Kansas Geological Survey

HYDROGEOLOGIC CHARACTERISTICS AND HYDROLOGIC CHANGES IN THE CIMARRON RIVER BASIN, SOUTHWESTERN KANSAS

Part of Data, Research, and Technical Support for Ogallala-High Plains Aquifer Assessment, Planning, and Management – Kansas Water Plan – FY 2005

By

D.P. Young, P.A. Macfarlane, D.O. Whittemore, and B.B. Wilson

Kansas Geological Survey Open File Report 2005-26
June 2005

GEOHYDROLOGY

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INTRODUCTION

The Cimarron River basin lies within the High Plains and Plains Border sections of the Great Plains physiographic province (Fenneman, 1931). The basin covers all or portions of Morton, Stevens, Seward, Meade, Clark, Comanche, Kiowa, Ford, Gray, Haskell, Grant, Stanton, Hamilton, and Kearny counties in southwest Kansas and is approximately 6,800 mi^2 in size.

Ground-water table declines in the High Plains aquifer caused by high-volume, consumptive pumping of ground water for irrigation have occurred in the basin. The water-level declines have decreased or eliminated ground-water discharge to the perennial stretches of the Cimarron River, thereby decreasing flow to or shortening the length of the perennial reaches. The primary area of perennial stretch shortening has occurred in northwest Seward County and the main location of current decrease in perennial streamflow is in southeast Seward County and southwest Meade County.

Knowledge of the lithologic characteristics of the High Plains aquifer is necessary for understanding stream/aquifer interactions and water-level changes in the basin. This report focuses on the hydrogeology and hydrologic changes in the portion of the basin where the High Plains aquifer is present below the surface, and particularly along the Cimarron River (Figure 1). A companion report by Whittemore et al. (2005) examines water quality in Seward and Meade counties.

BASIN DESCRIPTION

The climate of the region is semiarid. Mean annual precipitation ranges from about 16 inches in the west to 20 inches in the east (Meade County). About 75% of annual precipitation normally falls during the growing season. Due to the summer heat, low humidity, and high winds, most precipitation returns rapidly to the atmosphere through evaporation and transpiration (Gutentag et al., 1981). As illustrated in Figure 2, cropland is the dominant land use/land cover in the basin; some grassland remains, particularly along the rivers and on sand dunes. Irrigation with ground water is common in the basin.

Quaternary deposits are extensively exposed at the surface and include both eolian deposits (dune sand and loess) and alluvial deposits of silt, clay, sand, and gravel (Figure 3). The generally flat eastward-sloping terrain is characteristic of the High Plains surface and is interrupted by the drainage network and by subsidence along the traces of the Bear Creek and the Crooked Creek-Fowler fault zones. The prevailing eastward regional slope of the land surface is approximately 12 ft/mi. The flat-to-rolling terrain combined with the semiarid climate results in minimal surface runoff (Sophocleous, 2004). Exceptions occur along portions of the Cimarron River where the river has incised a steep valley into unconsolidated Cenozoic deposits. For example, in southeastern Seward County the land-surface elevation drops 200 ft or more from the upland to the river.

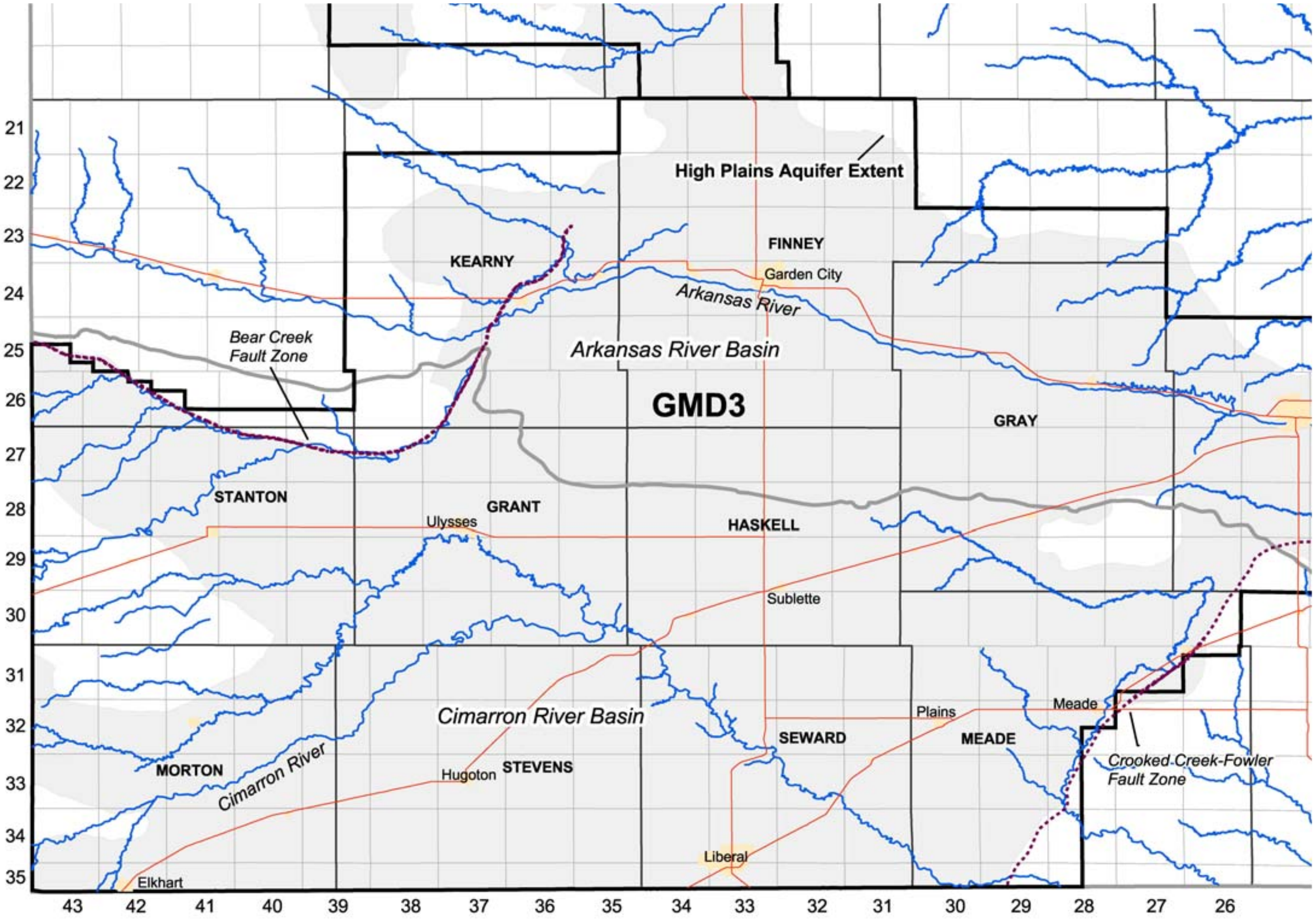


Figure 1. Base map of southwest Kansas showing political and basin boundaries, highways, rivers and streams, the High Plains aquifer extent, and the Bear Creek and Crooked Creek-Fowler fault zones. The study area for this report is the portion in the Cimarron River basin.

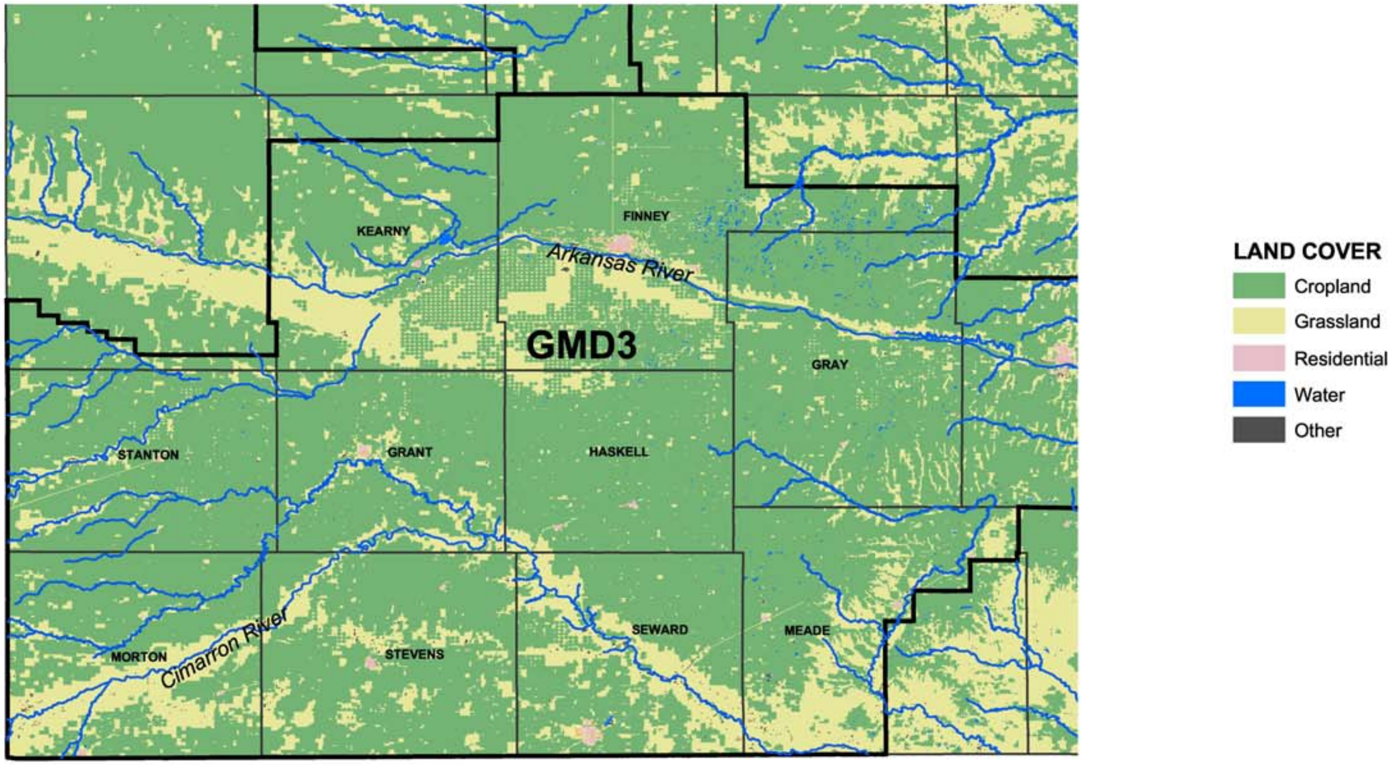


Figure 2. Land use/land cover.

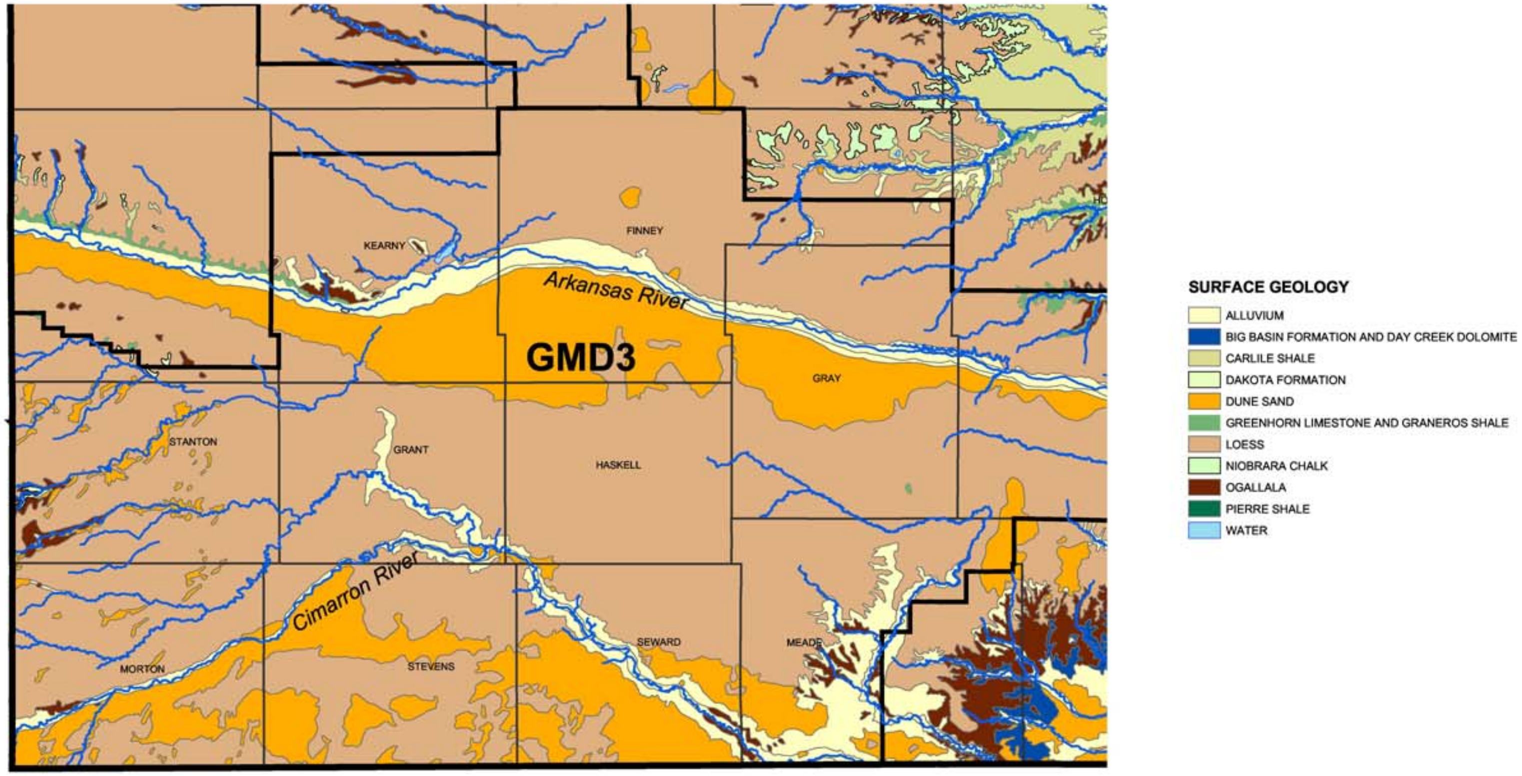


Figure 3. Surface geology.

The North Fork is the major tributary of the Cimarron River in the study area. From the Kansas-Colorado border to southwestern Meade County, the main stem of the Cimarron has a gradient of about 11 ft/mi. Today streamflow is intermittent along most of the river in southwestern Kansas.

Tertiary and Quaternary deposits underlie most of the study area and range in thickness up to more than 500 feet (Woods and Sophocleous, 2002). The Pliocene and undifferentiated Pleistocene deposits are hydraulically connected and lithologically similar. The saturated parts of the Ogallala Formation of Pliocene age, the undifferentiated Pleistocene deposits, and the Quaternary alluvium in the major stream corridors compose the High Plains aquifer in the study area.

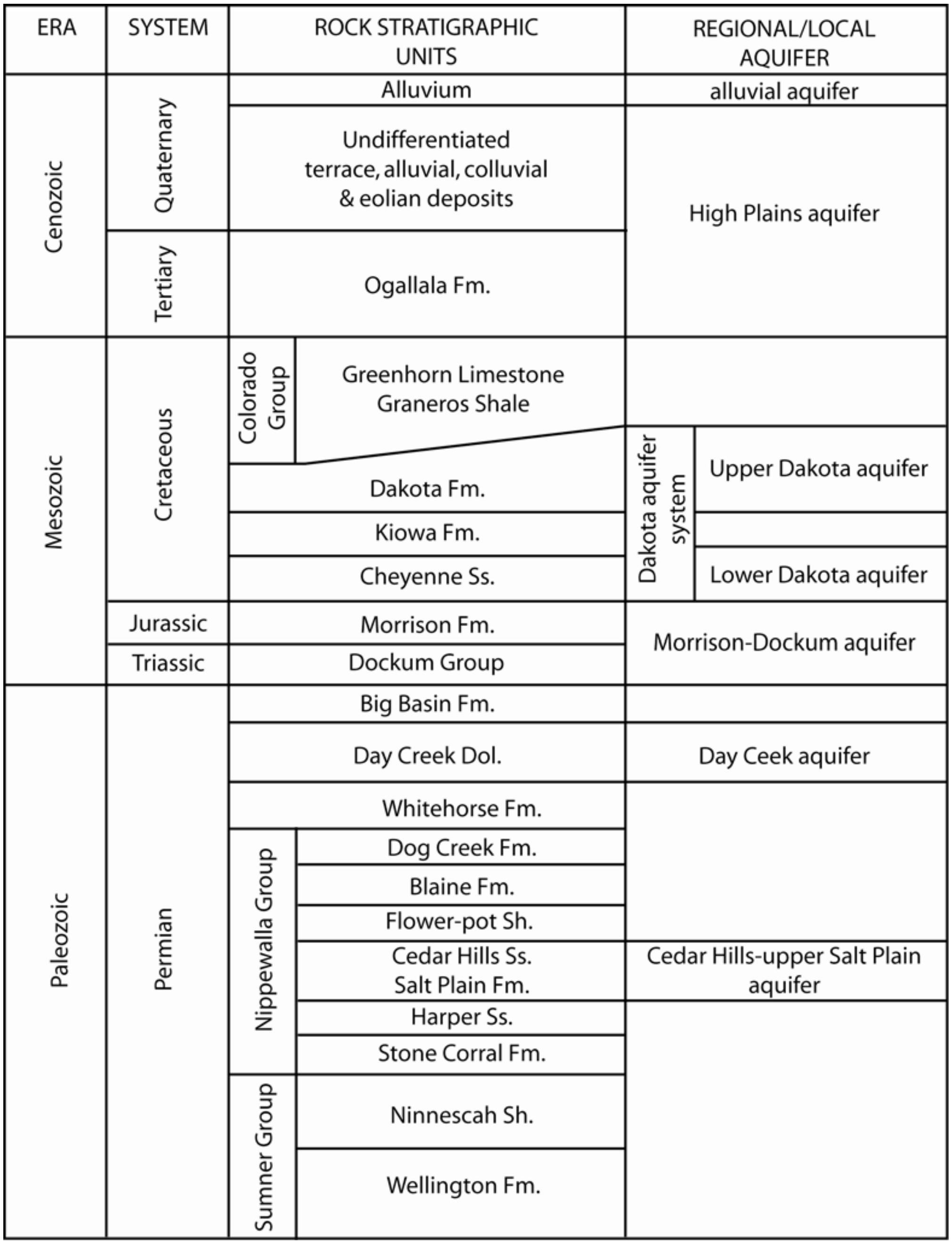
SHALLOW SUBSURFACE STRATIGRAPHY

Bedrock units ranging in age from Permian to Cretaceous underlie Tertiary and Quaternary unconsolidated deposits (Table 1). For the most part the High Plains aquifer overlies Lower Cretaceous bedrock in the north and Permian bedrock in the southern portion of the Cimarron River basin (Figure 4). The uppermost Permian bedrock units in the Cimarron River basin are the Flower-pot Shale, the Blaine, Dog Creek, and Whitehorse formations, the Day Creek Dolomite, and the Big Basin Formation (Table 1). Of the Permian units, Gutentag et al. (1981) indicate that only the Big Basin and Whitehorse formations and the Day Creek Dolomite subcrop beneath the High Plains aquifer in the basin. This sequence of Permian-age strata consists primarily of red shales and siltstones interbedded with sandstones and minor evaporites.

Below, the older Permian units are the Cedar Hills Sandstone, the Salt Plain Formation, the Harper Sandstone, and the Stone Corral Formation of the Nippewalla Group, and the Ninnescah Shale and Wellington Formation of the Sumner Group. Taken as a group these units consist of shales and siltstones, sandstone, gypsum, anhydrite, and dolomite (Swineford, 1955). In the southern Kansas outcrop area, Swineford estimated that gypsum/anhydrite makes up more than 60% of the Blaine and less than 1% of the Flower-pot and the Dog Creek shale. Swineford estimated that halite makes up approximately 20% and gypsum/anhydrite 2% of the Wellington Formation in the subsurface. Merriam (1963) mapped bedded salts in the subsurface Whitehorse Formation, Flower-pot Shale, and Wellington Formation in southern Kansas, including saliferous anhydrite or shale in the Stone Corral in Meade, Seward, Haskell, Grant, and Stevens counties. The total thickness of evaporites in Kansas is greatest in eastern Meade, Clark, and most of Comanche counties and exceeds 1,000 ft. Near the upper end of Cimarron River basin in Stanton and southern Hamilton counties, the Cedar Hills Sandstone is salt-cemented (Holdoway, 1978).

Younger Triassic, Jurassic, and basal Cretaceous units consisting of interbedded shales, mudstones, and sandstones subcrop or are present in isolated outcrops in the northern half of the Cimarron basin and near the Kansas-Colorado border (Figure 4). These include the Dockum Group, the Morrison Formation, the Cheyenne Sandstone, the Kiowa and Dakota Formations, and the Graneros Shale. At the upper end of the basin in southwest

Table 1. Regional and local aquifers in southwestern Kansas in relation to subsurface stratigraphy (adapted from Macfarlane, 2000).



ERA	SYSTEM	ROCK STRATIGRAPHIC UNITS		REGIONAL/LOCAL AQUIFER	
Cenozoic	Quaternary		Alluvium		alluvial aquifer
			Undifferentiated terrace, alluvial, colluvial & eolian deposits		High Plains aquifer
	Tertiary		Ogallala Fm.		
Mesozoic	Cretaceous	Colorado Group	Greenhorn Limestone Graneros Shale		
			Dakota Fm.	Dakota aquifer system	Upper Dakota aquifer
			Kiowa Fm.		
			Cheyenne Ss.		Lower Dakota aquifer
	Jurassic		Morrison Fm.		Morrison-Dockum aquifer
	Triassic		Dockum Group		
Paleozoic	Permian		Big Basin Fm.		
			Day Creek Dol.		Day Ceek aquifer
			Whitehorse Fm.		
		Nippewalla Group	Dog Creek Fm.		
			Blaine Fm.		
			Flower-pot Sh.		
			Cedar Hills Ss. Salt Plain Fm.		Cedar Hills-upper Salt Plain aquifer
			Harper Ss.		
			Stone Corral Fm.		
		Sumner Group	Ninnescah Sh.		
			Wellington Fm.		

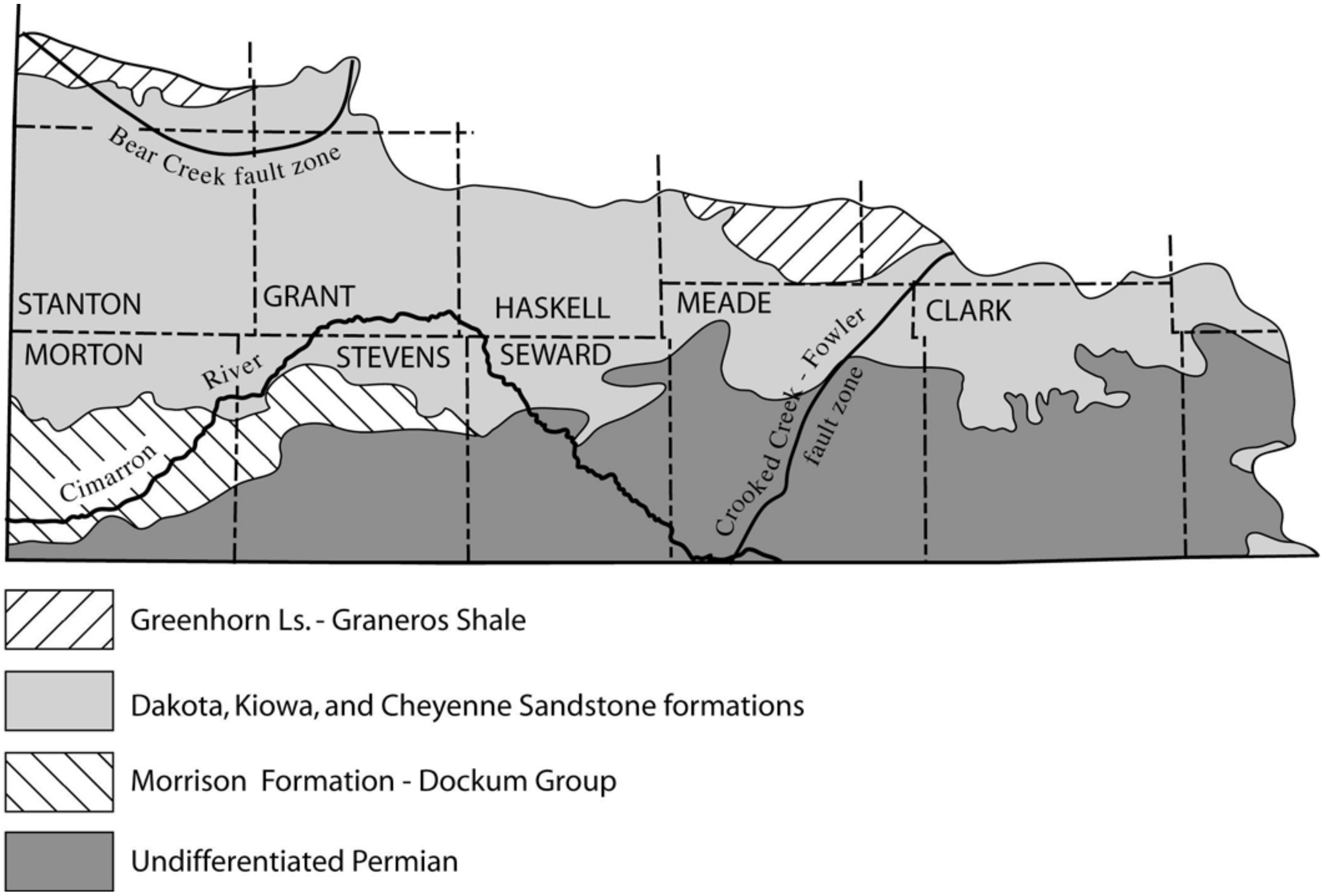


Figure 4. Bedrock geology in the Cimarron River basin.

Kearny and southern Hamilton counties and to the east in Gray County, the youngest bedrock units are the Cretaceous chalks and marls of the Carlile Shale and the Greenhorn Limestone. None of these units is known to contain significant amounts of evaporites.

The undifferentiated Quaternary and Tertiary Ogallala Formation sediments that compose the High Plains aquifer consist of clay, silt, sand, and gravel. Aquifer characteristics are described in more detail in following sections of this report. The unconsolidated sediments were deposited largely by eastward flowing streams. Wind-blown deposits of dune sand and loess mantle much of the surface, except along the major river/stream valleys (Figure 3). The total thickness of these unconsolidated deposits ranges up to more than 500 ft in parts of Seward, Stevens, and Haskell counties.

The bedrock surface between the Bear Creek and Crooked Creek-Fowler faults generally slopes at about 13.5 ft/mi to the east-southeast from southwest Stanton County to the town of Meade in Meade County **(**Stullken et al., 1985). Local relief may be as much as 250 ft across the fault zones, which are the result of dissolution and subsidence (discussed more in the following section).

REGIONAL AND LOCAL GEOLOGIC STRUCTURE

In this part of southwest Kansas, the bedrock units are tilted to the east and northeast away from the Sierra Grande uplift in Baca County, southeast Colorado (Gutentag et al., 1981; Macfarlane, 1993). Gutentag et al. (1981) show the dip of the Permian units near the bedrock surface steepening in Morton and Stanton counties from approximately 9 ft/mi to more than 35 ft/mi near the Sierra Grande uplift in southeastern Colorado.

The regional geologic structure has been modified by widespread and continuing evaporite dissolution in the bedrock and collapse of overlying units from local to regional scale. Substantial thicknesses of bedded salt and gypsum are present in the bedrock units within the upper 1,000 ft of the subsurface in the Nippewalla Group (Merriam, 1963) in southwest Kansas (Frye, 1950).

The Bear Creek (in Hamilton, Kearny, Stanton, and Grant counties) and the Crooked Creek-Fowler (in Meade and Ford counties) fault zones, shown on Figure 1, define an area in southwest Kansas where circulating ground waters have dissolved out and removed halite and other evaporite minerals from the Blaine Formation, Flower-pot Shale, and Stone Corral Formation (Frye, 1950; Walters, 1978; Gutentag et al., 1981). Vertical displacement is as much as 250 ft along the Bear Creek and Crooked Creek-Fowler faults. The Crooked Creek-Fowler fault was initially mapped as two faults in Meade County (Frye and Schoff, 1942; Merriam, 1963). Later, Gutentag et al. (1981) argued that since both faults are part of the same zone of dissolution and collapse, their names should be combined to indicate their genetic relationship. Spinazola and Dealy (1983) used geophysical logs to extend the Crooked Creek-Fowler fault into southern Ford County. They attributed faulting and subsidence features in Ford County to dissolution of gypsum in the Blaine.

Lines of sinkholes, partially filled sinkholes, and altered drainage patterns define the traces of the Bear Creek and the Crooked Creek-Fowler faults at the surface. Smith (1940, p. 137) described the north branch of Bear Creek where it intersects the trace of the Bear Creek fault as "marked by a series of depressions, presumably of solutional origin, and localized by the fault." He continues: "A short en echelon fault at the northwest is suggested by a linear tributary valley, also marked by depressions, one of which was formed in historic times [1929],…" Smith noted that when there was streamflow in this reach of Bear Creek it was lost to the sinkholes. McLaughlin (1946) described the north branch of Bear Creek in northwestern Grant County as a series of sinkholes with short intermittent stream segments rather than one continuous stream. He hypothesized that the sinks in the Stanton area probably began to form as folding and faulting progressed and believed this process to be continuing.

In Meade County, Smith (1940) described the Meade salt sink which developed in 1879 and is located just to the east of the Crooked Creek-Fowler fault. An unusual change in the flow direction of Crooked Creek occurs where the drainage crosses the trace of the fault zone north of Fowler in southwestern Ford County. As a result the stream flows parallel to the trace of the fault zone through northeastern and central Meade County before it returns to a more southeastward course. Smith also describes the Jones Ranch basin, located eight miles southeast of Meade, as an isolated, subcircular structural depression related to dissolution of Permian evaporites and collapse of overlying units.

More recently, Macfarlane and Wilson (in review) concluded that it is more likely that the Crooked Creek and Bear creek faults are not continuous, but rather area dissolution zones characterized by subsidence features and local small-scale faulting.

AQUIFER AND CONFINING UNITS

The Kansas aquifer nomenclature has recently been revised by Macfarlane (2000) and is used here to identify the aquifer units in the Cimarron River basin. Accordingly, aquitard (confining) units are unnamed. The hydrostratigraphic units of the Cimarron river basin (Table 1) are:

- the High Plains aquifer,
- an aquitard consisting of the Greenhorn Limestone and the Graneros Shale,
- the upper and lower Dakota aquifers of the Dakota aquifer system separated by an aquitard of Kiowa Formation shale,
- the Morrison-Dockum aquifer,
- an aquitard consisting of the Big Basin Formation,
- the Day Creek aquifer,
- an aquitard consisting of the Whitehorse, Dog Creek and Blaine formations, and the Flower-pot Shale, and
- the Cedar Hills-upper Salt Plain aquifer.

The High Plains aquifer consists of the Tertiary Ogallala Formation and hydraulically connected Quaternary deposits, including the alluvium in the Cimarron River and hydraulically connected terrace deposits, dune sands, and valley-fill deposits where saturated. The sediments are composed of a heterogeneous assortment of sand, gravel, silt, and clay deposited by streams that flowed eastward from the Rocky Mountains. This sequence overlies an eroded bedrock surface of Permian to Cretaceous age. The Ogallala Formation makes up the main part of the aquifer in western Kansas. Because of the similarity in their composition, the Tertiary sediments are difficult to distinguish from the younger Quaternary sediments.

The High Plains aquifer varies widely in type of material, thickness, and layer continuity. Individual beds generally are not continuous and within short distances may grade laterally or vertically into material of different composition. Hydraulic conductivity and specific yield depend on sediment types, and vary widely both vertically and laterally. Some cemented layers, referred to as mortar beds and caliche, occur. Although the aquifer is generally unconfined, confined and semi-confined conditions may occur locally. Gutentag et al. (1981, p. 60) indicated that ground-water pumping has reduced the confinement in some of the deeper zones of the aquifer.

Unconsolidated sediment thickness varies greatly due mostly to the uneven bedrock surface. Saturated thickness ranges up to more than 500 ft (Woods and Sophocleous, 2002). The greatest thicknesses are found between the Bear Creek and Crooked Creek-Fowler faults, which are shown on Figure 1. Thickness may change by as much as 250 ft across the fault zones, which are a result of subsidence associated with the dissolution of Permian evaporites. Saturated thickness is greatest in southern Stevens and Seward counties. Thick clays are present in the deeper portion of the aquifer in southern Seward County.

Regional ground-water flow is from west to east in response to the hydraulic gradient or slope of the water table. Based on average values of hydraulic gradient and aquifer characteristics, the velocity of water moving through the aquifer is about 1 ft/day, which is typical of sand and gravel aquifers (Gutentag et al., 1984). Figure 5 shows the water-table contours based on the average of water-level measurements taken in 2003 and 2004; ground-water flow is perpendicular to the contours. Depth to water is variable and exceeds 300 feet in a large portion of Haskell County and in portions of Grant and Stanton counties (Woods and Sophocleous, 2001).

In Meade County, the High Plains aquifer is subdivided into a confined part in the Meade Artesian basin on the west down-dropped side of the Crooked Creek-Fowler fault zone and an unconfined (water table) part that is present throughout the remainder of its extent in the county (Frye, 1942). According to Frye, water levels in wells penetrating the confined aquifer were more than 10 above land surface in two wells in 1939. A separate alluvial aquifer is distinguished in Crooked Creek valley because widespread clay layers separate the alluvial aquifer from the High Plains aquifer. Geohydrologic characteristics of the High Plains aquifer are discussed in more detail in the following sections of this report.

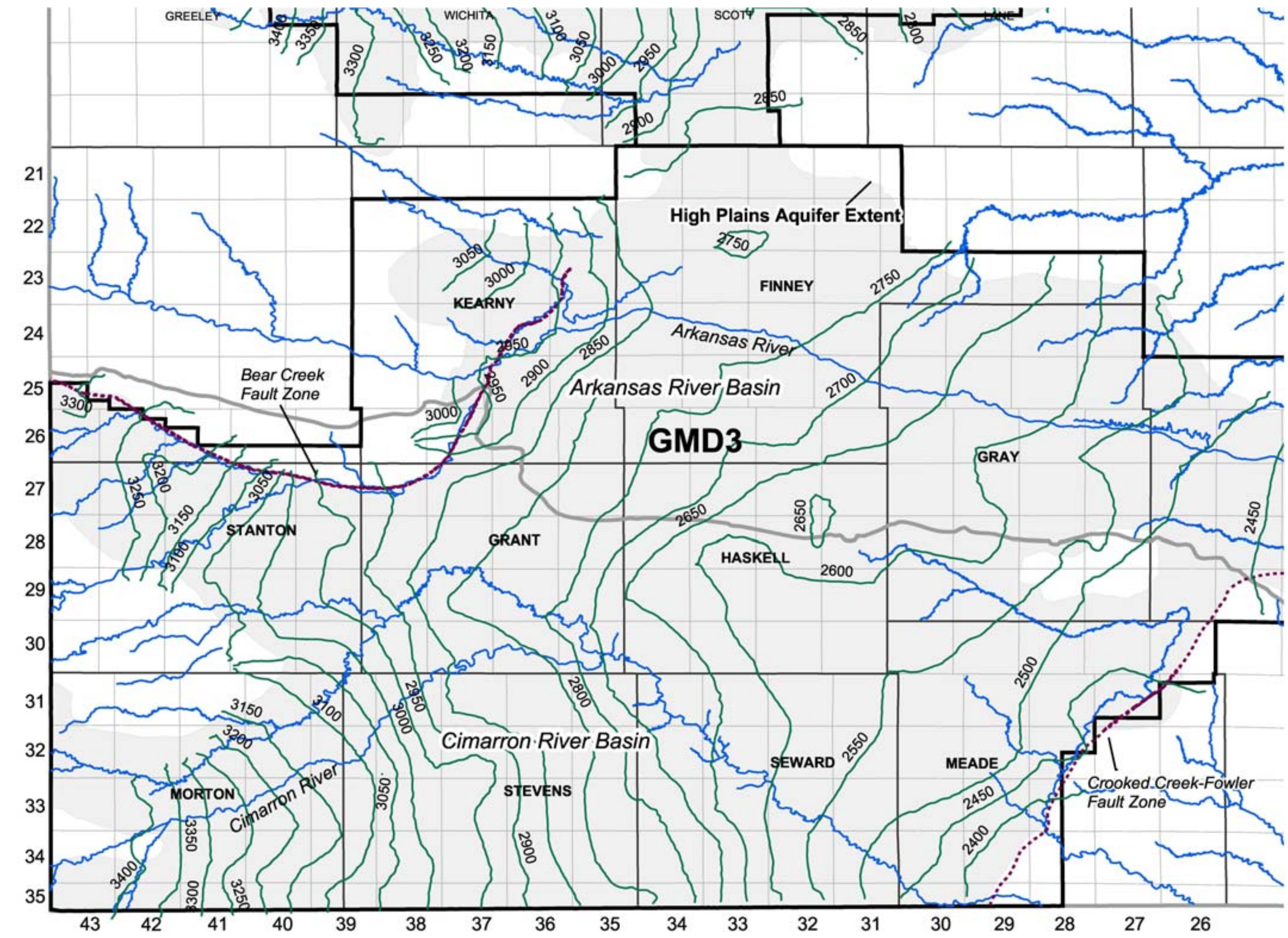


Figure 5. Current ground-water table contours.

Ground-water flow within the bedrock aquifers is eastward across the Cimarron River basin (Kume and Spinazola, 1985; Macfarlane, 1993). Macfarlane showed that prior to development regional topographic slope, local topographic relief, and the properties and the arrangement of the aquifer/aquitard units in southeastern Colorado and western and central Kansas primarily influenced regional ground-water flow.

The upper and lower Dakota aquifers consist of sandstone units in the Dakota, Kiowa, and Cheyenne Sandstone formations. Over most of the northern half of the Cimarron River basin, the Dakota and the High Plains aquifers are hydraulically connected except where the aquitard of younger Cretaceous rocks overlies the upper Dakota aquifer or where erosion has removed the overlying Dakota Formation and Kiowa Formation shale overlies the lower Dakota aquifer. The Morrison-Dockum aquifer consists of sandstones in the Morrison Formation and in the Dockum Group. In Stanton, Hamilton, Kearny, Grant, and Morton counties, the sandstone aquifers in the Morrison-Dockum and in the overlying lower Dakota are hydraulically connected.

In the southern half of the river basin, the High Plains aquifer overlies Permian bedrock units (Figure 4). These units consist primarily of low permeability red shales and siltstones with interbedded evaporites and permeable sandstones. The Permian strata above the Cedar Hills Sandstone-upper Salt Plain aquifer are considered a regional aquitard for the most part because they do not yield significant amounts of water to wells. However, some geologic units are more permeable locally or regionally and are considered as local or regional aquifers. In central Morton County highly permeable zones exist in locally cavernous anhydrite and gypsum beds interbedded with shale in the Permian Day Creek Dolomite (Gutentag et al., 1981). Wells tapping these zones in the vicinity of Richfield typically flowed at the surface with initial well yields ranging up to 1,000 gallons per minute (McLaughlin, 1942). Deeper in the subsurface is the Cedar Hills Sandstone-upper Salt Plain aquifer. This regional aquifer consists of sandstones belonging to the Cedar Hills Sandstone and the underlying Salt Plain Formation. The Cedar Hills contains natural salt water from halite dissolution and injected brines from oil and gas operations in the Hugoton gas field.

PREDEVELOPMENT HYDROLOGIC CONDITIONS

Historically, the High Plains aquifer was in a state of approximate equilibrium where recharge to the aquifer equaled discharge. Recharge was from precipitation, underflow from the west, and seepage from streams above and from bedrock below. Most of the natural discharge was to surface waters – springs, seeps, and streams – but also included underflow to the east and evapotranspiration where the water table was shallow.

Perennial flow in the Cimarron River historically began in northwestern Seward County and continued eastward. Perennial flow also occurred in parts of southwestern to south-central Grant County, as indicated by McLaughlin (1946). Within the basin, a predevelopment contour map of the water table elevation of the High Plains aquifer (Figure 6) indicates that the eastward sloping water table is not much affected by the

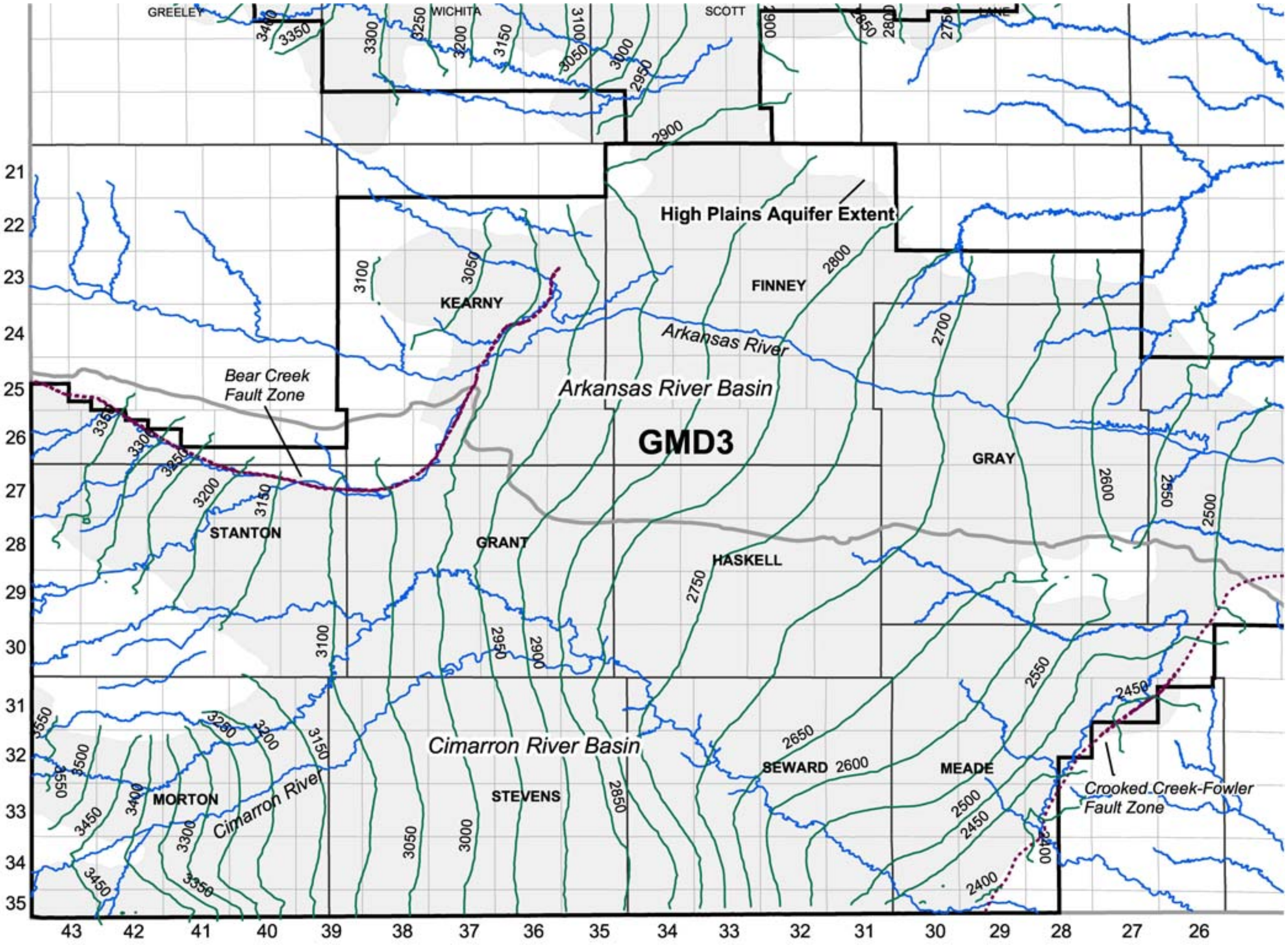


Figure 6. Predevelopment ground-water table contours.

Cimarron River and the North Fork of the Cimarron in Morton, Stanton, Grant, and Stevens counties. However, to the east, the elevation contours bend toward the Cimarron River, indicating discharge from the High Plains aquifer to the stream. The flexing of the contours towards the stream is most pronounced near the southeastern edge of Seward County.

Using stream elevations and water levels in nearby wells, McLaughlin (1946) demonstrated that the Cimarron was a naturally gaining stream throughout most of its southeastward course through Seward County. He reported that in 1942-43 streamflow losses occurred between the Elkhart bridge and the Satanta gaging stations but streamflow gains occurred from a gage north of Liberal to the gage south of Plains in Meade County near the Kansas-Oklahoma state line. Byrne and McLaughlin (1948) noted streamflow occurring on a regular basis in the southeastern half of the river's mainstem through Seward County. Gutentag et al. (1981) reported steadily increasing river flows beginning approximately 50 miles upstream of the Kansas-Oklahoma border in November, 1974.

In the Crooked Creek drainage, the contours of the predevelopment water-table surface of the High Plains aquifer (Figure 6) do not suggest significant streamflow gains in the upper stream reach in Haskell County and near the Ford-Meade county line. The lower reach of Crooked Creek from the Ford-Meade county line down through Meade County is parallel to the predevelopment water table. Along this reach low permeability clay layers subdivide the High Plains aquifer into a deep confined aquifer west of Crooked Creek and the Crooked Creek-Fowler fault and a shallow water table aquifer east of Crooked Creek. Frye (1941) reported seepage of ground water from the shallow aquifer into fields north of Fowler within the valley. From 1939 water-level measurements, he showed the potentiometric surface of the confined aquifer to have been higher than the creek level and the water table of the shallow aquifer. This indicates that the High Plains aquifer naturally discharged to Crooked Creek at least in the vicinity of Meade, Kansas.

CURRENT HYDROLOGIC CONDITIONS

Whereas most of the natural discharge from the High Plains aquifer was to surface waters, today withdrawals by wells far exceed all other discharges from the aquifer. Development of water resources in the High Plains aquifer in the Cimarron River basin began sometime prior to 1900 in the Meade Artesian basin (Johnson, 1901). Frye (1941) reported slight reductions of fluid pressure (less than 10 ft) in most of the flowing wells tapping the confined High Plains aquifer between the 1923 and 1939. Frye (1942, p. 49) noted that approximately 1,000 flowing wells had been drilled in the Meade artesian basin since 1886, but only a few hundred were operable in 1942. Large-scale development did not begin until the 1960s and 1970s in the upper parts of the basin.

Gutentag et al. (1981, p. 62) noted that a comparison of well locations and water-level declines suggests the cause and effect relationship between well density and water-level changes. The areas of greatest well density generally correspond to the areas of greatest withdrawals and water-level declines. Irrigation development was depleting ground water in storage (ground-water mining). They also noted that areas with declines of 40 percent or more had already experienced a large reduction in well yields and a large increase in the cost of pumping. A comparison of current maps -- Water Rights (Figure 7), Water-Use Density (Figure 8), and Change in Saturated Thickness (Figure 9) -- illustrates that the correlation among well density, water-use density, and water-level declines continues today. Water-level declines up to and exceeding 200 ft have occurred in large areas of Grant, Haskell, and eastern Stanton counties and in northern Stevens County. This equates to more than a 40 percent decline in saturated thickness in much of this area.

The water-level declines have reduced the discharge of ground water to the Cimarron River, resulting in decreased streamflow. Further, the point at which perennial flow begins in the Cimarron River has migrated downstream roughly 15 miles. The following section contains a more detailed presentation and discussion of changes in hydrologic conditions.

CROSS SECTIONS AND HYDROGRAPHS ILLUSTRATING HYDROGEOLOGIC CHARACTERISTICS AND HYDROLOGIC CHANGES

A number of new hydrogeologic cross sections and hydrographs were produced for this report. Figure 10 shows locations of the cross sections, rivers and streams, river basin, county, and GMD boundaries, extent of the High Plains aquifer, and the Crooked Creek-Fowler and Bear Creek fault zones.

Lithologic Cross Section Along the Cimarron River

A color-coded lithologic cross section along the Cimarron River was produced using methods of Young et al. (2000). The coarser, more permeable, sediments are lighter and the fine-grained sediments are darker in color. The range of colors corresponding to the different texture classifications (permeability) of the sediment materials is shown in Figure 11. An attempt was made to use only logs from locations in the Cimarron River valley alluvium. However, the alluvium is so narrow that too few logs were available to produce meaningful sections. Therefore, some locations were just outside of the valley, though most or all were within about a mile of the river. Well locations are listed in Table 2.

Published logs of wells and test holes were used where available. The main source of lithologic information was Water Well Completion Records (WWC-5s) submitted to the Kansas Department of Health and Environment (KDHE) and filed at the Kansas Geological Survey (KGS). Accuracy of locations (and therefore elevations) is always an issue when using the WWC-5s. Because of the relatively steep slopes of the valley walls, surface elevations were at times difficult to estimate with confidence. Elevations were initially assigned using Digital Elevation Models (DEMs) of the USGS National Elevation Dataset (http://gisdata.usgs.gov/NED/), but many elevations were reassigned using 1:24,000 scale topographic maps. One advantage of using published logs of test

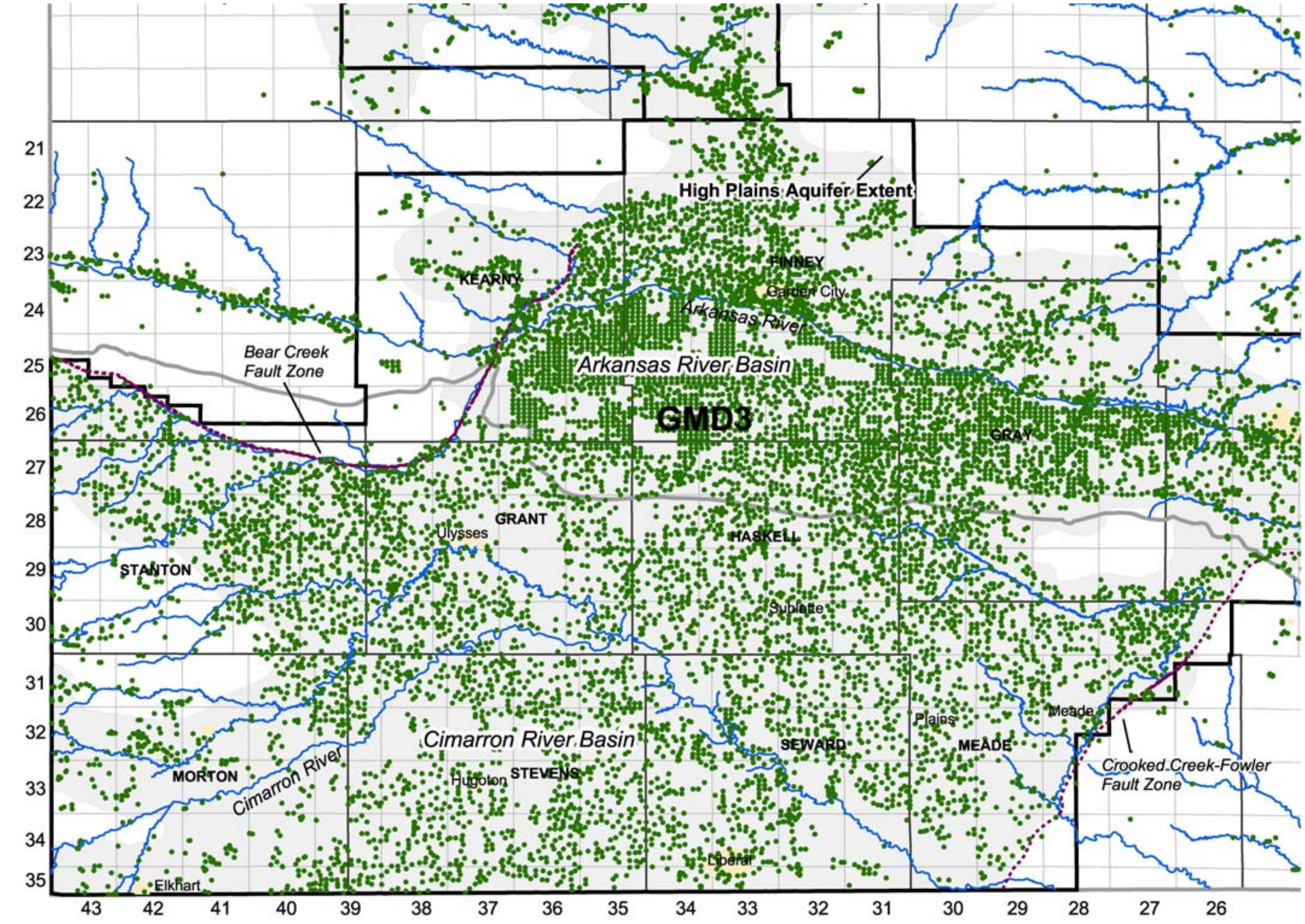
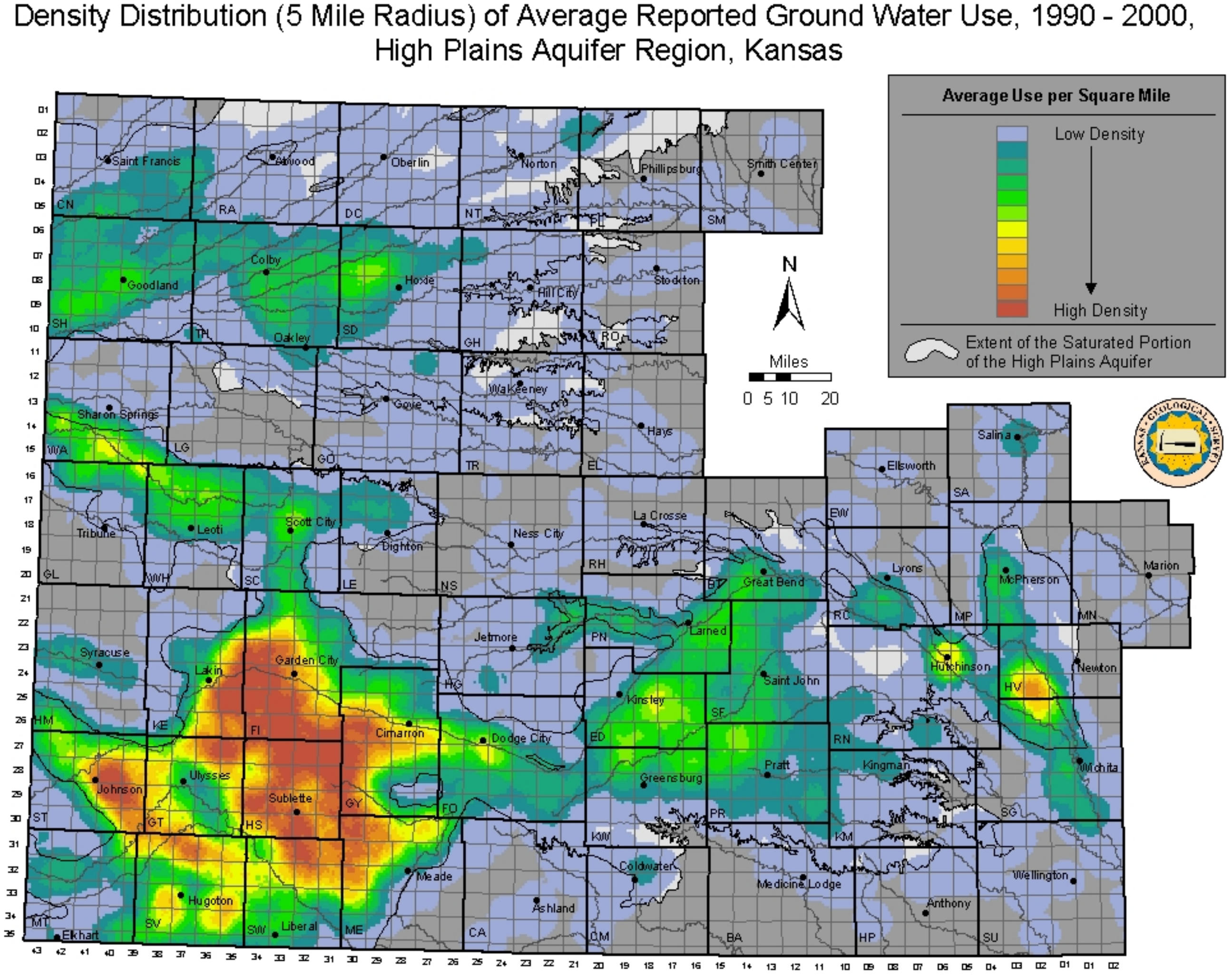


Figure 7. Points of diversion (water rights).



Density Distribution (5 Mile Radius) of Average Reported Ground Water Use, 1990 - 2000, High Plains Aquifer Region, Kansas

Figure 8. Water-use density (from Wilson et al., 2002).

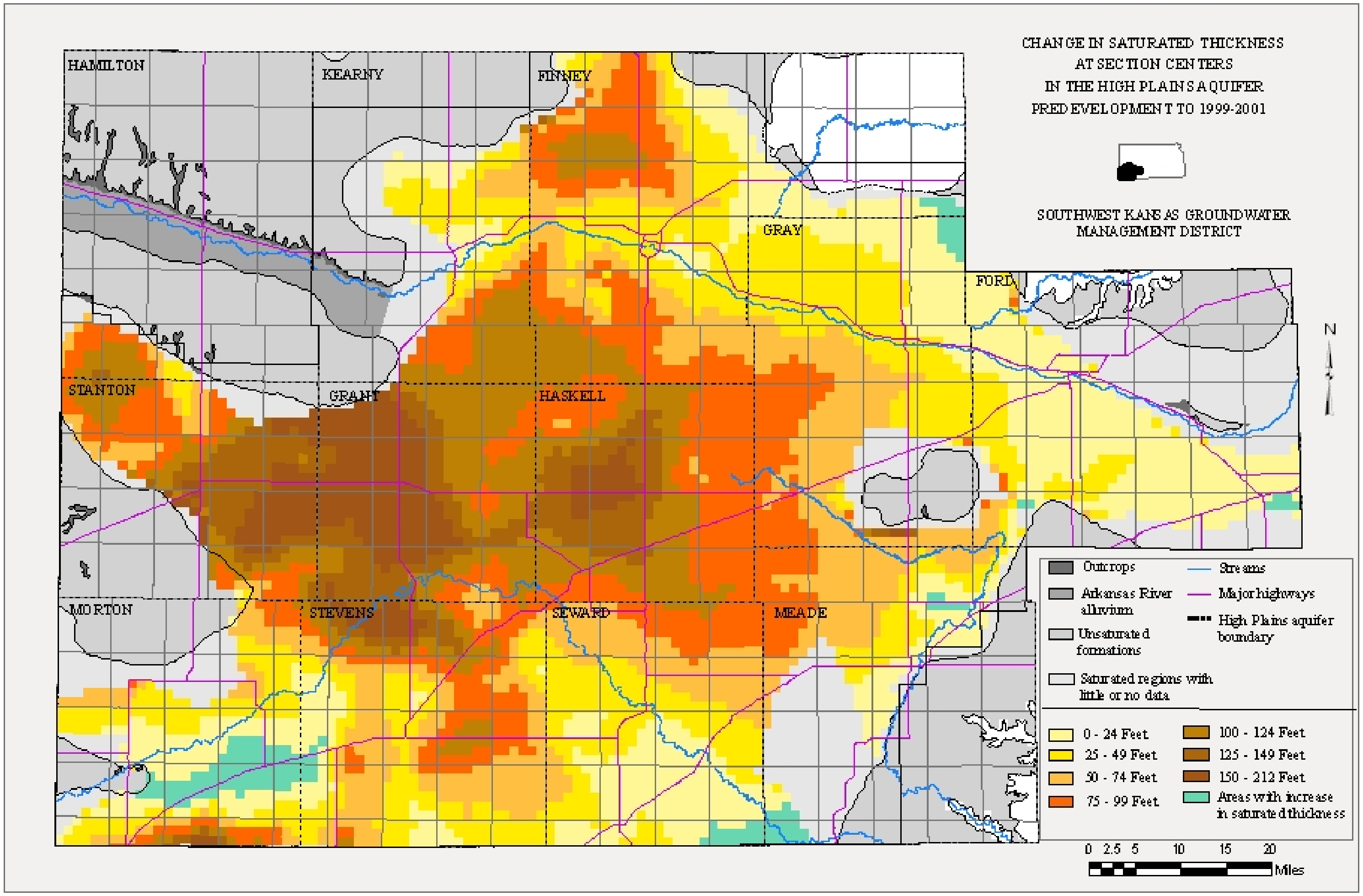


Figure 9. Change in saturated thickness, predevelopment to 1999-2001 (modified from Woods and Sophocleous, 2002).

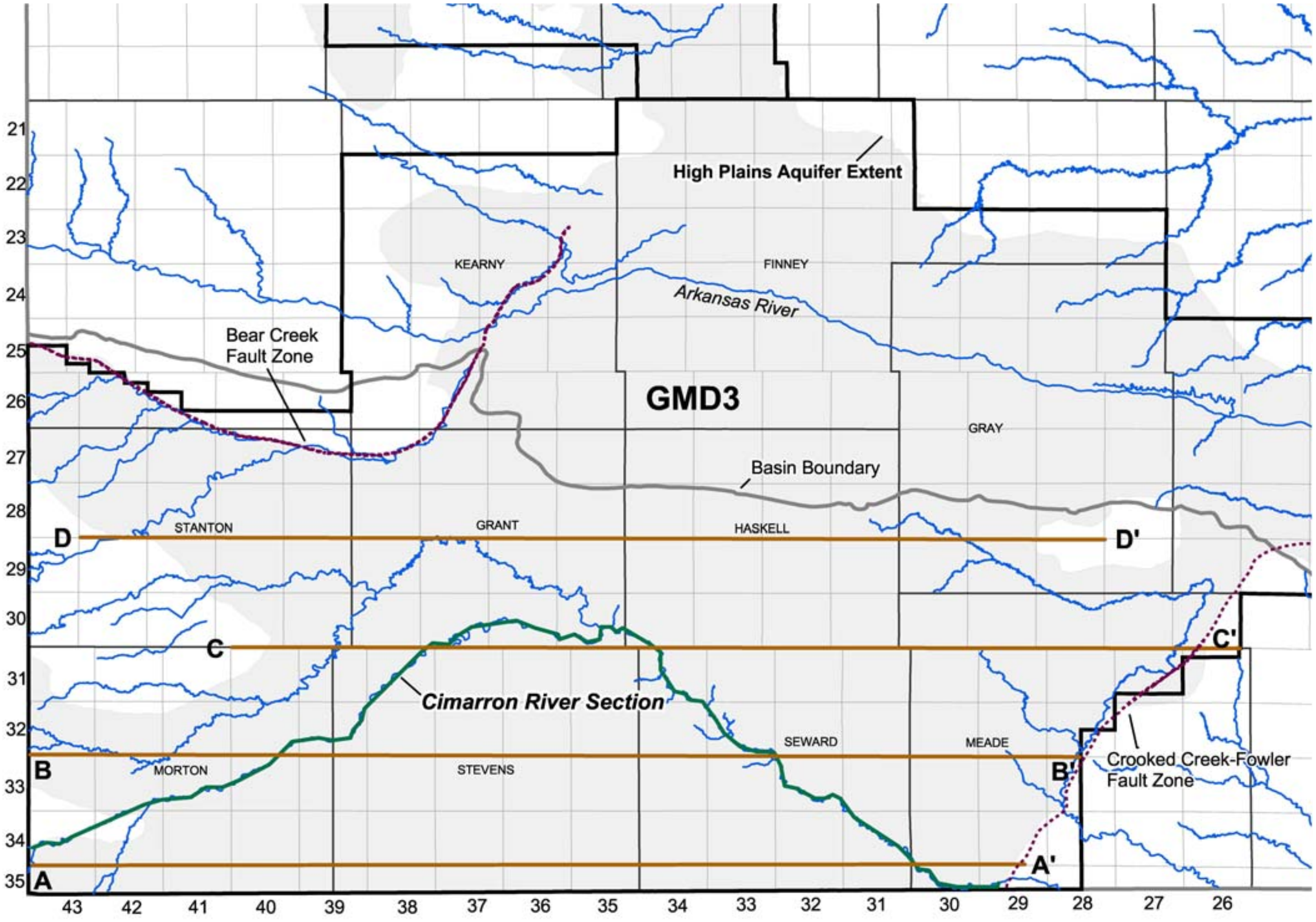
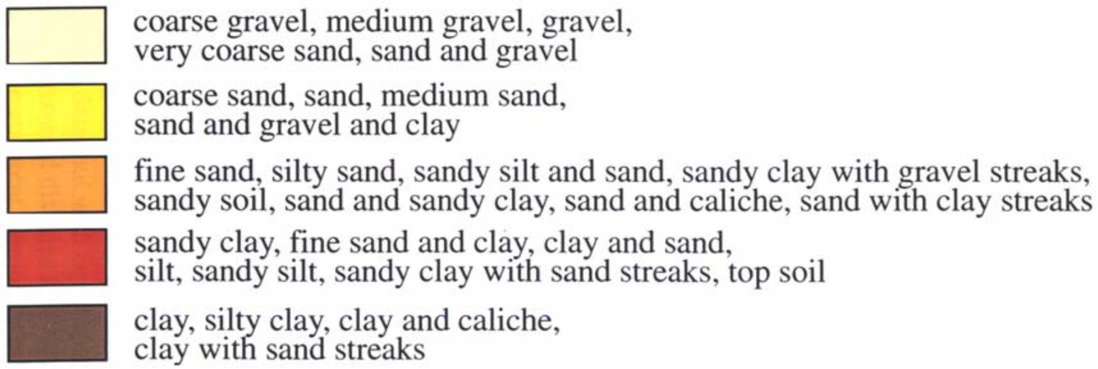


Figure 10. Locations of cross sections, rivers and streams, river basin, county, and GMD boundaries, extent of the High Plains aquifer, and the Crooked Creek-Fowler and Bear Creek fault zones.



⬜	coarse gravel, medium gravel, gravel, very coarse sand, sand and gravel
🟨	coarse sand, sand, medium sand, sand and gravel and clay
🟧	fine sand, silty sand, sandy silt and sand, sandy clay with gravel streaks, sandy soil, sand and sandy clay, sand and caliche, sand with clay streaks
🟥	sandy clay, fine sand and clay, clay and sand, silt, sandy silt, sandy clay with sand streaks, top soil
🟫	clay, silty clay, clay and caliche, clay with sand streaks

Figure 11. Material identification color codes.

Table 2. Locations of wells and test holes used in the lithologic cross section along the Cimarron River.

MORTON	34S 43W 20 DD
	34S 43W 16 C
	34S 43W 21 AA
	34S 43W 22 DBB
	34S 43W 12 D
	34S 42W 07 BB
	33S 42W 33 CBD
	33S 42W 33 ADD
	34S 42W 02 B
	33S 41W 31 ACC
	33S 41W 21 CCC
	33S 41W 28 DDD
	33S 41W 13 DAB
	33S 40W 17 BDD
	33S 40W 16 B
	33S 40W 09 CDC
	33S 40W 03 ABD
	32S 40W 36 AB
	32S 39W 30 CCA
	32S 39W 20 CCC
STEVENS	32S 39W 27 ACD
	32S 39W 14 ADC
	32S 39W 14 AAA
	32S 39W 13 BBC
	32S 39W 12 AAC
	32S 38W 06 BDB
	31S 38W 31 BAC
	31S 38W 29 B
	31S 38W 21 ABA
	31S 38W 01 ADB
GRANT	30S 37W 30 DD
	30S 37W 32 AA
	30S 37W 33 D
	30S 37W 27 BCD
	30S 37W 27 DDD
	30S 37W 26 CDB
	30S 37W 23 DB
	30S 37W 25 AC
	30S 36W 20 B
	30S 36W 17 DB
	30S 36W 17 D
	30S 36W 23
	30S 36W 24 CCC
	30S 35W 33 AA
	30S 35W 34 CCC
	30S 35W 26 B
	30S 35W 24 ACC
	30S 35W 24 DAA
HASKELL	30S 34W 32 B
SEWARD	31S 34W 05 DB
	31S 34W 04 BBA
	31S 34W 08 D
	31S 34W 16 CDB
	31S 34W 21 CBA
	31S 34W 28 BBA
	31S 34W 27 CAA
	31S 34W 35 CD
	31S 34W 36 D
	32S 33W 06 BA
	32S 33W 18 ACA
	32S 33W 20 ACB
	32S 33W 20 DDB
	32S 33W 28 A
	32S 33W 28 CDB
	32S 33W 27 BCC
	32S 33W 34 AB
	32S 33W 36 BBB
	33S 32W 06 BBA
	33S 33W 01 DCD
	33S 32W 07 B
	33S 32W 18 AD
	33S 32W 17 C
	33S 32W 21 BBB
	33S 32W 27 AB
	33S 32W 26 AAA
	33S 32W 25 BA
	34S 31W 06 AAA
	34S 31W 08 AA
	34S 31W 09 DC
	34S 31W 23 DDD
	34S 31W 36 ADA
MEADE	34S 30W 31 CA
	35S 30W 06 AA
	35S 30W 05
	35S 30W 17 AA
	35S 30W 09 CAC
	35S 30W 16 DA
	35S 29W 07 CAC
	35S 29W 09 CAD
	35S 29W 11 BB
	35S 29W 13 AD
	35S 28W 18 CBA

holes is that the surface elevation was commonly surveyed or previously estimated from USGS topographic maps.

An attempt was made to trace the base of the aquifer by using only logs that intercept the bedrock surface, but because of the scarcity of logs, logs that did not go to bedrock were included. Further, because of the complexity of the geology and that fact that true bedrock in the area is (in reality, and especially from the logs) commonly difficult to distinguish from the Cenozoic deposits, the deepest logs give only an approximation of the bedrock surface. Bedrock surface profiles are included in the water-level cross sections in the following subsection.

Most notable in the lithologic section (Figure 12) is the west-to-east transition from an abundance of fine-grained deposits to primarily coarser-grained materials in extreme eastern Grant County. West of there, an alternating sequence of fine- and coarse-grained deposits with few substantial beds of coarse deposits dominates the section, except in the vicinity where the river crosses the Stevens-Grant County line, where relatively thick sand and gravel beds are present. This relatively permeable portion of the aquifer is reflected by high water use in the water-use density maps (Wilson et al., 2002), of which Figure 8 is an example. Beneath the river valley in Seward County, the aquifer contains primarily thick beds of productive sand and gravel with thinner interlayers and lenses of silt and clay. The lithologic variations along the river are reflected in the map of hydraulic conductivity (Figure 13), which shows mostly lower-permeability sediments in the west (except for a local area of higher-permeability sediments where the river crosses the Stevens-Grant County line), and generally higher-permeability sediments in the east (in Seward and Meade counties).

The shallow alluvial aquifer appears variable in thickness and composition. However, in reality it is probably more continuous than it appears in the section. First, many of the wells with logs are located far enough from the river so that no little or no alluvium is present. Topographic maps indicate sand (and presumably gravel) along much of the river’s course. Also, very few of the logs were located in the base of the valley; most had surface elevations tens of feet above river level. Therefore many of the logs contain tens of feet of terrace deposits above the recent alluvium. Thus, the alluvial aquifer is expected to be more continuous than it appears on the section, but is commonly only a few tens of feet thick.

In the western part of the section (Morton and Stevens counties), the alluvial aquifer is for the most part distinguishable from the deeper High Plains aquifer. The coarser grained alluvium overlies a substantial thickness of fine-grained silts and clays. In fact the logs show mostly fine-grained deposits, with some coarser beds at the base of the aquifer. The alluvium is perhaps thickest and most permeable in Morton County, at the western extent of the High Plains aquifer where the bedrock surface is shallow. In Grant County the continuity and character of the alluvium becomes less discernible. Here the main aquifer appears most heterogeneous, consisting of alternating layers of fine- and coarse-grained sediment. There is probably not a good hydraulic connection between the

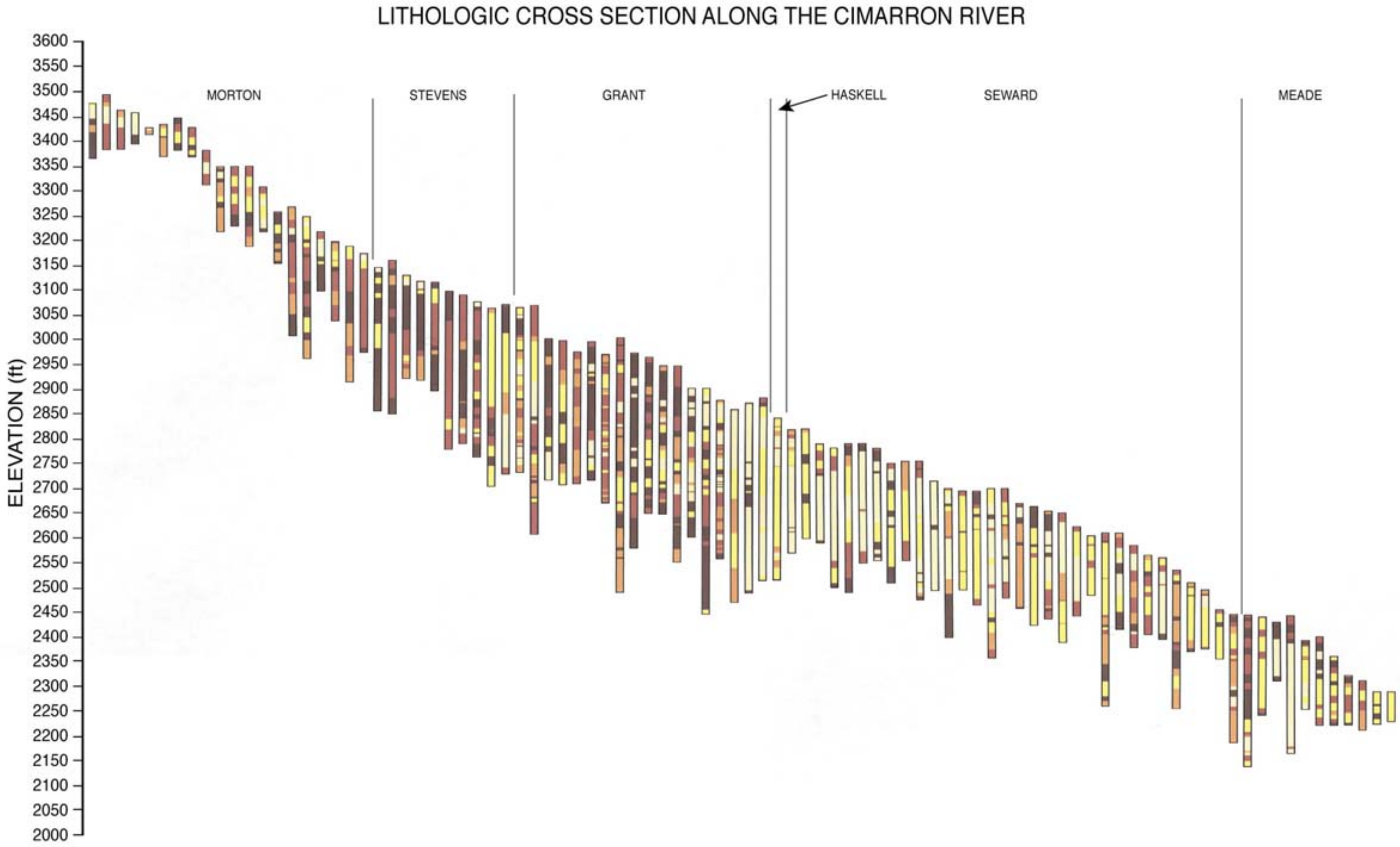


Figure 12. Lithologic cross section along the Cimarron River.

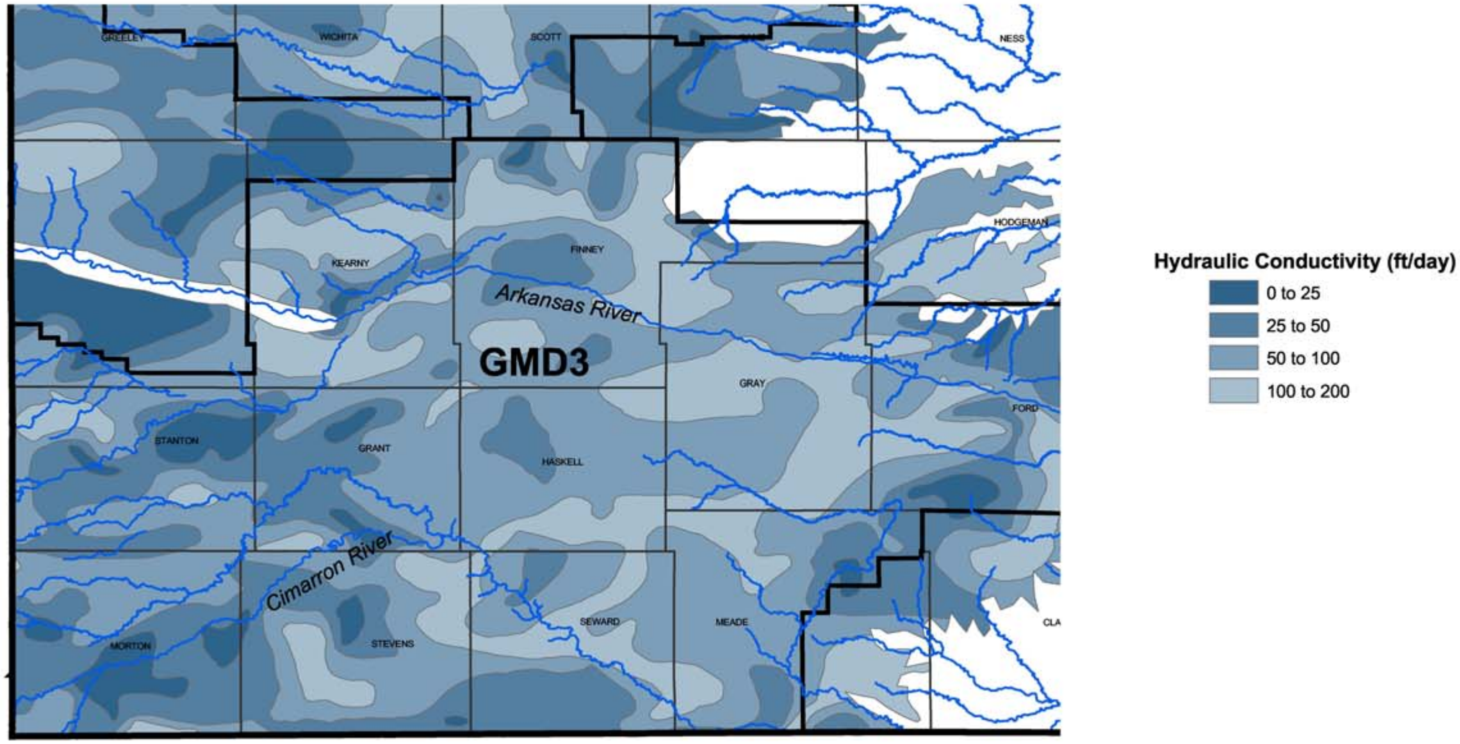


Figure 13. Hydraulic conductivity of the High Plains aquifer (data from Cederstrand and Becker, 1998).

shallow alluvium and the deeper aquifer along the course of the river in most of Grant County.

While a permeable zone in the High Plains aquifer is evident in a small area where the river crosses from Stevens to Grant County, southeastern Grant County marks the main transition to primarily coarse-grained deposits. Interestingly, perennial flow in the river historically began a short distance downgradient of where the transition from fine- to coarse-grained materials occurs. If (semi)confined conditions existed, the lithology change might have allowed greater discharge of ground water to occur. The coarse deposits predominate beneath the river valley through most of Seward County, and the shallow alluvium is generally not distinguishable from the main aquifer (based on these readily-available logs). Clay layers appear thin and of variable continuity; nonetheless, they may retard the vertical movement of water. The deepest logs show very little basal sands and gravels. Thus, the most productive part of the aquifer appears to be above the depth to which most of the wells were drilled, roughly 200 ft. The drillers commonly stopped when they encountered a substantial thickness of clayey material at depth or only installed production wells to the top of the clay after drilling test holes.

From southeastern Seward County into southwestern Meade County, the aquifer again becomes more heterogeneous. A test hole in extreme southwestern Meade County (NE, SW Sec. 31, T. 34 S, R. 30 W) encountered nothing but fine-grained materials and caliche down to more than 200 ft. The geology becomes complex in this area and the valley becomes very narrow. Frye (1942) attributed the constriction to resistant Laverne beds that dip below the river. The test hole referred to above probably encountered a lacustrine deposit related to local dissolution and subsidence. Both Smith (1940) and Frye (1942) suggest that such lacustrine deposits located a short distance from the river are related to solution and collapse of the underlying bedrock prior to deposition. Macfarlane and Wilson (in review) mapped several areally extensive closed depressions in the bedrock surface in southern Seward County. East of the aforementioned test hole, the aquifer contains mostly permeable sediments. The aquifer thins abruptly in Meade County approaching the Crooked Creek-Fowler fault, the eastern extent of the High Plains aquifer.

Ground-Water Level Cross Sections and Hydrographs

The Cimarron River Section and Sections A-A’, B-B’, C-C’ and D-D’ (hereafter referred to as A, B, C, and D; Figures 14 thru 18) include profiles of land surface, predevelopment ground-water table, 2004 ground-water table, and bedrock elevations. Locations of the sections are shown in Figure 10. Water table and bedrock data were obtained from the KGS section-level database available at http://www.kgs.ku.edu/HighPlains/data.htm. The USGS National Elevation Dataset (http://gisdata.usgs.gov/NED/, 30 m resolution) was used for land surface elevation because section-level database (1 mile resolution) was too coarse.

The Cimarron River cross section (Figure 14) resembles the river cross section produced by McLaughlin (1946, p. 49), but shows greater detail. The surface gradient along the

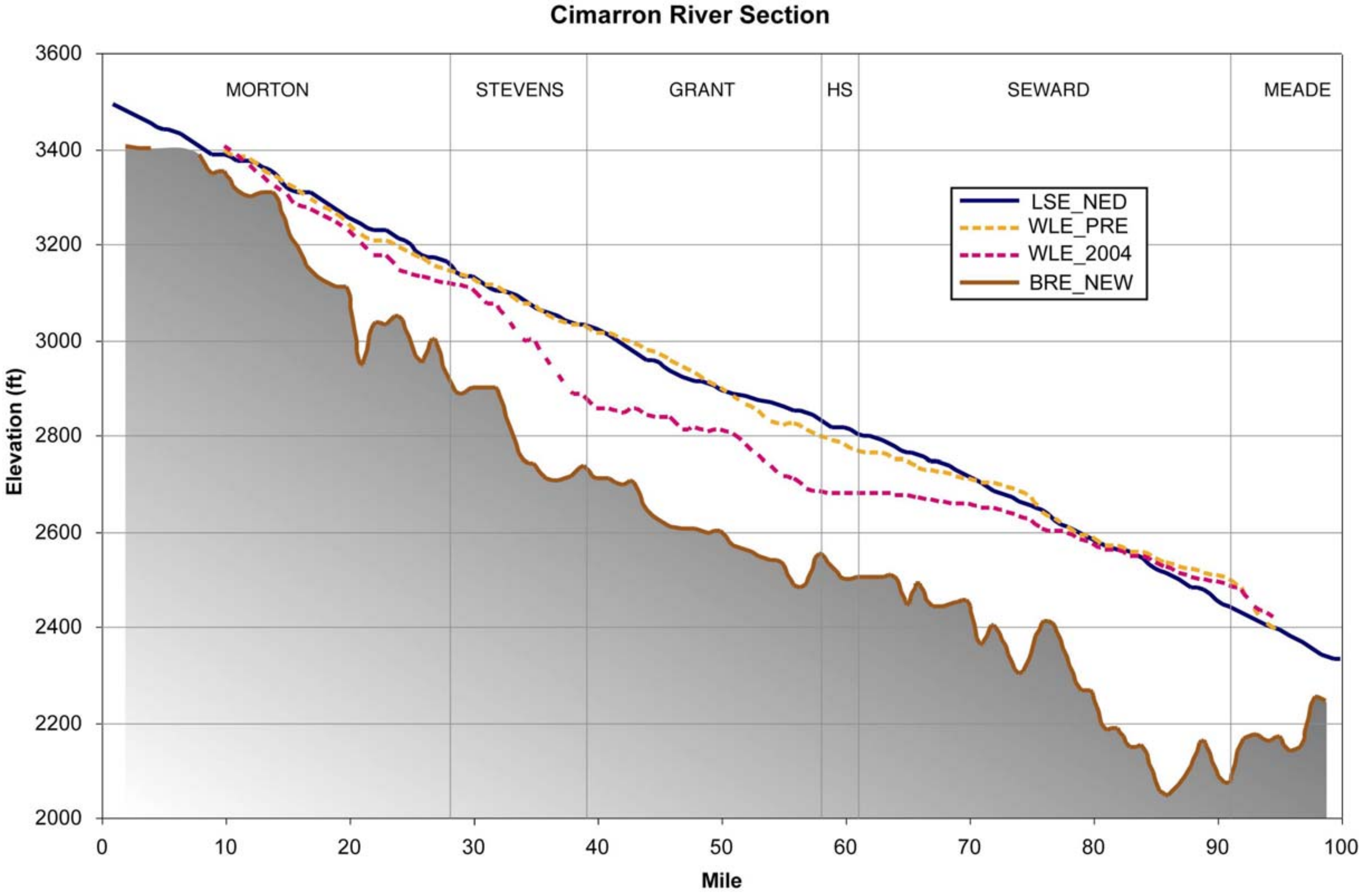


Figure 14. Cimarron River Section showing profiles of land surface, predevelopment ground-water table, 2004 ground-water table, and bedrock elevations. Ground-water table elevations are indicative of conditions near but upland of the river.

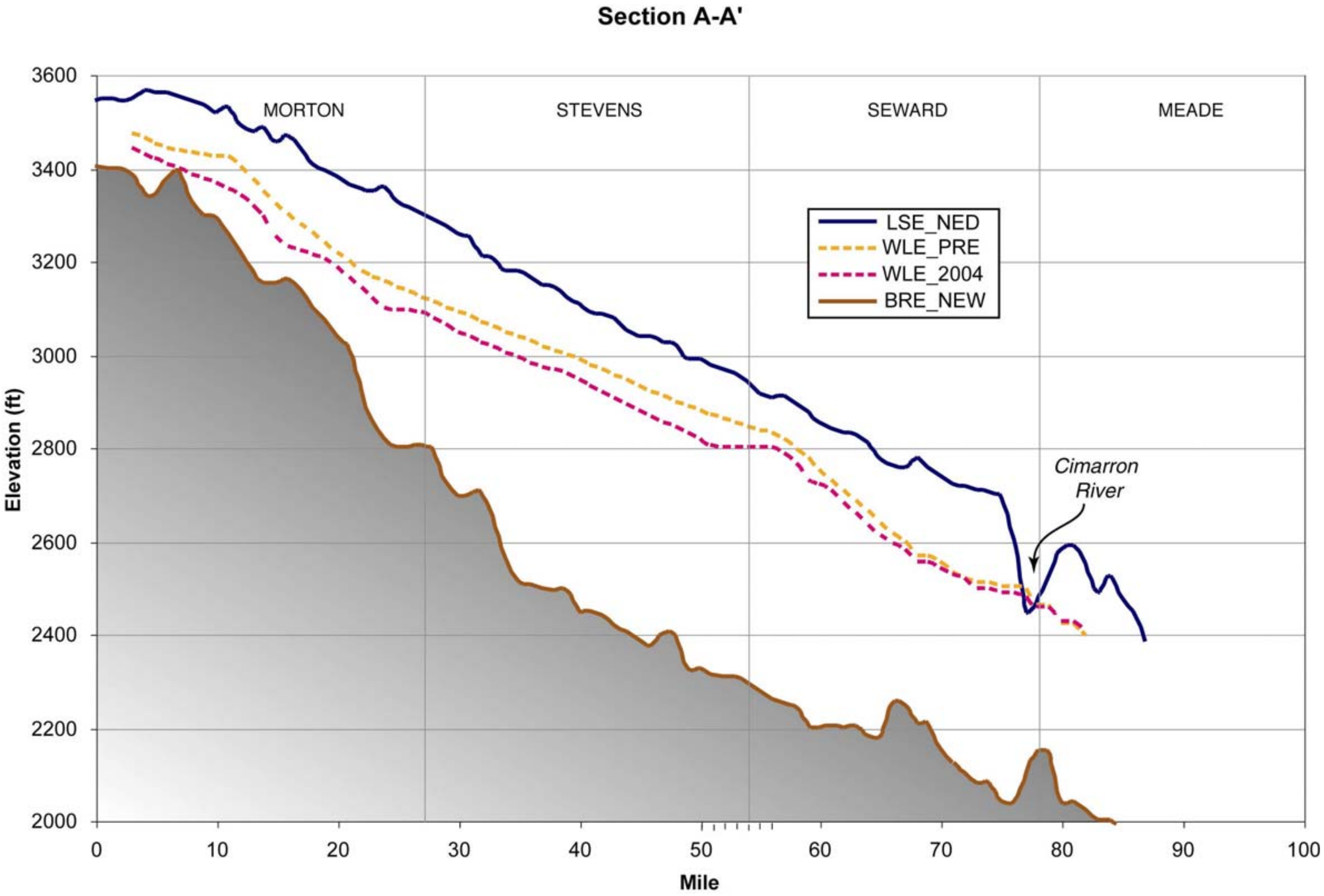


Figure 15. Section A-A' showing profiles of land surface, predevelopment ground-water table, 2004 ground-water table, and bedrock elevations.

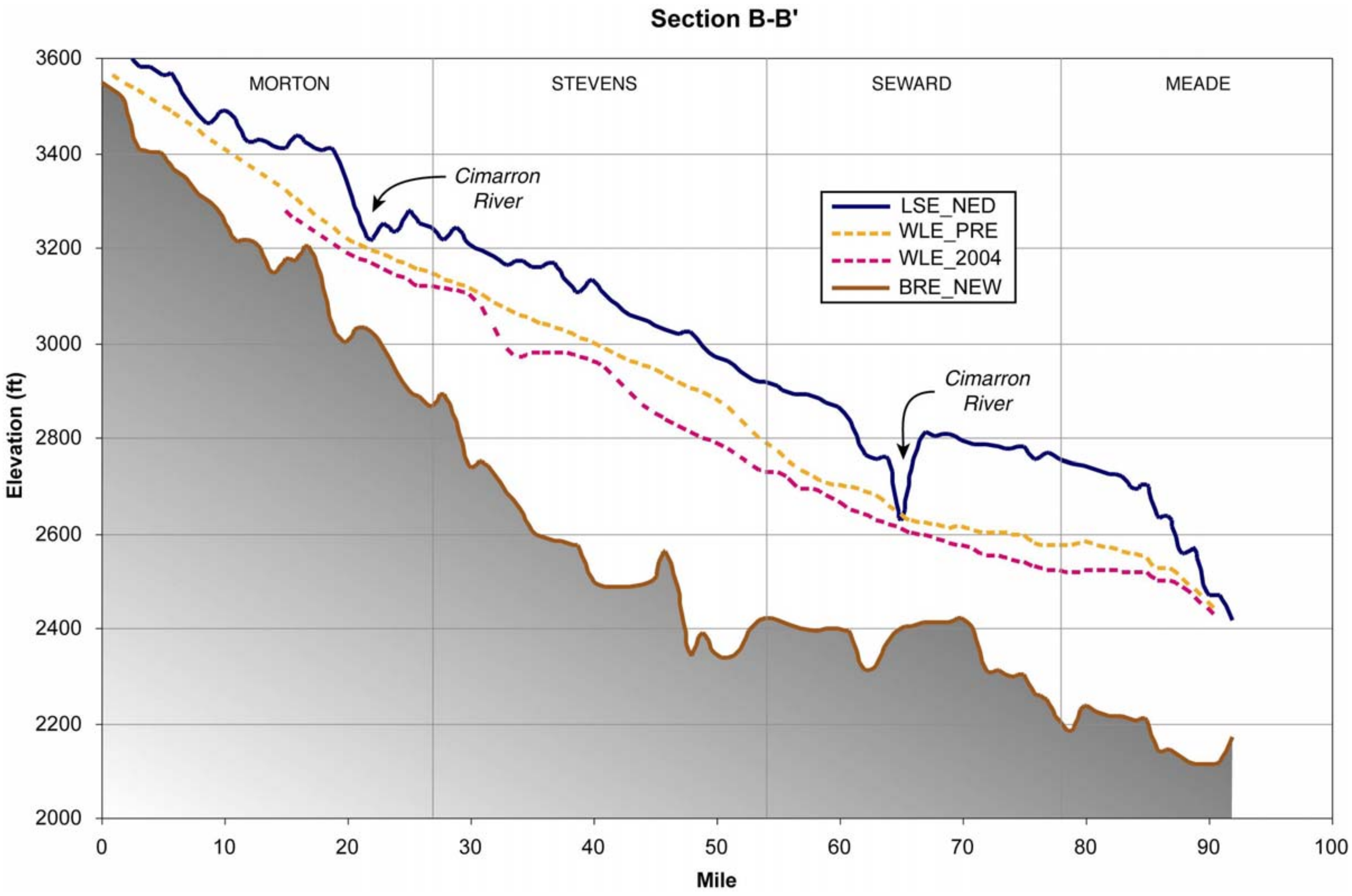


Figure 16. Section B-B' showing profiles of land surface, predevelopment ground-water table, 2004 ground-water table, and bedrock elevations.

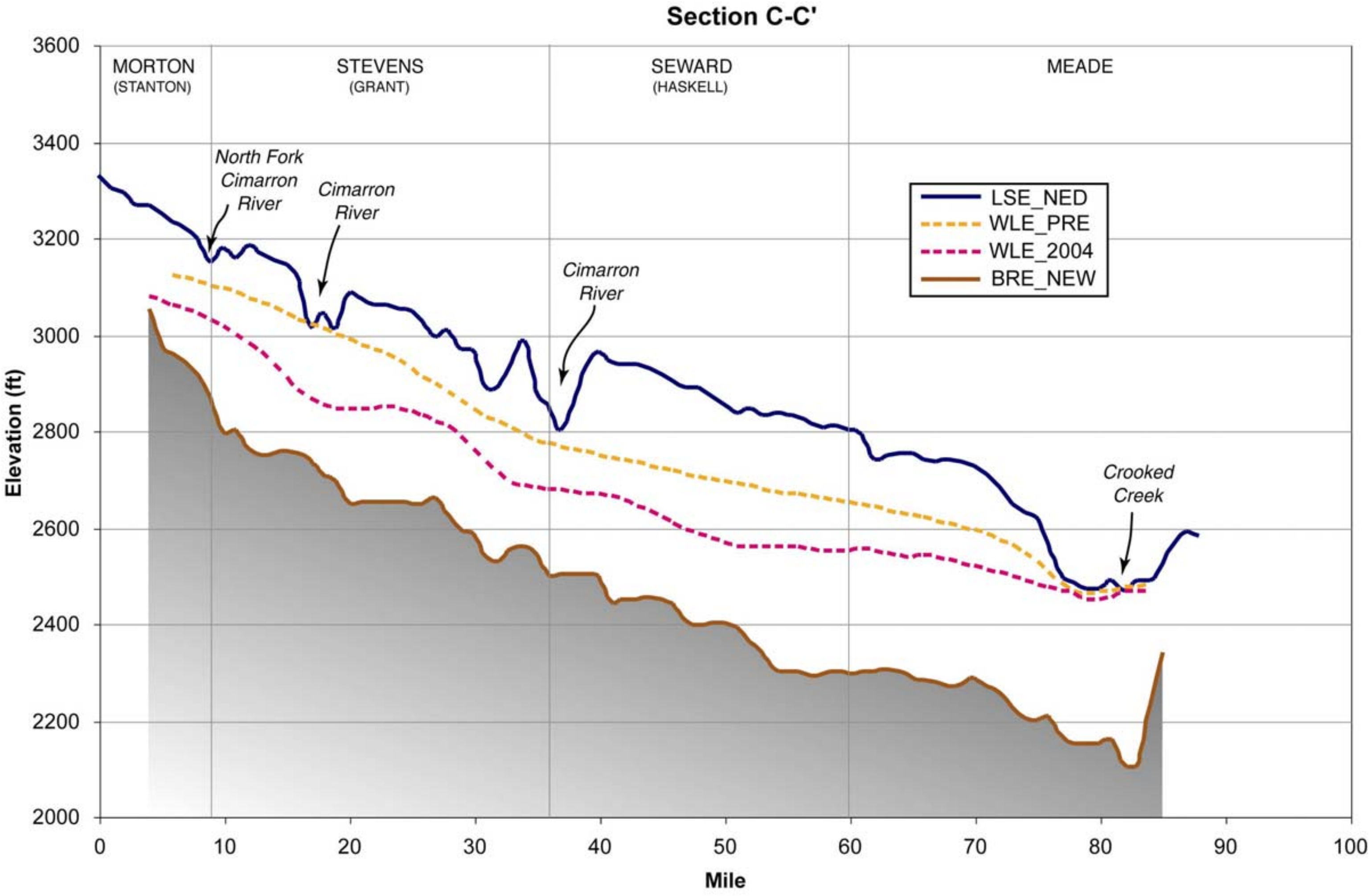


Figure 17. Section C-C' showing profiles of land surface, predevelopment ground-water table, 2004 ground-water table, and bedrock elevations.

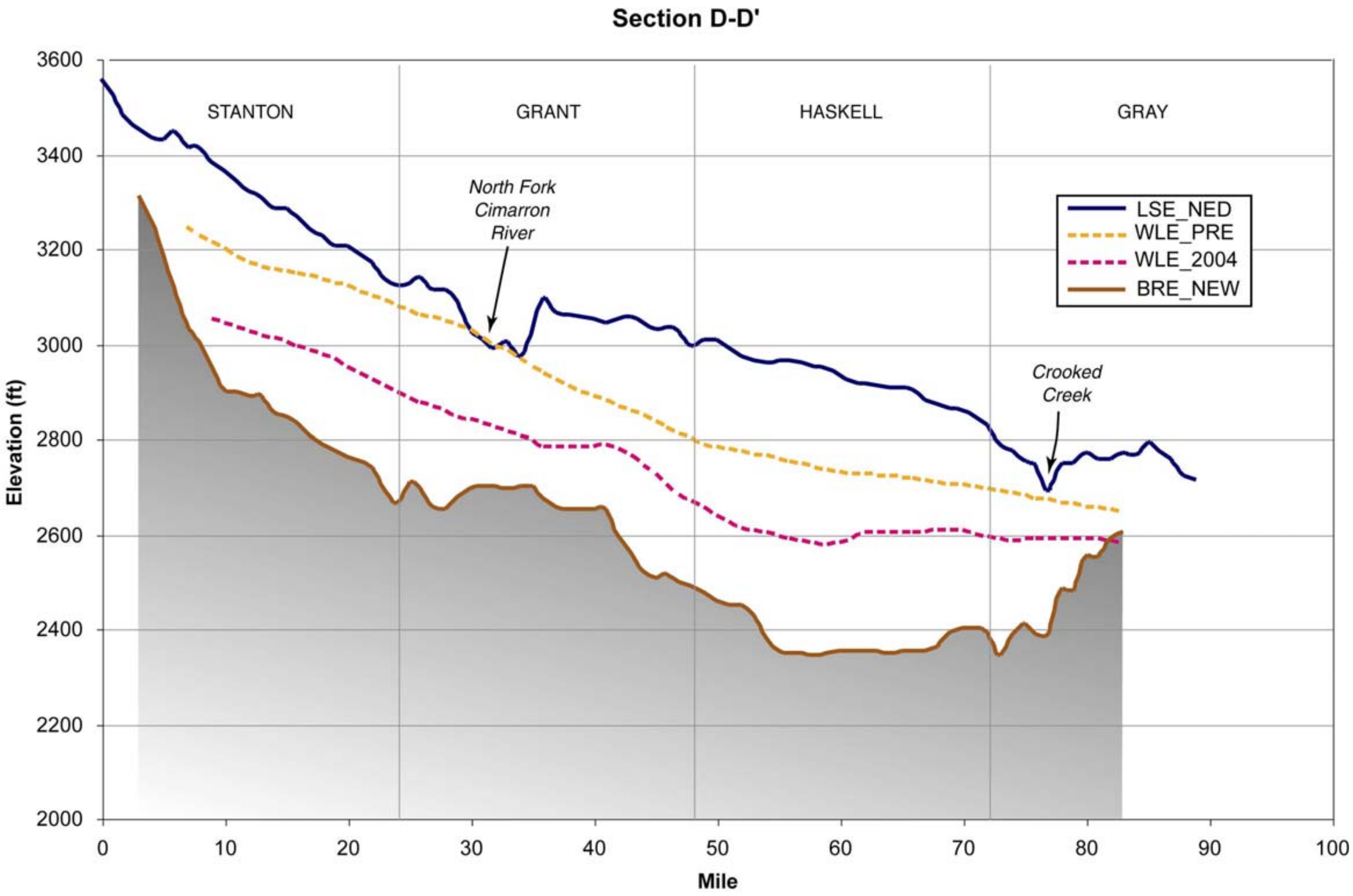


Figure 18. Section D-D’ showing profiles of land surface, predevelopment ground-water table, 2004 ground-water table, and bedrock elevations.

river channel is about 11 ft/mi. Along the Cimarron River, the greatest saturated thickness in the High Plains aquifer occurs in eastern Seward County. At the downstream end of the Cimarron River cross section in southern Meade County, the bedrock surface elevation increases and the aquifer thins abruptly toward the Crooked Creek-Fowler fault zone.

Prior to ground-water development, the surface of the ground-water table in the Cimarron valley was relatively near the bottom of the river channel along the entire length of the river in Kansas. The predevelopment water table indicates that perennial flow in the Cimarron River historically occurred in southwest and south-central Grant County and began again in northwestern Seward County and continued eastward. A graph in McLaughlin (1946; p. 50) based on streamflow measurements in 1942 and 1943 showed that the river generally lost flow from near Elkhart to the northwest part of Seward County and gained flow from northwest Seward to southwest Meade County. A map of water-table contours for the High Plains aquifer in 1940 (Byrne and McLaughlin, 1948; Plate 1) indicates that perennial flow in the river began in the northwest part of T. 32 S., R. 33 W in northwest Seward County. This is approximately the same vicinity as the start of the perennial portion of the river indicated on the USGS Sublette SW topographic quadrangle of 1968 based on aerial photographs of 1966.

The 2004 water table lies below the level of the riverbed from southwest Morton County to southeast of the center of Seward County. The water-level surface in the river valley is near or above the land surface only in southwesternmost Morton County, where the bedrock surface is relatively close to the land surface, and in southeast Seward County and eastward. Thus, the point at which perennial flow began in Seward County has migrated downstream some 15 miles.

High Plains aquifer saturated thickness declines of over 50% are evident along stretches of the river, such as where the river crosses from Stevens to Grant County (Figure 14), an area characterized by relatively permeable sediments and high water-use density. The 2004 water table is more than 100 ft below the river channel at this county boundary and to the east where the river crosses the southwest corner of Haskell County.

Ground-water table declines have caused long-term flow decreases in the Cimarron River and other rivers that originate mainly within the extent of the High Plains aquifer (Buddemeier et al., 2003). The decrease in fresh ground-water discharge from the High Plains aquifer, caused by declines in ground-water levels, has resulted in an increase in the salinity of the river (see Whittemore et al., 2005). The water-level declines have led to increases in streambed recharge during substantial precipitation events along upstream stretches of the rivers that no longer have perennial flow.

The mean annual flows of the Cimarron River have declined at the current USGS gaging stations in southwest Morton County near Elkhart and in southeast Meade County north of Forgan, Oklahoma (Figure 19). The flow of the river in southeast Meade County during 2000-2002 was less than half of that during 1966-1969. The decline in the difference in the flow between southwest Morton and southeast Meade counties (Figure

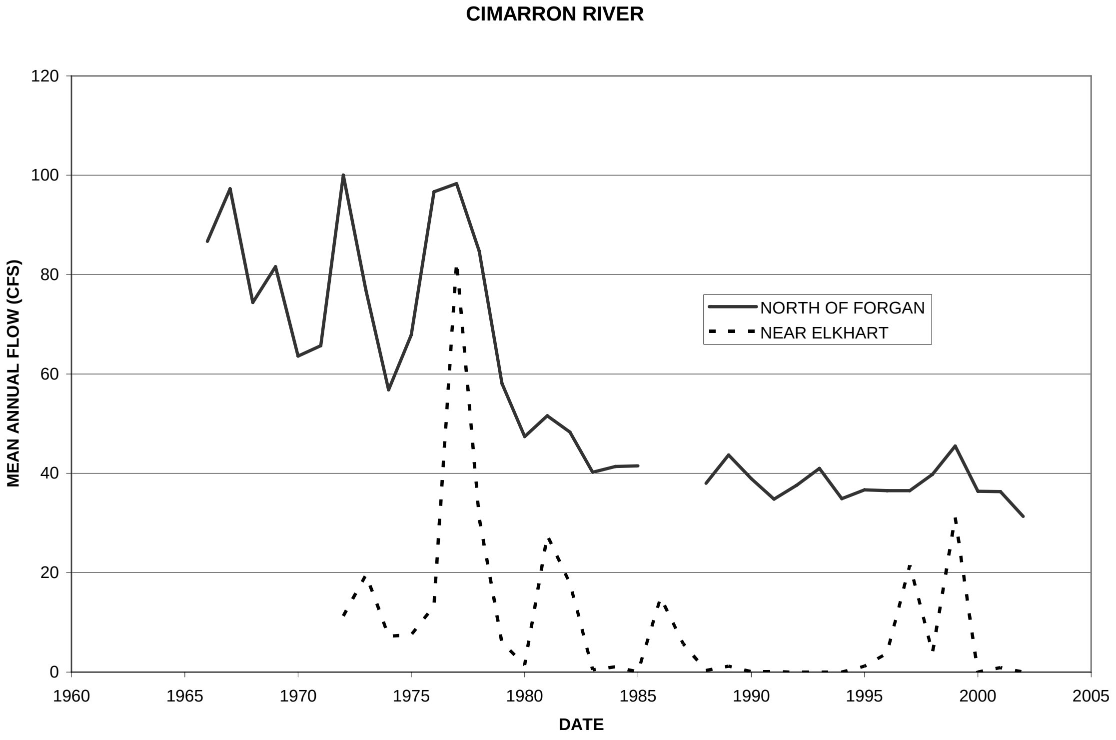


Figure 19. Cimarron River flows (USGS data).

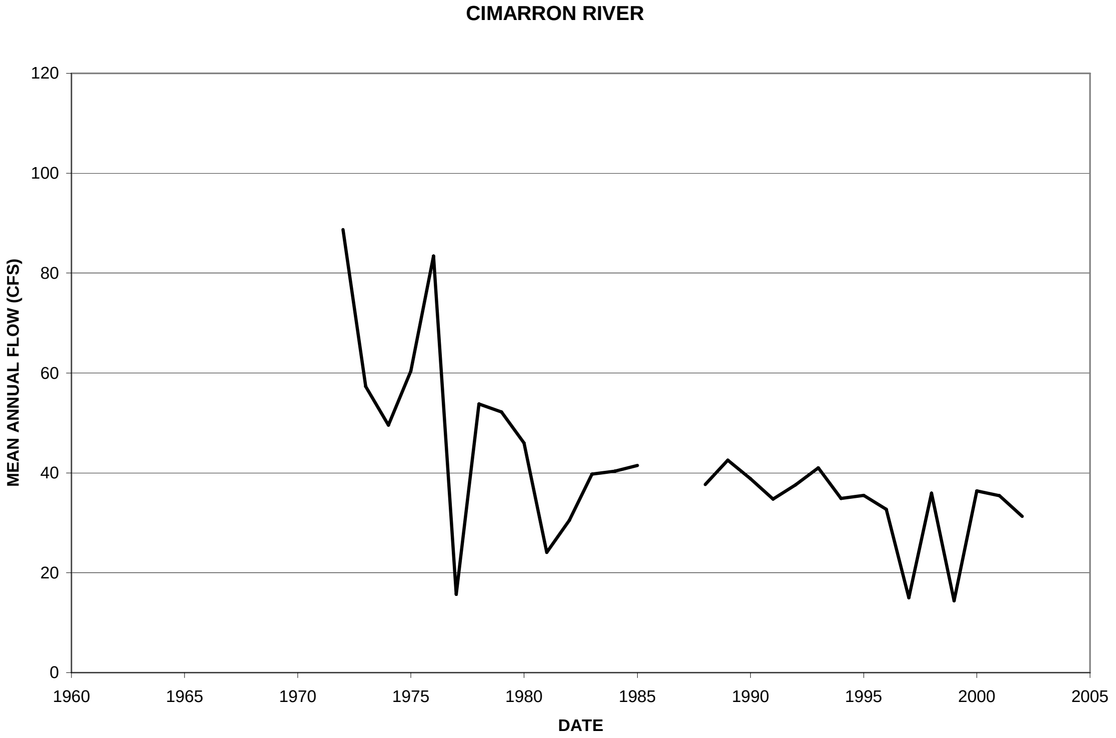


Figure 20. Difference between flows north of Forgan and flows near Elkhart (USGS data).

20) represents an increase in recharge from the river across the High Plains aquifer from near Elkhart downstream into northwest Seward County and a decrease in the ground-water discharge from the aquifer to the river from northwest Seward to southwest Meade counties.

The decline in the High Plains aquifer water table along the Cimarron River corridor is the main cause of the decrease in river flow. Gutentag et al. (1981) described substantial water-level drops in the aquifer in southwest Kansas through the 1960s to 1975. A seepage run conducted in November 1974 indicated that the point where flow began in the Cimarron River was approximately in the center of T. 32 S., R. 33 W., a distance of about 3-4 channel miles downstream of the beginning of perennial flow on the 1968 USGS topographic map. The location where the ground-water levels in the aquifer change from below to above the river channel (and thus, the start of perennial flow) has migrated another 11-12 channel miles downstream from the 1974 survey to just southeast of the center of the county, based on KGS and DWR measurements in annual network wells within 2.5 miles of the river (Table 3). This transition point is near the old town of Arkalon in the southwest part of T. 33 S., R. 32. W. McLaughlin (1942) cited data from the USGS that the mean daily discharge of the Cimarron River near Arkalon in 1938-1939 was 42.3 ft^3/sec. Today, this is the area where the river would be expected to begin its perennial flow based on the water-level data.

As indicated in Table 3, water levels during the last five years continue to decline where the water level in the High Plains aquifer is below the riverbed but have not changed substantially in the area where the aquifer water levels are close to or above the riverbed.

Hydrographs showing ground-water levels in wells within about 2.5 miles of the Cimarron River are displayed in Figures 21-24. The wells are listed in order from west to east in the legends. Data were obtained from the KGS WIZARD database (http://www.kgs.ku.edu/Magellan/WaterLevels/index.html).

The Morton County hydrographs (Figure 21) indicate that ground-water levels have remained largely unchanged along the river in that county, except in well 32S 39W 09DD 01, which showed a decline of about 50 ft from the mid 1960s to the mid 1980s. This well is located in extreme eastern Morton County, essentially the only area along the river in Morton County with substantial water right development (Figures 7 and 8).

In Stevens County (Figure 22), substantial declines approaching 150 ft are observed in the wells with longest period of record (31S 37W 09BCC 01 and 31S 37W 09BBC 01). Along the river in Stevens County, this area has the largest decline and the largest decline rate (over 3 ft/yr) and is located in the area with the highest water-use density (Figure 8). The wells closest to the river tend to have the least declines and lowest decline rates, suggesting enhanced recharge from the river when it flows. It should be noted that some stretches along the river remain as grassland with relatively low water use density (Figure 2).

Table 3. Elevation of water levels in DWR-KGS annual network wells and a USGS multi-level well within 2.8 miles of the Cimarron River relative to the river channel elevation in Seward and southwestern Meade counties.

Well location and ID	General descriptive location	Well depth ft	Land surface elevation at well ft	Well location relative to Cimarron R	River channel elevation ft	Elevation difference between channel and land surface at well ft	Depth to water ft	Date of depth to water	Elevation difference between channel and water level ft
31S 34W 18BBB 01	NW corner Seward Co.	375	2951	1.9 mi to W	2778	173	252.3	1/2000	-79
31S 34W 30DBA 01	NW Seward Co.	530	2946	1.9 mi to W	2759	187	251.6 254.5	1/2003 1/2005	-65 -68
32S 34W 10DAA 01	NW Seward Co.	350	2925.4	2.3 mi to W	2710	215	259.6 263.2	1/2003 1/2005	-45 -48
32S 33W 32DBD 01	NW of center Seward Co.	?	2820	1.6 mi to SW	2660	160	185.8 189.2	1/2003 1/2005	-26 -29
33S 33W 12AAD 01	Center of Seward Co.	140	2626	0.65 mi to W	2612	14	23.8 25.2	1/2003 1/2005	-10 -11
33S 32W 28CDD 02	SE of center Seward Co.	205	2630	1.0 mi to SW	2565	65	62.8 62.6	1/2003 1/2005	2 2
33S 31W 20ACA 01	SE Seward Co.	418	2750	2.1 mi to NE	2532	218	214.3 215.2	1/2003 1/2005	4 3
33S 31W 28DDB 01	SE Seward Co.	?	2720	2.5 mi to NE	2510	210	192.8	1/1998	17
34S 31W 22BDD 04*	SE Seward Co.	65	2530	0.4 mi to SW	2467	63	56.0 55.5 56.6	10/1999 1/2000 10/2004	7.0 7.5 6.4
35S 31W 10AAC 01	SE Seward Co.	480	2680	2.8 mi to SW	2420	260	200.7 201.3	1/2003 1/2005	59 59
35S 30W 10CDA 01	SW corner of Meade Co.	260	2420	0.6 mi to NNE	2376	44	26.7 25.6	1/2003 1/2005	17 18

* The surface elevation for the UGSS multi-level well site is listed as 2444 ft above sea level in McMahon (2000). The KGS visited the site with the USGS in 2004 to verify the location of the site and determined that the surface elevation is 2530 ft. The depth to water is for the shallowest well (screened from a depth of 45 to 65 ft).

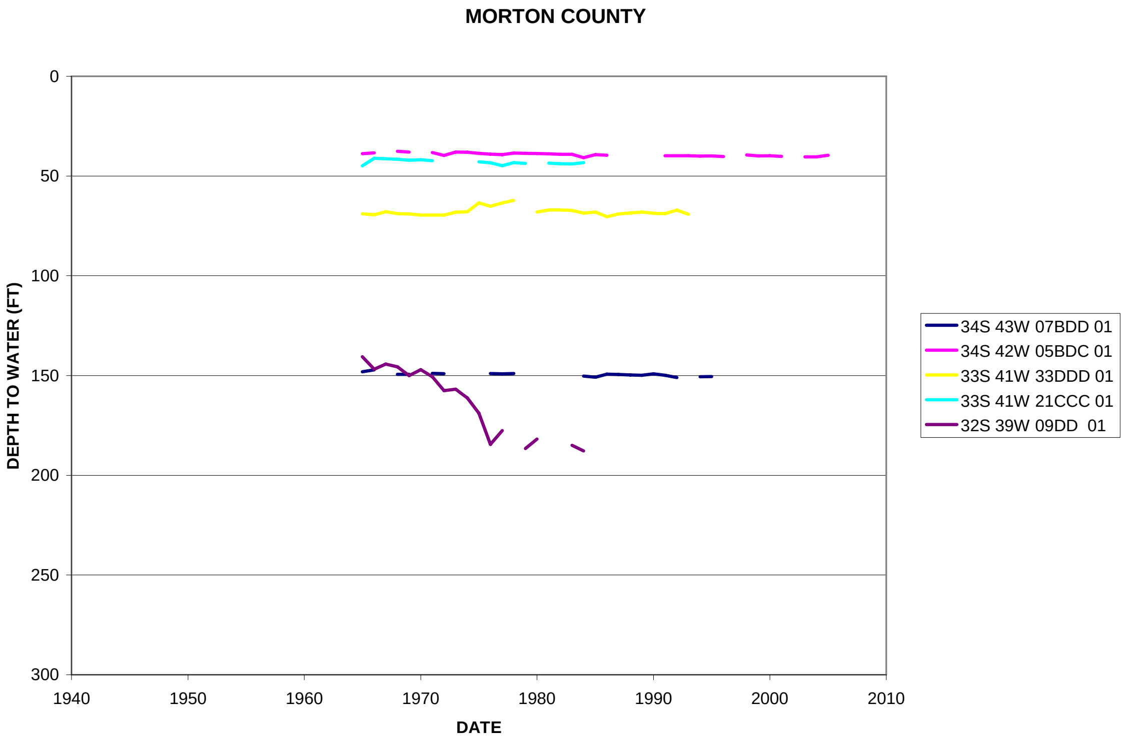


Figure 21. Hydrographs for wells within about 2.5 miles of the Cimarron River in Morton County.

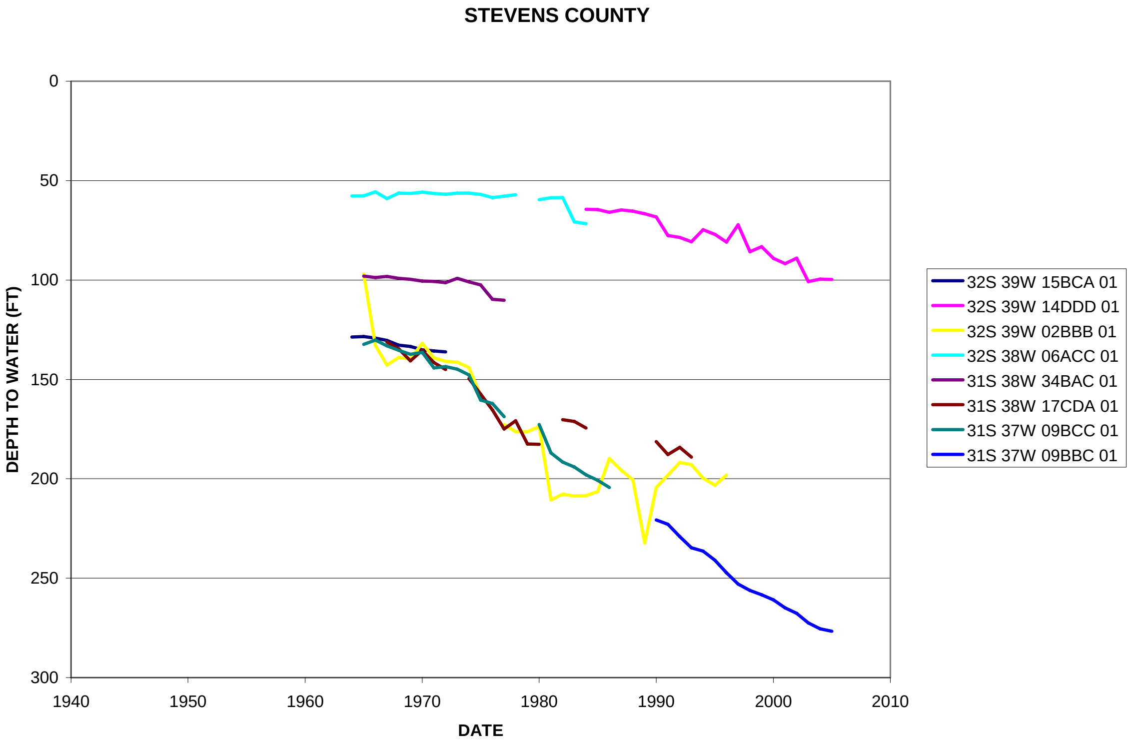


Figure 22. Hydrographs for wells within about 2.5 miles of the Cimarron River in Stevens County.

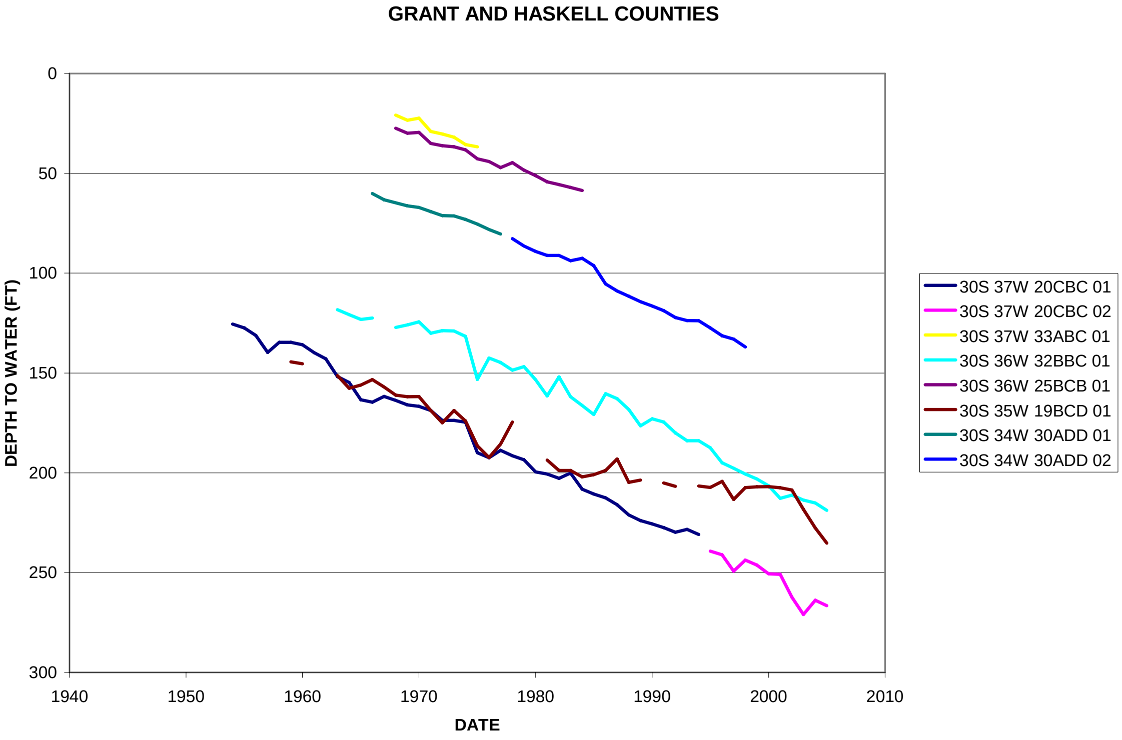


Figure 23. Hydrographs for wells within about 2.5 miles of the Cimarron River in Grant and Haskell counties.

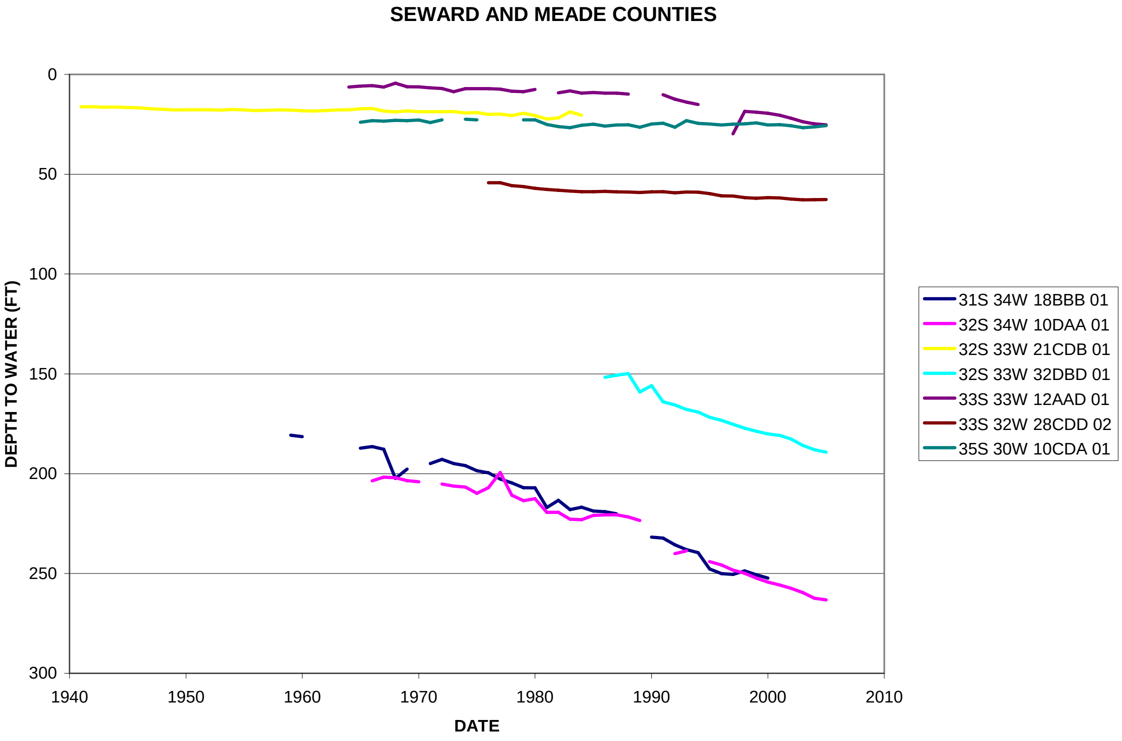


Figure 24. Hydrographs for wells within about 2.5 miles of the Cimarron River in Seward and Meade counties.

Water-level declines in wells near the river are large and decline rates are similar across Grant and Haskell counties (Figure 23). Similar to Stevens County, the maximum decline is about 150 ft. Decline rates are slightly lower, approximately 3 ft/yr.

Declines and decline rates decrease from west to east across Seward and into Meade County (Figure 24). The water level in the well in the northwest corner of Seward County (31S 24W 18BBB 01) dropped over 70 ft from December 1959 to January 2000 (the level in the well could not be measured after 2000 and the well was removed from the network). The water level elevation at this well in December 1958 would have been only about 8 ft below the elevation of the riverbed (Table 3). The water level in the network well in southwest Meade County (35S 30W 10CDA 01), located 0.6 mile north of the river, shows a general correlation with the mean annual flow of the Cimarron River (Figure 25).

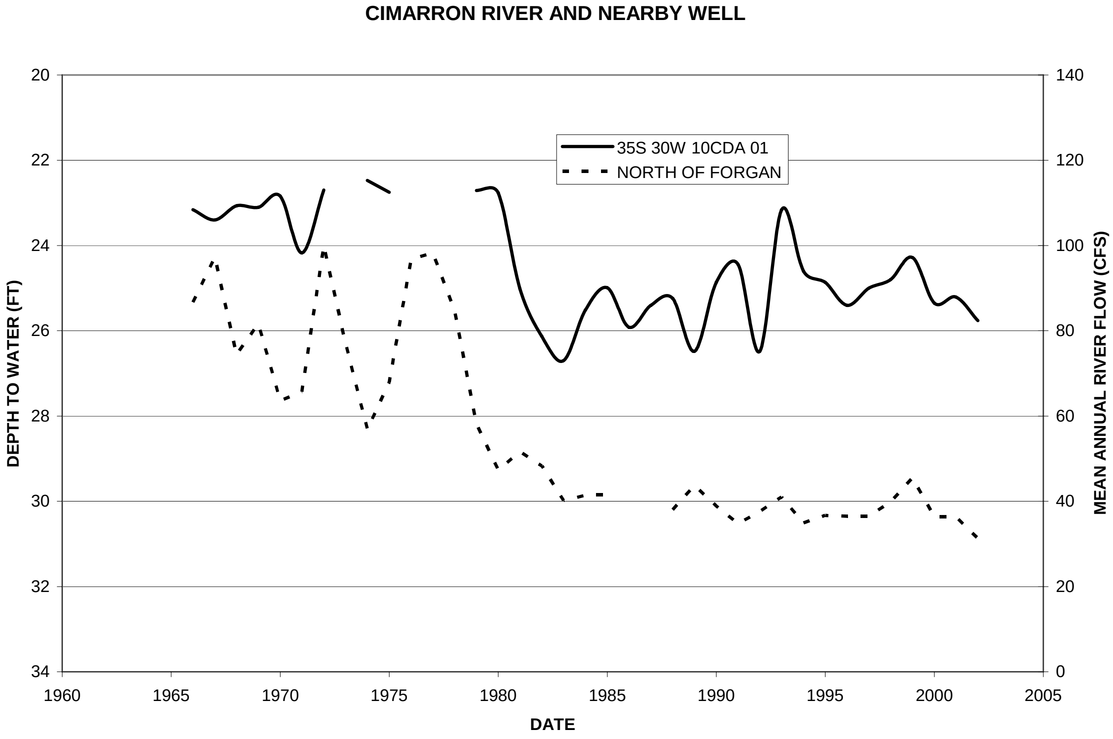


Figure 25. Ground-water level in well 35S 30W 10CDA 01 compared to mean annual flow in the Cimarron River north of Forgan, Oklahoma (KGS and USGS data).

The alluvial well in Seward County (32S 33W 21CDB 01 in Figure 24) shows very little decline, but the water-level record only goes through 1984. A nearby deeper well (32S 33W 32DBD 01) shows a higher decline rate but the period of record is later. No substantial new development occurred in this area in the 1980s. It is probable that clays at the base of the alluvial aquifer provide some hydraulic separation between the alluvium and the deeper portion of the aquifer. This scenario, along with the fact that water-level declines tend to be smaller in wells closer to the river, suggests that water from the river recharges the alluvium, where its vertical movement is retarded, and then leaks into the deeper aquifer.

Sections A through D (Figures 15-18) are aligned west to east along the general direction of regional ground-water flow. Locations of the sections are shown on Figure 10. These sections display deep, steep valleys that were carved by the Cimarron River and other surface waterways. The valleys commonly have in excess of 200 ft of relief. Except for the valleys, the land surface slopes fairly uniformly from west to east. The surface of the predevelopment water table generally reflects the land surface topography, which is common in unconsolidated aquifers. The surface and predevelopment water-table gradients are greater in the south -- about 12 ft/mi in Sections A and B, and about 9 ft/mi in Sections C and D. The slope of the bedrock surface, which has been subject to erosion and faulting, is less uniform. The bedrock surface becomes shallow in the east as the Crooked Creek fault zone and the eastern extent of the aquifer are approached. The fault zone is essentially coincident with eastern extent of the aquifer in the Cimarron basin.

Ground-water pumping has substantially lowered the 2004 water-table surface relative to the predevelopment surface. Areas of high water-level declines are correlated with high water-use density (Figure 8). Water-level declines increase from south to north in the Cimarron basin, with the largest declines in Section D, reflecting the relation to water-use density. This relationship holds within each cross section as well. For example, large declines are evident in Haskell County and in the western portion of Section D. In Sections C and D, troughs are visible in the 2004 water table in southern Grant/northern Stevens counties and in Haskell/northern Seward counties. The area with the greatest remaining saturated thickness is in the south (Section A), but concerns about lithology (thick clays in the deeper portion of the aquifer) and water quality remain (see Whittemore et al., 2005).

CONCLUSIONS

Ground-water pumping is resulting in substantial ground-water level declines in portions of the Cimarron River basin. The High Plains aquifer is being mined. Water-level declines exceeding 150 ft, over 40 percent of the saturated thickness, have occurred along the Cimarron River; even larger declines have occurred elsewhere in the basin. Areas of the largest ground-water level declines are correlated with high water-use density. Overall, decline rates along the Cimarron River corridor do not appear to be decreasing. Ground-water level declines have resulted in reduced streamflows. Streamflows in the Cimarron River have declined, and portions of the river which previously flowed perennially now flow only intermittently. The point at which perennial flow begins in Seward County has migrated downstream roughly 15 miles.

Most notable in the lithologic cross section along the Cimarron River is a west-to-east transition from an abundance of fine-grained deposits to primarily coarser-grained materials in extreme eastern Grant County. The shallow alluvial aquifer is variable in thickness and composition, but is primarily composed of coarse-grained sediments and is only a few tens of feet thick. While this report improves our knowledge of the lithology, more field data are necessary to improve the lithologic characterization, particularly along the alluvial valley of the Cimarron River.

ACKNOWLEDGMENTS

The work on this study was funded in part by the Kansas Water Plan. This report benefited from reviews by Susan Stover (Kansas Water Office) and Rex Buchanan (KGS). Mark Schoneweis, KGS graphic artist, assisted with graphics. Melany Miller, KGS administrative assistant, assisted with final preparation of the report.

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