GROUNDWATER LEVEL CHANGES IN OKLAHOMA 1978-1998

Technical Report 99-4

By Mark H. Belden

Oklahoma Water Resources Board

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INTRODUCTION

Water Level Network

The Oklahoma Water Resources Board (Board) conducts a state-wide annual groundwater level measurement program utilizing approximately 750 observation wells. The measuring of static water levels in these wells occurs during the first quarter of each year when the majority of agricultural irrigation wells in western Oklahoma have been turned off for several months, enabling water levels to recover.

Some of the earliest water level data collected in Oklahoma date back to the mid-late 1930s for a small number of wells in southwestern Oklahoma. In the mid 1950s, to assist in the evaluation and study of the Tillman Terrace aquifer in southwest Oklahoma, a network of wells was established and monthly measurements were carried out. Later, in the early-to-mid 1960's, as the affects of intensive irrigated agriculture began to impact the Ogallala aquifer in northwest Oklahoma, a network of wells was developed to monitor water level fluctuations in the Oklahoma Panhandle. By the mid 1970's, as awareness and concerns over declining water levels in aquifers in the western part the state became more apparent, a state-wide monitoring program was put into place.

Emphasis of the network was and has been in high groundwater use areas. The aquifers most heavily monitored by the Board are the Ogallala, Rush Springs and alluvium and terrace deposits of the Cimarron River, North Canadian River and the North Fork of the Red River.

Drillers' logs provided by licensed water well drillers are used to select the observation wells. The completion data provided on the drillers' logs (total depth, lithologies, first zone of water encountered and screened interval) enable the Board to determine the aquifer which will be monitored.

The Board obtains its water level measurements using graduated steel tapes that are marked in hundredths, tenths and one foot increments. The tapes are lowered into the well bore through access ports constructed in the base of the well pump, sanitary well seal or well casing cap.

The Board produces a water level publication once every three years. Information for each observation well includes the legal location, geographic positions (latitude-longitude), altitude of the land surface, the most recent water level, the mean water level over the period of record, the minimum and maximum water level over the period of record, the total change (+,-) in water level over the period of record and the 1, 5 and 10 year change in water level.

Oklahoma's Aquifers

Groundwater is water that percolated downward from the surface, filling voids or open spaces in rock formations. An aquifer is a subsurface unit that can yield useful quantities of water. Oklahoma's aquifers can be divided into two general groups: bedrock and alluvium and terrace deposits. These two groups are classified as being either a major or minor aquifer based on their yield capabilities. The major bedrock aquifers can be generally placed in one of the following categories: sandstone; interbedded sandstone, limestone, and shale; soluble carbonate or evaporite; and semi-consolidated sand and gravel. Major alluvium and terrace aquifers consist of unconsolidated deposits of sand and gravel.

The OWRB considers major aquifers to be those bedrock aquifers that yield on average at least 50 gallons per minute (gpm), and those alluvium and terrace aquifers which yield at least 150 gpm. The Board has designated 13 bedrock and 10 alluvium and terrace aquifers as major aquifers. The geologic age, type, thickness and well yield attributes of Oklahoma's major aquifers are shown in Table 1 (Christenson and Parkhurst,1994; Hart, 1974, 1981; Hoffman and Goemaat, 1975; and hydrologic atlases published by the Oklahoma Geological Survey). The description given for alluvium and terrace aquifers (row 1 of Table 1) is generic and intended to be representative of all the major alluvium and terrace aquifers. A map of the locations and names of the major bedrock aquifers is shown in Figure 1.

Minor bedrock and alluvium and terrace aquifers yield lesser quantities of water. They generally fall into the same groupings (types) as those for the major aquifers. Minor aquifers exhibit lower effective porosity and permeability (which relates to their ability to store and transmit water) and are usually thinner than major aquifers. In 1993 the Board set out to characterize the groundwater resources in the state's minor aquifers. The purpose of these investigations was to determine the aquifer's areal and vertical boundaries and to estimate the storage of these lesser known groundwater resources for the purposes of allocating groundwater rights from them. The Board has completed hydrologic investigations of 11 minor bedrock aquifers and 12 minor alluvium and terrace aquifers. Figure 2 shows the boundaries of the major and minor aquifers in Oklahoma (Note: At the time of this publication, 9 of the 12 minor alluvium and terrace aquifers and 7 of the 11 minor bedrock aquifers had been mapped).

DYNAMICS OF WATER LEVEL FLUCTUATIONS

Water level fluctuations are a function primarily of recharge to and discharge from the aquifer. Storage of groundwater within aquifers can vary from season to season and year to year, principally due to natural recharge (inflow of water to the aquifer) and natural discharge (outflow of water from the aquifer). When the inflow to the aquifer is equal to the outflow, the aquifer is considered to be in equilibrium. Recharge occurs when precipitation falling on the land percolates through soil and rock layers by the force of gravity until it reaches the water table surface. When it rains, most of the precipitation flows overland until it discharges in streams and rivers; some of the water is utilized by vegetation and some of the water may be available for recharge. Water enters (percolation of precipitation) an aquifer system in recharge areas and moves through them toward discharge areas. This movement of water within the aquifer is primarily controlled by hydraulic gradient and aquifer permeability. The recharge area is where the aquifer is exposed, or outcrops, at or near the land's surface. The recharge area is usually topographically higher and larger in areal extent than the discharge area.

Aquifer (Name)	Geologic Period	Type	Thickness (feet)	Yield (gpm)
Alluvium and Terrace Deposits (generic)	Quaternary	Unconsolidated, Clay, Silt, Sand and Gravel	usually <100	150-600
Ogallala	Tertiary	Semi-Consolidated Sand & Gravel	0-650	300-2500
Antlers	Cretaceous	Sandstone	0-900	100-500
Elk City	Permian	Sandstone	0-185	50-300
Blaine	Permian	Soluble Gypsum/Dolomite	0-275	300-2500
Rush Springs	Permian	Sandstone	0-300	150-1000
Cedar Hills	Permian	Sandstone	0-180	50-300
Garber-Wellington	Permian	Interbedded SS/SH	0-1600	200-600
Oscar	Pennsylvanian	Interbedded SS/LS/SH	0-500	50-200
Vamoosa-Ada	Pennsylvanian	Interbedded SS/SH	0-1000	50-300
Arkansas Novaculite & Big Fork Chert	Silurian and Ordovician	Fractured LS/Chert	0-1200	50
Roubidoux	Ordovician and Cambrian	Soluble Carbonate	0-1860	100-1000
Arbuckle-Timbered Hills	Ordovician and Cambrian	Soluble Carbonate	0-6000	50-600
Simpson-Arbuckle	Ordovician and Cambrian	Soluble Carbonate	0-5000	100-2800

SS- Sandstone; SH - Shale; LS - Limestone

TABLE 1 DESCRIPTION OF MAJOR AQUIFERS IN OKLAHOMA

Other sources of recharge include irrigation return flow and artificial recharge. Where irrigated agriculture is a prominent land use, a percentage of the irrigation water percolates back to the aquifer. Artificial recharge increases aquifer storage by diverting surface water directly into the aquifer by recharge wells or by filling shallow recharge basins (created by excavation or utilization of natural surficial depressions) and filling them with an external source of water to increase the vertical flow of water into the aquifer.

Many factors can influence whether recharge will occur after a precipitation event. Soil moisture is especially important. If soil moisture is in a deficit condition, then the first wave of infiltrating water will be utilized to restore soil moisture, which in turn will be available for uptake by vegetation. If soil conditions are already moist, or become that way during the course of a rain event and are sufficient to meet the water requirements of the overlying plant vegetation, then water would be available to percolate to the underlying aquifer. Table 2 shows two groundwater recharge scenarios: scenario A represents favorable

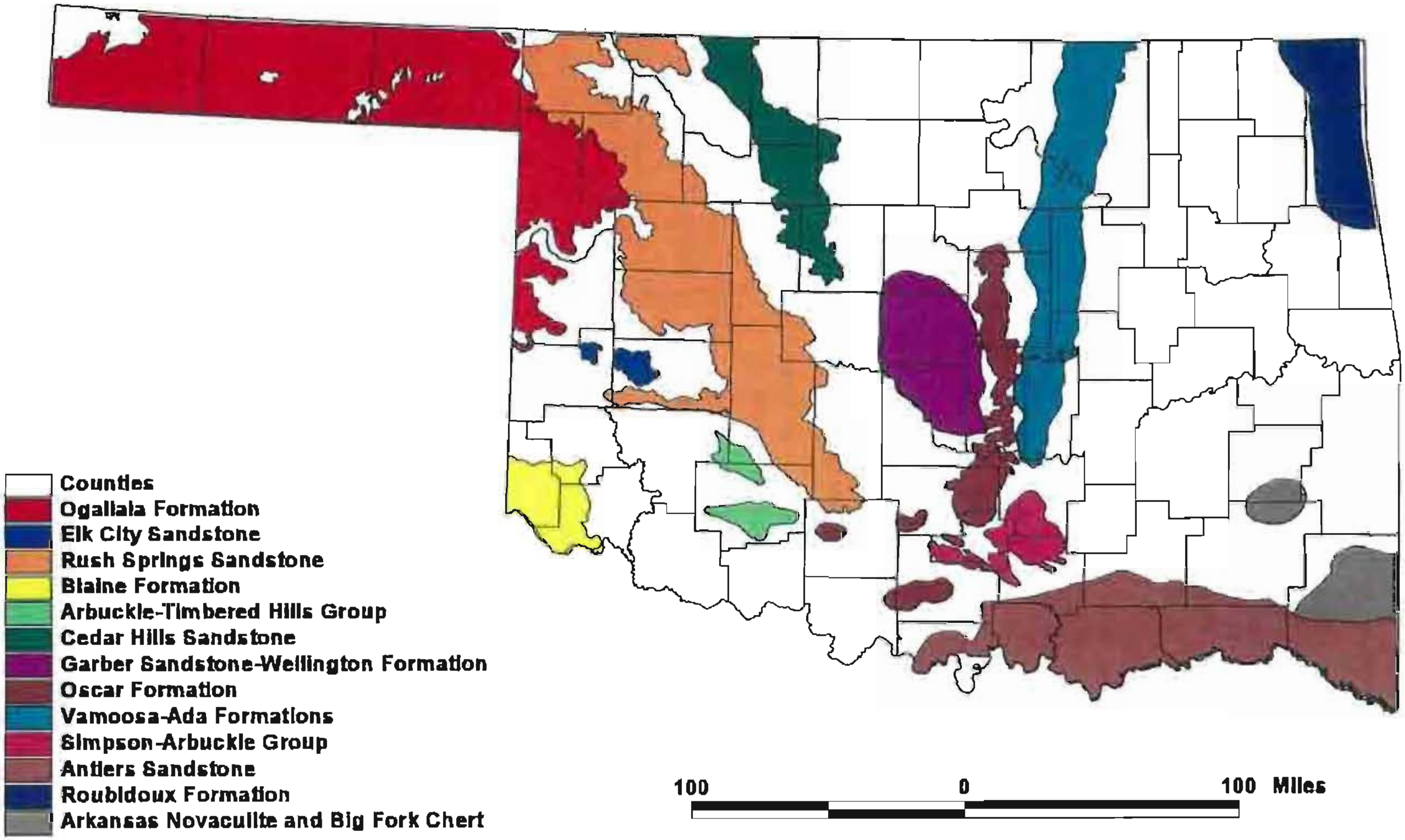


FIGURE 1 Major Bedrock Aquifers in Oklahoma

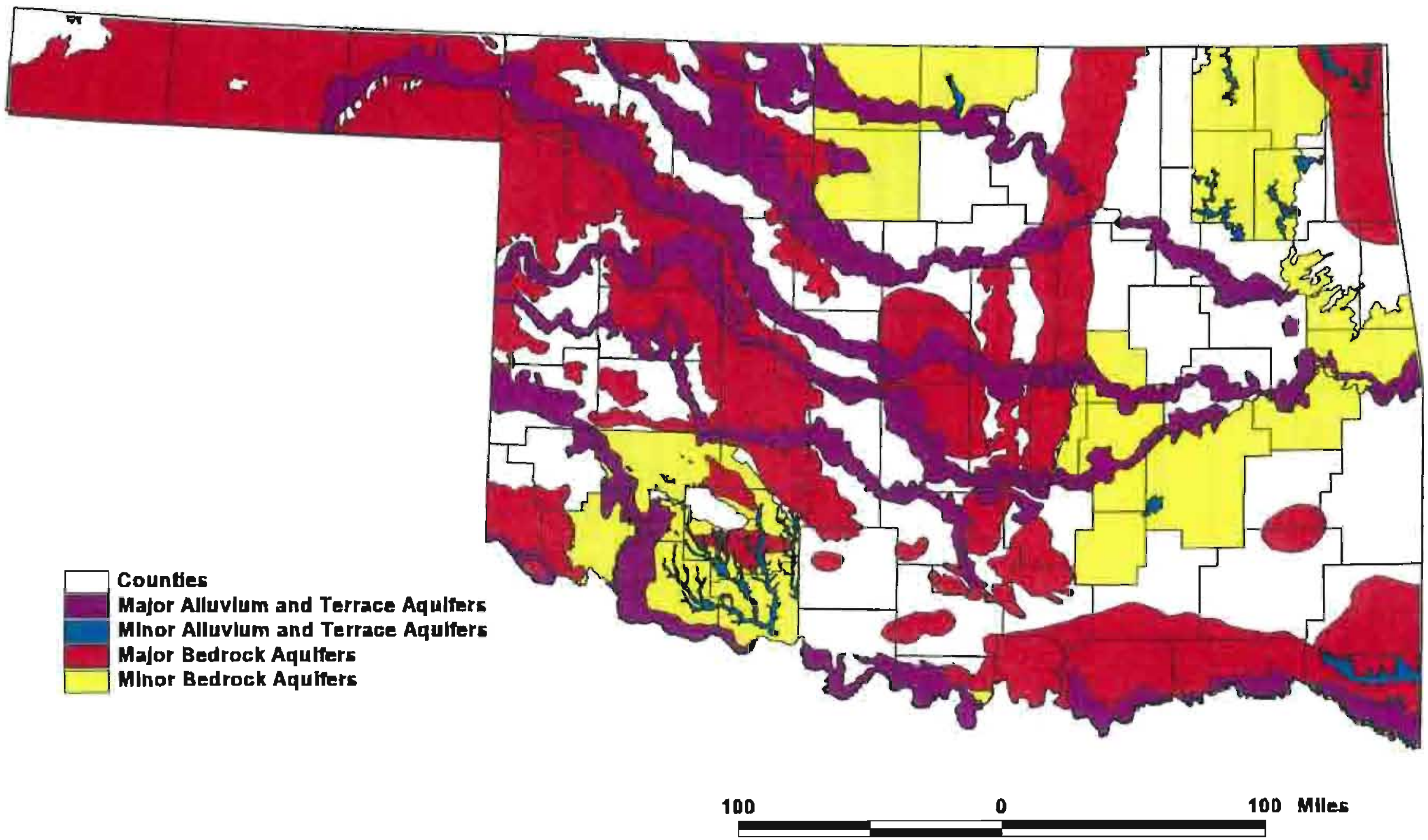


FIGURE 2 Major and Minor Aquifers of Oklahoma

conditions for groundwater recharge, and scenario B represents poor conditions.

	Scenario A Favorable Conditions for Recharge	**Scenario B** Poor Conditions for Recharge
Precipitation	Long duration/Low intensity	Short duration/High intensity (Thunderstorm)
Temperature	Moderate (Humid)	Hot (Arid)
Soil Conditions	Moist	Dry; Deficit
Depth to Water	< 50 Feet	> 50 Feet
Aquifer Type	Extensive surface exposures, thin, porous and permeable or types which exhibit strong secondary porosity, i.e. karst aquifers; where solution of mineral matrix creates larger interconnected pathways	Confined and/or thick and/or interbedded with minimal secondary openings (fractures or solution channels)

TABLE 2 COMPARATIVE CONDITIONS OF RECHARGE POTENTIAL

Pettyjohn (1983) made estimates of effective annual recharge rates for Oklahoma using stream hydrographs (period of record 1970-1979) which were separated into groundwater base flow and streamwater runoff. Groundwater base flow was then related to the size of the drainage basin above the stream gage and converted to inches. Estimated groundwater recharge rates in Oklahoma correspond closely to precipitation patterns. Precipitation ranges from ~ 16 inches in the Oklahoma Panhandle to 54 inches in southeastern Oklahoma. Estimated recharge rates range from 0.1 inches in the Panhandle to 10 inches per year in southeastern Oklahoma (Pettyjohn, 1983).

Groundwater leaves an aquifer as discharge to streams, evapotranspiration, leakage to other aquifers and to well pumpage. As groundwater flows away from the recharge area of an aquifer, it seeks a point of discharge. The site of discharge generally corresponds to where a stream or river intersects the aquifer. The components of evapotranspiration (evaporation of soil moisture to the atmosphere and utilization of soil moisture by vegetation), the effects being greatest during the summer, strip away water which might otherwise be available to recharge an aquifer.

Irrigation wells in western Oklahoma pump vast quantities of groundwater. Groundwater supplies 74 percent of all irrigation water in Oklahoma. Estimated fresh groundwater withdrawals for Oklahoma in 1990 were approximately 662 million gallons per day (mgd) (Lurry and Tortorelli, 1995). Of that, nearly 485 mgd, or 73 percent of the estimated groundwater withdrawals come from three bedrock aquifers, those being the Ogallala, Rush Springs and Blaine; and from two alluvium and terrace aquifers associated with the

Cimarron and North Canadian Rivers.

As a result of this pumping, substantial drawdown in many of the western aquifers occurs during the summer months. When precipitation occurs can affect the amount of water pumped during the year. If useful quantities of precipitation (those that restore or maintain soil moisture) occur during the growing season, then lesser quantities of groundwater may be pumped. Subsequently, the seasonal drawdown within the aquifer may be less, permitting the water levels to recover more rapidly. Winter measurements (January-March) of depth to water following a summer growing season which was augmented by beneficial rains generally reflect either a rise or a slowing in the rate of decline in the static water level from the previous year.

Drought also plays an important role in aquifer storage. In humid climatic regions, once a drought is alleviated by a normalization of precipitation patterns, groundwater levels will generally rise as recharge replenishes the aquifer. In arid regions like the Oklahoma Panhandle, where evapotranspiration and precipitation are nearly equivalent and groundwater usage is high, recovery of water levels within an aquifer after drought conditions subside are associated with the overall recharge environment. Recharge potential in the Oklahoma Panhandle is poor due to factors already discussed such as low normal precipitation, deficit soil moisture and a thick unsaturated zone (depth to water which averages more than 150 feet).

Oklahoma's agricultural economy in the western third of the state is sustained through the beneficial use of groundwater for irrigation. The pumping of large quantities of water from irrigation wells tapping the Ogallala aquifer in the Oklahoma Panhandle, combined with a recharge environment which ascribes to scenario B in Table 2, has generally led to long-term water level declines.

Groundwater Basin Monitoring

Figure 3 shows the 1998 distribution of groundwater level observation wells in the monitoring network. The network is made up of 760 irrigation, oil field supply, public water supply, domestic and stock wells.

The Board's well measurement program focuses on high use, major bedrock and major alluvium and terrace aquifers. The two most heavily monitored bedrock aquifers in Oklahoma are the Ogallala, located in the Oklahoma Panhandle and far northwest Oklahoma, and the Rush Springs in west-central Oklahoma. Water levels are observed in nearly 300 wells in the Ogallala and over 90 wells in the Rush Springs. A substantial number of wells are monitored in the Blaine aquifer in southwest Oklahoma. Figure 4 shows the distribution of network wells in the state's major bedrock aquifers. Figure 5 shows the distribution of observation wells in the major alluvium and terrace aquifers in the state. Nearly 150 wells are monitored within the alluvium and terrace aquifers of the Cimarron, North Fork of the Red and North Canadian Rivers. Over 100 of the 760 network wells are completed in minor bedrock and alluvium and terrace aquifers (Figure 6).

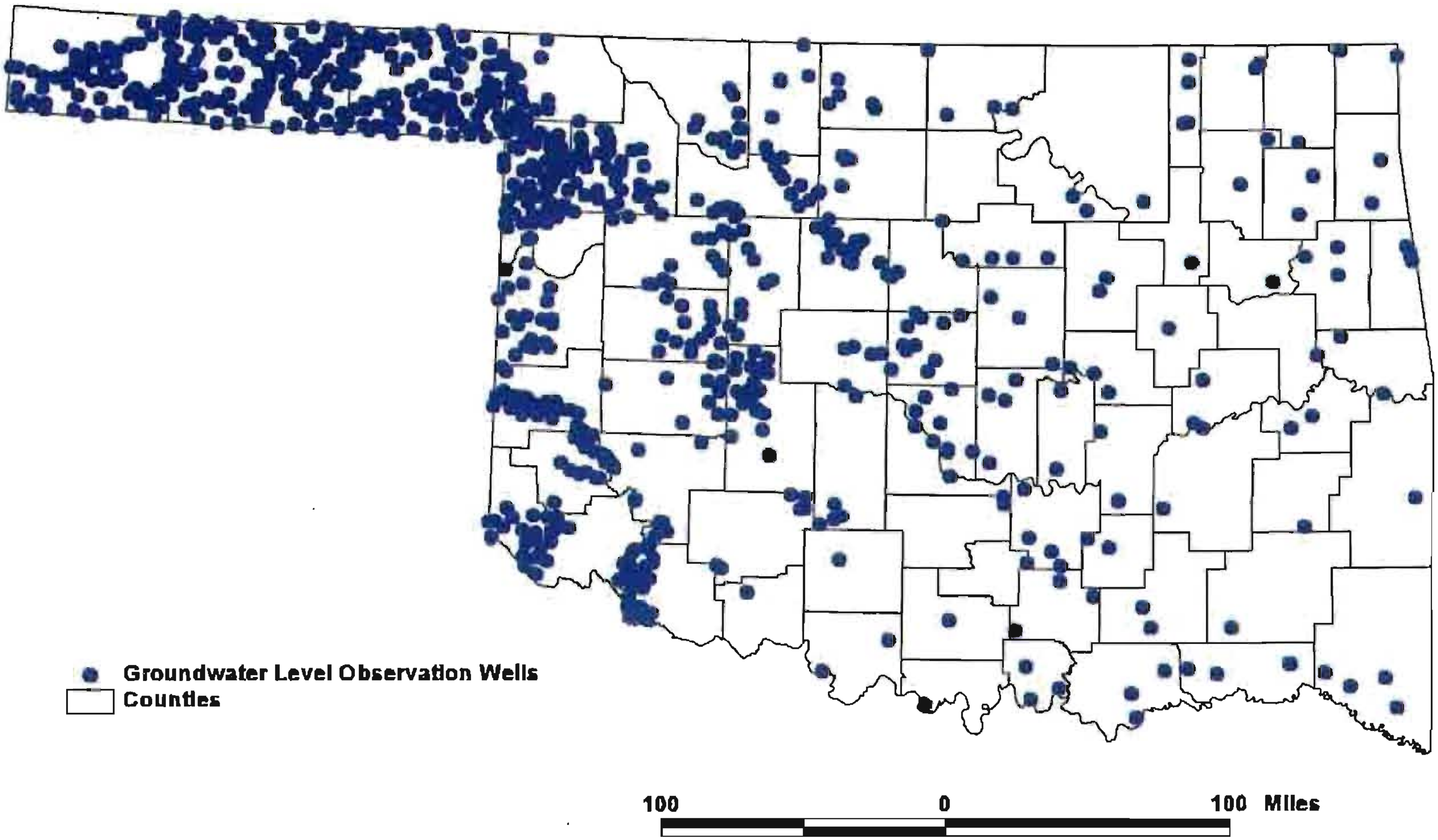


FIGURE 3 Groundwater Level Observation Wells in Oklahoma in 1998

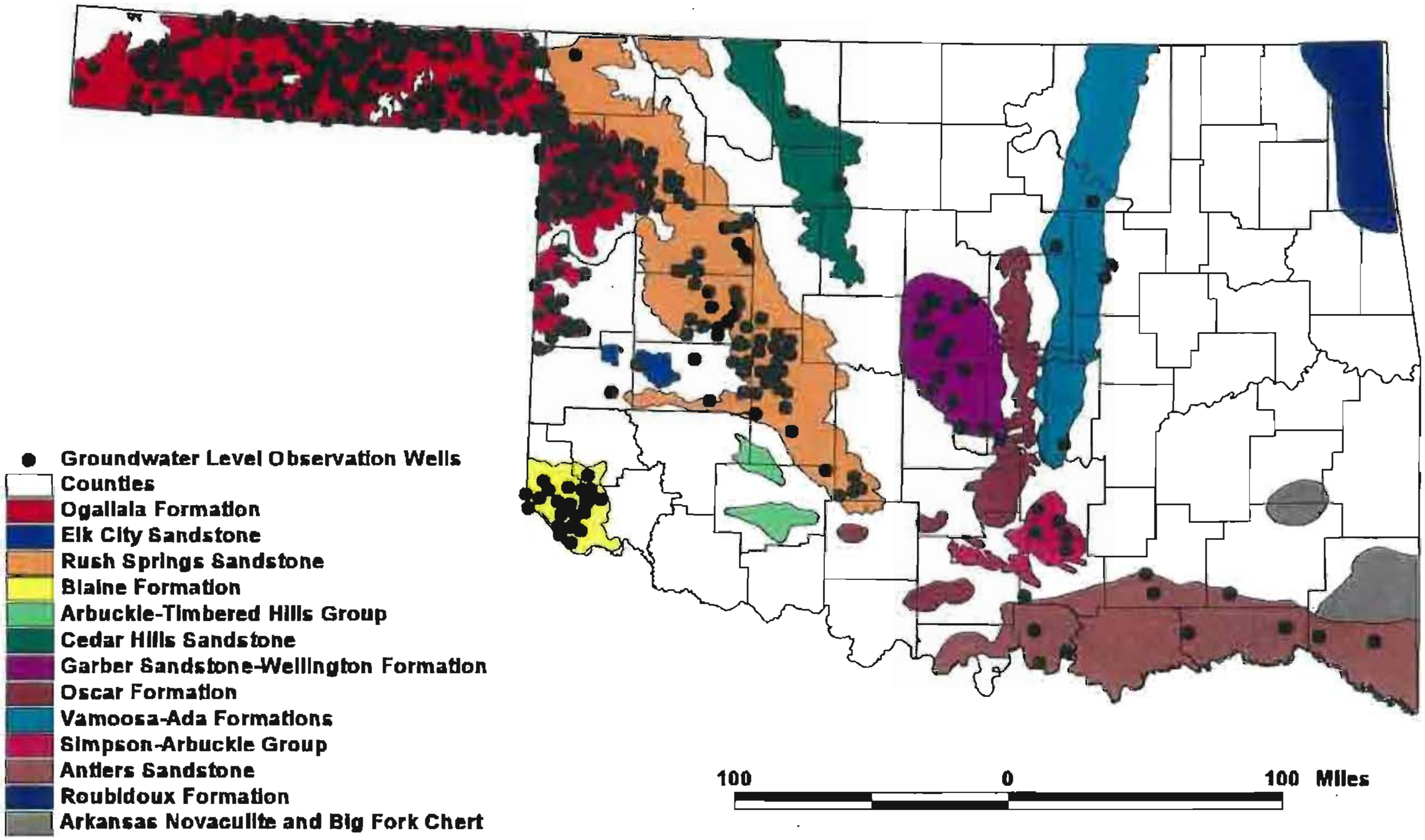


FIGURE 4 Observation Well Locations for Major Bedrock Aquifers

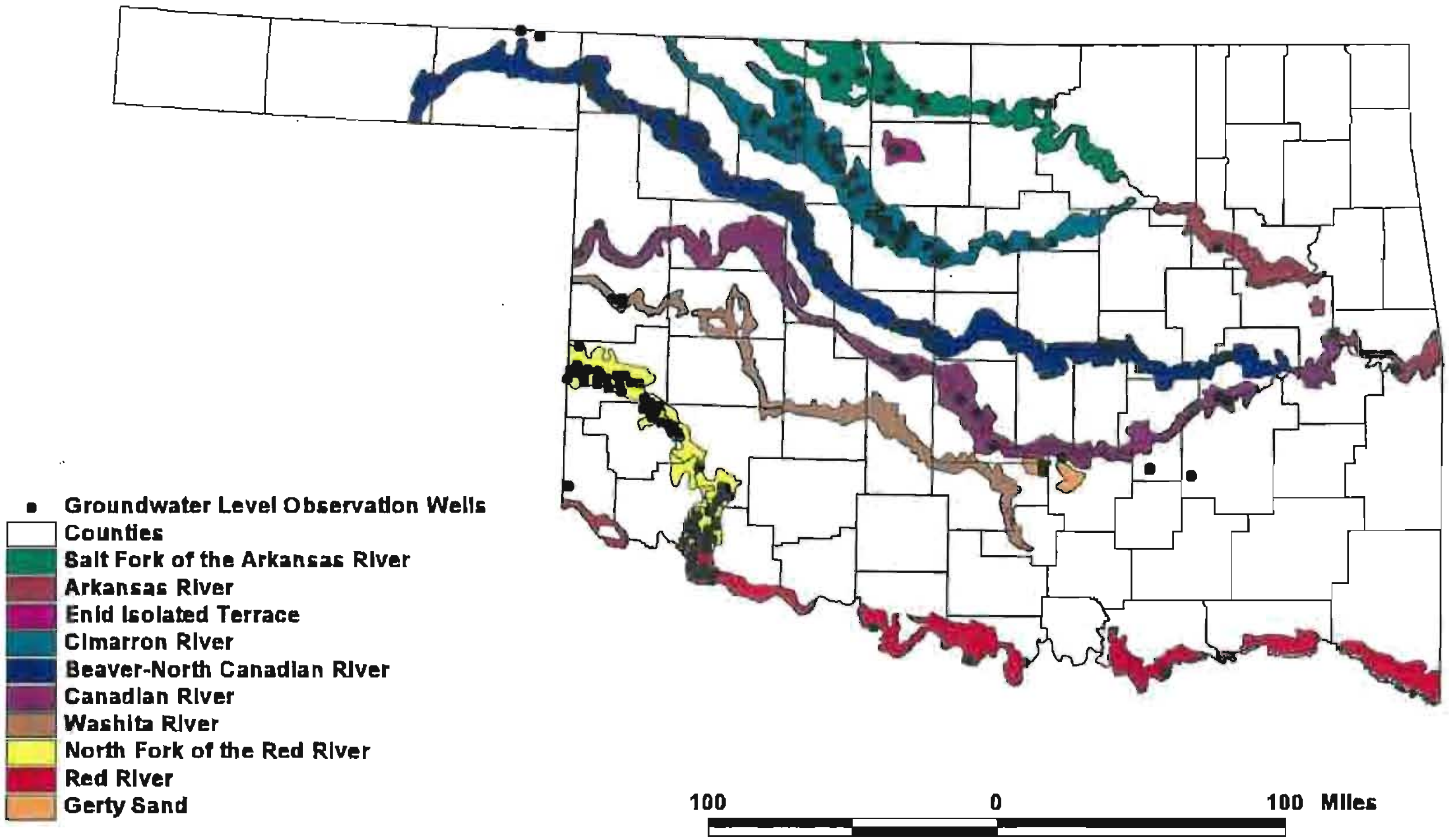


FIGURE 5 Observation Well Locations for Major Alluvium and Terrace Aquifers

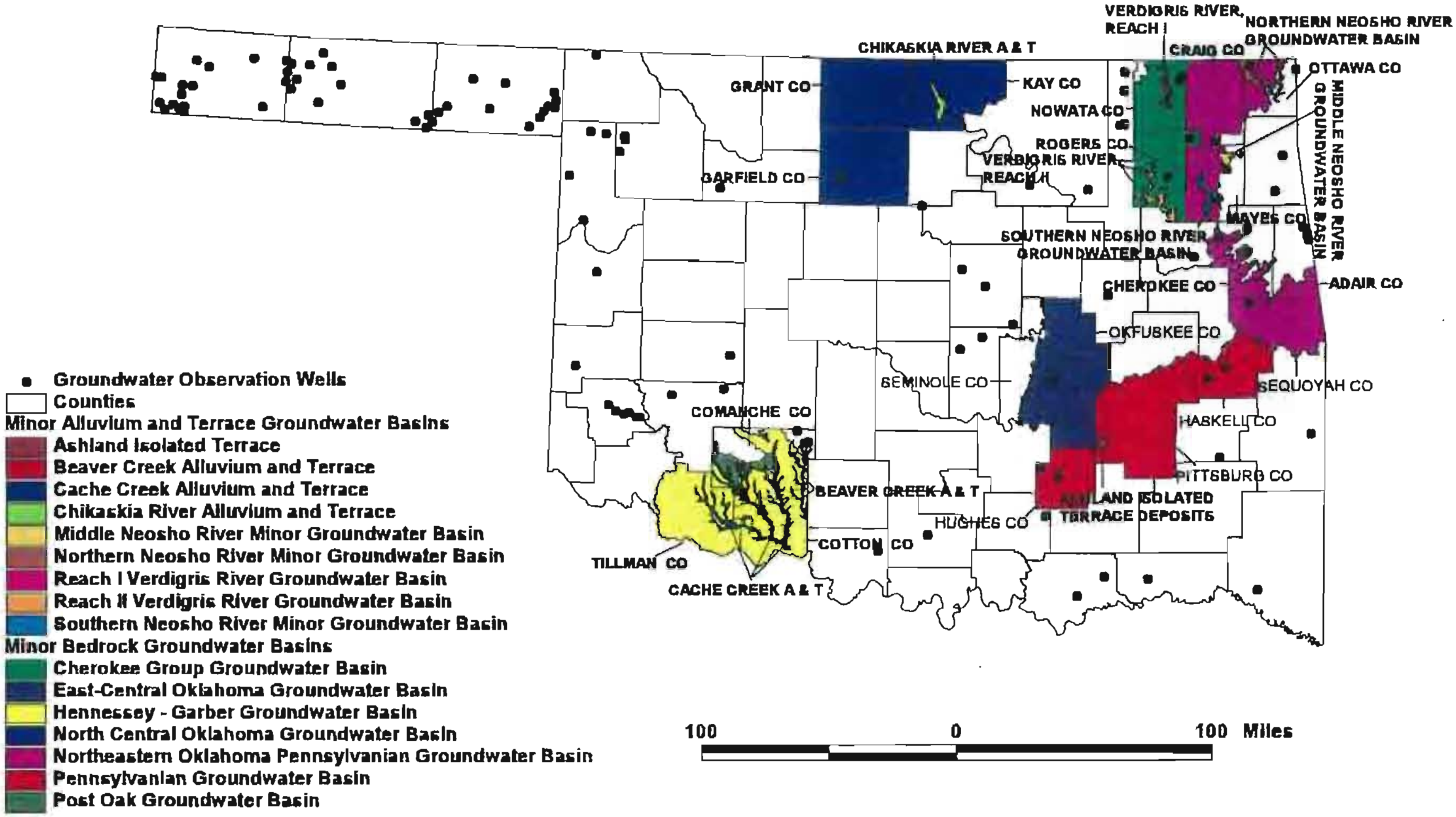


FIGURE 6 Observation Well Locations for Minor Aquifers

RESULTS

GENERAL WATER LEVEL OBSERVATIONS AND PATTERNS

Depth to groundwater varies greatly from one part of the state to another and among different aquifer types. In northwest Texas and eastern Cimarron Counties, depth to groundwater has been measured more than 335 feet below the land's surface. In Kingfisher County, water levels in shallow wells constructed into the alluvium and terrace deposits of the Cimarron River have recorded levels which stand above the land's surface.

In Oklahoma, the decade of the nineties has been termed a "wet" period as annual rainfall amounts have often exceeded the average for large areas of the state. Correspondingly, groundwater levels appear to be trending upward for most of the state's aquifers. Figures 7 and 8 show the average annual water level change, by county, for selected major bedrock and alluvium and terrace aquifers, respectively. Generally, most water level fluctuations range from a few tenths of a foot to 2-3 feet per year.

The impact of water use on groundwater level change is difficult to evaluate. The water use data the Board acquires comes from groundwater permit holders. It is estimated that in any given year, approximately 70 percent of the permit holders report their use. Furthermore, since the metering of withdrawals is not required, most permit holders estimate the amount of water used in a calendar year. Because of these problems, water use data could not be used to augment precipitation in reviewing groundwater level hydrograph data for determining influences on changing water levels. Although the quantities of water use reported are not accurate, the patterns of usage are instructive. Appendix A includes combination graphs of water use/precipitation/depth to water for various bedrock and alluvium and terrace aquifers. Miscellaneous hydrographs of both major and minor aquifers showing only depth to water are included in Appendix B.

A review of well hydrographs for many of the state's major aquifers (1980-1997) indicates groundwater levels were usually lowest during the mid 80s (1984-1986) and highest near the end of the period (1996-1997). Figure 9 shows representative well hydrographs depicting the mid-eighties water level lows, as well as the peaks near the end of period. Other hydrographs show water levels generally trending upward but are on occasion interrupted by flat periods or slight decreases (1 to 2 year periods) before returning to their upward ascent (Figure 10). Annual water level changes ranging from as much as 10 feet for an alluvium and terrace aquifer and greater than 30 feet for a bedrock aquifer are shown in Figure 11. Well hydrographs shown in figure 12 for the Ogallala aquifer in Cimarron and Texas Counties show a pattern of steady decline, ranging from 15 to 40 feet over the periord of record. The hydrographs displayed in Figures 9 through 12 are representative of the typical types of water level fluctuation patterns seen from 1980 to 1997. It is important to keep in mind, however, that many variations to these patterns exist.

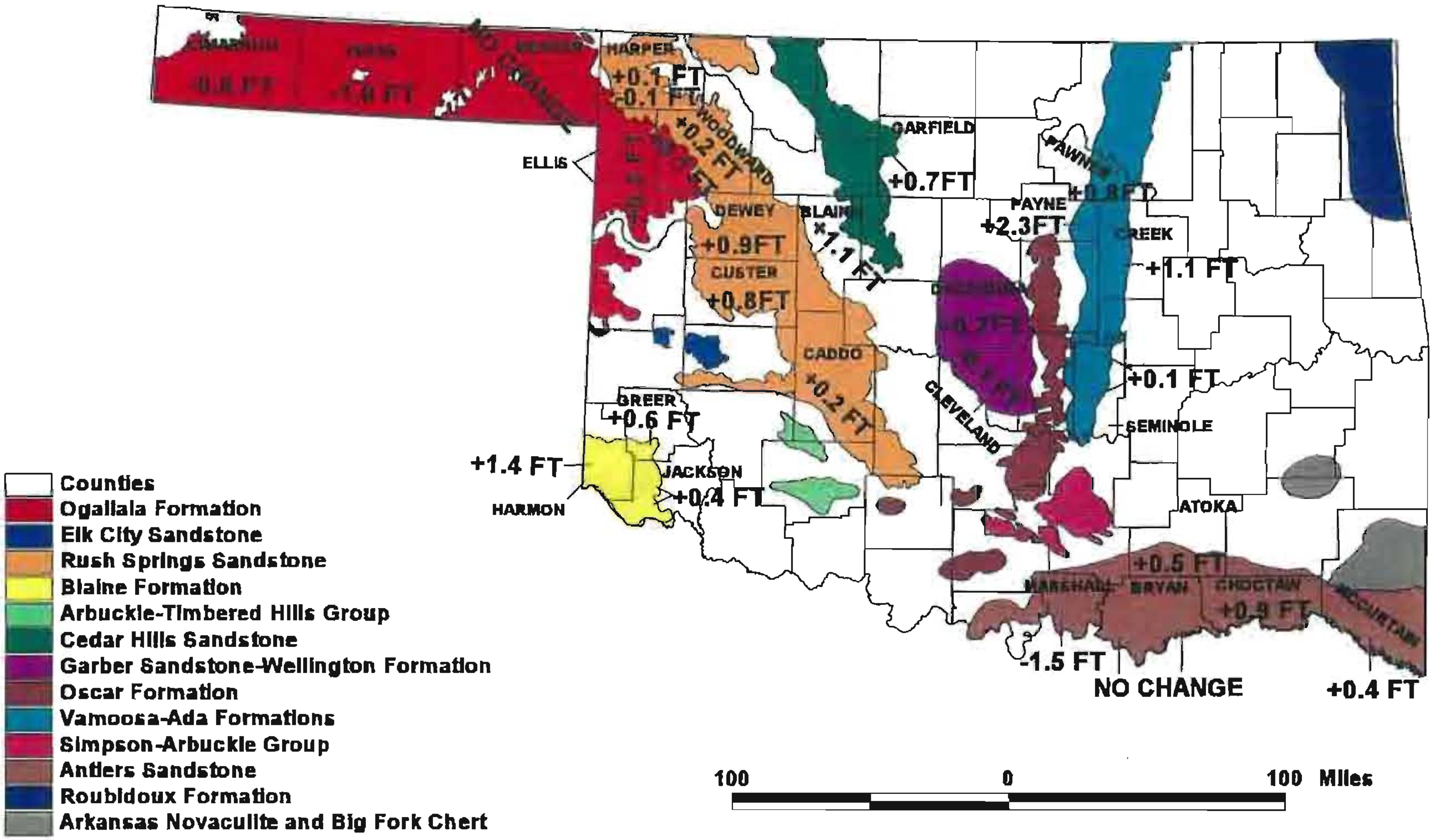


FIGURE 7 Average Annual Water Level Change (1978-1998) for Major Bedrock Aquifers by County

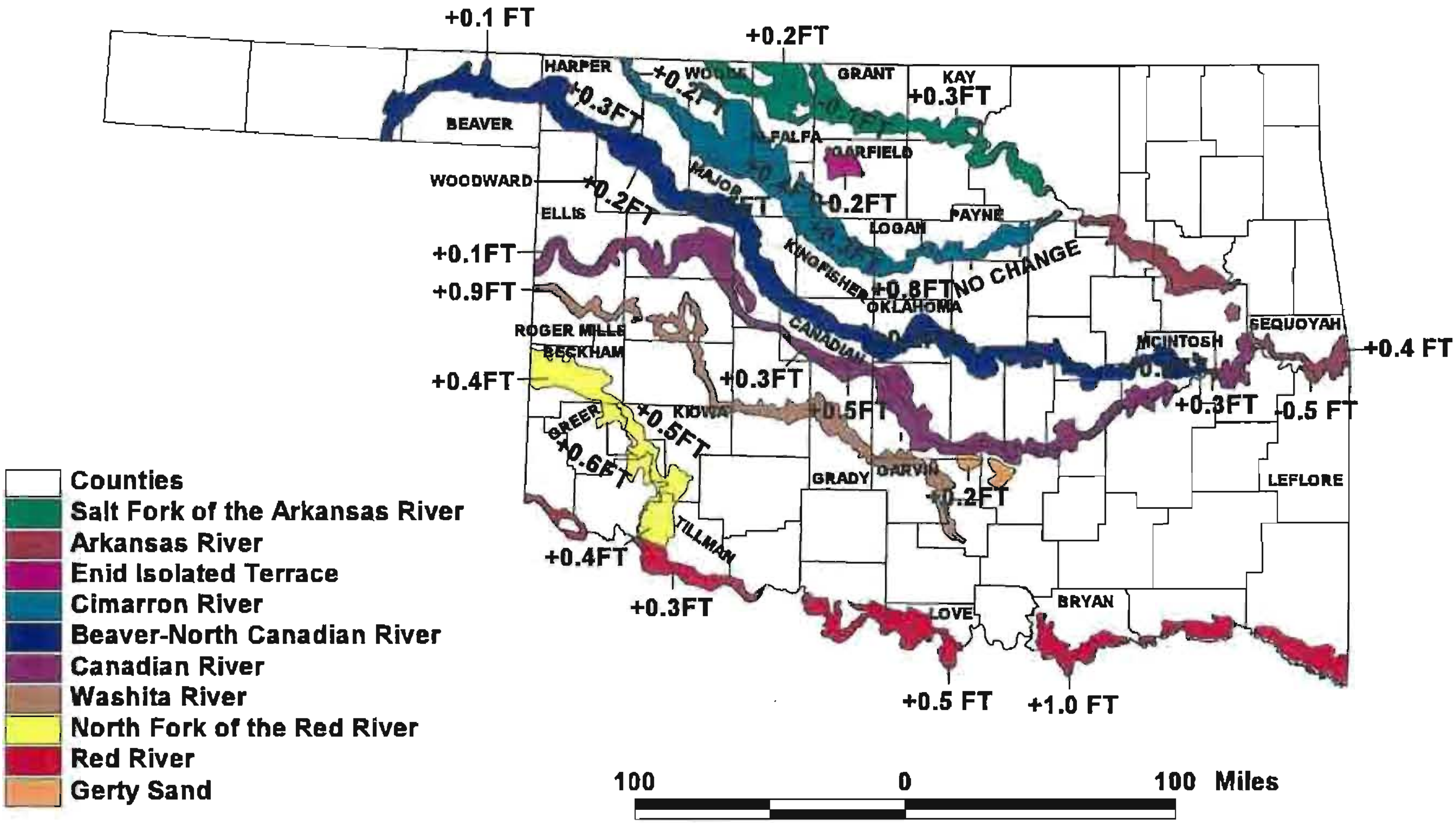


FIGURE 8 Average Annual Water Level Change (1978-1998) for Major Alluvium and Terrace Aquifers by County

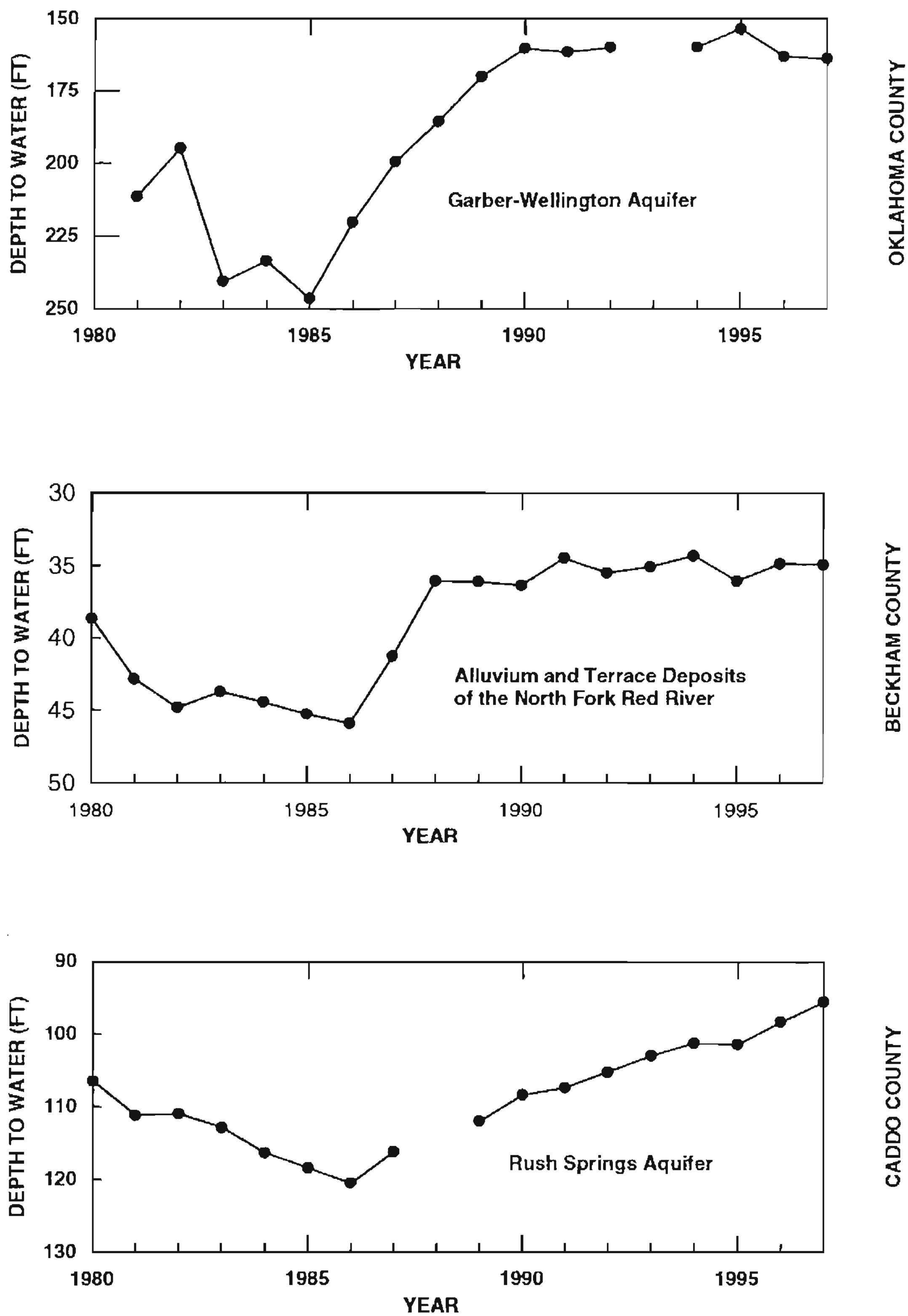


FIGURE 9 Well Hydrographs of the Garber-Wellington, Alluvium and Terrace Deposits of the North Fork of the Red River and Rush Springs in Oklahoma, Beckham and Caddo Counties Respectively

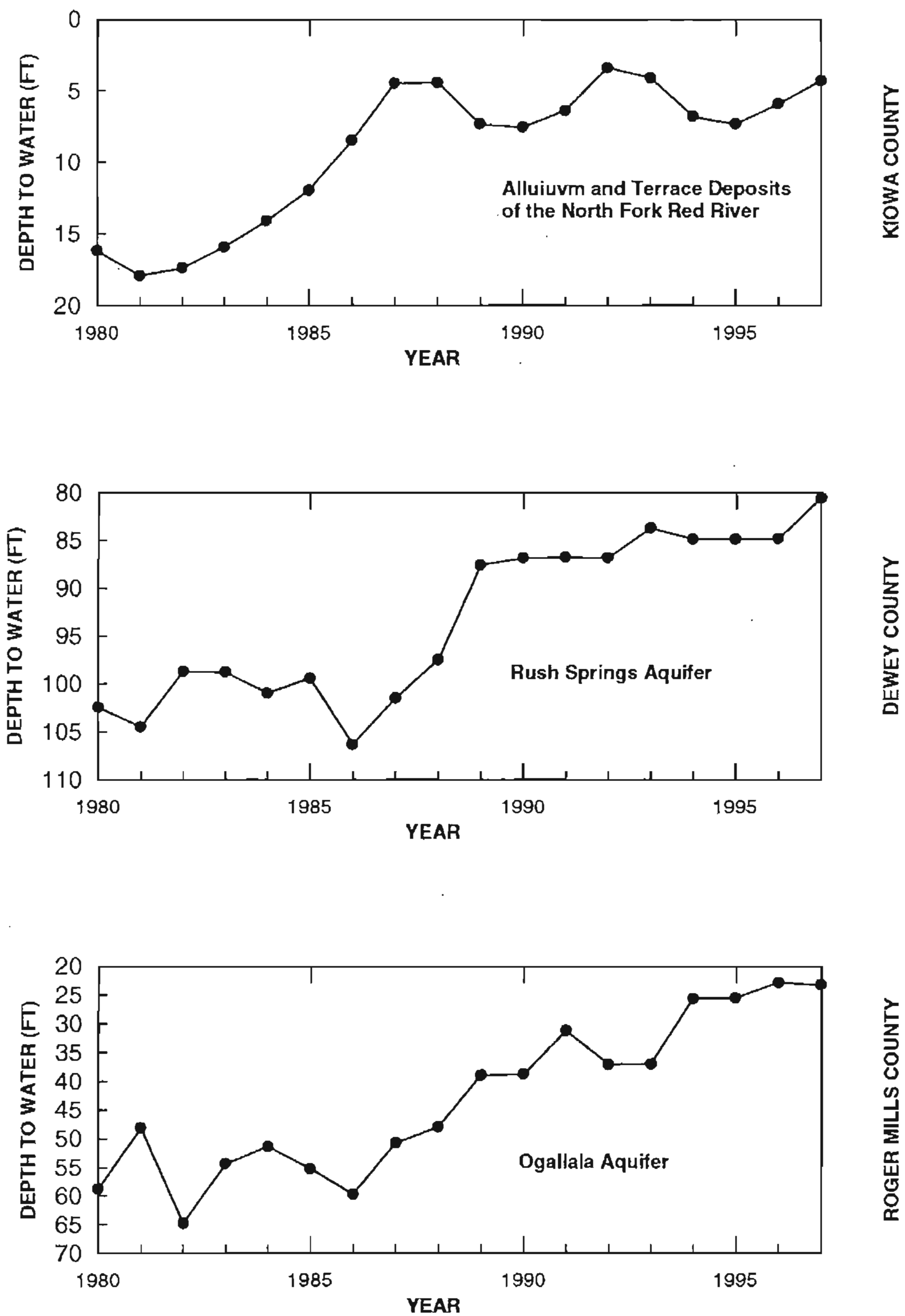
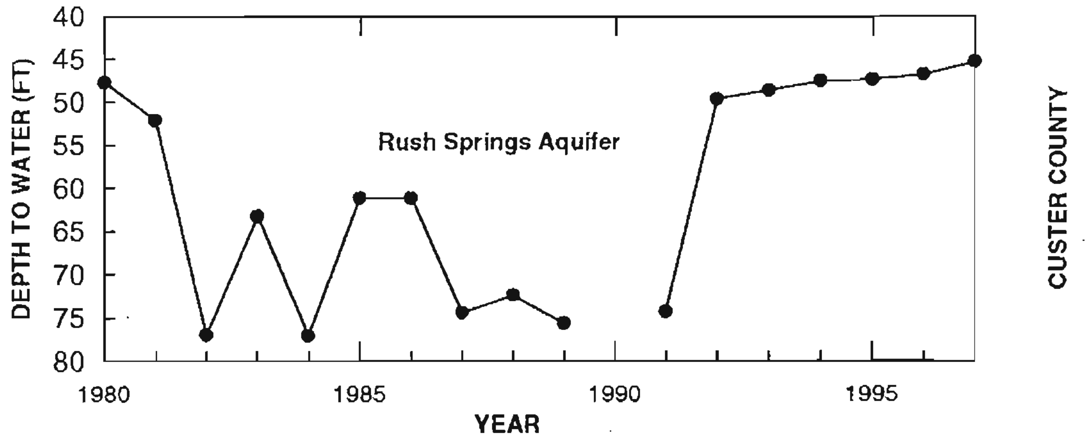
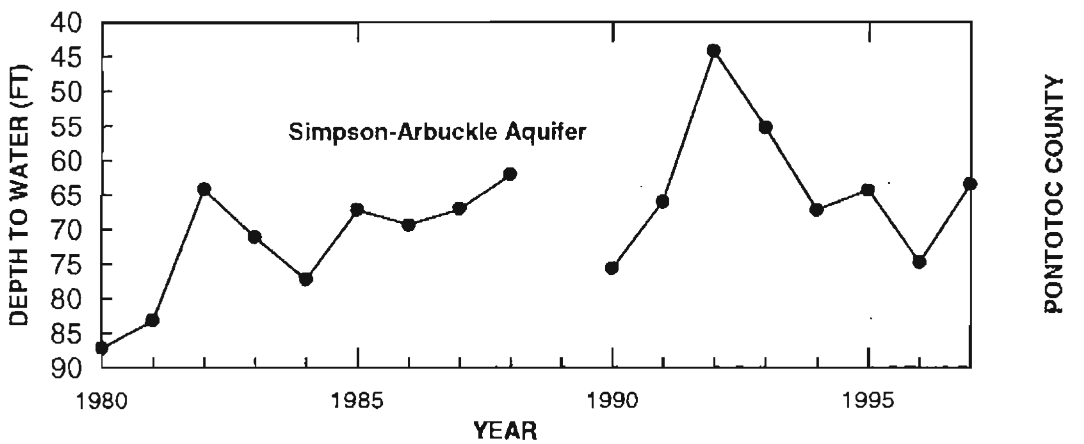


FIGURE 10 Well Hydrographs of the Alluvium and Terrace Deposits of the North Fork of the Red River, Rush Springs and Ogallala in Kiowa, Dewey and Roger Mills Counties Respectively





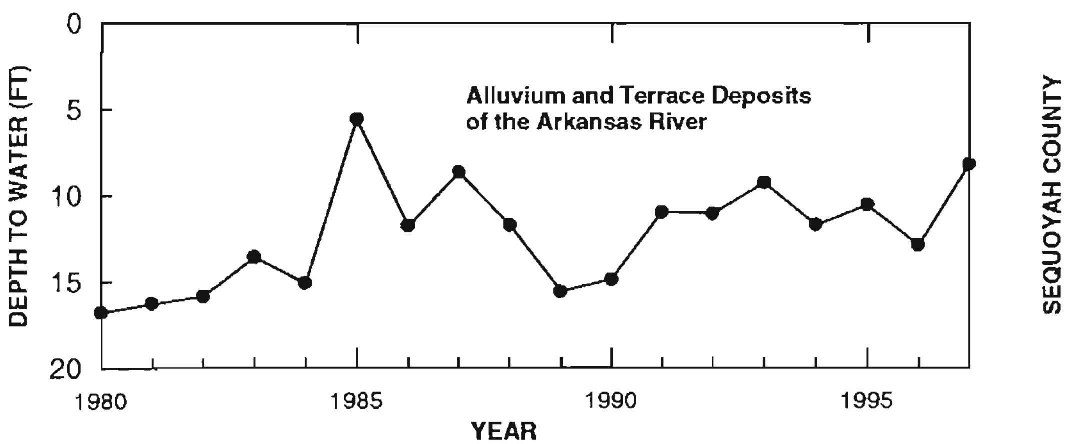


FIGURE 11 Well Hydrographs of the Rush Springs, Simpson-Arbuckle and Alluvium and Terrace Deposits of the Arkansas River in Custer, Pontotoc and Sequoyah Counties Respectively

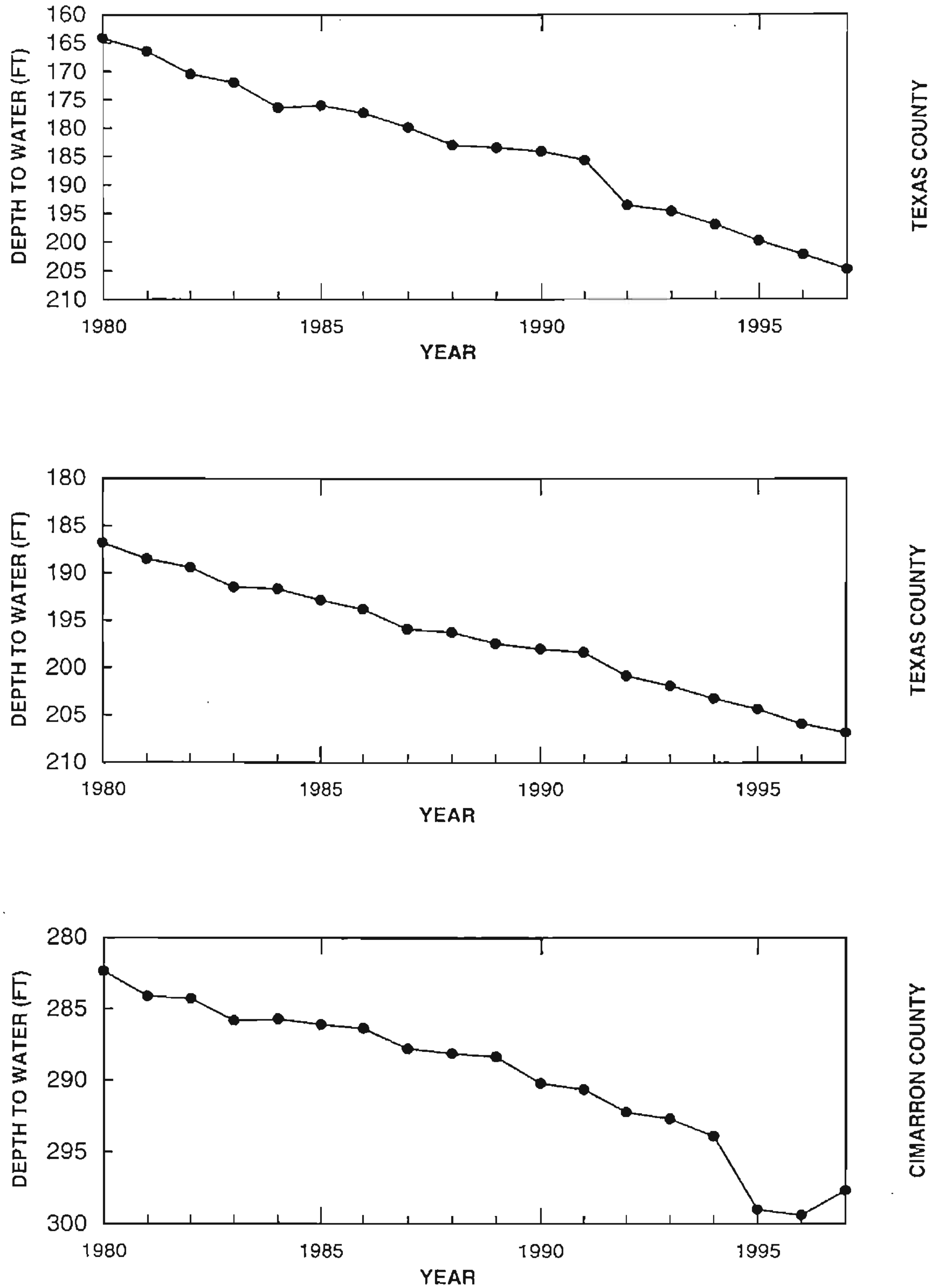


FIGURE 12 Well Hydrographs of the Ogallala in Texas and Cimarron Counties

Historical Water Level Changes

Summary statistics were compiled for the observation well network by aquifer. The statistics include the number of wells, average well depth, average depth to water, the minimum and maximum historical depth to water and the average annual change over the period of record. Table 3 summarizes the data for the bedrock aquifers and Table 4 summarizes the data for the alluvium and terrace aquifers.

For the purposes of this report, historical changes in observed water levels relates primarily from 1978 until the present. Prior to this time the network was incomplete. The data reflect that over the last twenty years a majority of the state's aquifers exhibit rising water levels. As shown in the last column of the tables, the decrease in depth to water (shown as a positive change) has ranged from a modest one tenth of an inch to more than 1.5 feet per year.

The area of the state which varies from this pattern is in the Panhandle. Two hundred network wells monitored since 1978 show the Ogallala aquifer declining at an average annual rate of 1 foot/year in Texas County, 0.6 foot/year in Cimarron County and less than 0.1 foot/year in Beaver County. The average annual rate of decline for the three- county area is approximately 0.6 foot/year. However, since 1978, water level declines around Boise City, Cimarron County, and areas north of Guymon, Texas County, have averaged 1.5 and 2.5 feet per year respectively. In contrast, water levels in the remainder of the counties underlain by the Ogallala have increased approximately three tenths of a foot per year over the last twenty years. Figure 13 is a contour map which shows the 1, 5, 10 and 20 year changes in water levels for the Panhandle based on 250 water level observation wells. Increases in water level are shown in blue and green; decreases are shown in yellow, orange and red.

Figures 14 through 16 are composite graphs displaying annual reported water use, precipitation and well hydrographs. The water use is for the particular county and aquifer in which the well is located, and the precipitation amounts are from the nearest reporting station to the observation well.

Figure 14 is a hydrograph of an irrigation well, completed in the Ogallala aquifer in north-central Texas County. Reported water use varied from about 8,000 acre-feet (a.f.) in 1992 to more than 40,000 a. f. in 1995. Precipitation ranged from 15-22 inches per year. The downward trending water level shown in this hydrograph is representative of what is occurring over broad areas of Texas and Cimarron Counties. The cause is due to substantial groundwater withdrawals combined with low recharge rates.

Figure 15 is a hydrograph of an unused oil field supply well completed in the alluvium and terrace deposits of the Cimarron River in Kingfisher County. There appears to be some correlation to the water level fluctuations and water use and precipitation. In 1986, the reported water use was 5,000 a.f., the precipitation was nearly 10 inches above normal, and the water level rose 7-8 feet the following year. In 1987, precipitation decreased to near normal levels, reported water use more than doubled, and the water level decreased

SUMMARY WATER LEVEL STATISTICS FOR MAJOR BEDROCK AQUIFERS						
BASIN	**# Wells**	**Average Well Depth**	**Average DTW**	**Minimum DTW**	**Maximum DTW**	**Average Annual Change in DTW (POR)**
OGALLALA (PANHANDLE)	200	307 Ft.	152 Ft.	5.3 Ft.	349 Ft.	-0.60 Ft./Yr.
OGALLALA (OTHER)	90	225 Ft.	77 Ft.	1.7 Ft.	229 Ft.	+0.30 Ft./Yr.
RUSH SPRINGS SANDSTONE	86	261 Ft.	56 Ft.	0.9 Ft.	199 Ft.	+0.70 Ft./Yr.
BLAINE GYPSUM	27	136 Ft.	39 Ft.	3.6 Ft.	89 Ft.	+0.90 Ft./Yr.
ANTLERS SS (UNCONFINED)	10	147 Ft.	47 Ft.	8.0 Ft.	88 Ft.	NO CHANGE
ANTLERS SS (CONFINED)	6	367 Ft.	92 Ft.	18.7 Ft.	151 Ft.	-0.2 Ft./Yr.
VAMOOSA-ADA	5	272 Ft.	79 Ft.	23.4 Ft.	149 Ft.	+1.10 Ft./Yr.
ARBUCKLE GP	4	173 Ft.	36 Ft.	17.1 Ft.	87 Ft.	+1.00 Ft./Yr.
GARBER-WELLINGTON (UNCONFINED)	13	151 Ft.	61Ft.	4.7 Ft.	134 Ft.	+0.40 Ft./Yr.
GARBER-WELLINGTON (CONFINED)	5	640 Ft.	169 Ft.	41.6 Ft.	315 Ft.	+0.30 Ft./Yr.
KEOKUK-REEDS SPRINGS (BOONE FM)	10	151 Ft.	66 Ft.	0.5 Ft.	380 Ft.	+1.70 Ft./Yr.

SUMMARY WATER LEVEL STATISTICS FOR MINOR BEDROCK AQUIFERS						
BASIN	**# Wells**	**Average Well Depth**	**Average DTW**	**Minimum DTW**	**Maximum DTW**	**Average Annual Change in DTW (POR)**
PERMIAN AQUIFERS	23	150 Ft.	45 Ft.	0.4 Ft.	217 Ft.	+ 0.3 Ft./Yr.
PENNSYLVANIAN AQUIFERS	23	124 Ft.	29 Ft.	0.1Ft.	144 Ft.	+0.40 Ft./Yr.
CRETACEOUS & TRIASSIC AQUIFERS	24	343Ft.	159 Ft.	75.0 Ft.	334 Ft.	-0.50 Ft./Yr.

DTW - Depth to Water; POR - Period of Record

TABLE 3 SUMMARY WATER LEVEL STATISTICS FOR BEDROCK AQUIFERS

SUMMARY WATER LEVEL STATISTICS FOR MAJOR ALLUVIUM AND TERRACE AQUIFERS						
BASIN	**# Wells**	**Average Well Depth**	**Average DTW**	**Minimum DTW**	**Maximum DTW**	**Average Annual Change in DTW (POR)**
NORTH CANADIAN	47	58 Ft.	22 Ft.	2.5 Ft.	65 Ft.	+ 0.40 Ft./Yr.
CIMARRON RIVER	47	53 Ft.	14 Ft.	-0.5 Ft.	41 Ft.	+ 0.20 Ft./Yr.
NORTH FORK RED RIVER	59	62 Ft.	24 Ft.	1.9 Ft.	74 Ft.	+0.50 Ft./Yr.
S. CANADIAN RIVER*	10	65 Ft.	18 Ft.	0.2 Ft.	73 Ft.	+ 0.90 Ft./Yr.
SALT FORK ARKANSAS R.**	15	41 Ft.	12 Ft.	2.4 Ft.	33 Ft.	+ 0.10 Ft./Yr.
ENID ISOLATED TERRACE	7	60 Ft.	29 Ft.	3.6 Ft.	55 Ft.	+ 0.80 Ft./Yr.
RED RIVER***	16	52 Ft.	25 Ft.	1.9 Ft.	47 Ft.	+ 0.30 Ft./Yr.
WASHITA RIVER	2	168 Ft.	4 Ft.	- 0.8 Ft.	13 Ft.	+ 0.80 Ft./Yr.

SUMMARY WATER LEVEL STATISTICS FOR MINOR ALLUVIUM AND TERRACE AQUIFERS						
BASIN	**# Wells**	**Average Well Depth**	**Average DTW**	**Minimum DTW**	**Maximum DTW**	**Average Annual Change in DTW (POR)**
ALL	30	52 Ft.	19 Ft.	1 Ft.	36 Ft.	+ 0.10 Ft./Yr.

* - Includes two observation wells in the Gerty Sand Groundwater Basin.
** - Includes three observation wells in the Arkansas River Basin Groundwater Basin.
*** - Includes observation wells within the Salt Fork and Elm Fork of the Red River Groundwater Basins.

DTW - Depth to Water Below Land Surface. A negative value in the field Minimum DTW indicates that a measured water level actually occurred above ground level inside the casing.

POR - Period of Record.

TABLE 4 SUMMARY WATER LEVEL STATISTICS FOR ALLUVIUM AND TERRACE AQUIFERS

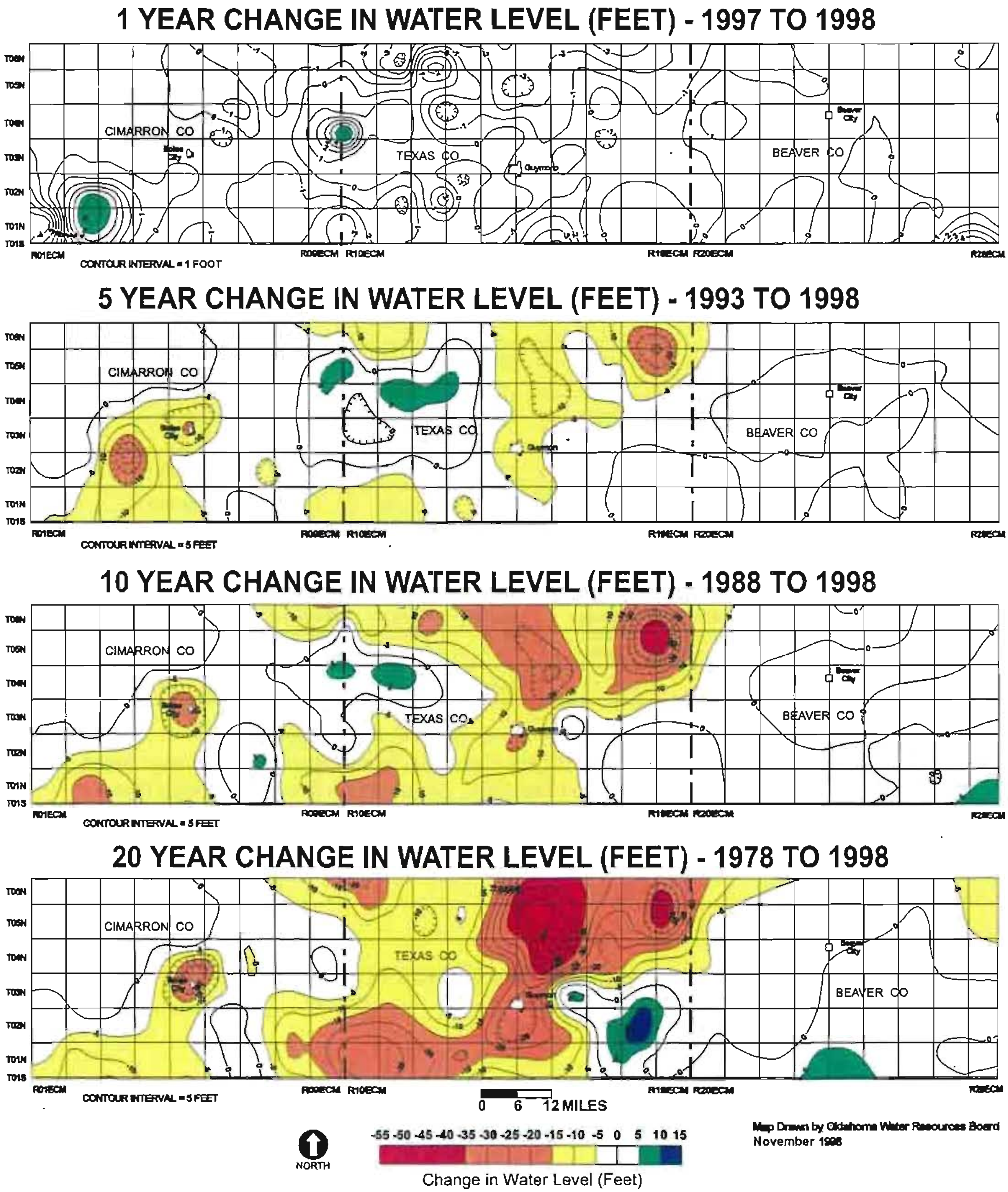


FIGURE 13 Changes in Water Level in the Oklahoma Panhandle

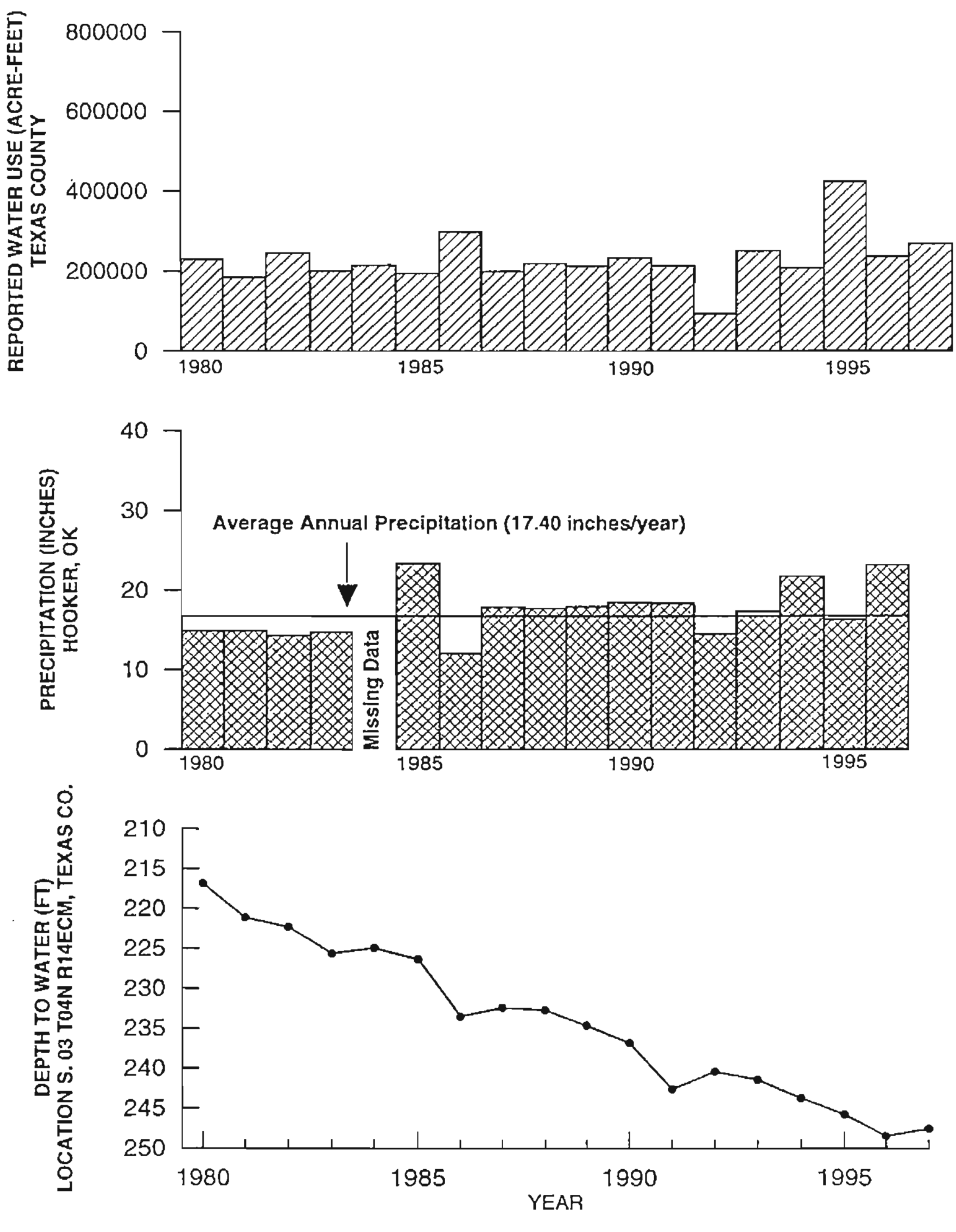


FIGURE 14 Hydrologic Data for the Ogallala Aquifer

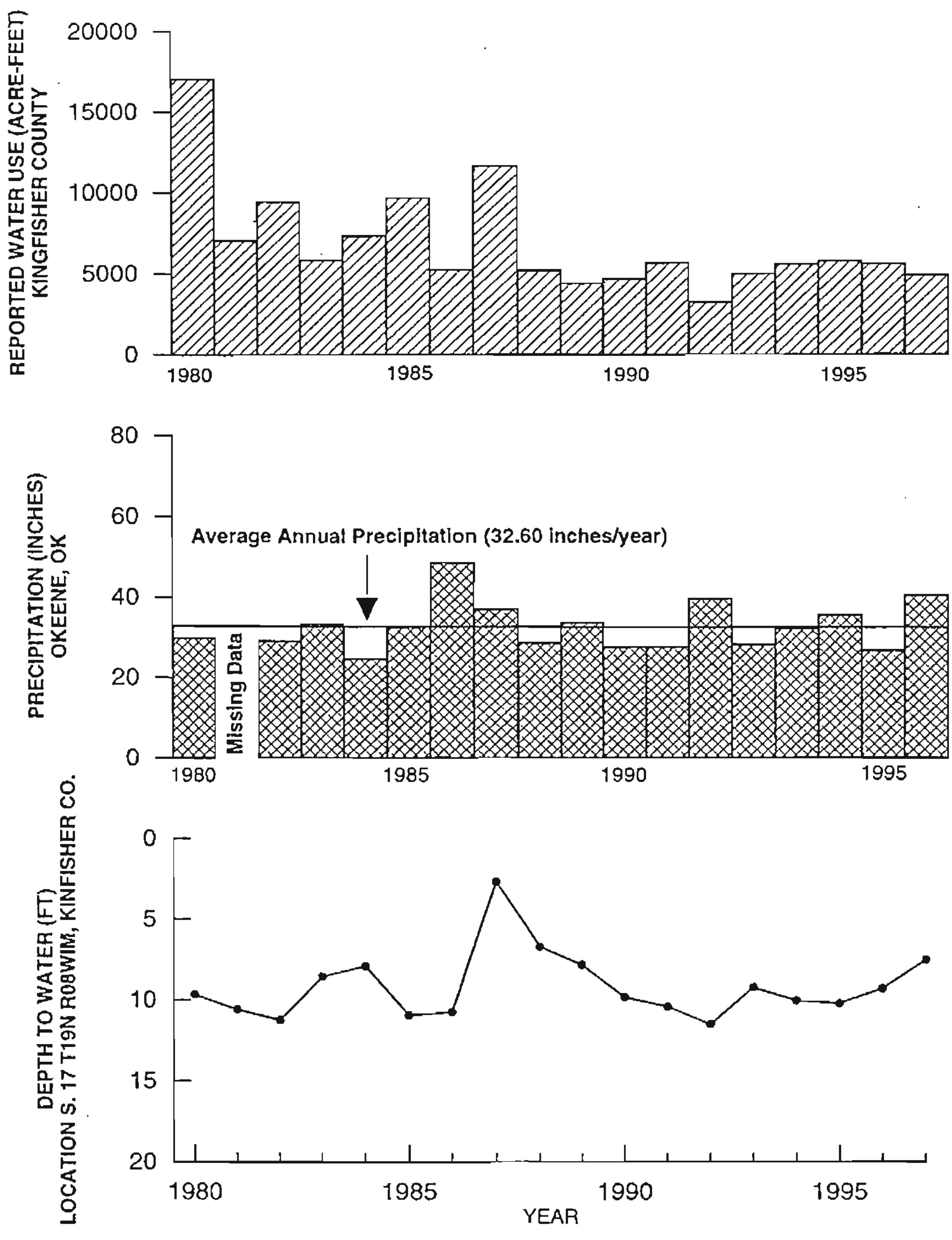


FIGURE15 Hydrologic Data for the Alluvium and Terrace Deposits of the Cimarron River

about four feet the following year.

Figure 16 shows a hydrograph of an irrigation well completed in the Blaine aquifer. As is typical of karst aquifers, the water level responds rapidly to pumping and precipitation. The hydrograph suggests that the aquifer is very sensitive to precipitation changes. It shows a low water level in 1980 that increased dramatically (55 feet) through 1987, apparently in response to 3-fold increase in precipitation from 1984 through to 1987. As precipitation decreased in 1988 and 1989, water levels decreased about 30 feet.

Figures 17 and 18 show well hydrographs for different aquifer types and precipitation graphs within the same county. Figure 17 presents hydrographs for the alluvium and terrace deposits of the North Fork of the Red River and the Blaine aquifer in Greer County. The precipitation graph indicates that rainfall in the 1980s was generally below average, with the converse being true for the 1990s. The hydrographs show generally low water levels between 1980 and 1985 followed by an increase with two peaks in 1993 and 1997. Each hydrograph shows a decline in 1995. The main difference between the two aquifer types is in the magnitude of change. The alluvial and terrace aquifer's change in water level is more subtle (generally less than 2 feet in any given year), whereas the hydrograph of the Blaine aquifer shows changes approaching 10 feet.

Figure 18 presents well hydrographs for the Rush Springs Sandstone and alluvium and terrace deposits of the North Canadian River in Woodward County. Precipitation data indicate that the amount of rainfall was fairly uniform from 1980 to 1997. Both hydrographs show similar water level responses both in time and magnitude. The greatest depth to water was recorded in 1980 followed by a gentle water level rise through 1990 (a total of approximately 5 feet in both cases). This was followed by a modest decline through 1992 before beginning a general ascent for the last 5 years.

Figures 19 and 20 are hydrographs which compare water level changes in the same aquifer but different counties. In Figure 19, hydrographs of the Rush Springs aquifer in Dewey and Caddo Counties show comparable patterns with both hydrographs reaching their low and peak in 1986 and 1997 respectively. From 1980-1997, water levels rose by more than 20 feet in Dewey County and by more than 12 feet in Caddo County. In Figure 20, hydrographs of the alluvium and terrace deposits of the Cimarron River in Kingfisher and Major Counties show a generally upward trend with their peaks occurring in 1988. From 1980-1997, the water level rose about 1 foot in the Kingfisher County well and approximately 7 feet in the Major County well.

Figure 21 shows the difference in water level response in the confined and unconfined portions of the Garber-Wellington aquifer. The observation well representing the confined portion of the Garber-Wellington is a public water supply well drilled to a depth of 743 feet. Depth to water ranged from 250 to 150 feet. The well has been taken out of service as evidenced by the near 100 foot rise in water level since 1985. The well representing the unconfined portion was drilled to a depth of 180 feet and depth to water ranged from 25 to nearly 40 feet. In 1985, both hydrographs show low water levels followed by an increase through the mid 1990s.

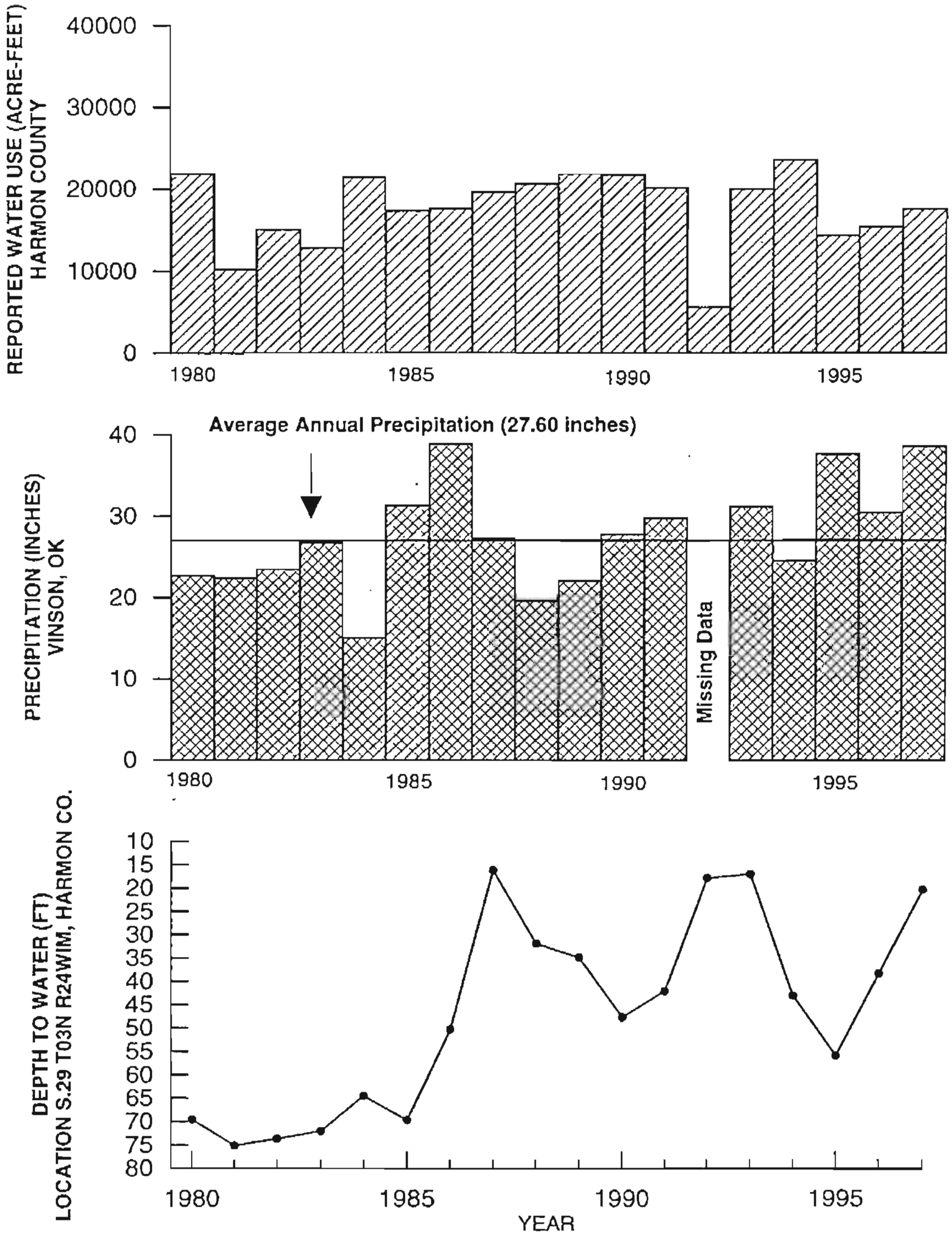


FIGURE 16 Hydrologic Data for the Blaine Aquifer

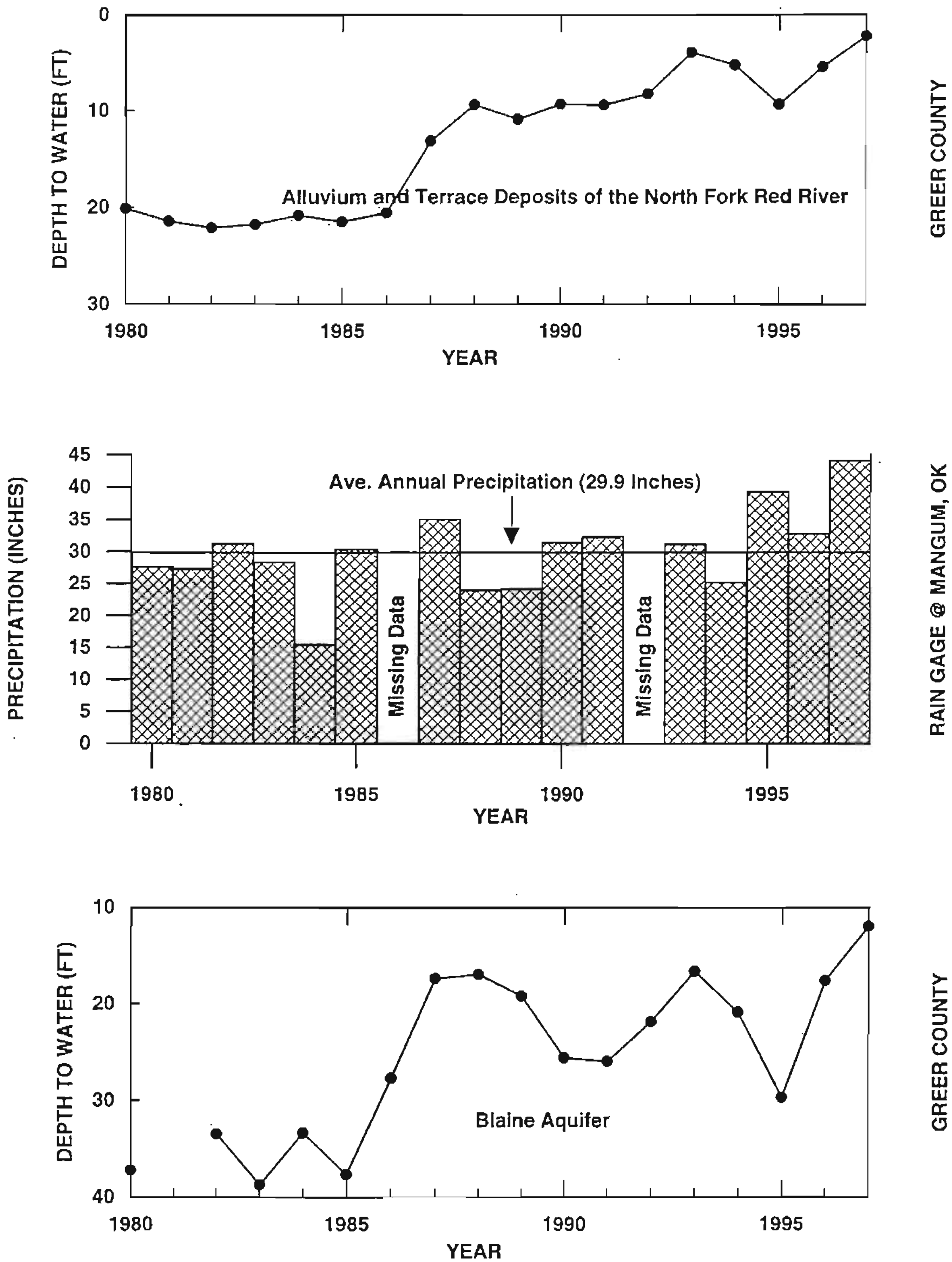


FIGURE 17 Depth to Water and Precipitation Data for Greer County

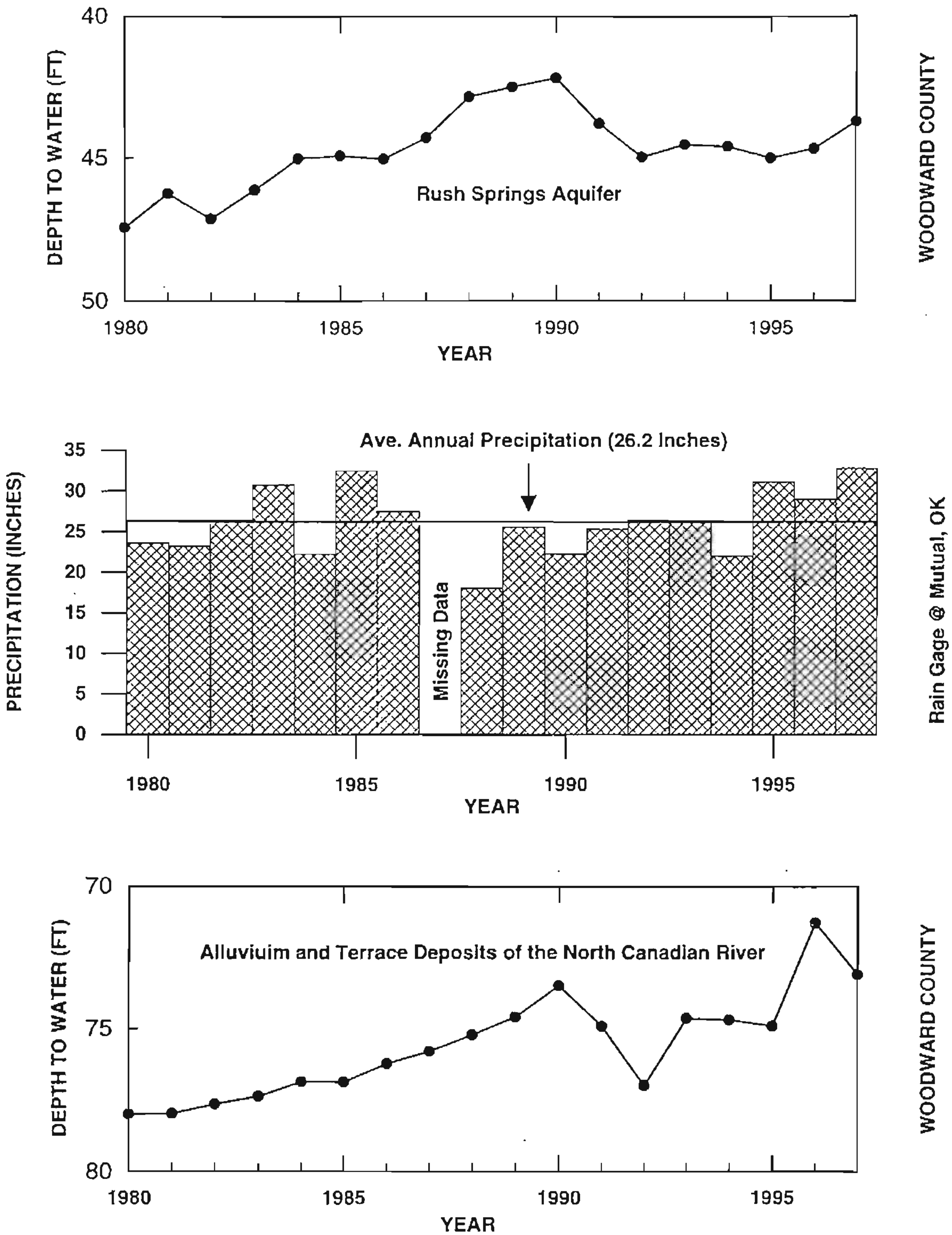


FIGURE 18 Depth to Water and Precipitation Data for Woodward County

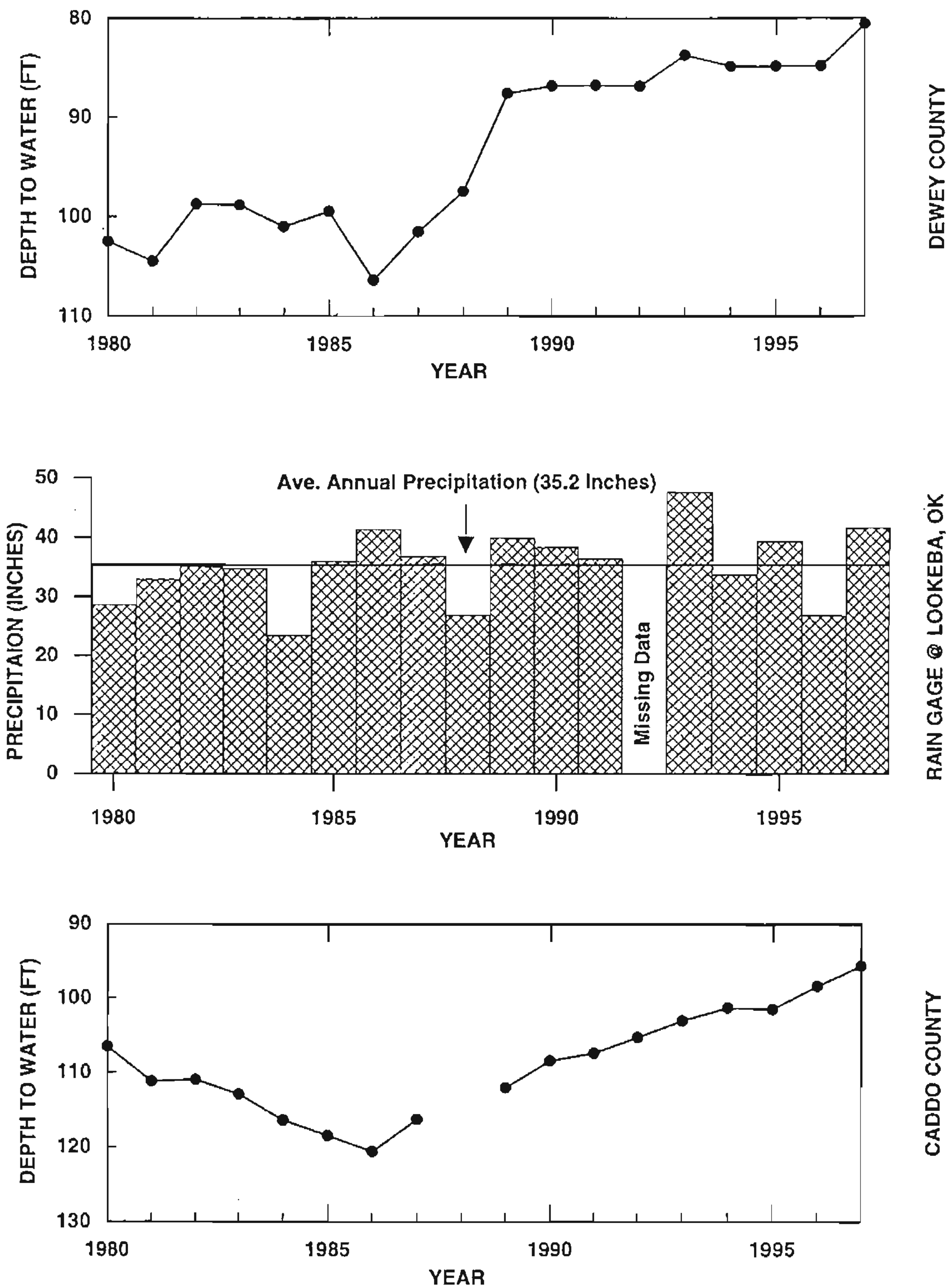


FIGURE 19 Depth to Water and Precipitation Data for the Rush Springs Aquifer in Dewey and Caddo Counties

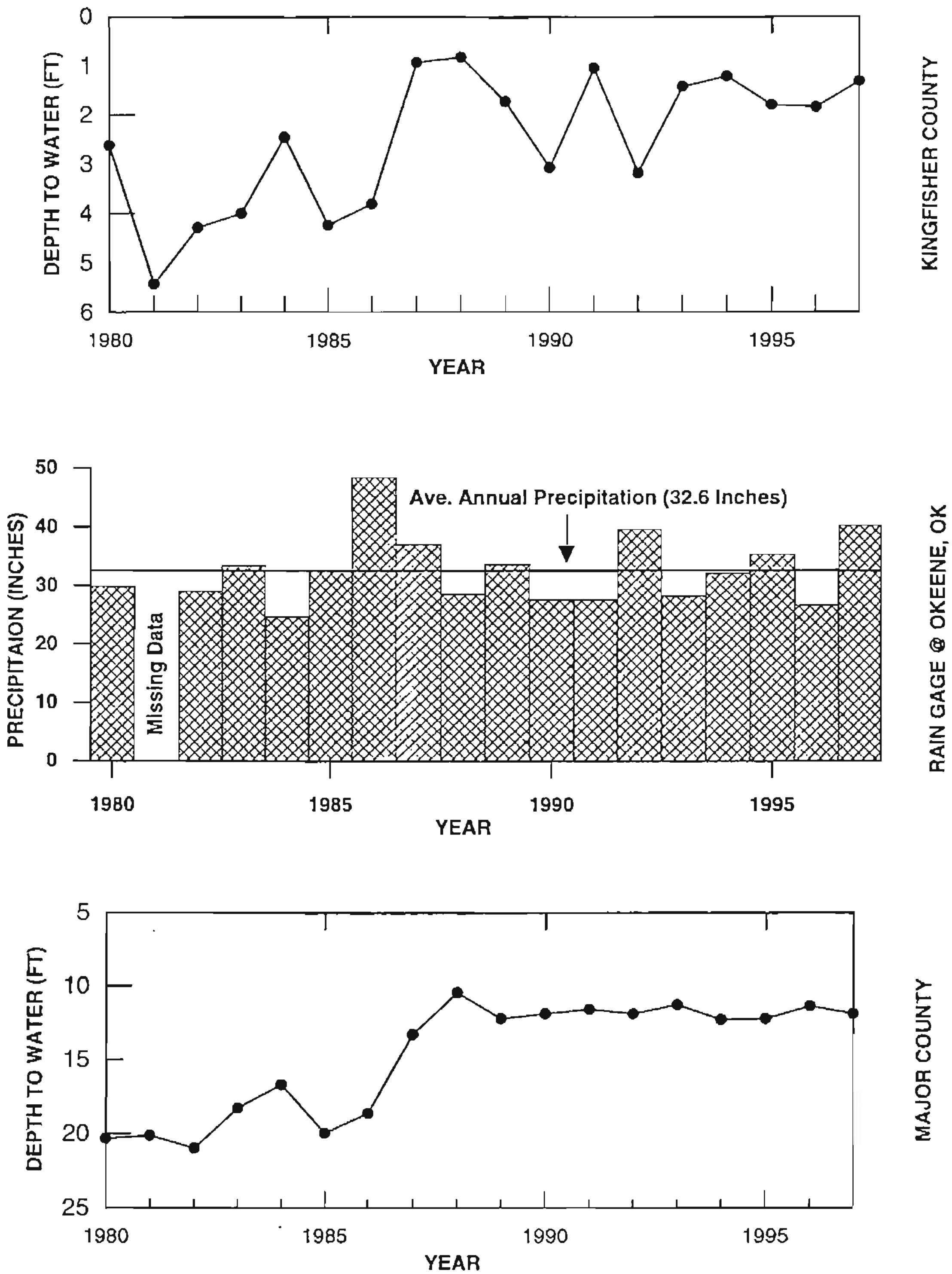


FIGURE 20 Depth to Water and Precipitation Data for the Alluvium and Terrace Deposits of the Cimarron River in Major and Kingfisher Counties

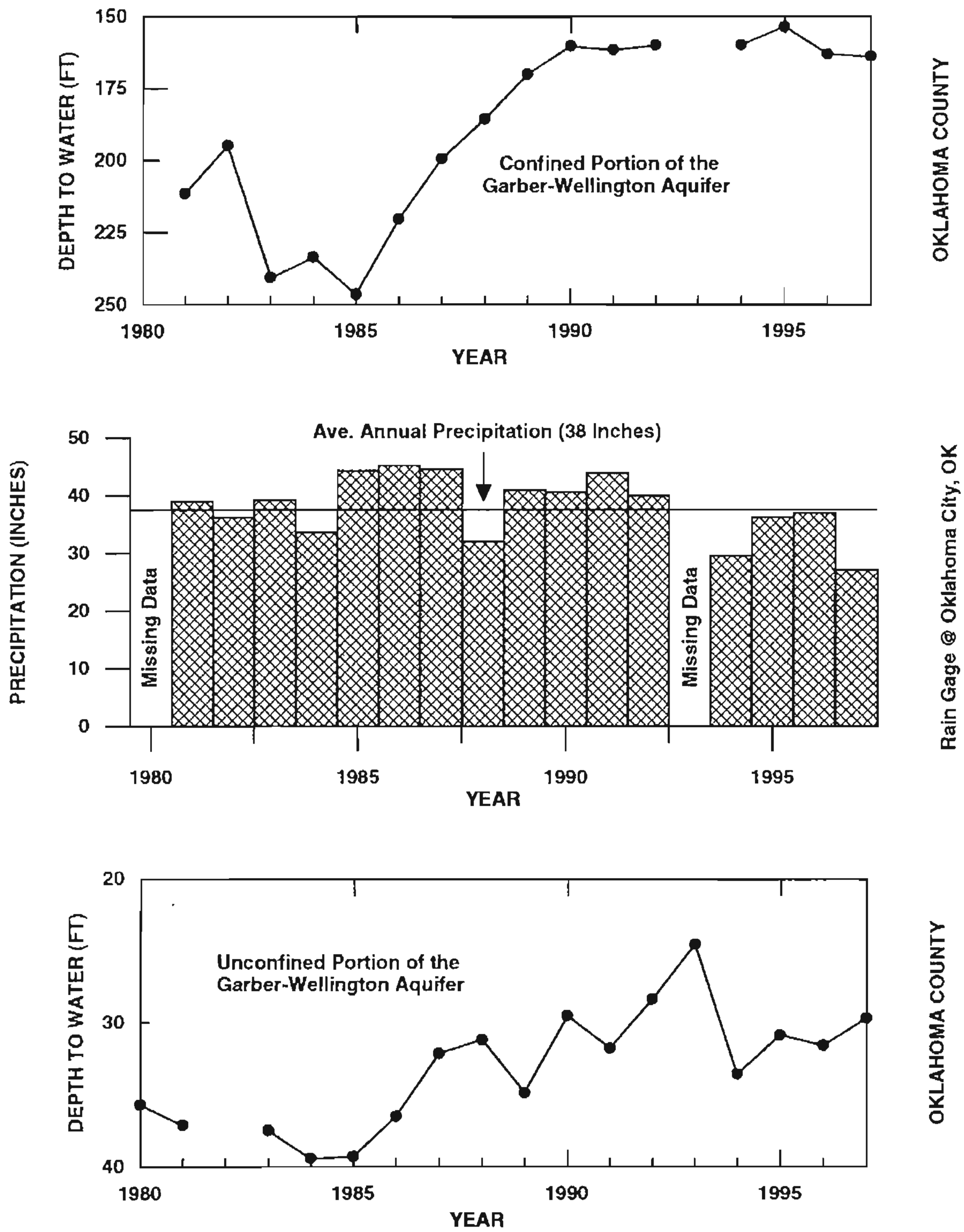


FIGURE 21 Depth to Water in the Garber-Wellington Aquifer and Precipitation Data for Oklahoma County

CONCLUSIONS

Groundwater level observation data have been presented in tabular, graphical and map formats to illustrate the nature of groundwater level changes which have occurred in Oklahoma over the past twenty years. These data are very important in the Board's efforts to make reliable estimates of aquifer storage and to plan for future water needs. Water levels in most of the State's aquifers have shown modest increases ranging generally from one tenth to five tenths of an inch per year over the last 20 years. An exception is in the Ogallala aquifer in the Panhandle, in which water levels have decreased at an average rate of 0.6 foot per year due to higher levels of beneficial use.

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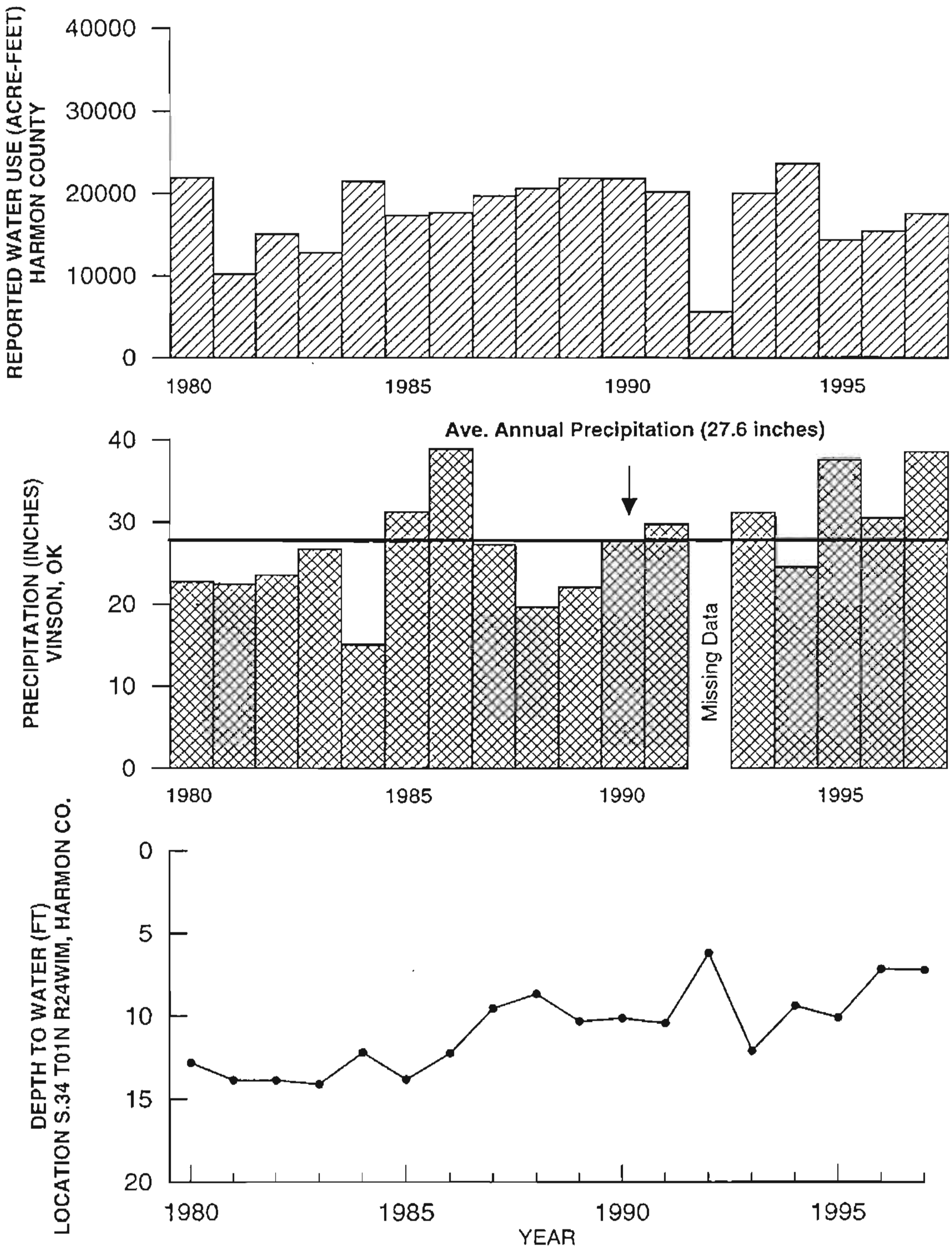
Center for Water Research, Oklahoma State University (66 pgs).

APPENDIX A

COMBINATION GRAPHS OF WATER USE, PRECIPITATION AND DEPTH TO WATER

HYDROLOGIC DATA FOR THE BLAINE AQUIFER



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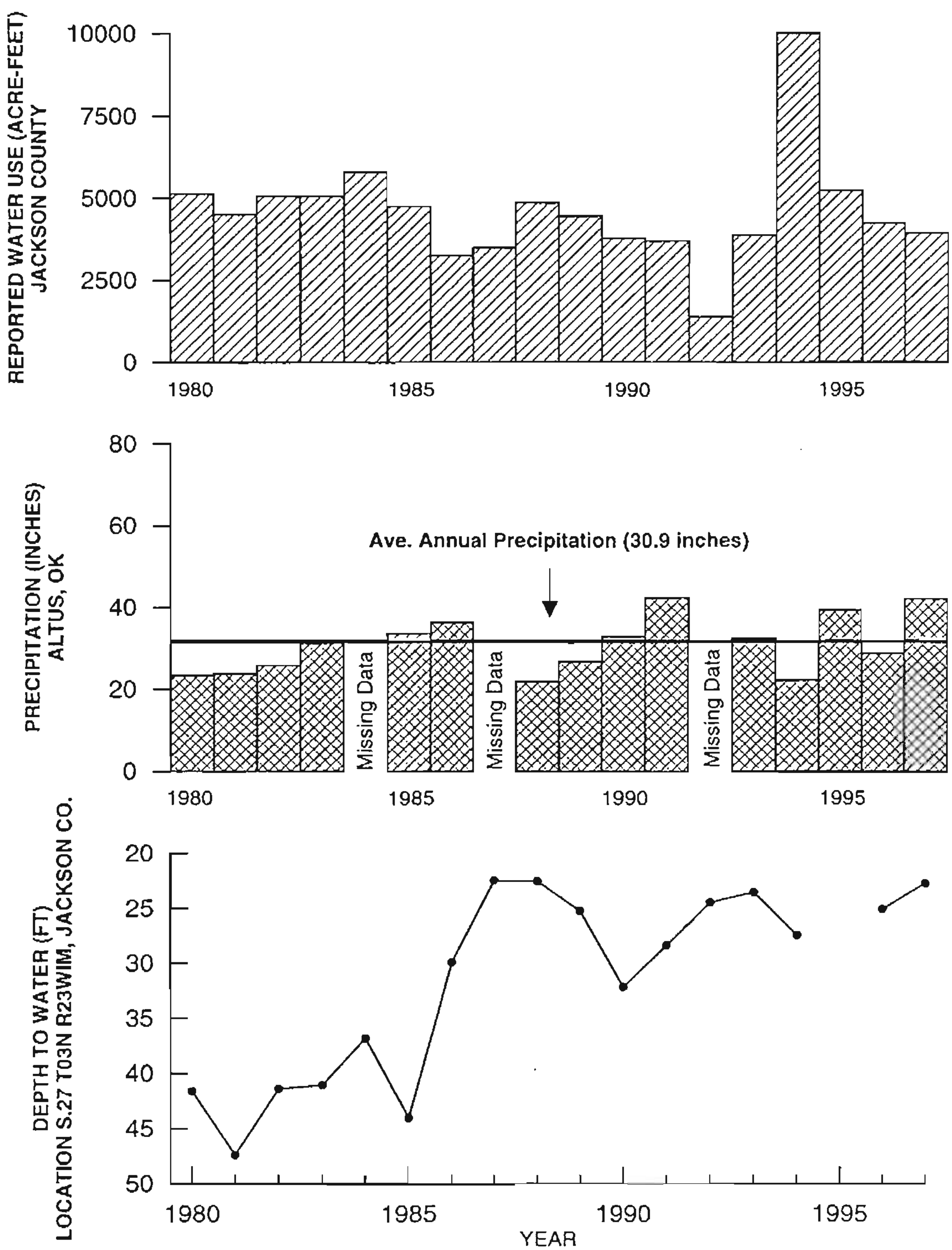

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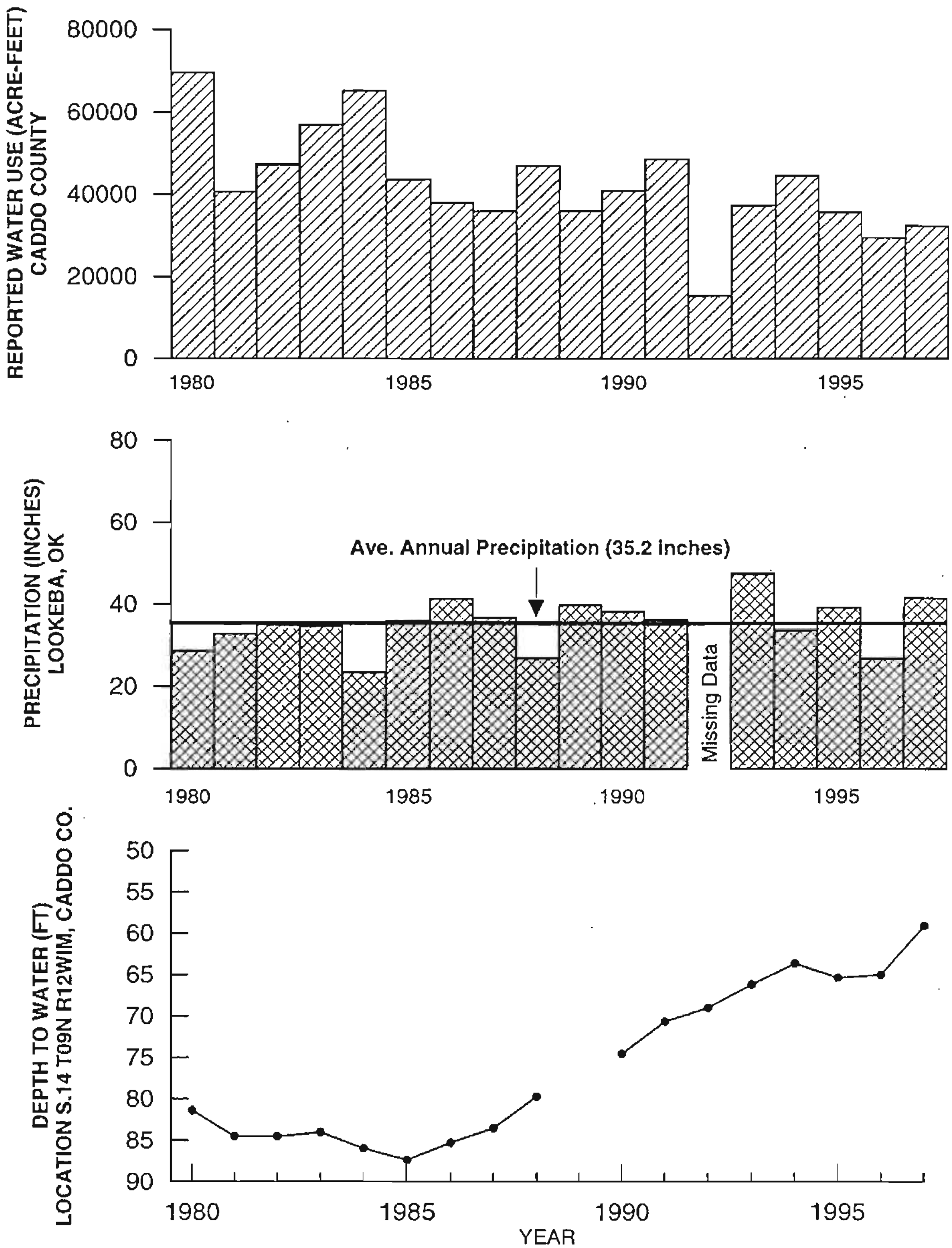

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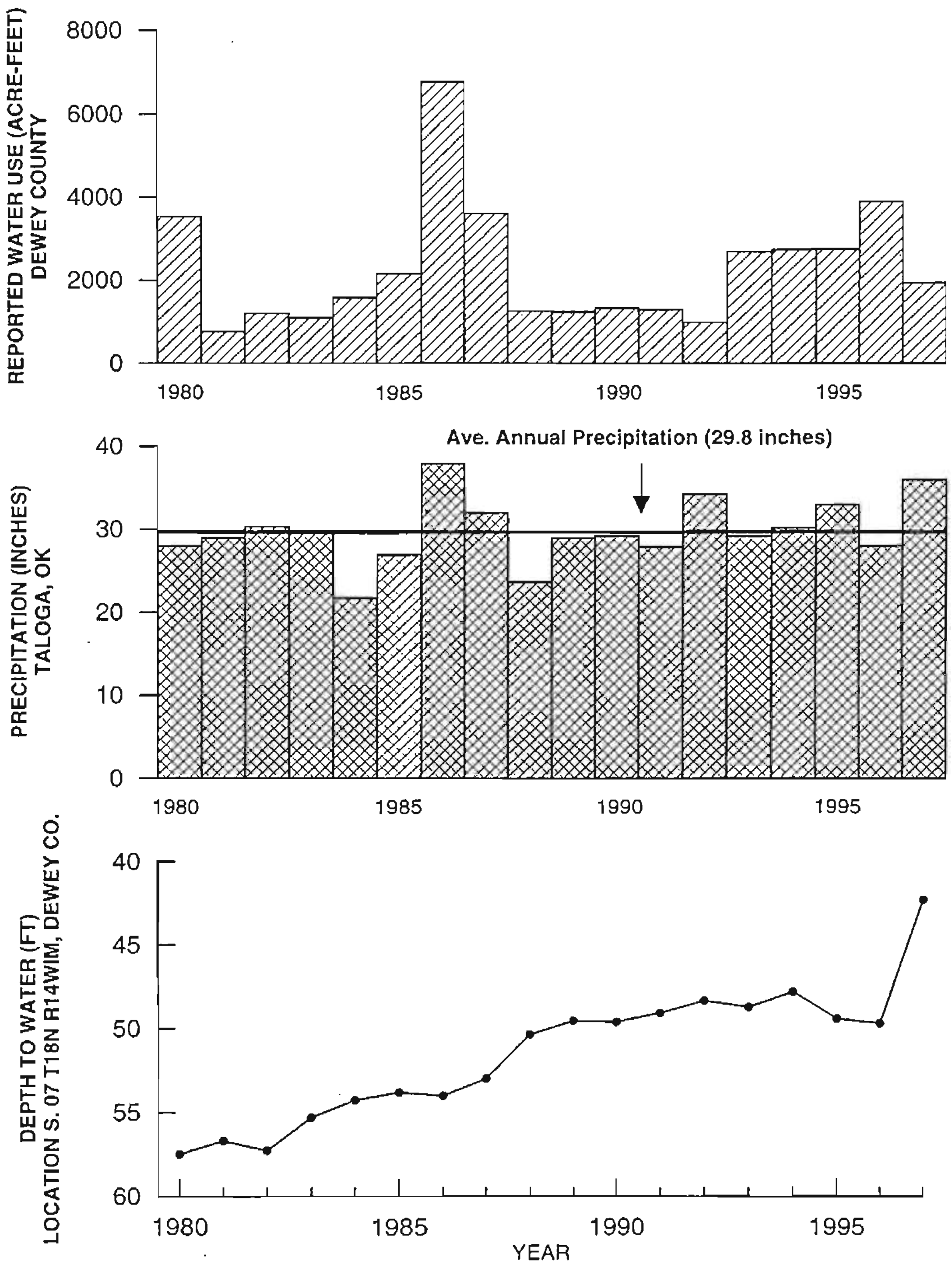

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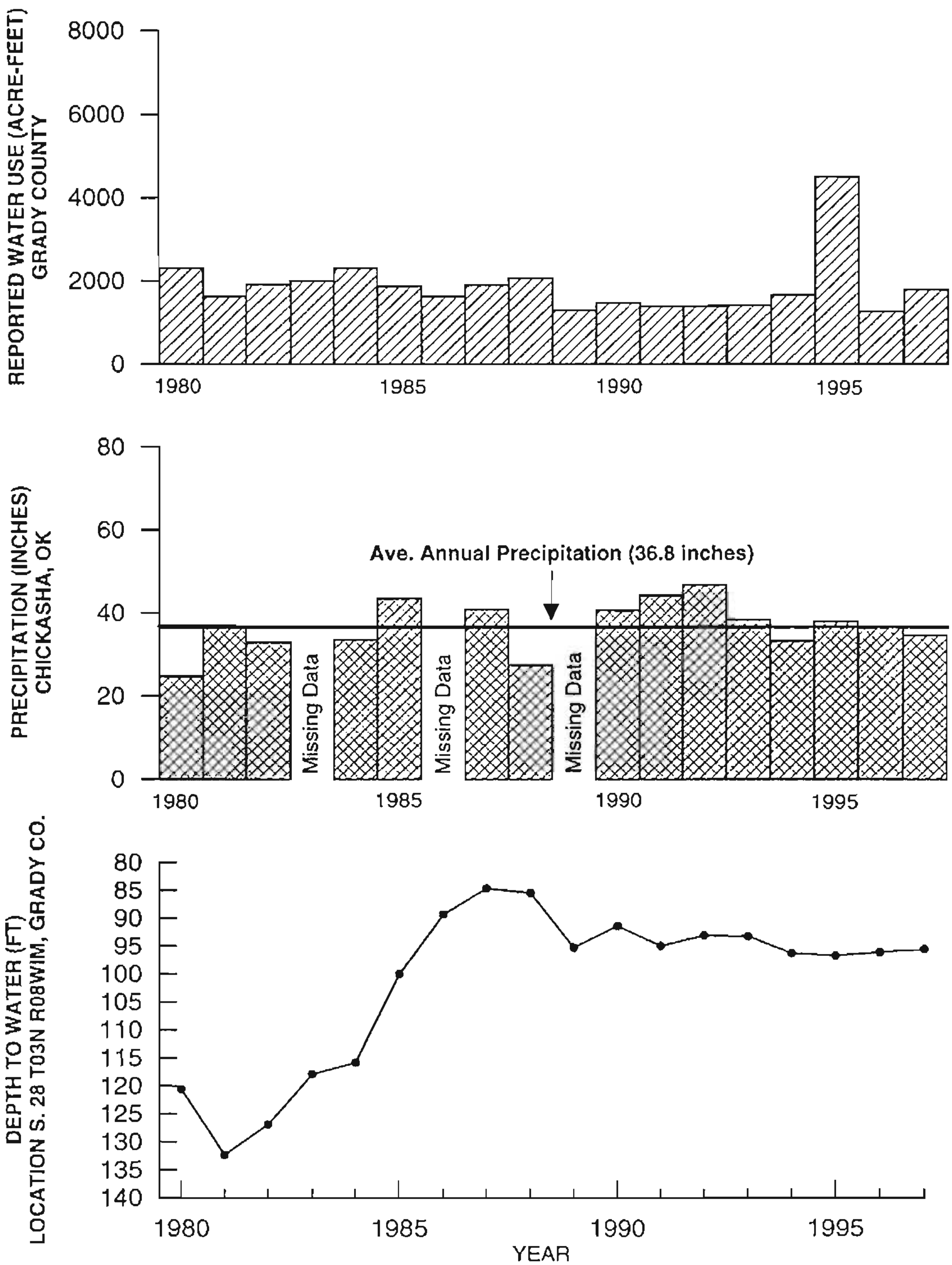

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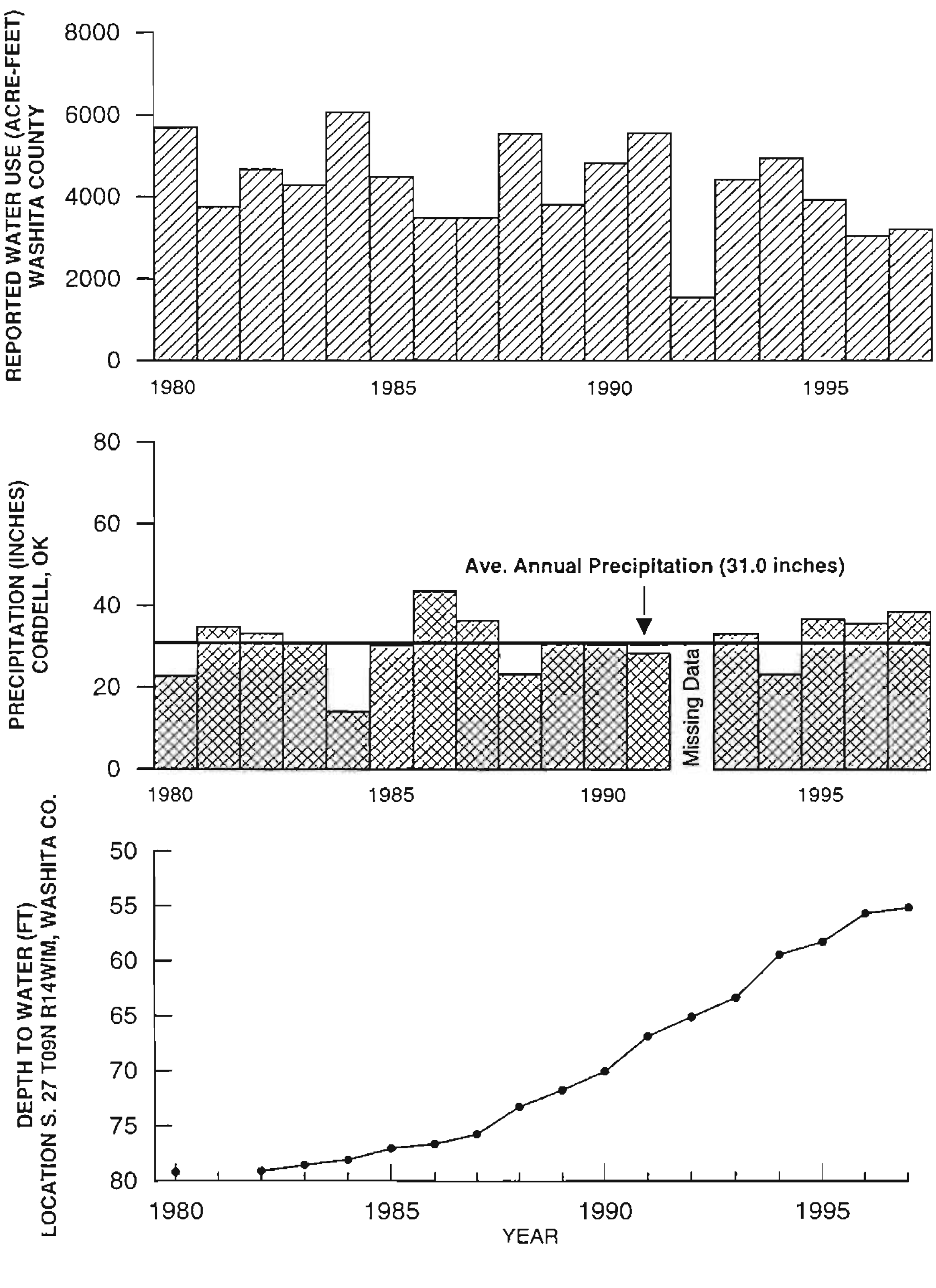

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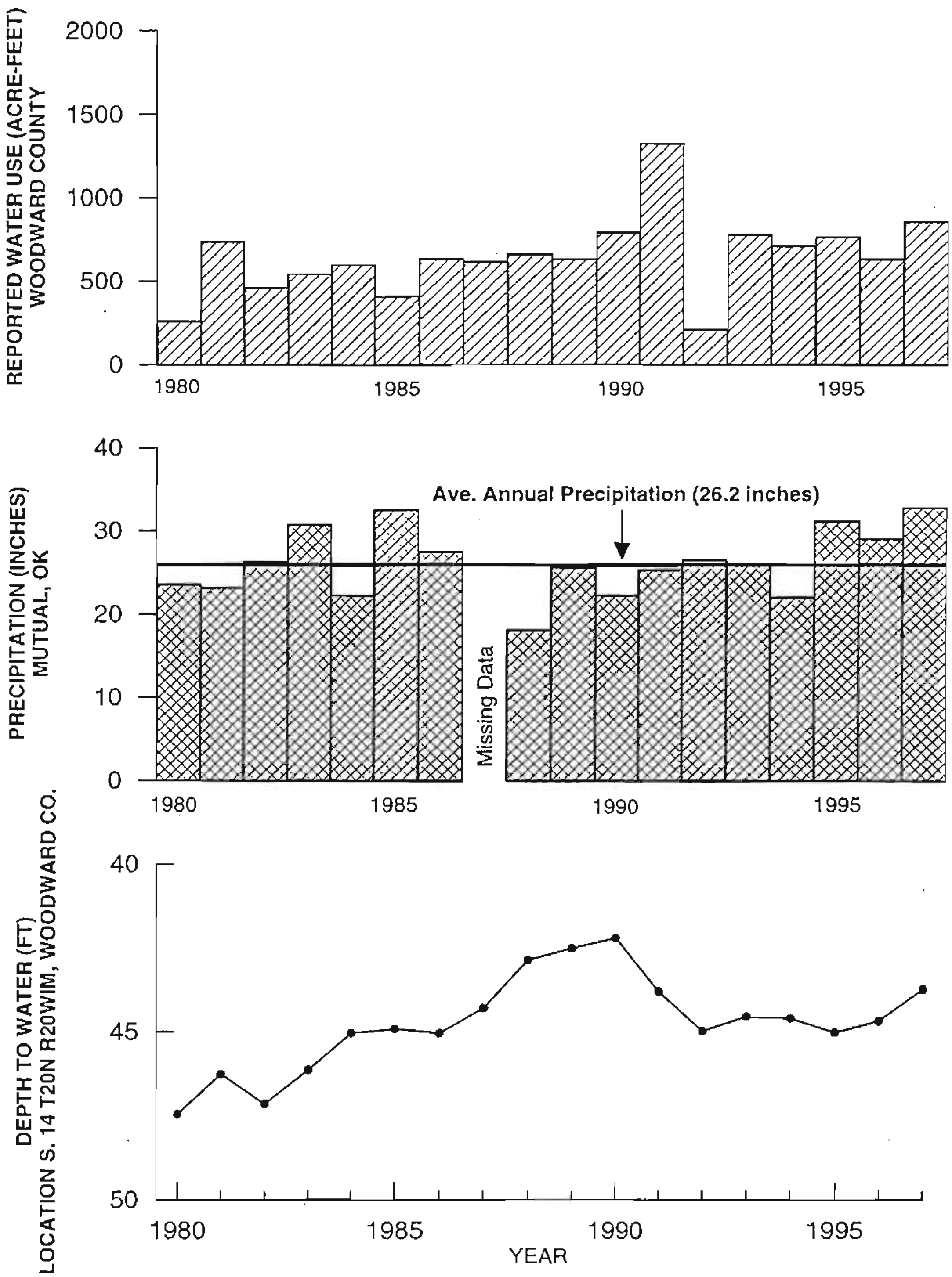

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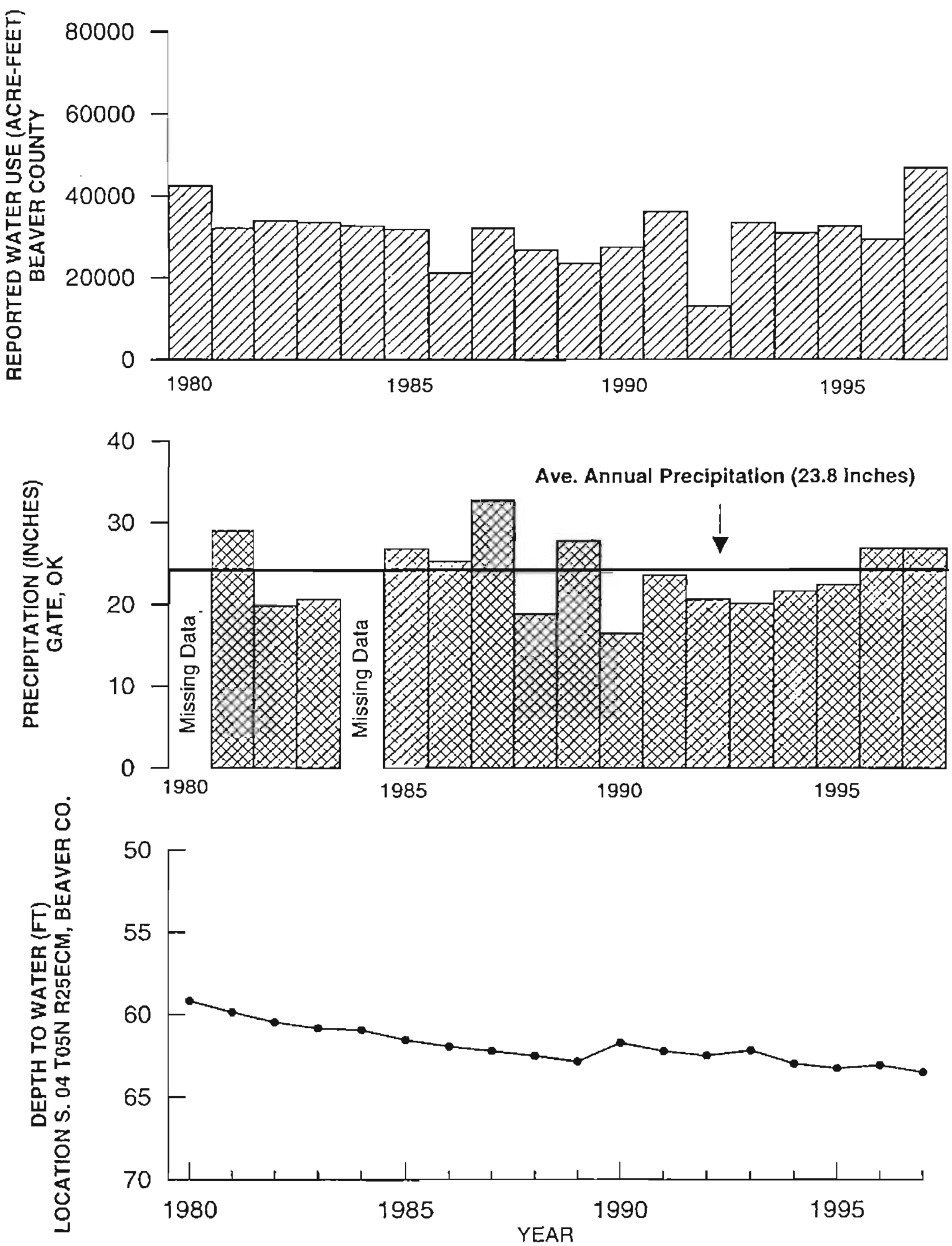

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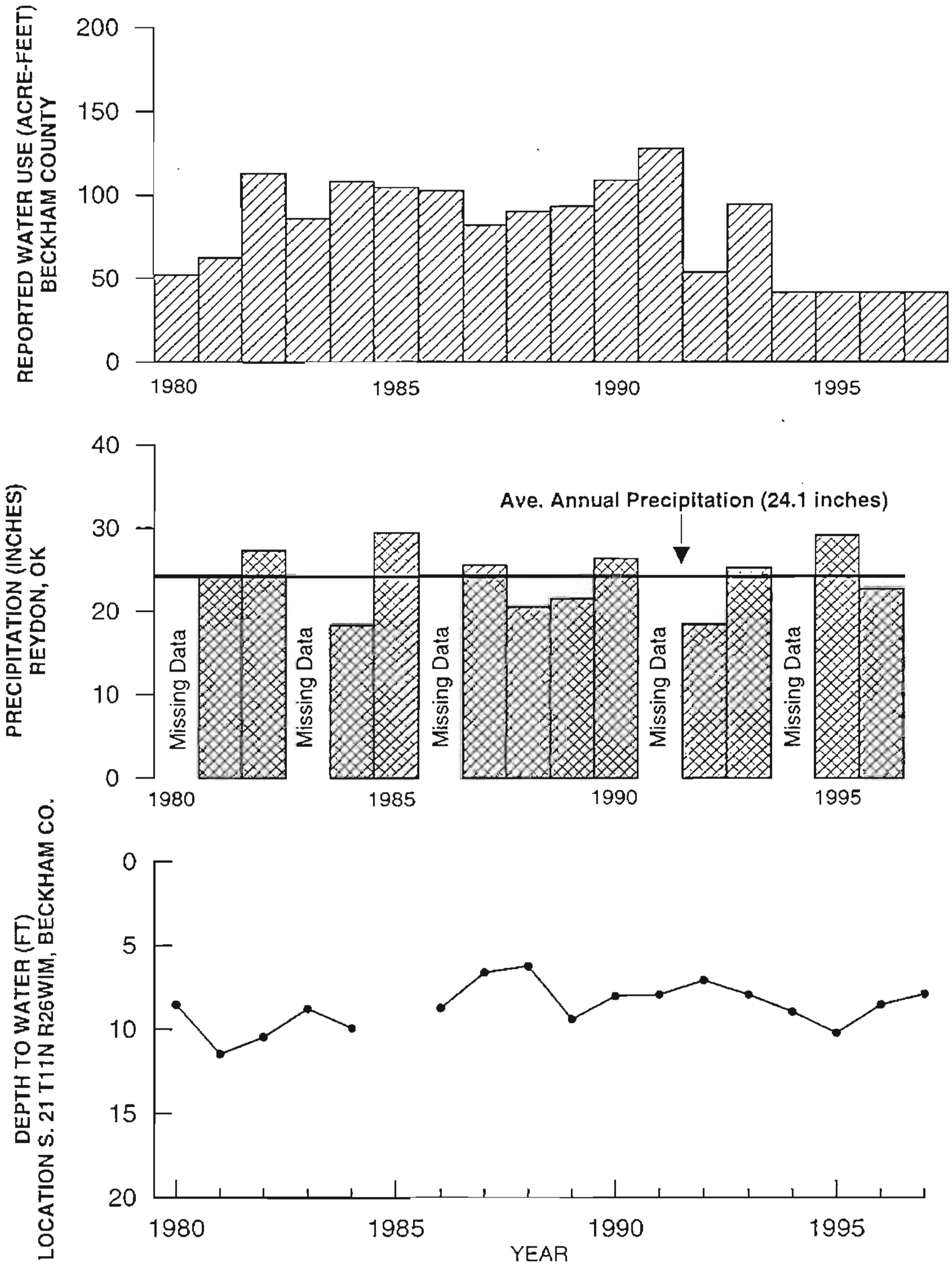

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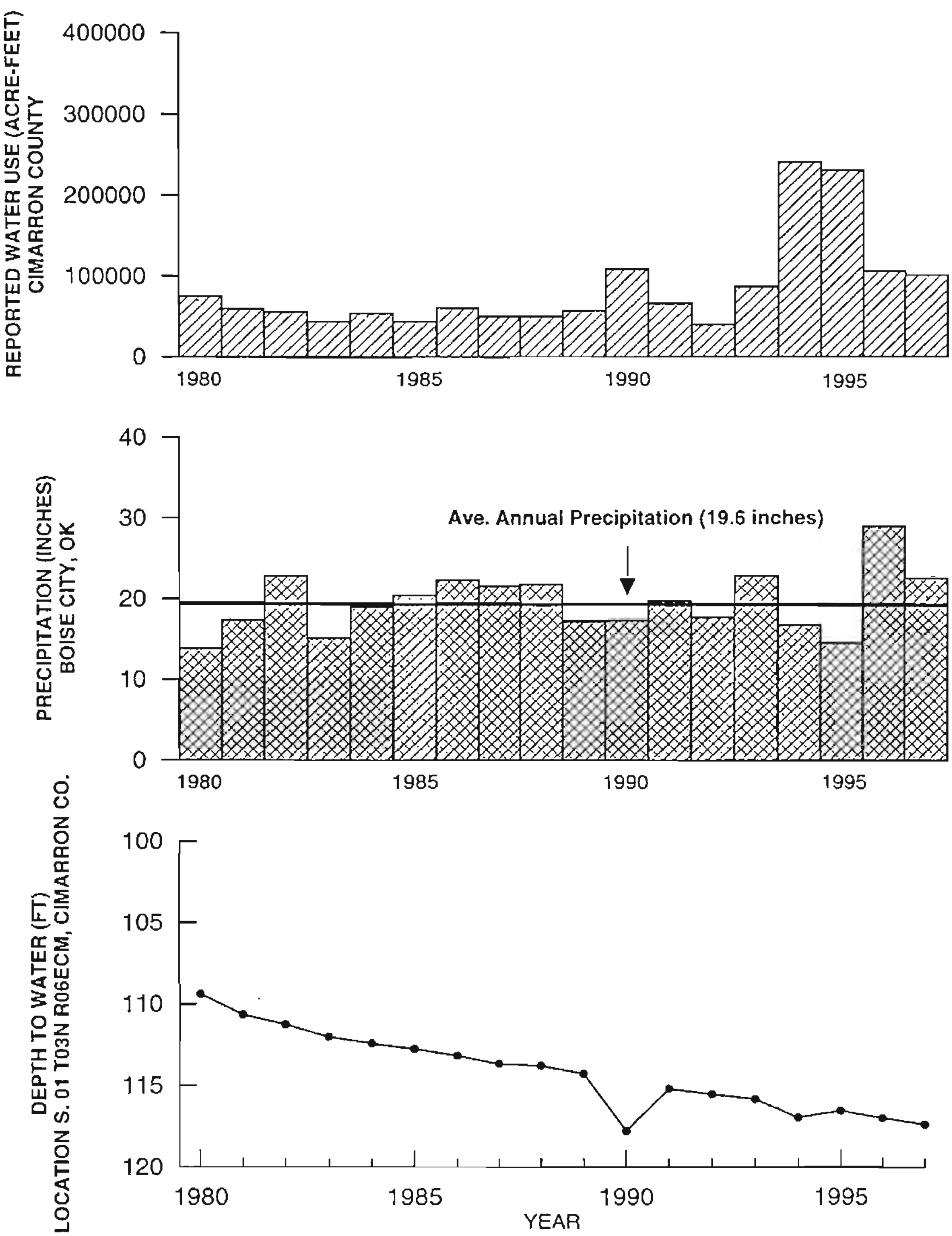

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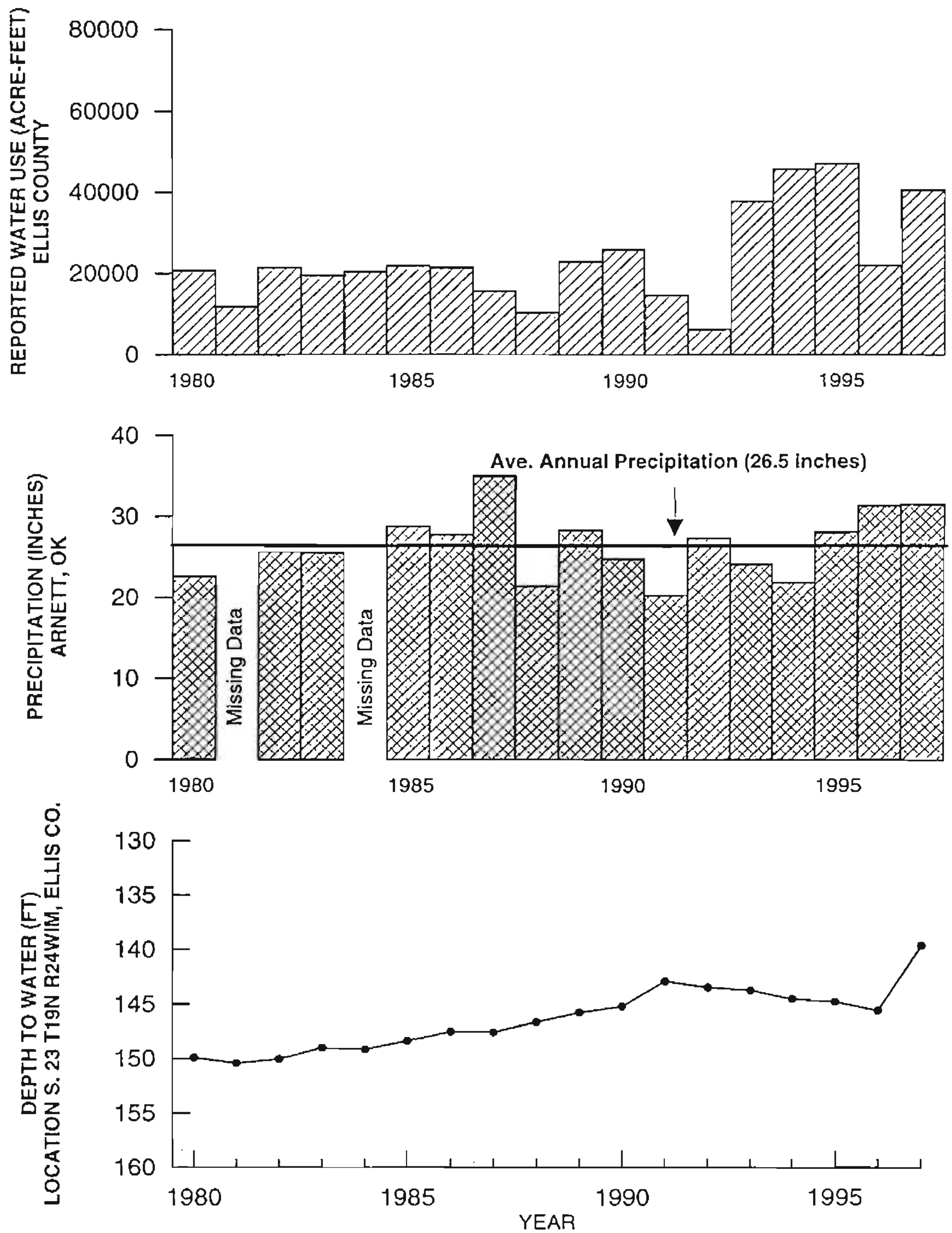

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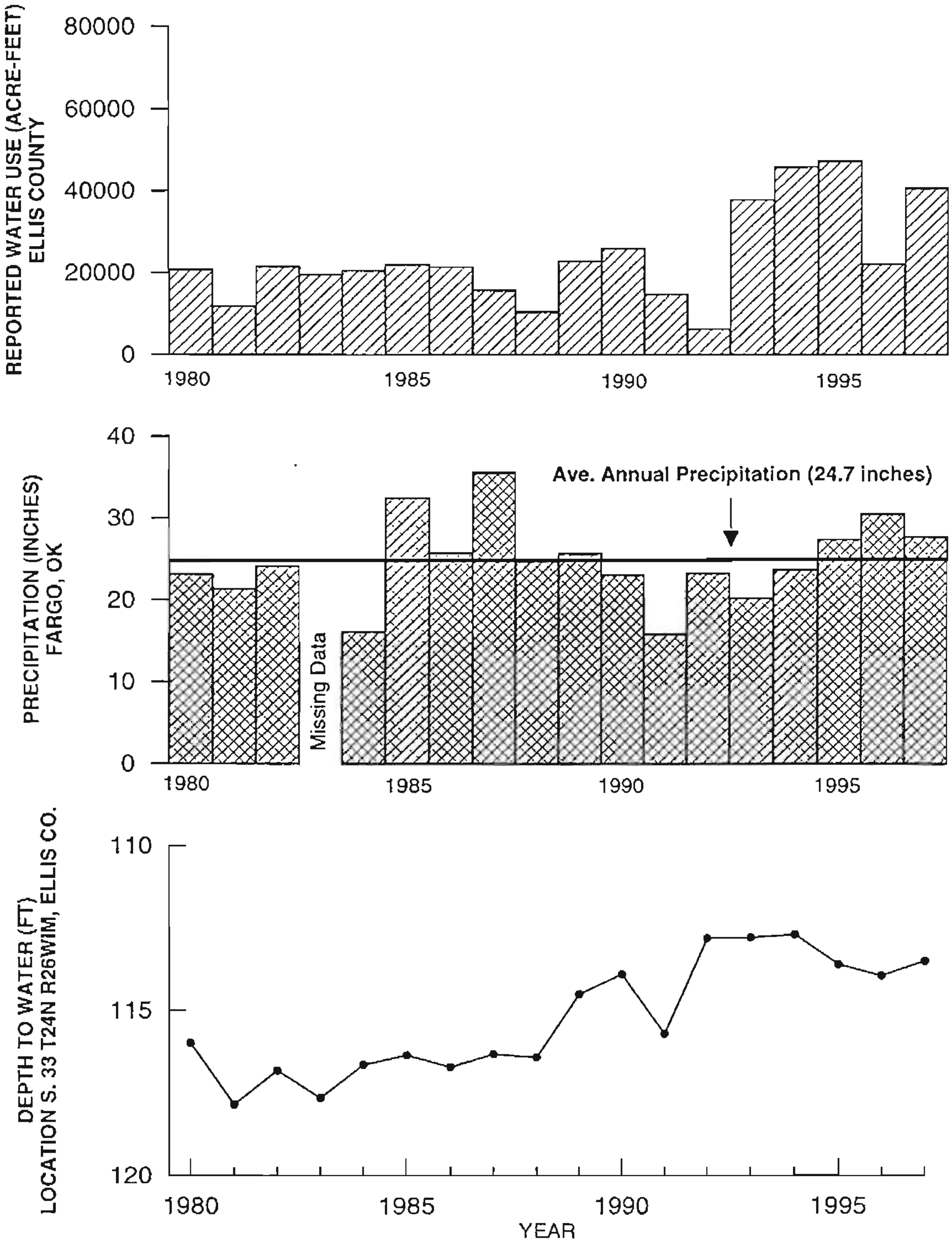

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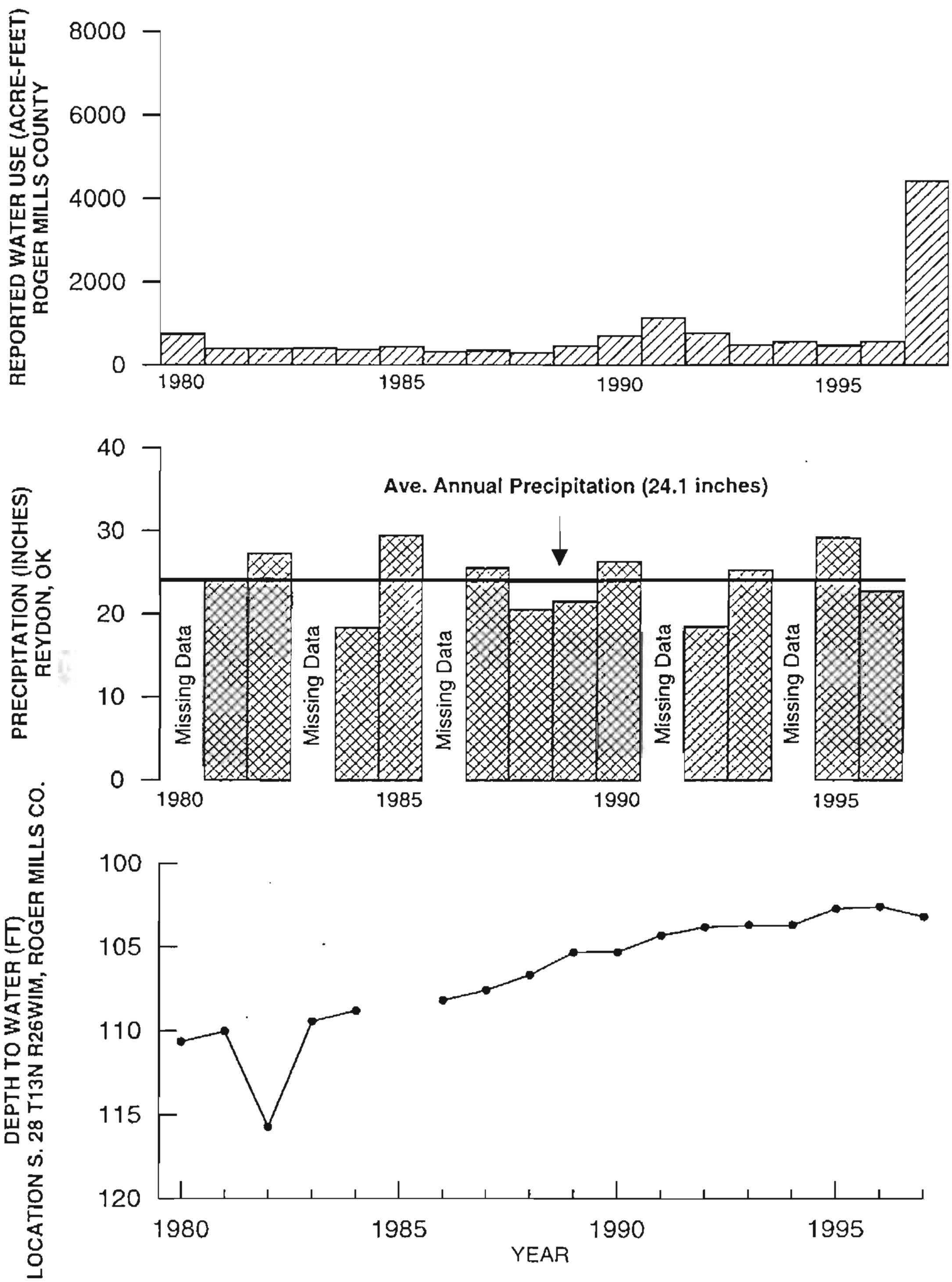

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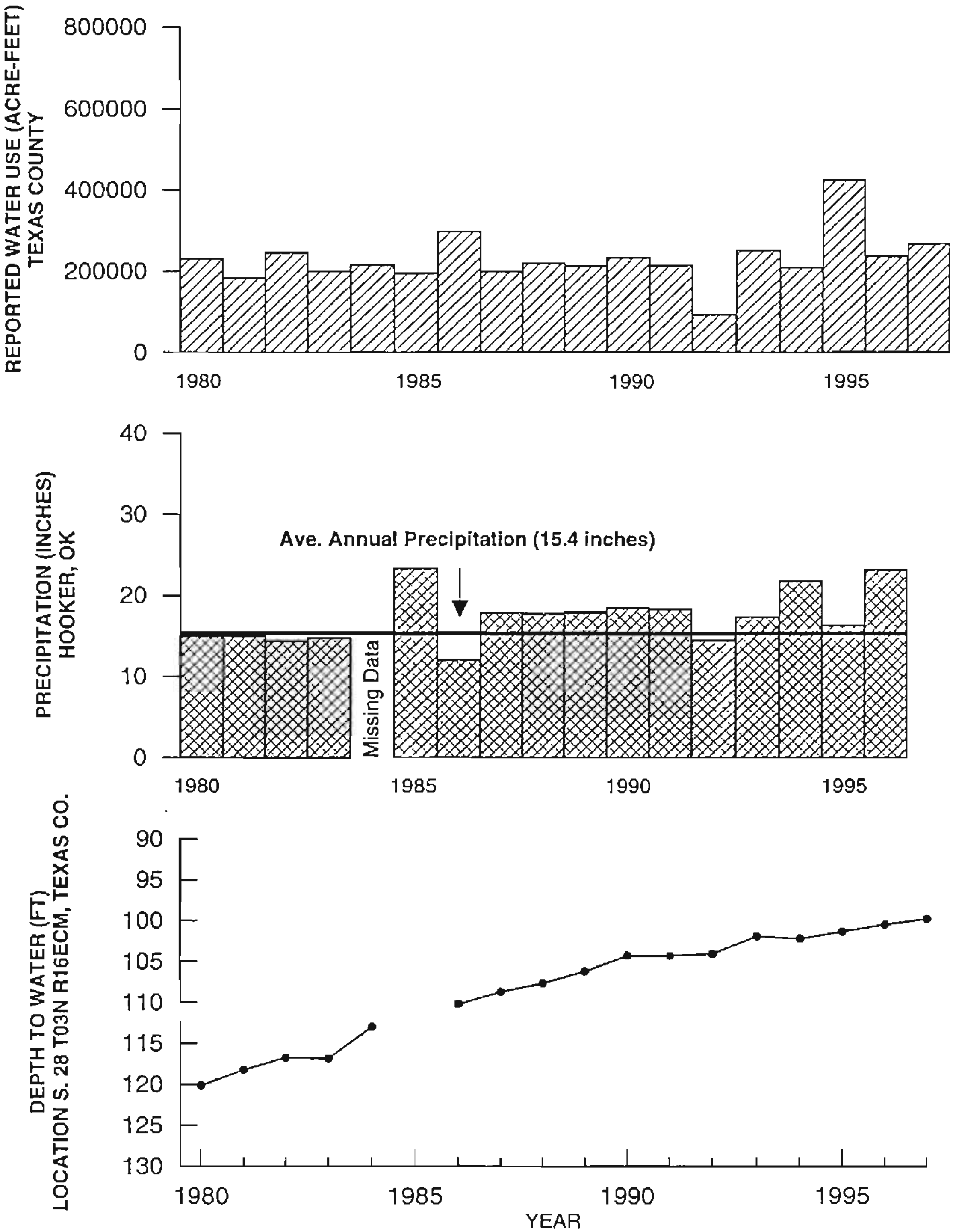

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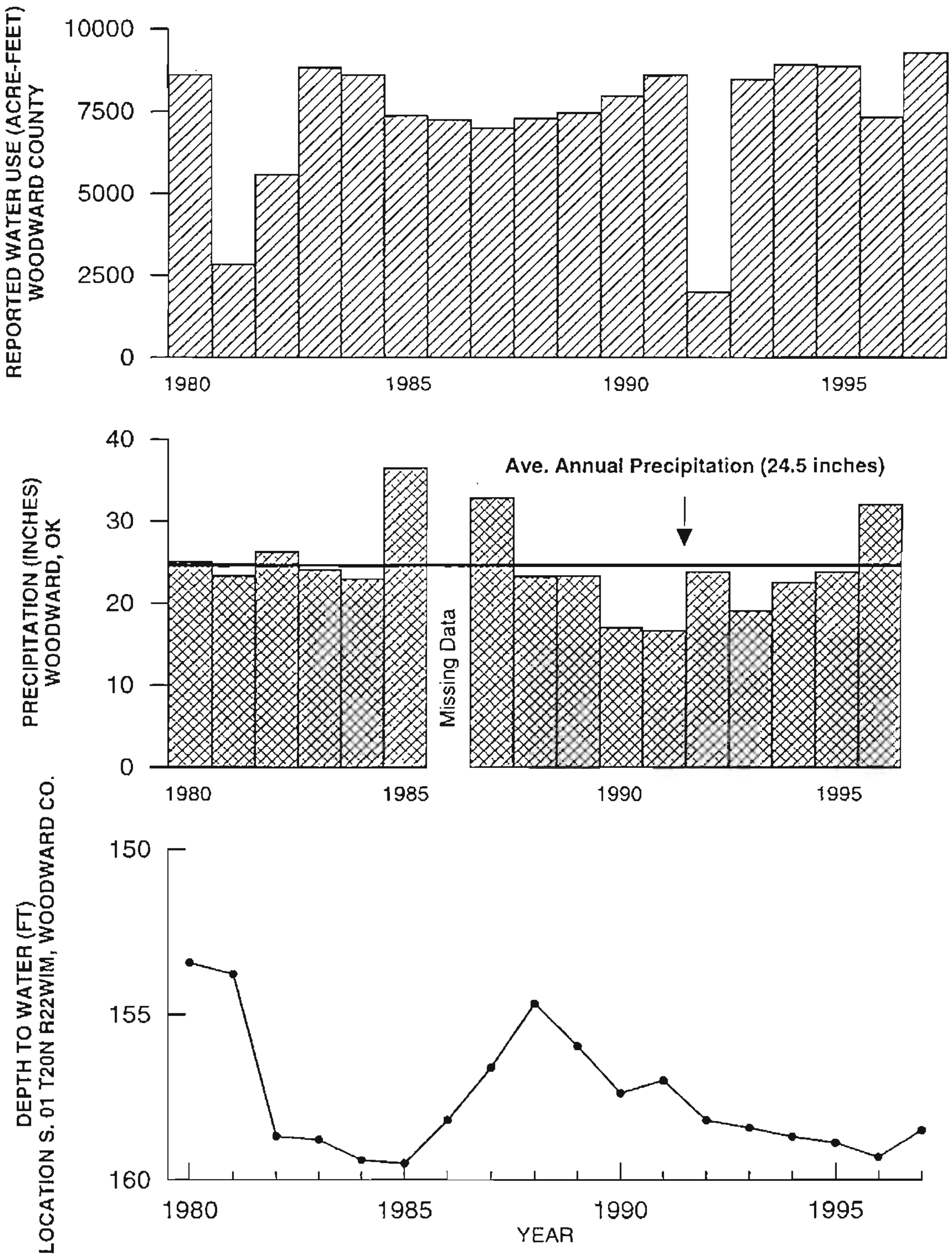

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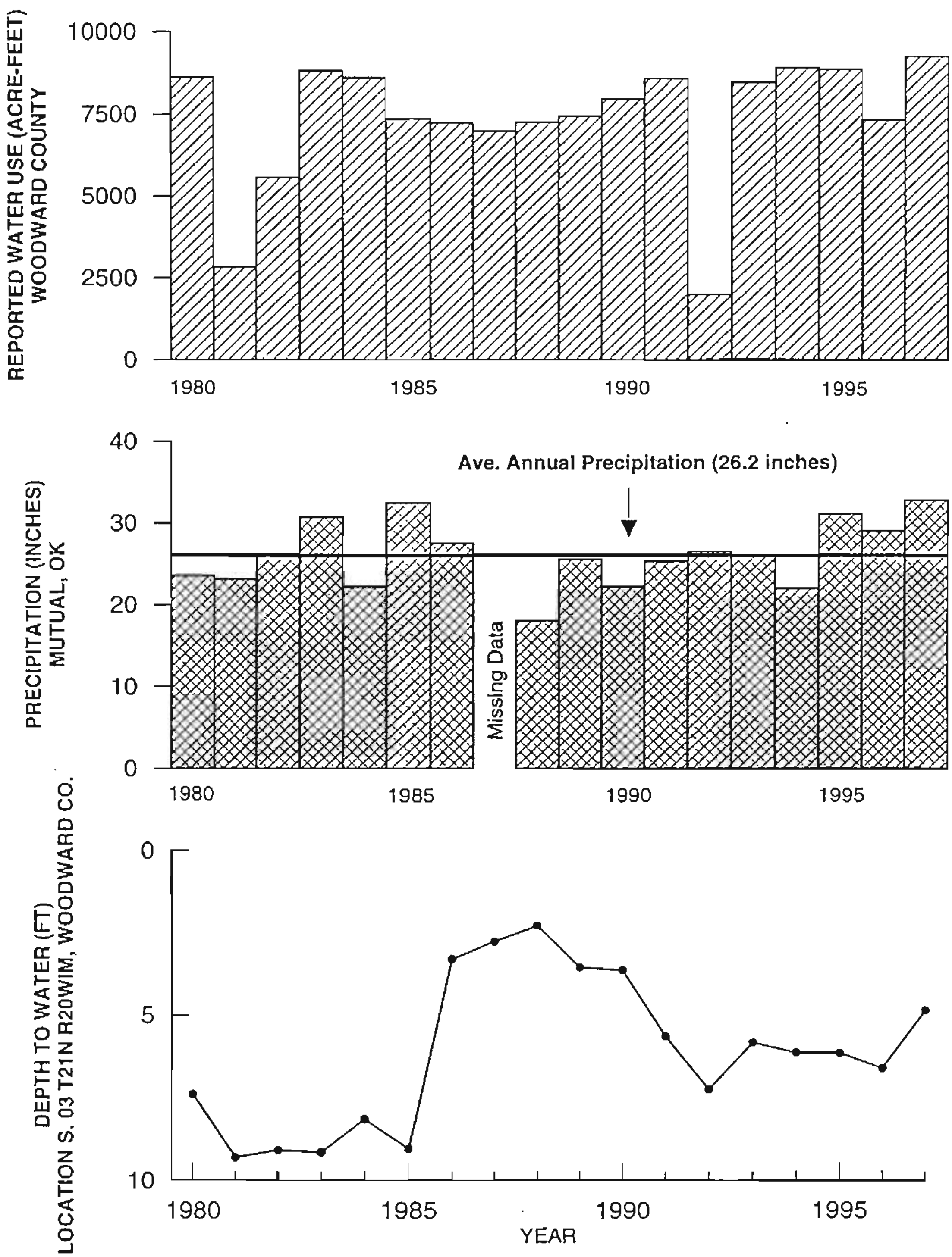
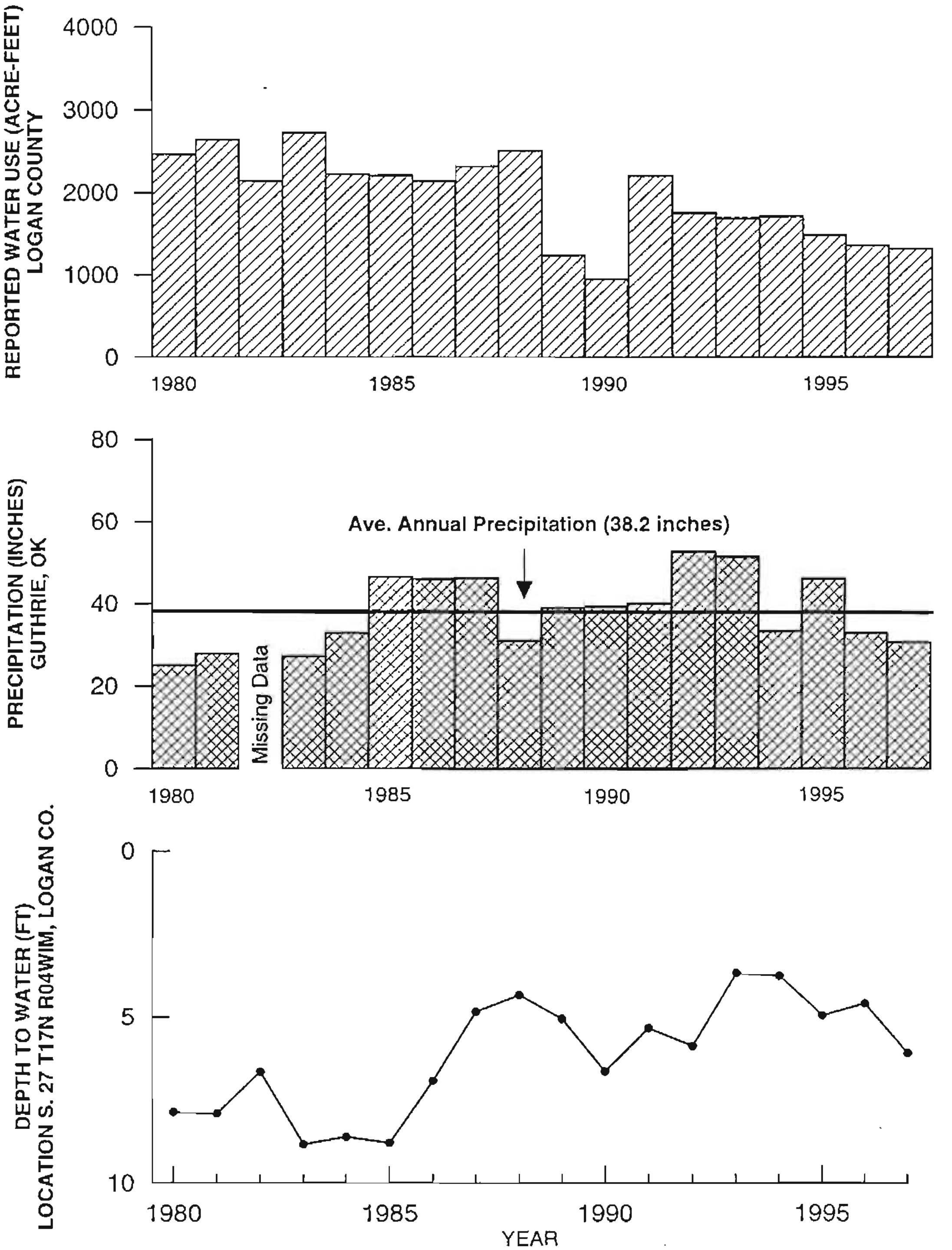


HYDROLOGIC DATA FOR THE ALLUVIUM AND TERRACE DEPOSITS OF THE CIMARRON RIVER



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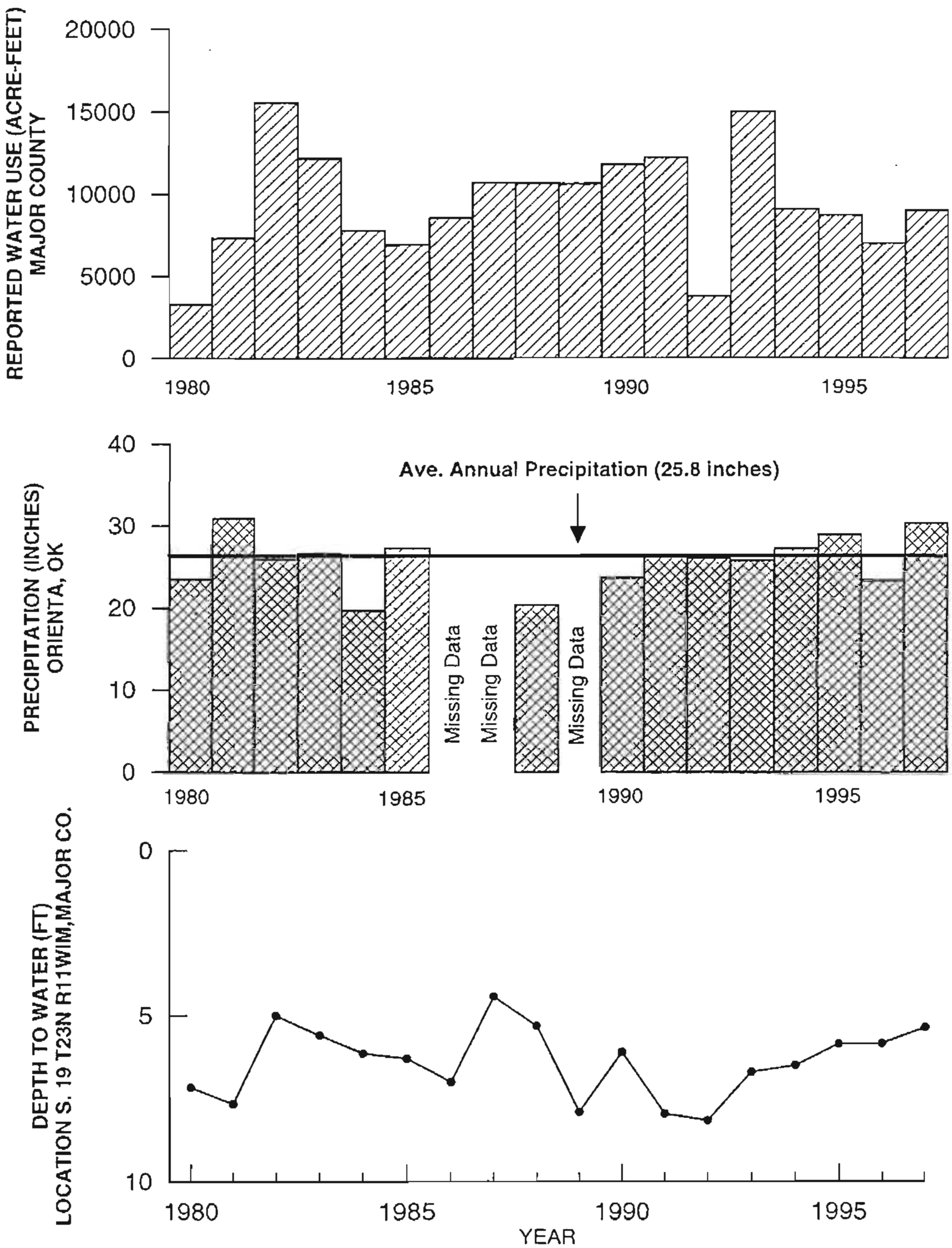

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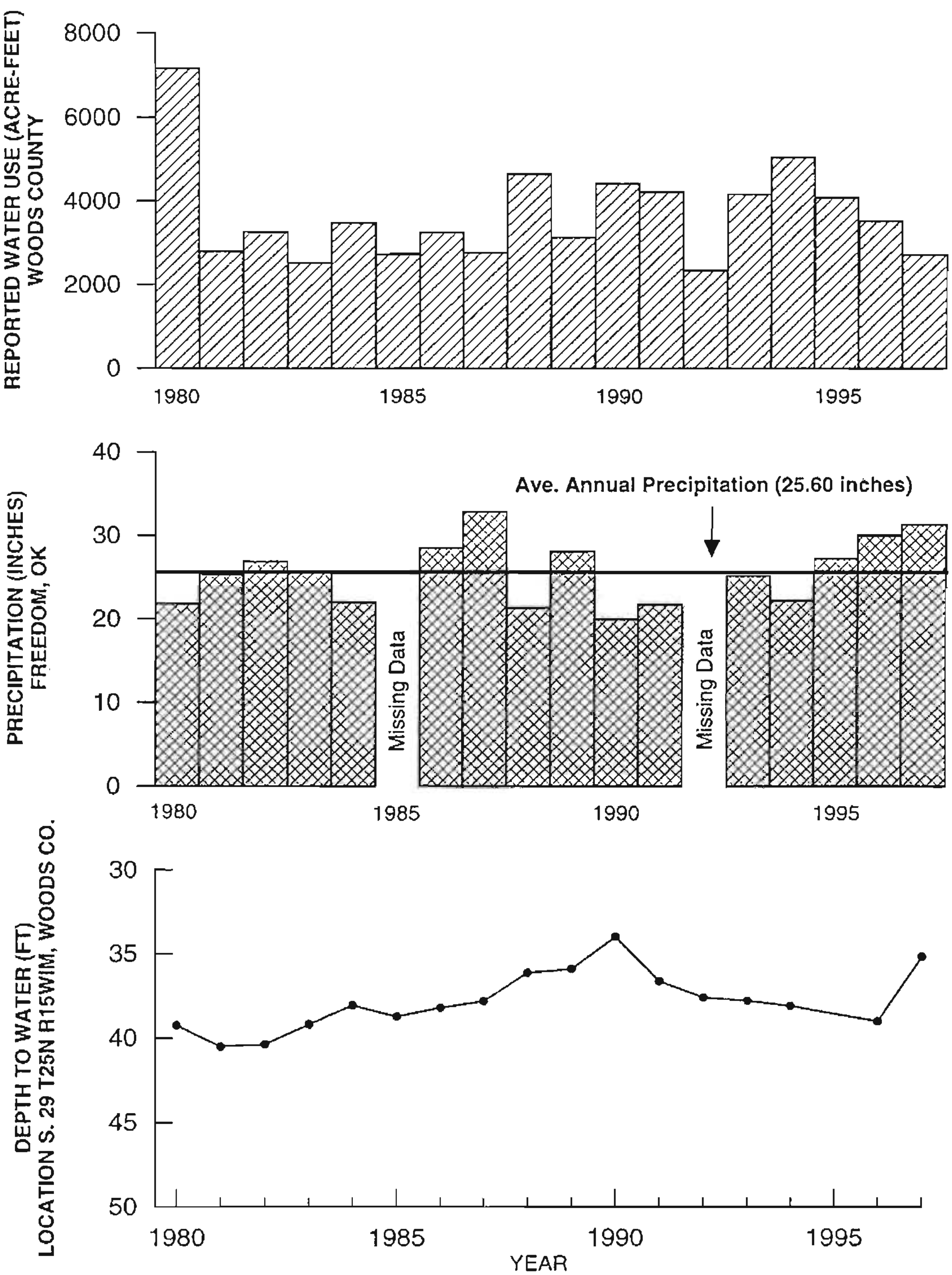

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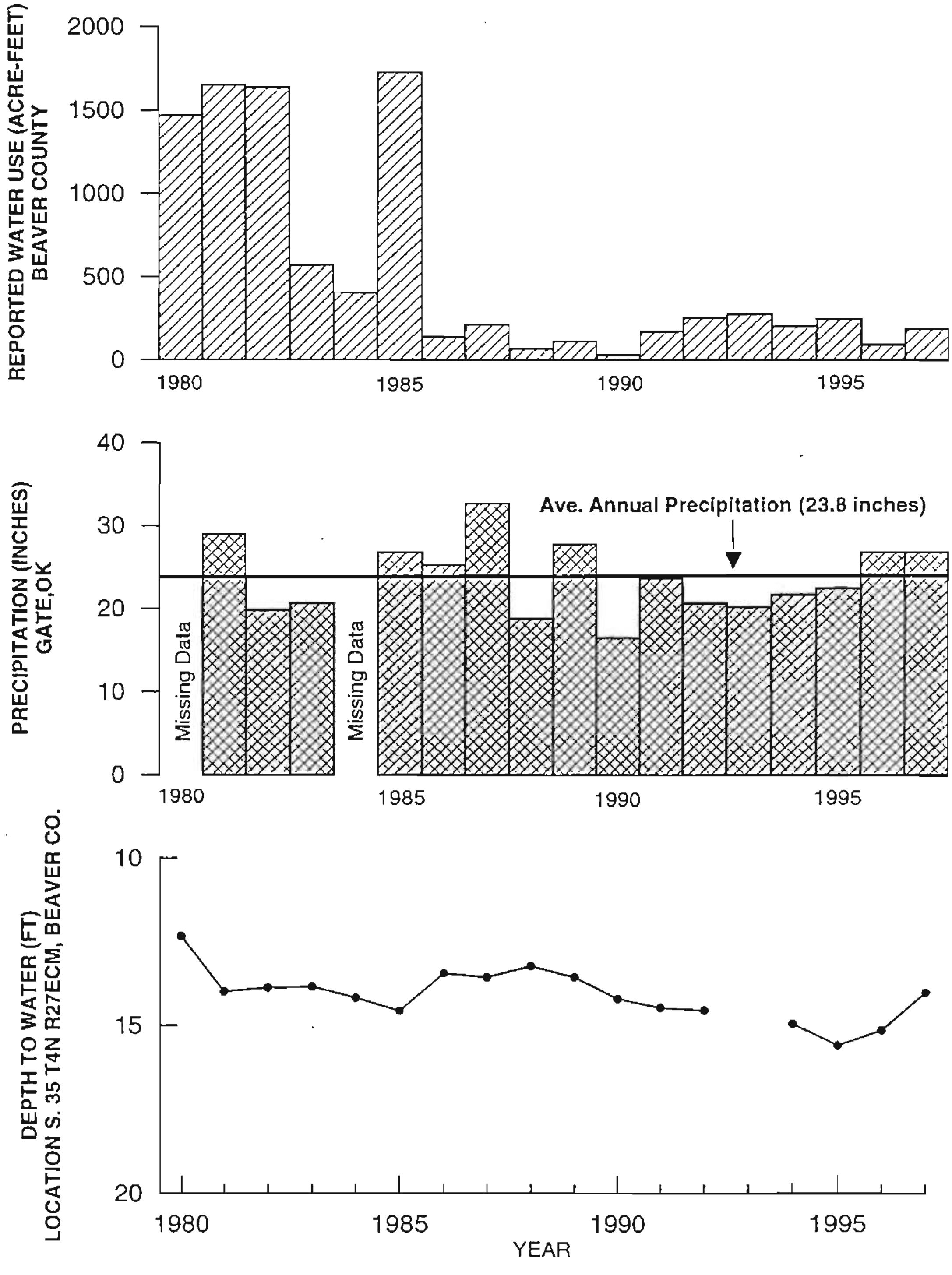

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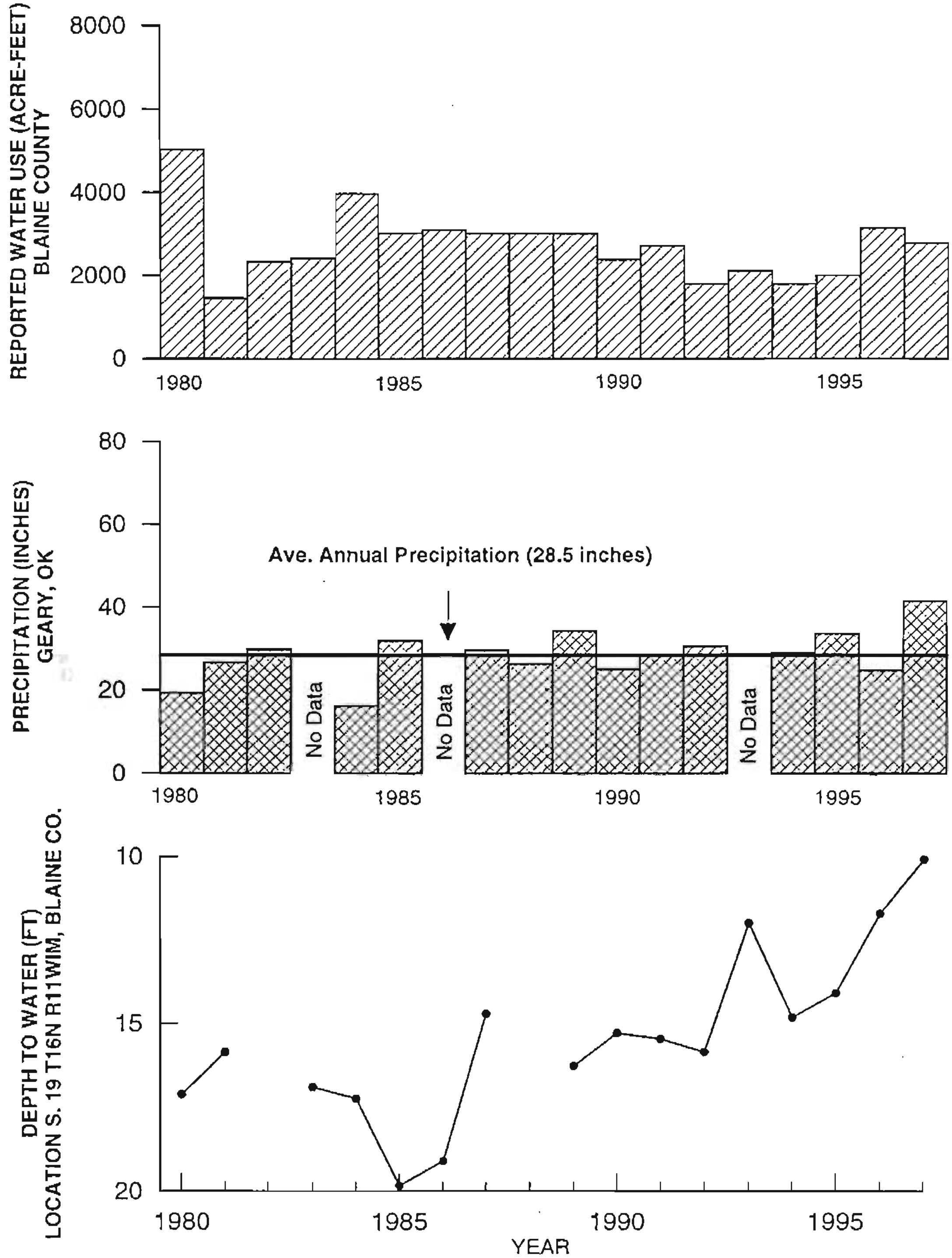

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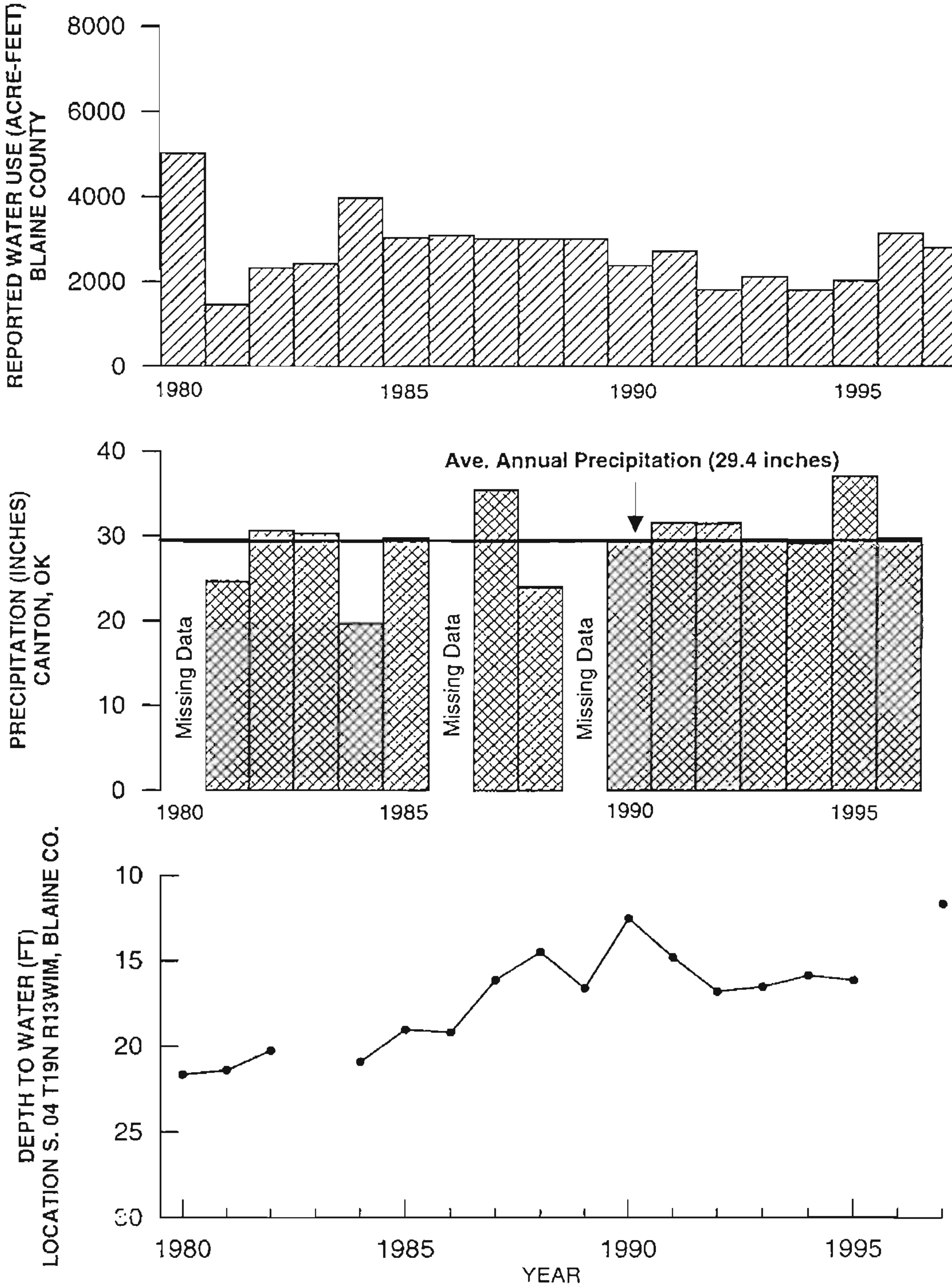

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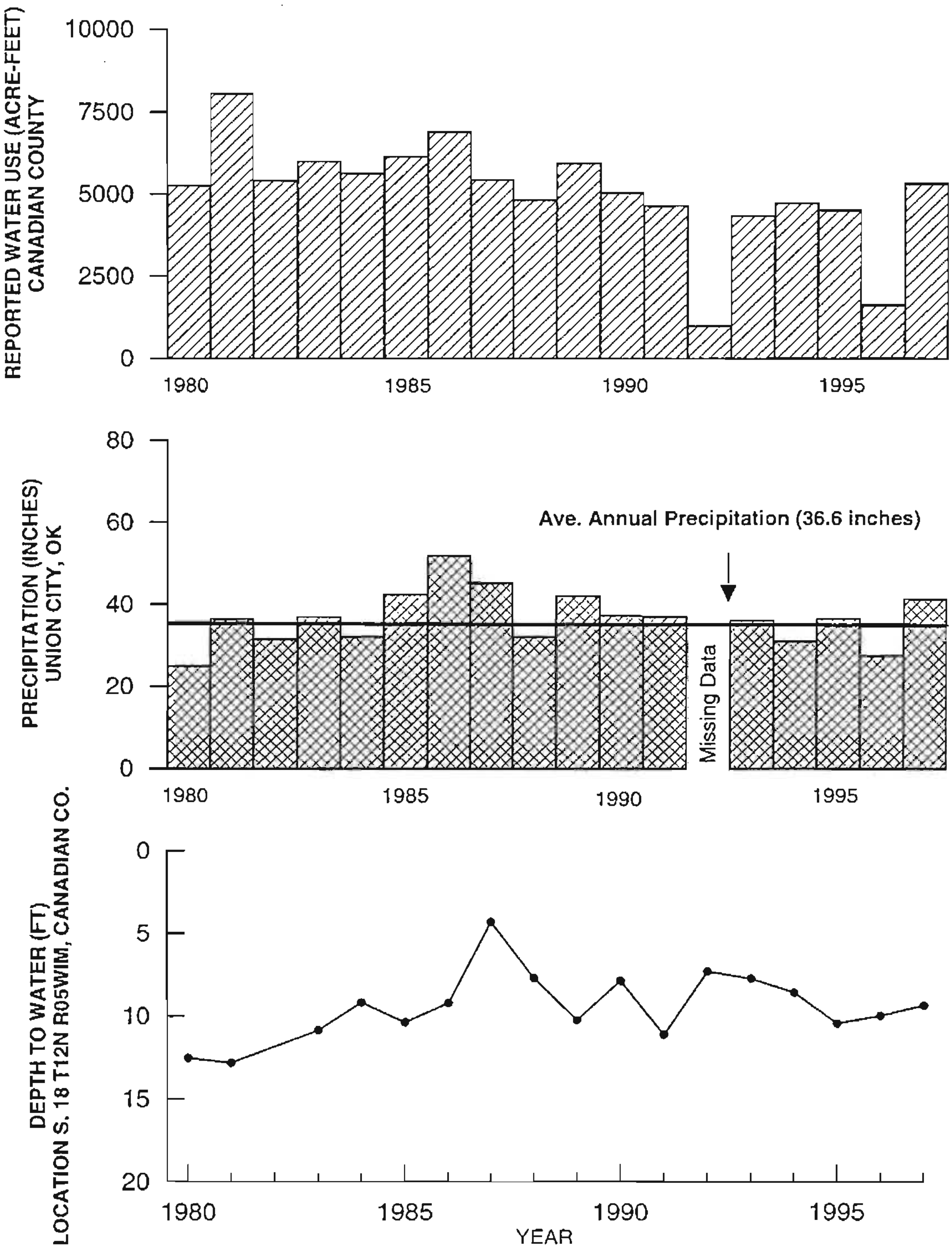

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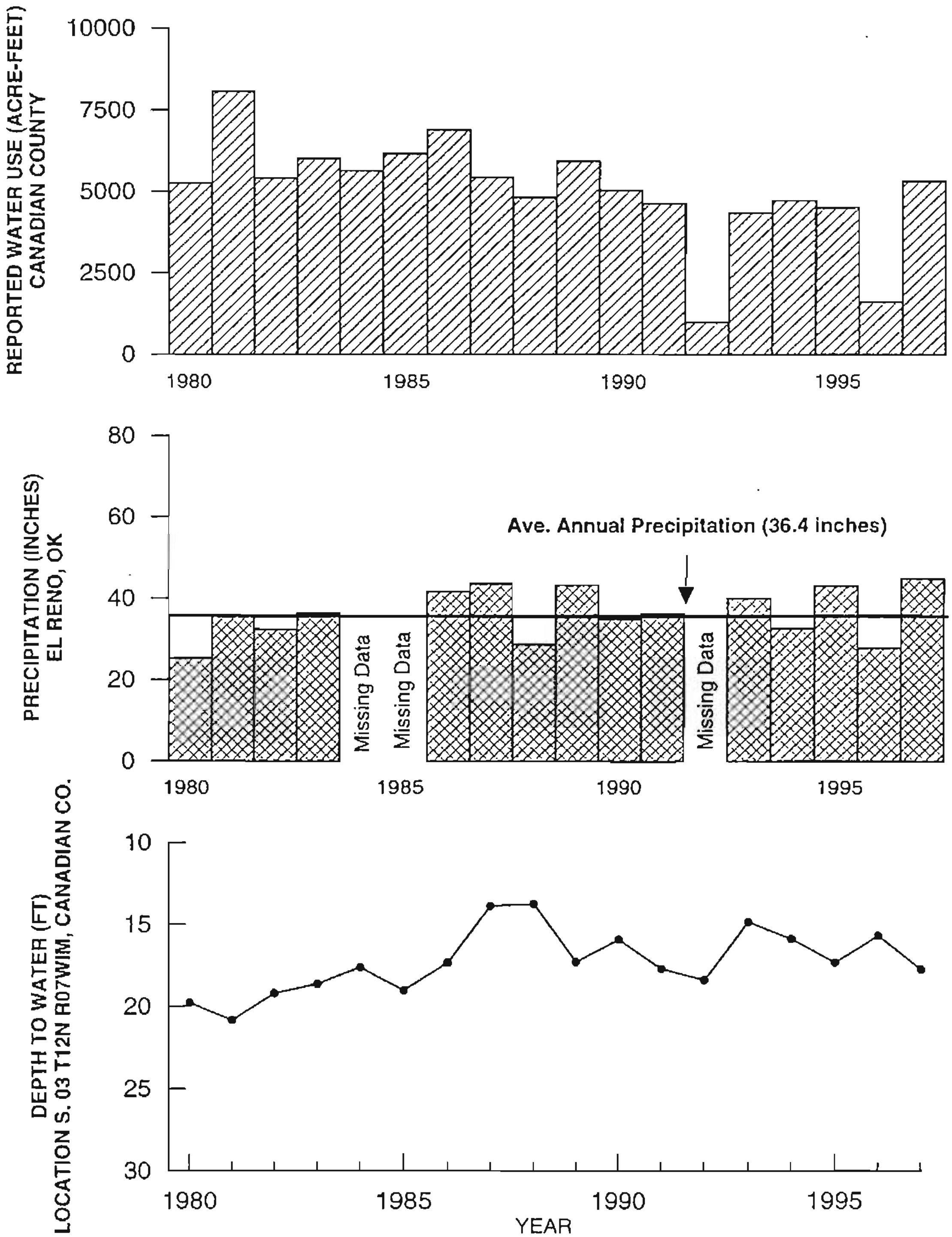

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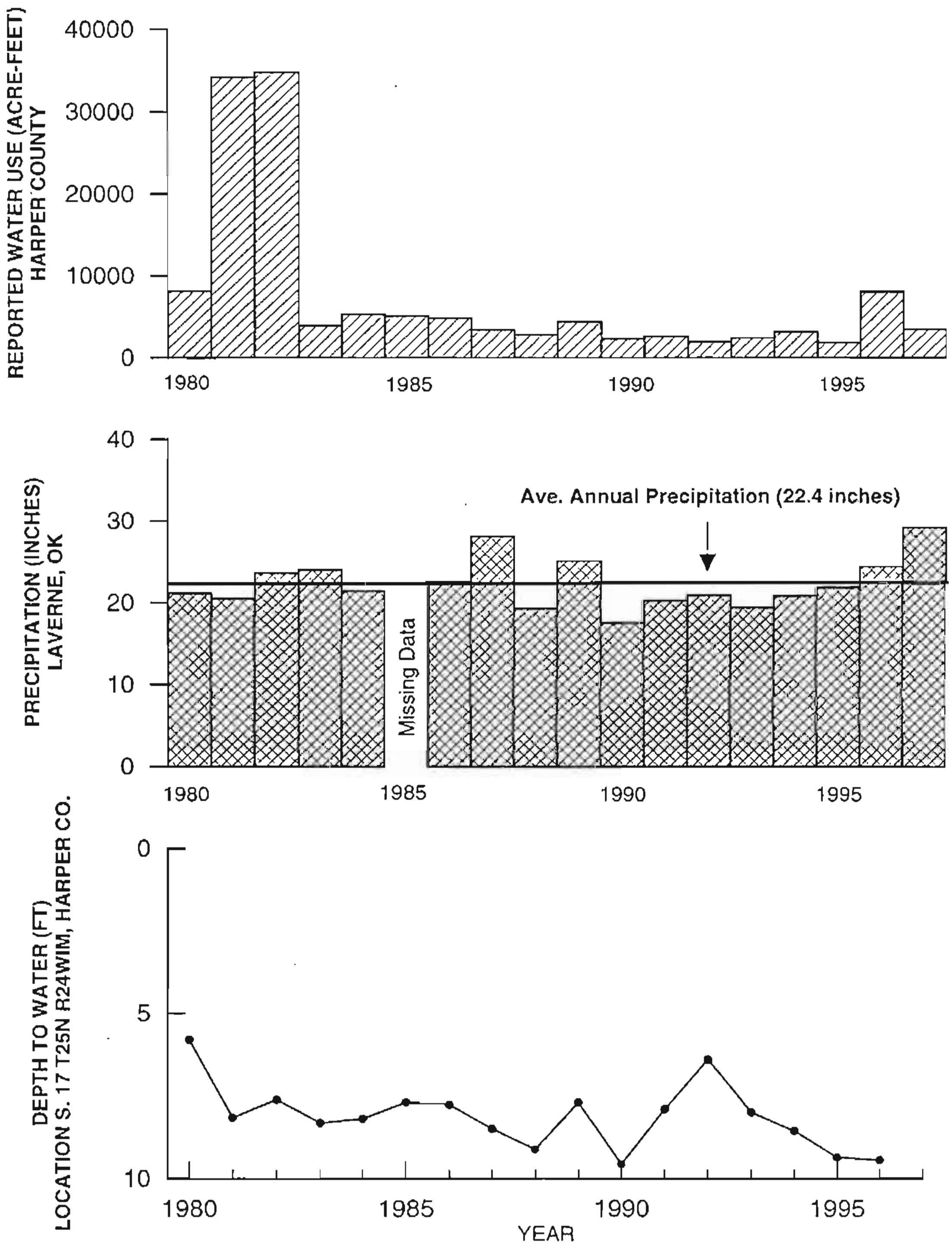

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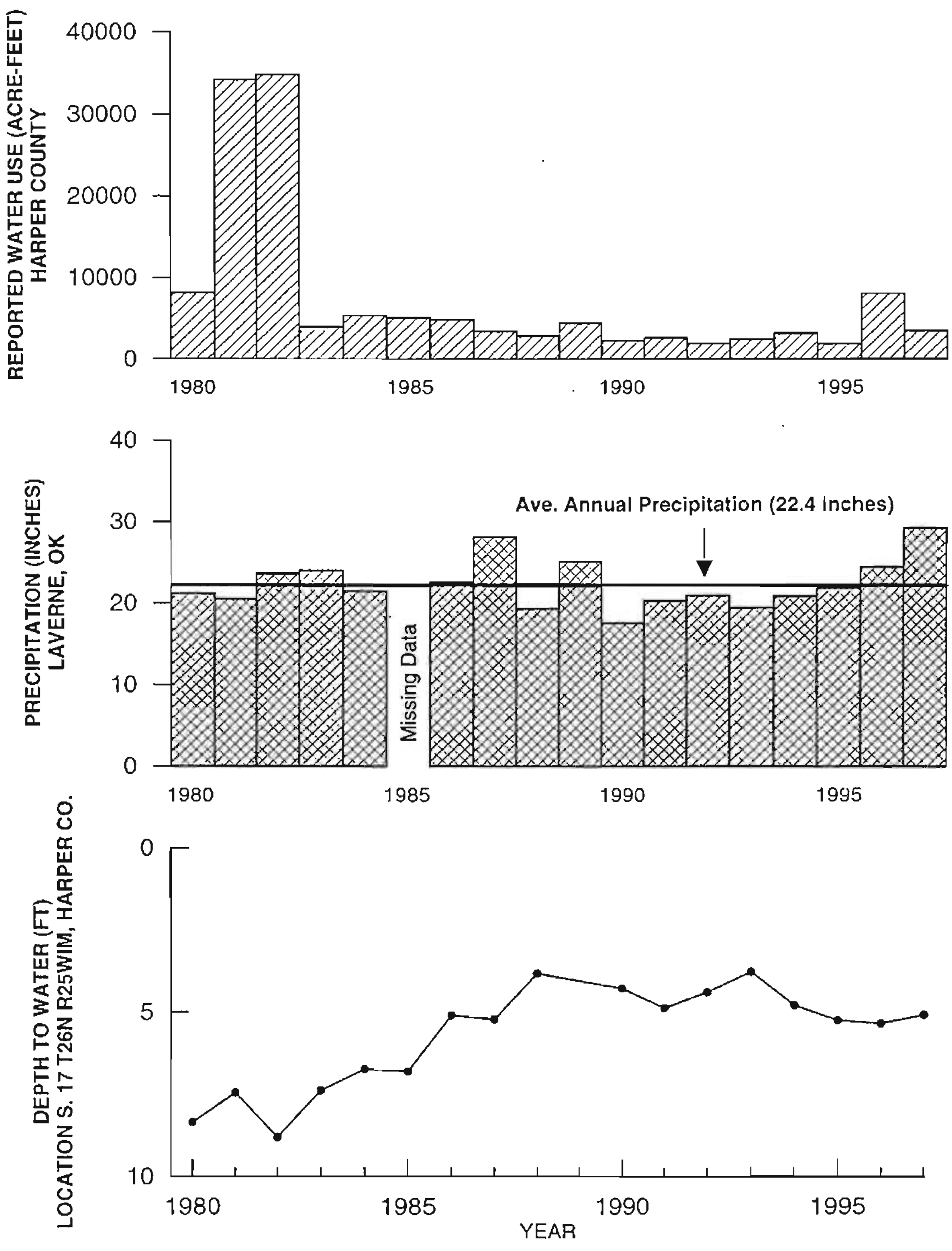

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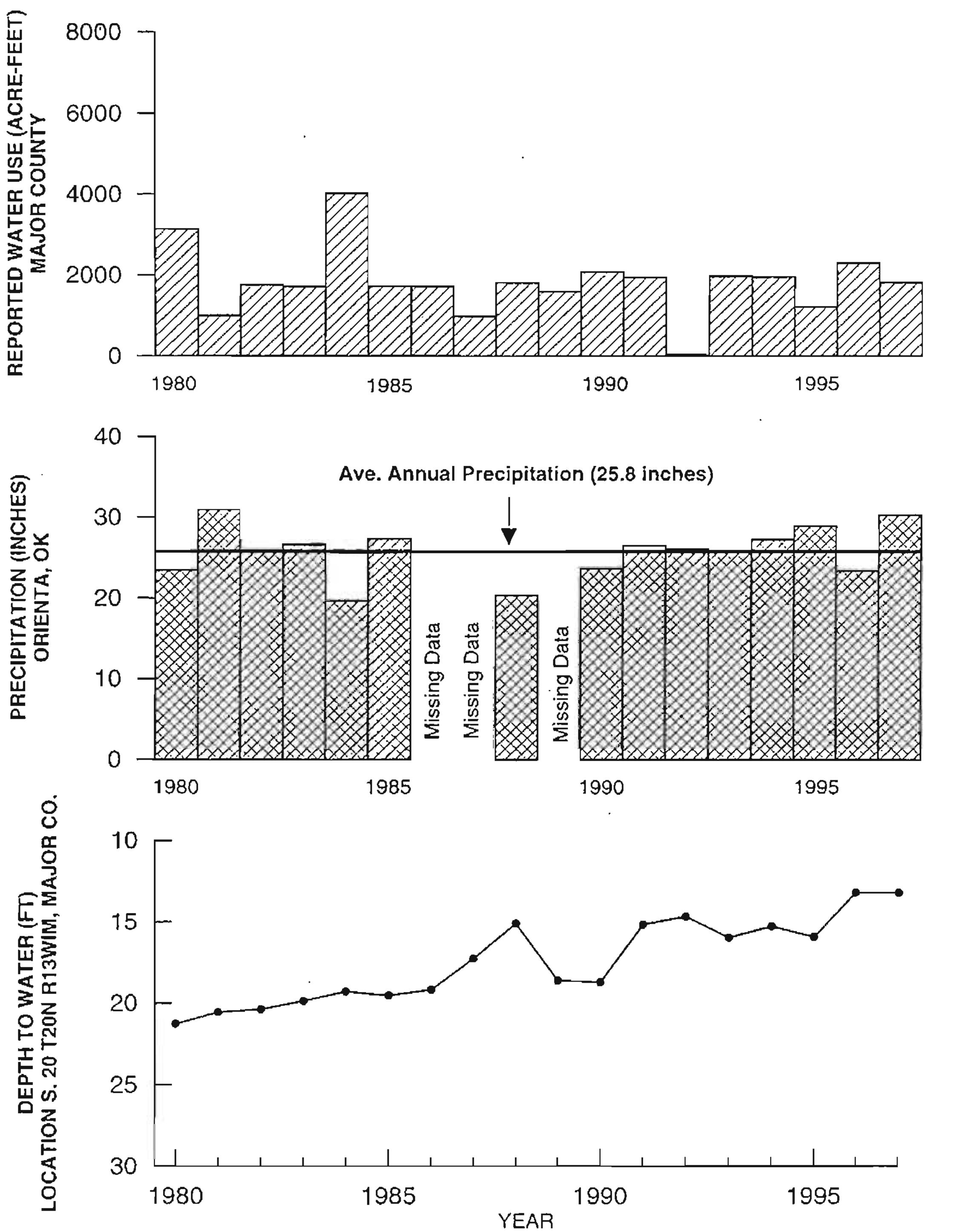

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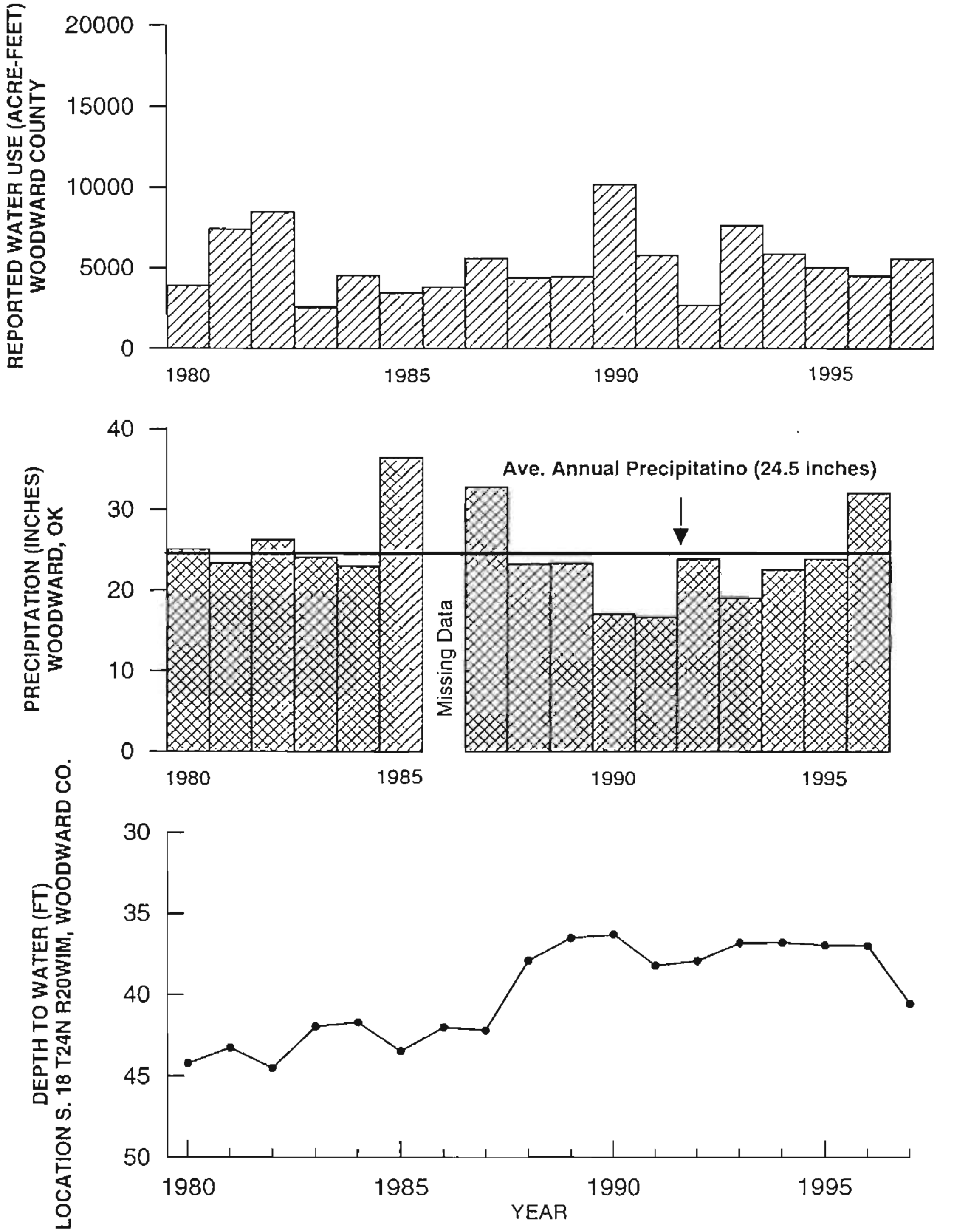

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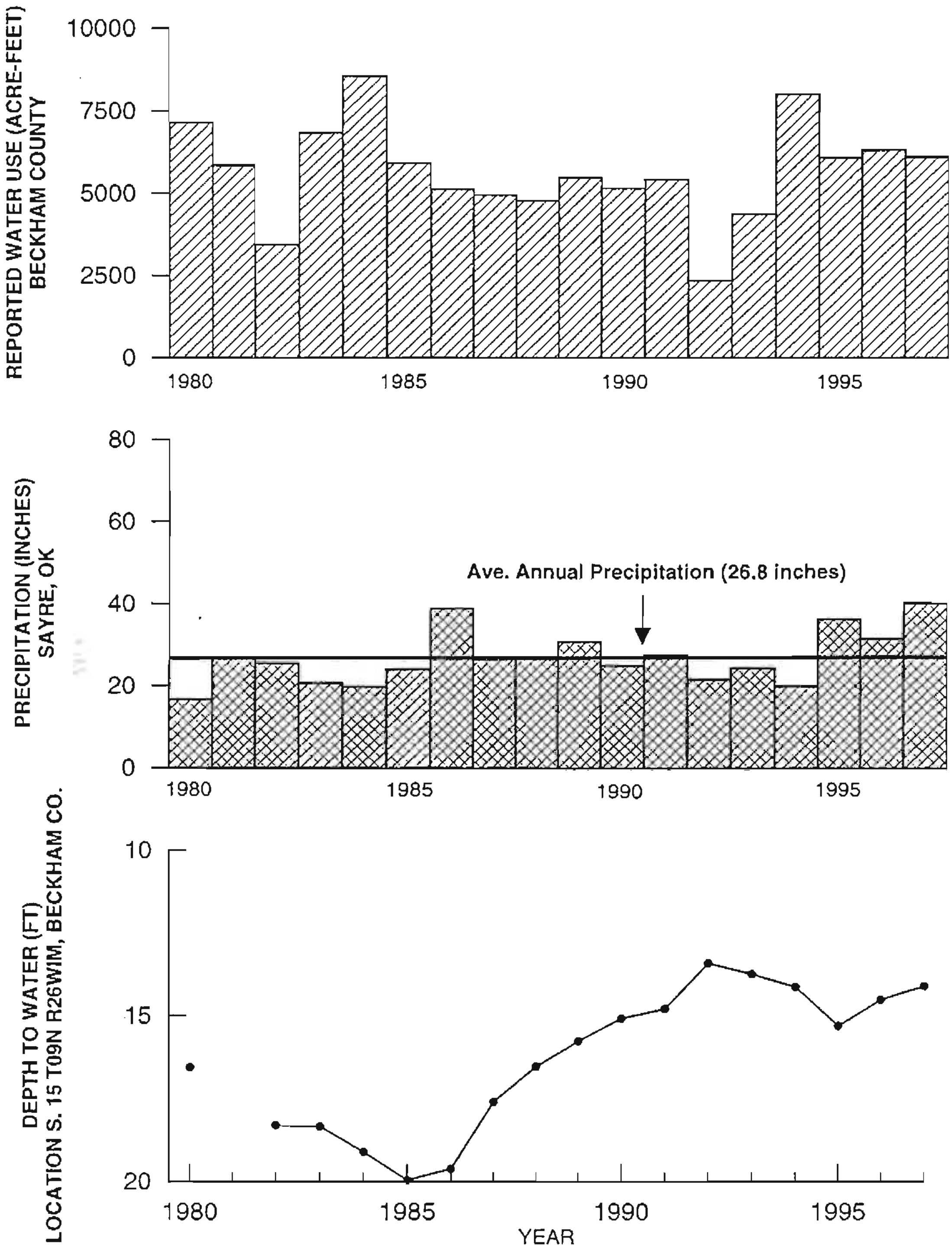

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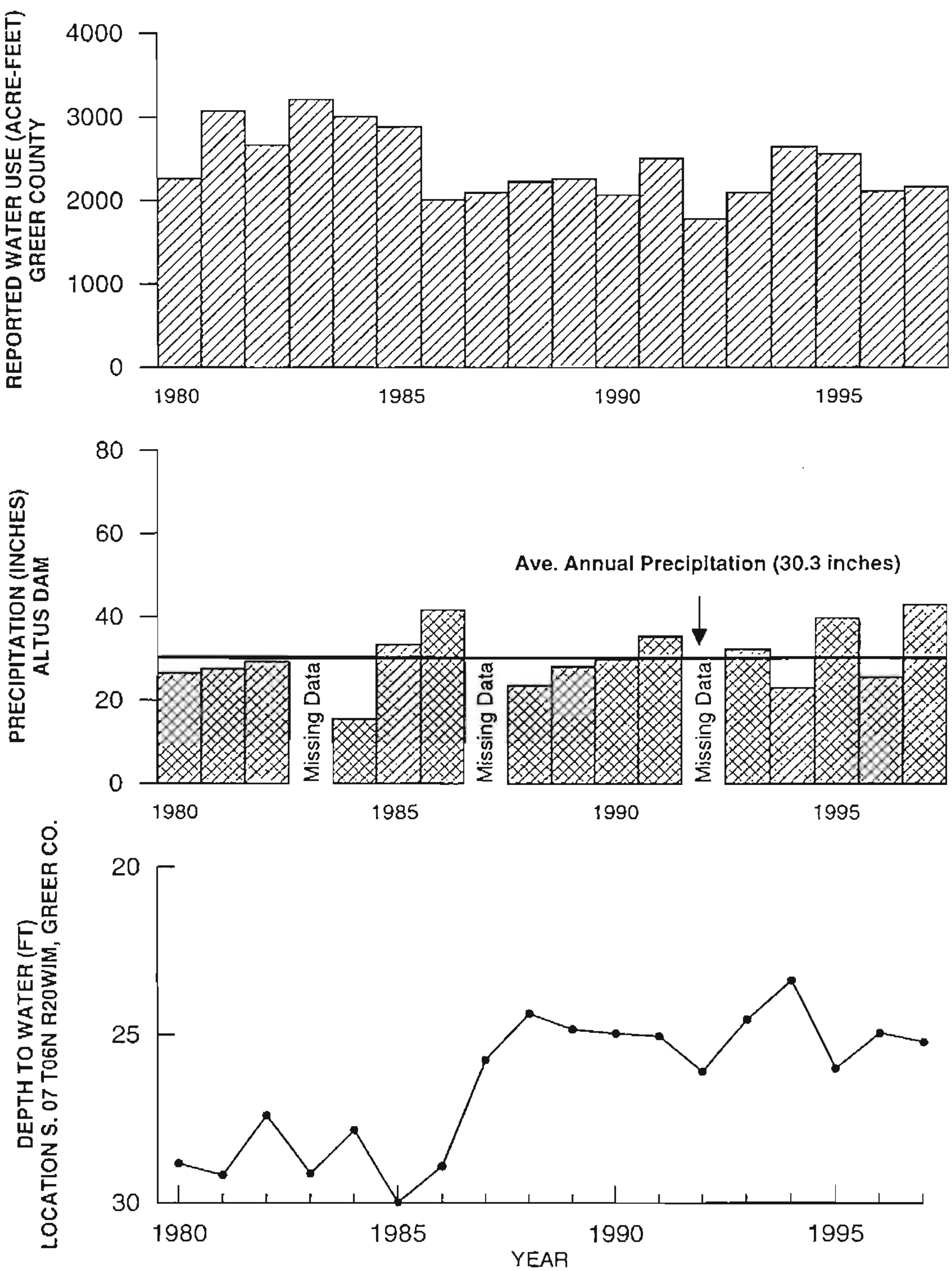

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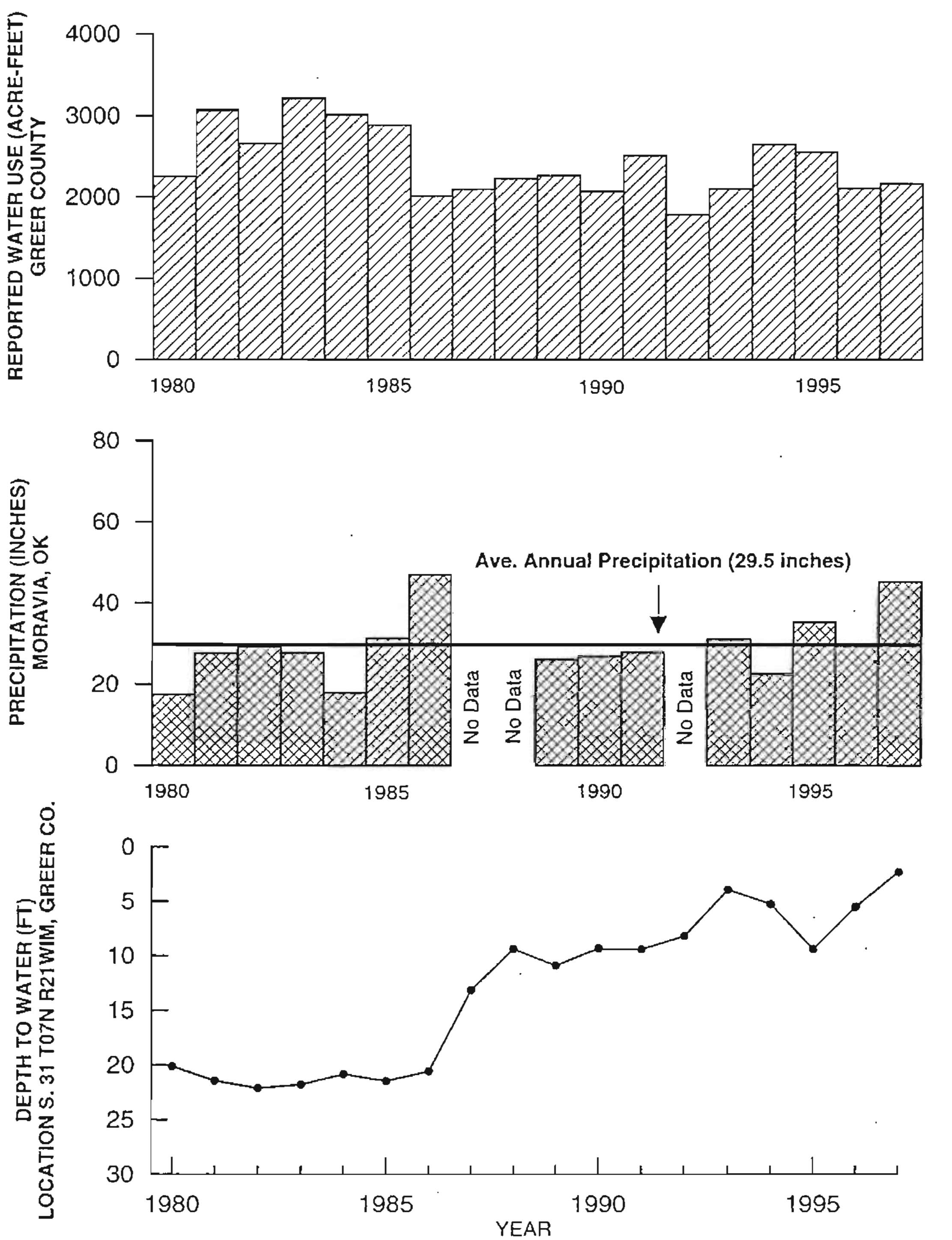

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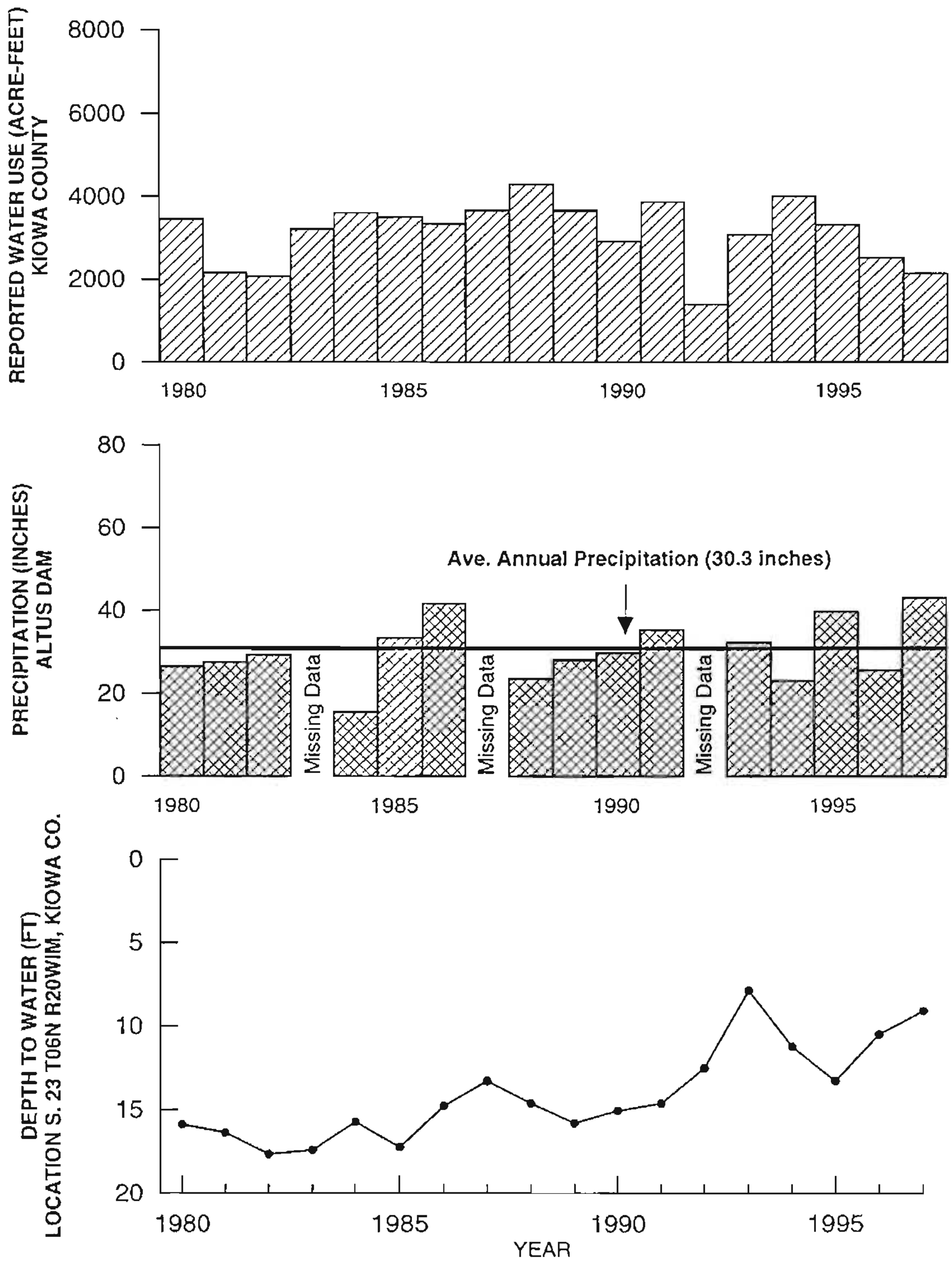

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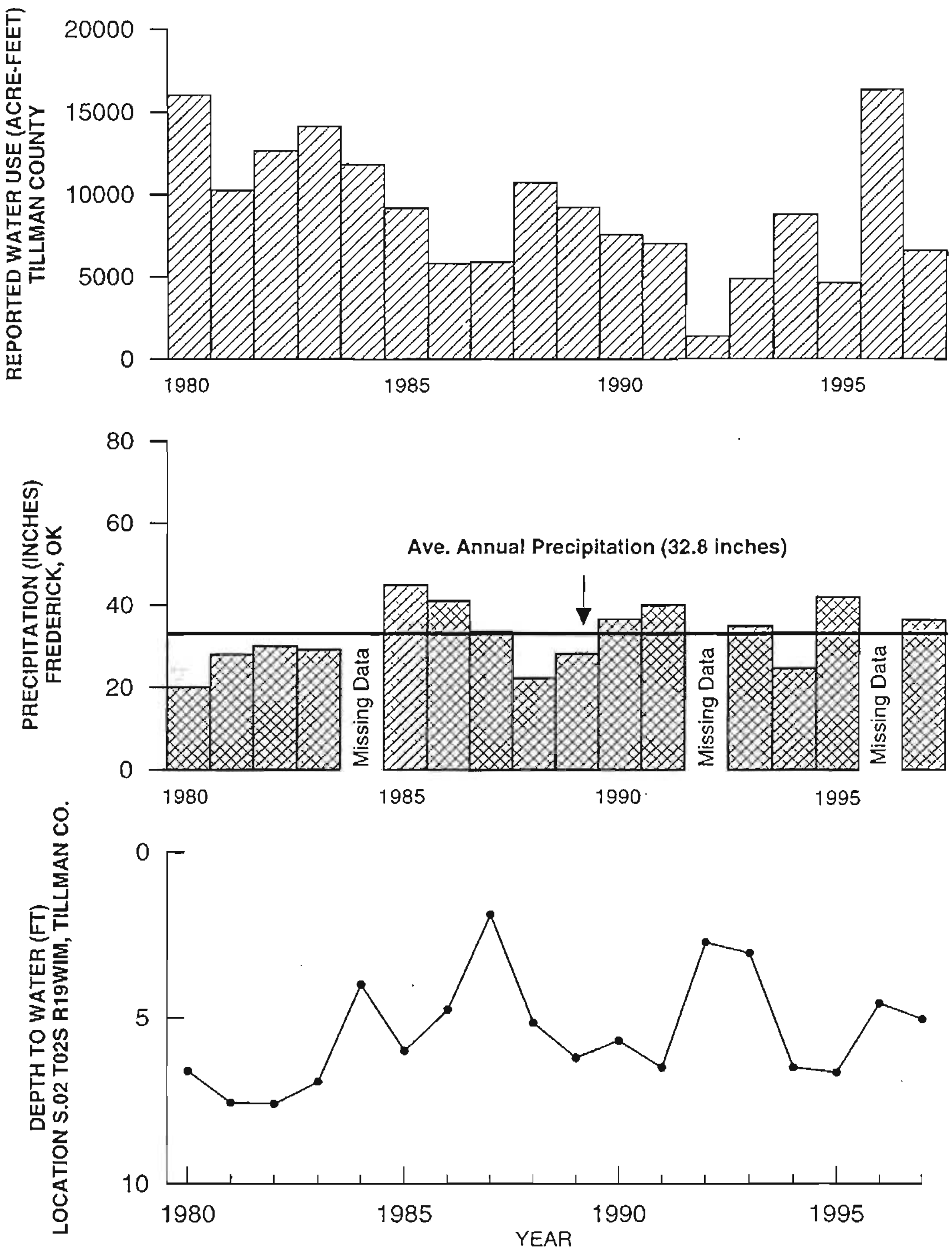

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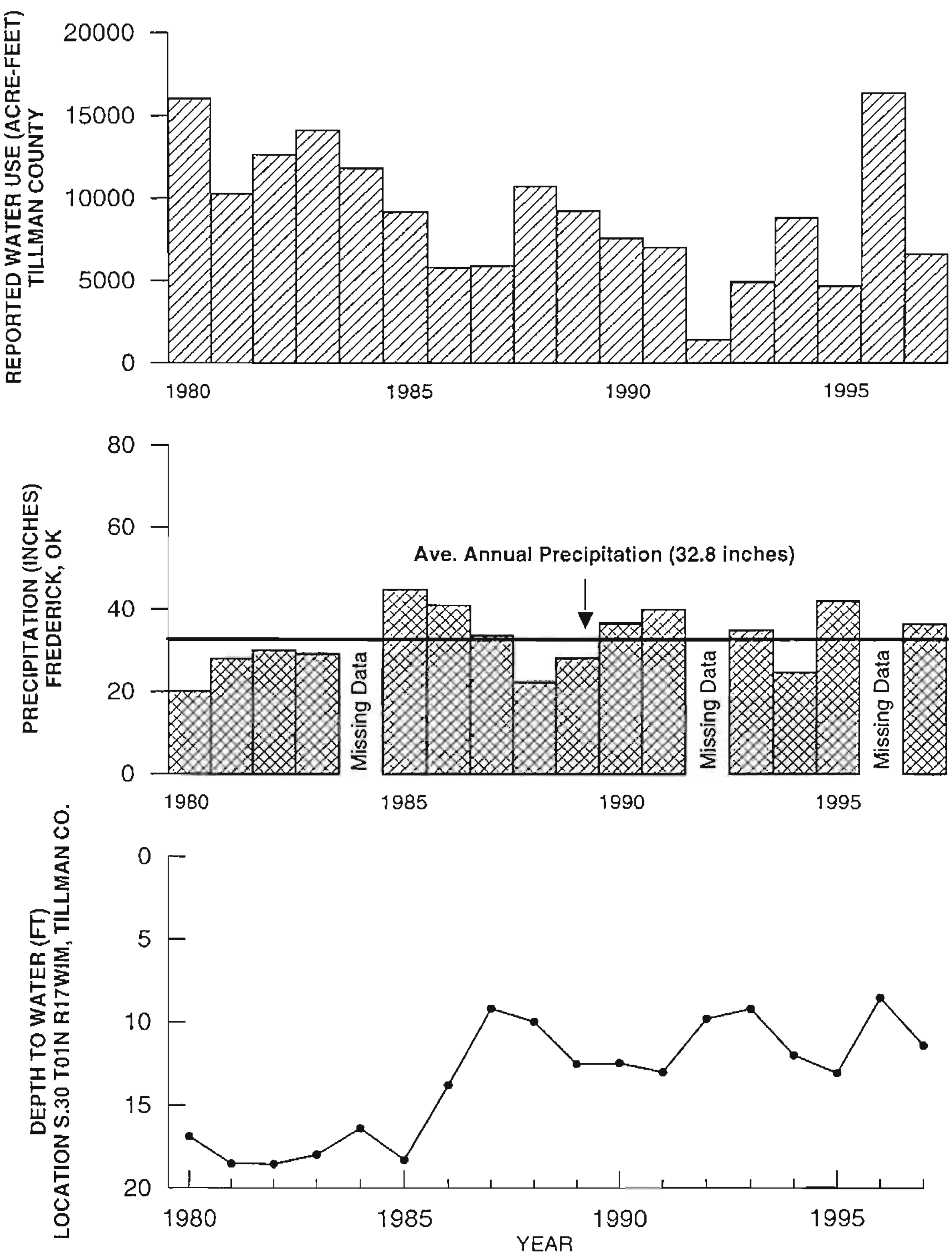
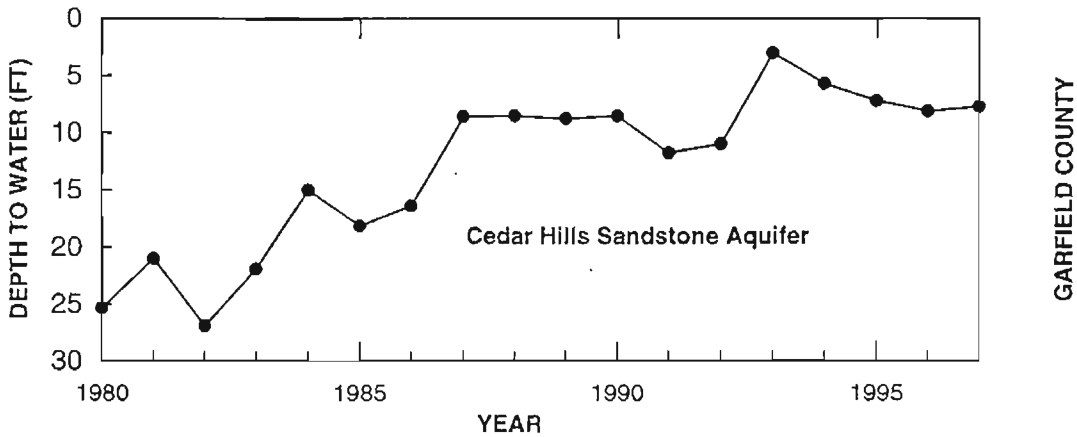
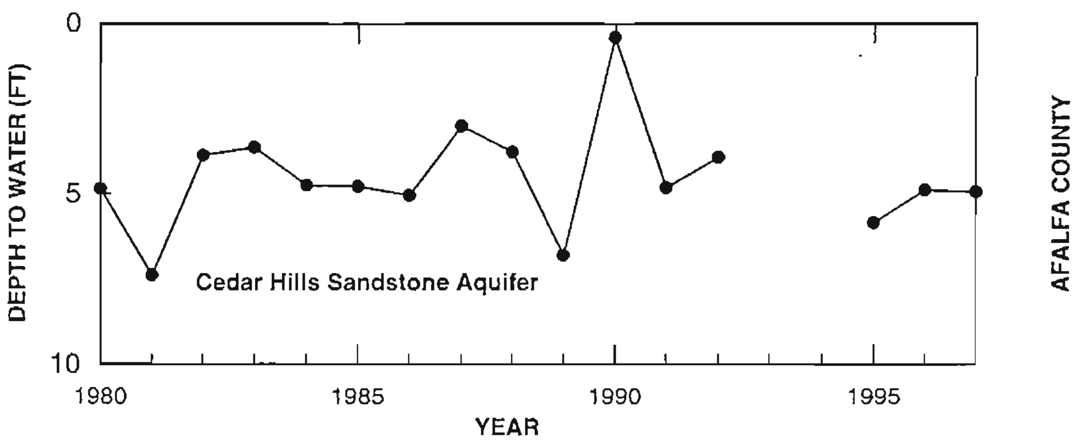


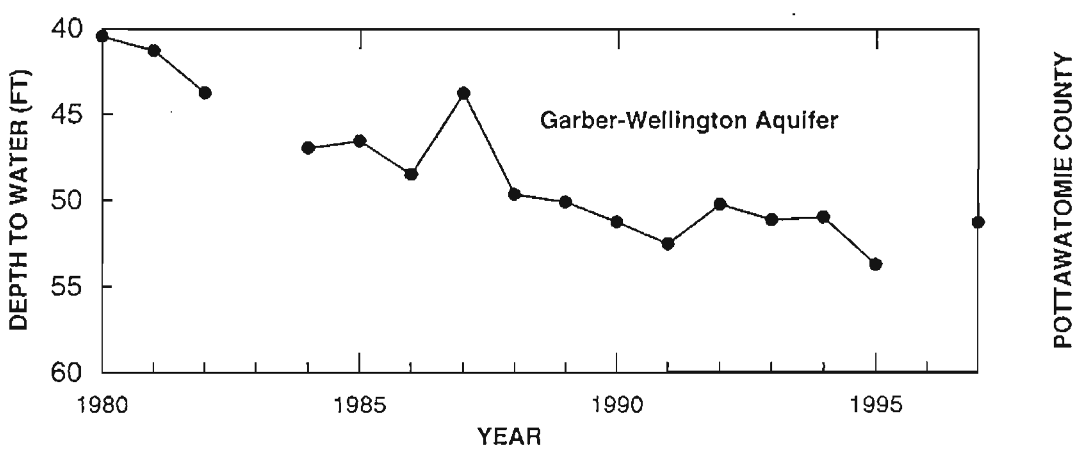
APPENDIX B

MISCELLANEOUS WELL HYDROGRAPHS

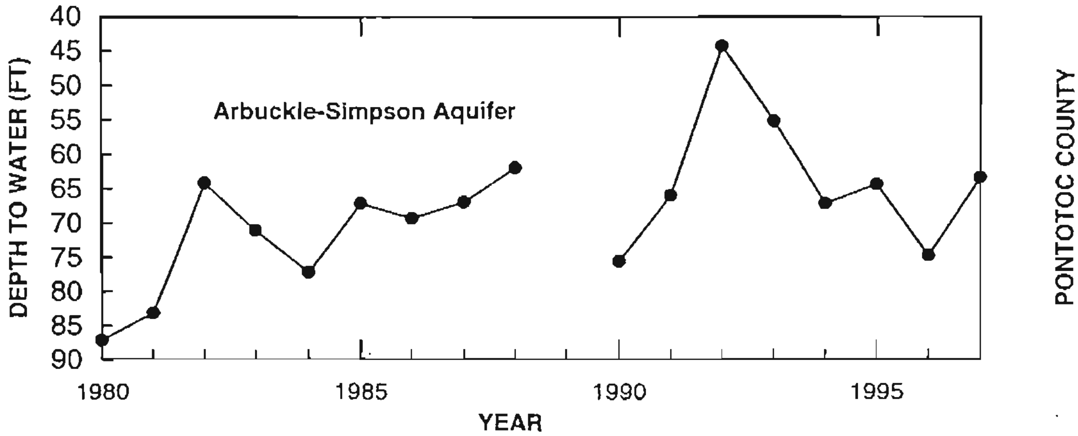
MISCELLANEOUS HYDROGRAPHS FOR BEDROCK AQUIFERS

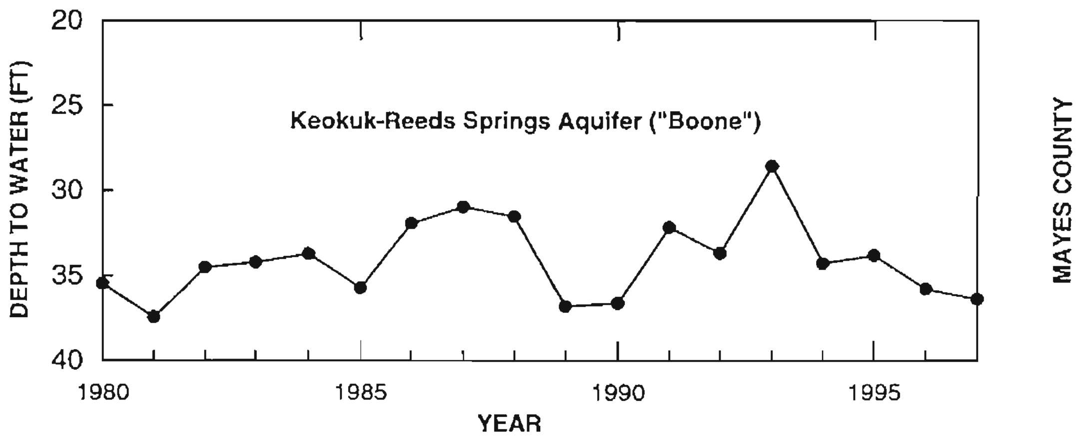


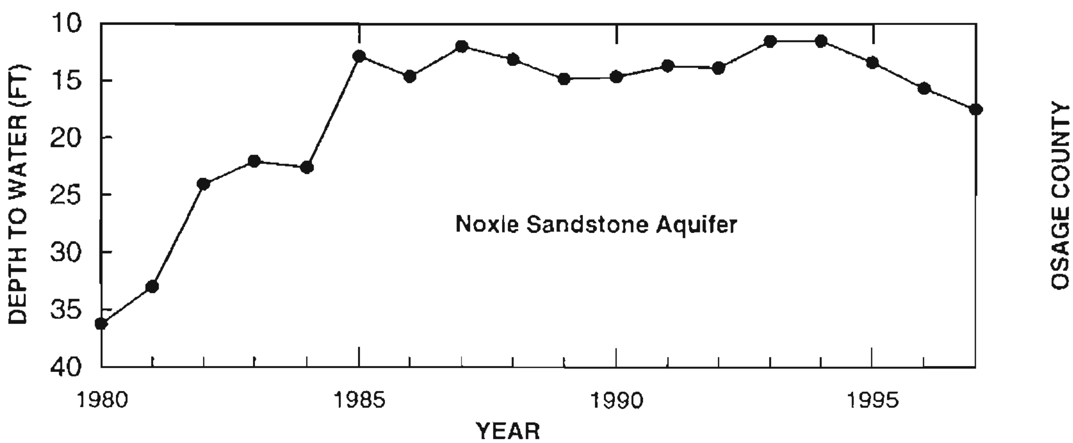




MISCELLANEOUS HYDROGRAPHS FOR BEDROCK AQUIFERS







MISCELLANEOUS HYDROGRAPHS FOR ALLUVIUM AND TERRACE AQUIFERS