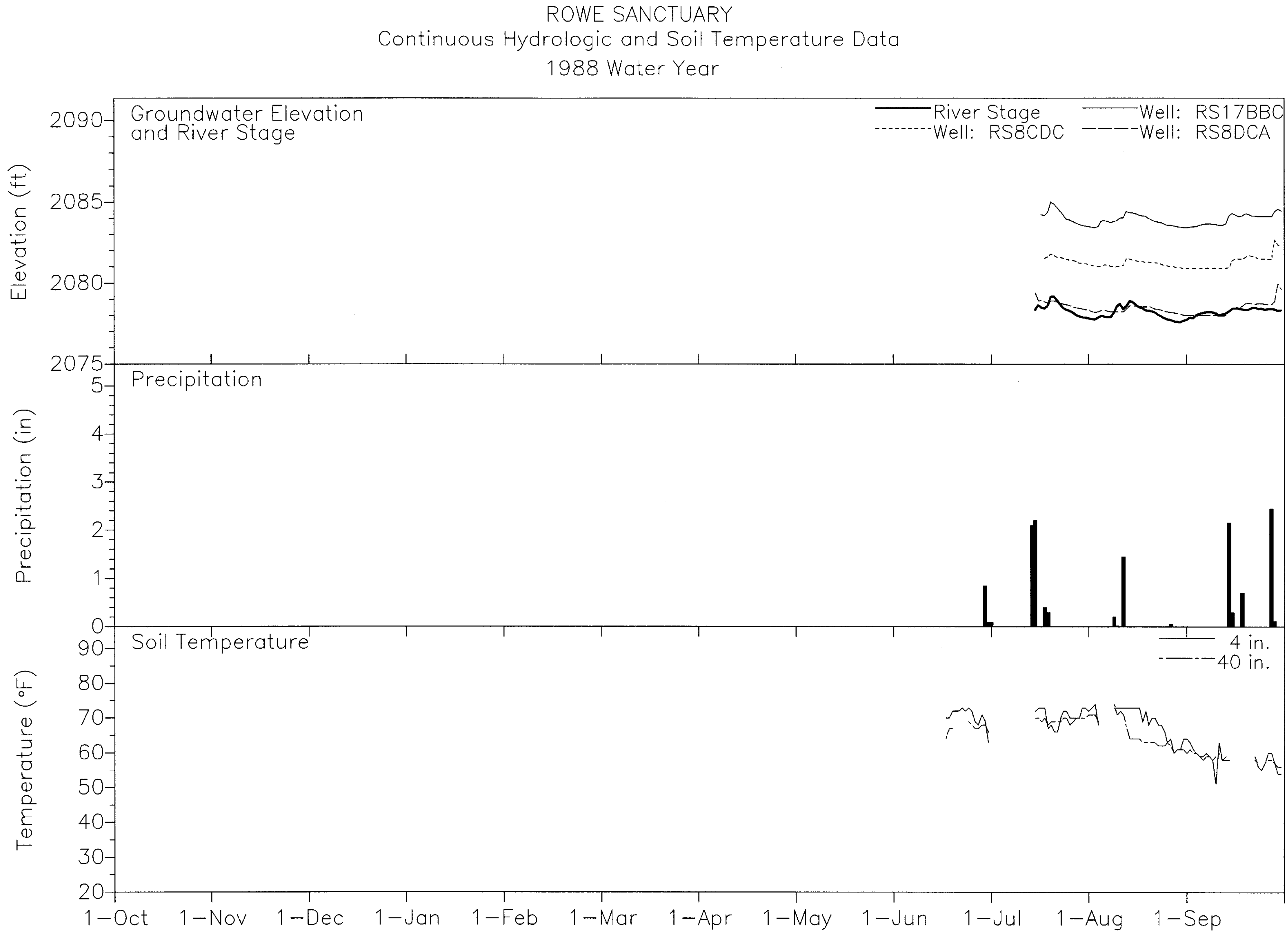

Figure 74a. Rowe Sanctuary continuous hydrologic, and soil temperature data for water year 1988.

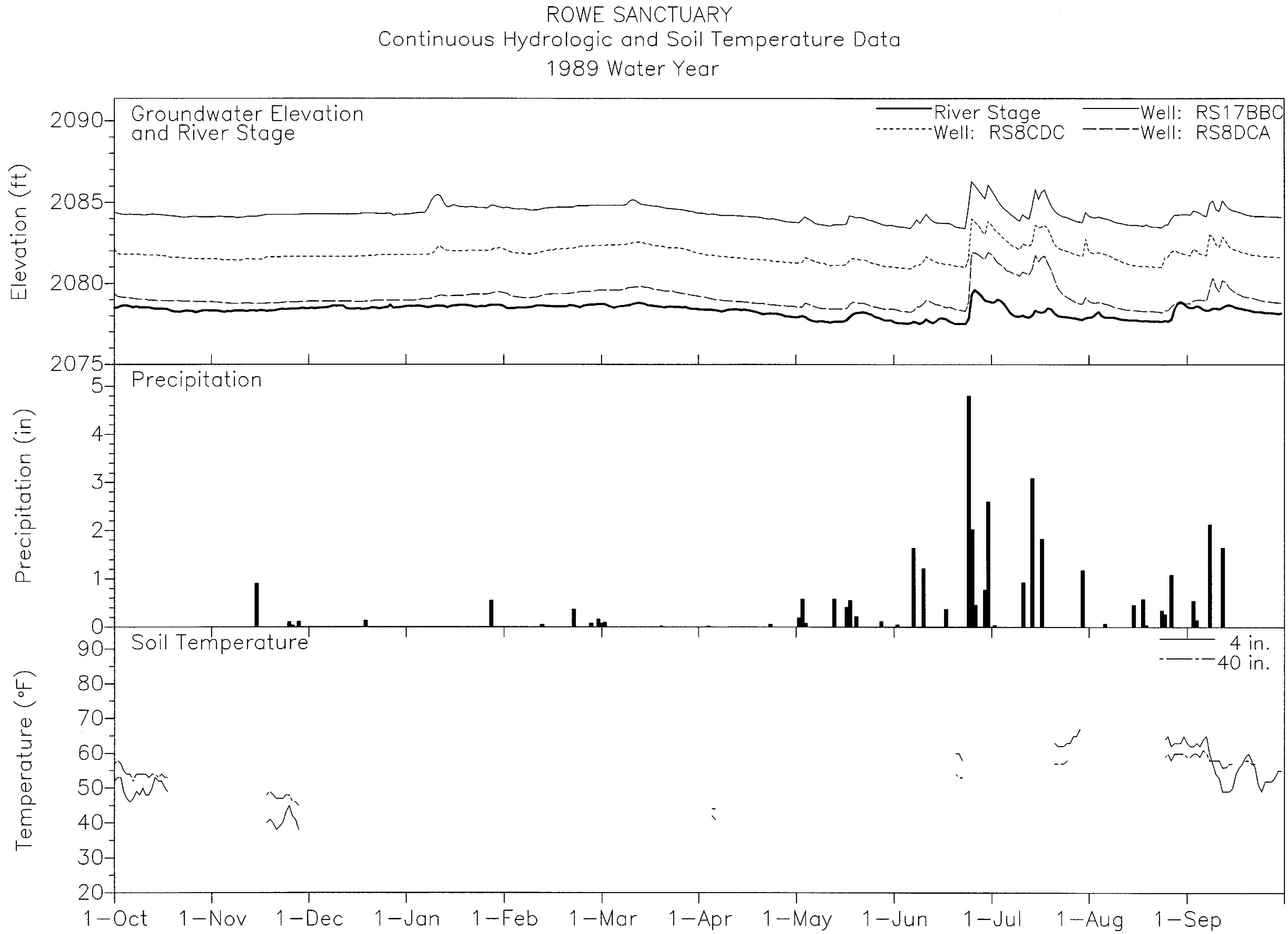

Figure 74b. Rowe Sanctuary continuous hydrologic, and soil temperature data for water year 1989.

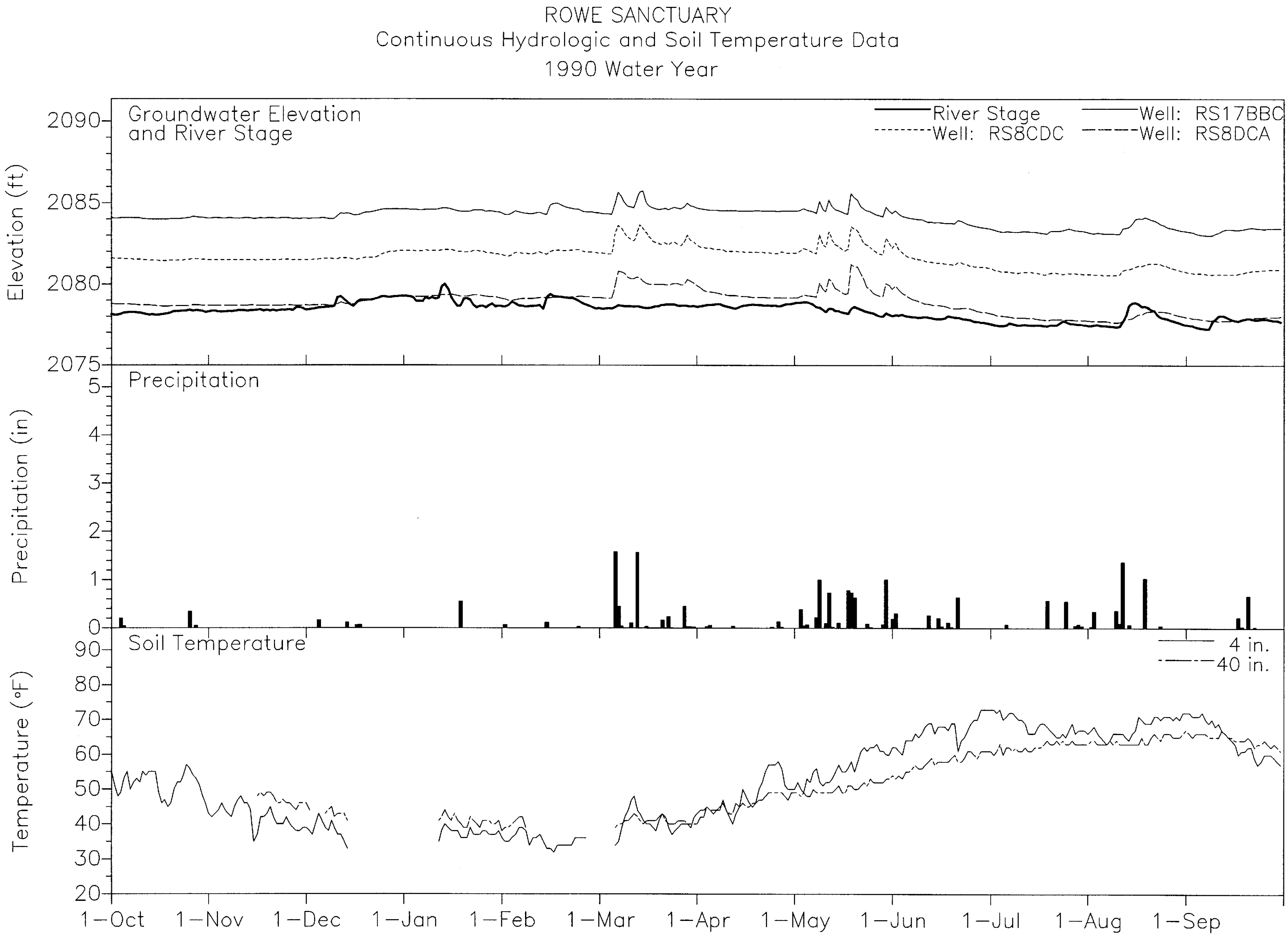

Figure 74c. Rowe Sanctuary continuous hydrologic, and soil temperature data for water year 1990.

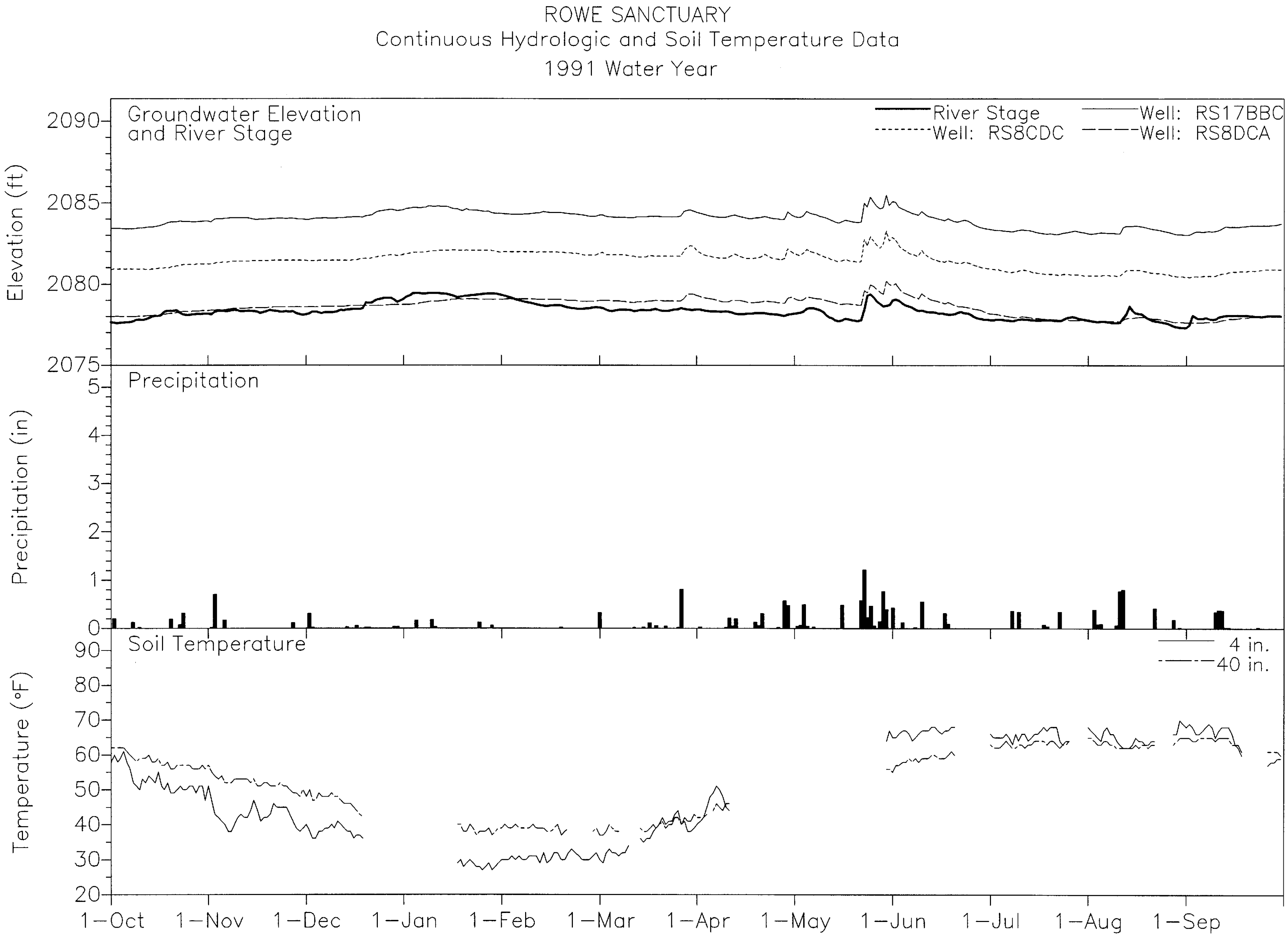

Figure 74d. Rowe Sanctuary continuous hydrologic, and soil temperature data for water year 1991.

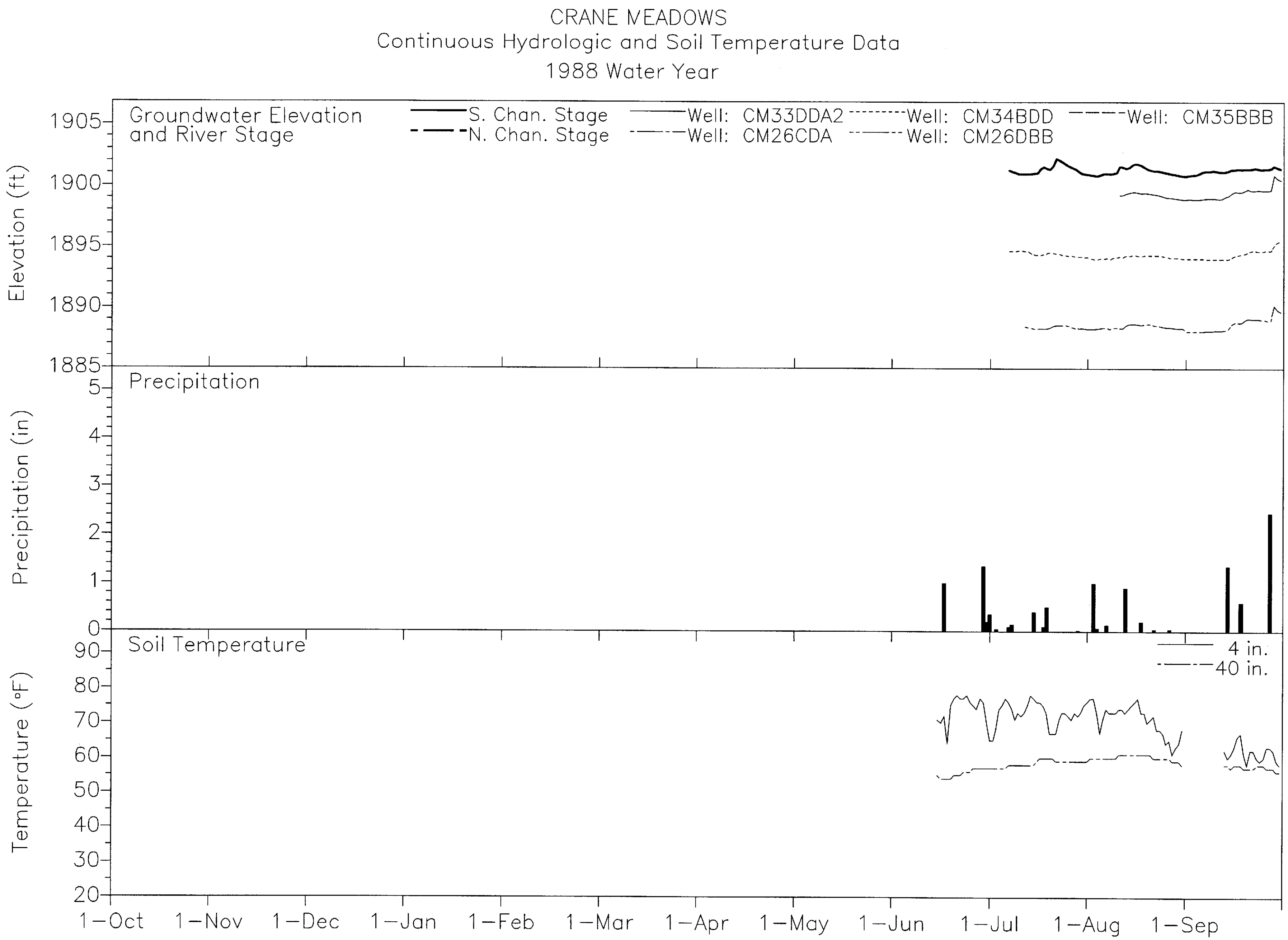

Figure 75a. Crane Meadows continuous hydrologic, and soil temperature data for water year 1988.

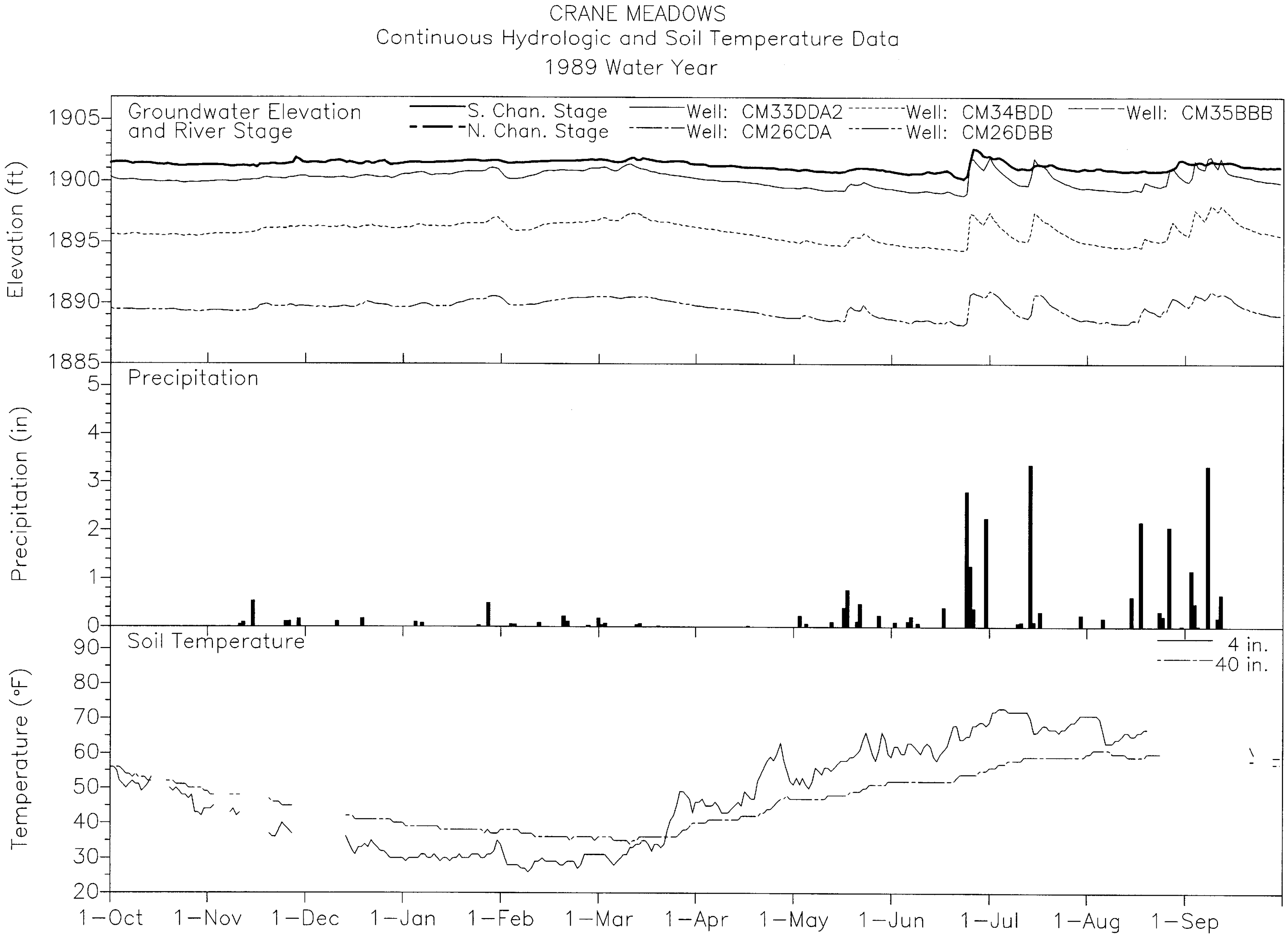

Figure 75b. Crane Meadows continuous hydrologic, and soil temperature data for water year 1989.

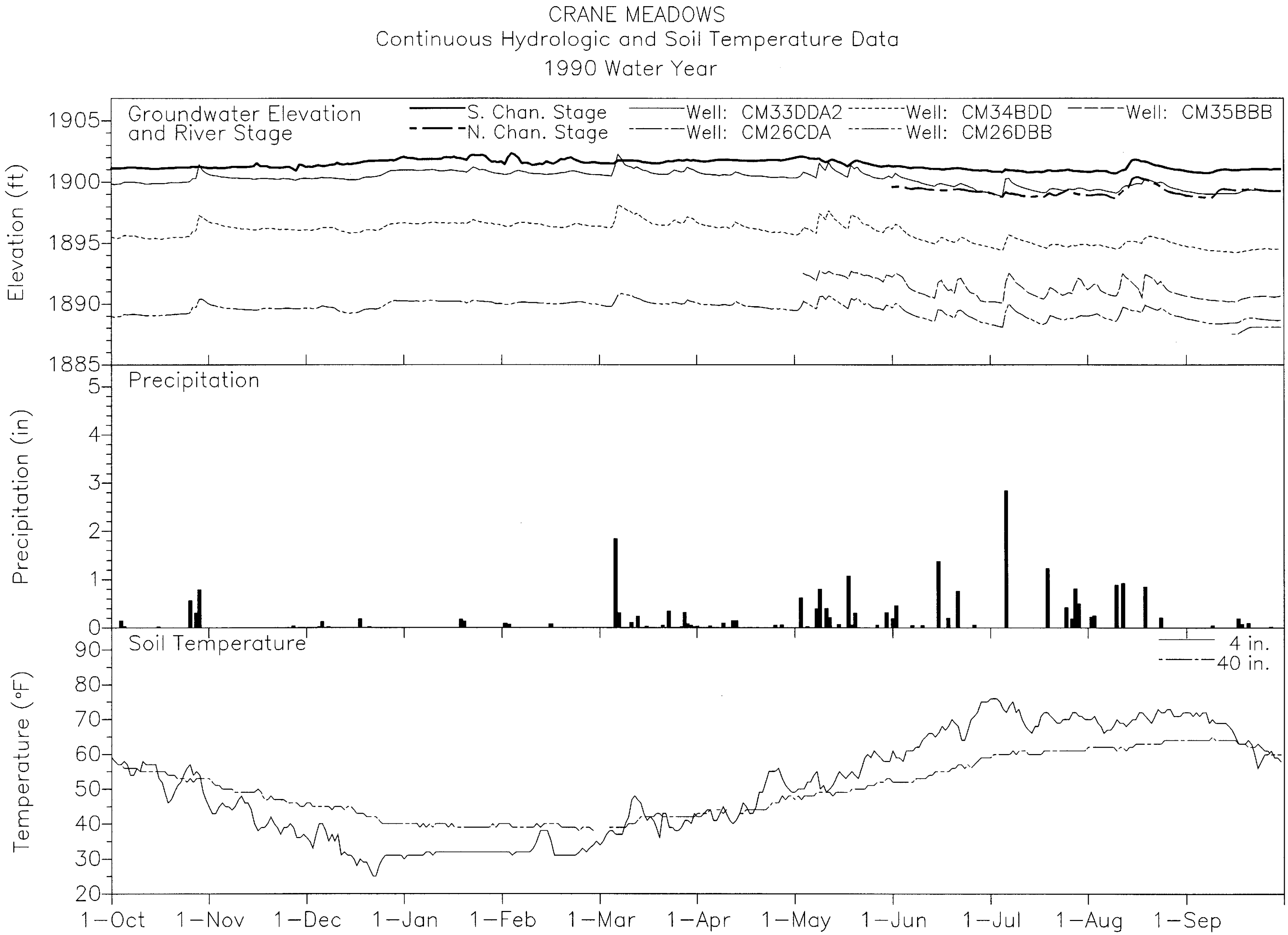

Figure 75c. Crane Meadows continuous hydrologic, and soil temperature data for water year 1990.

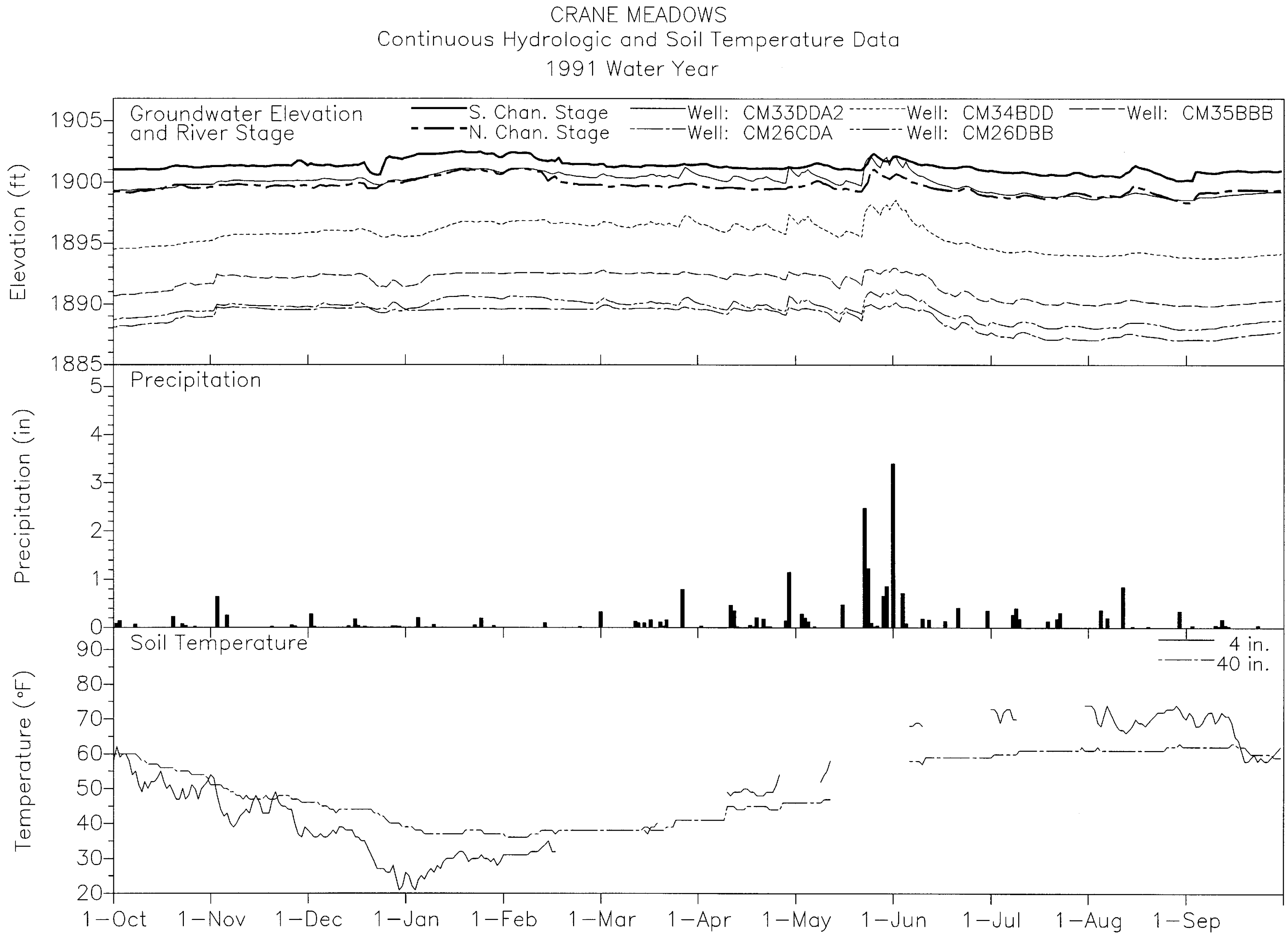

Figure 75d. Crane Meadows continuous hydrologic, and soil temperature data for water year 1991.

APPENDIX C

DISTRIBUTION OF SURVEY POINTS FOR THE DETAILED SURFACE TOPOGRAPHY

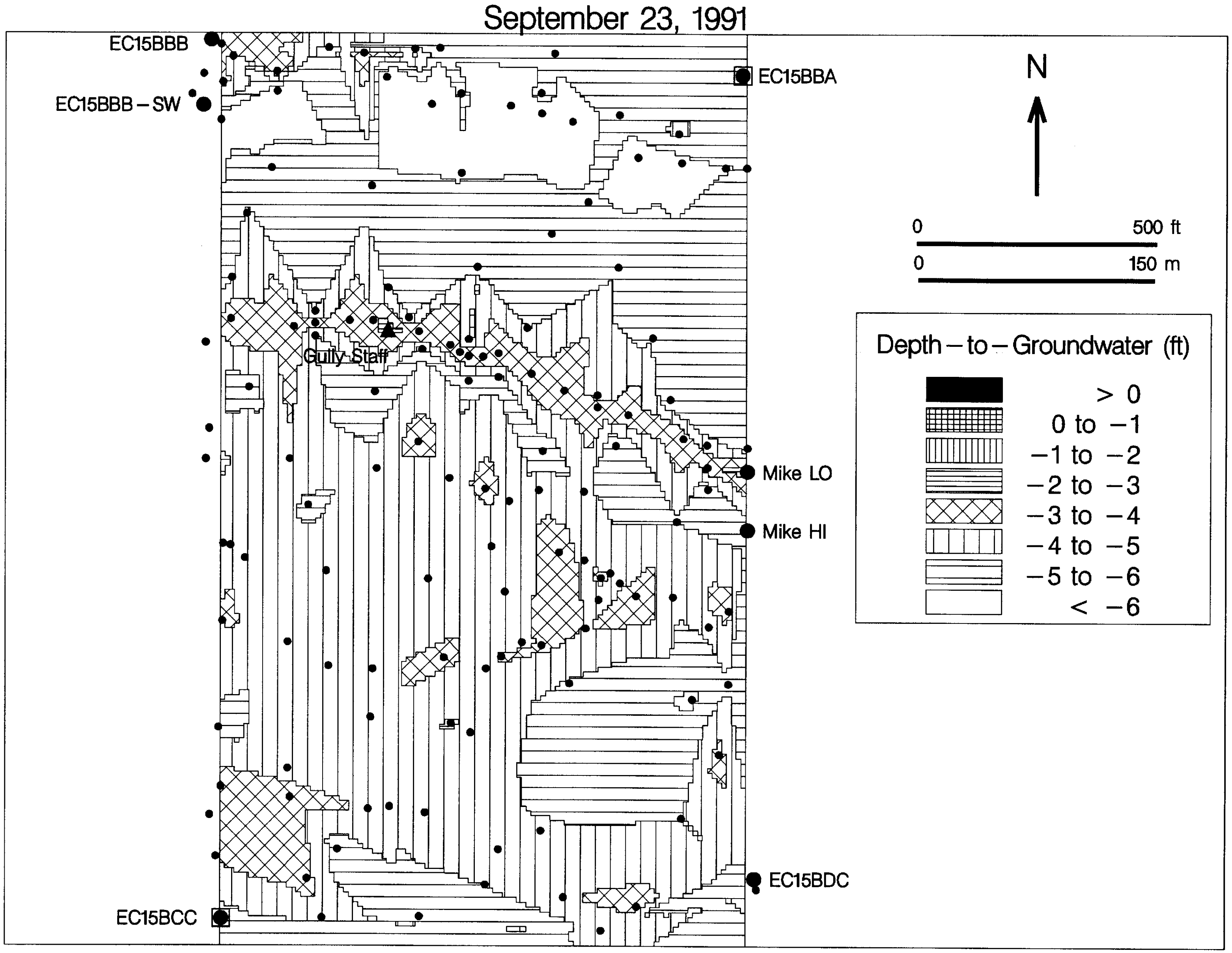

Figure 76. Distribution of survey points for the detailed topographic survey of a representative area at Elm Creek.

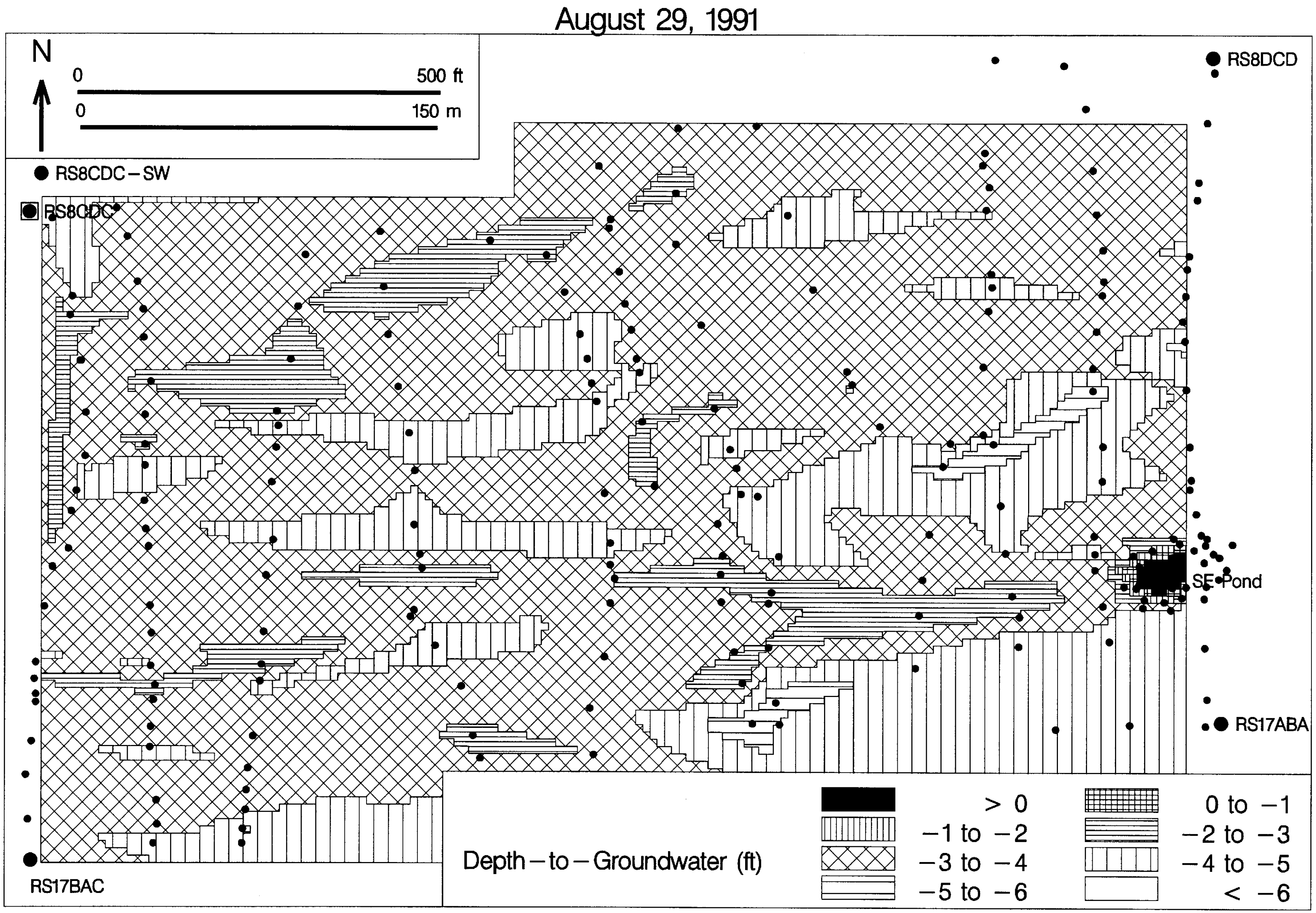

Figure 77. Distribution of survey points for the detailed topographic survey of a representative area at Rowe Sanctuary.

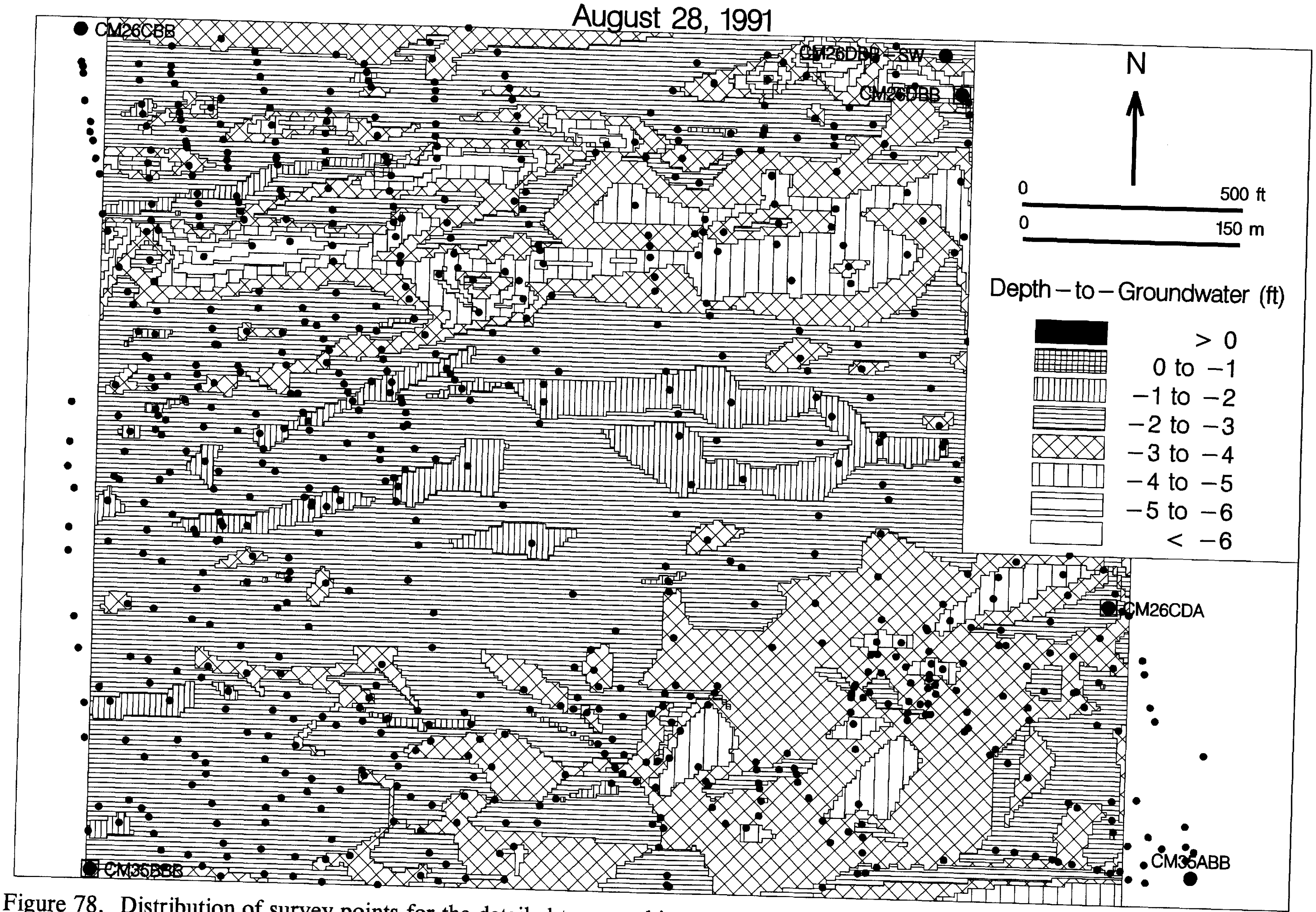

Figure 78. Distribution of survey points for the detailed topographic survey of a representative area at Crane Meadows.

APPENDIX D

ADDITIONAL ADJACENT GROUNDWATER WITHDRAWAL FOR IRRIGATION DATA

Groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation at Elm Creek, Rowe Sanctuary, and Crane Meadows for years other than 1991 are presented in the following figures.

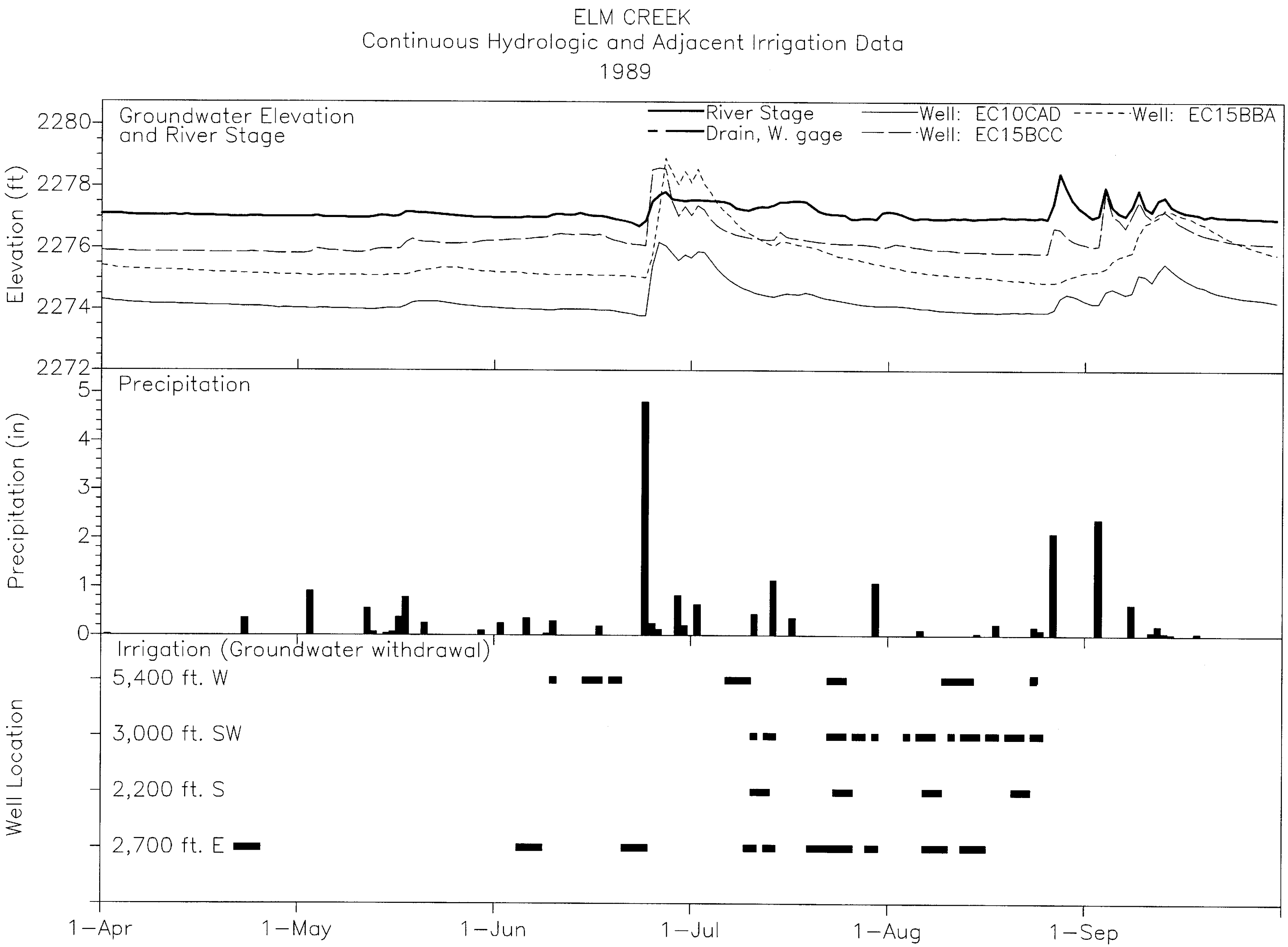

Figure 79. Elm Creek groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1989. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

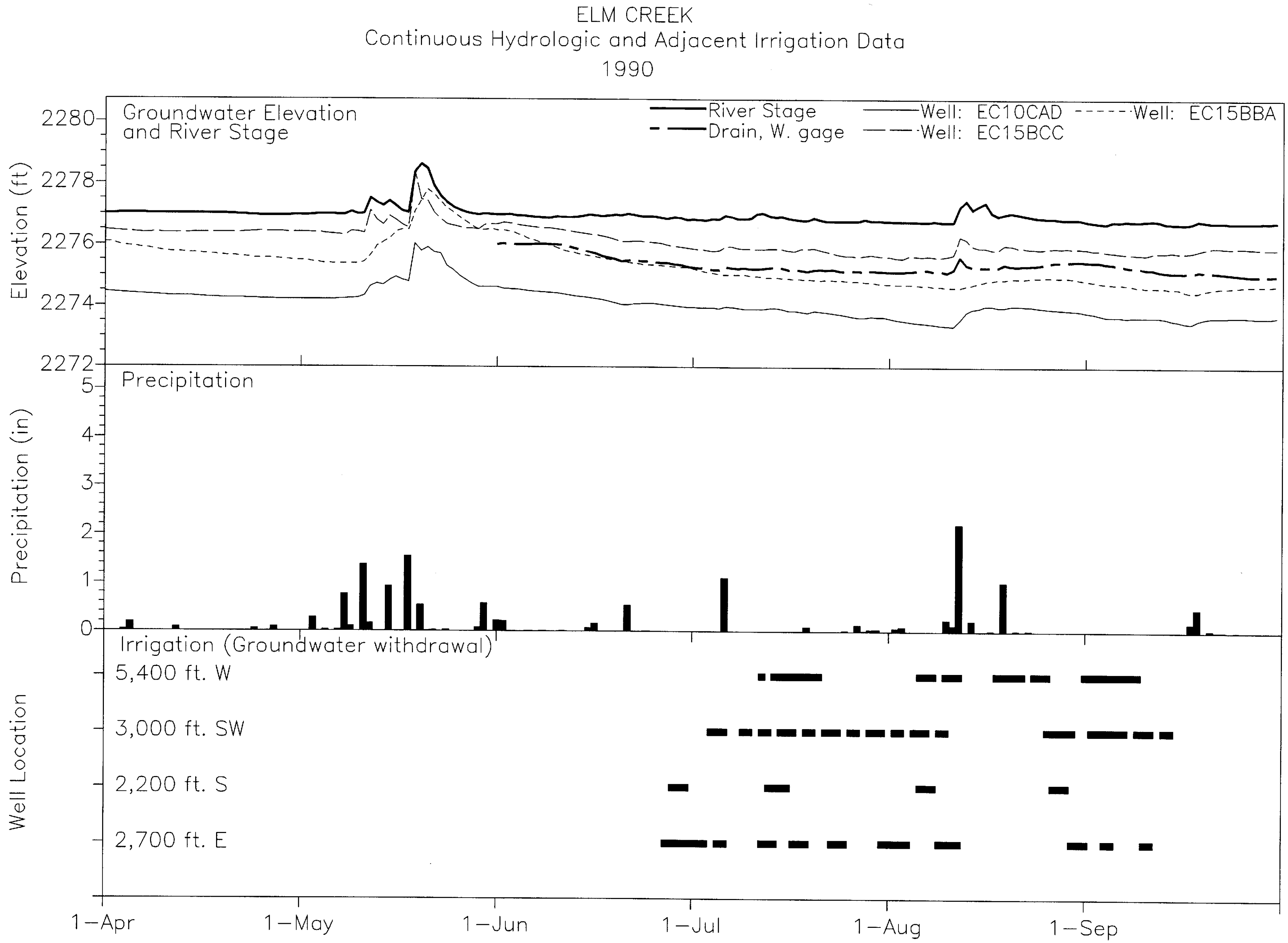

Figure 80. Elm Creek groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1990. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

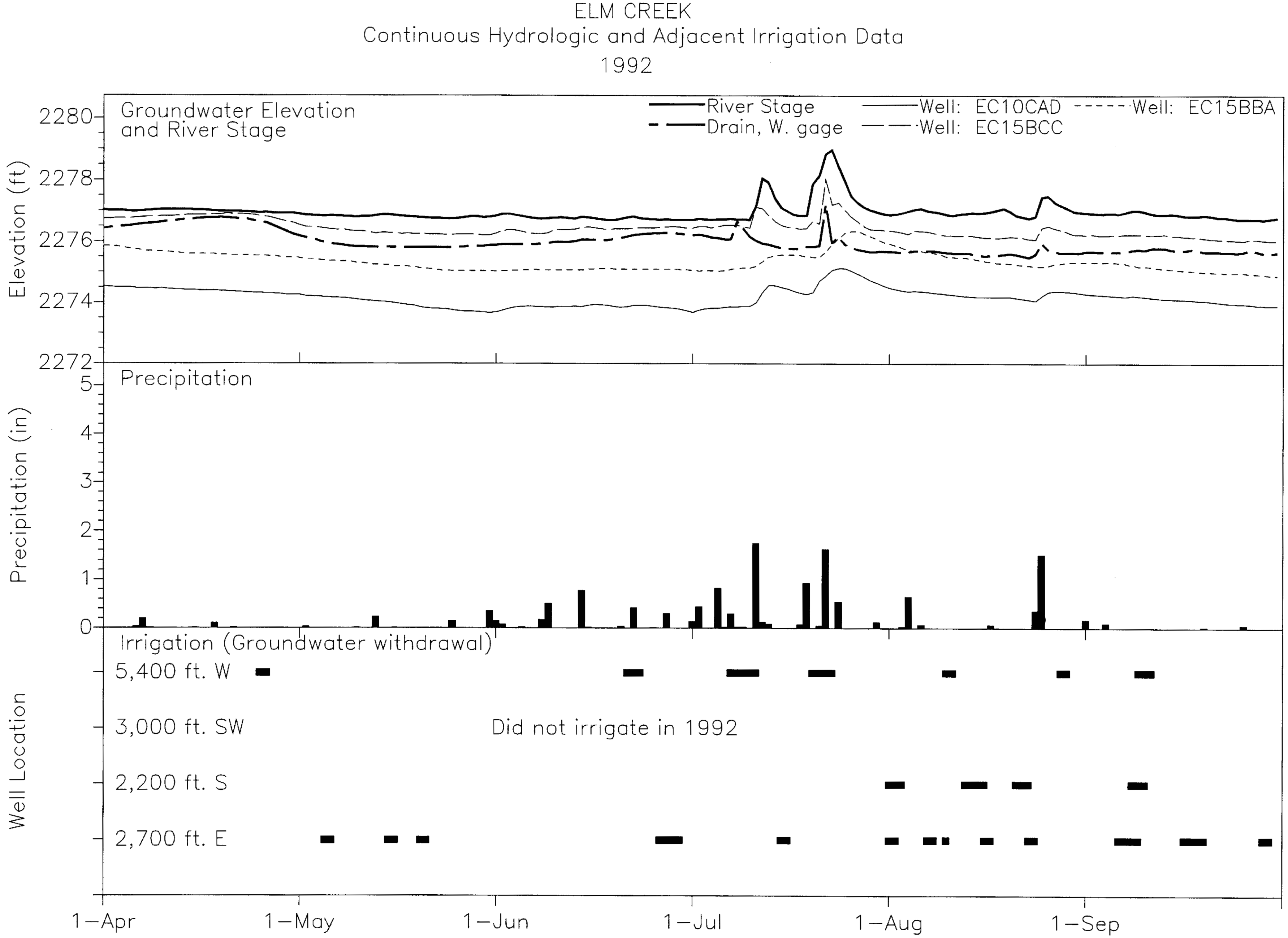

Figure 81. Elm Creek groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1992. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

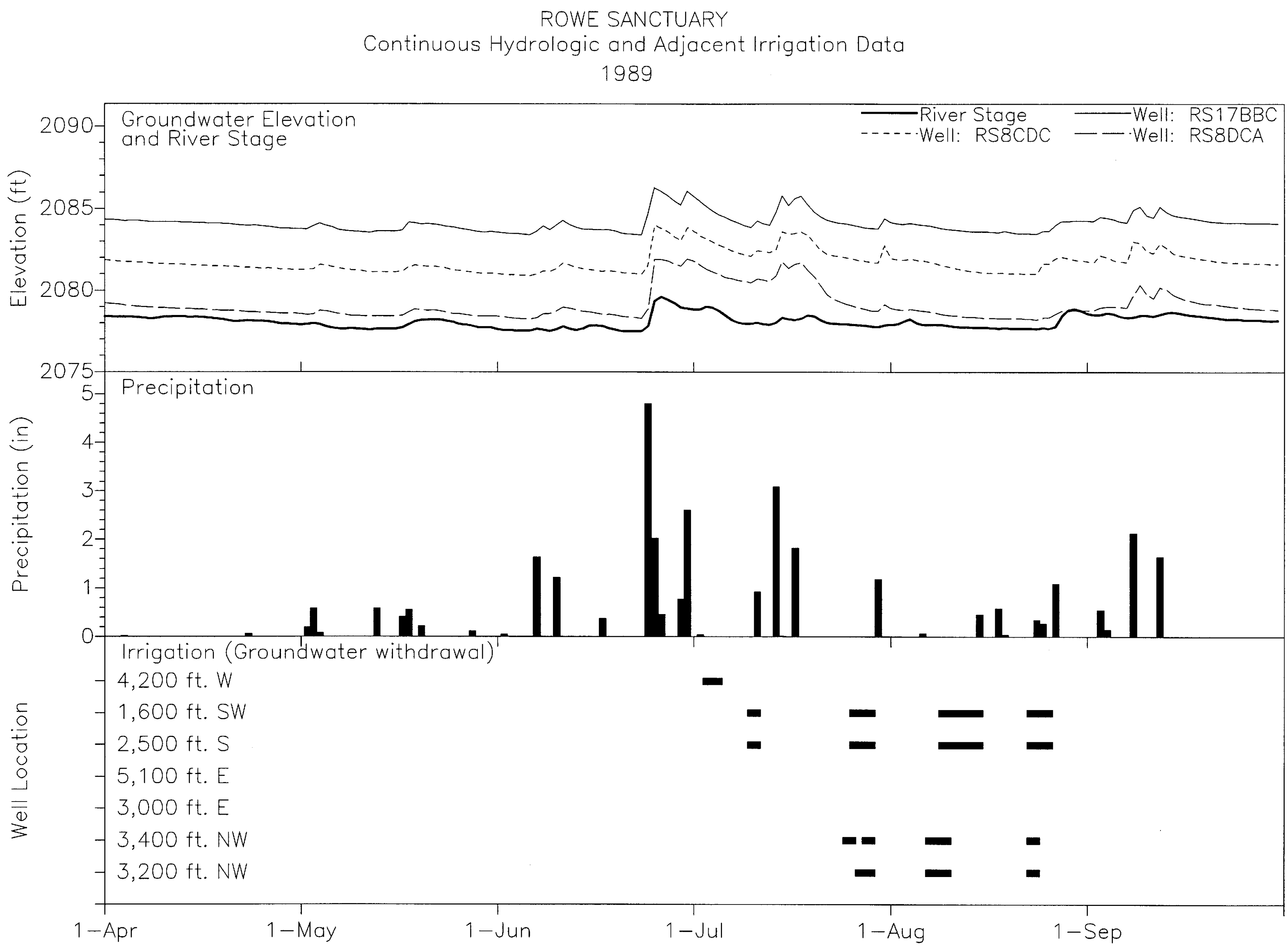

Figure 82. Rowe Sanctuary groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1989. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

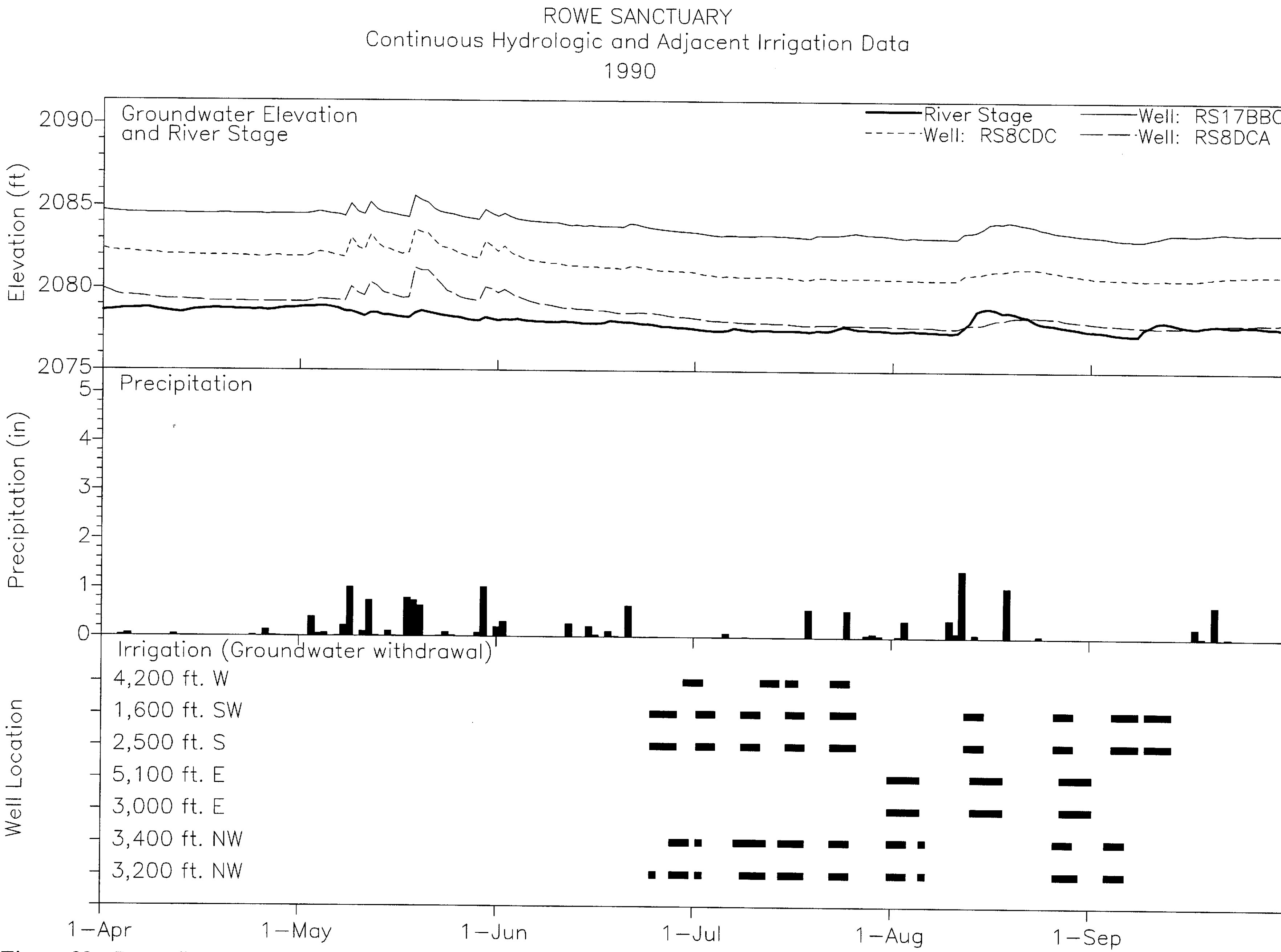

Figure 83. Rowe Sanctuary groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1990. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

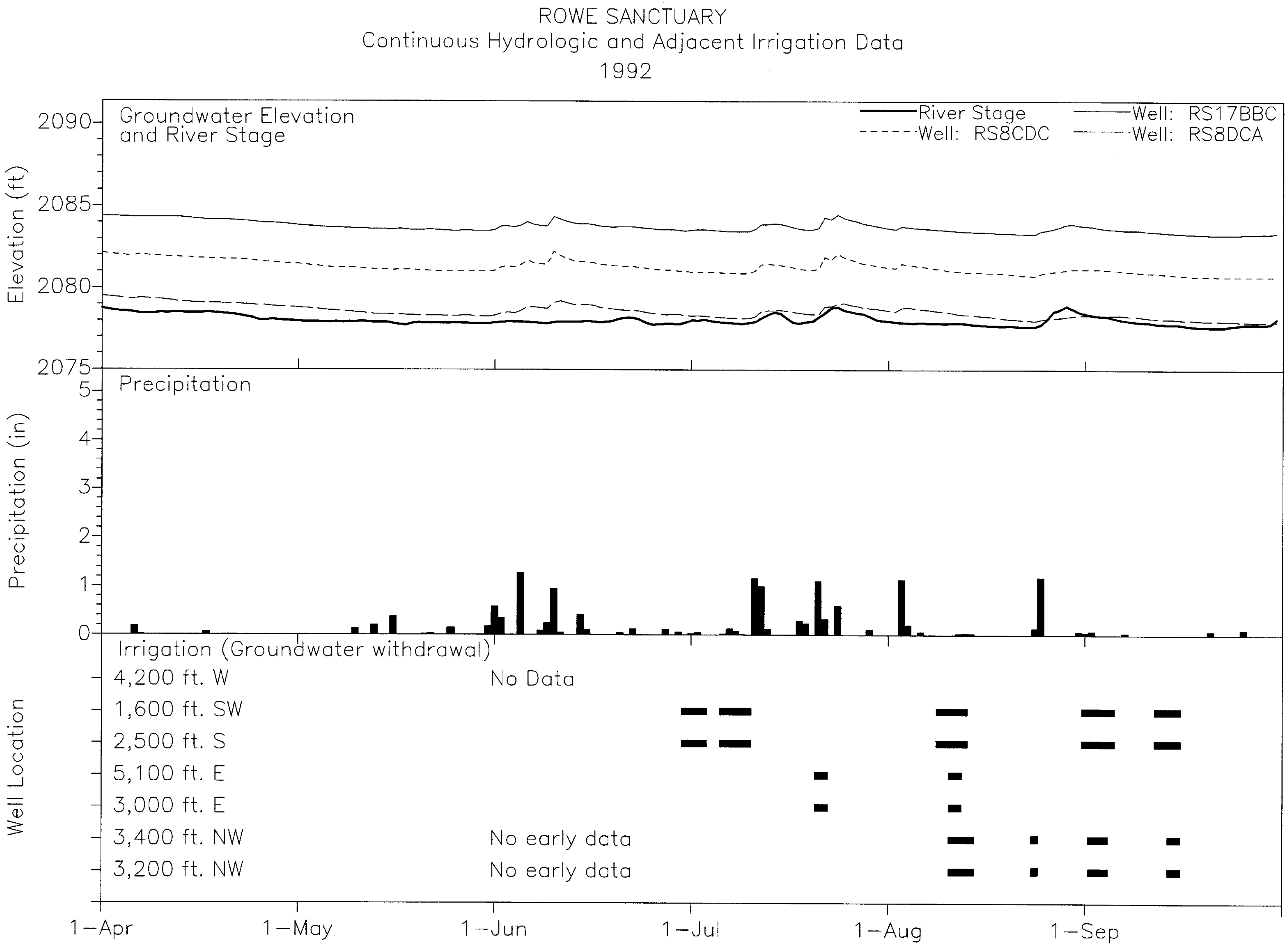

Figure 84. Rowe Sanctuary groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1992. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

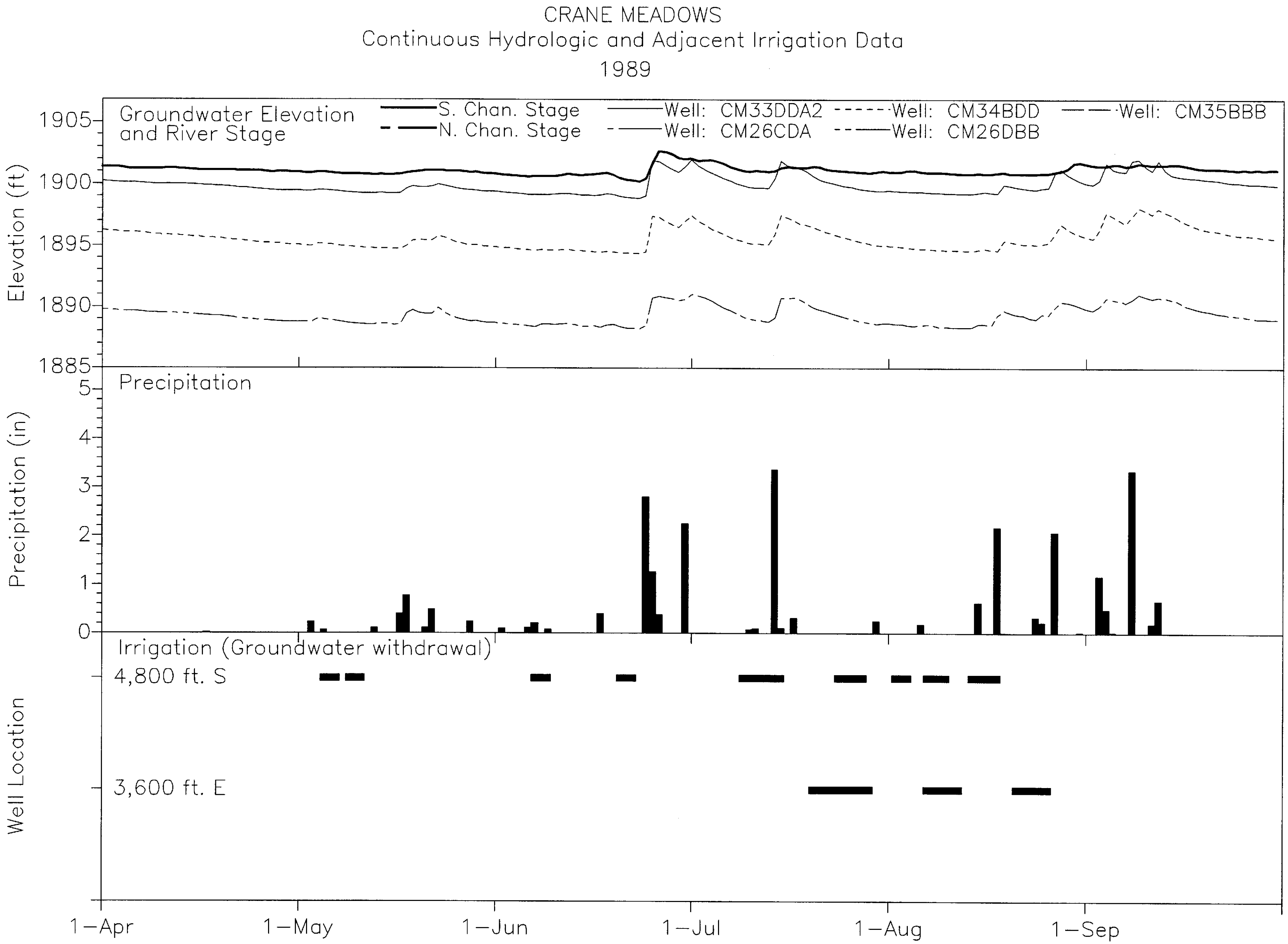

Figure 85. Crane Meadows groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1989. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

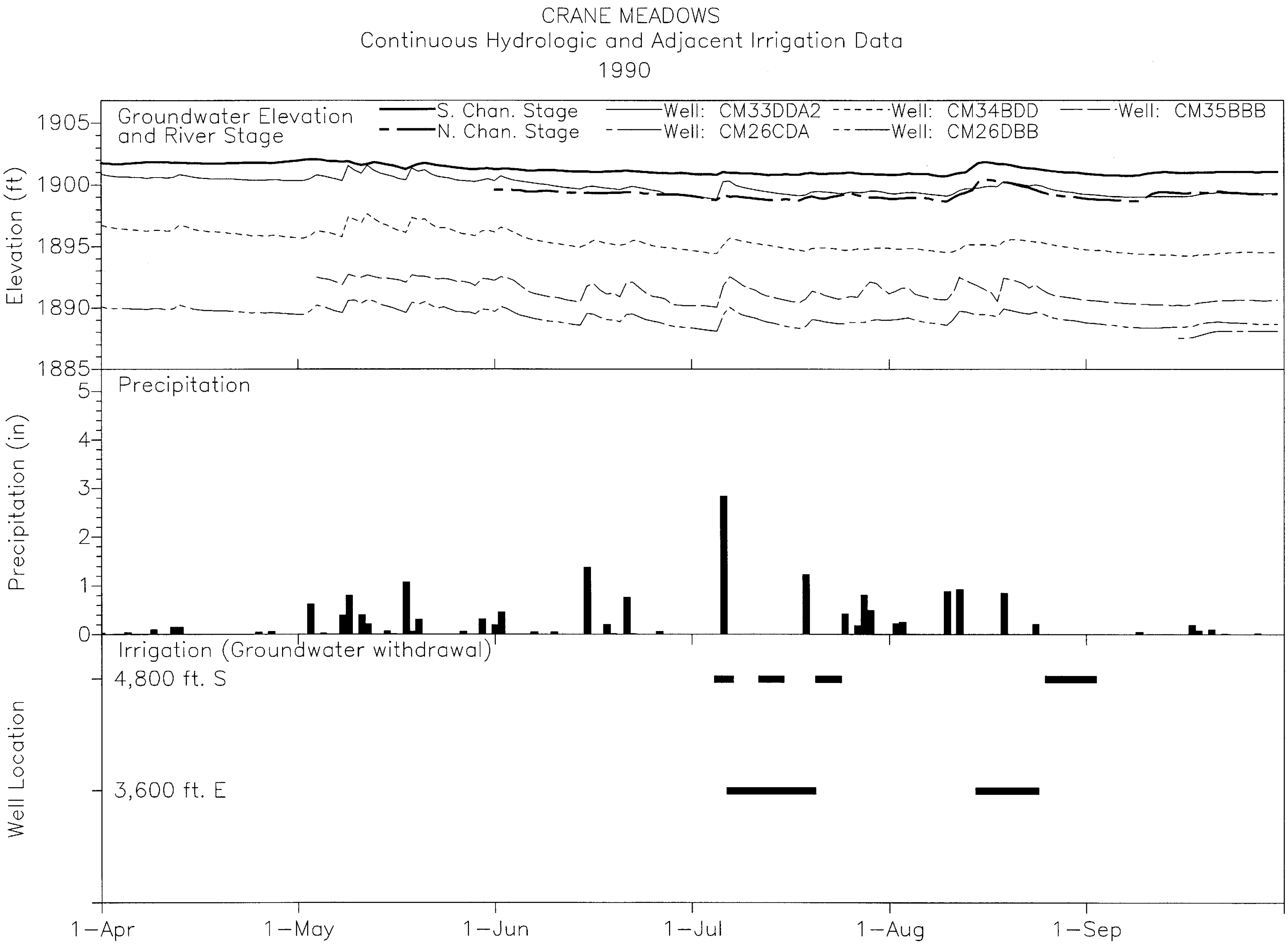

Figure 86. Crane Meadows groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1990. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.

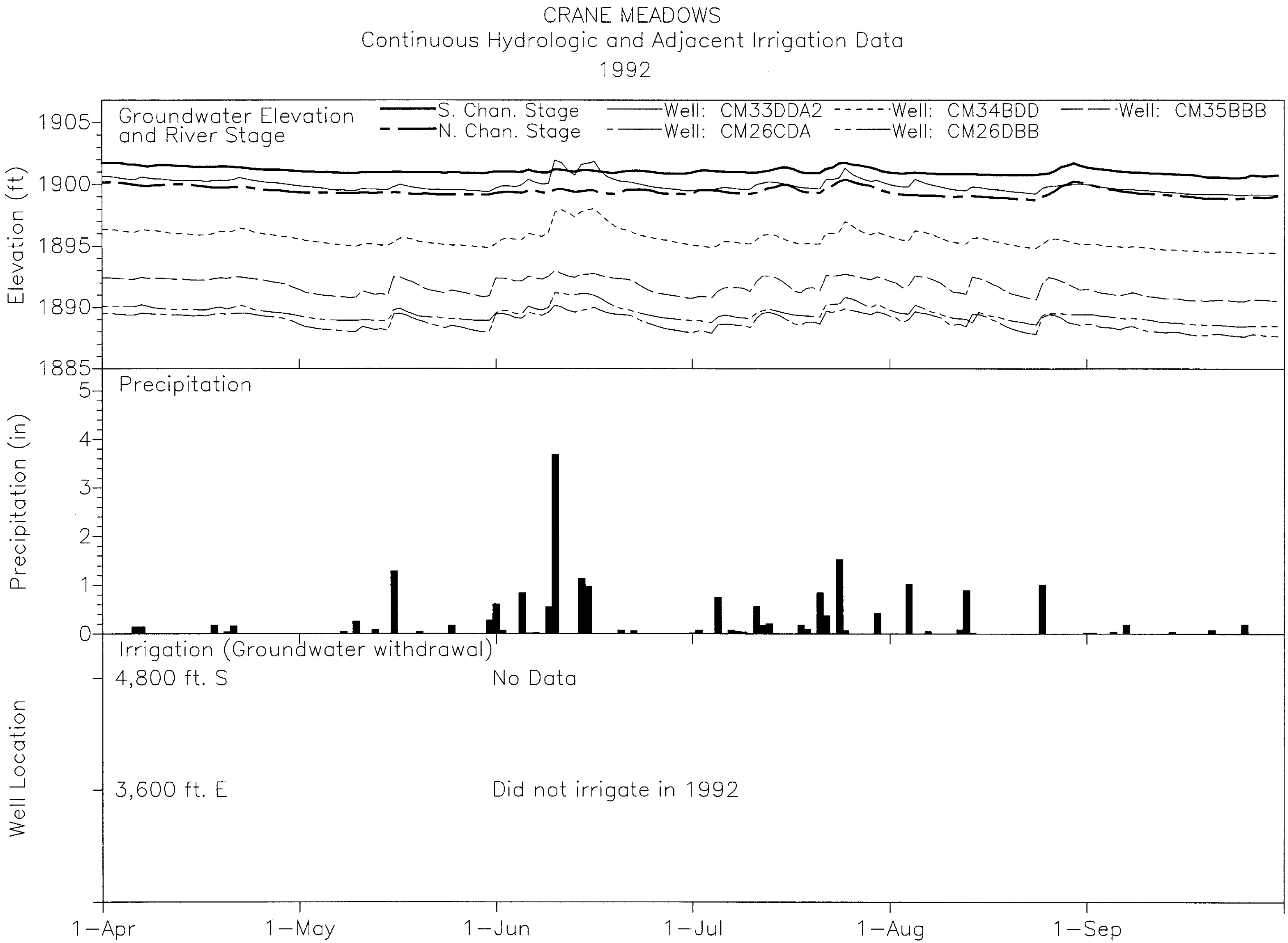

Figure 87. Crane Meadows groundwater elevation, river stage, precipitation, and adjacent groundwater withdrawal for irrigation April-October 1992. Well location shows the distance and direction from the nearest study-site well with a recorder to the irrigation well.