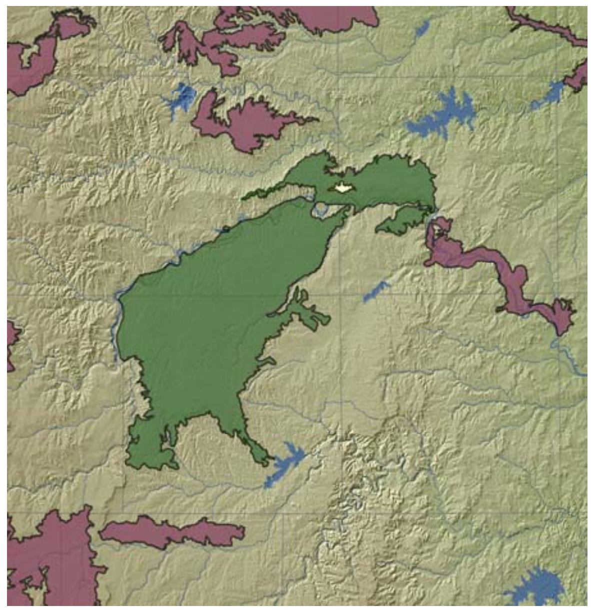
Final Report Conceptual Model for the Refined Seymour Aquifer Groundwater Availability Model: Haskell, Knox, and Baylor Counties

Prepared by:

Toya L. Jones, P.G.
John E. Ewing, P.E.
Tingting Yan
John F. Pickens, Ph.D., P.E., P.G.
Bridget R. Scanlon, Ph.D., P.G.
Jeff Olyphant
Andrew Chastain-Howley, P.G., MCSM



Prepared for:

Texas Water Development Board

February 2012

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John F. Pickens, Ph.D., P.E. P.G.
INTERA Incorporated

Bridget R. Scanlon, Ph.D., P.G.
Jeff Olyphant
Bureau of Economic Geology
University of Texas at Austin

Andrew Chastain-Howley, P.G., MCSM
Water Prospecting Resource Consultants, LLC

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Geoscientist and Engineering Seal

This report documents the work of the following Licensed Texas Geoscientists and Licensed Texas Professional Engineer:

John F. Pickens, Ph.D., P.G.

Dr. Pickens was the Project Manager for this work and was responsible for oversight on the project.

STATE OF TEXAS
JOHN F. PICKENS
GEOLOGY
No. 1962
LICENSED
PROFESSIONAL GEOSCIENTIST

J. Pickens ______ Signature   2/8/12 ______ Date

John Ewing, P.E.

Mr. Ewing, along with Ms. Jones, was responsible for development of the conceptual model for the Seymour Aquifer.

STATE OF TEXAS
JOHN E. EWING
92817
LICENSED
PROFESSIONAL ENGINEER

John E. Ewing ______ Signature   2/8/12 ______ Date

Toya Jones [Dale], P.G.

Ms. Jones, along with Mr. Ewing, was responsible for development of the conceptual model for the Seymour Aquifer.

STATE OF TEXAS
TOYA JONES DALE
GEOLOGY
No. 2497
LICENSED
PROFESSIONAL GEOSCIENTIST

Toya Jones Dale ______ Signature   2/8/12 ______ Date

Bridget Scanlon, Ph.D., P.G.

Dr. Scanlon was responsible for the evaluation of recharge to the Seymour Aquifer.

STATE OF TEXAS
BRIDGET SCANLON
GEOLOGY
NO. 1645
LICENSED
PROFESSIONAL GEOSCIENTIST

Bridget R Scanlon ______ Signature   2/8/12 ______ Date

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1.0 Introduction

The Texas Water Development Board (TWDB) has identified the major and minor aquifers in Texas on the basis of regional extent and amount of water produced. The major and minor aquifers are shown in Figures 1.0.1 and 1.0.2, respectively. General discussion of the major and minor aquifers is given in Ashworth and Hopkins (1995). Aquifers that supply large quantities of water over large areas of the state are defined as major aquifers and those that supply relatively small quantities of water over large areas of the state or supply large quantities of water over small areas of the state are defined as minor aquifers (Ashworth and Hopkins, 1995).

A groundwater availability model was completed for the entire Seymour Aquifer, a major aquifer in Texas, in 2004 (Ewing and others, 2004). That modeling effort used a single model to represent the entire Seymour Aquifer, which consists of isolated "pods" that are not hydraulically connected. In their discussion of possible future improvements, Ewing and others (2004) recommended that future modeling of the Seymour Aquifer consider each pod individually using a refined grid design based on the size of the pod, the hydraulic stresses within the pod, and the ultimate goals of the model. They suggested that the large pod of the Seymour Aquifer located in Haskell, southern Knox, and western Baylor counties (pod 7 in their report) was a candidate for a refined model due to the quantity of pumping occurring in that pod of the aquifer.

Consequently, a refined groundwater availability model was developed for the portion of the Seymour Aquifer located in Haskell, southern Knox, and western Baylor counties. The TWDB has recently decided to provide documentation of conceptual models and the resulting numerical groundwater flow models in two separate reports. This report documents the development of the conceptual model for the portion of the Seymour Aquifer located in Haskell, southern Knox, and western Baylor counties. A conceptual model assembles field data collected on the aquifer; allows the researchers to identify system boundaries and hydrostratigraphic units; and provides the foundation for building a numerical groundwater flow model (Anderson and Woessner, 1992). It is through this process that a better understanding of the aquifer flow system is ascertained.

The refined model will provide an improved tool for the Rolling Plains Groundwater Conservation District, the TWDB, and the Region B and G Regional Water Planning Areas to perform groundwater management and planning. In the remainder of this report, reference to the Seymour Aquifer means the Haskell-Knox-Baylor pod of the Seymour Aquifer considered by this study, unless specifically stated otherwise.

The majority of the water pumped from the Seymour Aquifer is used for irrigation purposes (Ashworth and Hopkins, 1995) with minor pumpage for livestock, domestic, municipal, and manufacturing uses. Groundwater in the Seymour Aquifer is predominately fresh with slightly saline groundwater is some areas.

The modeling approach adopted for the refined model of the Seymour Aquifer is to represent the aquifer as a single layer and the upper portion of the underlying Permian-age strata as a second layer having separate hydraulic characteristics. The second layer was included in the model to capture any cross-formational flow between the Seymour Aquifer to the underlying Permian-age strata.

The Texas Water Code codified the requirement for generation of a State Water Plan that allows for the development, management, and conservation of water resources and the preparation and response to drought, while maintaining sufficient water available for the citizens of Texas (TWDB, 2002). Senate Bill 1 and subsequent legislation directed the TWDB to coordinate regional water planning with a process based upon public participation.

Groundwater models provide a tool to estimate groundwater availability for various water use strategies and to determine the cumulative effects of increased water use and drought. A groundwater model is a numerical representation of the aquifer system capable of simulating historical conditions and predicting future aquifer conditions. Inherent to the groundwater model are a set of equations that are developed and applied to describe the physical processes considered to be controlling groundwater flow in the aquifer system. Groundwater models are essential to performing complex analyses and in making informed predictions and related decisions (Anderson and Woessner, 1992). As a result, development of groundwater availability models for the major and minor Texas aquifers is integral to the state water planning process. The purpose of the groundwater availability model program is to provide a tool that can be used to develop reliable and timely information on groundwater availability for the citizens of Texas and to ensure adequate supplies or recognize inadequate supplies over a 50-year planning period. The groundwater availability models also serve as an integral part of the process of determining managed available groundwater based on desired future conditions, as required by House Bill 1763 passed in 2005 by the 79th Legislature. Managed available groundwater was later re-defined in Senate Bill 737 passed in 2011 by the 82nd Legislature as modeled available groundwater. Modeled available groundwater is the amount of water that can be produced on an average annual basis to achieve a desired future condition as established by the groundwater conservation districts located within 16 groundwater management areas within Texas.

The modeling protocol standard to the groundwater modeling industry includes: (1) the development of a conceptual model for groundwater flow in the aquifer, (2) model design, (3) model calibration, (4) sensitivity analysis, and (5) reporting. The conceptual model is a conceptual description of the physical processes that govern groundwater flow in the aquifer system. Available data and reports for the model area were reviewed in development of the conceptual model. The conceptual model describes the hydrostratigraphy, structure, regional groundwater flow, transient groundwater conditions, recharge to, natural discharge from, hydraulic properties, water quality, and discharge via pumping for the aquifer.

Consistent with state water planning policy, the conceptual model for the Haskell-Knox-Baylor pod of the Seymour Aquifer was developed with the support of stakeholders through stakeholder forums. The purpose of the conceptual model documented here is to provide a description of the processes needed for development of a refined numerical groundwater availability model for the Seymour aquifer. The refined groundwater availability model will then provide a tool for Regional Water Planning Areas, Groundwater Conservation Districts, River Authorities, state planners, and other stakeholders for the evaluation of groundwater availability and to support the development of water management strategies and drought planning. The refined Seymour Aquifer groundwater availability model falls within two of the sixteen Texas Regional Water Planning Areas and one Groundwater Conservation District.

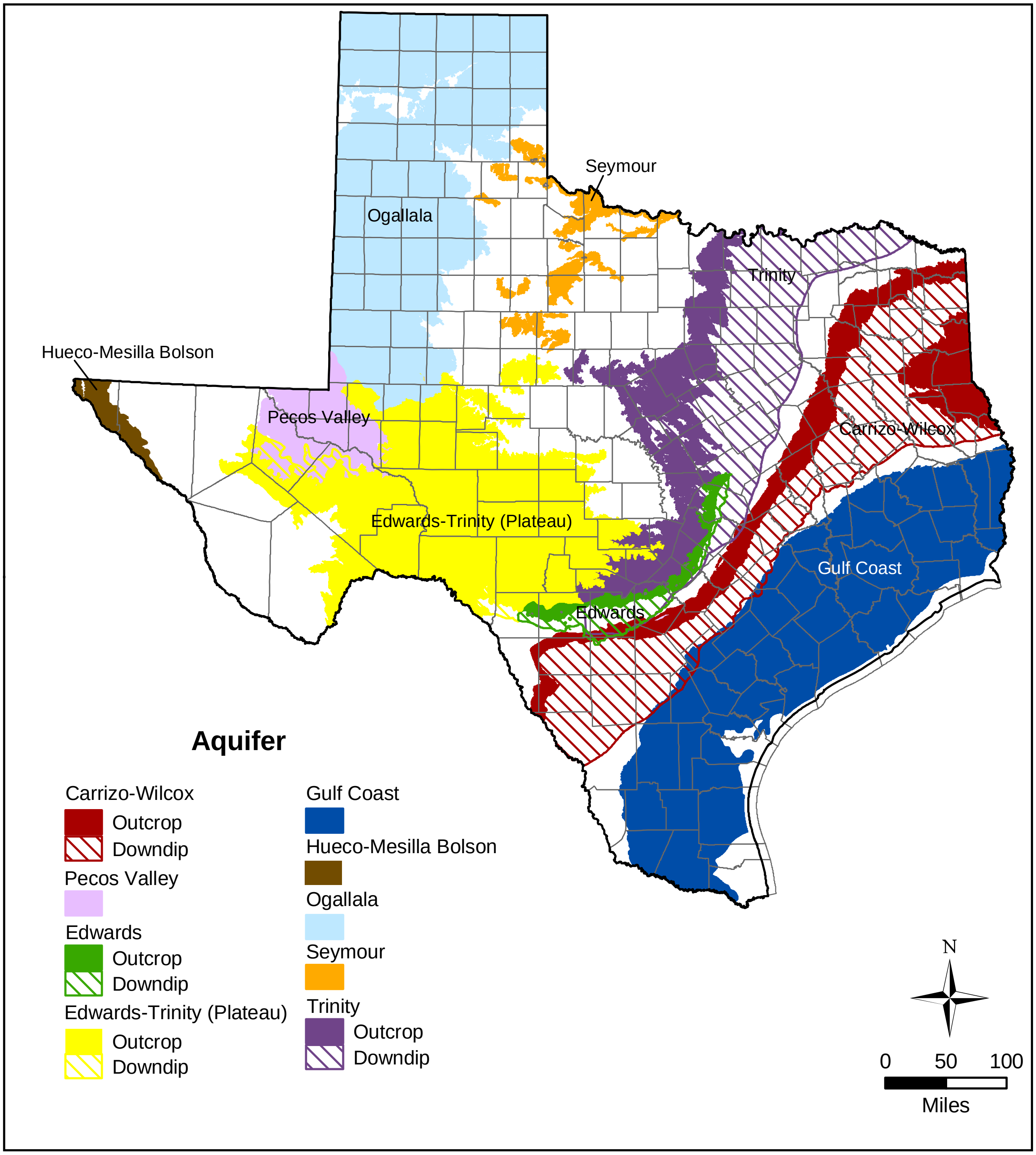

Figure 1.0.1 Locations of major aquifers in Texas (TWDB, 2006a).

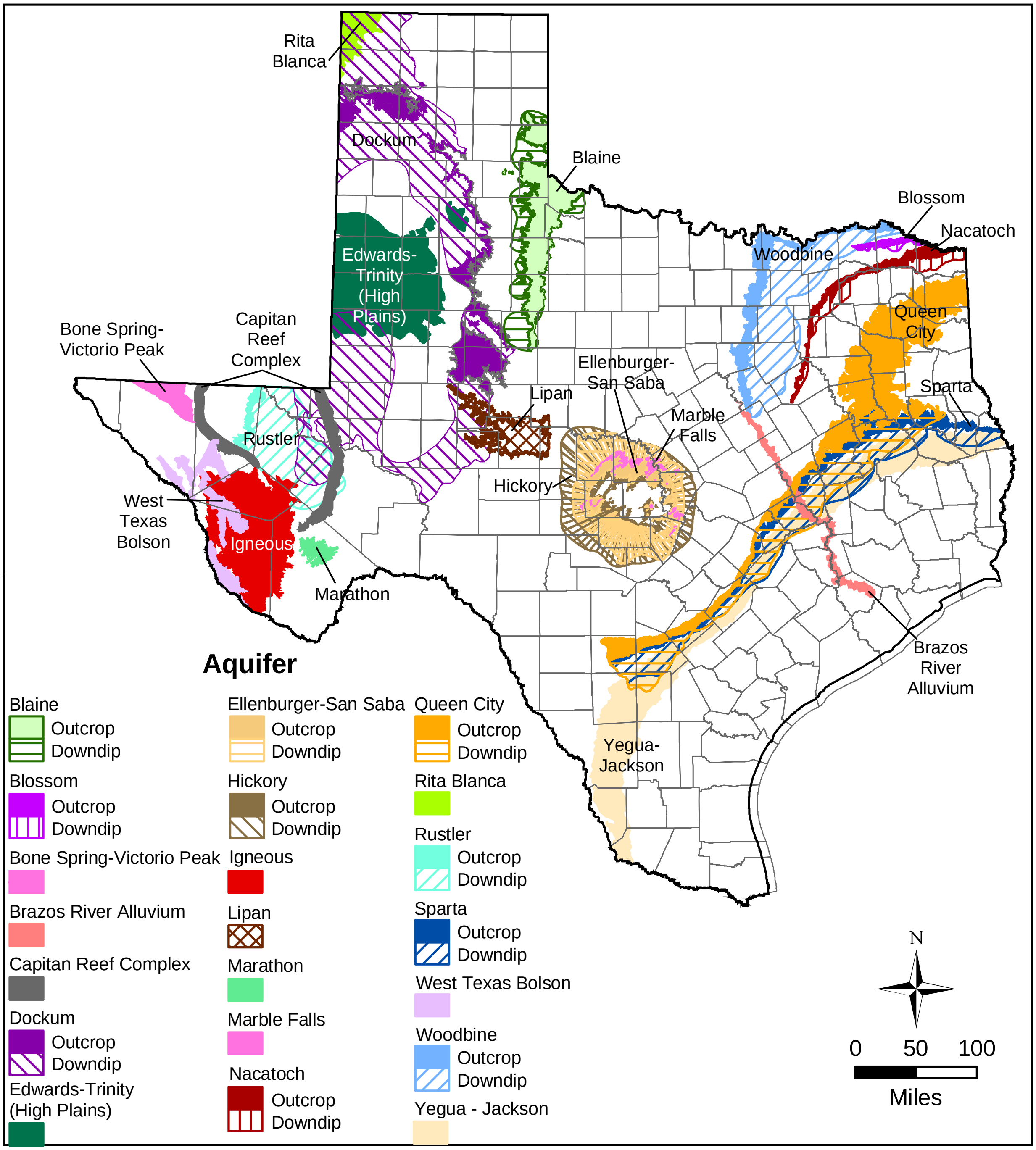

Figure 1.0.2 Locations of minor aquifers in Texas (TWDB, 2006b).

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2.0 Study Area

The Seymour Aquifer, as defined by the TWDB (Ashworth and Hopkins, 1995), consists of isolated pods of unconsolidated alluvium deposits of Quaternary age. The refined Seymour Aquifer groundwater availability model considers the pod located in Haskell, southern Knox, and western Baylor counties. The study area and active model boundary for this refined model are shown in Figure 2.0.1. Figure 2.0.2 shows the counties, roadways, cities, and towns included in the study area. The locations of rivers, streams, lakes, and reservoirs in the study area are shown in Figure 2.0.3. The extent of the Seymour Aquifer, the only major or minor aquifer located in the study area, is shown in Figure 2.0.4. Note that the Seymour Aquifer is exclusively a water-table aquifer with no subcrop.

Groundwater model boundaries are typically defined on the basis of surface or groundwater hydrologic boundaries. The lateral boundary of the active model area is defined to include the entirety of the large Seymour Aquifer pod located in Haskell, southern Knox, and western Baylor counties. The lateral boundary for the refined model was placed at the edge of the pod or along Lake Creek or the Brazos River where they fall outside of the pod. This boundary, projected to plan view, is shown in the report figures as a red solid line and provides the limits of the model area. Note that not all of the Seymour Aquifer located within the study area (see Figure 2.0.4) is included in the model area. This is because the objective of the refined model is to model only the large pod located in Haskell, southern Knox, and western Baylor counties.

The model area encompasses parts of two regional water planning areas (Figure 2.0.5). The majority of the model area lies within the Brazos G Regional Water Planning Area and a small portion lies within the Region B Regional Water Planning Area. The model area includes part of the Rolling Plains Groundwater Conservation District. This is the only Groundwater Conservation District located in the model area (Figure 2.0.6). The study area lies within a portion of one Groundwater Management Area (Figure 2.0.7). The Brazos River Authority, Red River Authority, and North Central Texas Municipal Water Authority are found in the study area (Figure 2.0.8). The major river basins in the active area are the Red and Brazos river basins (Figure 2.0.9).

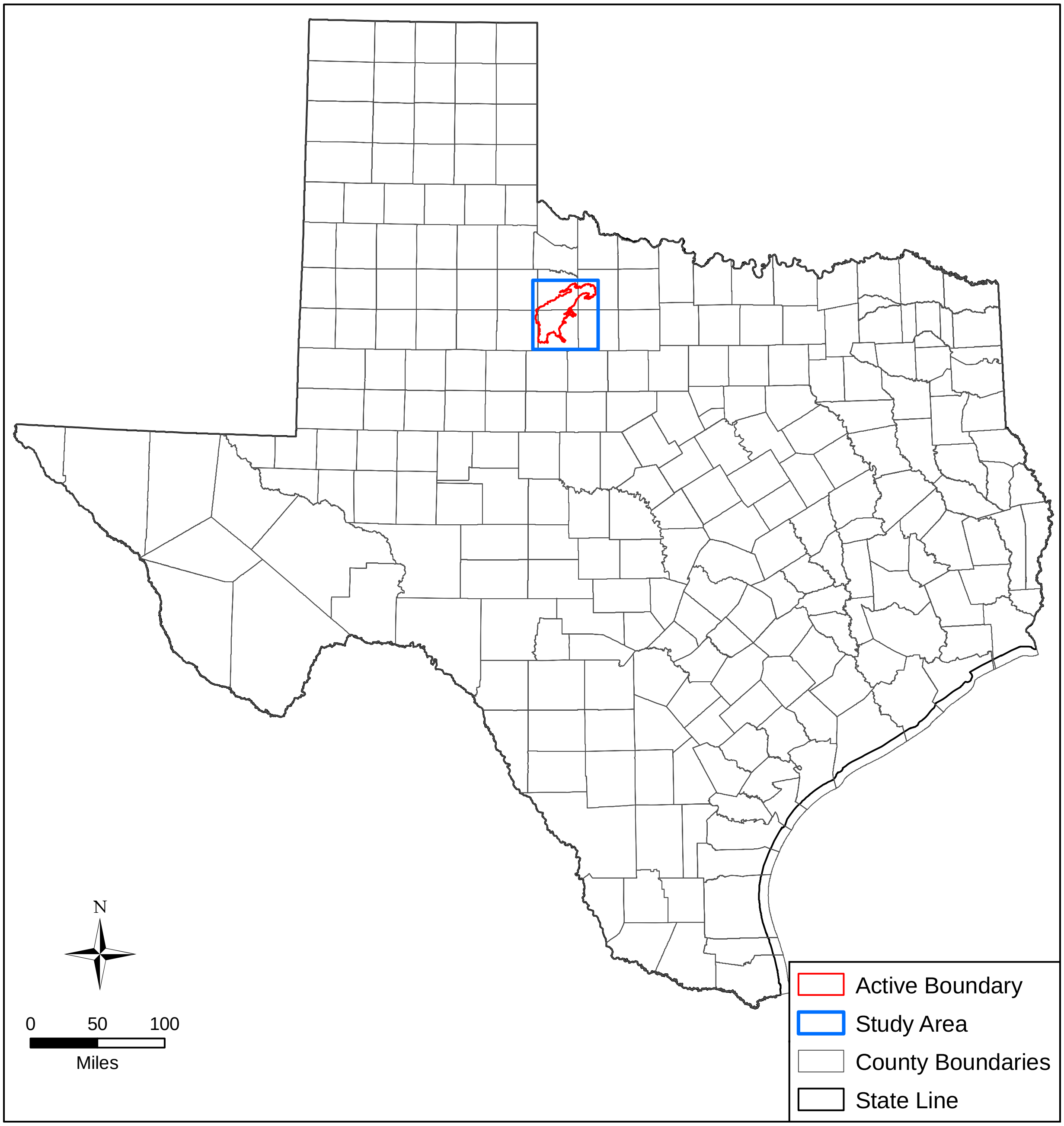

Figure 2.0.1 Location of study area and model boundary for the refined Seymour Aquifer groundwater availability model.

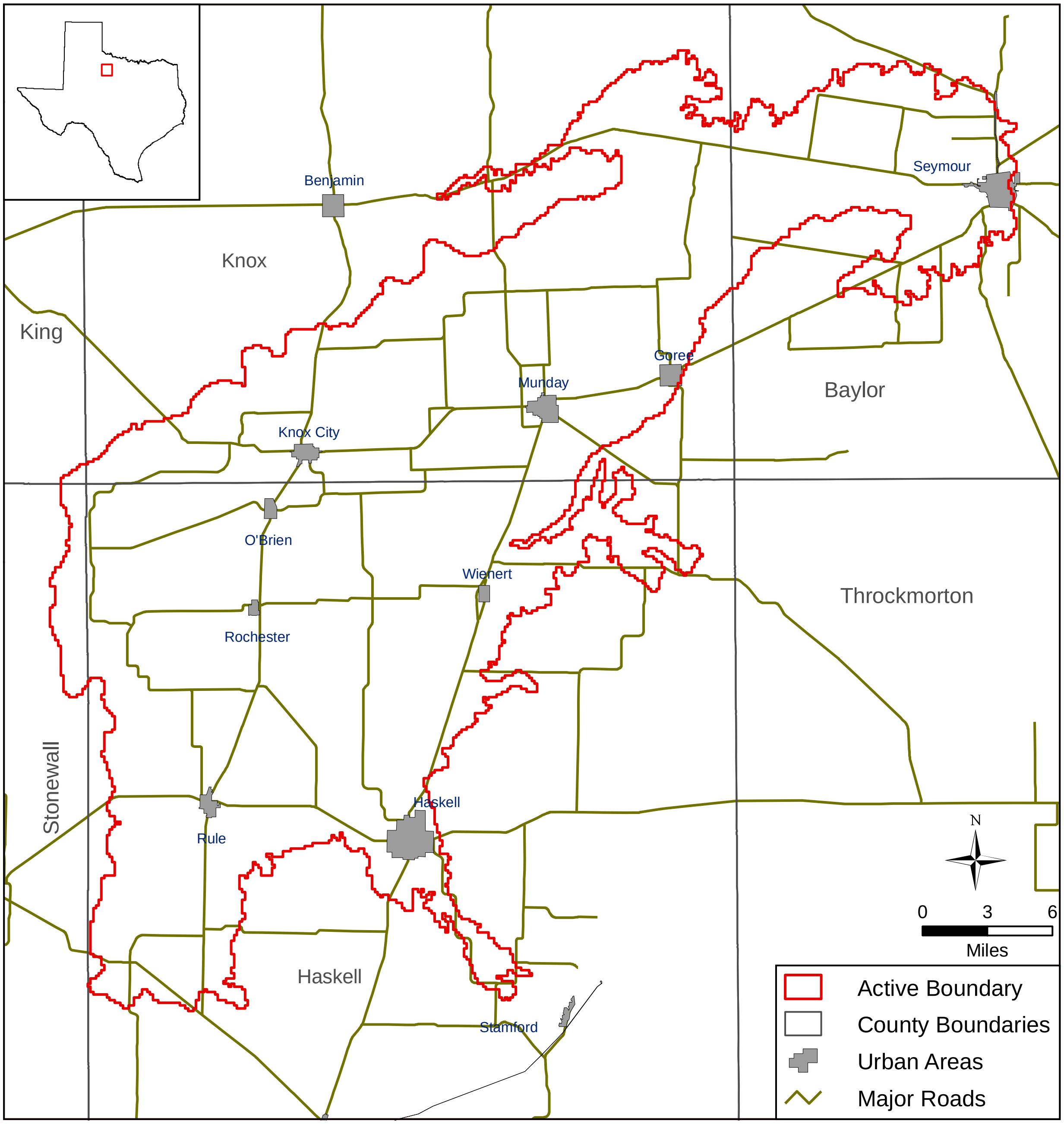

Figure 2.0.2 Location of study area showing county boundaries, cities, and major roadways (TWDB, 2006c; TWDB, 2006d).

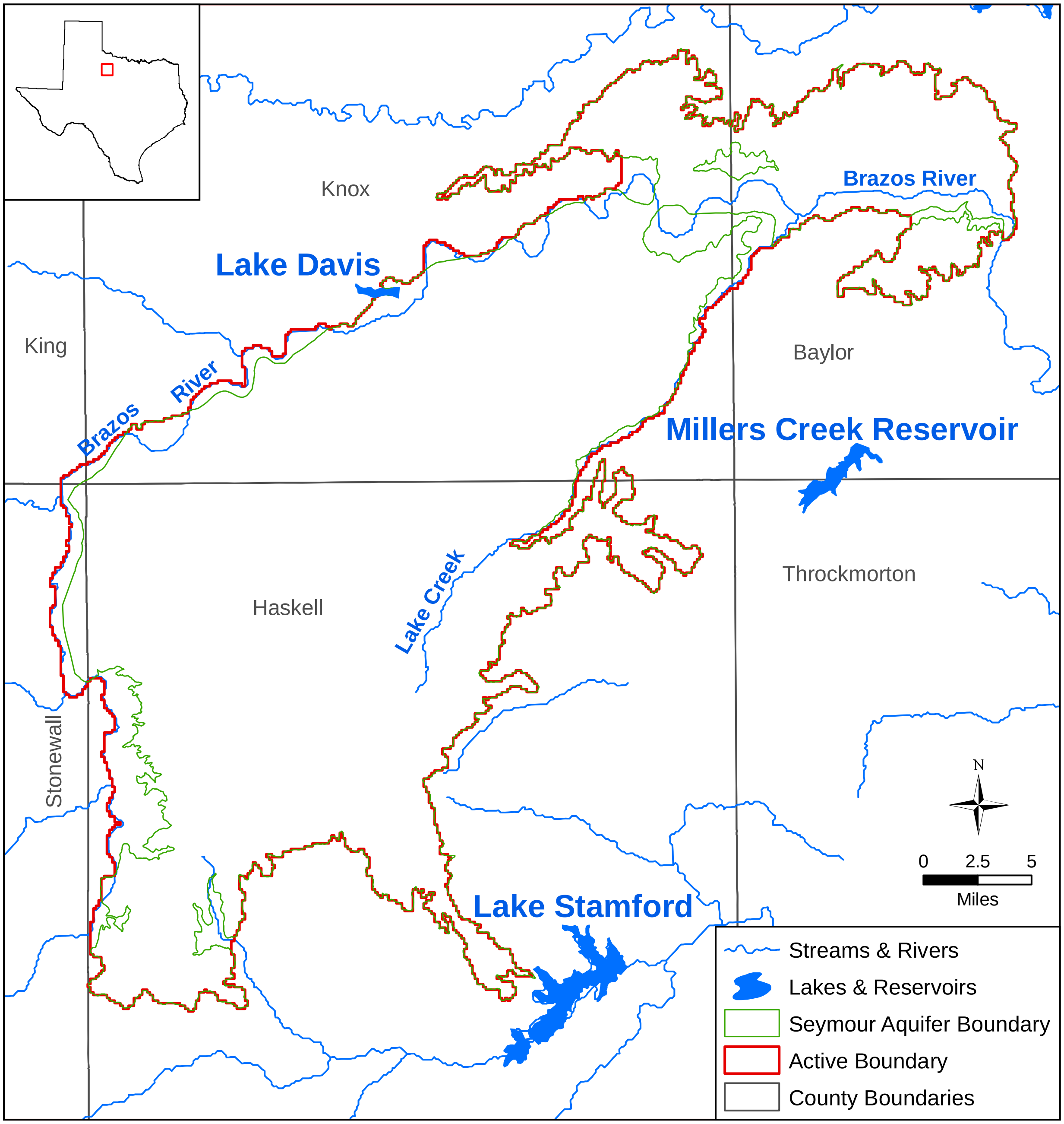

Figure 2.0.3 Location of study area showing lakes and rivers (TWDB, 2007a; Alexander and others, 1999).

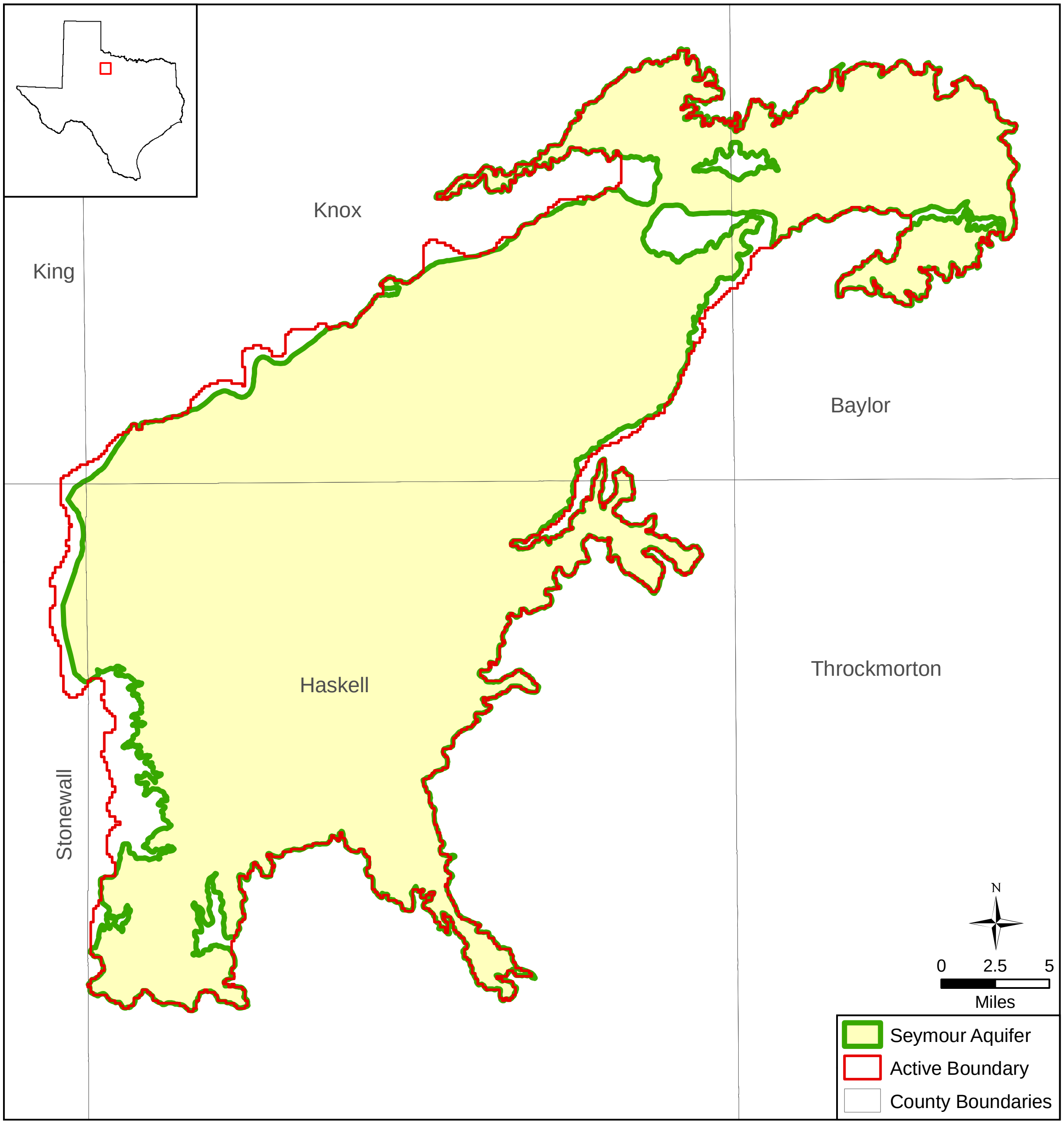

Figure 2.0.4 Areal extent of major aquifers in the study area (TWDB, 2006a).

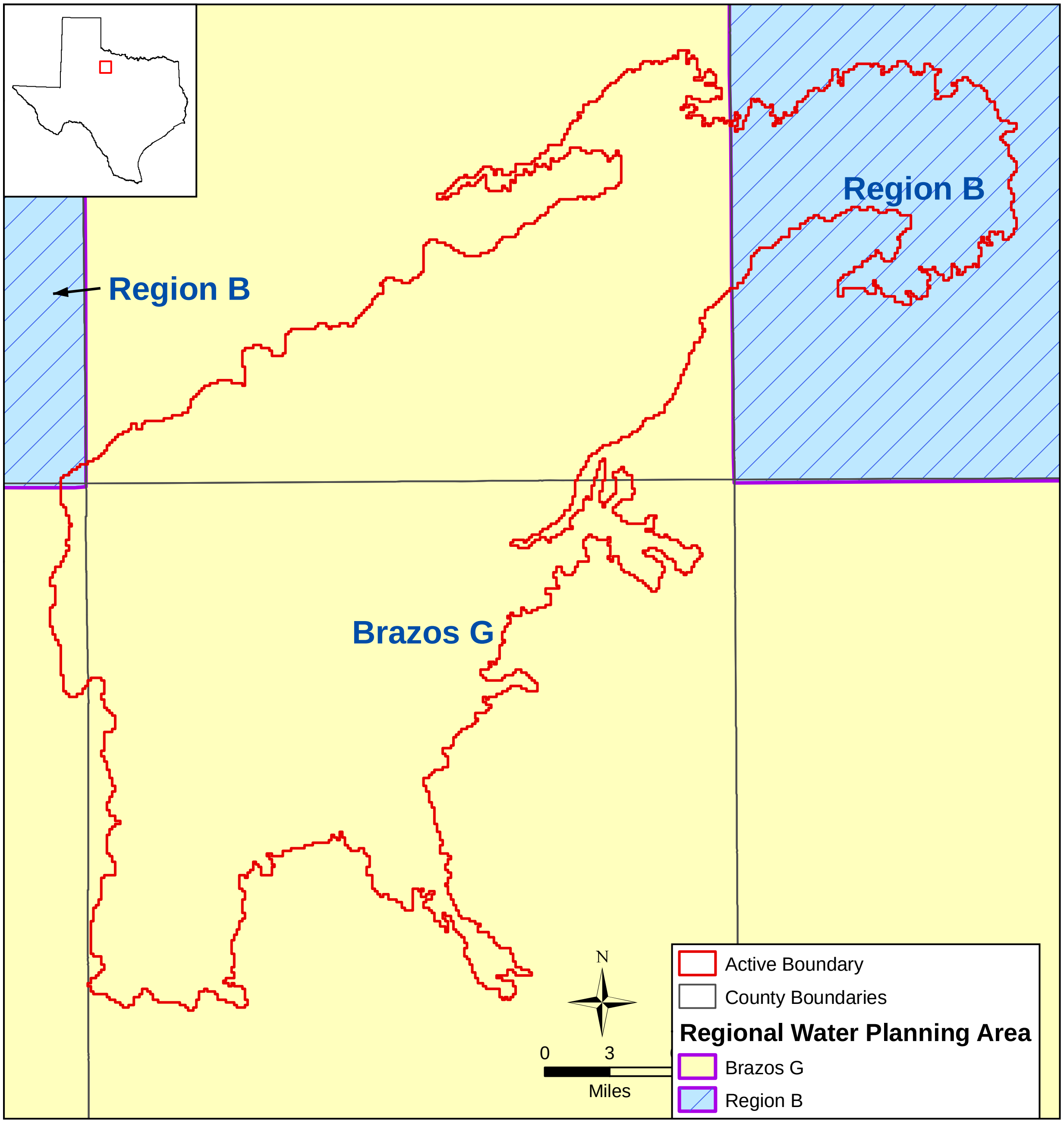

Figure 2.0.5 Locations of Regional Water Planning Areas in the study area (TWDB, 2008a).

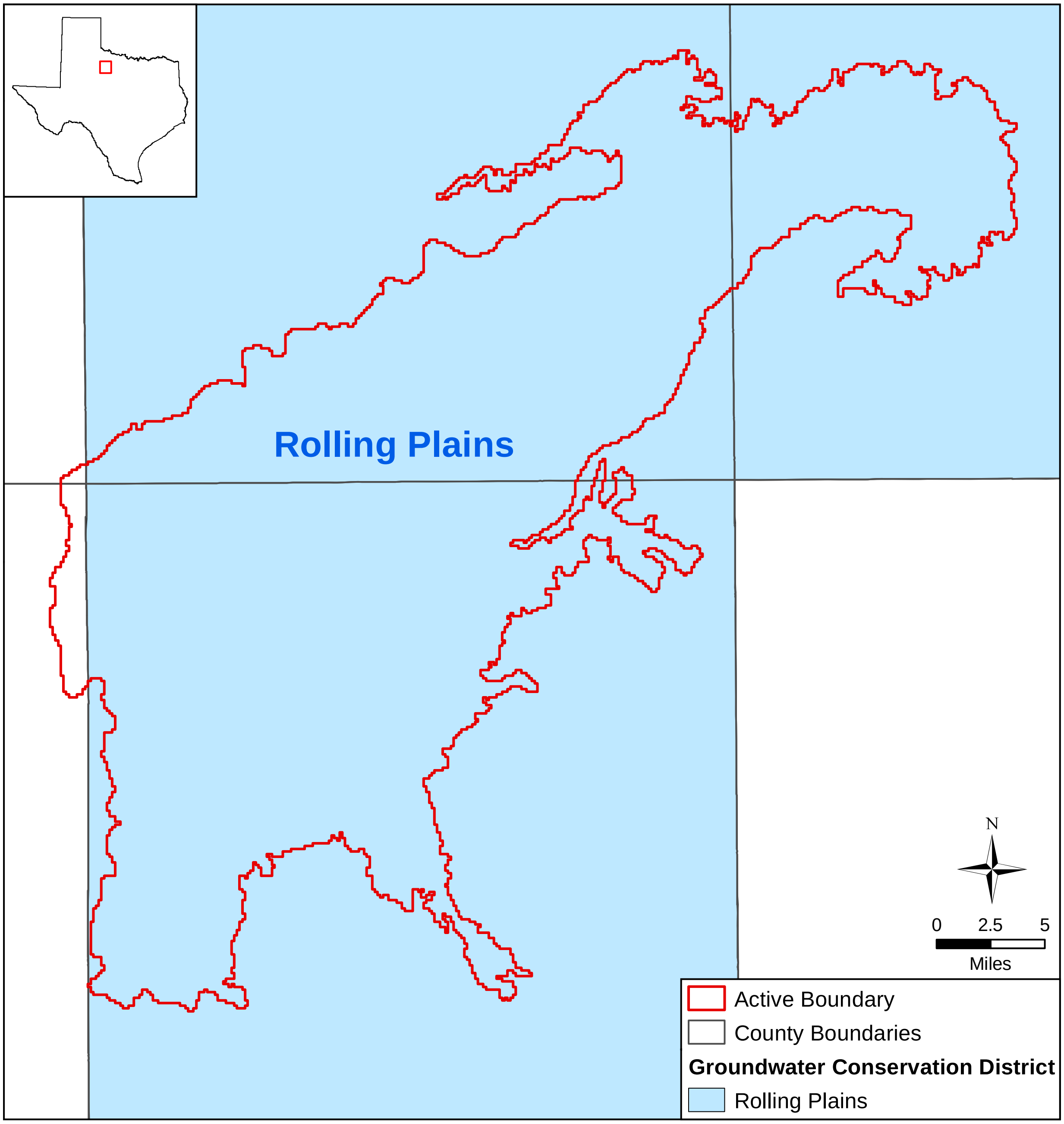

Figure 2.0.6 Location of the Groundwater Conservation District in the study area from the October 2008 Groundwater Conservation District map (TWDB, 2009a).

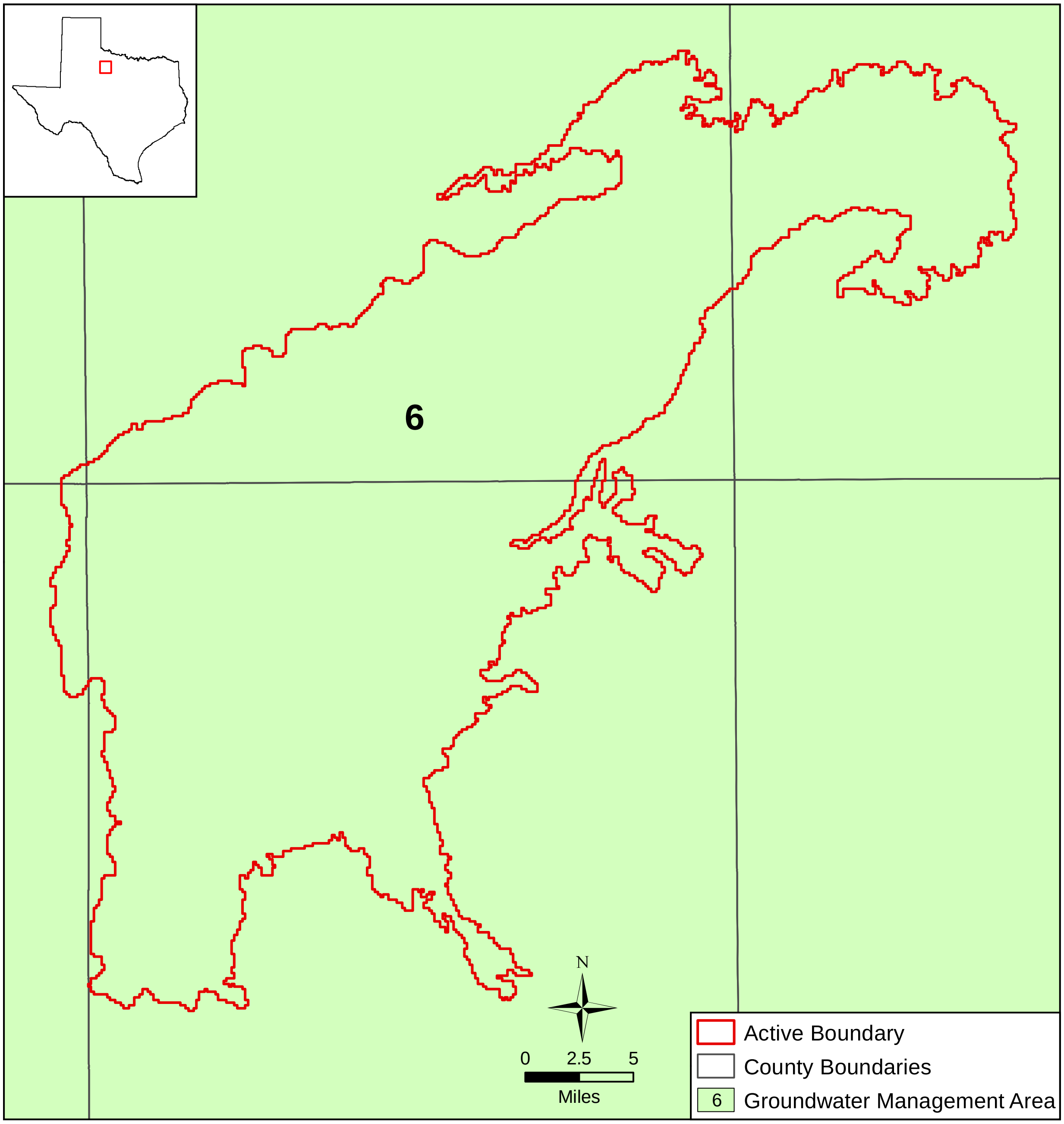

Figure 2.0.7 Location of the Groundwater Management Area in the study area (TWDB, 2007b).

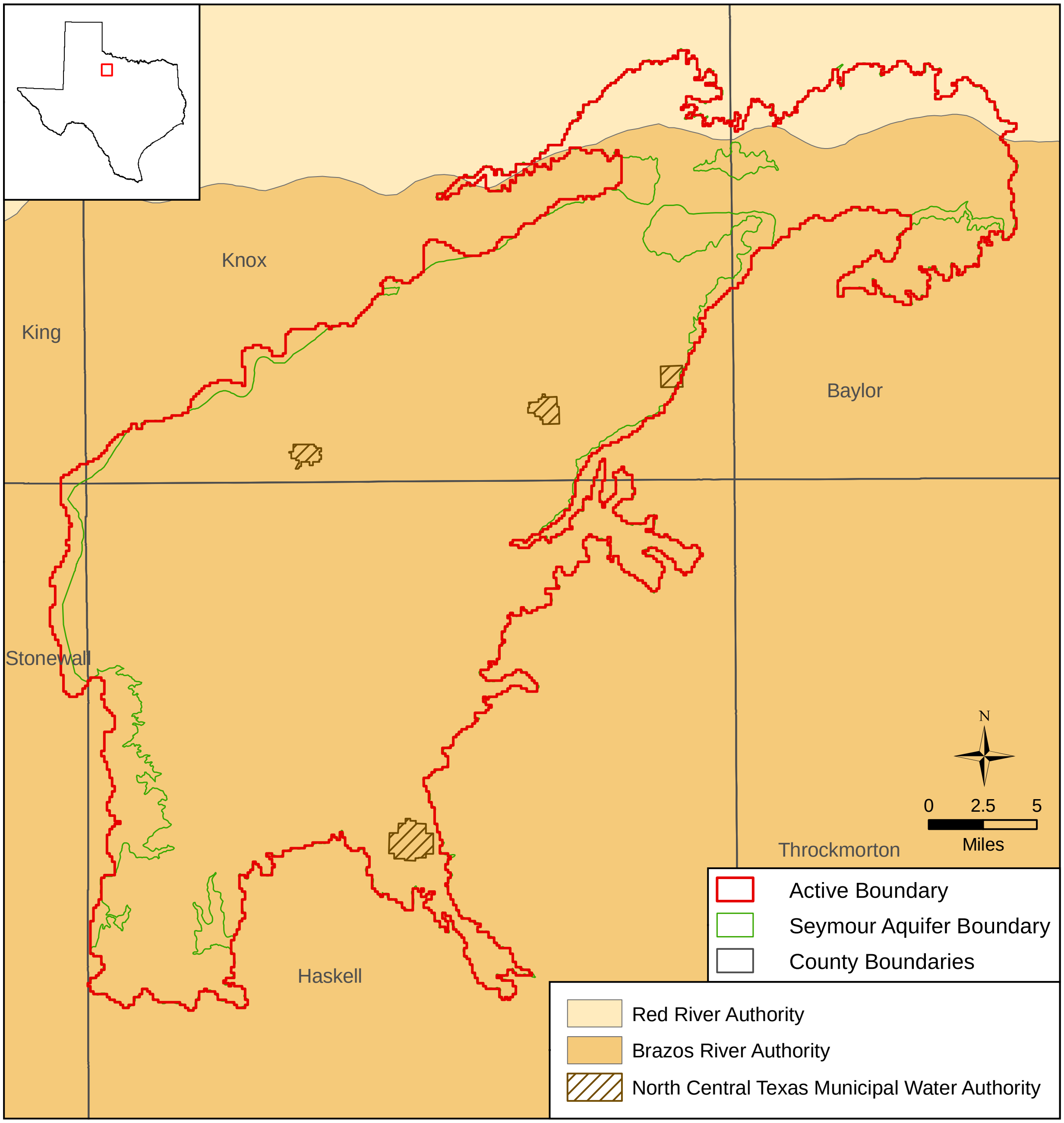

Figure 2.0.8 Location of River Authorities in the study area (TWDB, 1999).

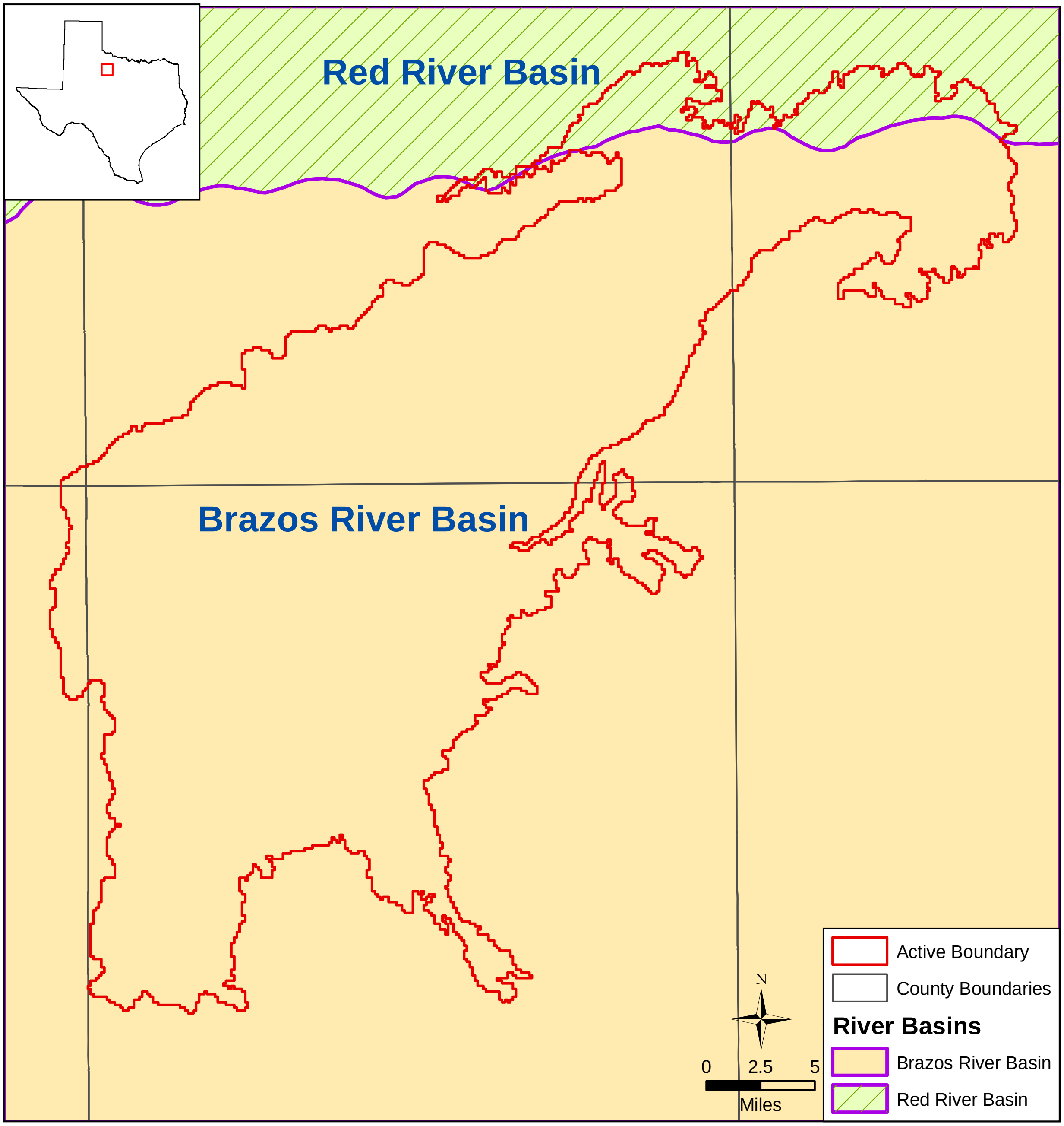

Figure 2.0.9 Major river basins in the study area (TWDB, 2008b).

2.1 Physiography and Climate

The study area is located completely within the North-Central Plains physiographic province (Figure 2.1.1). The North-Central Plains are "an erosional surface that developed on upper Paleozoic formations…" (Wermund, 1996). This province consists of local prairies as well as hills and rolling plains. The topography is characterized by low north-south trending ridges. The geologic structure is predominantly a westward dip with minor faults. The bedrock types for the North-Central Plains province are limestone, sandstone, and shale.

The study is located completely within the Rolling Plains ecological region (Texas Parks and Wildlife, 2009) (Figure 2.1.2). Together with the High Plains region, the Rolling Plains represent the southern end of the Great Plains of the central United States. This region originally consisted of grassland or savannah communities that, due to over grazing by domestic livestock and a reduction in natural fires, changed to predominately brushland and woodland habitats (Texas Parks and Wildlife, 2007). The region has also been impacted by the expansion of honey mesquite in the study area, which has increased erosion and decreased water absorption (Texas Parks and Wildlife, 2007). Much of the flat terrain within the region has been developed for agricultural purposes.

Figure 2.1.3 provides a topographic map of the study area. Generally, the surface elevation decreases from the southern portion of the Seymour Aquifer pod to the northeastern portion of the pod. The ground-surface elevation within the model boundaries varies from a high of about 1,700 feet above sea level in Haskell County to a low of about 1,240 feet above sea level just south of the Brazos River in Baylor County.

The climate in the active model area is classified as the Subtropical Subhumid subcategory of the Modified Marine or Subtropical climate. (Larkin and Bomar, 1983) (Figure 2.1.4). Larkin and Bomar (1983) state that "A marine climate is caused by the predominant onshore flow of tropical maritime air from the Gulf of Mexico. The onshore flow is modified by a decrease in moisture content from east to west and by intermittent seasonal intrusions of continental air". The Subhumid category of the Subtropical climate is characterized by hot summers and dry winters (Larken and Bomar, 1983). In general, most rainfall occurs during the growing season from

April through October. Often, rainfall is heavy over short periods of time. This leads to occasional flooding and significant periods of drought. A severe drought was experienced in the study area in the 1950s.

Figure 2.1.5 shows that the mean annual temperature in the study area ranges from a high of about 65 degrees Fahrenheit in the east to a low of about 63 degrees Fahrenheit in the west (Texas A&M University, 2002). Monthly variations in temperature are shown in Figure 2.1.6 for two locations in the study area. This figure shows monthly average mid-range, average maximum, and average minimum temperatures. These monthly temperatures were calculated by first averaging minimum and maximum daily temperatures from the National Climatic Data Center to get average monthly values. This was done for every month from January 1948 through August 2002. For each month, the average minimum and maximum values for all the years were then averaged to obtained the monthly average mid-range values shown in Figure 2.1.6.

Figure 2.1.7 shows that precipitation data are available at 13 stations in the study area (National Climatic Data Center, 2001). Measurement of precipitation at most gages began in the 1940s. In general, measurements are not continuous on a month-by-month or year-by-year basis for the gages. Annual precipitation recorded at two stations within the model area is shown in Figure 2.1.8. Figure 2.1.9 provides a raster data post plot of the Parameter-Elevation Regressions on Independent Slopes Model (Oregon State University, 2002) of average annual precipitation across the study area based on data for the period from 1971 to 2000. Generally, the average annual precipitation decreases from a high of about 27.5 inches per year in the east to a low of about 24.5 inches per year in the west.

The average annual net pan evaporation rate in the study area ranges from a high of 99 inches per year to a low of 90 inches per year (Figure 2.1.10). The majority of the model area falls within one-degree quadrangle 408, which has an average annual net pan evaporation rate of 92 inches per year. The pan evaporation rate significantly exceeds the annual average rainfall. The greatest rainfall deficit of about 68 inches per year occurs along the western side of the model area. Monthly variations in lake surface evaporation are shown in Figure 2.1.11 for one-degree quadrangle 408. These values represent the average of the monthly lake surface evaporation data for January 1954 through December 2004 (TWDB, 2009b). The annual average lake surface evaporation rate is about 63 inches per year for one-degree quadrangle 408. Potential evapotranspiration, a measure of the ability of the atmosphere to remove water from ground surface by evaporation and transpiration assuming an infinite water supply, ranges from a low of about 63.5 inches per year to a high of about 67 inches per year in the study area (Figure 2.1.12).

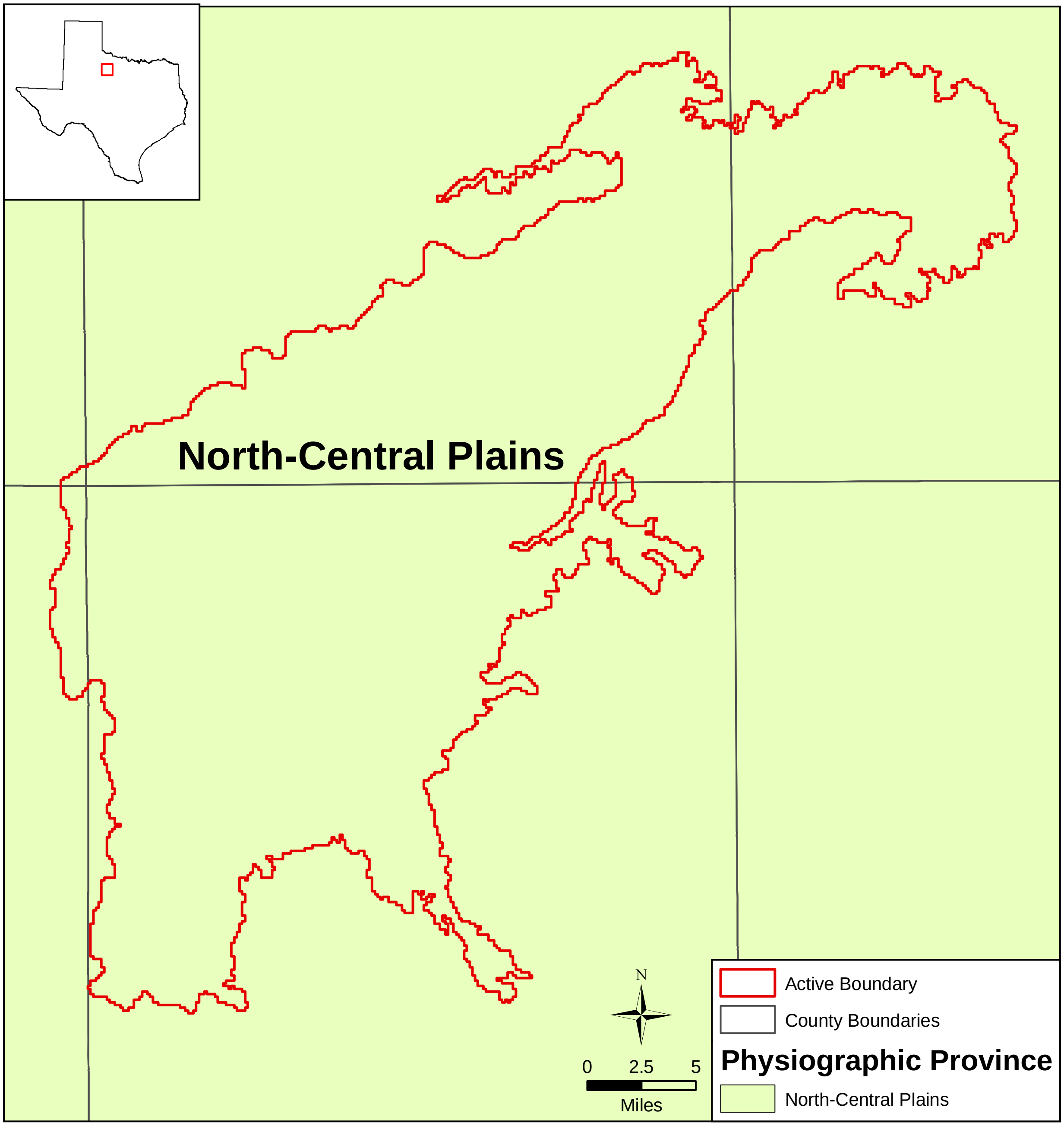

Figure 2.1.1 Physiographic province in the study area (University of Texas at Austin, Bureau of Economic Geology, 1996).

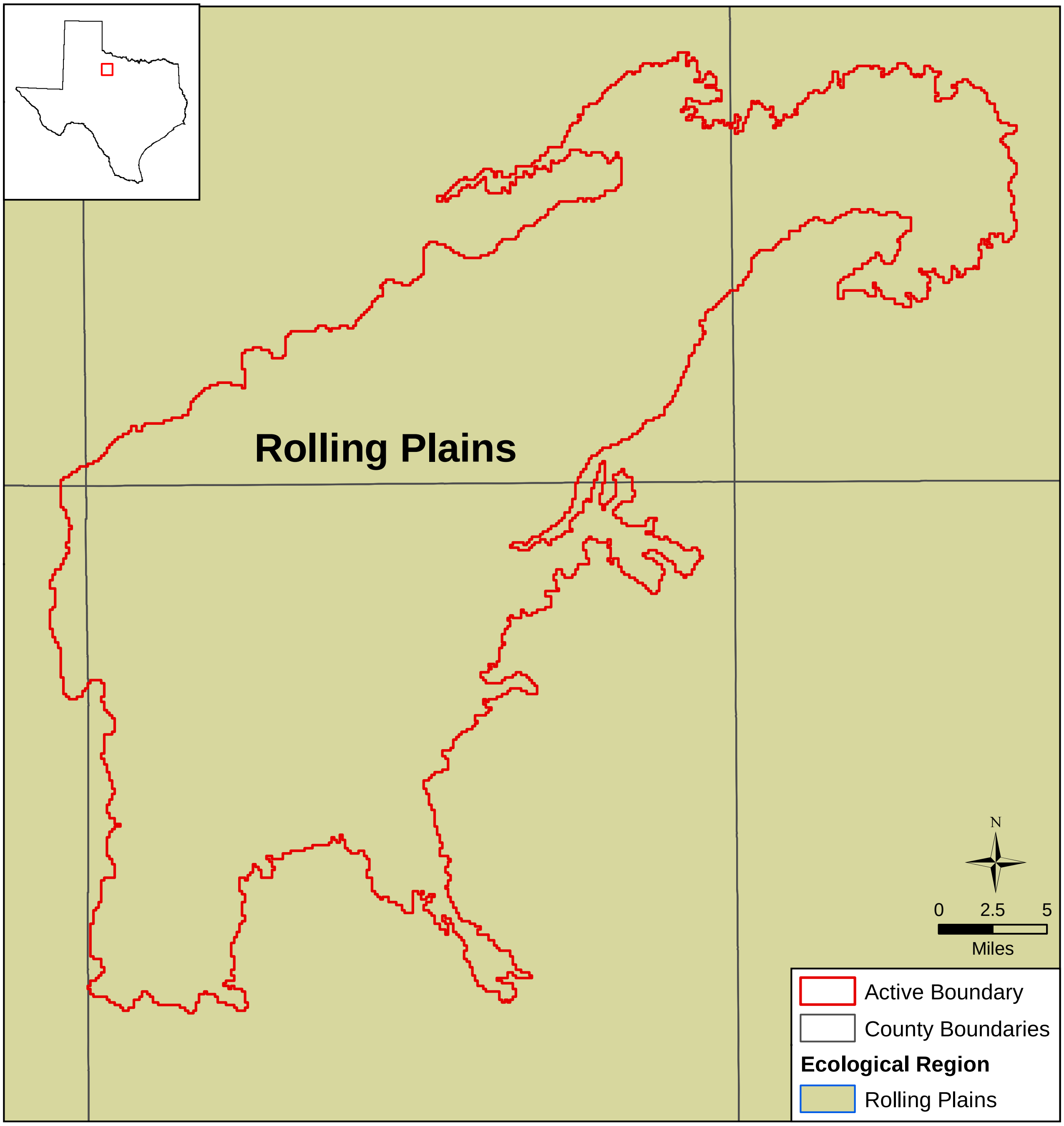

Figure 2.1.2 Ecological region in the study area (Texas Parks and Wildlife, 2009).

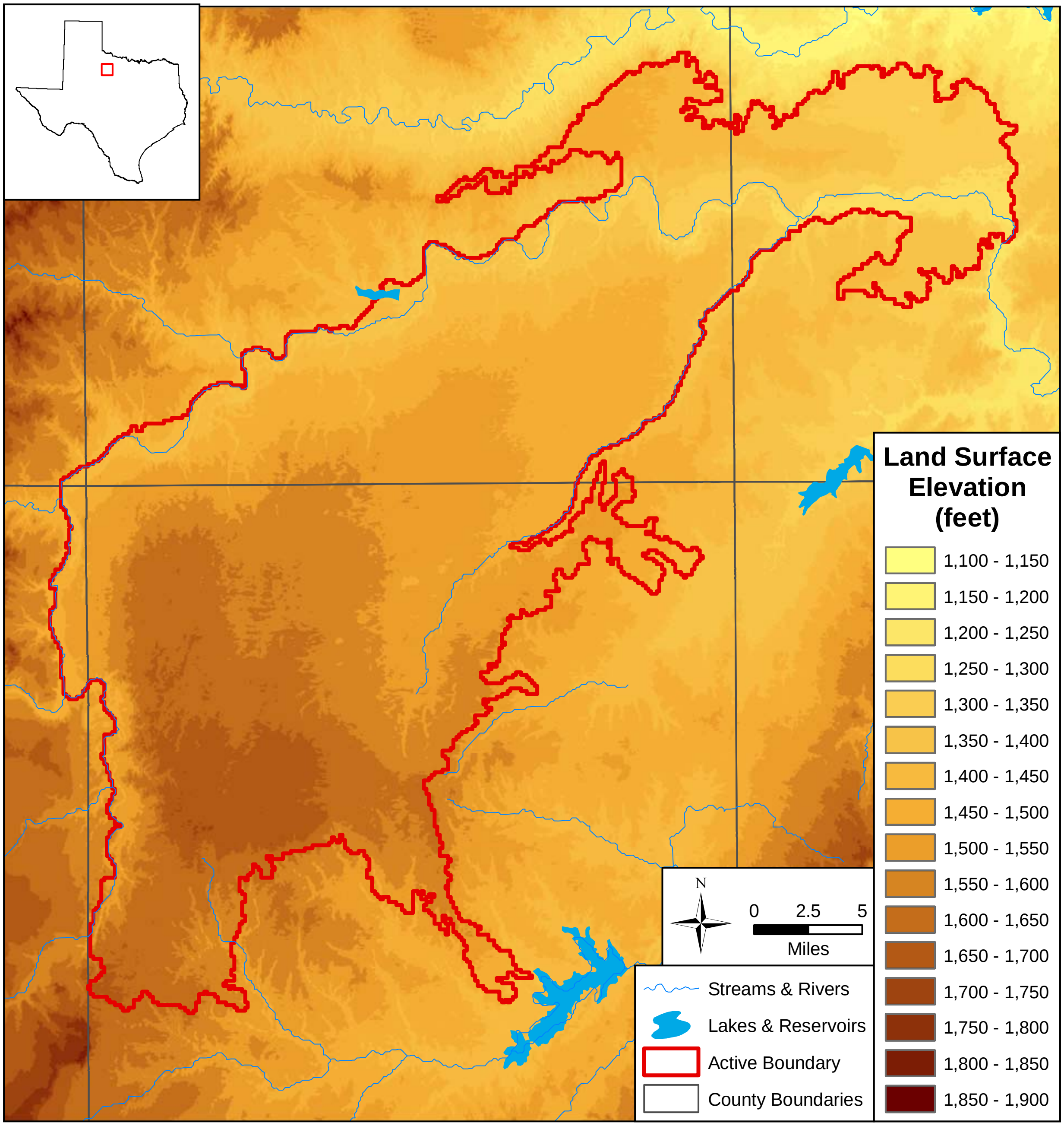

Figure 2.1.3 Topographic map of the study (United States Geological Survey, 2006).

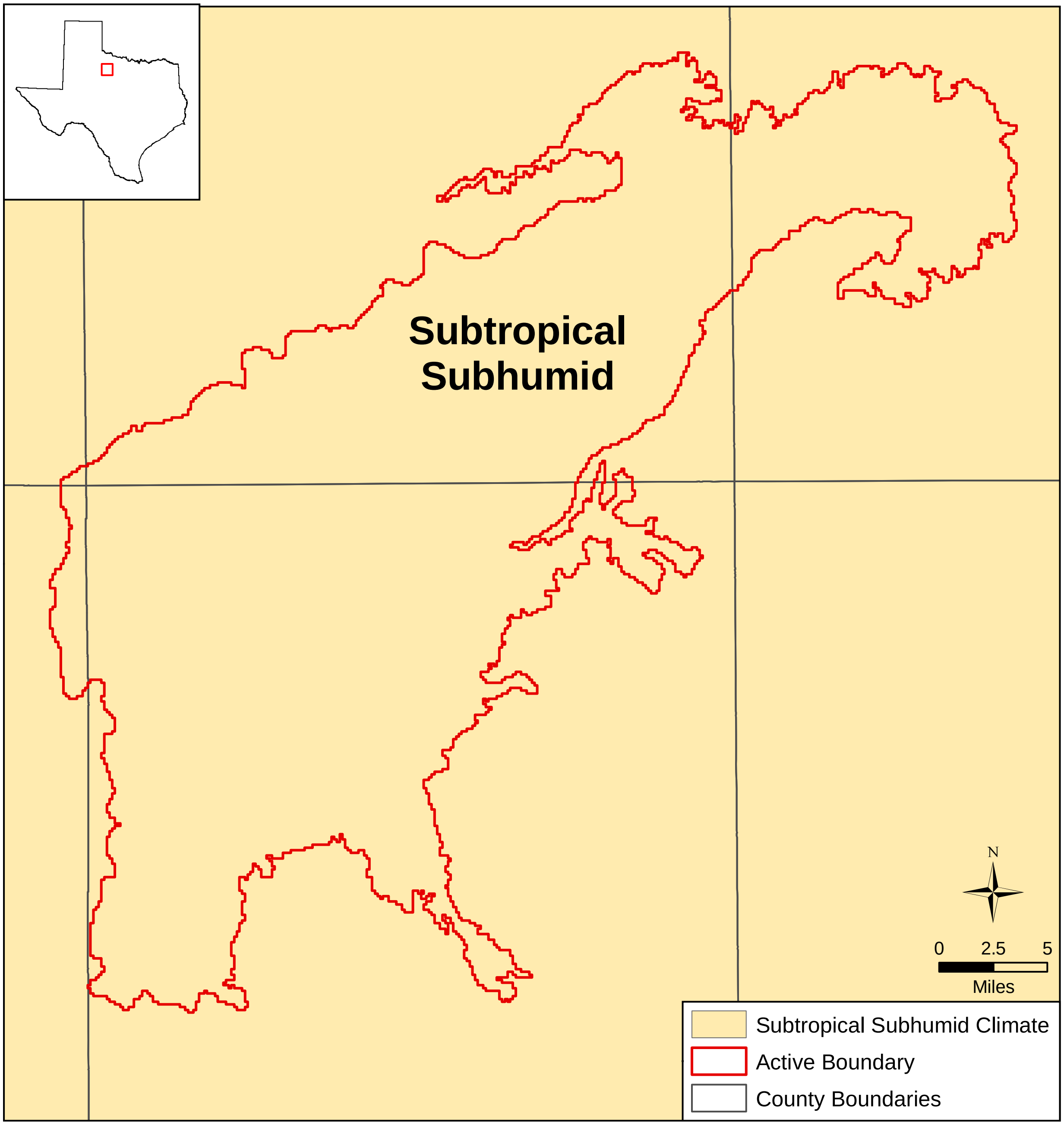

Figure 2.1.4 Climate classification in the study area (Larkin and Bomar, 1983).

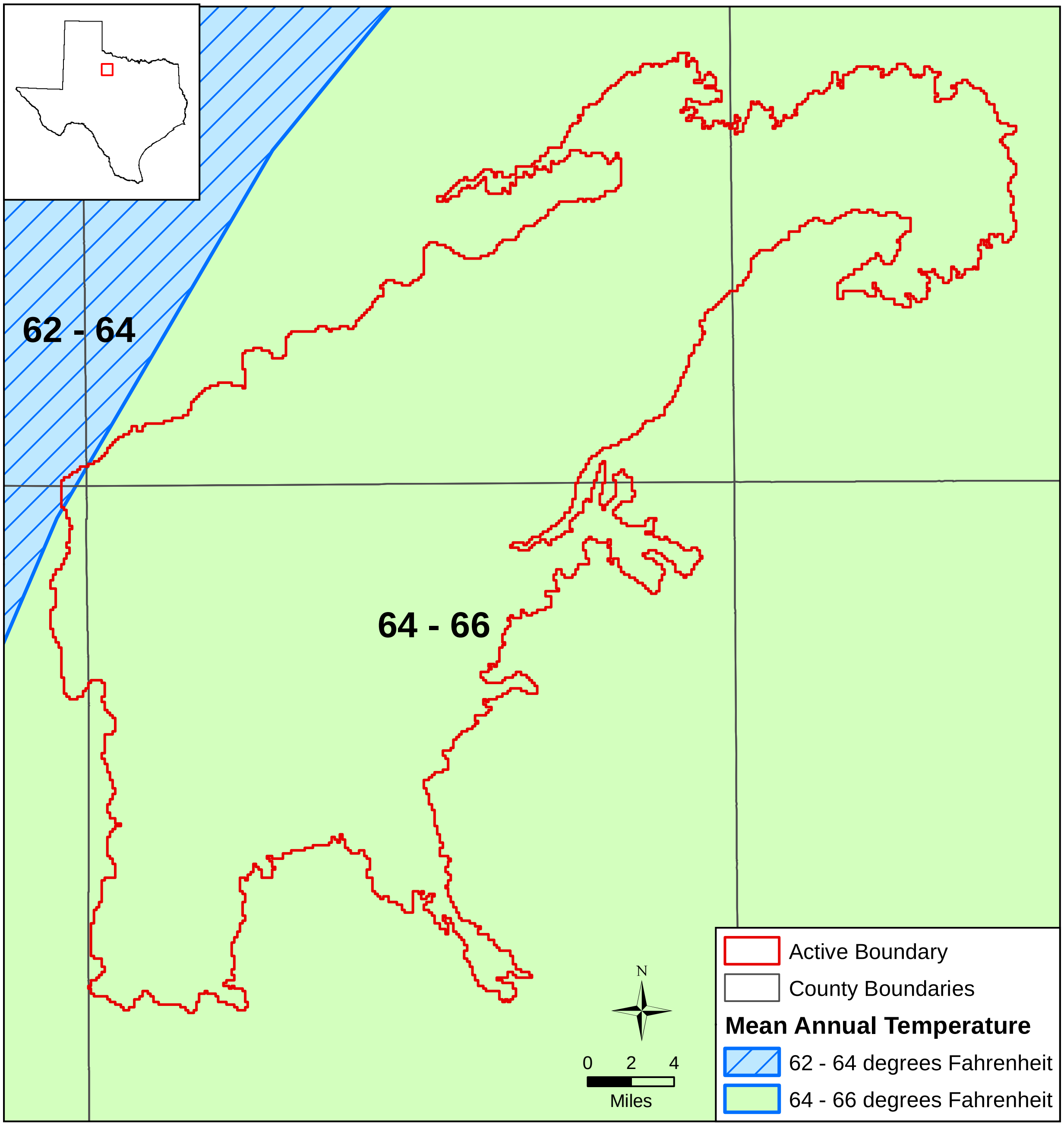

Figure 2.1.5 Average annual air temperature in the study area (Texas A&M University, 2002).

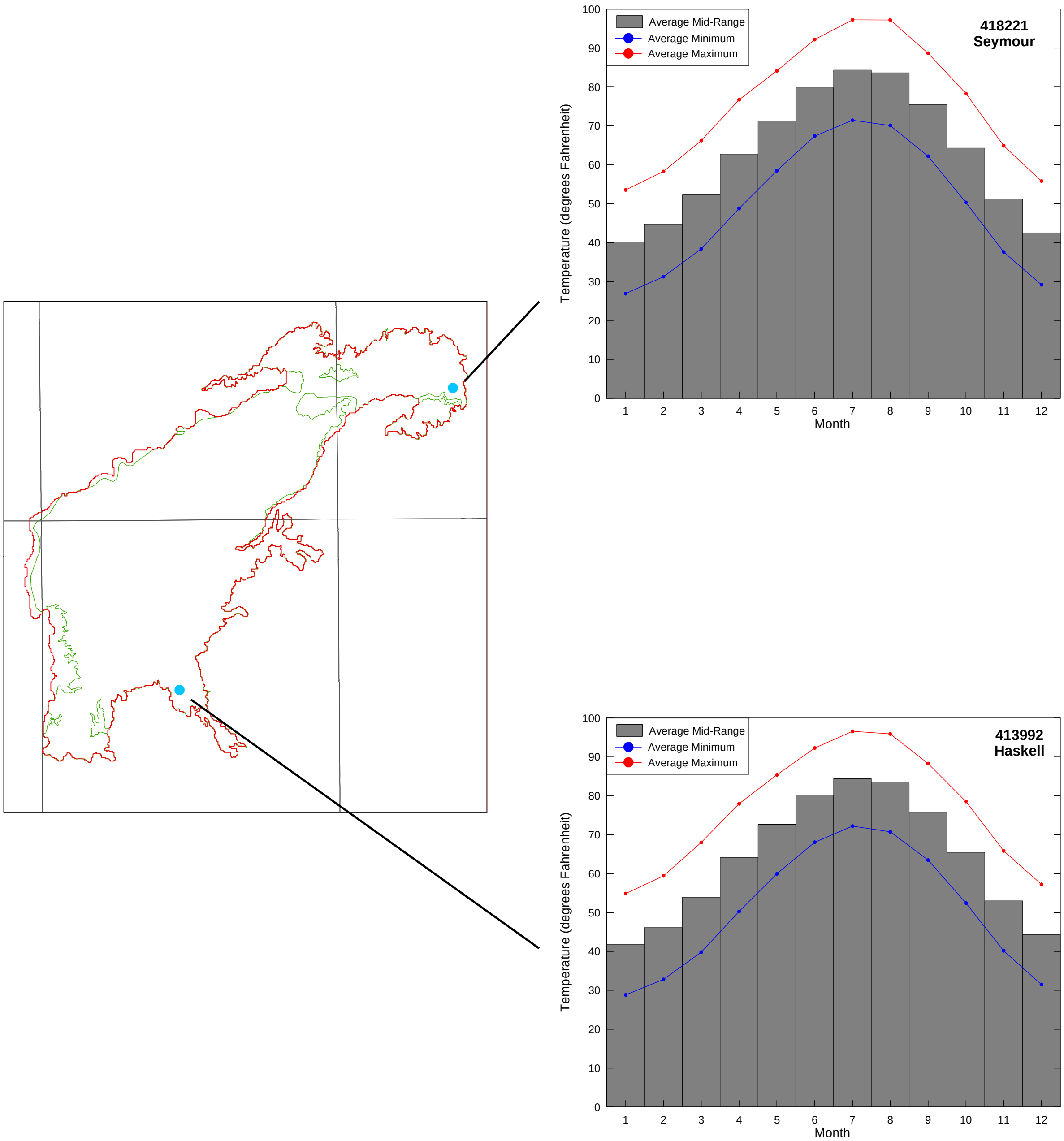

Figure 2.1.6 Average minimum, mid-range, and maximum monthly temperatures at two locations in the study area (National Climatic Data Center, 2001).

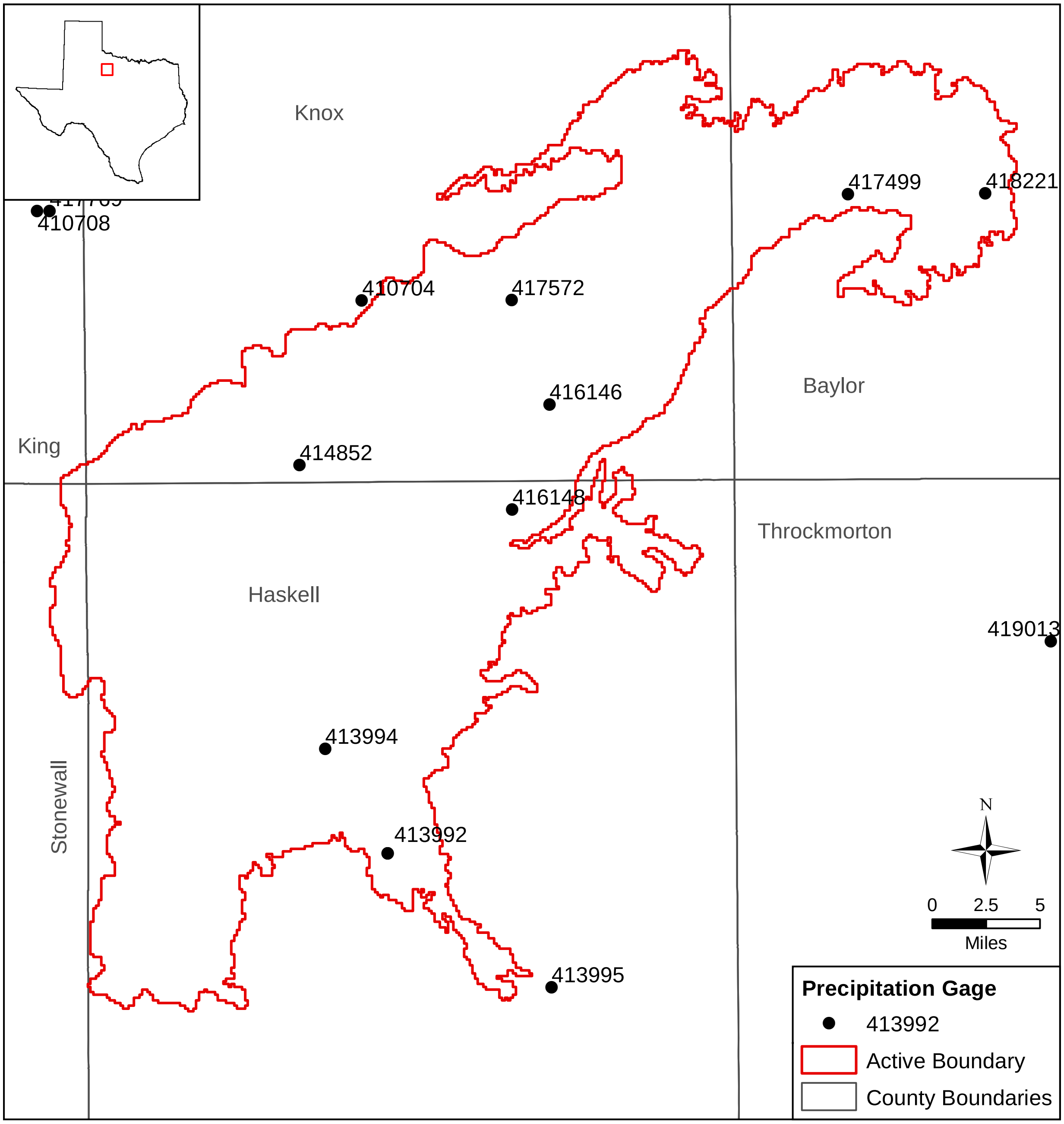

Figure 2.1.7 Location of precipitation gages in the study area (National Climatic Data Center, 2001).

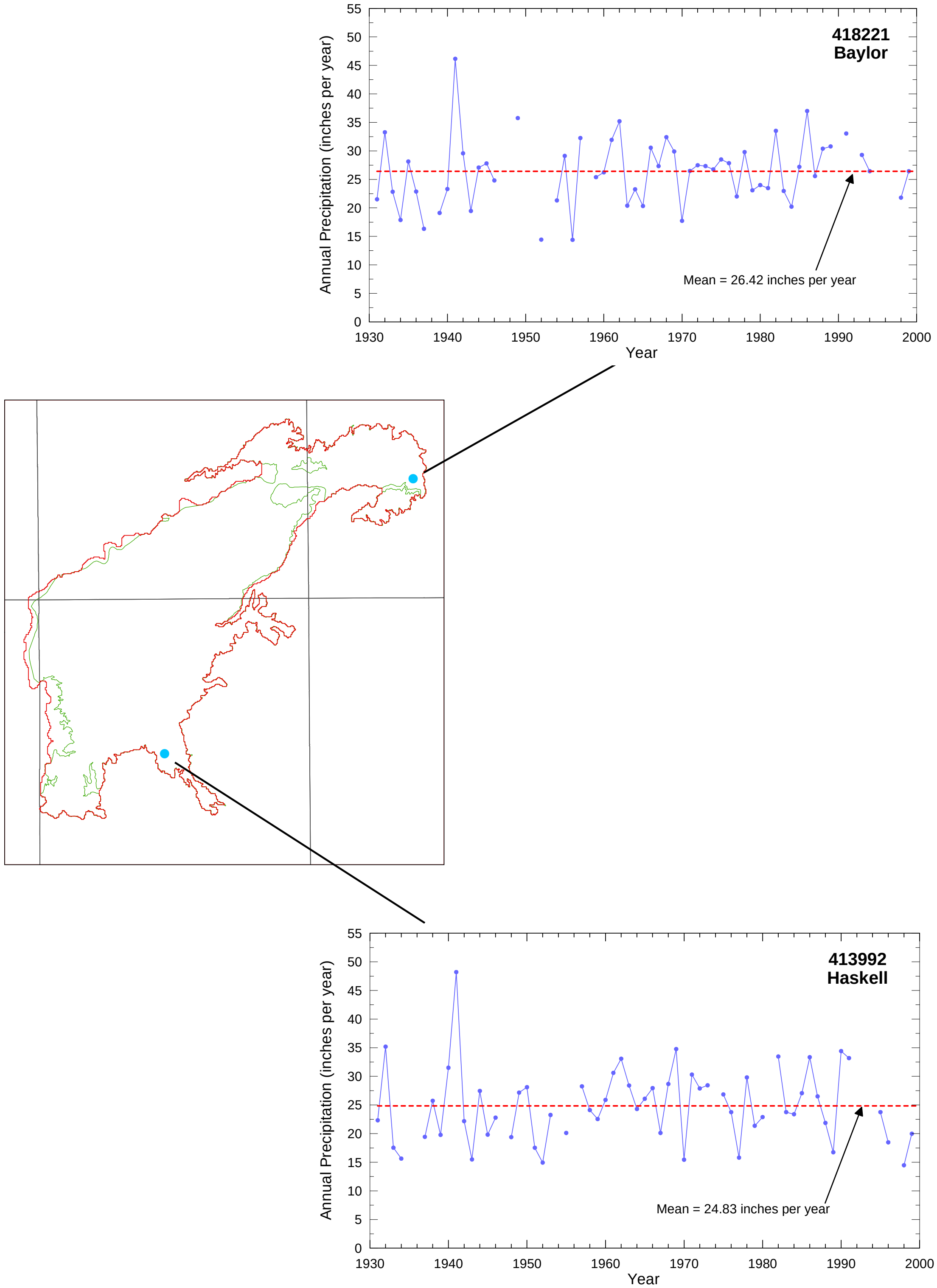

Figure 2.1.8 Annual precipitation time series at two locations in the study area (National Climatic Data Center, 2001). (A discontinuous line indicates a break in the data. The dashed red line represents the mean annual precipitation.)

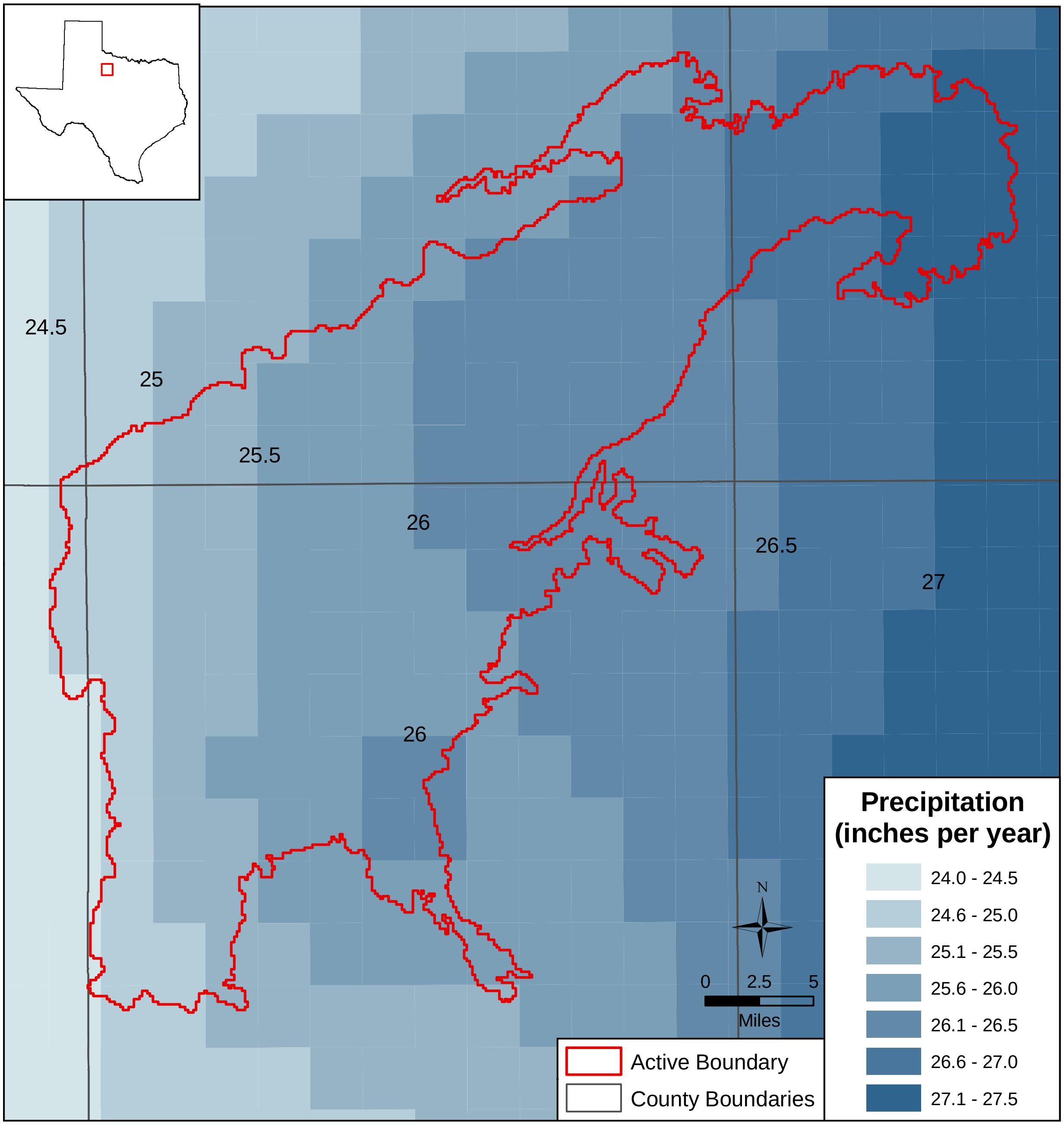

Figure 2.1.9 Average annual precipitation over the study area (Oregon State University, 2002).

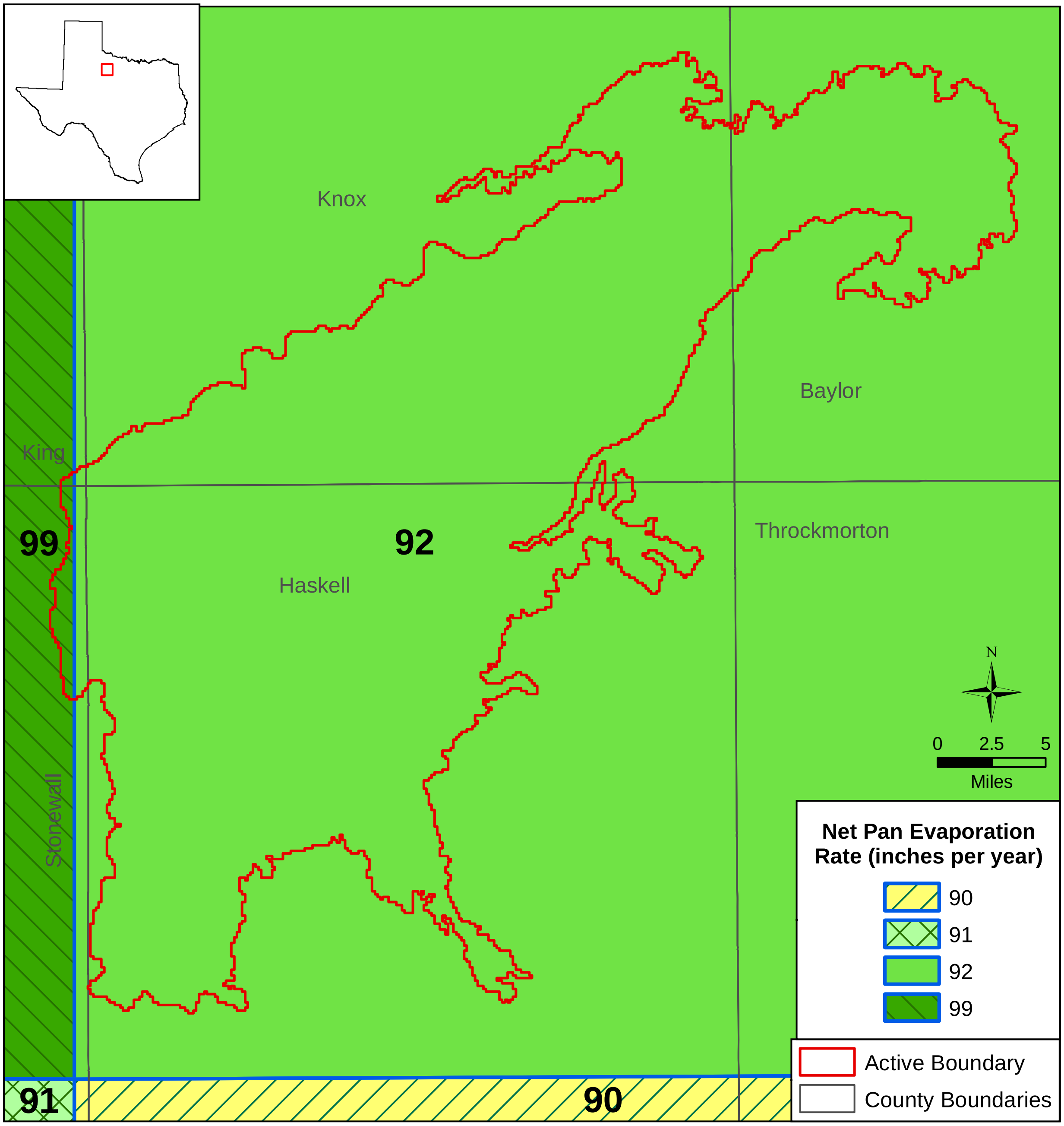

Figure 2.1.10 Average annual net pan evaporation over the study area (TWDB, 2009b).

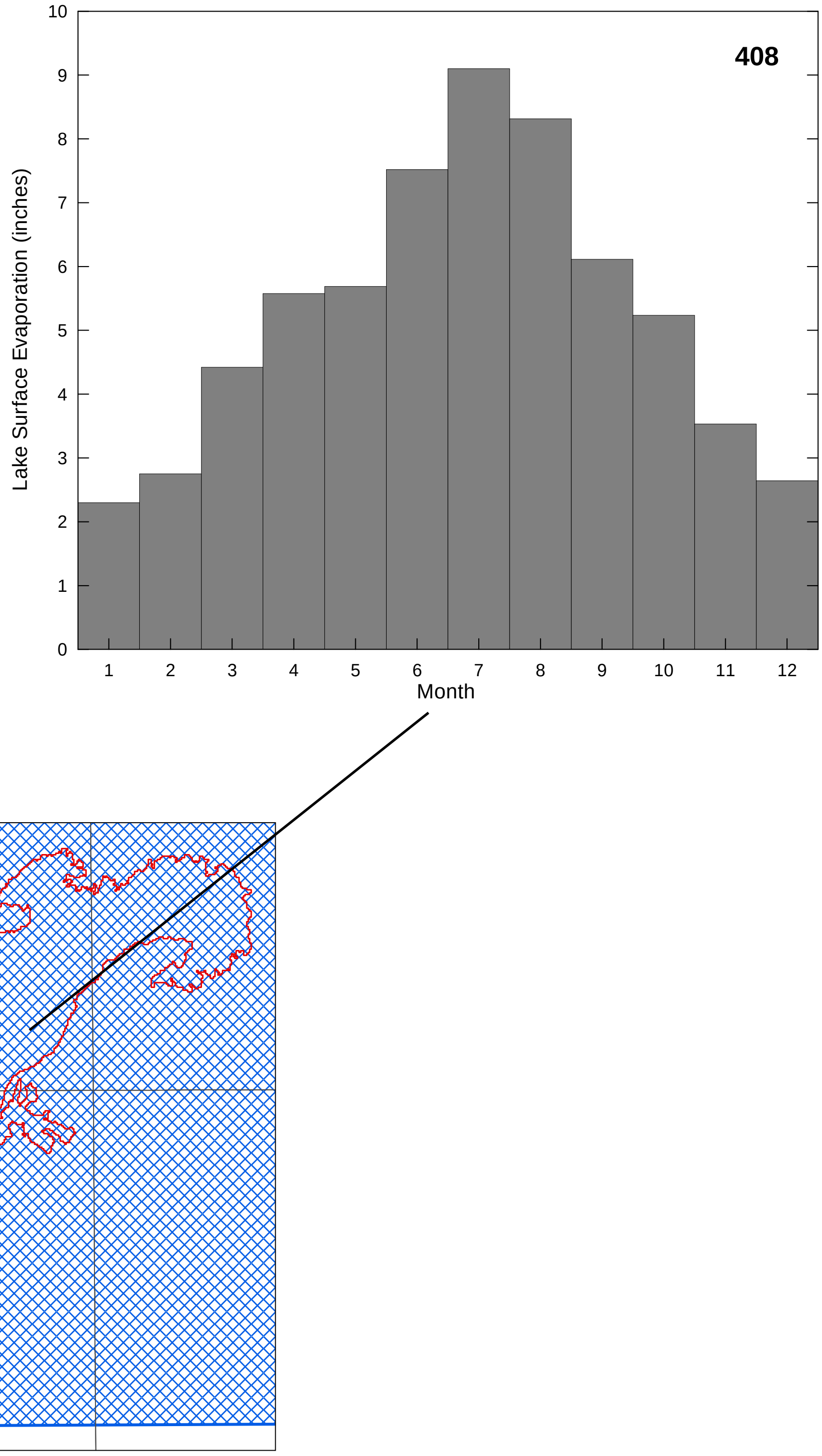

Figure 2.1.11 Average monthly lake surface evaporation for one-degree quadrangle 408 in the study area (TWDB, 2009b).

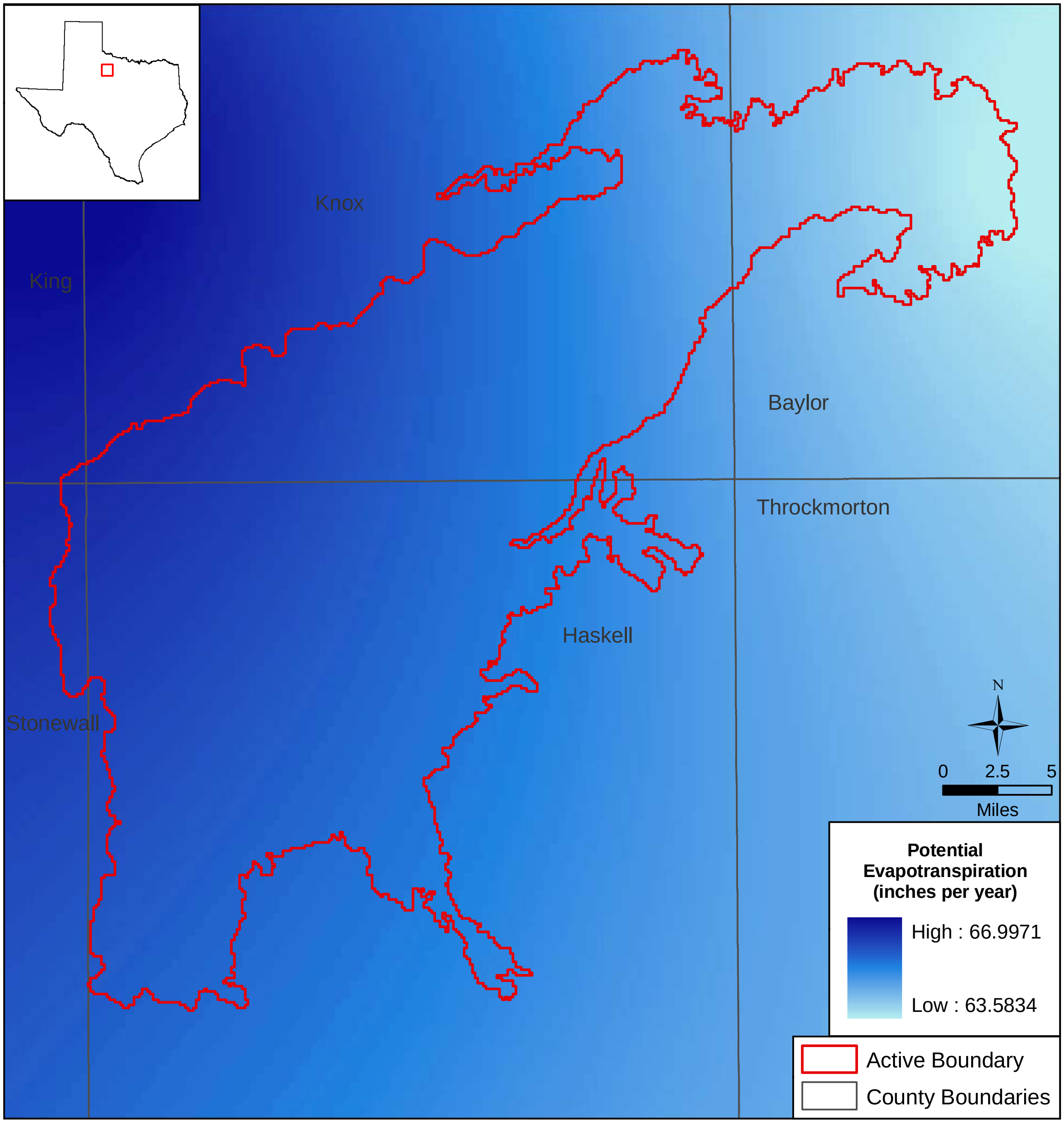

Figure 2.1.12 Potential evapotranspiration in the study area (Borrelli and others, 1998).

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2.2 Geology

The structural setting for the study area is shown in Figure 2.2.1. In the subsurface, the area is characterized by the Baylor Syncline, which was formed during Pennsylvanian time (Price, 1979). Structural deformation of the Baylor Syncline has no affect on the Seymour Aquifer.

The surface geology in the study area (Figure 2.2.2) consists of Permian- through Quaternary-aged deposits. The Quaternary-age deposits making up the Seymour Aquifer overlie Permian-age deposits. From oldest to youngest and east to west, the Permian-age deposits form the Wichita Group, the Clear Fork Group, and the Pease River Group. Table 2.2.1 summarizes the geologic units in the study area. A schematic of the stratigraphy in the study area is provided in Figure 2.2.3.

The following geologic history of the study area is taken primarily from Preston (1978). Shallow seas covered the study area from the Cambrian Period through the Permian Period. During the early time period (Cambrian through Mississippian), these seas were calm resulting in the deposition of limestone and shales characteristic of a stable environment with long periods of deposition. During the later Pennsylvanian and Permian periods, the relatively calm seas were replaced by "continued rapid transgression and regression of shallow epicontinental seas" (Preston, 1978). This resulted in "thick sequences of relatively thin-bedded deposits of almost every type of depositional environment from shallow-shelf, through deltaic, fluvial, and continental" (Preston, 1978). Deposits of the Permian Period dip to the west-northwest at about 20 to 40 feet per mile (Ogilbee and Osborne, 1962; Preston, 1978). A major erosional unconformity exists between the Permian and overlying Quaternary-age deposits in the study area. Therefore, no depositional record is available for that time period. The surface of the Permian-age deposits shows well-developed drainage patterns indicating a long period of erosion (R.W. Harden and Associates, 1978).

All material forming the Seymour Aquifer are unconsolidated alluvial sediments of non-marine origin deposited on the erosional surface of Permian-age beds. In general, sediments of the Seymour Aquifer are predominately material eroded from the High Plains and deposited by eastward moving streams (R.W. Harden and Associates, 1978; Nordstrom, 1991; Duffin and

Beynon, 1992). It is likely that the sediments originally blanketed the entire region where the Seymour Aquifer is found, but were subsequently eroded by recent streams, leaving only remnants of the once continuous deposits (Ogilbee and Osborne, 1962; Preston, 1978; Price 1978). These remnants, along with younger windblown, terrace, and surficial deposits, make up the Seymour Aquifer (see Figure 2.2.2).

Sediments of the Seymour Aquifer in the study area are composed of clay, silt, sand, conglomerate, gravel, and some caliche and volcanic ash (Ogilbee & Osborne, 1962). In general, the sediments are finer near the top and coarsen with depth. The upper portion contains beds of fine-grained sand with silt or clay and caliche in some locations. Where found, the caliche is typically located 1 to 2 feet below ground surface. A basal section of coarse sand and gravel beds is present in many portions of the aquifer in the study area. Individual beds within the Seymour aquifer are discontinuous and grade laterally into beds of coarser or finer grained material. The thickness of the Seymour Aquifer in the study area varies from 0 to about 110 feet. This variation is due to the uneven erosional surface of the Seymour Aquifer and the underlying Permian-age deposits. Where the aquifer overlies a buried channel, it typically has a greater thickness and an increased amount of coarse material at its base. Where the aquifer is thin, it consists predominantly of finer-grained material.

R.W. Harden and Associates (1978) indicate that the Seymour Formation in Haskell and southern Knox counties can be divided into older deposits in the south and east and younger deposits in the north and west (Figure 2.2.4). The distinction between these sediments is a small topographic break. R.W. Harden and Associates (1978) state that

> "The break represents an episode of valley deepening which was followed subsequently by alluviation. The younger deposits occur beneath a terrace extending along the northern and northwestern edge of the area in a belt approximately 4 miles wide."

Several cross-sections through the portion of the Seymour Aquifer in Haskell and Knox counties studied by R.W. Harden and Associates (1978) are shown in Figures 2.2.5 and 2.2.6. These cross-sections, taken directly from their report, show the relationship between the Seymour Formation and the underlying Clear Fork Group. These cross-sections also show the location of the water table in 1977. Figure 2.2.7 shows a cross-section through the Seymour Formation in

Baylor County. This cross-section provides a good illustration of the sediment types found in the Seymour Aquifer.

Table 2.2.1 Rock units in the study area (after United States Geological Survey-Texas Water Science Center and the Texas Natural Resources Information System, 2004).

Rock Unit Code	Rock Unit Name	Group	Period	General Description
Qal	Alluvium	na	Quaternary	floodplain and channel deposits of sand, silt, clay and gravel
Qds	Windblown deposits: dunes and dune ridges	na	Quaternary	massive sand and silt with local low-angle crossbeds
Qsh	Windblown deposits: sheet deposits	na	Quaternary	laminated silt and sand derived from nearby windblown accumulations
Qp	Playa lake deposits	na	Quaternary	lenticular, laminated, and desiccation-cracked clay and laminated silt and sand deposited principally on margins of playas
Qt	Fluviatile terrace deposits	na	Quaternary	sandy, lenticular, stratified, and cross bedded gravel with local calcite cement; laminated and crossbedded, fine- to coarse-grained sand; sandy/clayey silt bedded and lenticular; a veneer of windblown sand and silt covers upper terrace levels
Qs	Seymour Formation: thin deposits	na	Quaternary	silty sand with tiny gravel in basal part; generally massive to crudely stratified; locally cemented by calcite; some well developed caliche
Qs2	Seymour Formation: thick deposits	na	Quaternary	predominately gravel and thick-bedded, massive, silty sand with minor lenticular clay beds; well-developed caliche near the surface; basal lenticular, sandy, granule- to boulder-size gravel locally cemented with calcite
Qu	Surficial deposits undivided	na	Quaternary	sand, clay, silt, caliche, and gravel; includes thin remnants of older terraces and of Seymour Formation, lag gravel, windblown sand and silt, residual soil, and colluvium commonly cemented by caliche
Pb	Blaine Formation	Pease River	Permian	mudstone, gypsum, dolomite, and sandstone with the dolomite beds laterally persistent and predominant
Psa	San Angelo Formation	Pease River	Permian	predominantly mudstone and siltstone with thin lenses of gypsum in the upper portion and very fine to fine grained sandstone in the lower portion
Pcf	Clear Fork undivided	Clear Fork	Permian	predominately mudstone with thin beds of siltstone sandstone, dolomite, and limestone
Pl	Lueders Formation	Wichita	Permian	massive to thin beds of limestone interbedded with dolomite and shale
Pt	Talpa Formation	Wichita	Permian	predominantly shale with some limestone beds
Pgc	Grape Creek Formation	Wichita	Permian	thick-bedded shale with thin lentils of argillaceous limestone and calcareous siltstone
Pbe	Bead Mountain Formation	Wichita	Permian	predominantly shale with local limestone lentils in the upper portion and predominantly limestone with thin shale interbeds in the lower portion

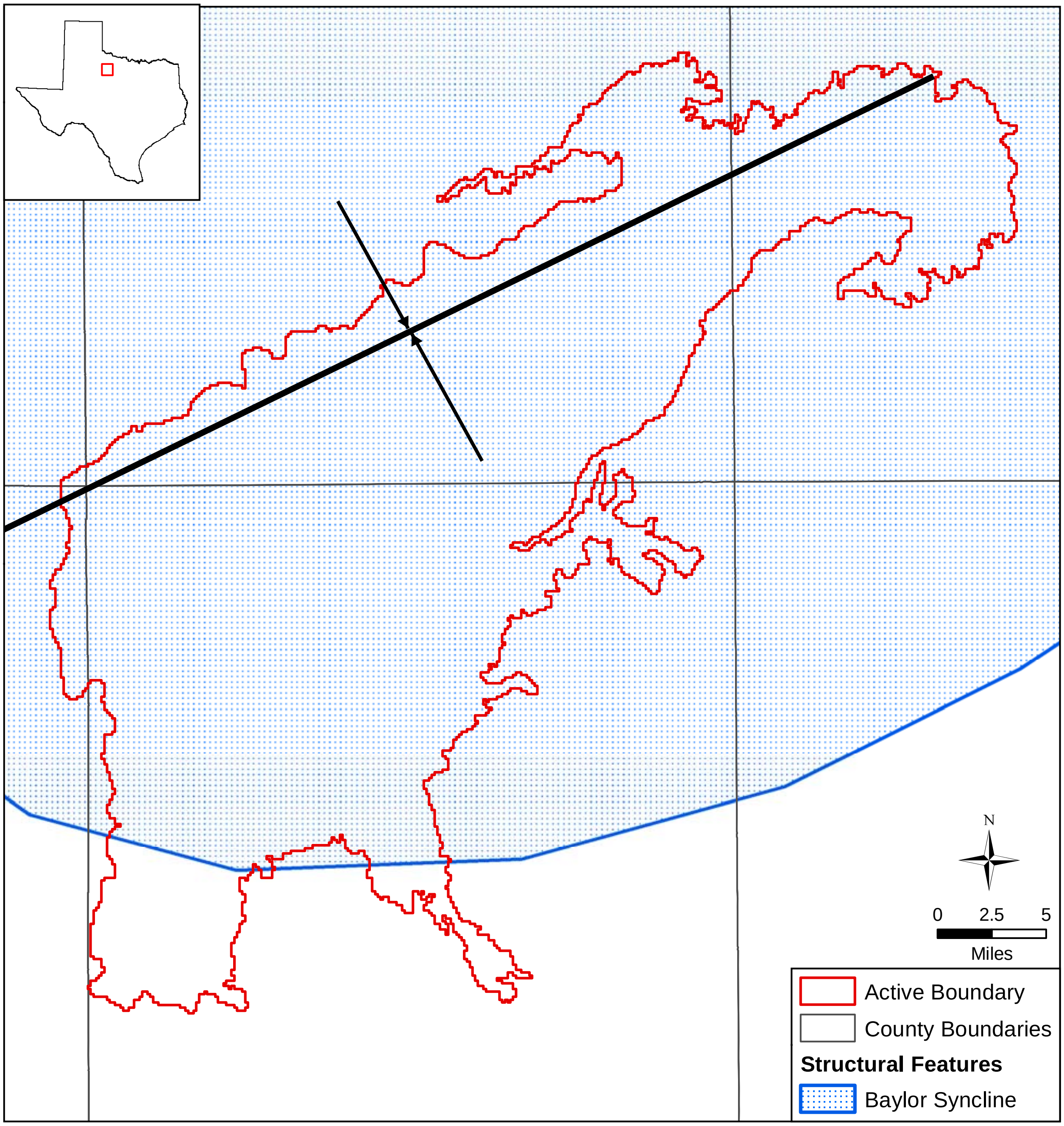

Figure 2.2.1 Major structural features in the study area (Price, 1979).

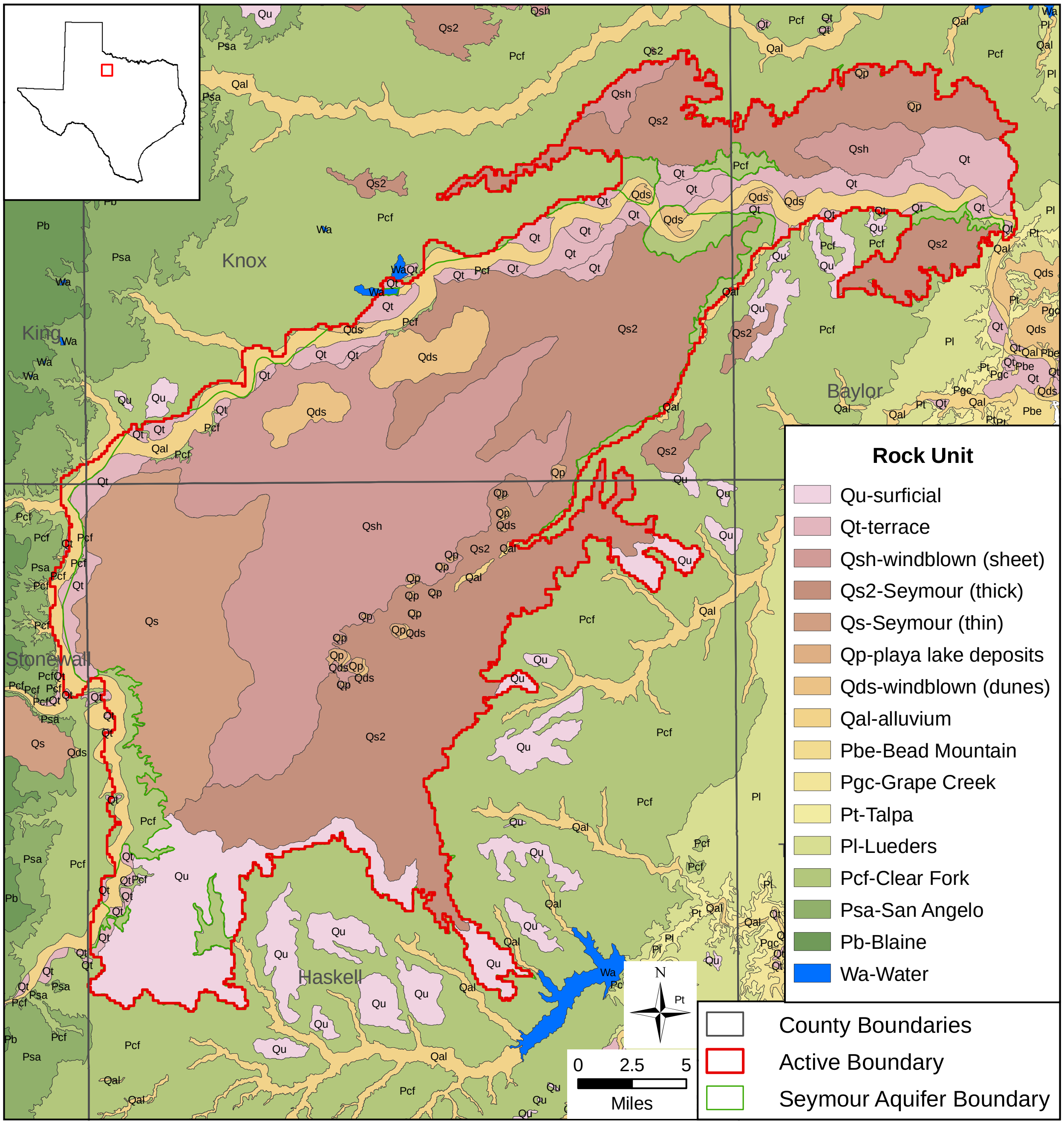

Figure 2.2.2 Surface geology of the study area (United States Geological Survey-Texas Water Science Center and the Texas Natural Resources Information System, 2004).

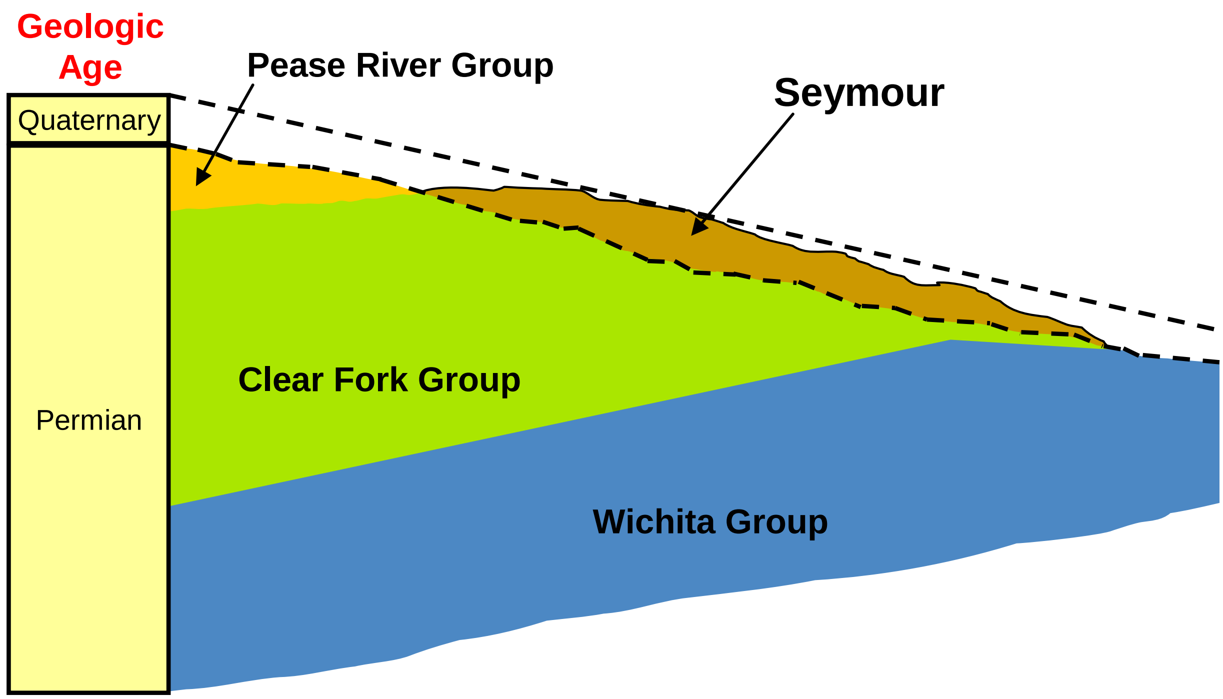

Figure 2.2.3 Schematic of generalized stratigraphy across the study area.

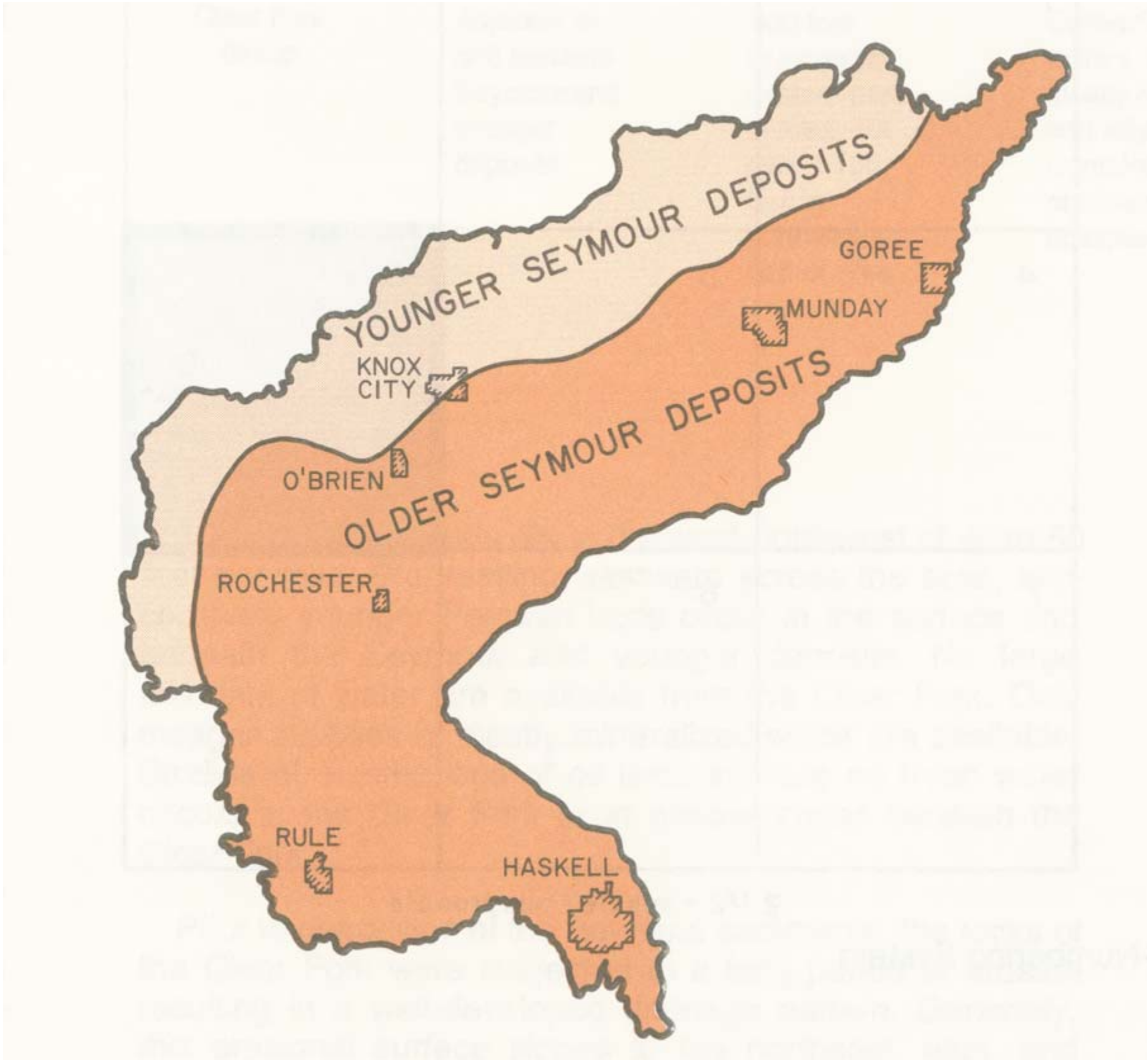

Figure 2.2.4 Location of older and younger Seymour Formation deposits (from R.W. Harden and Associates, 1978).

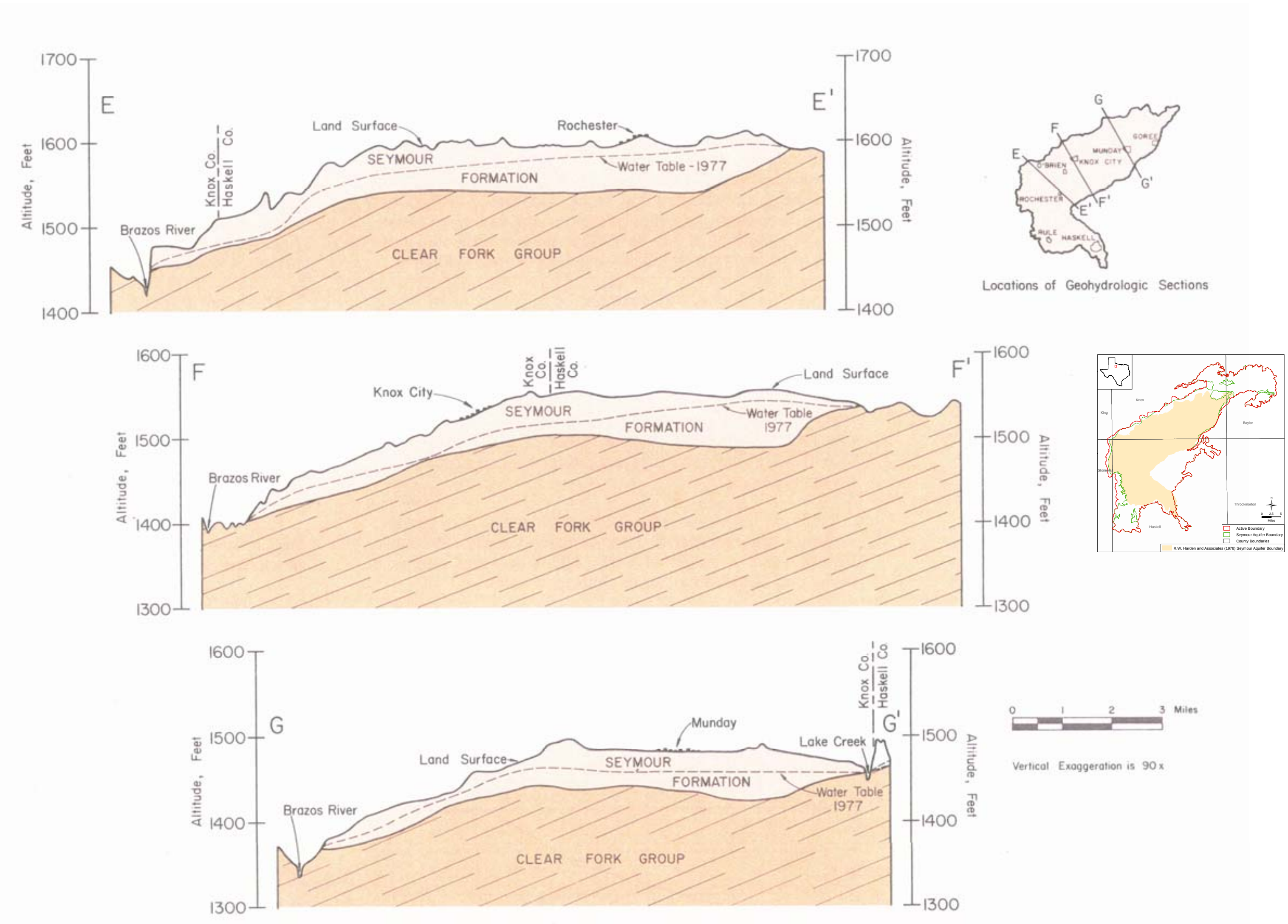

Figure 2.2.5 **A-A', B-B', C-C', and D-D' cross-sections from R.W. Harden and Associates (1978) showing the Seymour Formation and Clear Fork Group in Haskell and Knox counties.**

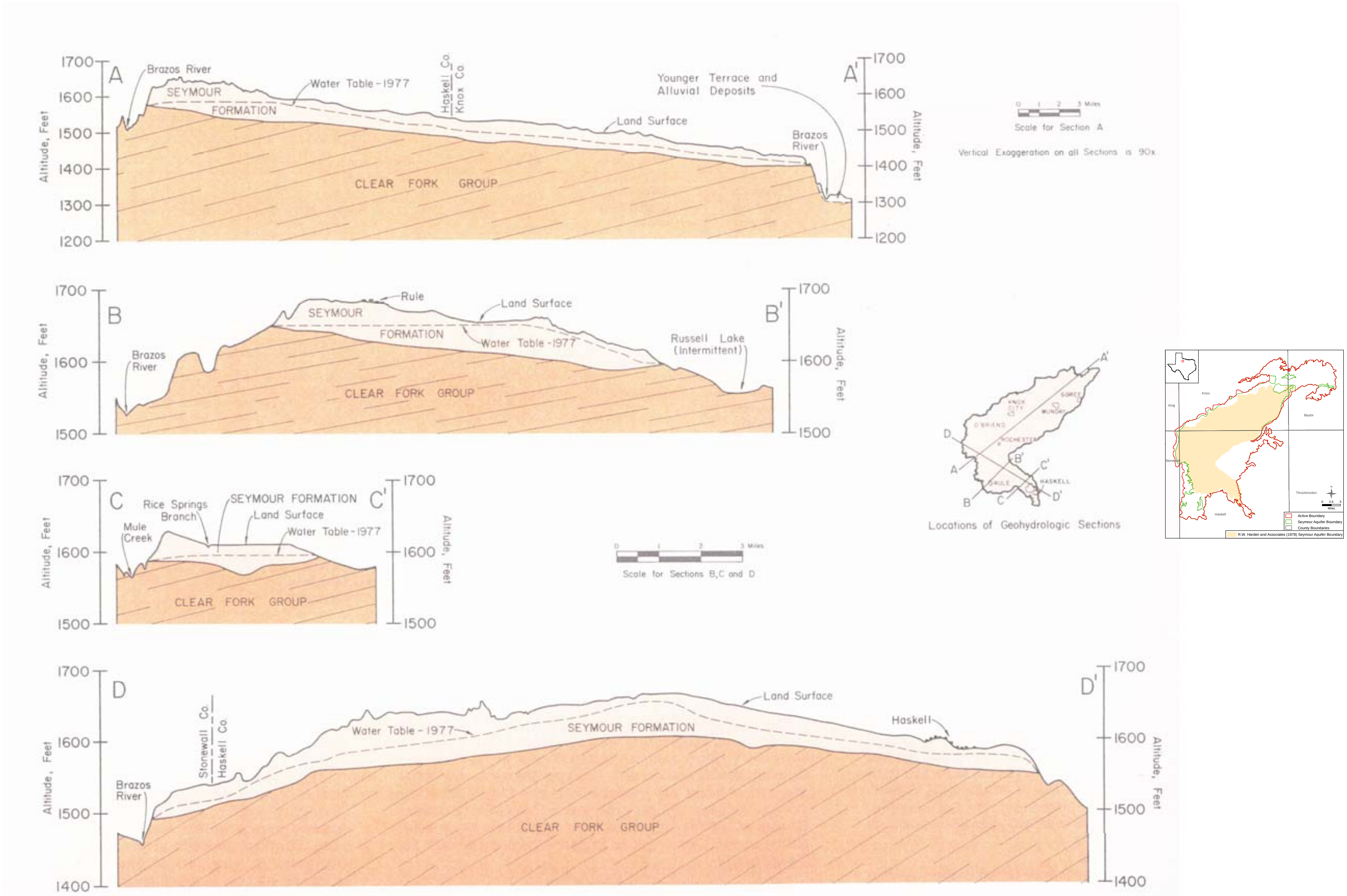

Figure 2.2.6 E-E', F-F', and G-G' cross-sections from R.W. Harden and Associates (1978) showing the Seymour Formation and Clear Fork Group in Haskell and Knox counties.

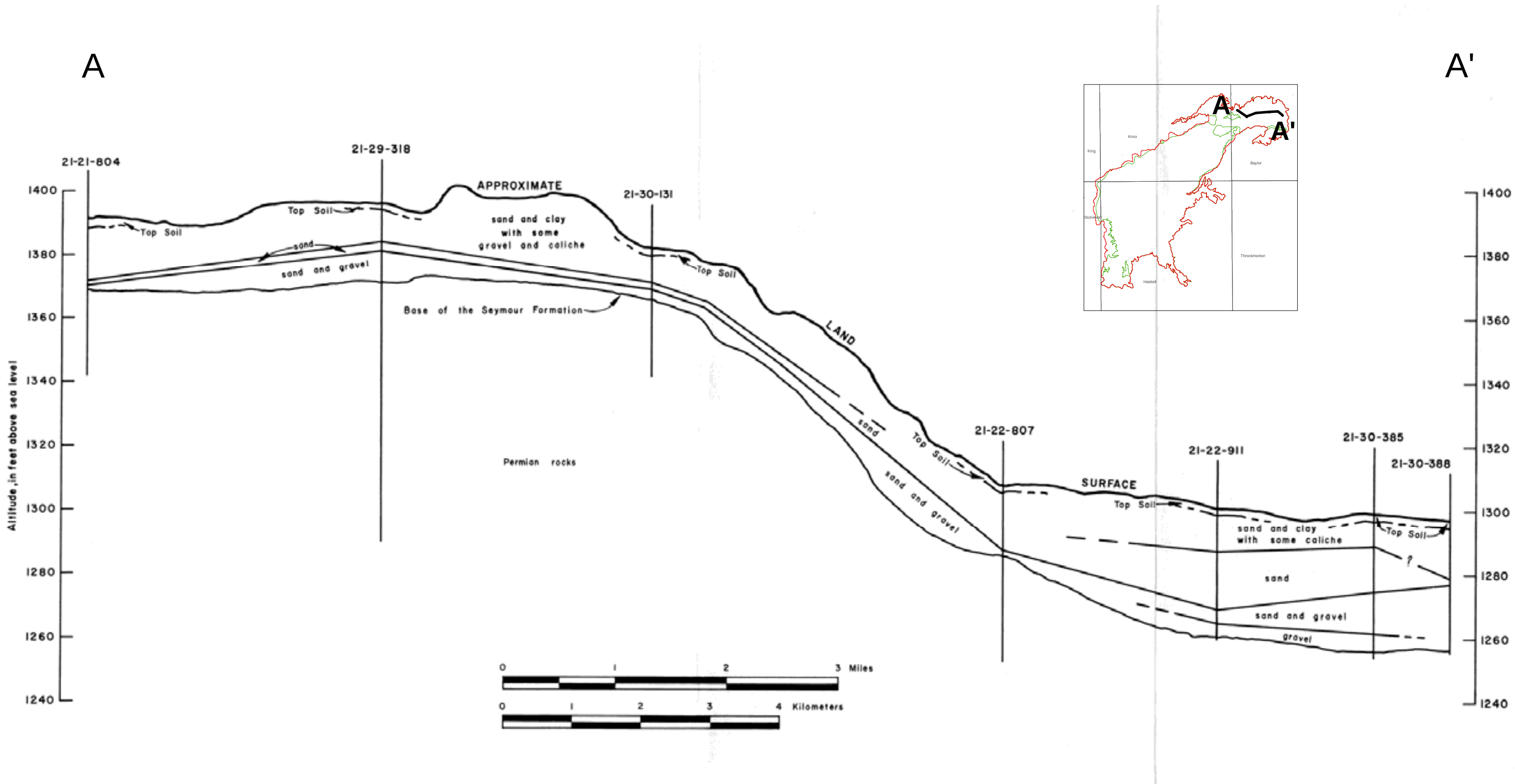

Figure 2.2.7 Geologic cross-section through the Seymour Formation in Baylor County (from Preston, 1978).

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2.3 Brief Land Use History of Baylor, Knox, and Haskell Counties

Water levels in the Seymour Aquifer have been affected by changes in land use since the arrival of Anglo residents in Haskell, Knox, and Baylor counties. This section provides a brief history of land use changes in these three counties. This history was predominately developed based on information provided in Texas State Historical Association (2008) and Texas Parks and Wildlife (2007). A discussion of water-level changes in the Seymour Aquifer is provided in Section 4.3.1.

Initially, Haskell, Knox, and Baylor counties were inhabited by nomadic Indians that used the region as a hunting ground for bison (Sherrill, 1965). In 1858, all three counties were created by the Texas legislature; however, they were not populated by Anglos at that time due to the threat of Indian attacks. Military camps were established in the counties after they were created, but it was not until the late 1870s, when buffalo herds were decimated by hunters, that the Indians were driven from the region and settlement of the counties by Anglos began. The first settlers into the area in the late 1870s were ranchers, quickly followed by farmers. Ranching dominated the region through the 1880's. Baylor County was formally organized with a county seat in 1879 and Knox and Haskell counties in 1885. Although ranching was still an important component of the economy, farming became firmly established in the counties by 1900. The land cover during this time period was predominately mid and tall grasses (Texas Parks and Wildlife, 2007). Ansley and others (1997), citing a report from 1854 and another from 1866, indicate that large mesquite were scattered among Texas rangeland and "honey mesquite was a natural part of the Texas vegetation complex prior to white settlement". These mesquite were located predominately in riparian areas and not on open grassland. Wilson and others (2001) suggest that the absence of mesquite on open range during this time period was due to fires, both natural and intentionally set by Indians, which "presumably minimized mesquite seedling establishment in open areas while allowing the continued presence of mesquite in sheltered drainage and riparian areas".

The replacement of buffalo with cattle and sheep had a significant impact on grazing in these counties, resulting in a significant change in native vegetation (Texas Parks and Wildlife, 2007). The migrant buffalo herds would graze down an area in a short period of time, consuming all of the palatable plants, and then move on leaving the area well fertilized and the soils tilled. Texas Parks and Wildlife (2007) states that "this type of grazing provided long rest periods to native grasslands, allowing for rapid responses of annual forbs and grasses". This increased plant diversity and allowed for the development of stands of dense grasses. The introduction of fencing and overgrazing by domestic livestock resulted in limited or no rest for pastures, reducing the desired deep-root grasses and increasing "less desirable shallow-rooted grasses and a few undesirable forbs" (Texas Parks and Wildlife, 2007). Grazing by domestic livestock also contributed to the expansion of honey mesquite into open grassland through the dispersal of mesquite seeds in livestock waste and the lack of herbaceous competition for mesquite seedlings (Wilson and others, 2001). The introduction of domestic livestock also brought a reduction in fires due to the elimination of intentionally set fires and the absence of herbaceous fuel to support natural fires. In summary, the switch from buffalo grazing to domestic livestock grazing, combined with the reduction in fires in the counties, caused “an increase in woody plant species and a change from grassland or savannah communities to more brushland or woodland habitat types" (Texas Parks and Wildlife, 2007) and the expansion of woody species, especially honey mesquite, on open grassland. In addition to expanding the range of honey mesquite, heavy grazing was also detrimental to the surface soil resulting in decreased infiltration of precipitation and increased soil erosion (Warren and others, 1986; Wilcox and others, 2008).

All three counties saw an increase in economic development from about 1900 to 1910 due to the introduction of railroads and a cotton boom. An increase in agriculture due to the cotton boom and to the selling of ranchland to farmers was also seen in this period. Baylor County experienced its largest population in 1910. The economic development slowed from about 1910 to 1920 due to droughts and falling crop prices during and after World War 1. A second economic boom was experience in these three counties from about 1920 to 1930 due predominately to a brief, intense cotton boom. According to the information available in the Texas State Historical Association (2008), the acreage used for agricultural purposes in these counties was greatest during this time period and Haskell and Knox counties experienced their largest population in 1930. Expansion in all three counties ended in the 1930s and farming suffered severely due to the Great Depression and the Dust Bowl. The population has steadily declined since 1930 in Knox and Haskell counties and since 1940 in Baylor County.

Development of the land for agriculture involved both plowing and terracing. Plowing was used to prepare the soil for seed and terracing was used as a method to retain water for crops. Sherrill (1965) indicates that terracing was being heavily pushed in Haskell County in 1928. Prior to about 1951, crops obtained their water almost exclusively from precipitation and crop yield was a function of the climate. Widespread irrigation of crops began in the 1950s due to a severe drought from about 1951 to 1957 and improvements in pumping technology. Row irrigation was the predominant irrigation method until the use of center pivot sprinklers began in about 1981.

The Conservation Reserve Program of the Farm Service Agency of the United States Department of Agriculture began in the three-county region in 1987. The purpose of this program is to replace crops with long-term, resource conserving covers on some land. Goals of the program include (1) the protection of topsoil from erosion, (2) the reduction of runoff, which increases aquifer recharge, (3) the reduction of sedimentation, which improves the condition of surface water, and (4) the increase in resource-conserving vegetation, which can increase wildlife population (United States Department of Agriculture, 2009). Table 2.3.1 summarizes the number of acres by year in the three-county area enrolled in the Conservation Reserve Program.

Table 2.3.1 Cumulative enrollment in the Conservation Reserve Program (United States Department of Agriculture, 2009).

Year	Baylor County (acres)	Haskell County (acres)	Knox County (acres)
1986	0	0	0
1987	0	7,841	1,425
1988	1,628	21,714	5,508
1989	2,041	32,299	9,950
1990	2,503	36,516	13,020
1991	2,503	36,637	13,020
1992	3,566	39,107	14,869
1993	3,566	40,426	17,056
1994	3,566	40,426	17,056
1995	3,566	40,472	17,056
1996	3,556	40,146	16,690
1997	3,556	39,843	16,975
1998	2,838	29,656	13,879
1999	2,736	23,386	10,788
2000	2,284	23,579	8,586
2001	3,076	27,842	8,976
2002	3,085	27,875	8,999
2003	3,086	28,708	9,119
2004	2,023	25,669	7,092
2005	2,023	25,613	7,030
2006	2,026	26,195	7,880
2007	2,263	27,078	7,817

3.0 Previous Investigations

The Haskell-Knox-Baylor pod of the Seymour Aquifer has been studied by the various past and present Texas state agencies responsible for water resources. The Seymour Formation was studied by Ogilbee and Osborne (1962) in their report on groundwater resources of Haskell and Knox counties, R.W. Harden and Associations (1978) in their report on groundwater quality and availability, and by Preston (1978) in his report on the occurrence and quality of groundwater in Baylor County. The development of the conceptual model for the refined Seymour Aquifer groundwater availability model has borrowed extensively from these works.

In addition to these studies, the Haskell-Knox-Baylor pod of the Seymour Aquifer was included in the groundwater availability model of the entire Seymour Aquifer (Ewing and others, 2004). Figure 3.0.1 shows the study area and active boundary for this model, which included the entire Seymour Aquifer in Texas and Oklahoma. The Seymour Aquifer groundwater availability model was a two layer model that included the Seymour Aquifer as the top layer and the upper portions of Permian-age sediments as the bottom layer. This bottom layer included the Blaine Aquifer, which is a minor aquifer in Texas. The model dimensions were 180 miles east-west by 208 miles north-south, with 3,436 active cells in the Seymour Aquifer layer and 20,001 active cells in the Permian layer. The model grid was one mile by one mile. The model incorporated the available information on structure, hydrostratigraphy, hydraulic properties, stream flow, recharge, and pumping.

The Seymour Aquifer groundwater availability model was calibrated to both steady-state and transient conditions. The time periods for steady state were selected for the individual pods of the Seymour Aquifer and included various time periods in the 1960s and 1970s. The steady-state time period for the Haskell-Knox-Baylor pod was 1967 through 1970. The time period for calibration of the model to transient aquifer conditions was January 1980 through December 1989. The transient calibration incorporated monthly variations in recharge, streamflow, and pumping. The transient-calibrated model was verified against aquifer conditions from January 1990 through December 1999. Model calibration yielded a geometric mean horizontal conductivity for the Seymour Aquifer of 68.5 feet per day and an average recharge rate of

2 inches per year. A sensitivity analysis was performed to determine which parameters had the most influence on model performance and calibration. The verified model was used to make predictions of aquifer conditions for the period 2000 to 2050 based on projected pumping demands. The predictive model indicated that average water levels in the Seymour Aquifer are not expected to change by more than several feet, but declines of up to about 30 feet were predicted in localized areas.

The Seymour Aquifer groundwater availability model provides information for the Seymour Aquifer as a whole, but does not specifically address each individual pod of the aquifer. In addition, hydraulic property data and pumping are averaged over a large area due to the one-mile by one-mile grid blocks relative to the area of the pods. The refined groundwater availability model for the Haskell-Baylor-Knox pod allows for model parameterization at a scale relative to the size of the pod.

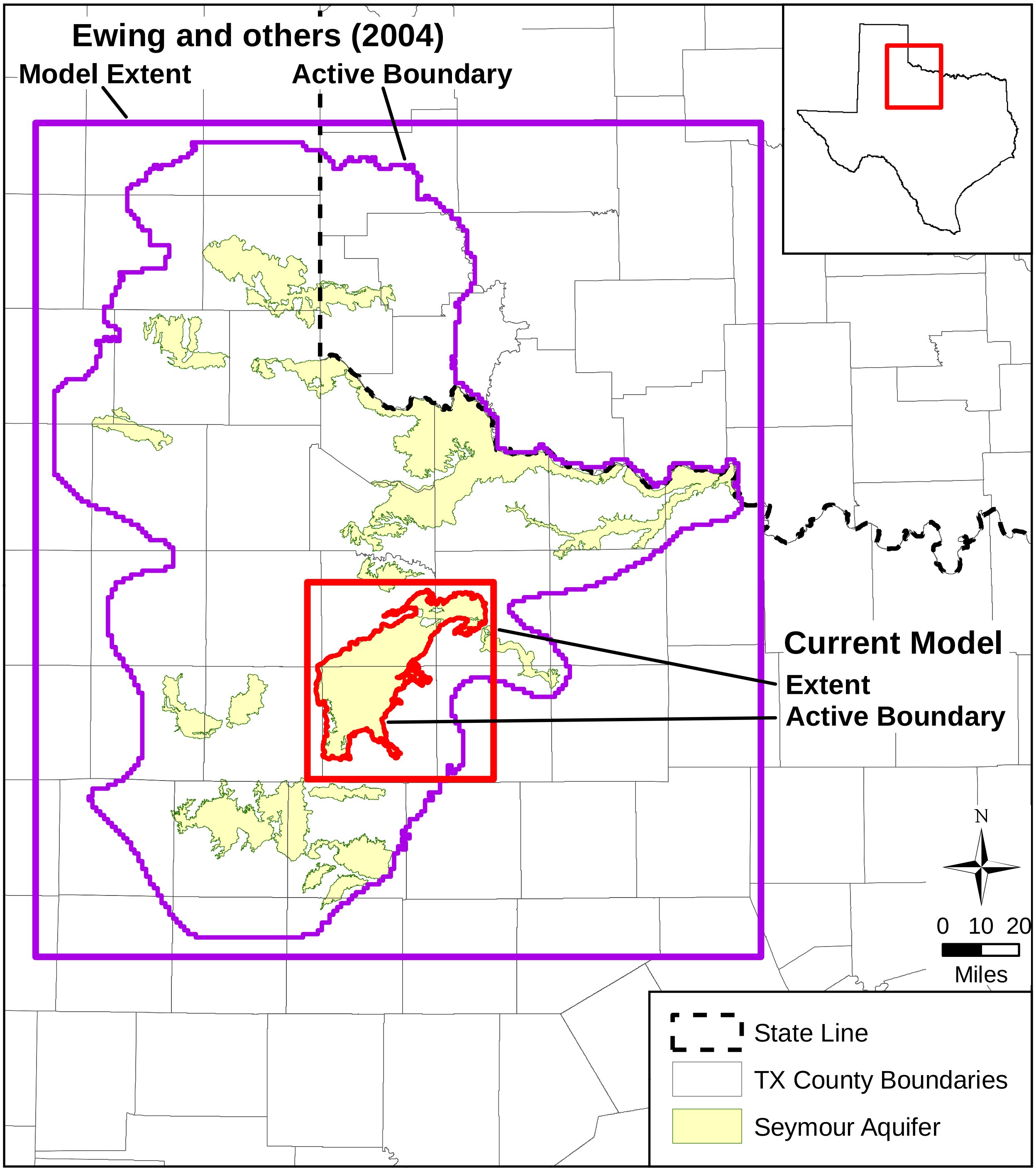

Figure 3.0.1 Location of extent and active area for the Seymour Aquifer groundwater availability model (Ewing and others, 2004) and the refined groundwater availability model for the Haskell-Knox-Baylor pod of the Seymour Aquifer.

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4.0 Hydrogeologic Setting

The hydrogeologic setting of the Haskell-Knox-Baylor pod of the Seymour Aquifer is defined by the hydrostratigraphy, structure, regional groundwater flow, recharge, surface and groundwater interaction, hydraulic properties, and discharge. The characterization of the hydrogeologic setting is based on previous geologic and hydrologic studies in the area and compilation and analyses of structure maps, hydraulic properties, water-level data, spring and stream flow data, and climatic information.

In late 2008, the TWDB changed the aquifer code in their database for many wells and a few springs located within the boundary of the Seymour Aquifer in Haskell, Knox, and Baylor counties from 112SYMR (Seymour Formation) to 110ALVM (alluvium) or UNKNOWN (Wade, 2009). The UNKNOWN aquifer code was assigned to wells with missing well depth data because their completion interval could not be verified (Boghici, 2009) and to some springs. Switching the aquifer code from 112SYMR to 110ALVM has no impact on the development of the conceptual model for the Seymour Aquifer because the aquifer includes both the Seymour Formation and alluvial sediments. The switch in aquifer code from 112SYMR to UNKNOWN does have an impact, however, because the wells and springs with an UNKNOWN aquifer code could be completed into or flowing from the Permian-age sediments underlying the Seymour Aquifer and, therefore, should not be included in developing the conceptual model for the aquifer. Within the boundary of the Seymour Aquifer, 479 wells and springs (about one-third) previously assigned an aquifer code of 112SYMR were assigned a new aquifer code of UNKNOWN. Since this is a large percentage of wells, and a few springs, to eliminate from use in developing the conceptual understanding of the Seymour Aquifer, an investigation was conducted to try to determine which of these wells and springs could be considered Seymour Aquifer wells or springs and which should be considered Permian wells or springs.

R.W. Harden and Associates (1978) identified 74 wells and five springs as completed into or flowing from Permian-age sediments and 20 wells as completed into both the Seymour Formation and underlying Permian-age sediments in Haskell, Knox, and Stonewall counties. A Permian aquifer code is assigned in the TWDB database (TWDB, 2009c) to 67 of the wells they identified as Permian wells and one spring they identified as flowing from Permian-age sediments. Since the aquifer code and water bearing unit from R.W. Harden and Associates (1978) agree, these 67 wells and one spring were considered to be completed into or flowing from Permian-age sediments in developing the conceptual model for the Seymour Aquifer. Two wells and four springs identified as completed into or flowing from Permian-age sediments by R.W. Harden and Associates (1978) had a previous aquifer code of 112SYMR and a new aquifer code of UNKNOWN. Since the completion interval for these wells and the source of water for the springs could not be verified and R.W. Harden and Associates (1978) identified these as Permian wells and springs, they were considered to be Permian wells and springs in the development of the conceptual model for the Seymour Aquifer. Of the remaining 466 wells and springs assigned an aquifer code of UNKNOWN and located within the Seymour Aquifer, R.W. Harden and Associates (1978), in their extensive investigation of the Seymour Aquifer in Haskell and Knox counties, identified 455 of them as wells or springs completed into or flowing from the Seymour Formation. All of those wells and springs were considered to be completed into or flowing from the Seymour Aquifer (i.e., either the Seymour Formation or alluvial sediments) in developing the conceptual model for the Seymour Aquifer, because it is unlikely that they were drilled past the Seymour Aquifer and completed into the lower quality water of the Permian-age sediments. The remaining 11 wells or springs were not found in R.W. Harden and Associations (1978). Therefore, the formation they are completed into or flow from could not be verified and they were not included in the development of the Seymour Aquifer conceptual model as either a Seymour Aquifer well or a Permian well.

Four wells identified by R.W. Harden and Associates (1978) as completed into Permian-age sediments and 16 wells and one spring they identified as completed into or flowing from both the Seymour Aquifer and Permian-age sediments had a previous aquifer code of either 110ALVM or 112SYMR and were assigned a new aquifer code of either 110ALVM or 112SYMR. In order to estimate which sediments these wells and spring are completed into or flowing from, the chemistry of water sampled from these wells and spring was compared to the chemistry of water from wells known to be completed into Permian-age sediment and wells known to be completed into the Seymour Formation or alluvial sediments. Based on this comparison, it was estimated that three of the wells are completed into Permian-age sediments rather than into the Seymour Formation or alluvial sediments. Those three wells were considered to be Permian wells in developing the conceptual model for the Seymour Aquifer.

One well and three springs located in Baylor County had an old aquifer code of 112SYM and were assigned a new aquifer code of UNKNOWN. One of those springs is located outside of the Seymour Aquifer and was not used. Information found in the records of wells and springs table in Preston (1978) indicates that the well is completed into the Seymour Aquifer and the other two springs flow from the Seymour Aquifer. Therefore, that well and those two springs were considered to be completed into and flowing from the Seymour Aquifer during conceptual model development.

Appendix A contains a table summarizing the changes discussed above. That table includes only wells and springs assigned a new aquifer code of UNKNOWN and wells and springs identified as completed into or flowing from Permian-age sediments or the Seymour Formation and Permian in R.W. Harden and Associates (1978).

A large portion of the Seymour Aquifer in north-central and north-eastern Haskell County is dry. In their report, R.W. Harden and Associates (1978) identify where the Seymour Formation contains groundwater. The outline of the Seymour Aquifer as defined by R.W. Harden and Associates (1978) is shown in Figure 4.0.1. A comparison between that outline and the outline of the Seymour Aquifer as defined by Ashworth and Hopkins (1995) shows some discrepancies. The discrepancy along the Brazos River is due to the presence of alluvial sediments rather than sediments of the Seymour Formation, and R.W. Harden and Associates (1978) investigated only the Seymour Formation. The discrepancy on the eastern side and southwestern toe of the aquifer in Haskell County is due to the fact that the aquifer is dry in those locations. It should be noted that the portion of the Seymour Aquifer north of the Brazos River in Knox and Baylor counties was not considered by R.W. Harden and Associates (1978), but does produce water.

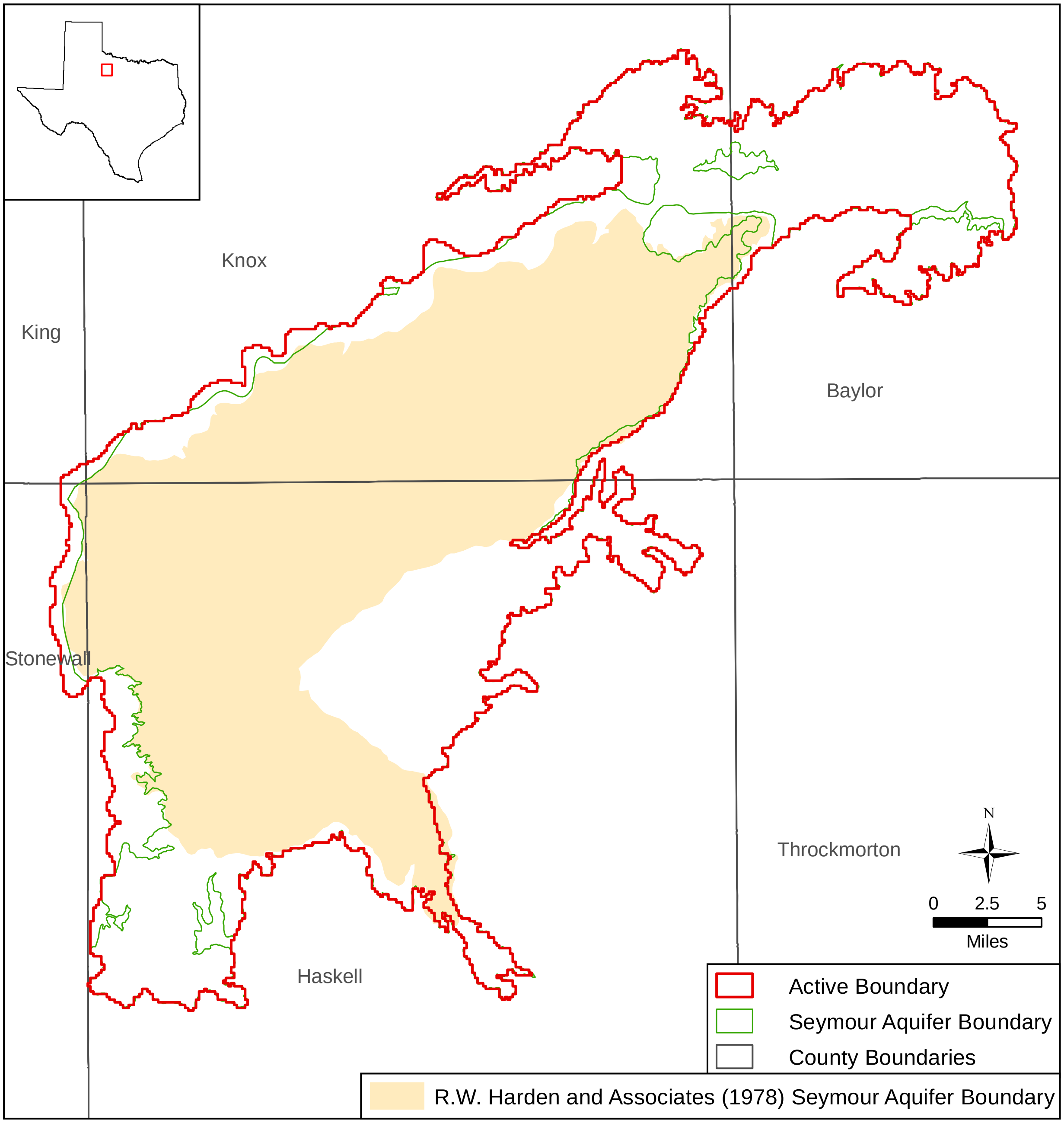


Figure 4.0.1 **Outline of the Seymour Aquifer as defined by the TWDB and of the water-bearing portion of the Seymour Formation as defined by R.W. Harden and Associates (1978).**

4.1 Hydrostratigraphy

The Seymour Aquifer consists of unconsolidated alluvial sediments of non-marine origin deposited on the erosional surface of Permian-age sediments. In general, sediments of the Seymour Aquifer are predominantly material eroded from the High Plains and deposited by eastward moving streams (R.W. Harden and Associates, 1978; Nordstrom, 1991; Duffin and Beynon, 1992). It is likely that the sediments originally blanketed the entire region but were subsequently eroded by recent streams leaving only remnants of the once continuous deposits (Ogilbee and Osborne, 1962; Preston, 1978; Price, 1978).

Sediments of the Seymour Aquifer are composed of clay, silt, sand, conglomerate, gravel, and some caliche and volcanic ash (Ogilbee & Osborne, 1962). Although the Seymour Aquifer consists primarily of unconsolidated sediments, cemented sandstone and conglomerate material can be found locally (R.W. Harden and Associates, 1978). In general, the sediments are finer near the top and coarsen with depth. The upper portion contains beds of fine-grained sand with silt or clay and some caliche. Where present, the caliche typically underlies several feet of topsoil (Ogilbee and Osborne, 1962). A basal portion of coarse sand and gravel beds is present in many portions of the aquifer. This basal section is the predominant water-bearing zone. Individual beds within the Seymour Aquifer are discontinuous and grade laterally into beds of coarser or finer grained material, with the exception of the basal coarse material which is present inconsistently throughout the aquifer.

As discussed in Section 2.2, R.W. Harden and Associates (1978) indicate that the Seymour Formation in Haskell and southern Knox counties can be divided into older deposits in the south and east and younger deposits in the north and west (see Figure 2.2.4). They state that the water levels indicate a steep gradient along the boundary between the older and younger sediments, suggesting that they are poorly connected hydraulically.

The Seymour Aquifer in the study area is underlain by Permian-age sediments of the Clear Fork Group (Table 4.1.1). The Clear Fork Group consists predominantly of shale with some thin layers of sandstone, dolomite, limestone, gypsum, and marl (Ogilbee and Osborne, 1962) and dips to the west while the land surface dips to the east. Formations of the Clear Fork Group are, from oldest to youngest, the Arroyo, Vale, and Choza formations. These formations consist predominately of shale with a few limestone, dolomite, and sandstone beds (Ogilbee & Osborne, 1962). The Arroyo Formation is not known to yield potable water, small quantities of slightly to moderately saline water has been obtained from the Vale Formation, and water too highly mineralized for human use has been obtained from the Choza Formation (Ogilbee & Osborne, 1962). Price (1979) from the Clear Fork Group is generally found in fractured and locally permeable dolomites and limestones.

The active boundary of the model was selected based predominantly in the outline of the Seymour Aquifer. However, in areas where the Brazos River or Lake Creek fall outside the aquifer boundary, the active boundary was extended to these surface water bodies.

Table 4.1.1 Hydrostratigraphy.

<table>
<tr><th>System</th><th>Series</th><th>Group</th><th>Formation</th></tr>
<tr><td rowspan="2">Quaternary</td><td rowspan="2">Recent to Pleistocene</td><td></td><td>Alluvium</td></tr>
<tr><td></td><td>Seymour</td></tr>
<tr><td>Tertiary</td><td colspan="3" rowspan="4">missing</td></tr>
<tr><td>Cretaceous</td></tr>
<tr><td>Jurassic</td></tr>
<tr><td>Triassic</td></tr>
<tr><td rowspan="4">Permian</td><td rowspan="4">Leonard</td><td rowspan="3">Clear Fork</td><td>Choza</td></tr>
<tr><td>Vale</td></tr>
<tr><td>Arroya</td></tr>
<tr><td>Wichita (upper portion only)</td><td>Lueders</td></tr>
</table>

4.2 Structure

The geologic structure of the Seymour Aquifer is dominated by the character of the erosional surface of the underlying Permian-age sediments, the character of the land surface, and the erosional characteristics of recent streams. In addition to the data sources used in the previous Seymour Aquifer groundwater availability model (Ewing and others, 2004), driller's logs for an additional 546 wells provided by the Rolling Plains Groundwater Conservation District were included in the estimation of the structure for the Seymour Aquifer. The data sources used to generate the structure for the Seymour Aquifer are summarized in Table 4.2.1.

All of the data listed in Table 4.2.1 are for specific point locations except for the data from the Texas Commission on Environmental Quality and the structure contours. Well-log records filed with the Texas Commission on Environmental Quality do not contain specific surface locations for wells. Rather, the records indicate in which 2.5-minute quadrangle the well is located. A 2.5-minute quadrangle corresponds to about 10 square miles. These quadrangles may contain a few wells or many wells. The latitude and longitude for the center of each quadrangle containing wells with records pertinent to the Seymour Aquifer were converted to groundwater availability model coordinates. Structure-related data for all wells in each quadrangle were arithmetically averaged to obtain a final value representative of the quadrangle. That final average value, applied to the quadrangle center location, was used to develop the structure surfaces for the model. The methodology used to determine and quality control/quality assurance check the structural picks from the Texas Commission on Environmental Quality records is described in detail in Appendix B of Ewing and others (2004). This methodology was developed to ensure that no anomalous data were included in the averaging process.

To benefit from the efforts of previous studies (R.W. Harden and Associates, 1978; Preston, 1978), two contour maps of the elevation of the Seymour Aquifer base were scanned, digitized, and projected into groundwater availability model coordinates. The average value of the contours was sampled using a 1-mile by 1-mile grid to obtain point data. For all data derived from driller's logs, the basal elevations of the Seymour Aquifer was calculated from the reported depth to the base of the aquifer and the digital elevation model elevation at that point. Because the elevation of land surface along the outcrop contact between an aquifer and the underlying unit describes the elevation of the base of the aquifer, the points defining the outline of the Seymour Aquifer were extracted from the polygons of the aquifer extents. The digital elevation model elevations at alternate points along the Seymour Aquifer outline were then used as additional point data. The locations of the various data sources used in constructing the basal elevation of the Seymour Aquifer (as listed in Table 4.2.1) are depicted in Figure 4.2.1. The base of the Seymour was developed using the point data obtained from the contour maps, the point data from the driller's logs, and the point data along the Seymour Aquifer outline.

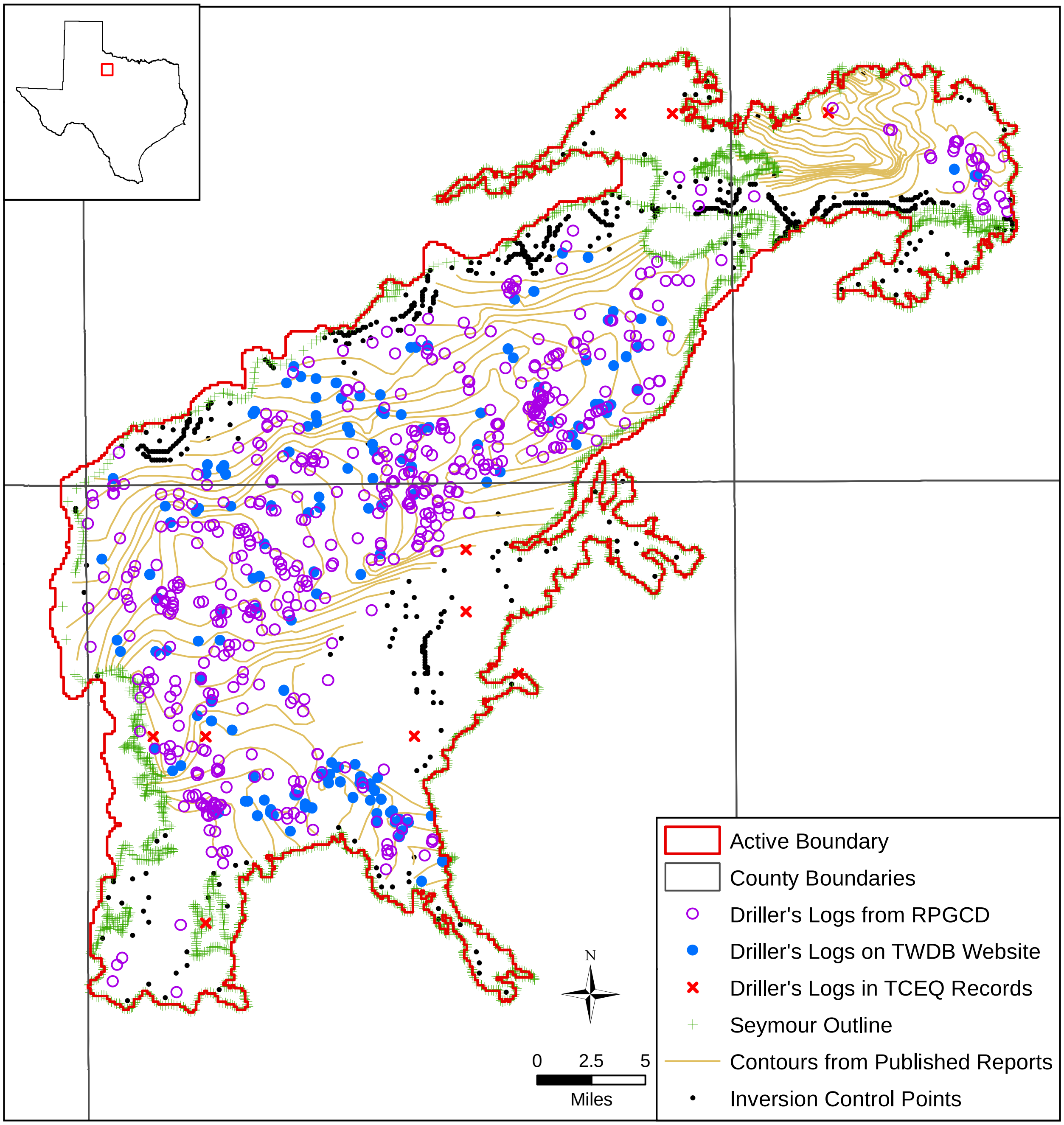
The interpolated surface of the base of the aquifer and the 30-meter digital elevation model (the top of the aquifer) were averaged onto the model grid, which is at a resolution of one-eighth mile by one-eighth mile. Once the model grid had been populated with the structure data, several tests were performed to ensure that the structure was reasonable and consistent with other soft data. Initially, there were many inversions, whereby the basal elevation was higher than land surface. These inversions tended to occur in areas with a paucity of structure data coupled with depressions in the local topography, particularly around the Brazos River, Lake Creek, and other smaller surface drainages. Control points consisting of cells with inversions that intersected the national hydrography dataset polyline coverage, representing local surface depressions, were then used to augment the structure dataset. The basal elevation of the Seymour Aquifer at these control points was assumed to be 20 feet below land surface and the basal surface was contoured again incorporating these control points. Finally, a practical minimum thickness of 20 feet was assumed for the aquifer and applied to all grid cells not initially meeting this requirement.

Figures 4.2.2 through 4.2.4 depict the structure of the Seymour Aquifer. The large-scale structure of the Seymour Aquifer is dictated largely by topography. The elevation of the top of the Seymour Aquifer is shown in Figure 4.2.2. The elevation of the Seymour Aquifer base varies several hundred feet across the aquifer, as shown in Figure 4.2.3, while the Seymour Aquifer thickness is generally less than 100 feet as evident in Figure 4.2.4. The top surface of the underlying Permian-age units is shown in Figure 4.2.5. The Permian beds are thick, however, their structure is considered of minimal importance with respect to the hydrologic flow system of the Seymour Aquifer.

Table 4.2.1 Data sources for the basal elevation of the Seymour Aquifer.

Data Source	Type of Data	Data Use	Data Location
R.W. Harden and Associates (1978)	Contours of altitude of base of Seymour Formation	Digitized and used directly	Haskell County and portions of Knox County
Preston (1978)	Contours of approximate altitude of base of Seymour Formation	Digitized and used directly	West-central Baylor County
Drillers' logs on TWDB website	Base of Seymour Formation as given in drillers' logs	Used directly as point data	Throughout model area
Well logs in TCEQ records	Base of Seymour Formation as given in drillers' logs	Used directly as point data	Throughout model area
Drillers' logs from RPGCD	Base of Seymour Formation as given in drillers' logs	Used directly as point data	Throughout model area
USGS Quads	30-meter DEM elevations	Calculated average DEM elevation for the center of each model grid block	Throughout model area
TWDB website	Polygon extent of Seymour Aquifer	Points extracted from polygons and DEM elevations at points used as data	Throughout model area
National Hydrography Dataset	High resolution stream polyline coverage	Used to pick control points where inversions occurred	Throughout model area

TWDB = Texas Water Development Board
TCEQ = Texas Commission on Environmental Quality
RPGCD = Rolling Plains Groundwater Conservation District
USGS = United States Geological Survey
DEM = Digital Elevation Model



RPGCD = Rolling Plains Groundwater Conservation District
TCEQ = Texas Commission on Environmental Quality
TWDB = Texas Water Development Board

Figure 4.2.1 Data sources for the Seymour Aquifer structure.

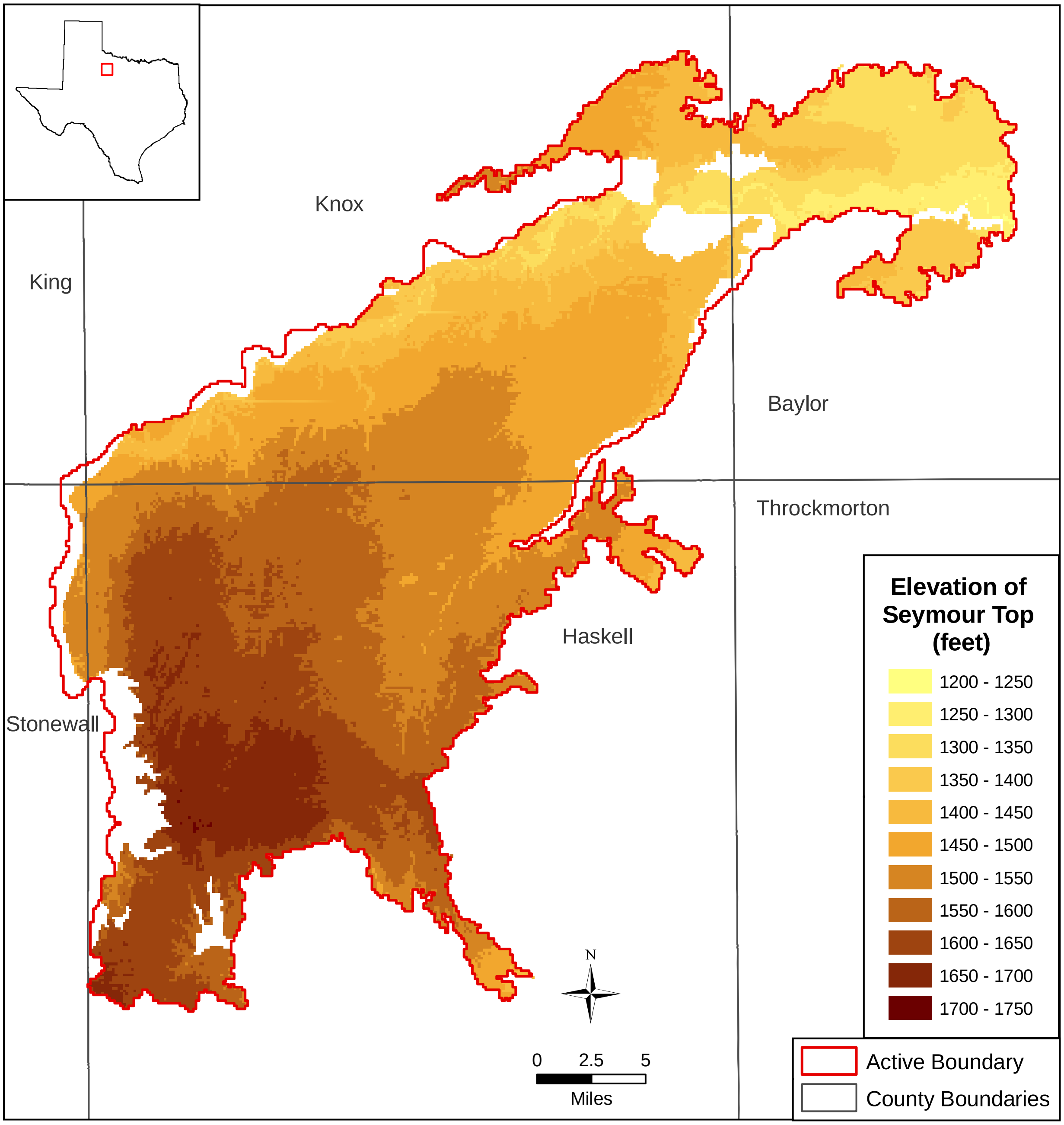


Figure 4.2.2 Structure map of the top of the Seymour Aquifer.

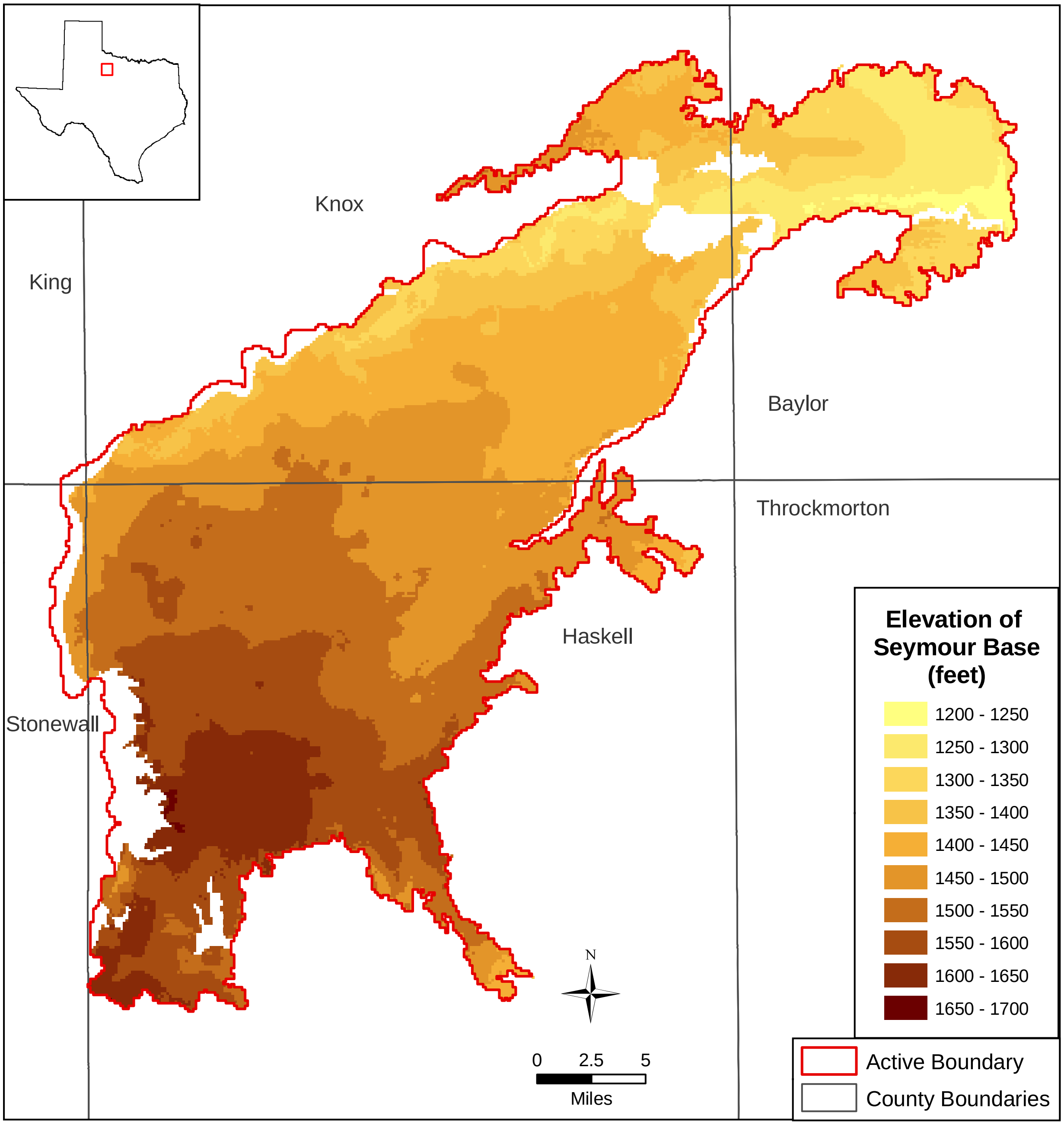


Figure 4.2.3 Structure map of the base of the Seymour Aquifer.

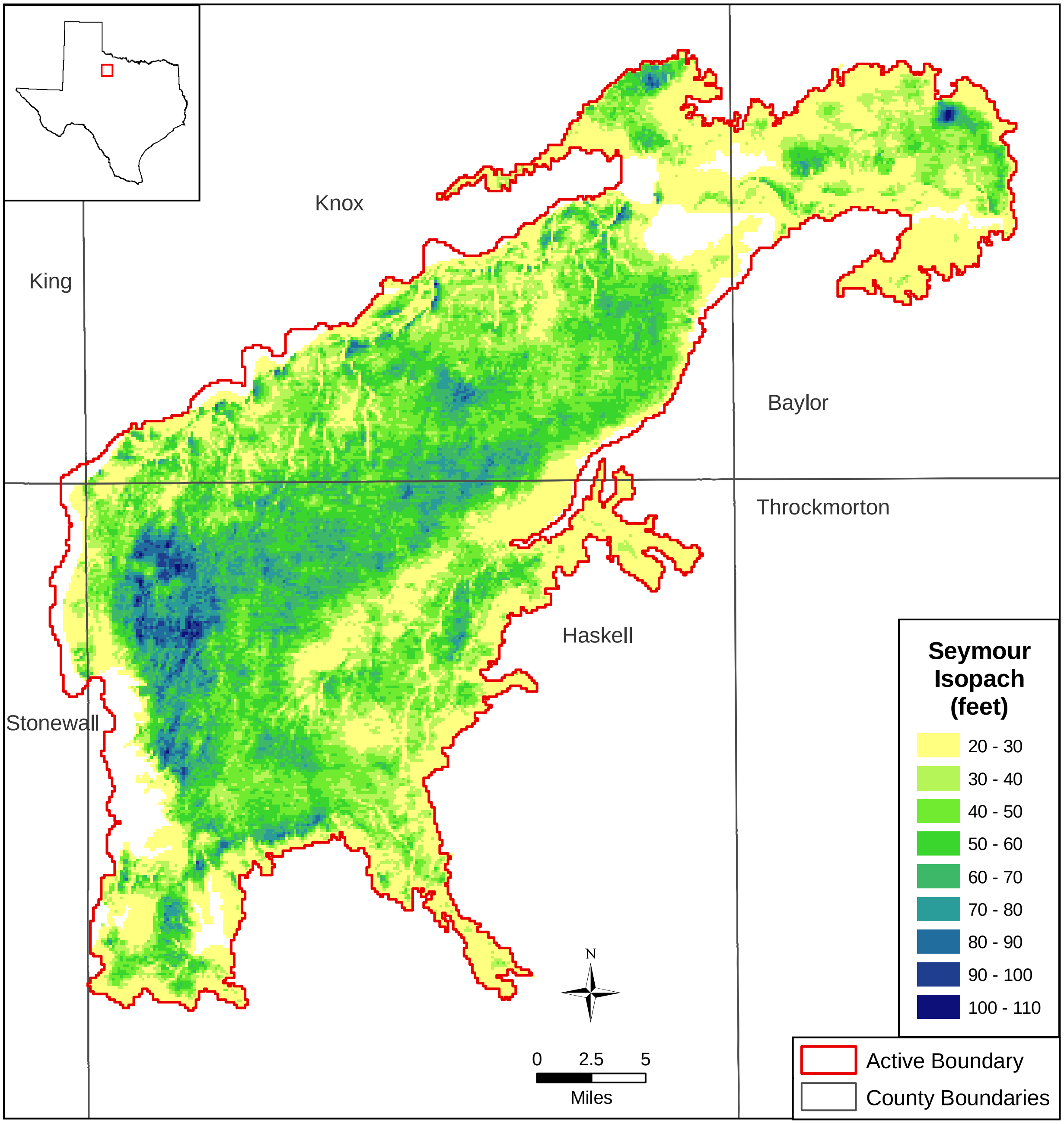


Figure 4.2.4 Isopach map of the Seymour Aquifer.

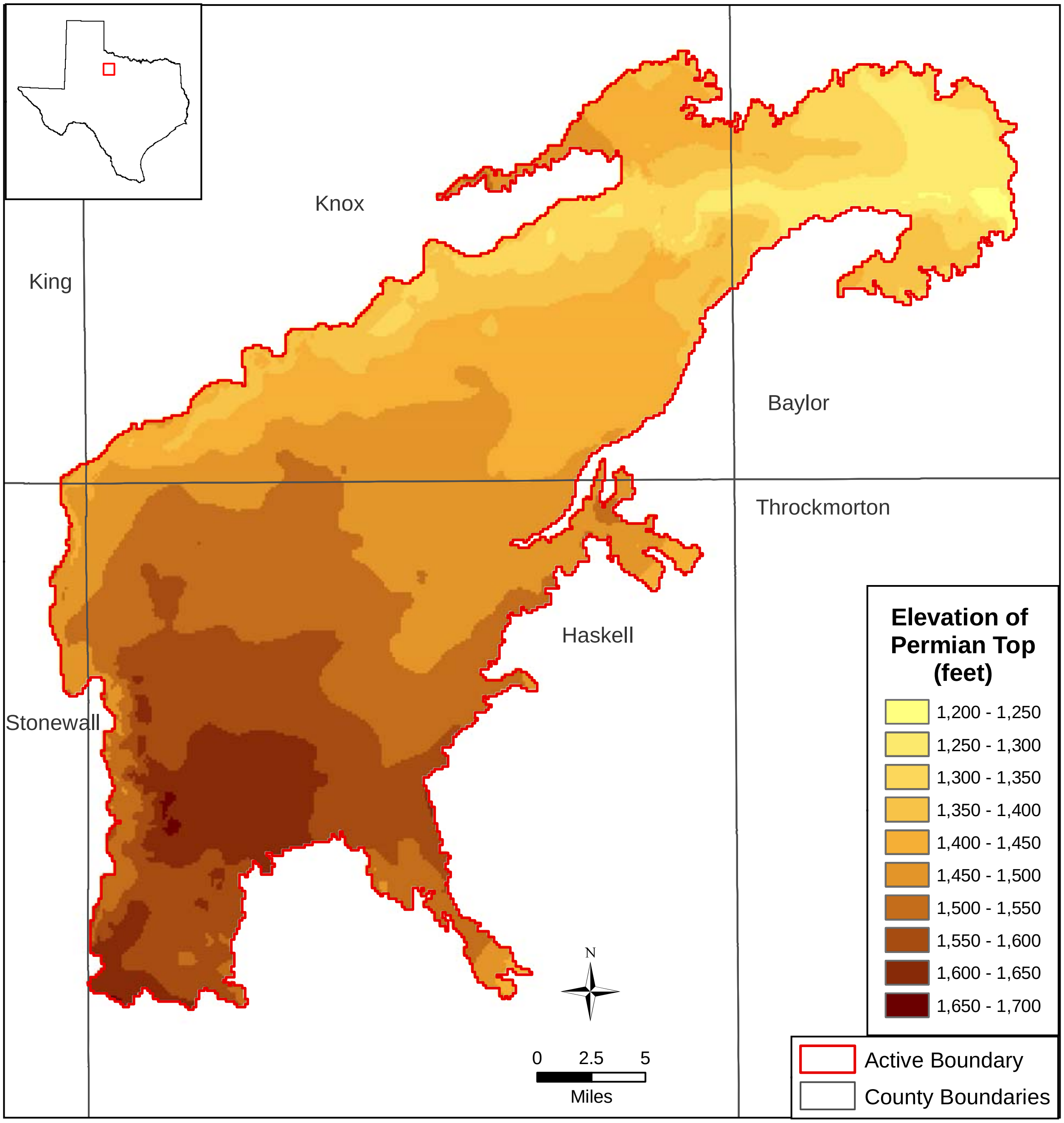


Figure 4.2.5 Structure map of the top of the Clear Fork Group.

4.3 Water Levels and Regional Groundwater Flow

A literature search was conducted to understand regional groundwater flow and historical conditions in the Seymour Aquifer. The primary sources used to obtain information regarding groundwater flow in the Seymour Aquifer were the report on groundwater resources in Haskell and Knox counties by Ogilbee and Osborne (1962), the report on the occurrence and quality of groundwater in Baylor County by Preston (1978), the report on the Seymour Aquifer in Haskell and Knox counties by R.W. Harden and Associates (1978), the survey of public water supplies in central and north-central Texas by Sundstrom and others (1949), and the report on the geology and groundwater of the Wichita Region in north-central Texas by Gordon (1913). In addition, water-level data provided on the TWDB website (TWDB, 2008c) and the United States Geological Survey website (United States Geological Survey, 2009a) were used to (1) develop water-level elevations for steady-state conditions, the start time for the transient model calibration period (January 1980), the middle time for the transient model calibration period (January 1990), and the end of the transient model calibration period (December 1997); (2) investigate transient water-level conditions; and (3) investigate cross-formational flow. Note that almost all of the water-level data on the United States Geological Survey website (United States Geological Survey, 2009a) are contained in the data from the TWDB website (TWDB, 2008c).

Water-level data for the Seymour Aquifer from the TWDB website (TWDB, 2008c), the United States Geological Survey website (United States Geological Survey, 2009a), and Sundstrom and others (1949) consist of 5,993 water-level measurements taken in 1,503 wells. The locations of wells with water-level data are shown in Figure 4.3.1. Five hundred and sixty eight, 630, and 305 Seymour Aquifer wells are located in Haskell, Knox, and Baylor counties, respectively. Only six wells and a total of 29 water-level measurements are available for the portion of the pod in Stonewall County. For this discussion, those wells and measurements have been combined with those for Haskell County. The number of water-level measurements by county is 3,124 for Haskell County, 2,092 for Knox County, and 777 for Baylor County. The frequency of water-level measurements with time is shown in Figure 4.3.2. The largest number of measurements was taken in 1956 in Haskell and Knox counties and in 1969 in Baylor County. The low number of measurements prior to 1956 is likely due to there being fewer wells completed into the

Seymour Aquifer prior to that time. Note that the number of water-level measurements for the time period corresponding to the beginning (1980), middle (1990), and end (1997) of model calibration is low.

4.3.1 Historical Water-Level Fluctuations in the Seymour Aquifer

Land use over the Haskell-Knox-Baylor pod of the Seymour Aquifer changed significantly between about 1880 and 1930 as summarized in Section 2.3. Those changes appear to have impacted recharge to and natural discharge from the Seymour Aquifer, which caused significant fluctuations in water levels in portions of the aquifer. The fact that large changes in water levels resulted from changes in recharge and natural discharge is likely due to the thin nature of the aquifer and the relatively short time required for water to infiltrate through the unsaturated zone and reach the water table. This section contains a summary of historical water levels in the Seymour Aquifer prior to significant pumping, which began in the 1950s. A description of land use changes and how they affected the Seymour Aquifer can be found in Section 5.0.

Groundwater in the Seymour Aquifer was under steady-state conditions, where recharge and natural discharge were balanced resulting in no net change in storage, prior to about 1880. Water levels in the Seymour Aquifer under this steady-state condition are unknown. However, it is likely that the aquifer had some saturated thickness over most of its area because of the sandy nature of the surface soil and the fact that the aquifer is shallow. The presence of buffalo bones and Indian artifacts at several springs flowing from the Seymour Aquifer (see Section 4.5.2) supports this theory.

The steady-state condition of the Seymour Aquifer was disrupted by anthropogenic activities related to the introduction of livestock and agriculture to the area. Overgrazing by domestic livestock and the resultant increase in number and areal distribution of honey mesquite may have caused an increase in natural aquifer discharge due to an increase in water-table evapotranspiration by mesquite tap roots. In addition, degradation of the surface soil caused by overgrazing probably resulted in some decrease in aquifer recharge due to decreased infiltration of precipitation. Sherrill (1965) reports that Haskell County experienced two years of major drought (1886 and 1896) and several years of light rainfall (1890 through 1893, 1901, 1904, and 1910) between 1880 and 1910. These periods of reduced precipitation would have also contributed to decreased aquifer recharge. It is possible that water levels in portions of the Seymour Aquifer declined as a result of increased natural aquifer discharge and decreased recharge, which may have caused drying out of the aquifer in areas where it is thin and the density of phreatophytes was high and/or located in areas where recharge was reduced. Historical accounts by Gordon (1913), based on field work conducted in 1906 and 1907, indicate that portions of the Seymour Aquifer were dry in the early 1900s. Gordon (1913) reports that groundwater was not found throughout the Seymour Formation in Haskell and Knox counties. He does not mention specific locations in Knox County where groundwater was found in the Seymour Formation, but does provide some detail for Haskell County. He states that groundwater was found in the basal gravel in the Seymour Formation in the city of Haskell but that "On approaching the Double Mountain Fork, … these beds appear to be bereft of water and the wells extend some distance into the red clays (Permian) before striking water…" However, he also states that "many wells in the western part of Haskell County derive their supplies from the Seymour formation at depths of 40 to 50 feet". Based on the driller's record given in Gordon (1913) for two wells in the city of Rule, one well 10 miles northwest of the city, and one well about 12 miles southwest of the city, water was not found in these wells until they penetrated the Permian-age sediments. Gordon (1913) reports that water was found in the Seymour Formation at depths of about 15 to 45 feet in western Baylor County, suggesting that this portion of the aquifer received sufficient recharge to sustain some saturated thickness. Preston (1978) states that "oldtimers" in Baylor County report that "where the Seymour Formation is well developed…there were only small amounts of water available from the Seymour 40 or 50 years ago".

Farming in Haskell, Knox, and Baylor counties boomed between about 1900 and 1910 and about 1920 and 1930 (Texas State Historical Association, 2008), which brought with it land use changes. Improving the surface soil through clearing, plowing, and terracing the land appears to have increased recharge to the Seymour Aquifer. It is also likely that clearing honey mesquite and the native grasses and planting crops reduced natural discharge via evapotranspiration. These changes in recharge and natural discharge could have caused the water-level rises experienced in some areas of the aquifer due to aquifer recharge exceeding natural aquifer discharge. Bandy (1934), as reported in Ogilbee and Osborne (1962) and R.W. Harden and Associates (1978), provides information on significant water-level rises in portions the Seymour

Aquifer between about 1909 and 1934. He interviewed residents and inventoried wells in northwestern Haskell County in 1934 to investigate reported rises in water levels in the aquifer. Some of the information reported by Bandy (1934) based on those interviews includes:

- the depth to water in the city of Rochester well was 45 feet below ground surface in 1926 and 35 feet below ground surface in 1934 with 4 feet of the water-level rise occurring in the last two years (1932 to 1934),
- water in a well located 5 miles west of the city of Rochester was 70 to 75 feet below ground surface and hard and gip 25 years ago (about 1909) and 45 feet below ground surface and soft and fresh in 1934,
- water in a well located 8 miles west of the city of Rochester was 74 feet below ground surface when it was dug (date not given) and 13 feet below ground surface in 1934,
- in a well located near the old city of Judd, the depth to water was 10 feet when it was dug (date not given) and water was running out of the well in 1934,
- in a well located 1 mile west of Rochester, the depth to water was 75 feet below land surface when it was dug (date not given) and was 45 feet below ground surface in 1934, and
- water has risen to the top of several wells resulting in the development of marsh land.

Bandy (1934) also stated that:

"…the rise of ground water in this area is no myth, but a fact, that the rise has been about a foot per year with some little acceleration during the last few years, and the water has changed from hard, gip and salt water to soft, fresh water. …. This has been very beneficial to this county until recent years; for fresh water had been very hard to obtain, but in 1928 numerous small spots of water-logged land began to appear here and there, the following year changing to a salt marsh which was wholly non-productive. These spots have increased in size year by year until at this date there are some of from five to one hundred twenty acres; they would aggregate probably 200 acres at the present time."

R.W. Harden and Associates (1978) tried to determine the locations of the wells in Bandy's investigation, but could not. They did conclude that his records indicated that the water-level rises were observed in the vicinity of the cities of Rochester and O'Brien. R.W. Harden and Associates (1978) summarized the water-level rises reported by Bandy (1934) in a figure, which is reproduced in Figure 4.3.3. This figure indicates rises of up to about 69 feet over about a 20-year period.

Additional information regarding the rise in water levels in the Seymour Aquifer is found in Sundstrom and others (1949), who inventoried public water supplies in the central and north-central Texas. They report that:

- a municipal well for the city of Rochester had a depth to water of 46 feet below ground surface when dug in 1926 and 15 feet below ground surface on March 24, 1944,

- a municipal well for the city of Rule had a depth to water of 28 feet below ground surface when dug in 1923 and 32 feet below ground surface on March 20, 1944; recall that Gordon (1913) stated that groundwater was not found in the Seymour Formation in 1906/1907 in the vicinity of the city of Rule, and

- a municipal well for the city of Goree, dug in 1925, had a depth to water of 28 feet below ground surface in 1938 and 21.7 feet below ground surface on March 22, 1944.

The information reported in Bandy (1934), Sundstrom and others (1949), and Preston (1978) support the theory that water levels in the Seymour Aquifer increased substantially in some areas after the early 1900s. These water-level rises appear to be the result of increased aquifer recharge and decreased natural aquifer discharge due to land use changes related to agricultural development in the area. Ogilbee and Osborne (1962) state that "The period of rising water levels corresponds with the period of rapid agricultural development and also approximately corresponds with a period of above normal precipitation. Both conditions may be factors in causing the rise in water levels."

How water levels in the Seymour Aquifer changed between 1934 and the early 1950s is unknown. Water-level measurements are available for six wells in 1944 and then again in 1951.

Half of these wells showed an increase in water level of about 2 feet over this time period and the other half showed a decrease in water level of about 2 feet. Significant pumping of the Seymour Aquifer began in the 1950s for irrigation purposes as a result of a severe drought from about 1951 to 1957 and the introduction of new technologies that enabled efficient pumpage of groundwater. Ogilbee and Osborne (1962) state that there were 25 irrigation wells in Haskell and Knox counties in 1951 and 1,100 in 1956. Pumping of the aquifer during the 1950s generally resulted in declines in water level across large portions of the aquifer. Since the late 1950s, water levels in the Seymour Aquifer have fluctuated due to changes in precipitation and pumping but have, in general, remained relatively stable (i.e., no significant, permanent drawdown and no significant, permanent gains in storage). A discussion of transient water levels in the Seymour Aquifer since about 1950 can be found in Section 4.3.6.

4.3.2 Regional Groundwater Flow

Regional groundwater flow in the Seymour Aquifer under steady-state conditions prior to about 1880 was topographically driven from areas of high topography near the city of Rule in Haskell County to areas of low topography along the Brazos River and Lake Creek. Once land use in the area stabilized in about the 1930s to 1940s, this regional flow pattern returned. In the portion of the Seymour Aquifer located in Baylor County, a groundwater divide oriented west-northwest to east-southeast is present from the Baylor-Knox county line to about the center of the Seymour Aquifer (Preston, 1978). The location of this divide is approximately along the divide between the Red River Basin and Brazos River Basin (see Figure 2.0.9). Groundwater north of this divide flows to the north and northeast toward seeps and springs along the northern edge of the aquifer and groundwater south of the divide flows to the south and southeast towards the Brazos River. In addition, groundwater in the narrow portion of the aquifer located south of the Brazos River flows northward to the river.

Figure 4.3.4 shows the approximate direction of groundwater flow, assuming no pumping effects, in the Seymour Aquifer in Knox and Haskell counties as reported by R.W. Harden and Associates (1978). The direction of groundwater flow in the Seymour Aquifer in Haskell and southern Knox counties is generally to the northwest, north, and northeast following the slope of the ground surface and the slope of the underlying Permian-age beds. In the very southern portion of the aquifer in Haskell County, groundwater flow is generally to the east and southeast with some flow also to the southwest.

4.3.3 Steady-State Conditions

Steady-state conditions for typical aquifers coincide with the time period prior to significant pumpage. For the Seymour Aquifer, however, steady-state conditions were disrupted by land use changes beginning in about 1880, many years prior to the advent of significant pumping in the 1950s. Brune (2002) reports that buffalo bones and Indian artifacts were found at several springs flowing from the Seymour Aquifer. This is evidence that the aquifer had some saturated thickness under steady-state conditions. Water-level data are not available prior to the late 1800s; therefore, no water-level targets for the steady-state period are available. However, the elevations of the springs flowing from the aquifer during this time provide a minimum elevation for water levels. The exact location is available for only a few of these historical springs (see Section 4.5.2). The elevations of the historical springs with known locations are posted on Figure 4.3.5. No attempt was made to contour these elevations because the data are insufficient to appropriately represent the variability in the water table due to the variability in the topography. The elevations on Figure 4.3.5 provide a minimum elevation for the Seymour Aquifer under steady-state conditions.

Estimated steady-state water-level elevations for the Permian-age formations are shown in Figure 4.3.6. Due to the sparse data for the Permian formations in the model area, data from several counties surrounding the model area, as shown in Figure 4.3.7, were included in developing these contours. The steady-state water-level elevations for the Permian-age formations were taken as the first water-level measurements for wells with relatively stable water levels throughout time and with depths to water less than 200 feet. This latter criterion was used because only the upper portion of the Permian-age formations may affect the hydrologic flow system of the Seymour Aquifer.

4.3.4 Water-Level Elevations for Transient Model Calibration

Transient model calibration considers the time period from January 1, 1980 to December 31, 1997. Water-level data obtained from the TWDB website (TWDB, 2008c) and the United States

Geological Survey (United States Geological Survey, 2009a) were used to develop water-level elevations for the Seymour Aquifer and the underlying Clear Fork Group for the start of the transient model calibration (January 1980), the middle of the transient model calibration (January 1990), and the end of the transient model calibration (December 1997). These water-level elevations were used to aid in assessing the transient model's ability to represent observed conditions.

Water-level data are not available at regular time intervals in every well. Therefore, the coverage of water-level data for a particular month or even a year is very sparse. Since the amount of water-level data available for the times of interest were not sufficient to develop contours, data for the year of interest and for two years prior to and two years after the year of interest were used. If a well had only one water-level measurement during that time, that measurement was used. If a well had several water-level measurements during that time, the average of the water levels was used.

Because the Seymour Aquifer is shallow, thin, and responds quickly to recharge, seasonal changes in precipitation and pumping are readily observed in water levels in most areas of the aquifer as discussed in Section 4.3.6. In order to compare water levels in the aquifer at the beginning, middle, and end of the transient model calibration period, only water levels measured during the winter months (November through March), when water levels in the aquifer are least effected by irrigation pumping and precipitation, were used to create contours of water-level elevations for these three time periods. In order to meaningfully evaluate the model's ability to reproduce observed conditions, water-level elevations predicted by the model during the winter months was compared to these contours.

Figures 4.3.8, 4.3.9, and 4.3.10 show water-level elevation contours in the Seymour Aquifer at the beginning, middle, and end of the model calibration period, respectively. These contours show that the water level was highest near the city of Rule and decreased in all directions out from the maximum for all three time periods. Table 4.3.1 presents the water-level elevations for wells having data for at least two out of the three years of interest for the transient model calibration. This table also provides an indication of the trend in the water level, the magnitude of observed increases and decreases in water level, and the overall change in water level between

1980 and 1997, with the exception of well 21-33-940 where the overall change is for the period between 1990 and 1997. The information in Table 4.3.1 is also plotted on Figure 4.3.11. The site numbers used to identify wells on this figure are included in Table 4.3.1. An overall increase of more than 5 feet was observed at site 1 in Baylor County, site 23 in Knox County, and sites 13 and 17 through 19 in Haskell County. An overall decrease of more than 5 feet was observed only at site 12 in Haskell County. In general, overall increases were observed in Baylor, Knox, and the southern portion of the pod in Haskell County and overall decreases were observed in the central portion of the pod in Haskell County.

Figures 4.3.12, 4.3.13, and 4.3.14 show water-level elevation contours for the Permian-age formations in the model area at the start, middle, and end of the transient model calibration period, respectively. Due to the sparse data for the Permian-age formations within the model area, data from several counties surrounding the model area (see Figure 4.3.7) were included in developing these contours. These figures indicate that flow in the Permian-age formations is from topographic highs on the western side of the model area to topographic lows on the eastern side. Very little change in water levels occurred in the Permian-age formations between 1980 and 1997. A comparison of these contours to the contours of steady-state water-level elevations in Figure 4.3.6 indicate that water levels in the Permian-age formations were about 25 feet higher under steady-state conditions.

4.3.5 Cross-Formational Flow

An exercise was conducted to investigate cross-formational flow between the Seymour Aquifer and the underlying Clear Fork Group. Vertical flow within the Seymour Aquifer itself was not evaluated due to the thin nature of the aquifer. At three locations in the model area, wells completed separately to the Seymour Aquifer and the Clear Fork Group share a similar surface location. The comparison of water-level elevations in those wells is shown in Figure 4.3.15 and Table 4.3.2.

For the location in Haskell County, the water-level elevations in the wells completed into the Seymour Aquifer are higher than those in the wells completed into the Clear Fork Group. For all the wells at this location, the water level was measured in January, March, or October, with the exception of one measurement in May 1956 for well 21-49-902 completed into the Clear Fork

Group. In this area, the water-level elevations in the Seymour Aquifer are higher than those in the Clear Fork Group. This could indicate a potential for flow from the Seymour Aquifer to the Clear Fork Group. However, the land surface elevations for the wells completed into the Seymour Aquifer are higher than those for the wells completed into the Clear Fork Group. This difference in land surface elevation could explain the difference in water-level elevations. If a downward gradient does exist between the two formations, the amount of flow is most likely small due to the low permeability of the sediments making up the Clear Fork Group. This conclusion is supported by the difference in the chemical quality of the water in the Seymour Aquifer and the Clear Fork Group (Ogilbee and Osborne, 1962).

For the western-most cluster in Baylor County, the water-level elevation in the well completed into the Clear Fork Group is lower than that in one nearby Seymour Aquifer well and higher than that in three other nearby Seymour Aquifer wells. The wide range in water-level elevations for wells completed into the Seymour Aquifer at this location likely reflects the range in water levels in the aquifer due to seasonal changes (see Section 4.3.6) and/or the range in land surface elevation. For the wells completed into the Seymour Aquifer at this location, the water level was measured in April or June in the three wells with a water-level elevation below the water-level elevation in the Clear Fork Group (wells 21-29-310, 21-29-307, and 21-29-302) and was measured in January and February in the one well (well 21-29-306) with a water-level elevation above the water-level elevation in the Clear Fork Group. In addition, the land surface elevation at the well completed into the Clear Fork Group is 19 feet below that for the Seymour Aquifer well with the higher water-level elevation (well 21-29-306) and is 21 to 33 feet above that for the three Seymour Aquifer wells with the lower water-level elevation (wells 21-29-310, 21-29-307, and 21-29-302). The fact that the water-level elevation in the Clear Fork Group at this location falls between the water-level elevations in the Seymour Aquifer could be a function of seasonal fluctuations in water levels in the Seymour Aquifer and/or a function of the difference in the ground surface elevation at the wells. Therefore, no clear conclusion can be made regarding the direction of the gradient between the Seymour Aquifer and the Clear Fork Group at this location.

For the eastern-most cluster in Baylor County, the water-level elevation in the well completed into the Clear Fork Group is about 10 feet lower than the water-level elevation in three nearby wells completed into the Seymour Aquifer (wells 21-30-110, 21-30-118, and 21-30-121) and about 50 feet higher than the water-level elevation in two other nearby wells completed into the Seymour Aquifer (wells 21-30-109 and 21-30-124). At this location, the large range in water-level elevations in the Seymour Aquifer appears to be due to the large difference in ground surface elevation at the wells rather than seasonal fluctuations in water levels. For the two Seymour Aquifer wells with water-level elevations below that in the Permian well, the ground surface elevation is about 40 feet below the ground surface elevation of the Clear Fork Group well. For the three Seymour Aquifer wells with water-level elevations above that in the Clear Fork Group well, the ground surface elevation is 16 feet above the ground surface elevation of the Clear Fork Group well. The fact that the water-level elevation in the Clear Fork Group at this location falls between the water-level elevations in the Seymour Aquifer could be a function of the differences in ground surface elevation at the wells. Therefore, no clear conclusion can be made regarding the direction of the gradient between the Seymour Aquifer and Clear Fork Group at this location.

All of the water-level data shown in the comparisons in Figure 4.3.15 are for a time prior to the time period for the transient model calibration. A comparison of the water-level elevation contours for the start, middle, and end of the transient model calibration period between the Seymour Aquifer (Figures 4.3.8 through 4.3.10) and the Permian-age formations (Figures 4.3.12 through 4.3.14) indicate higher water levels in the Seymour Aquifer than in the Permian-age formations for all three times in Baylor County and in Haskell County in the vicinity of the city of Rule where the maximum water levels in the Seymour Aquifer are observed. The water level in the Permian-age formations is higher than in the Seymour Aquifer along the western edge of the pod in Haskell and Knox counties. Although the water level in the Seymour Aquifer is higher than in the Permian-age formations in some areas, low flow rates from the Seymour Aquifer to the underlying Permian-age formations are expected due to the low permeability of the predominantly shale Permian-age sediments. The difference in the chemical quality of the groundwater in the Seymour Aquifer and Permian-age formations also suggests little flow between the two, however, the chemical quality in the Permian-age formations may be more indicative of long-term, pre-development conditions than of more recent (since 1910) conditions where recharge is conceptualized to have increased. The low cross-formational flow rates, when aggregated over the entire aquifer, may amount to a significant portion of the Seymour Aquifer water budget.

4.3.6 Transient Water Levels

Transient water-level data are used in calibration of the transient model. Figure 4.3.16 shows the locations of the 135 wells for which transient water-level data, defined as five or more water-level measurements, are available for the Seymour Aquifer based on data found on the TWDB and United States Geological Survey websites (TWDB, 2008c and United States Geological Survey, 2009a, respectively) and in Sundstrom and others (1949). Table 4.3.3 summarizes the wells with transient water-level data, the year of the first and last water-level measurement, and the total number of water-level measurements. For a little over half of these wells, ten or fewer measurements are available over a period of only a year or two. Therefore, data for those wells give little information on long-term trends within the aquifer. Notice that no water-level data during the time period when the aquifer was filling up (about 1910 to 1940) are available for any of these wells. Note that although the wells from Bandy (1934) do have data during this time period, their locations and state well numbers, if any, are not known.

Figures 4.3.17 through 4.3.23 contain hydrograph plots of the transient water-level data at selected wells. Most of these hydrographs are plotted with a 50-foot elevation difference on the y-axis. In some cases, the difference in water-level elevations was greater than 50 feet and the y-axis was expanded. In all cases, the interval between grid lines on the y-axis is 5 feet. The base of the well is shown on all of the hydrograph plots. The base of the well is assumed to represent the base of the Seymour Aquifer because most wells were drilled only into the top few inches of the underlying Clear Fork Group. Adding the base of the well to the hydrograph plots provides a means to evaluate the saturated thickness of the aquifer with time.

Water-level elevations for the five wells in Baylor County with the most comprehensive transient data are shown in Figure 4.3.17. This figure shows that the water level has remained relatively stable in one of the wells, has slightly increased in three of the wells, and has slightly decreased in one of the wells. The magnitude of the observed increases ranges from less than 5 feet to about 10 feet and the magnitude of the observed decrease is about 5 feet.

In Haskell County, long-term water-level data extending through the transient model calibration period are available for 19 wells. The data for 13 of these wells shows a decrease in water level from the start of the record in the 1950s to around 1960 or 1965 followed by an increase in water level until about 1990 and then another decrease in water level, with the magnitude of the decreases and increases ranging from about 10 to 30 feet. Transient data at several wells that exhibit this trend in long-term water levels are shown in Figure 4.3.18. Although the water levels in these wells show fairly large fluctuations relative to the saturated thickness of the aquifer, they do not indicate an overall increase or decrease in water level in the aquifer. In addition to the fluctuating trend observed in most wells in Haskell County, an increase in water level is observed in five wells for which long-term data are available and a stable water-level trend is observed in one well (Figure 4.3.19). The magnitude of the increases ranges from about 3 to 25 feet. The earliest water-level measurement in Haskell County was taken in 1926 in a city of Rochester well (well 21-42-401). The transient data for this well (Figure 4.3.19) shows an increase in water level of about 30 feet between 1926 and 1944. This increase reflects a portion of the time period during which parts of the Seymour Aquifer were gaining water. After 1944, the water level in this well had decreased about 10 feet by about 1965, increased about 20 feet by about 1995, and then decreased until the last measurement in 1996. The transient data for this well indicates that, although the water level in the well fluctuated after the Seymour Aquifer gained water, it never decreased to the level observed in 1926.

In Knox County, long-term water-level data extending through the transient model calibration period are available for 16 wells. The water levels in four of those wells show an overall decrease since about 1950 (Figure 4.3.20). The magnitude of the decreases ranges from about 6 feet to about 20 feet. For all four wells, the water levels remained stable or even increased slightly from about 1980 to 2000, even though the overall long-term trend was a decline in water level. The water levels in five wells with long-term data in Knox County show an initial decrease followed by an increase (Figure 4.3.21). The time at which the trend changed from decreasing to increasing ranges from about 1965 to about 1990. The magnitude of the decreases ranges from about 10 to 20 feet and the magnitude of the increases ranges from about 5 to 15 feet. The water levels in four of the wells with long-term water-level data in Knox County show an overall increasing trend since about 1955 to about 1990 (Figure 4.3.22). For three of these wells, the water levels slightly decreased between 1990 and the end of the record. The magnitude of the increases ranges from about 8 to 15 feet and the magnitude of the decreases ranges from about 5 to 8 feet. The water levels in another three of the wells with long-term data in Knox County show an overall stable trend (Figure 4.3.23). Although the water level in these wells fluctuated with time, the overall trend is stable.

Long-term water-level data sufficient to evaluate seasonal trends are available for three unused wells located in Knox and Haskell counties (Figure 4.3.24). The water level was measured several times monthly in well 21-36-103 located in Knox County between July 1975 and November 1977 and in well 21-35-748 located in Haskell County between August 2002 and February 2008. In well 21-42-409 located in Haskell County, the water level was measured several times monthly between July 1975 and December 1982 and approximately monthly between January 1983 and March 1986. The water-level data for well 21-36-103 in Knox County indicates a consistent decline in water level of about 3 feet over the 2.5-year record with no indication of seasonal fluctuations. The first 3 years of data for well 21-35-748 in Haskell County clearly show seasonal fluctuations with the minimum water level observed in about August and the maximum water level observed in about April. The difference in water level between the summer and winter seasons ranged from about 2 to 5 feet. The remaining 2.5 years of the water-level record for this well also shows a minimum water level in about August but does not show the clear fluctuations observed in the first 3 years of the record. The water-level data for well 21-42-409 in Haskell County show an overall decline in the water level between July 1975 and about August 1980 followed by an overall increase in the water level to the end of the record. Superimposed on this general trend for well 21-42-409 are shorter term fluctuations, but those fluctuations do not appear to reflect a consistent seasonal trend. For example, the water level is relatively higher in the June to August period and relatively lower in the December to March period for several years (i.e., 1976-1977, 1981-1982, and 1985), which seems inconsistent with higher pumping and lower precipitation in summer months relative to winter months. The expected trend is a lower water level in the summer months when irrigation pumping is high and precipitation is low, which is observed only in 1978 and 1980. The data from these three wells suggests that the water level in the Seymour Aquifer in Haskell and Knox counties fluctuates seasonally in some areas but not in other areas.

Water levels measured every few months between December 1968 and February 1970 are available for 15 wells in Baylor County. The locations of those wells along with their water-level data during this time period and primary use, as indicated on the TWDB website (TWDB, 2008c), are shown in Figure 4.3.25. Note that the y-axis is different for every plot shown on this figure and ranges from 10 to 20 feet. For the majority of these wells, the lowest water level was observed in the July to September months and the highest water level was observed in the winter months. The difference in water level between the summer and winter seasons ranged from as little as about 0.5 feet to as much as about 5 feet. For the remaining wells, no seasonal change in water level was observed over this time period. Note that a seasonal change was observed in all of the wells whose primary use is irrigation. Based on these data, it appears that water levels in the portion of the Seymour Aquifer located in Baylor County are lower in the summer months and higher in the winter months.

Table 4.3.1 Comparison of average 1980, 1990, and 1997 water-level elevations in the Seymour Aquifer.

State Well Number	County	Site Number[1]	Average 1980 Water-Level Elevation (feet)	Average 1990 Water-Level Elevation (feet)	Average 1997 Water-Level Elevation (feet)	Trend[2]	Magnitude of Increase (feet)	Magnitude of Decrease (feet)	Overall Change (feet)[3]
21-22-802	Baylor	1	1283.79	1288.96	1290.43	increasing	6.65		6.65
21-30-202	Baylor	2	1279.32	1283.34	1281.60	increasing-decreasing	4.02	1.74	2.29
21-30-204	Baylor	3	1272.91	1274.26	1272.90	increasing-decreasing	1.34	1.36	-0.01
21-34-702	Haskell	4	1533.93		1537.61	increasing	3.67		3.67
21-34-902	Haskell	5	1522.34		1519.16	decreasing		3.18	-3.18
21-35-702	Haskell	6	1507.41		1508.61	increasing	1.20		1.20
21-35-801	Haskell	7	1491.73		1493.14	increasing	1.41		1.41
21-42-104	Haskell	8	1567.65		1564.66	decreasing		2.99	-2.99
21-42-201	Haskell	9	1540.89		1540.95	increasing	0.06		0.06
21-42-202	Haskell	10	1535.64		1530.98	decreasing		4.66	-4.66
21-42-502	Haskell	11	1553.89		1552.43	decreasing		1.46	-1.46
21-42-701	Haskell	12	1623.10		1615.58	decreasing		7.52	-7.52
21-49-211	Haskell	13	1605.78		1613.20	increasing	7.42		7.42
21-49-301	Haskell	14	1648.42		1652.38	increasing	3.96		3.96
21-49-601	Haskell	15	1649.66		1650.11	increasing	0.45		0.45
21-49-603	Haskell	16	1648.12		1650.01	increasing	1.89		1.89
21-50-401	Haskell	17	1637.81		1647.67	increasing	9.86		9.86
21-50-402	Haskell	18	1632.80		1638.13	increasing	5.33		5.33
21-50-506	Haskell	19	1625.41		1632.04	increasing	6.62		6.62
21-51-702	Haskell	20	1564.85		1566.33	increasing	1.48		1.48
21-51-710	Haskell	21	1572.96		1575.36	increasing	2.40		2.40
21-20-901	Knox	22	1407.80	1411.46	1410.64	increasing-decreasing	3.66	0.82	2.85
21-27-801	Knox	23	1419.73	1428.49	1427.17	increasing-decreasing	8.76	1.32	7.43
21-29-102	Knox	24	1403.24	1406.44	1406.41	increasing-decreasing	3.20	0.03	3.17
21-33-940	Knox	25		1479.51	1478.55	decreasing		0.96	-0.96
21-34-202	Knox	26	1434.11	1434.65	1437.80	increasing	3.69		3.69
21-34-402	Knox	27	1456.79	1459.47	1457.07	increasing-decreasing	2.68	2.39	0.28
21-34-501	Knox	28	1509.76	1514.93	1511.91	increasing-decreasing	5.17	3.02	2.15
21-34-601	Knox	29	1489.40	1491.83	1493.90	increasing	4.50		4.50

Table 4.3.1, continued

State Well Number	County	Site Number[1]	Average 1980 Water-Level Elevation (feet)	Average 1990 Water-Level Elevation (feet)	Average 1997 Water-Level Elevation (feet)	Trend[2]	Magnitude of Increase (feet)	Magnitude of Decrease (feet)	Overall Change (feet)[3]
21-35-201	Knox	30	1471.32	1469.38	1469.79	increasing-decreasing	1.94	0.41	-1.53
21-35-301	Knox	31	1448.36	1455.94	1452.54	increasing-decreasing	7.58	3.39	4.18
21-35-501	Knox	32	1483.09	1487.45	1486.12	increasing-decreasing	4.36	1.34	3.02
21-35-502	Knox	33	1476.22	1480.10	1480.79	increasing	4.57		4.57
21-35-602	Knox	34	1456.44	1458.56	1457.53	increasing-decreasing	2.13	1.03	1.10
21-36-201	Knox	35	1425.95	1427.10	1428.06	increasing	2.11		2.11

[1] corresponds to site numbers in Figure 4.3.11

[2] if one trend is given, it reflects the overall trend from the first year to the last year of data; if two trends are given, the first trend corresponds to the time period from 1980 to 1990 and the second trend corresponds to the time period from 1990 to 1997

[3] overall change from 1980 to 1997; positive values indicate an overall increase in water-level elevation and negative values indicate an overall decrease in water-level elevation

Table 4.3.2 Summary of data used to compare water-level elevations in the Seymour Aquifer and the underlying Clear Fork Group.

State Well Number	County	Unit	Date of Water-Level Measurement	Elevation of Land Surface Datum (feet)	Depth to Water (feet)[1]	Water-Level Elevation (feet)[2]
Haskell County						
21-49-907	Haskell	Seymour Aquifer	3/21/1944	1683	-15.4	1667.6
21-49-907	Haskell	Seymour Aquifer	1/6/1977	1683	-26.7	1656.3
21-49-906	Haskell	Seymour Aquifer	1/6/1977	1690	-30.7	1659.3
21-49-606	Haskell	Seymour Aquifer	1/6/1977	1686	-29.1	1656.9
21-49-903	Haskell	Seymour Aquifer	3/21/1944	1686	-28.6	1657.4
21-49-903	Haskell	Seymour Aquifer	10/18/1956	1686	-37.4	1648.6
21-49-903	Haskell	Seymour Aquifer	1/6/1977	1686	-27.6	1658.4
21-49-901	Haskell	Clear Fork Group	10/17/1956	1662	-32.6	1629.4
21-49-901	Haskell	Clear Fork Group	1/6/1977	1662	-20.7	1641.3
21-49-901	Haskell	Clear Fork Group	1/6/1977	1662	-20.7	1641.3
21-49-902	Haskell	Clear Fork Group	5/25/1956	1636	-18.2	1617.8
21-49-902	Haskell	Clear Fork Group	1/2/1957	1636	-20.4	1615.6
21-49-902	Haskell	Clear Fork Group	1/6/1977	1636	-3.0	1633.0
21-49-801	Haskell	Clear Fork Group	10/17/1956	1651	-37.3	1613.7
21-49-801	Haskell	Clear Fork Group	1/27/1976	1651	-23.8	1627.2
21-49-801	Haskell	Clear Fork Group	1/6/1977	1651	-24.6	1626.4
western Baylor County						
21-29-306	Baylor	Seymour Aquifer	2/25/1969	1369	-12.7	1356.3
21-29-306	Baylor	Seymour Aquifer	1/21/1970	1369	-11.8	1357.2
21-29-310	Baylor	Seymour Aquifer	6/26/1969	1329	-25.1	1303.9
21-29-307	Baylor	Seymour Aquifer	4/8/1969	1317	-17.2	1299.8
21-29-302	Baylor	Seymour Aquifer	6/26/1969	1318	-20.3	1297.7
21-29-311	Baylor	Clear Fork Group	6/20/1969	1350	-36.4	1313.6
eastern Baylor County						
21-30-110	Baylor	Seymour Aquifer	4/9/1969	1361	-9.2	1351.8
21-30-110	Baylor	Seymour Aquifer	12/18/1969	1361	-9.7	1351.3
21-30-110	Baylor	Seymour Aquifer	3/17/1970	1361	-8.7	1352.3
21-30-110	Baylor	Seymour Aquifer	5/13/1970	1361	-8.7	1352.3
21-30-118	Baylor	Seymour Aquifer	9/16/1969	1361	-15.9	1345.1
21-30-121	Baylor	Seymour Aquifer	10/1/1969	1357	-12.5	1344.5
21-30-109	Baylor	Seymour Aquifer	2/25/1969	1303	-10.3	1292.7
21-30-109	Baylor	Seymour Aquifer	1/22/1970	1303	-9.3	1293.7
21-30-124	Baylor	Seymour Aquifer	10/16/1969	1308	-19.7	1288.3
21-30-119	Baylor	Clear Fork Group	9/16/1969	1345	-6.5	1338.5

[1] negative values indicate water level is below ground surface
[2] calculated as the elevation of land surface datum plus the depth to water

Table 4.3.3 Summary of transient water-level data for the Seymour Aquifer.

State Well Number	County	Date of First Water-Level Measurement	Date of Last Water-Level Measurement	Number of Water-Level Measurements
21-21-801	Baylor	1969	1970	6
21-21-803	Baylor	1969	1970	6
21-21-902	Baylor	1969	1970	6
21-21-912	Baylor	1969	1970	6
21-21-926	Baylor	1969	1970	6
21-21-930	Baylor	1969	1970	6
21-21-939	Baylor	1969	1970	6
21-21-940	Baylor	1969	1970	6
21-21-941	Baylor	1969	1970	6
21-22-402	Baylor	1969	1969	5
21-22-701	Baylor	1956	1988	28
21-22-703	Baylor	1956	1994	40
21-22-704	Baylor	1969	1970	6
21-22-707	Baylor	1969	1970	7
21-22-714	Baylor	1969	1970	6
21-22-720	Baylor	1970	1970	5
21-22-801	Baylor	1969	1970	8
21-22-802	Baylor	1957	2007	42
21-22-806	Baylor	1960	1972	13
21-22-904	Baylor	1969	1970	7
21-22-911	Baylor	1969	1969	6
21-22-912	Baylor	1969	1969	6
21-22-913	Baylor	1969	1969	6
21-29-103	Baylor	1969	1970	7
21-29-305	Baylor	1969	1970	6
21-30-101	Baylor	1956	1970	9
21-30-102	Baylor	1958	1962	5
21-30-106	Baylor	1969	1970	7
21-30-202	Baylor	1960	2007	46
21-30-204	Baylor	1955	1996	40
21-30-206	Baylor	1955	1970	9
21-30-213	Baylor	1960	1970	5
21-30-267	Baylor	1955	1962	7
21-30-303	Baylor	1957	1969	5
21-30-332	Baylor	1969	1970	7
21-30-341	Baylor	1969	1970	5
21-30-386	Baylor	1969	1969	5
21-30-387	Baylor	1969	1969	5
21-34-701	Haskell	1951	1960	10
21-34-702	Haskell	1958	1996	33
21-34-731	Haskell	1998	2007	10

Table 4.3.3, continued

State Well Number	County	Date of First Water-Level Measurement	Date of Last Water-Level Measurement	Number of Water-Level Measurements
21-34-902	Haskell	1955	2003	49
21-34-903	Haskell	1953	1963	10
21-34-904	Haskell	1952	1963	11
21-34-905	Haskell	1952	1972	22
21-35-702	Haskell	1953	2006	53
21-35-703	Haskell	1955	1961	8
21-35-748	Haskell	2002	2008	403
21-35-801	Haskell	1957	1996	34
21-41-801	Haskell	1955	1986	34
21-41-818	Haskell	1998	2006	9
21-41-913	Haskell	1956	1977	6
21-42-102	Haskell	1953	1971	20
21-42-103	Haskell	1953	1960	8
21-42-104	Haskell	1956	2003	47
21-42-201	Haskell	1955	2007	47
21-42-202	Haskell	1952	2002	50
21-42-256	Haskell	1952	1960	10
21-42-258	Haskell	1998	2007	10
21-42-320	Haskell	1957	2007	6
21-42-401	Haskell	1926	1996	33
21-42-402	Haskell	1944	1988	35
21-42-409	Haskell	1975	1986	636
21-42-459	Haskell	1997	2001	5
21-42-460	Haskell	1998	2007	10
21-42-502	Haskell	1958	1996	35
21-42-701	Haskell	1944	1998	46
21-49-211	Haskell	1956	2003	38
21-49-301	Haskell	1944	1995	37
21-49-509	Haskell	1955	1961	5
21-49-601	Haskell	1944	2003	44
21-49-602	Haskell	1944	1962	9
21-49-603	Haskell	1951	2003	28
21-50-401	Haskell	1954	1995	42
21-50-402	Haskell	1955	2001	43
21-50-403	Haskell	1954	1961	10
21-50-404	Haskell	1955	1961	6
21-50-436	Haskell	1956	2007	12
21-50-445	Haskell	1944	1961	8
21-50-506	Haskell	1954	1996	38
21-50-507	Haskell	1954	1963	7
21-50-529	Haskell	1956	1977	5
21-50-601	Haskell	1956	1977	5

Table 4.3.3, continued

State Well Number	County	Date of First Water-Level Measurement	Date of Last Water-Level Measurement	Number of Water-Level Measurements
21-51-402	Haskell	1953	1958	5
21-51-422	Haskell	1951	1963	12
21-51-702	Haskell	1944	2003	44
21-51-703	Haskell	1951	1963	10
21-51-704	Haskell	1954	1961	6
21-51-705	Haskell	1951	1961	10
21-51-707	Haskell	1944	1961	8
21-51-710	Haskell	1951	1996	42
21-51-713	Haskell	1951	1963	11
21-51-721	Haskell	1956	1977	5
21-51-801	Haskell	1998	2006	11
21-20-901	Knox	1956	2003	42
21-27-801	Knox	1956	1998	41
21-27-904	Knox	1977	2007	10
21-27-905	Knox	1956	1977	5
21-27-913	Knox	1956	1977	5
21-28-301	Knox	1956	1963	7
21-28-401	Knox	1956	1977	5
21-28-814	Knox	1956	1977	5
21-29-102	Knox	1956	2003	44
21-33-901	Knox	1956	1994	30
21-33-940	Knox	1988	1996	8
21-34-202	Knox	1956	1996	37
21-34-218	Knox	1956	1977	5
21-34-402	Knox	1956	2003	47
21-34-501	Knox	1951	2003	36
21-34-601	Knox	1958	1996	35
21-34-602	Knox	1955	1977	9
21-34-603	Knox	1955	1963	7
21-34-801	Knox	1954	1960	6
21-34-802	Knox	1944	1961	10
21-35-102	Knox	1955	1980	26
21-35-103	Knox	1955	1960	5
21-35-104	Knox	1955	1961	7
21-35-201	Knox	1956	2003	42
21-35-301	Knox	1954	2003	44
21-35-401	Knox	1953	1961	8
21-35-402	Knox	1955	1993	36
21-35-501	Knox	1955	2000	43
21-35-502	Knox	1955	1996	36
21-35-503	Knox	1958	1962	5
21-35-602	Knox	1954	2003	39

Table 4.3.3, continued

State Well Number	County	Date of First Water-Level Measurement	Date of Last Water-Level Measurement	Number of Water-Level Measurements
21-35-603	Knox	1953	1960	5
21-36-103	Knox	1975	1986	191
21-36-201	Knox	1952	2003	49
21-36-243	Knox	1998	2007	10
21-36-302	Knox	1953	1963	10
21-36-303	Knox	1944	1988	34
21-36-401	Knox	1951	1982	24
21-36-501	Knox	1954	1994	42
21-36-502	Knox	1956	1964	5
21-41-436	Stonewall	1982	2008	24

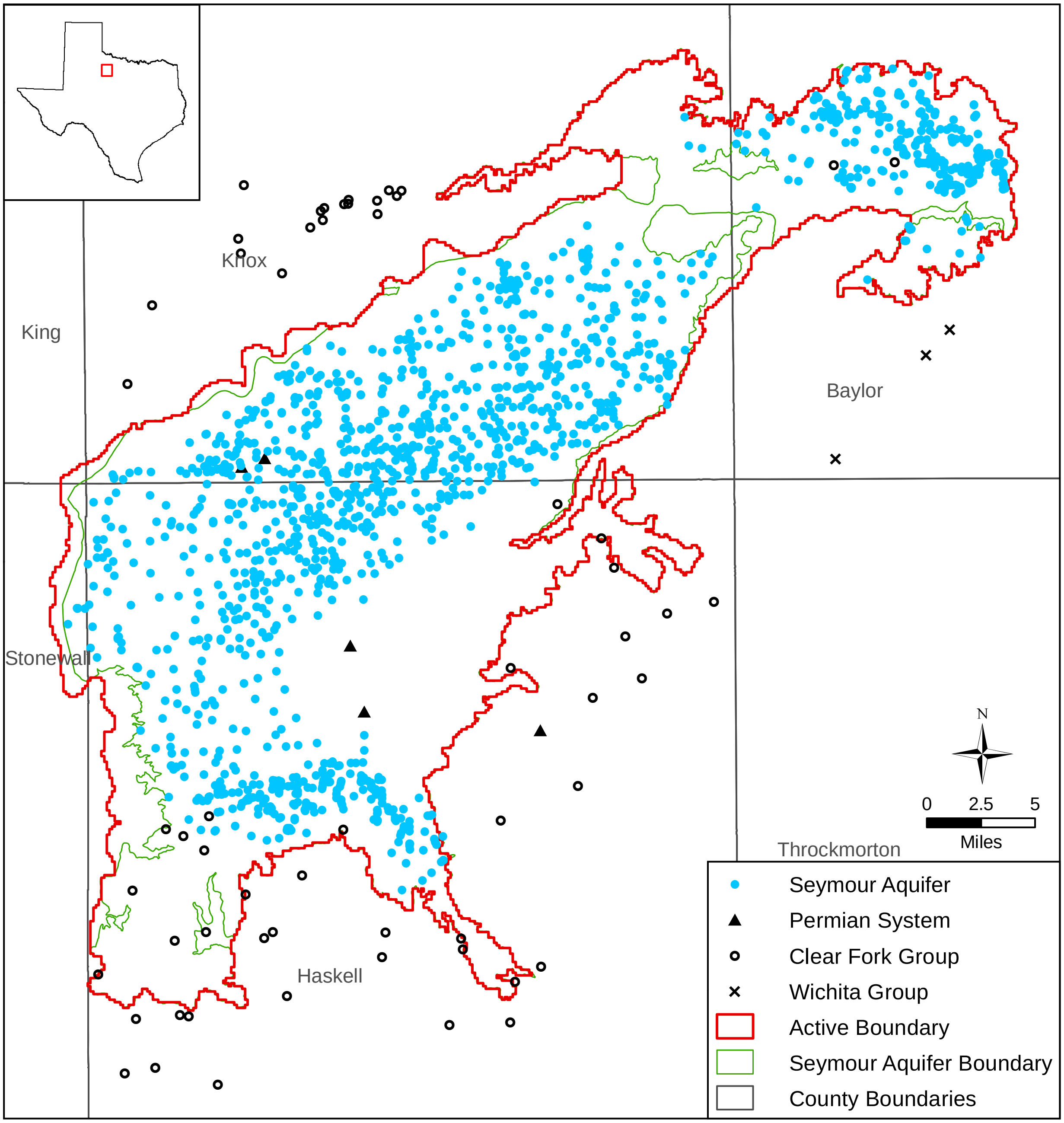


Figure 4.3.1 Water-level measurement locations for the Seymour Aquifer and Permian-age formations in the study area.

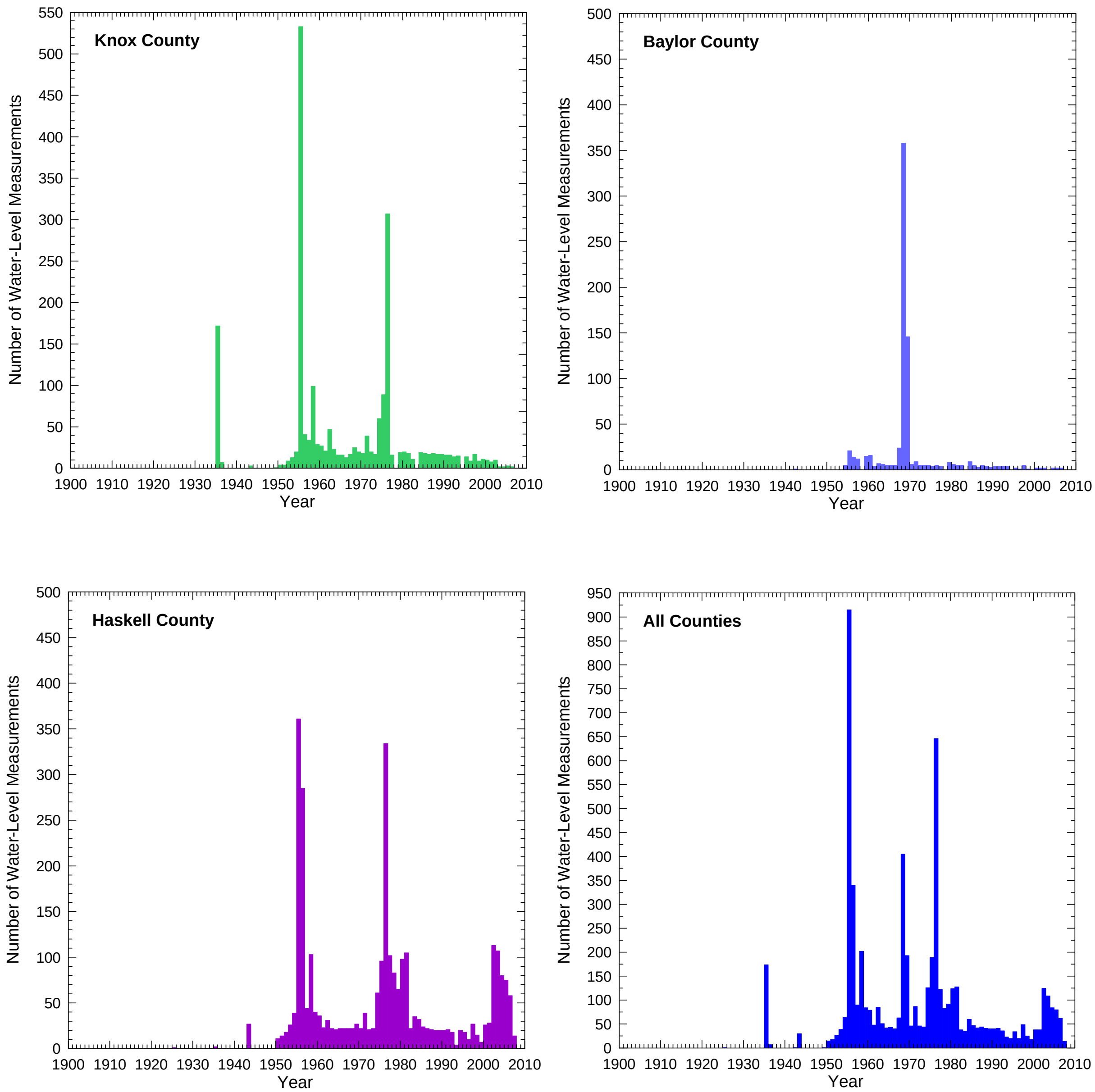


Figure 4.3.2 Temporal distribution of water-level measurements in the Seymour Aquifer in the study area.

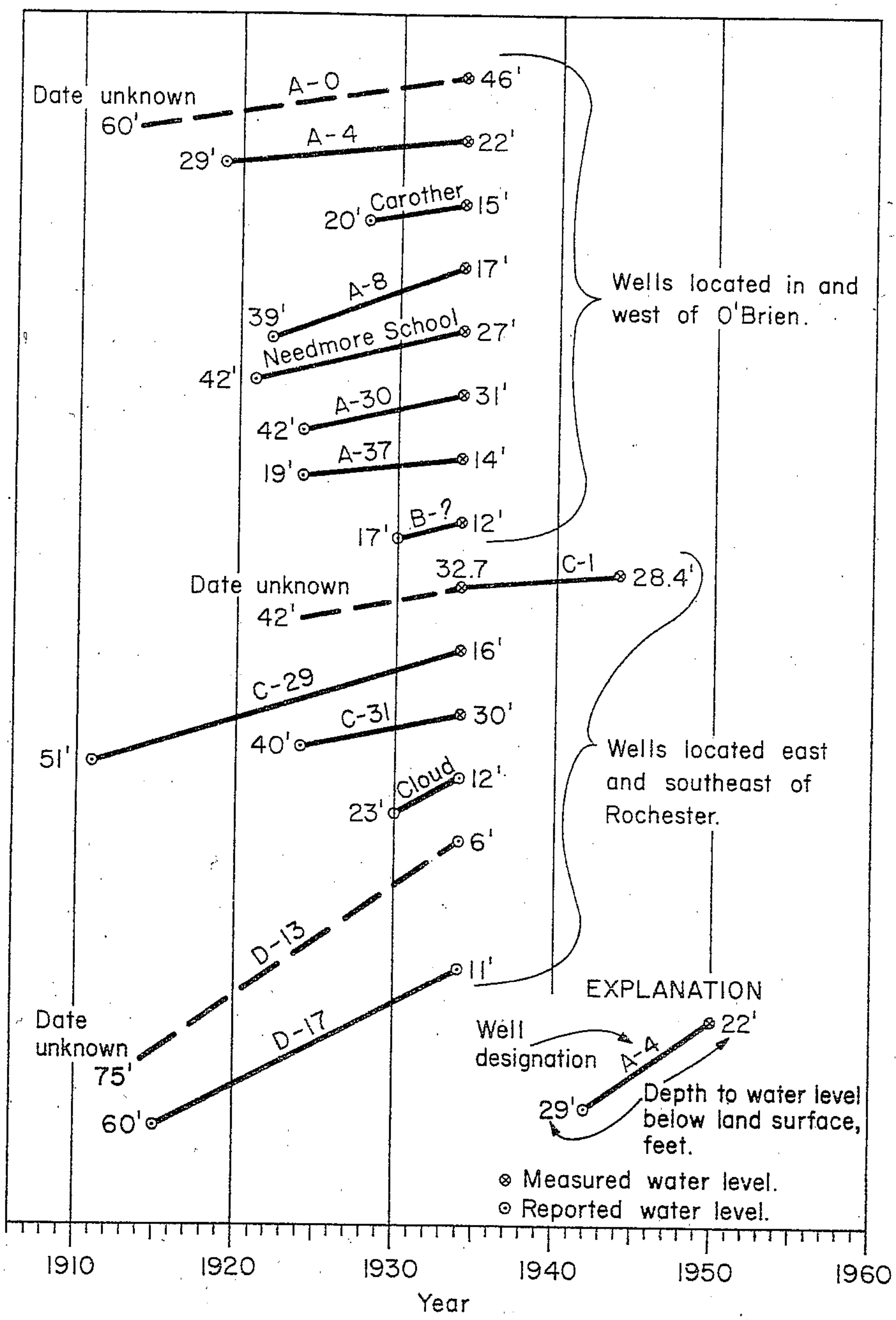


Figure 4.3.3 Water-level rises reported in the Seymour Formation in western Haskell County by Bandy (1934) (from R.W. Harden and Associates, 1978).

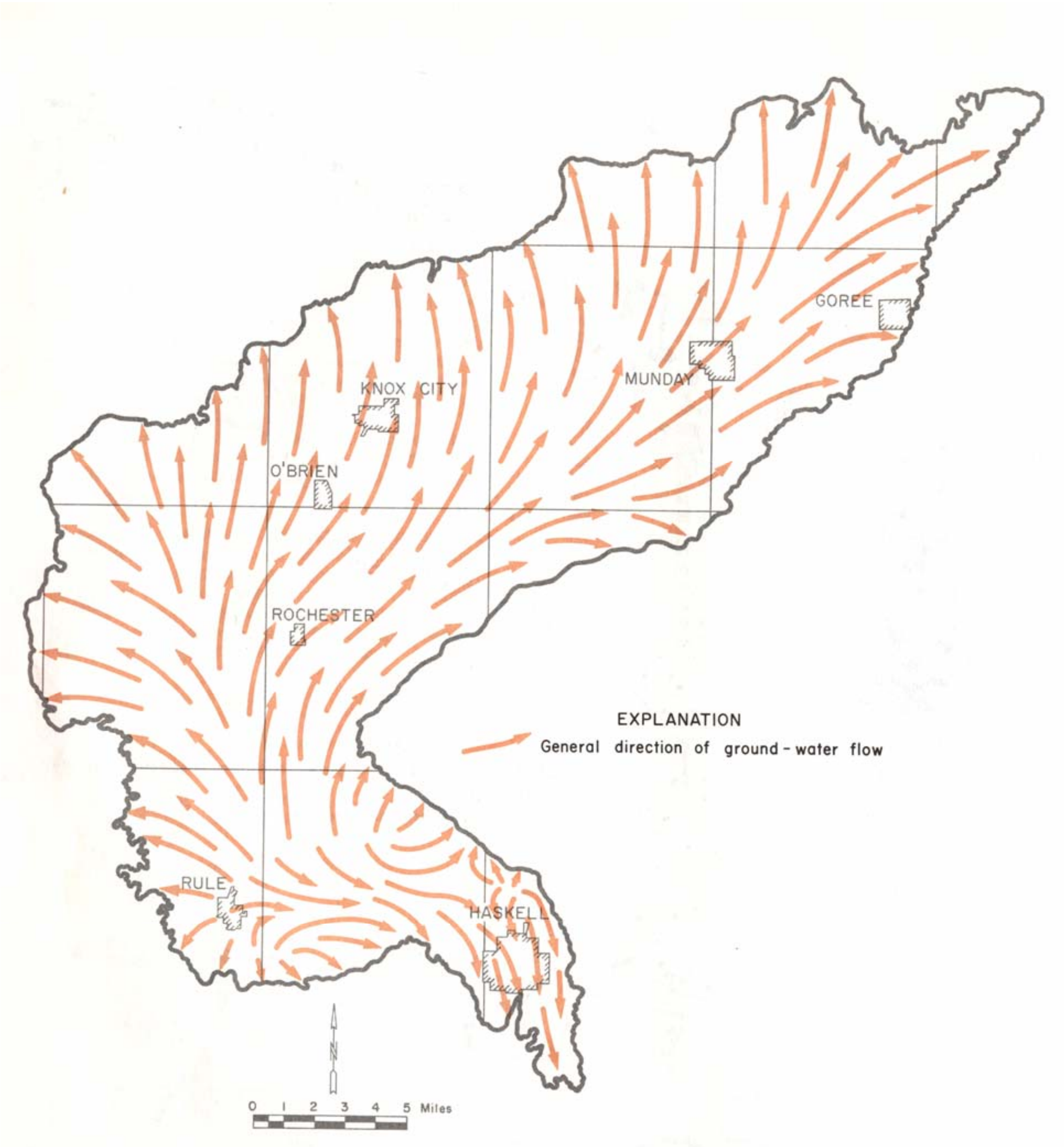


Figure 4.3.4 Groundwater flow directions in the Seymour Aquifer in Haskell and southern Knox counties (from R.W. Harden and Associates, 1978).

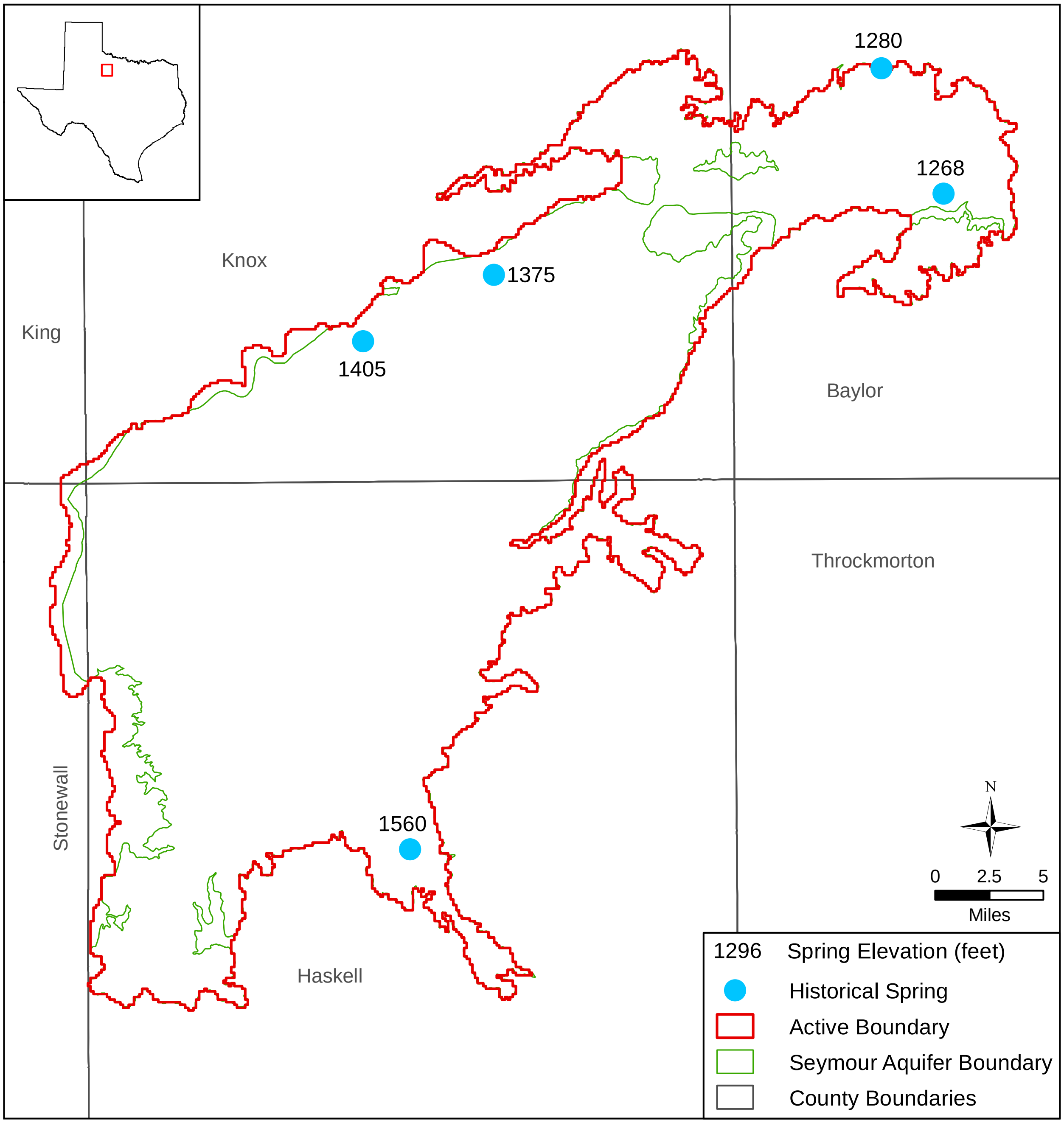


Figure 4.3.5 Elevations of springs flowing from the Seymour Aquifer under steady-state conditions.

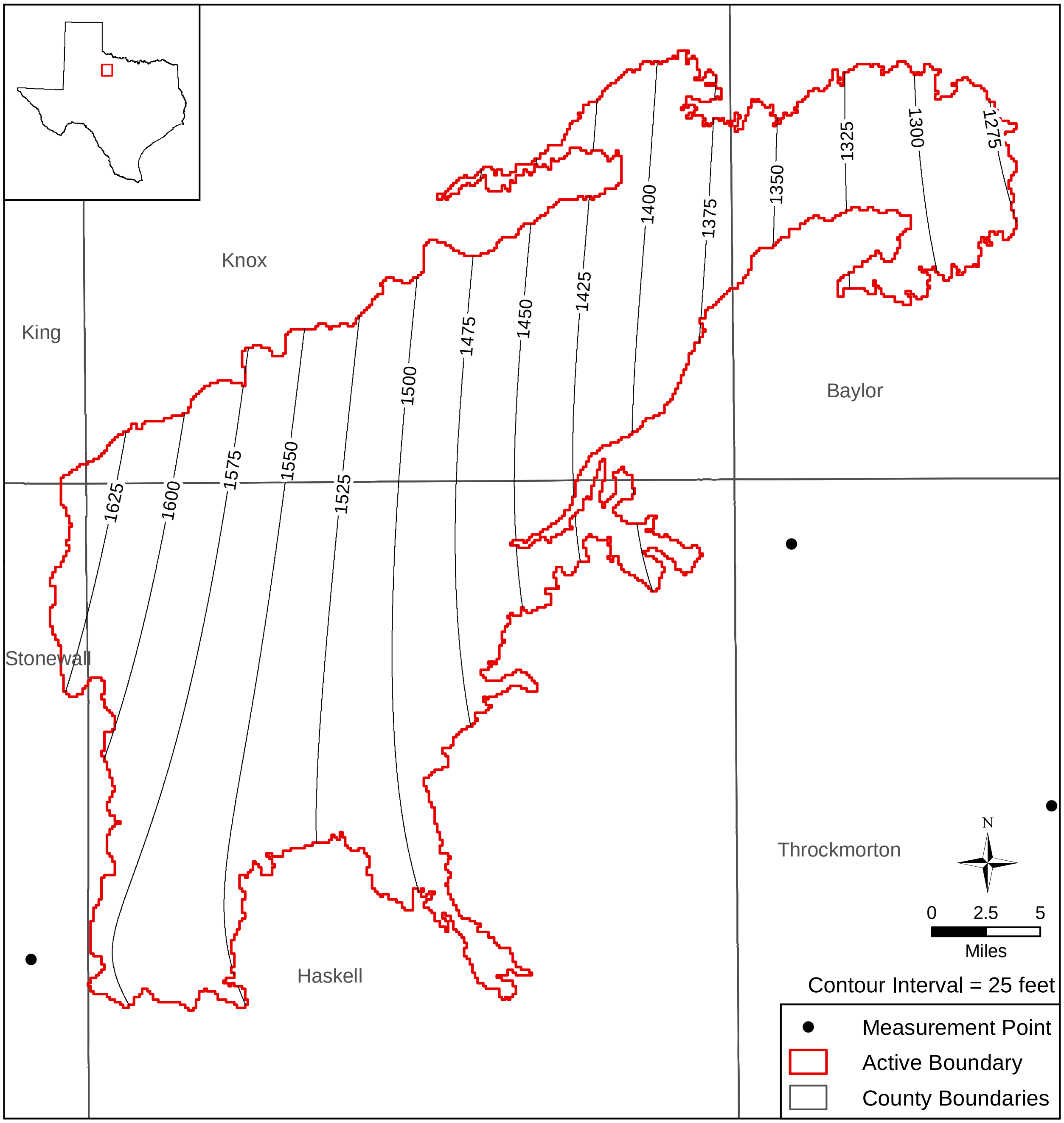


Figure 4.3.6 Estimated steady-state water-level elevation contours for the Permian-age formations in the study area.

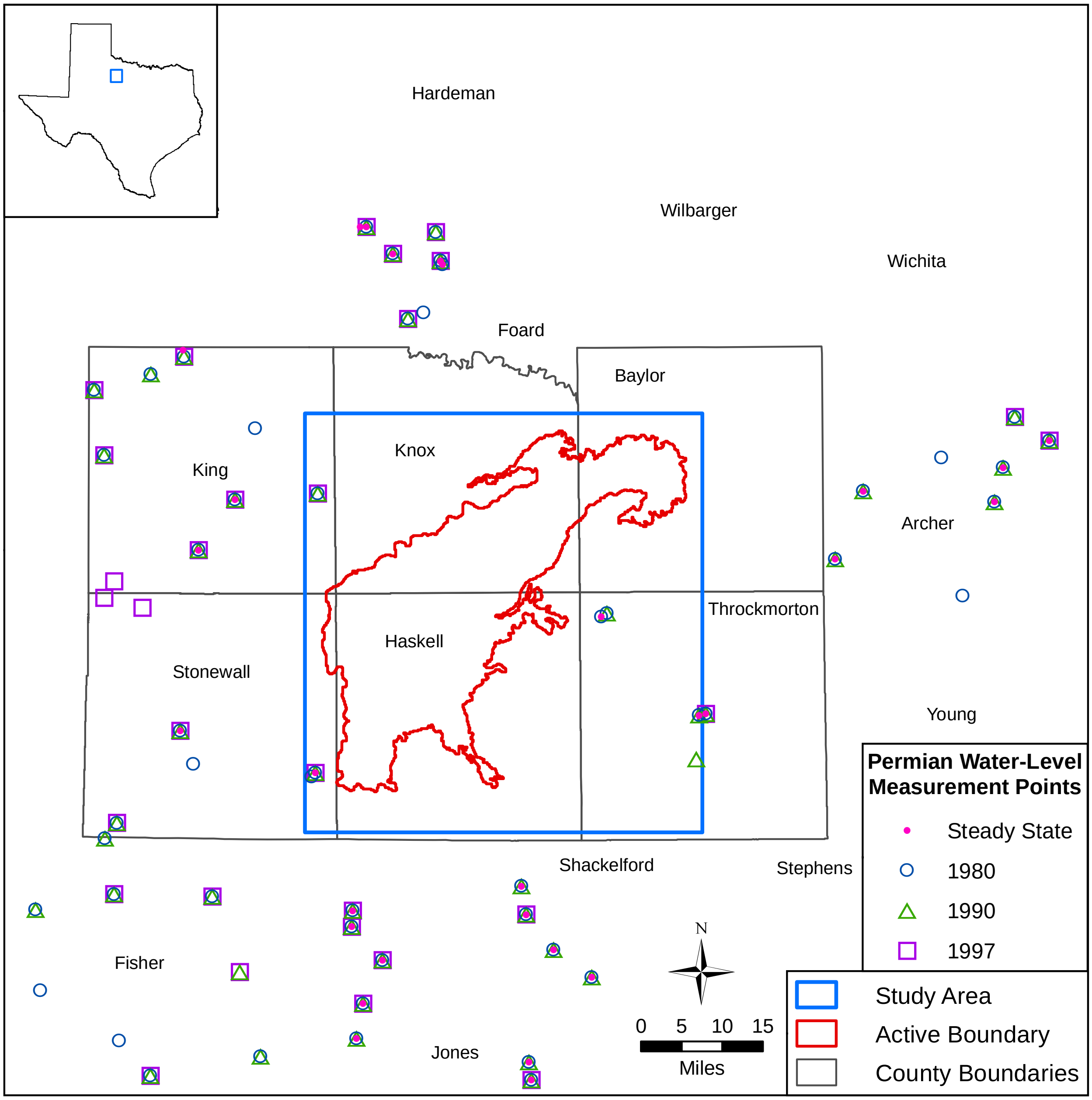


Figure 4.3.7 **Locations of data points used to develop estimated steady-state, 1980, 1990, and 1997 water-level elevation contours for the Permian-age formations.**

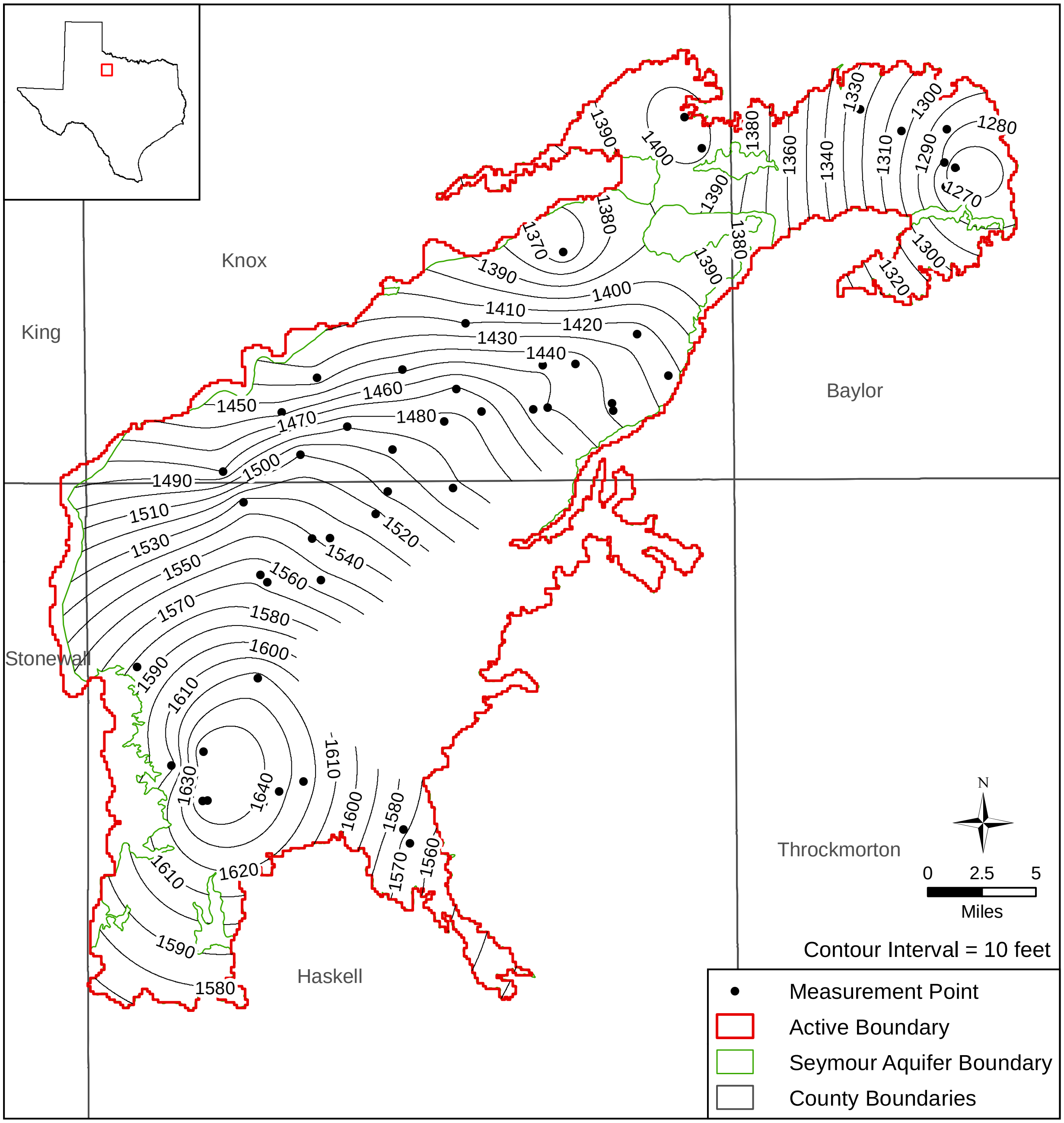


Figure 4.3.8 Estimated water-level elevation contours in the Seymour Aquifer in the study area at the start of the transient model calibration period (January 1980).

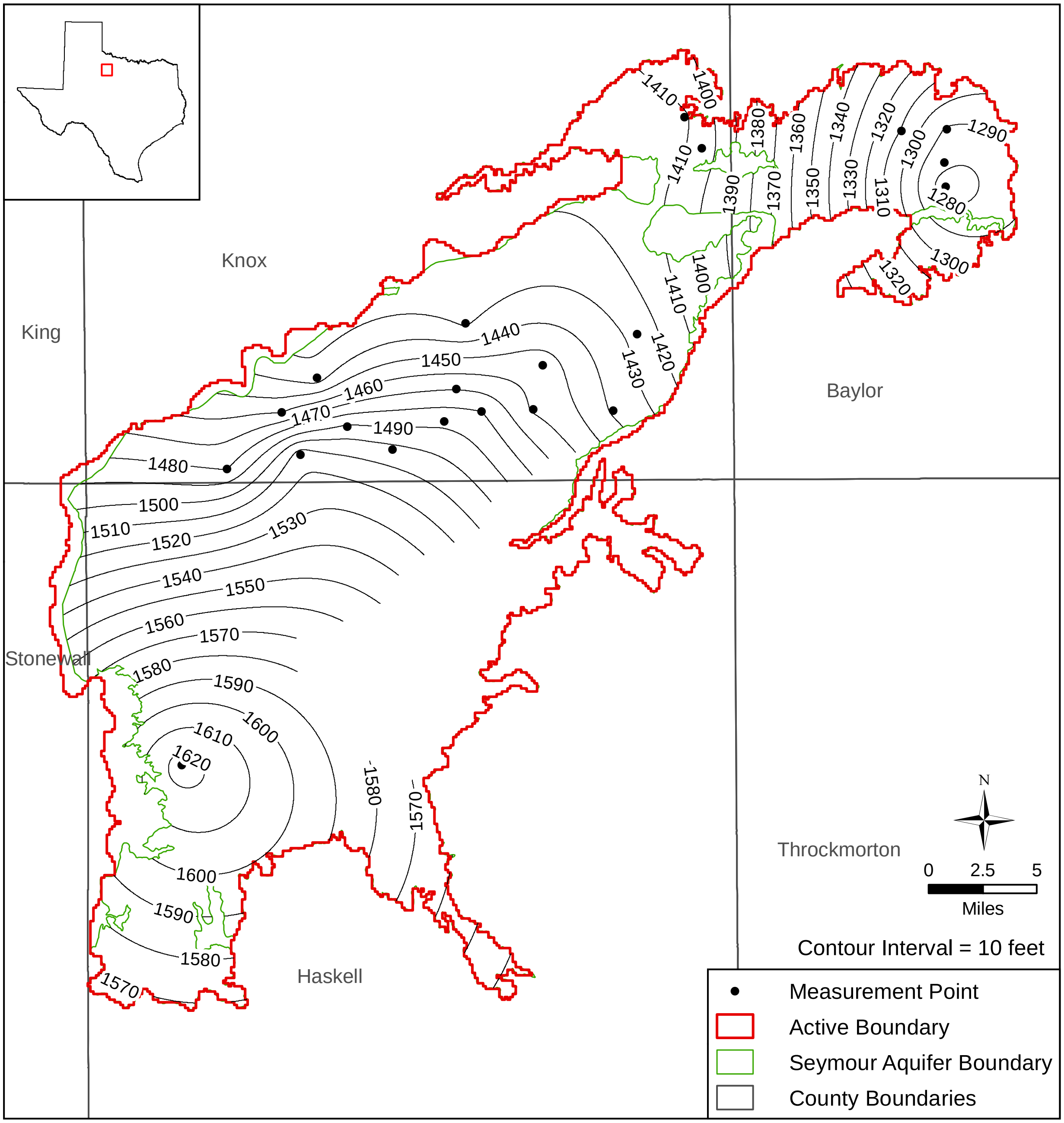


Figure 4.3.9 Estimated water-level elevation contours in the Seymour Aquifer in the study area at the middle of the transient model calibration period (January 1990).

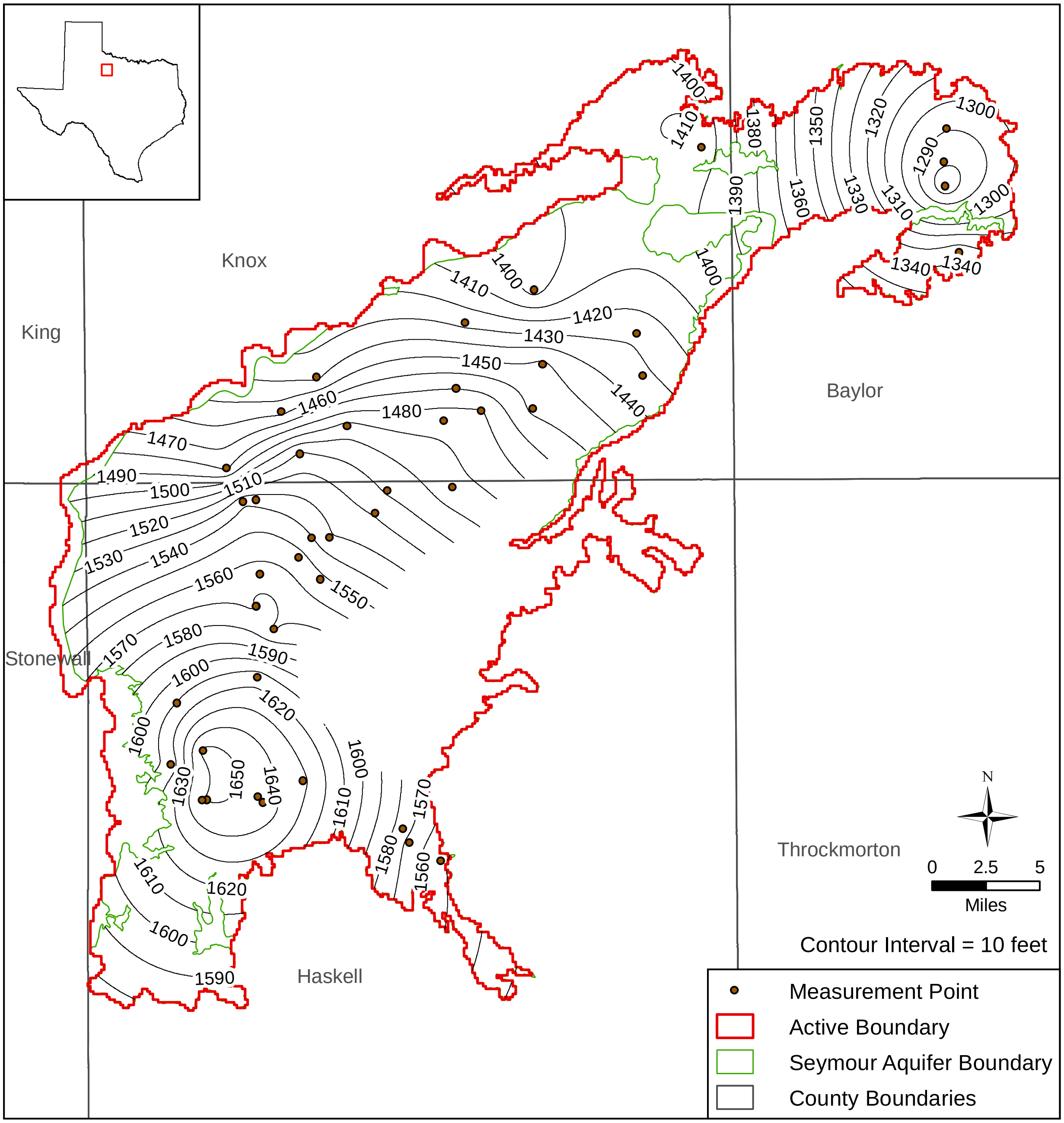


Figure 4.3.10 Estimated water-level elevation contours in the Seymour Aquifer in the study area at the end of the transient model calibration period (December 1997).

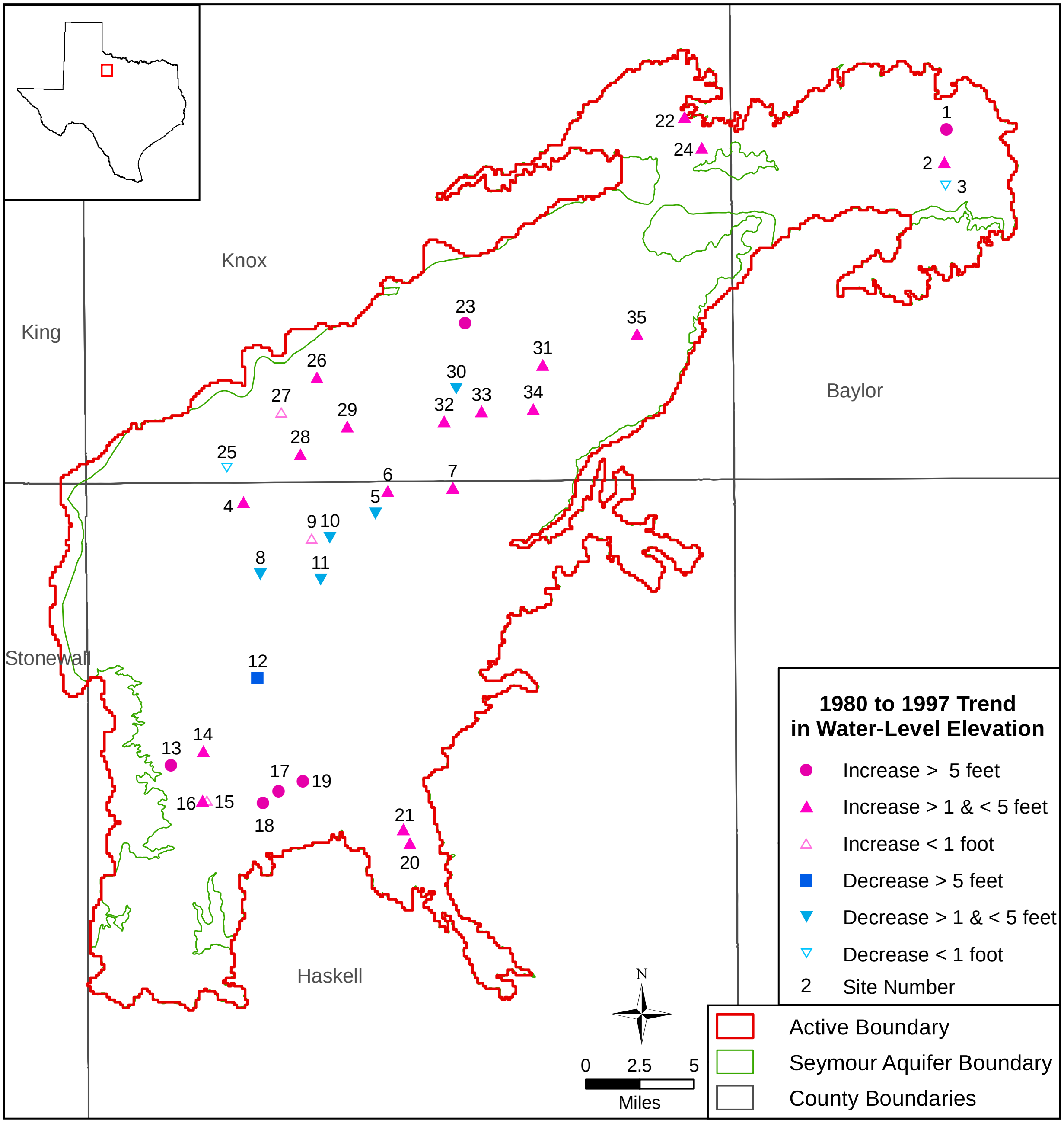


Figure 4.3.11 Estimated 1980 to 1997 trends in water-level elevations in the Seymour Aquifer in the study area.

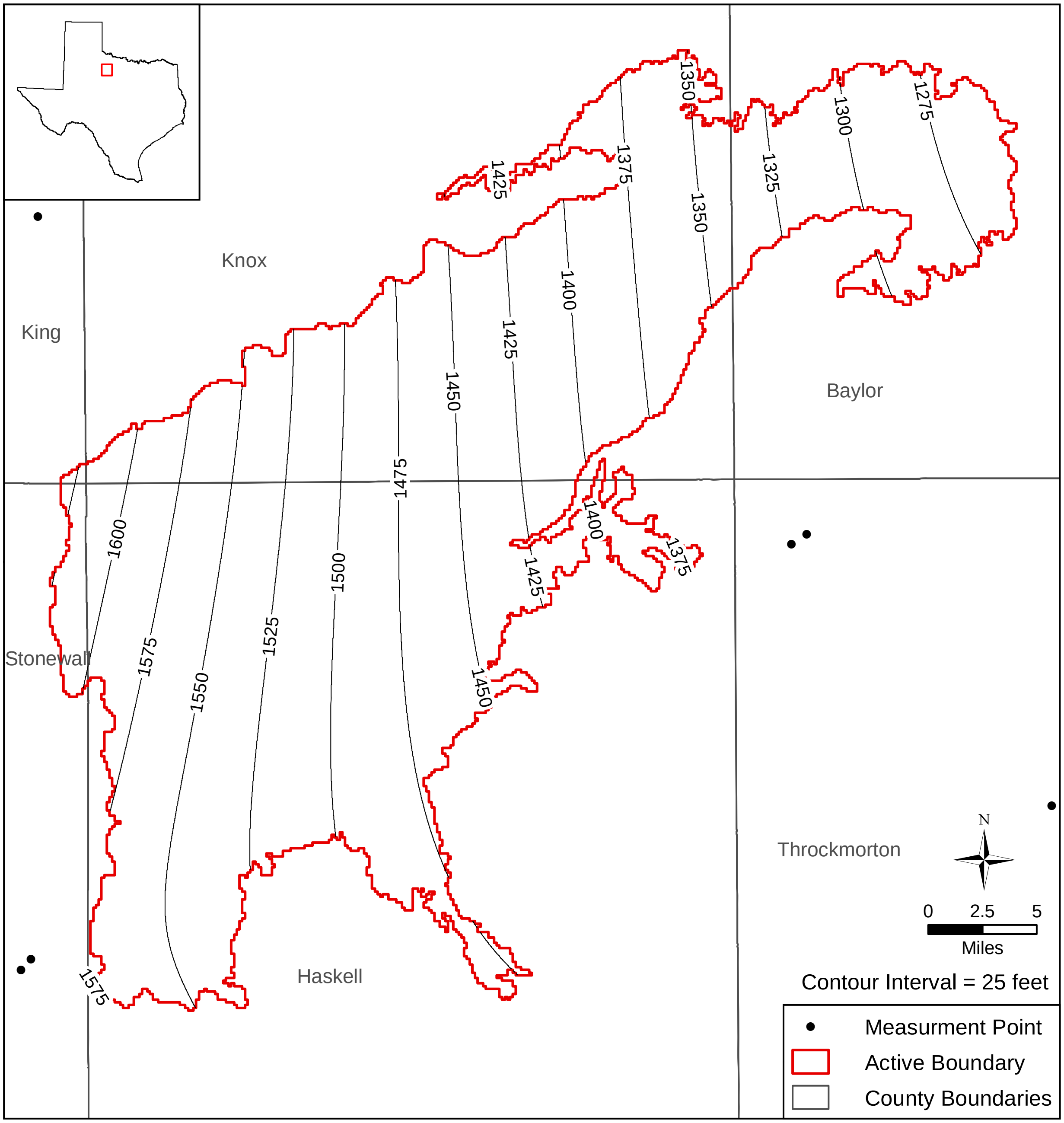


Figure 4.3.12 Estimated water-level elevation contours in the Permian-age formations in the study area at the start of the transient model calibration period (January 1980).

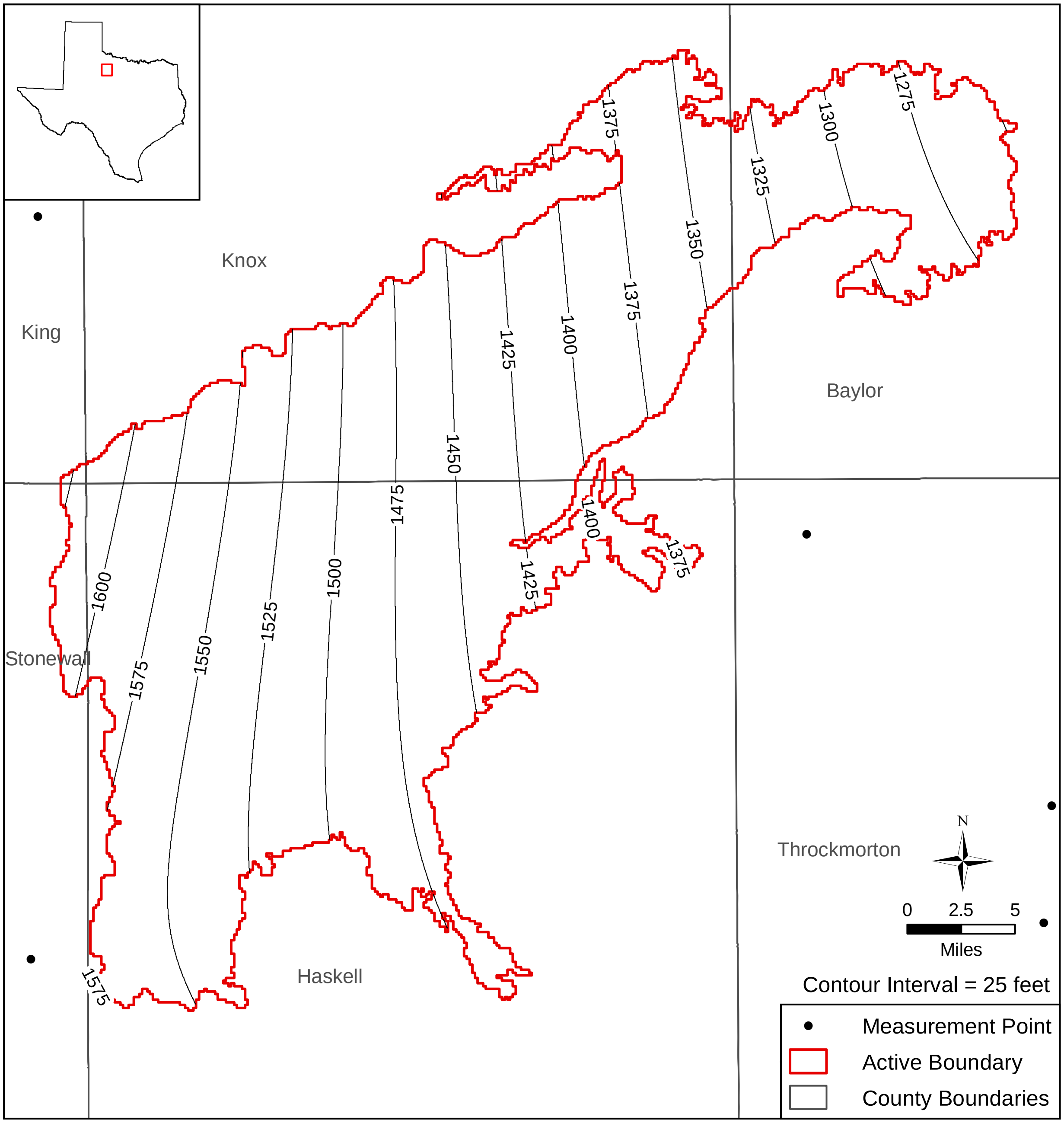


Figure 4.3.13 Estimated water-level elevation contours in the Permian-age formations in the study area at the middle of the transient model calibration period (January 1990).

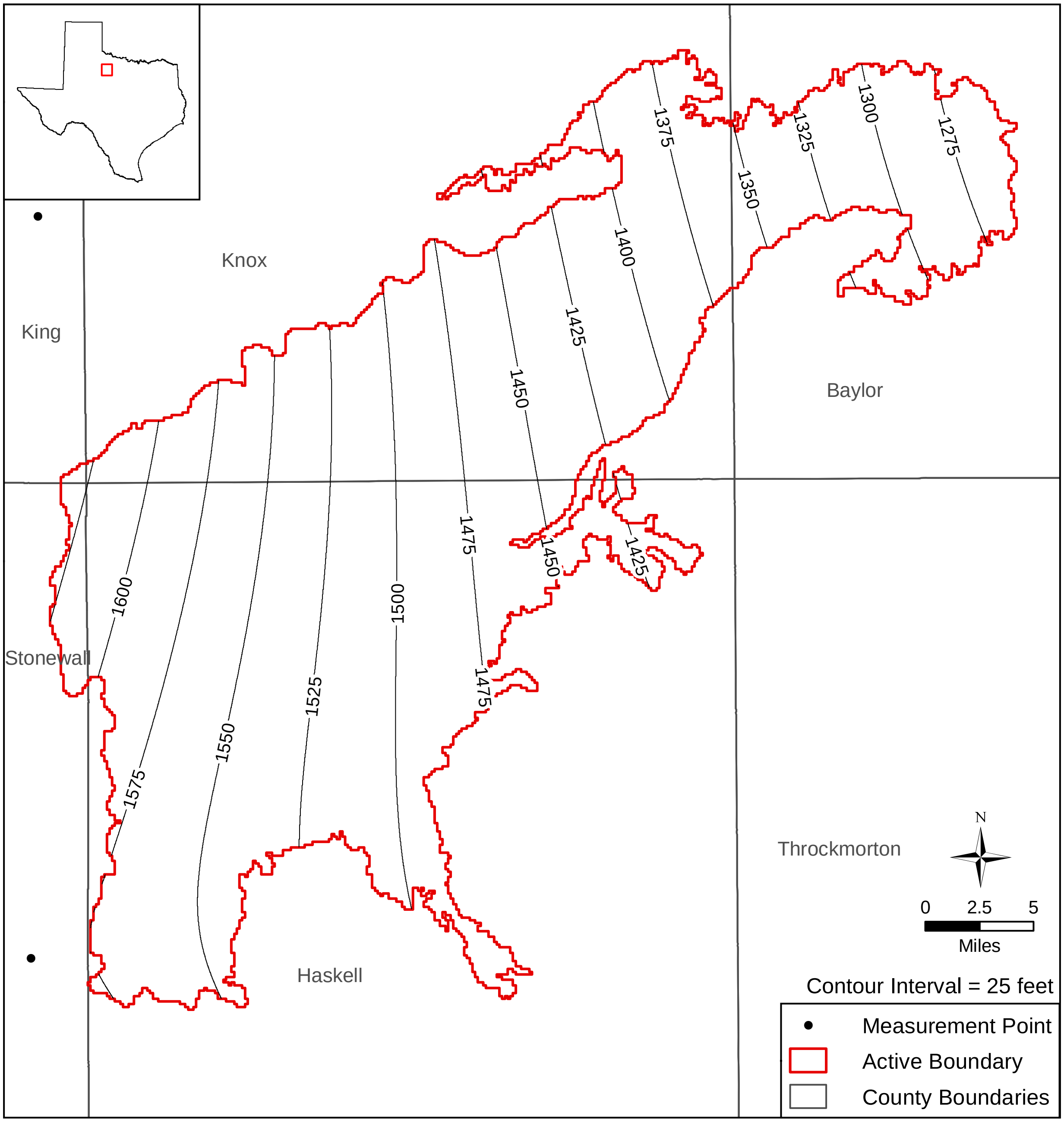


Figure 4.3.14 Estimated water-level elevation contours in the Permian-age formations in the study area at the end of the transient model calibration period (December 1997).

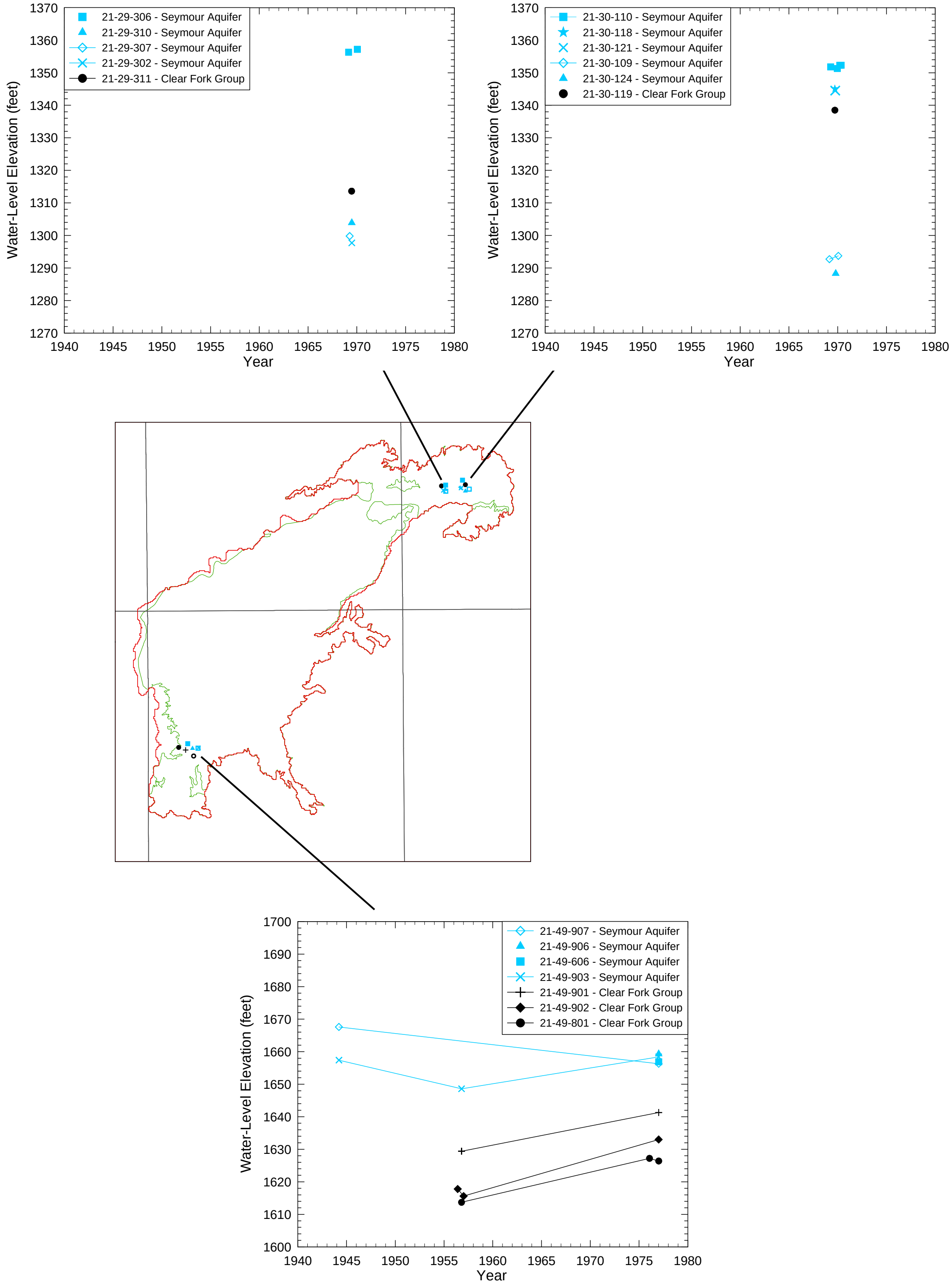


Figure 4.3.15 Comparison of water-level elevations in the Seymour Aquifer and underlying Clear Fork Group in the study area.

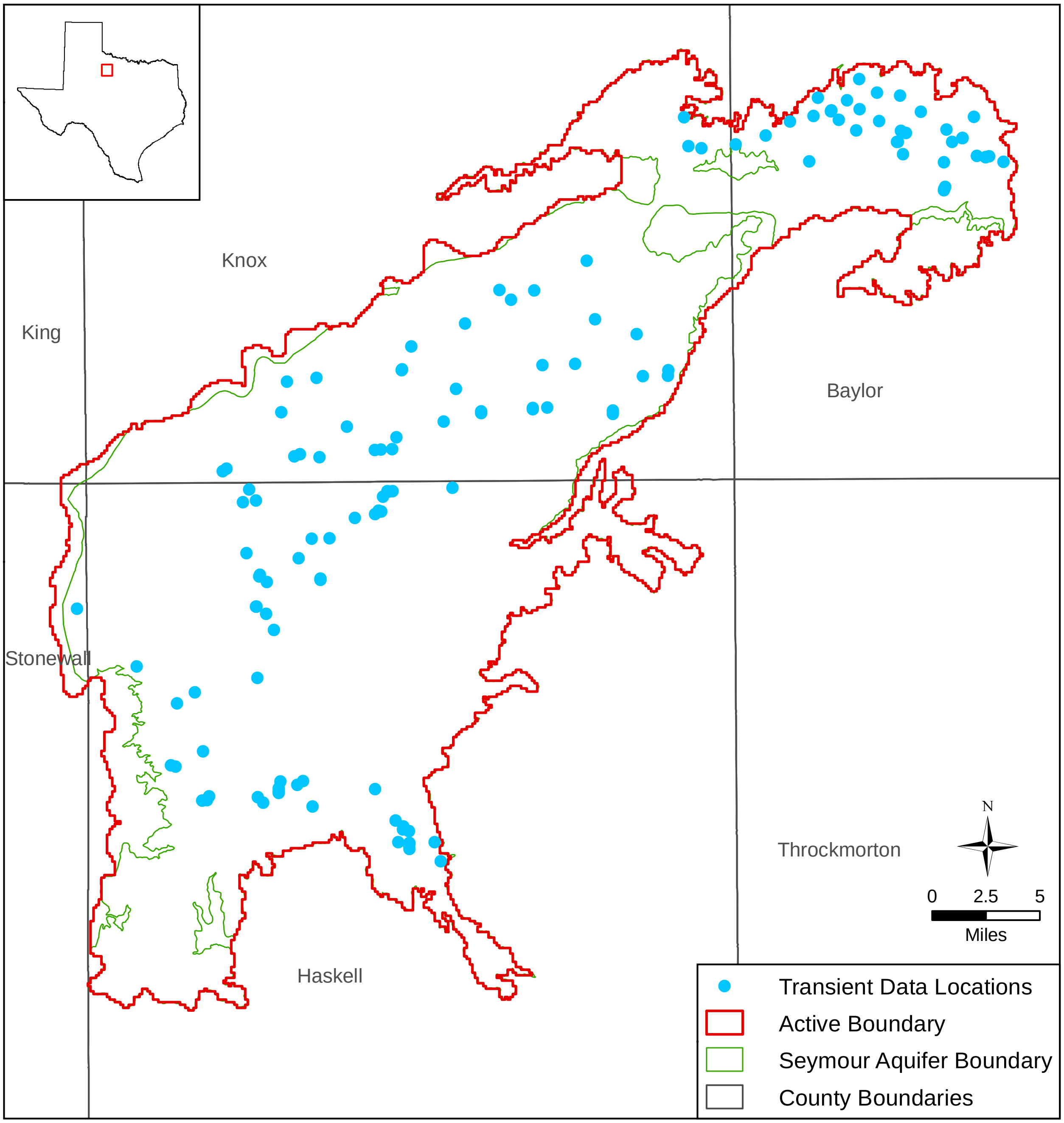


Figure 4.3.16 Locations of Seymour Aquifer wells in the study area with transient water-level data.

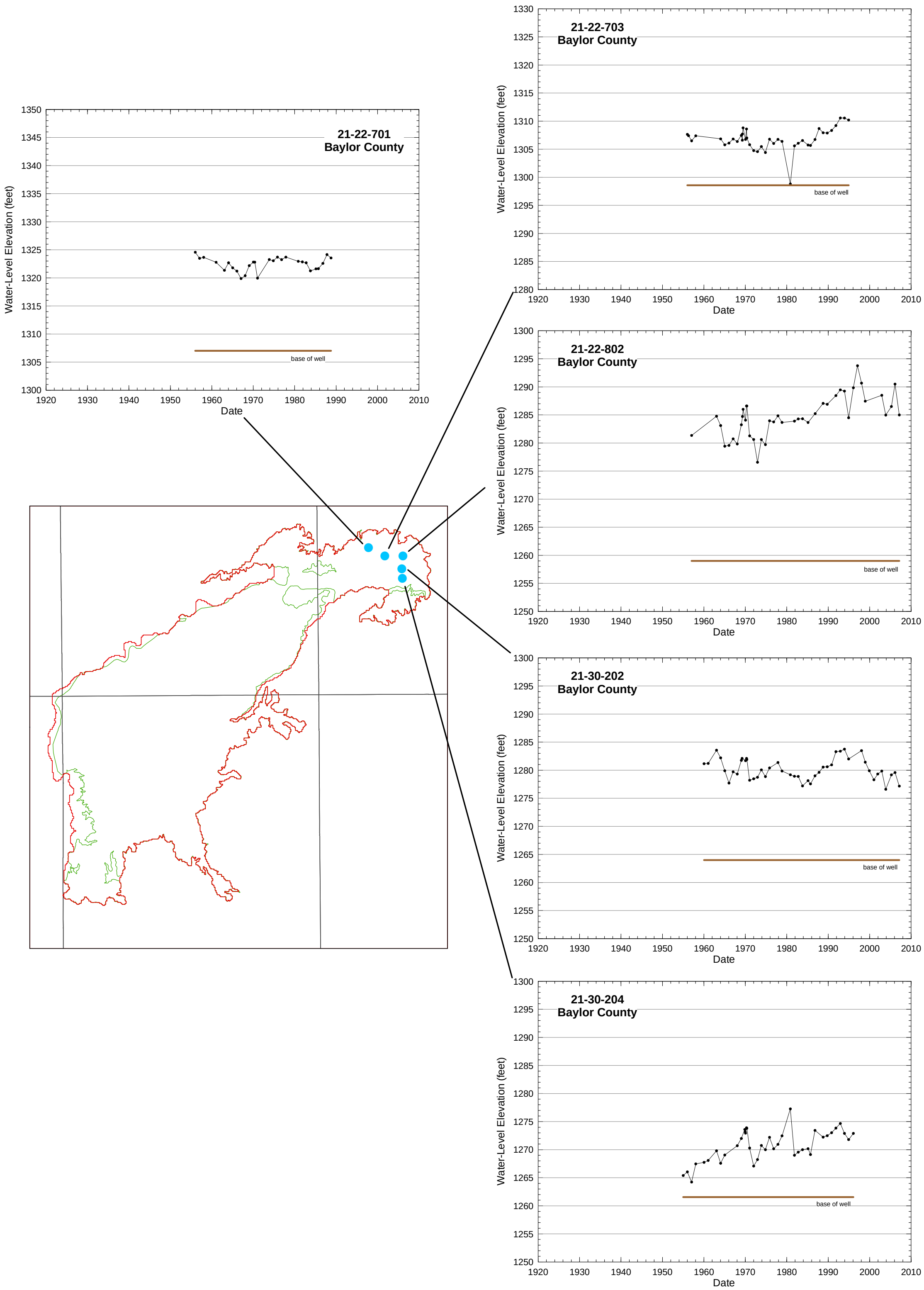


Figure 4.3.17 Hydrographs for the five Seymour Aquifer wells in Baylor County with long-term transient water-level data.

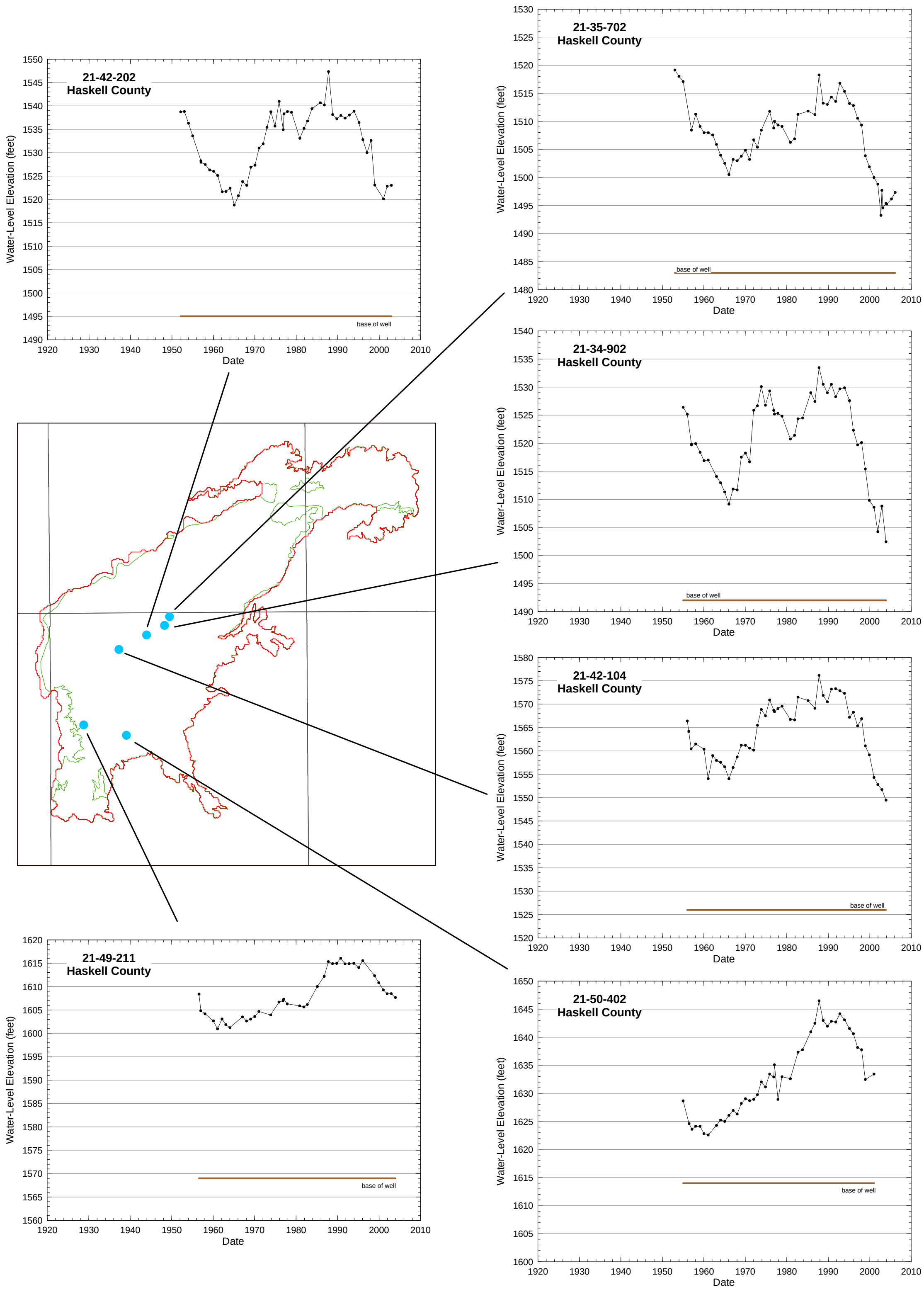


Figure 4.3.18 Example hydrographs showing fluctuating water-level elevations with time in the Seymour Aquifer in Haskell County.

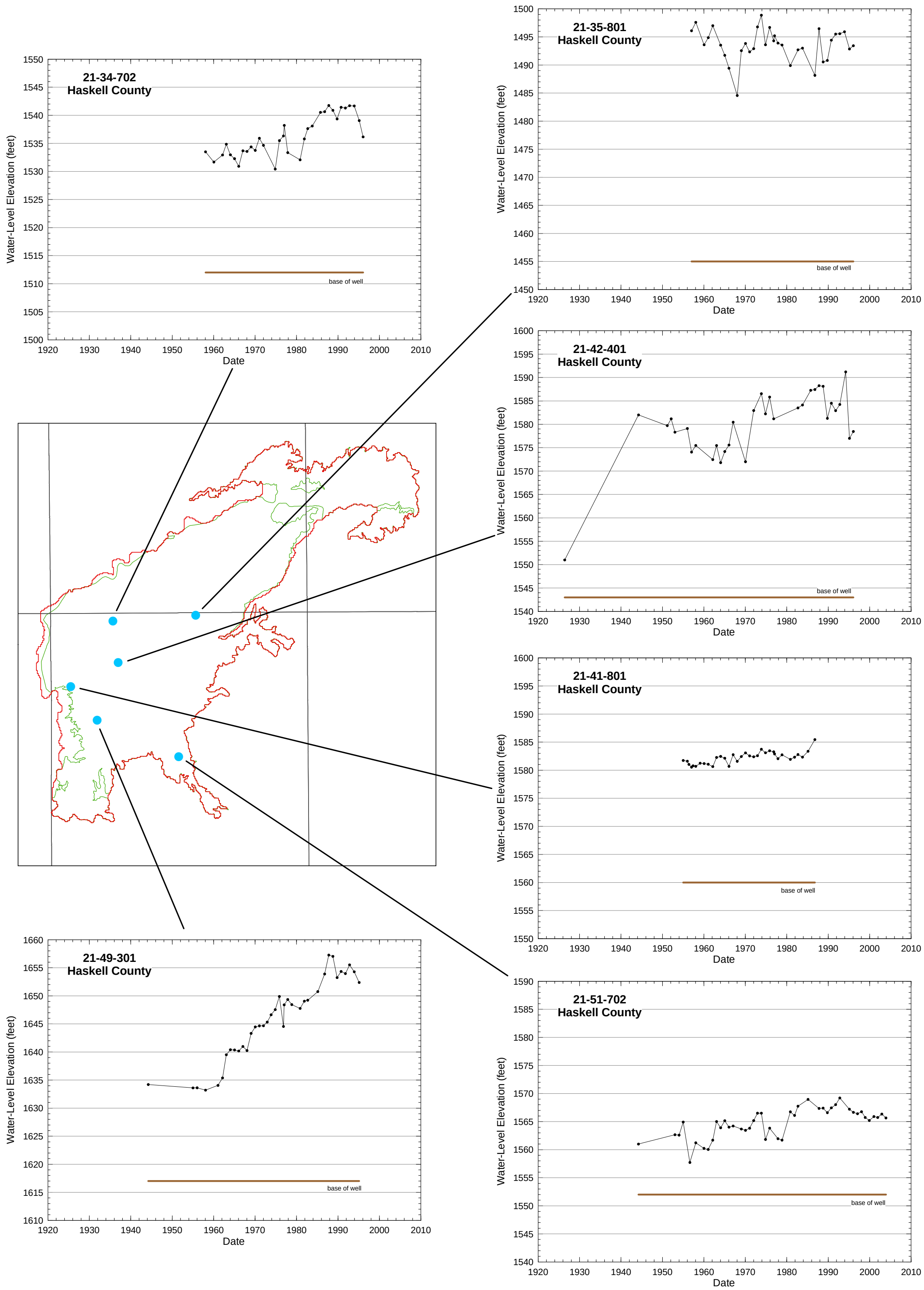


Figure 4.3.19 Example hydrographs showing increasing and stable water-level elevations with time in the Seymour Aquifer in Haskell County.

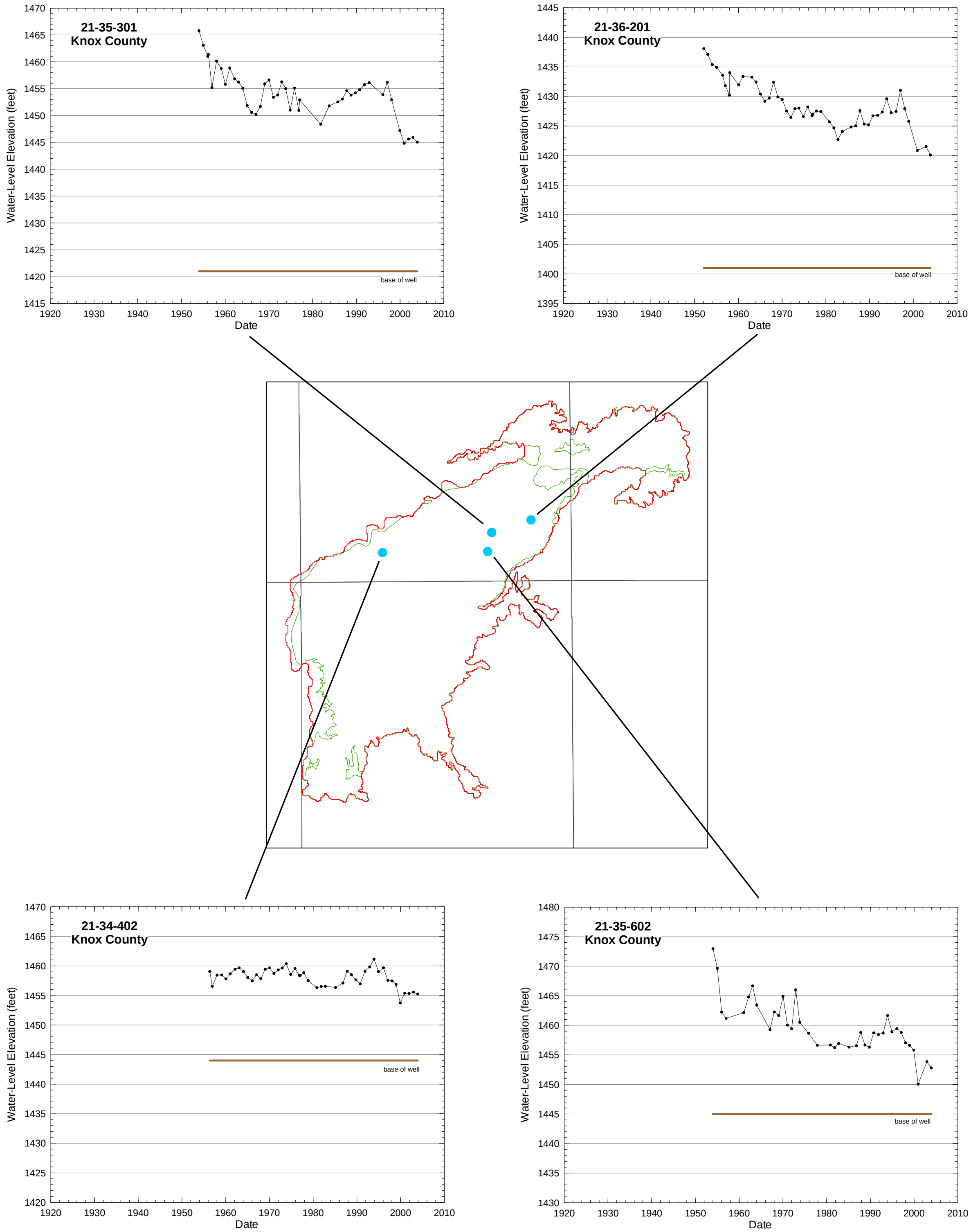


Figure 4.3.20 Hydrographs for the four Seymour Aquifer wells in Knox County with long-term transient water-level data showing a decreasing trend.

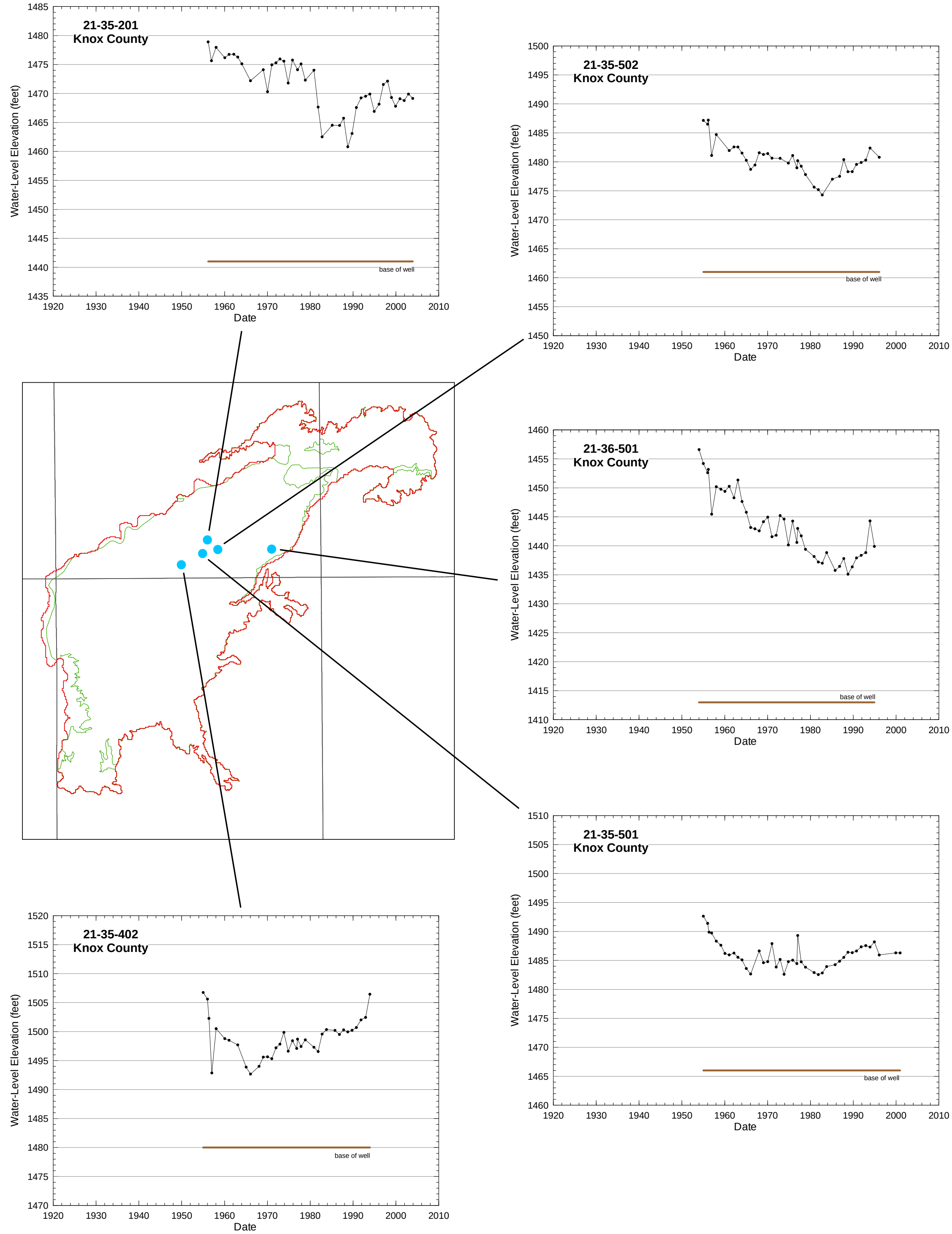


Figure 4.3.21 Hydrographs for the five Seymour Aquifer wells in Knox County with long-term transient water-level data showing a decreasing and then increasing trend.

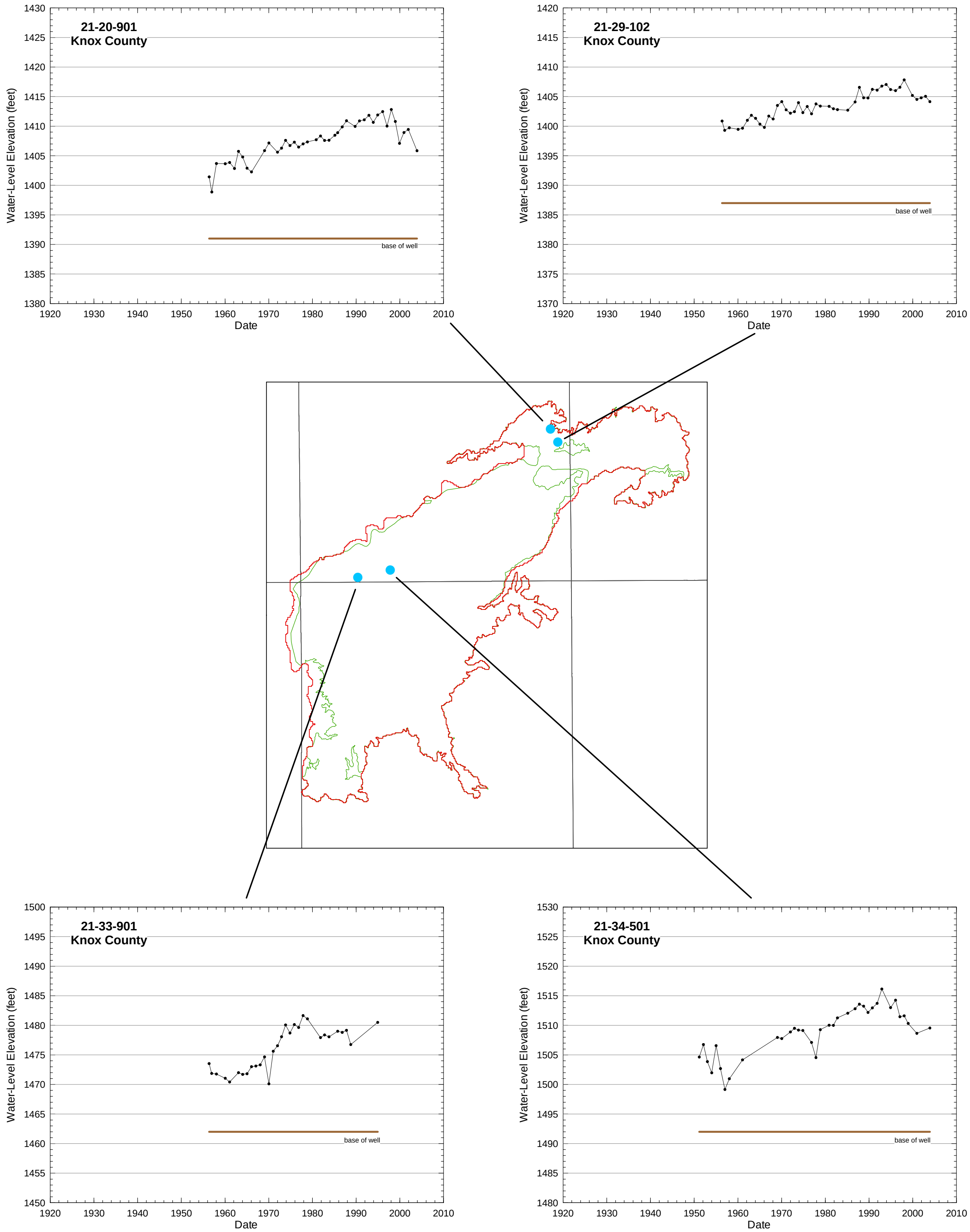


Figure 4.3.22 Hydrographs for the four Seymour Aquifer wells in Knox County with long-term transient water-level data showing an increasing trend.

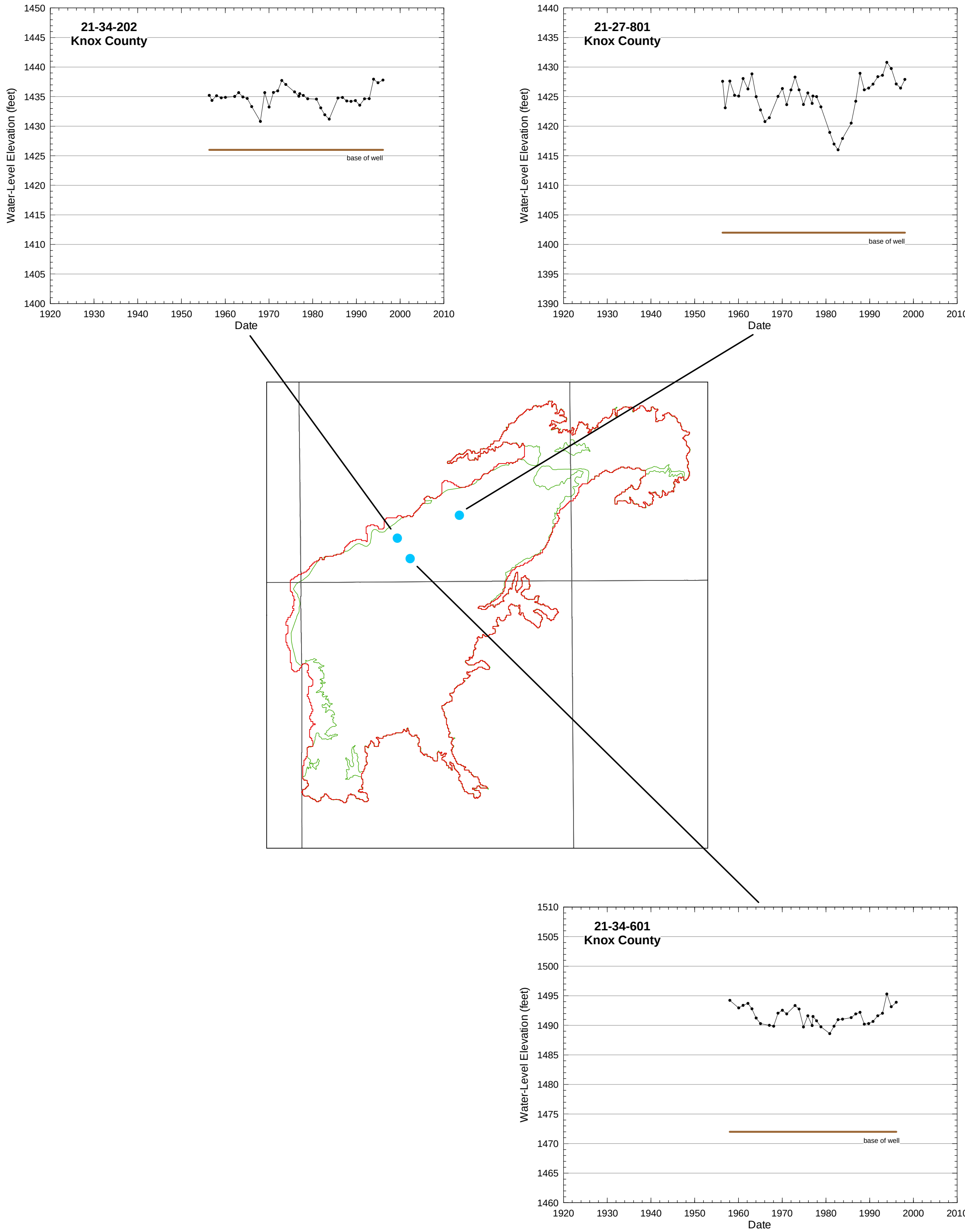


Figure 4.3.23 Hydrographs for the three Seymour Aquifer wells in Knox County with long-term transient water-level data showing a stable trend.

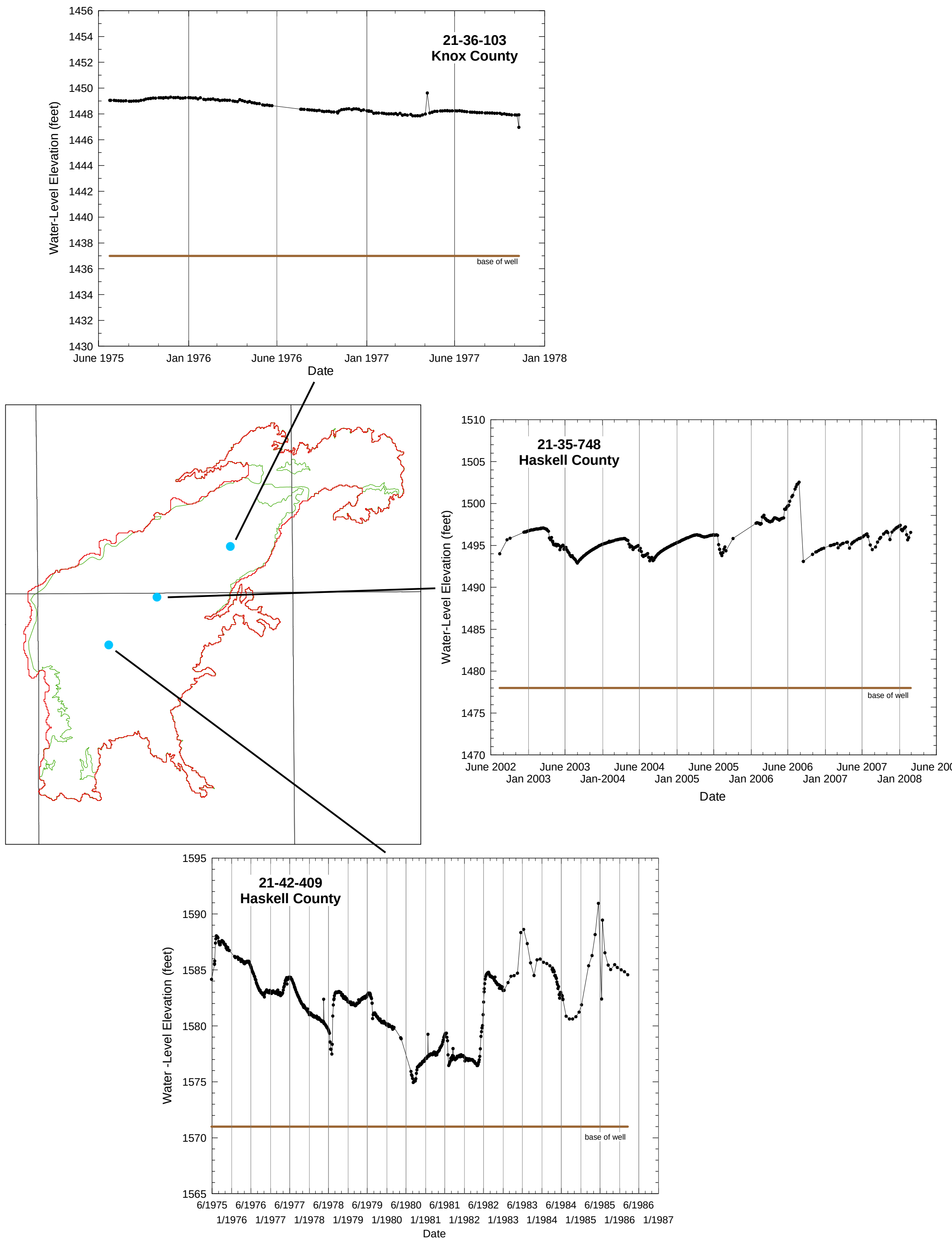


Figure 4.3.24 Hydrographs for the three Seymour Aquifer wells with sufficient data to evaluate long-term seasonal fluctuations in water-level elevations.

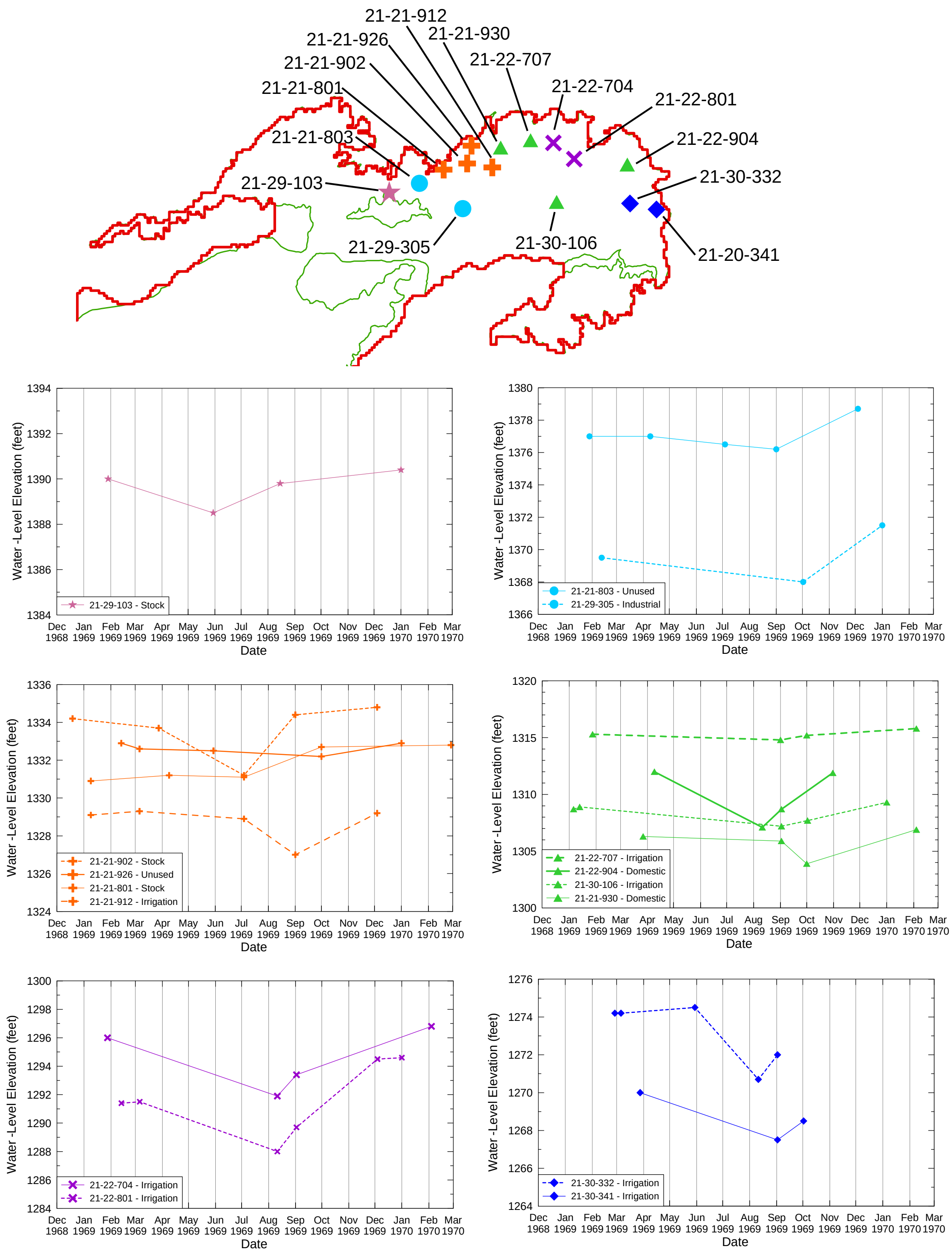


Figure 4.3.25 Hydrographs for the 15 Seymour Aquifer wells in Baylor County with data to evaluate seasonal fluctuations between December 1968 and February 1970.

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4.4 Recharge

Recharge refers to water that enters the saturated zone at the water table (Freeze, 1969). Potential controls on recharge include climate (precipitation, evapotranspiration), vegetation and land use, soil type, and topography (Keese and others, 2005). Sources of recharge to the Haskell-Knox-Baylor pod of the Seymour Aquifer include precipitation and irrigation return flow and, to a much lesser extent, streams. In a natural system unaffected by anthropogenic activities, an aquifer should be in a steady-state condition where aquifer recharge is balanced by natural aquifer discharge resulting in no net change in groundwater storage. Due to the low permeability of the Permian-age sediments, recharge on the Permian outcrops was assumed to be zero. The following discussion relates to the development of recharge estimates for the Seymour Aquifer.

Several changes in land use over the Seymour Aquifer have resulted in changes in the balance between aquifer recharge and natural aquifer discharge and have caused associated changes in water levels in the aquifer. The Seymour Aquifer was at steady state prior to 1880. The native vegetation at that time consisted of tall grass prairie with small pockets of timberland, primarily mesquite, in riparian zones. Grass species included wild rye, fescue, buffalo, grama, and needle grass, which ranged in height from 1.5 feet to over 3 feet with rooting depths that could have extended 5 feet (Sherrill, 1965; Weaver, 1926).

In about 1880, large herds of domestic livestock were brought into the area, which resulted in overgrazing of the land and two significant changes that affected water levels in the aquifer. First, overgrazing damages surface soil such that runoff increases and infiltration of precipitation decreases, resulting in less recharge (Warren and others, 1986; Wilcox and others, 2008). Second, overgrazing results in the expansion of honey mesquite into open grassland through the dispersal of seeds (Wilson and others, 2001), resulting in increased water-table evapotranspiration. The time period associated with overgrazing of the land is estimated to be from 1880 to about 1910 based on historical records in Sherrill (1965) and Texas State Historical Association (2008). In addition to reductions in recharge due to land-use changes, Sherrill (1965) reports that Haskell County experienced two years of major drought (1886 and 1896) and several years of light rainfall (1890 through 1893, 1901, 1904, and 1910) between 1880 and 1910, which could have contributed to a reduction in recharge during this time.

Significant changes in land use occurred again from about 1900 to 1910 due to increased farming in the area as a result of agricultural booms from about 1900 to 1910 and then again from about 1920 to 1930. Historical farming practices included deep plowing, row cropping, and long fallow periods during the winter months (Ogilbee and Osborne, 1962). Deep plowing of bare soil during the spring months could increase the potential for recharge by increasing the permeability of the soil and, thus, increasing infiltration into the subsurface. Terracing and contour farming became popular in the region in about 1929 to reduce soil erosion and likely increased recharge by reducing the amount of overland flow and enabling more precipitation to infiltrate (Ogilbee and Osborne 1962; Sherrill, 1965). In addition, clearing the land of woody vegetation and replacing it with crops resulted in decreased evapotranspiration due to fallow periods when crops are not grown and shallower rooting depths associated with short growth cycles for crops. These factors likely resulted in significant increases in recharge to the aquifer.

Historical accounts indicate that (1) the Seymour Aquifer had some saturated thickness under steady-state conditions prior to 1880 as evidenced by the existence of springs (Brune, 2002), (2) the aquifer was saturated in some areas and unsaturated in others prior to agricultural activities in the early 1900s (Gordon, 1913; Bandy, 1934, Ogilbee and Osborne, 1962; R.W. Harden and Associates, 1978), and (3) the saturated thickness of the aquifer increased dramatically in some areas due to the development of the land for agricultural purposes between about 1910 and the 1940s (Bandy, 1934; Ogilbee and Osborne, 1962; R.W. Harden and Associates, 1978). Prior to 1880, a natural, predevelopment condition is thought to have existed whereby some amount of recharge was in balance with natural discharge and the aquifer exhibited some degree of saturated thickness. Overgrazing of the land between about 1880 and 1910 resulted in recharge rates overcome by natural discharge resulting in a reduction in saturated thickness, with some areas of the aquifer becoming dry. Development of the land for agricultural purposes resulted in greater aquifer recharge than natural aquifer discharge, resulting in an increase in the saturated thickness of the aquifer.

The land use in 1992 by percentage of cultivated area (Figure 4.4.1) included 77 percent rainfed agriculture, dominated by wheat production, 13 percent irrigated agriculture, dominated by cotton production, 2 percent shrubland, 5 percent grassland, 1 percent urban, 1 percent water, and less than 1 percent forest. The area over the Seymour Aquifer that is flood irrigated, labeled as irrigated agriculture on Figure 4.4.1, was inferred from agricultural fields that display strong infrared signals and was estimated to be about 4 percent. The remaining categories of cultivated land were determined by combining land cover data from the United States Geological Survey (1992) as summarized in Table 4.4.1. Note that irrigated agriculture took precedence over all land cover data. Although, historically, the dominant crop grown in the region was cotton, over the last 30 years, it has been replaced with winter wheat. The United States Department of Agriculture (2006) indicates that the mean cultivated area for wheat was 56 percent, with a range of 30 to 70 percent, from 1973 to 2006. Cotton is still the second most produced crop in the region having a mean cultivated area of 34 percent, with a range of 23 to 50 percent, from 1973 to 2006 (United States Department of Agriculture, 2006). Other crops include alfalfa hay, corn, sorghum, oats, and peanuts. Irrigation did not become popular in the area until 1951, with the number of irrigation wells increasing from 25 to 1,100 over the period of 1951 to 1956. Table 4.4.2 provides the number of irrigation wells, estimated irrigation pumpage, and estimated acres irrigated for the years 1950 through 1956 as reported in Ogilbee and Osborne (1962). Current center pivot irrigation represents about 9 percent of the land surface over the Seymour Aquifer based on estimates calculated from 2006 county mosaics from the United States Department of Agriculture (2006).

The clay content in the upper 3 to 6 feet of the surface soil ranges from 10 to 55 percent with a mean of 32 percent based on the Soil Survey Geographic database (United States Department of Agriculture, 2007). The mean clay content is lowest in the alluvium along the Brazos River and in the sand hills in the northwestern part of Haskell County and highest along the eastern and southern edges of the aquifer in Haskell County (Figure 4.4.2). Note that the areas with the highest clay content in the surface soil generally coincide with areas of the aquifer that are dry (see Section 4.1).

The long-term mean annual precipitation, based on data from 1900 to 2007 in the city of Haskell, is 24.5 inches, with 81 percent of that occurring during the growing season of March to October

(National Climatic Data Center, 2008) (Figure 4.4.3). The coefficient of variation for this precipitation is 0.11.

The purpose of the recharge analysis presented in this section was to determine recharge rates for the Haskell-Knox-Baylor pod of the Seymour Aquifer under modern conditions and to bound recharge estimates under pre-development, steady-state conditions and estimate recharge during the time when the aquifer was gaining water. Unsaturated zone profiles from three different land-use settings were used to estimate aquifer recharge under modern conditions and historical water-table rises were used to estimate groundwater recharge for the time period from about 1910 to the 1940s when the aquifer was gaining water and for modern conditions in the aquifer. There is currently little direct evidence of recharge under steady-state conditions due to the lack of native vegetation in the area. About 97 percent of the land overlying the Seymour Aquifer was under cultivation in 1978 (R.W. Harden and Associates, 1978) and about 90 percent in 1992 (United States Geological Survey, 1992). The following sections discuss the methods used to investigate recharge to the Seymour Aquifer, discuss the results of that investigation, and summarize estimates of recharge for steady-state conditions, conditions when water levels in the aquifer were rising, and modern conditions.

4.4.1 Methods Used to Estimate Recharge

Two methods were used to investigate recharge to the Seymour Aquifer. Modern recharge was estimated using the chloride mass balance method and the results from unsaturated zone studies conducted on the Seymour Aquifer in Haskell and Knox counties. Estimated recharge during the time period of rising water levels from about 1910 to the 1940s and under modern conditions were estimated from observed water-level changes.

4.4.1.1 Chloride Mass Balance Method

From April 2003 to January 2009, the Bureau of Economic Geology conducted unsaturated zone studies in boreholes drilled into the Seymour Aquifer to estimate recharge to the aquifer. A total of 19 boreholes were drilled in three different land-use settings in Haskell and Knox counties. Two boreholes were drilled in a natural setting, 11 in a rainfed agricultural setting, and 6 in an irrigated agricultural setting (Figure 4.4.4). The boreholes were drilled using a Geoprobe direct push drill rig and the collected cores were sealed and cold stored. Soil samples from the boreholes were analyzed in the laboratory for water content, matric potential, and chloride concentrations in soil water. Gravimetric water content was calculated by weighing each sample before and after oven drying at 105 degrees Celsius for 48 hours. Matric or water potentials were measured on soil samples to determine the vertical gradient in matric potential at the time the sample was collected. Potential gradients help to determine the direction of water movement in the unsaturated zone and can provide information on both the depth of wetting fronts and evapotranspiration. Water-extractable chloride concentrations in soil water were determined by adding approximately 40 milliliters of double-deionized water to 25 grams of the soil. The mixtures were agitated on a reciprocal shaker for 4 hours, centrifuged, and the resulting supernatant was filtered through a 0.2 micrometer filter. Extract chloride concentrations were measured using ion chromatography. Soil, pore-water chloride concentrations were then calculated by dividing the supernatant chloride concentration by the gravimetric water content and multiplying by water density. Soil texture analyses of the soil samples (sand, silt, clay fractions) were conducted by hydrometric methods.

The chloride mass balance method for estimating the rate of recharge balances inputs from precipitation (P) and chloride concentration in precipitation (Cl_P) with outputs from deep drainage or recharge (R) below the root zone and chloride concentration in soil water (Cl_{sw}):

$$P \times Cl_p = R \times Cl_{sw} \qquad \Rightarrow \qquad R = \frac{P \times Cl_P}{Cl_{sw}} \tag{4.4.1}$$

The mean precipitation was taken from the long-term, city of Haskell data, which indicates a mean value of 24.5 inches per year. The chloride concentrations in precipitation were interpolated from the National Atmospheric Deposition Program (2008), for the nearest station to Haskell and Knox counties, which is in Throckmorton County. Chloride data for this station are available for the 9 years from 1984 to 1992 and yield a mean concentration of 0.19 milligrams per liter, which was increased by a factor of two to account for dry deposition (Scanlon, 2000). These data, along with the laboratory results for the borehole soil samples, were used in the chloride mass balance method.

The time required to accumulate chloride in the flushed zone was used to estimate the timing of land-use change in profiles that had not been completely flushed. This accumulation time, t, was calculated by dividing the total mass of the chloride from the land surface to the depth of interest, z, by the chloride input:

$$t = \int_0^z \frac{\theta Cl_{sw} dz}{P \times Cl_p} \qquad (4.4.2)$$

where θ is the volumetric water content. Aerial photographs and land owner records were also used to constrain the timing of the land-use change. Photographs were available for 1939 and 1972.

4.4.1.2 Water-Table Fluctuation Method

The water-table fluctuation method was used to estimate groundwater recharge for modern time and for the time period when water levels in the Seymour Aquifer rose. This method is based on the premise that water-level rises in unconfined aquifers are due to recharge water arriving at the water table. The impact of discharge is neglected. Recharge is calculated as:

$$R = S_y \frac{dh}{dt} = S_y \frac{\Delta h}{\Delta t} \qquad (4.4.3)$$

where S_y is aquifer specific yield, h is water-table height, and t is time. The water-table fluctuation method can be applied to estimate the net change in subsurface storage, also referred to as net recharge. This method is not restricted by preferential flow paths in the unsaturated zone and, in addition, may be useful to determine estimates of recharge at the location of wells exhibiting periods with long-term water-level rises.

4.4.2 Results and Discussion

This section presents the recharge estimates determined using the chloride mass balance method and the water-table fluctuation method.

4.4.2.1 Chloride Mass Balance Method

Data for the 19 boreholes used to estimate recharge using the chloride mass balance method are summarized in Table 4.4.3. This table includes the borehole number, the land-use setting, the location, the vegetation or crop coverage, the depth, the average texture determined for the soil, the laboratory-determined values for water content, matric potential, and chloride concentration, the calculated recharge rate, and the calculated chloride accumulation times. Based on the data from the boreholes, spatial variability in water content in the vadose zone of the Seymour Aquifer appears to be primarily a function of the differences in sediment texture. Variations in water content are positively correlated with percent clay and negatively correlated with percent sand (Figure 4.4.5). Chloride concentration and matric potential results do not indicate that land use is the primary control on water content in the region (Figure 4.4.6). High matric potentials and low chloride concentrations seen in the natural boreholes on the Seymour Aquifer are not consistent with unsaturated zone studies conducted in the Texas High Plains, where large chloride bulges and low matric potentials indicate that chloride has been accumulating since the Pleistocene (10,000 to 15,000 years) or longer (Scanlon and Goldsmith, 1997; Scanlon and others, 2005; 2007). The high matric potentials measured for the boreholes drilled on irrigated sites indicate that the profiles are flushed; suggesting that the variability in chloride concentrations observed in these boreholes is due to variability in the chloride concentration in the applied irrigation water. Chloride concentrations in the Seymour Aquifer are highly variable ranging from 3 to over 6,000 milligrams per liter (TWDB, 2009c).

Estimated Recharge for Natural Rangeland

Due to intensive cultivation of the land in Haskell and Knox counties over the years, representative natural land use areas are difficult to locate. Only two boreholes were drilled in a natural rangeland setting and it is questionable whether they represent natural land use prior to the introduction of ranching and farming in the area. At both locations, the mean sediment is coarse grained, with the sand content ranging from 83 to 90 percent, and mean water contents are low, ranging from 0.04 to 0.06 kg/kg. For borehole HAS03-05, the mean matric potential in the measured profile was high at -0.8 meters and the mean chloride concentrations were low, ranging from 6 to 17 milligrams per liter. The low chloride concentrations throughout borehole

HAS03-05 indicate flushing of the profile. The mean chloride concentrations in borehole HAS04-29 varied from 11 to 132 milligrams per liter and exhibit what is likely a displaced chloride bulge at the 5 meter depth, indicating deep drainage. Assuming a root zone depth of 3 feet, estimated recharge rates for the natural rangeland setting range from 0.3 to 1.1 inches per year, with a mean and median of 0.7 inches per year, and represent chloride accumulation times ranging from 23 to 130 years.

Although the natural rangeland present today likely does not completely represent land cover on the aquifer during the period of steady state prior to 1880, the recharge estimates for this land use provide the best estimates of recharge under steady-state conditions. It is estimated that recharge under steady-state conditions was near or less than the mean value of 0.7 inches per year estimated for natural rangeland.

Estimated Recharge for Rainfed Agriculture

A total of 11 boreholes were drilled beneath rainfed (dryland) agriculture. The profile was partially flushed in two of the boreholes and totally flushed in nine of the boreholes. Sediments in the profiles of these boreholes are generally coarse grained, with a mean sand content of 75 percent, and textures range from sandy clay loam to sandy loam. All but borehole HAS03-07 are located in the sand hills on the western side of the aquifer in northwestern Haskell County (see Figure 4.4.4). Although borehole HAS03-07 is located northeast of the sand hills, the textural variation in this borehole is not significantly different from that in the boreholes located in the sand hills (Table 4.4.3). The range in mean water content for the rainfed profiles is low, ranging from 0.07 to 0.14. Mean chloride concentrations are also low, ranging from 6 to 37 milligrams per liter, and mean matric potentials are high, ranging from -1.8 to -5.4 meters. Estimated recharge rates for rainfed agriculture range from 0.4 to 1.7 inches per year, with a mean of 1.1 inches per year and a median of 0.9 inches per year. These rates are similar to those estimated for rainfed agriculture in the Southern High Plains (Scanlon and others, 2007). Chloride accumulation times for the rainfed profiles range from 21 to 98 years.

The timing of land-use change for partly flushed borehole HAS03-07 is 60 years, which correlates well with land owner records of initial cultivation in 1945. Although the land-use transition date is not known for the other partly flushed borehole (HAS04-27), the calculated chloride accumulation time of 75 years indicates a transition date of about 1933. This date is older than the earliest available aerial photography from 1939, which indicates that the area was cultivated by that time. The profiles in the other boreholes did not extend deep enough to provide data with which the date of land-use change could be estimated.

Estimated Recharge for Irrigated Agriculture

Six boreholes from irrigated sites were evaluated. There were strong variations in the soil texture in these boreholes; three were drilled in the sand hills where the mean clay content of the surface soil is 22 percent and three were drilled where the mean clay content of the surface soil is 29 percent. The profiles in these six boreholes have mean water contents that range from 0.11 to 0.15 and high mean matric potentials that range from -1.2 to -34.2 meters. Mean chloride concentrations in the profiles are highly variable, ranging from 23 to 2,586 milligrams per liter. This variability likely represents variations in the concentration of chloride in the irrigation water. Chloride concentrations in the Seymour Aquifer are highly variable and range from 3 to over 6,000 milligrams per liter (TWDB, 2009c).

Although there are significant uncertainties associated with variability in the amount of irrigation water applied and the chloride concentrations of the irrigation water, estimates of irrigation amounts and chloride concentrations were used to calculate recharge rates using the data from the boreholes drilled beneath irrigated sites. Actual irrigation water inputs were estimated where owner records were available; otherwise, an application rate of 1 foot per year was assumed. Chloride concentrations in the irrigation water were estimated from mean chloride concentrations of water in nearby wells. The estimated chloride concentrations for the irrigation water at the six borehole locations were highly variable, ranging from 7 to 330 milligrams per liter. Estimated recharge rates for irrigated profiles range from 1.5 to 5.8 inches per year, with a mean of 3.2 inches per year and a median of 2.6 inches per year. Although there were distinct textural variations with three of the profiles located in the higher clay content soils to the northeast, calculated recharge rates did not vary systematically with soil texture. Estimated chloride accumulation times for the irrigated profiles range from 16 to 64 years.

Spatial Mean Recharge Estimate

A spatial mean recharge rate of 1.3 inches per year was estimated for the Seymour Aquifer in Haskell and Knox counties by weighting the estimated mean recharge rates for the generalized 1992 National Land Cover Data land use areas. Rainfed agriculture was weighted as 79 percent, irrigated agriculture as 13 percent, and shrubland, grassland, and forest areas were combined to form the natural land use representing the remaining 8 percent. Urban and water land cover were not included in the spatial estimate.

4.4.2.2 Water-Table Fluctuation Method

Recharge rates were calculated using the water-table fluctuation method and the water-level rises documented in Bandy (1934) and using water levels observed in three Seymour Aquifer wells having long-term data. Bandy (1934) reported several accounts of large water-level rises in wells during the period from about 1910 to 1934 from longtime residents in the vicinity of the cities of O'Brien and Rochester in Haskell County. Those rises ranged from 5 to 49 feet over time periods ranging from 4 to 23 years (Table 4.4.4). Wells located to the west of O'Brien showed a range in increase of 0.5 to 1.8 feet per year with a mean of 1 foot per year. Wells located east and southeast of Rochester showed a range in increase of 1.0 to 2.8 feet per year with a mean of 2.0 feet per year. Note that increases in two of the wells could not be used in this analysis because the date of the first measurement was not given in Bandy (1934). Assuming a specific yield of 0.15 (R.W. Harden and Associates, 1978), these water-level rises indicate recharge rates ranging from 0.8 to 5.0 inches per year, with a mean of 2.5 inches per year and a median of 2.0 inches per year. This range corresponds to 3 to 20 percent of the long-term average precipitation of 24.5 inches per year.

Long-term water-level data for three Seymour Aquifer wells in three different locations indicate varying responses to precipitation and irrigation within the aquifer (Figure 4.4.7). The water table was most responsive to precipitation events in well 21-34-902 located in the central portion of the aquifer. The water-level response was slightly reduced in well 21-42-701 located in the sand hills to the southwest, and substantially reduced in well 21-35-301 located in an area predominately covered with surface soil having a clay content of 29 percent. There are limited data available for water levels in the 1940s, but the decline in water levels from 1944 to 1951, seen in well 21-42-701 (see Figure 4.4.7), along with a decreasing trend in precipitation over that time period (see Figure 4.4.3), indicate that water levels were declining from highs seen in the 1930s. Water levels continued to decline during the 1950s, due to the drought conditions and the widespread implementation of irrigation pumpage in the region. Use of groundwater for irrigation purposes began in about 1951, when over the subsequent 5-year period the number of irrigation wells increased from 25 to 1,100. Water levels began to rise in well 21-42-701 in the late 1950s, highlighting the wells quick response to the above average precipitation that occurred in 5 out of the 8 years between 1957 and 1964. Over the same period, water levels in wells 21-35-301 and 21-34-902 showed a delayed regional response to the increased precipitation, with rises not occurring until the mid-1960s.

From 1965 to 1973, water levels in wells 21-42-701 and 21-34-902 show a general increase until 1973 due to higher than normal precipitation in 7 of the 9 years. Although increases in water level are seen during this period in well 21-35-301, the overall water level is decreasing. The decrease in water levels recorded in all three wells between 1974 and 1980 corresponds to a period when precipitation in 5 out of the 7 years fell below average. Water levels then rose until a significant decrease was seen in the mid-1990s in response to drought conditions.

The water-table fluctuation method to estimate recharge rates was applied to the long-term water-level trends in these three wells. However, heavy pumping of the aquifer could impact the recharge calculation by altering the water-table response during times of peak drawdown and well recovery. Evaluations of regional response in other localized wells were used to help constrain these impacts. Recharge rates were calculated from the documented long-term water-table rises between the periods of January 9, 1957 to December 5, 1972 and November 15, 1977 to October 14, 1986 in well 21-42-701; January 19, 1966 to January 6, 1974 and November 11, 1980 to October 12, 1987 in well 21-34-902; and January 20, 1967 to November 12, 1970, January 11, 1971 to December 7, 1972, and November 5, 1981 to October 16, 1987 in well 21-35-301 (Table 4.4.5). Using a specific yield of 0.15 (R.W. Harden and Associates, 1978), estimated recharge rates of 2 to 5.5 inches per year, with a mean of 3.5 inches per year and a median of 2.7 inches per year, were calculated. These recharge rates correspond well with the range of 0.8 to 5.0 inches per year, with a mean of 2.5 inches per year and a median of 2.0 inches per year, calculated from the water-level rises observed prior to the introduction of heavy pumping for irrigation purposes reported by Bandy (1934), as well as to the rates of 1.5 to 5.8 inches per year, with a mean of 3.2 inches per year and a median of 2.6 inches per year, calculated using data from the irrigation boreholes. These average values are higher than the 2.2 inches per year reported by R.W. Harden and Associates (1978), but may be considered an upper bound.

4.4.3 Summary and Recommendations

Historical accounts indicate that the Haskell-Knox-Baylor pod of the Seymour Aquifer had some saturated thickness, as evidenced by flowing springs, under steady-state conditions prior to 1880. Water levels in the aquifer appear to have fallen during the period of overgrazing of the land by domestic livestock from about 1880 to 1910 resulting in local areas where the aquifer was dry. Large water-table rises occurred after the area was cultivated in the early 1900s, which resulted in an increase in the saturated thickness of the aquifer.

Modern recharge rates were calculated using the chloride mass balance method and data collected from 19 boreholes located in three land-use settings and using water-level fluctuation observations in three Seymour Aquifer wells. The recharge rates calculated with the chloride mass balance method varied based on the land-use setting (Table 4.4.6). Data collected from the boreholes drilled in natural rangeland indicate a range in recharge rate of 0.3 to 1.1 inches per year with a mean of 0.7 inches per year and a median of 0.7 inches per year. Estimated recharge rates ranging from 0.4 to 1.7 inches per year, with a mean of 1.1 inches per year and a median 0.9 inches per year, were determined using data collected from boreholes drilled in the rainfed agriculture setting. Data collected from the boreholes drilled in the irrigated agriculture setting yielded a range in recharge rate of 1.5 to 5.8 inches per year, with a mean of 3.2 inches per year and a median of 2.6 inches per year. Weighting the recharge estimates by land cover area resulted in a spatial mean recharge estimate for the Seymour Aquifer of 1.3 inches per year.

Due to uncertainties associated with irrigation water inputs, the most reliable estimates are from the rainfed sites. Although recharge rates under irrigation sites were high, they are consistent with the range of values calculated using the water-table fluctuation method and long-term water-level data from three wells (range of 2 to 5.5 inches per year, with a mean of 3.5 inches per year and a median of 2.7 inches per year) as well as the values calculated using the large water-level rises reported in Bandy (1934) (range of 0.8 to 5.0 inches per year, with a mean of 2.5 inches per year and a median of 2.0 inches per year). The recharge estimates calculated using both the chloride mass balance and water-table fluctuation methods are summarized in Table 4.4.6.

A spatial distribution of modern recharge based on land use and mean clay content of surface soil was developed using the estimated recharge rates calculated by the analysis presented here. For the sand hills, which have a mean clay content of 22 percent in the surface soil, in the western portion of the aquifer in northwestern Haskell County, recharge estimates were calculated for natural rangeland, rainfed agriculture, and irrigated agriculture based on data from boreholes drilled in these three land-use settings. The medians of those calculated values were applied to the different land-use types on the areas of the aquifer with a clay content of 22 percent in the surface soils. Although data were not available to directly estimate a recharge rate for natural and rainfed land-use settings on the other surface soils, a scaling factor based on the ratio of the unsaturated soil permeability for the new soil type to the unsaturated soil permeability for the soil type on the sand hills was used to estimate values. The values for the unsaturated soil permeability were developed using the Rosetta Model (United States Department of Agricultural, 1999), which uses soil texture data to estimate unsaturated hydraulic properties. Regardless of the mean soil content in the surface soil, all irrigated land was assigned a recharge rate of 3.2 inches per year, which is the value estimated for the boreholes drilled in irrigated areas. Figure 4.4.8 shows the resultant estimated spatial distribution in recharge rates for the Seymour Aquifer under modern conditions.

Figure 4.4.8 indicates the highest recharge rates in the portion of the aquifer overlain by surface soil with a mean clay content of 16 percent. Although the higher permeability of this soil would make it conducive to recharge, the portion of the aquifer adjacent to the Brazos River is an area of natural discharge. Groundwater levels in this area are very close to land surface and any recharge there is expected to be rejected to either evapotranspiration or baseflow to the Brazos River. The recharge in Figure 4.4.8 is therefore considered an overestimate in the region adjacent to the Brazos River.

None of the estimates of recharge to the Seymour Aquifer directly apply to the time period when the aquifer was at steady state prior to 1880. However, recharge during that time was likely similar to or less than that on current locations with natural rangeland. Recharge estimates using data for the boreholes drilling in areas of natural rangeland on the sand hills, which have a mean clay content in the surface soil of 22 percent, indicate a range in recharge of 0.3 to 1.1 inches per year, with a mean and median of 0.7 inches per year. It is estimated the recharge under steady-state conditions was around 0.7 inches per year where the clay content of the surface soil is 22 percent. Estimated steady-state recharge for the remainder of the aquifer with other surface soils was developed using the ratio of the unsaturated hydraulic conductivity for the new soil type and the unsaturated hydraulic conductivity for the soil type on the sand hills.

The portion of the aquifer where large water-level rises were observed in the early 1900s lies beneath the sand hills near the cities of Rochester and O'Brian. The mean recharge rate estimated using the observed water-level rises reported in Bandy (1934) is 2.5 inches per year. That rate was assumed for the time period from about 1910 to about 1940 for areas of the aquifer with a mean clay content of 22 percent in the surface soil. Estimated recharge during this time period for the remainder of the aquifer with other surface soil types was developed using the ratio of the unsaturated hydraulic conductivity for the new soil type and the unsaturated hydraulic conductivity for the soil type on the sand hills.

This section provides an estimate of recharge rates for the Seymour Aquifer under steady-state conditions, conditions when water levels in the aquifer were rising, and modern conditions. These estimates were developed based on limited point data from 19 boreholes drilled in the aquifer and on observed water-level rises. Therefore, their applicability to regional recharge is limited.

Table 4.4.1 Land use based on cultivated areas.

USGS (1992) Land Cover Class	Combined Land Cover Classes Based on Cultivated Area
Open water	Open water
Low Intensity Residential	Urban
High Intensity Residential	
Commercial/Industrial/Transportation	
Deciduous Forest	Forest
Evergreen Forest	
Mixed Forest	
Shrubland	Shrubland
Grasslands/Herbaceous	Grassland
Bare Rock/Sand/Clay Pasture/Hay Row Crops Small Grains Urban/Recreational Grasses	Rainfed Agriculture
Woody Wetlands	Wetlands
Emergent Herbaceous Wetlands	

USGS = United States Geological Survey

Table 4.4.2 Summary of development of irrigation pumpage in Haskell and Knox counties from 1950 to 1956 (after Ogilbee and Osborne, 1962).

Year	Number of Irrigation Wells	Estimated Irrigation Pumpage (acre-feet)	Estimated Irrigated Acres
1950	3	100	nr
1951	25	900	nr
1952	115	6,700	5,700
1953	170	9,900	8,500
1954	290	16,800	14,500
1955	600	34,800	30,000
1956	1,100	63,800	50,000

nr = no value reported in Ogilbee and Osborne (1962)

Table 4.4.3 Summary of recharge rates estimated from unsaturated zone studies in the Seymour Aquifer.

Borehole	Latitude	Longitude	Vegetation/Crop Coverage	Depth (m)	Average Soil Texture (%)			Water Content (kg/kg)			Matric potential (m)			Chloride Concentration (mg/L)			Recharge Rate (in/yr)	Chloride Accumula-tion Time (yr)
					Sand	Silt	Clay	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max		
Natural Land-Use Setting																		
HAS03-05	33.31190	-99.94210	Sage/Grass	5.79	90.2	3.1	6.9	0.06	0.01	0.15	-0.8	-1.0	-0.2	11	6	17	1.1	23
HAS04-26	33.34532	-99.90930	Mesquite/Grass	5.94	82.6	6.9	10.5	0.04	0.02	0.07	-	-	-	132	23	412	0.3	130
Rainfed Agriculture Land-Use Setting																		
HAS03-07	33.38490	-99.71950	Wheat	3.51	71.8	10.6	17.5	0.09	0.02	0.17	-	-	-	37	14	76	0.4	60
HAS04-27	33.21992	-99.88460	Wheat/Alfalfa/Cotton	5.56	75.0	13.0	12.0	0.11	0.06	0.16	-	-	-	32	6	80	0.9	75
HAS03-01	33.26880	-99.92290	Cotton/Wheat	6.10	80.9	6.2	12.9	0.07	0.02	0.12	-1.8	-4.4	-0.7	14	4	29	0.8	50
HAS03-03	33.26980	-99.91320	Cotton	6.10	78.4	7.2	14.5	0.09	0.02	0.15	-	-	-	21	6	74	0.8	59
HAS03-04	33.26360	-99.92380	Wheat	3.66	70.8	6.4	22.8	0.10	0.02	0.16	-	-	-	12	3	40	1.6	29
HAS04-30	33.19278	-99.86702	Cotton	4.57	56.8	15.1	28.1	0.14	0.10	0.16	-	-	-	7	6	9	1.4	27
HAS04-31	33.18933	-99.87683	Wheat	3.66	54.1	18.8	27.1	0.14	0.05	0.17	-	-	-	6	5	8	1.7	21
HAS04-32	33.25890	-99.88990	Cotton	9.75	78.8	8.6	12.6	0.08	0.03	0.14	-5.4	-6.8	-3.4	15	6	31	0.9	64
HAS04-25	33.21898	-99.89600	Cotton	12.19	80.7	7.5	12.3	0.09	0.03	0.17	-	-	-	19	4	66	1.1	98
HAS04-28	33.28415	-99.92400	Bermuda	10.36	79.0	5.2	15.8	0.08	0.03	0.18	-4.1	-6.2	-2.6	19	6	59	0.8	68
HAS04-24	33.21738	-99.89898	Cotton	9.60	75.5	9.2	15.3	0.10	0.03	0.15	-5.2	-6.3	-3.4	10	4	42	1.5	43
Irrigated Agriculture Land-Use Setting																		
HAS03-06	33.30910	-99.92450	Bermuda	6.10	77.3	7.6	15.1	0.12	0.05	0.15	-1.2	-2.1	-0.4	94	30	202	1.5	39
HAS04-23	33.34925	-99.89683	Peanuts	3.35	72.9	13.2	13.9	0.14	0.05	0.18	-	-	-	292	83	538	2.5	16
HAS04-29	33.21905	-99.88372	Cotton/Peanuts/Alfalfa	10.67	75.3	9.2	16.1	0.15	0.10	0.19	-	-	-	23	5	36	5.8	25
HAS07-01	33.39712	-99.66627	Cotton	6.92	46.3	23.9	29.7	0.12	0.08	0.18	-12.9	-38.2	-1.18	477	13	138	2.8	64
HAS07-02	33.43128	-99.58228	Cotton	6.40	49.4	26.4	24.2	0.14	0.05	0.19	-34.2	-71.7	-4.4	2586	1918	3956	1.6	28
HAS07-03	33.45912	-99.69360	Cotton	12.80	49.4	26.4	24.2	0.11	0.07	0.19	-3.2	-5.8	-0.5	205	132	372	4.7	19

m = meters
%= percent
kg/kg = kilograms per kilogram
mg/L = milligrams per liter
Min = minimum
Max = maximum
in/yr = inches per year
yr = years

Table 4.4.4 Average water-level rises reported in Bandy (1934) for the Rochester and O'Brien areas in Haskell County (after R.W. Harden and Associates, 1978).

Location	Well Number	Year	Depth-to-Water (feet)	Year	Depth-to-Water (feet)	Number of Years	Increase in Water Level (feet)
O'Brien	A-0	unknown	60	1934	46	unknown	14
O'Brien	A-4	1919	29	1934	22	15	7
O'Brien	Corother	1928	20	1934	15	6	5
O'Brien	A-8	1922	39	1934	17	12	22
O'Brien	Needmore School	1921	42	1934	27	13	15
O'Brien	A-30	1924	42	1934	31	10	11
O'Brien	A-37	1924	19	1934	14	10	5
Rochester	C-29	1911	51	1934	16	23	35
Rochester	C-31	1924	40	1934	30	10	10
Rochester	Cloud	1930	23	1934	12	4	11
Rochester	D-13	unknown	75	1934	6	unknown	69
Rochester	D-17	1915	60	1934	11	19	49

Table 4.4.5 Recharge rates estimated using the water-table fluctuation method and long-term water-level data for three Seymour Aquifer wells.

State Well Number	Time Period	Number of Years	Increase in Water Level (feet)	Estimated Recharge Rate (inches per year)
21-42-701	1/9/1957 to 12/5/1972	15.0	22.0	2.6
21-42-701	11/15/1977 to 10/14/1986	8.9	9.8	2.0
21-35-301	1/20/1967 to 11/12/1970	3.0	7.0	4.2
21-35-301	1/11/1971 to 12/7/1972	1.9	2.9	2.7
21-35-301	11/5/1981 to 10/16/1987	6.0	9.8	2.4
21-34-902	1/19/1966 to 1/6/1974	8.8	27.0	5.5
21-34-902	11/11/1980 to 10/12/1987	6.9	20.0	5.2

Table 4.4.6 Summary of all estimates of recharge rate for the Seymour Aquifer.

Method	Type Data	Recharge (inches per year)			
		Mean	Minimum	Maximum	Median
Chloride Mass Balance	Natural Boreholes	0.7	0.3	1.1	0.7
Chloride Mass Balance	Rainfed Boreholes	1.1	0.4	1.7	0.9
Chloride Mass Balance	Irrigated Boreholes	3.2	1.5	5.8	2.6
Water-Table Fluctuation	Long-Term Water-Level Data	3.5	2	5.5	2.7
Water-Table Fluctuation	Water-Level Rises Reported in Bandy (1934)	2.5	0.8	5.0	2.0

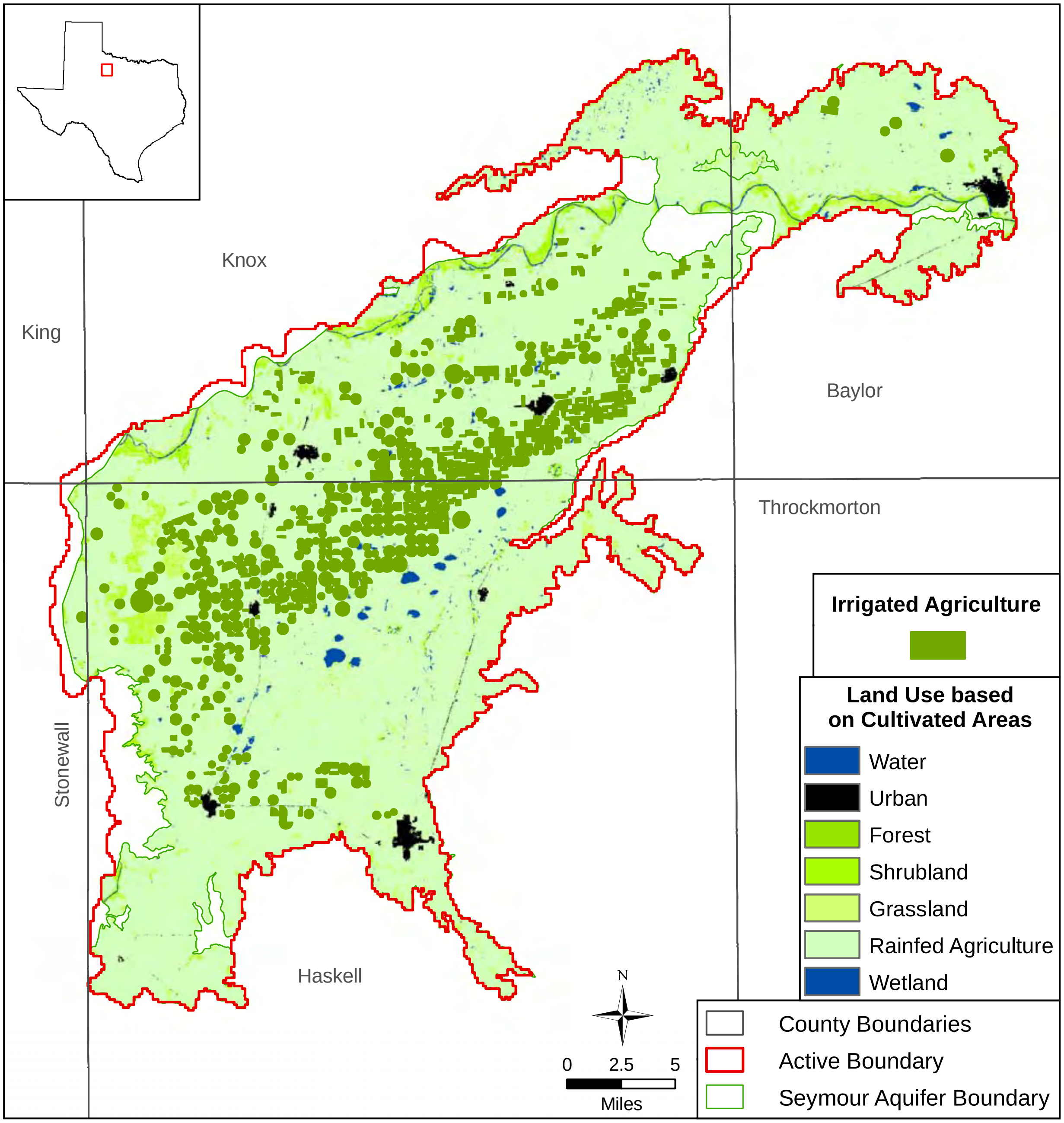

Figure 4.4.1 Land use based on cultivated areas (modified from United States Geological Survey, 1992) and irrigated agriculture.

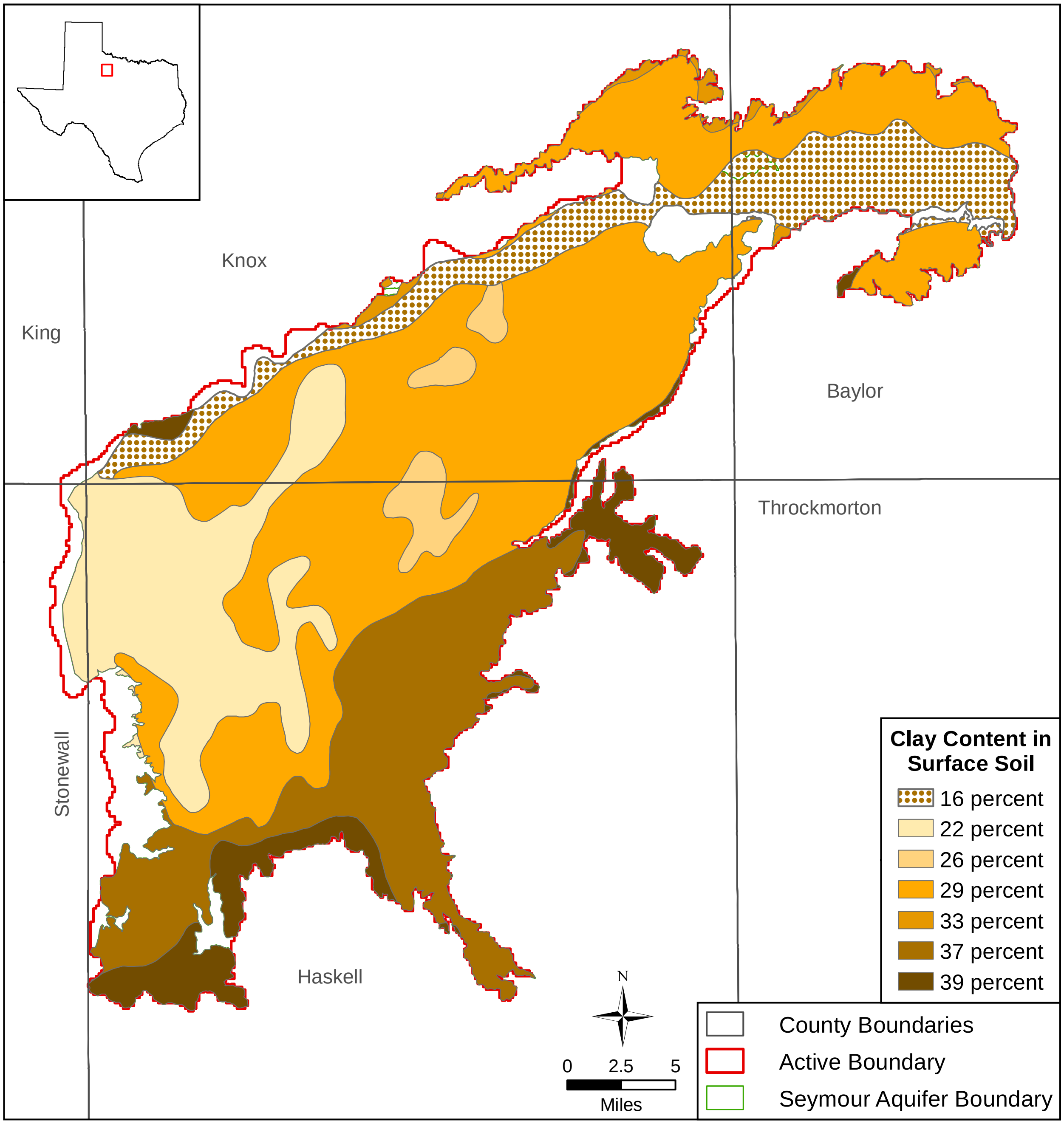

Figure 4.4.2 Clay content in surface soil (United States Department of Agriculture, 2007).

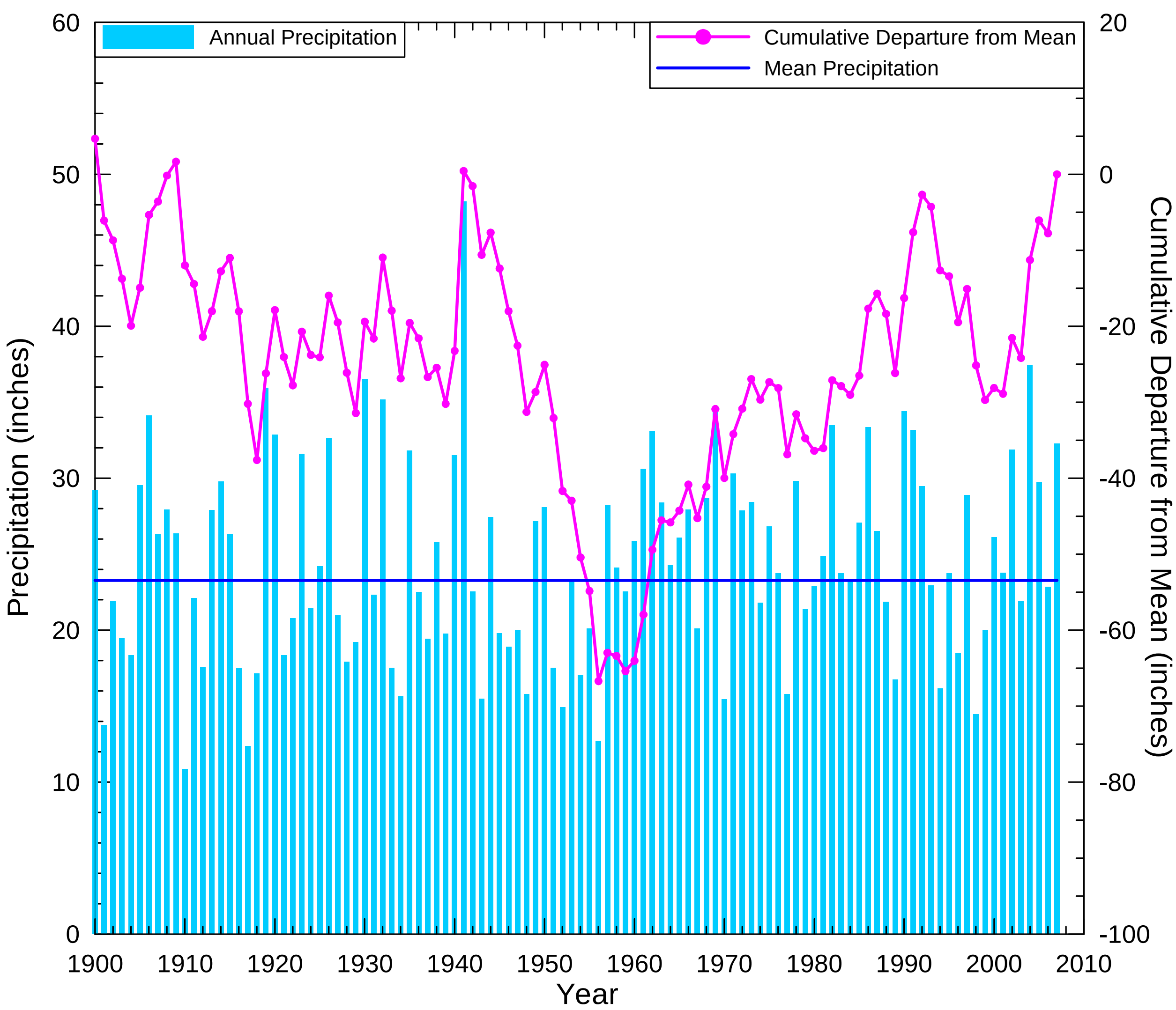

Figure 4.4.3 Annual precipitation for the city of Haskell (National Climatic Data Center, 2008).

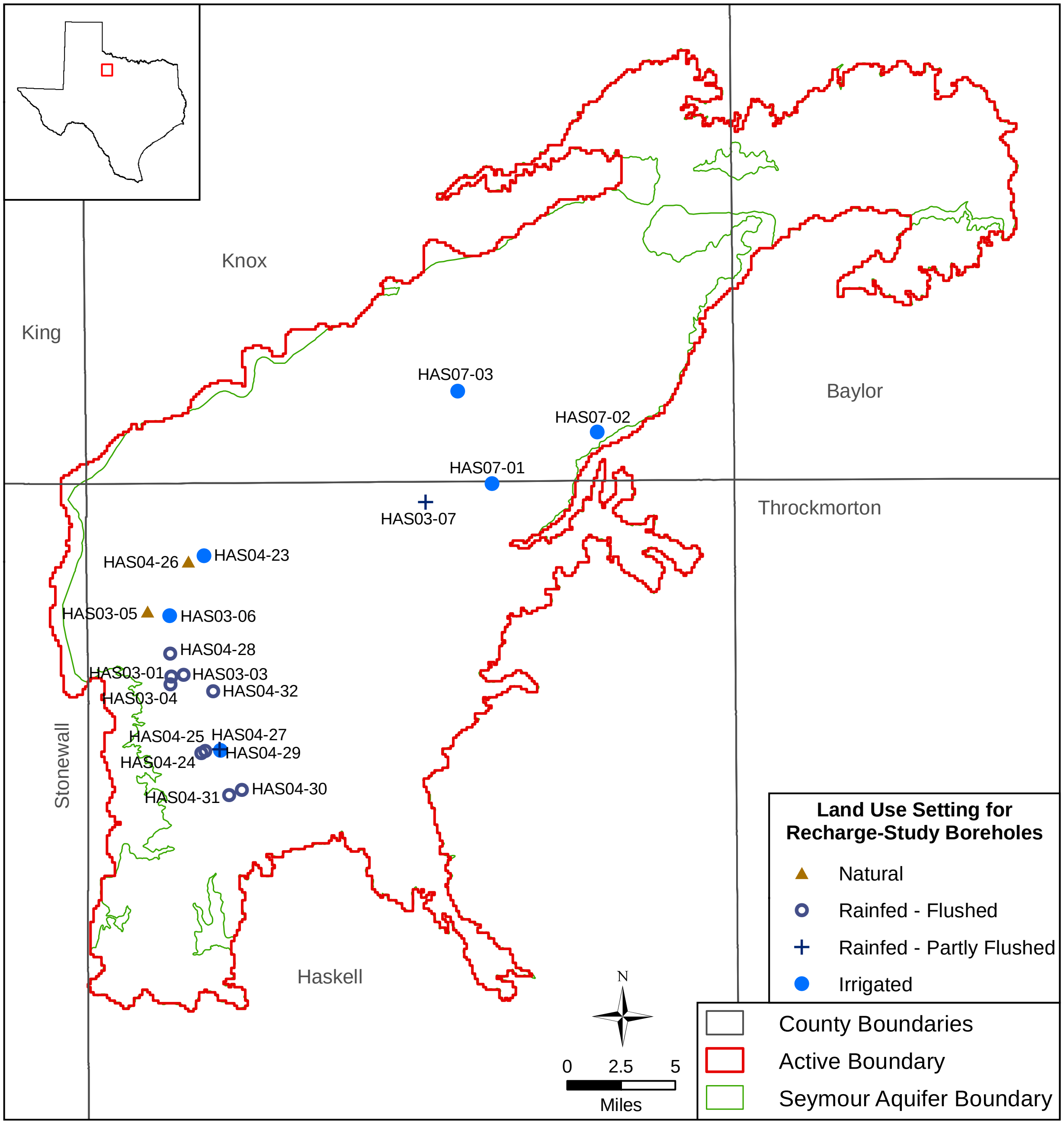

Figure 4.4.4 Location of boreholes for the unsaturated zone studies in the Seymour Aquifer.

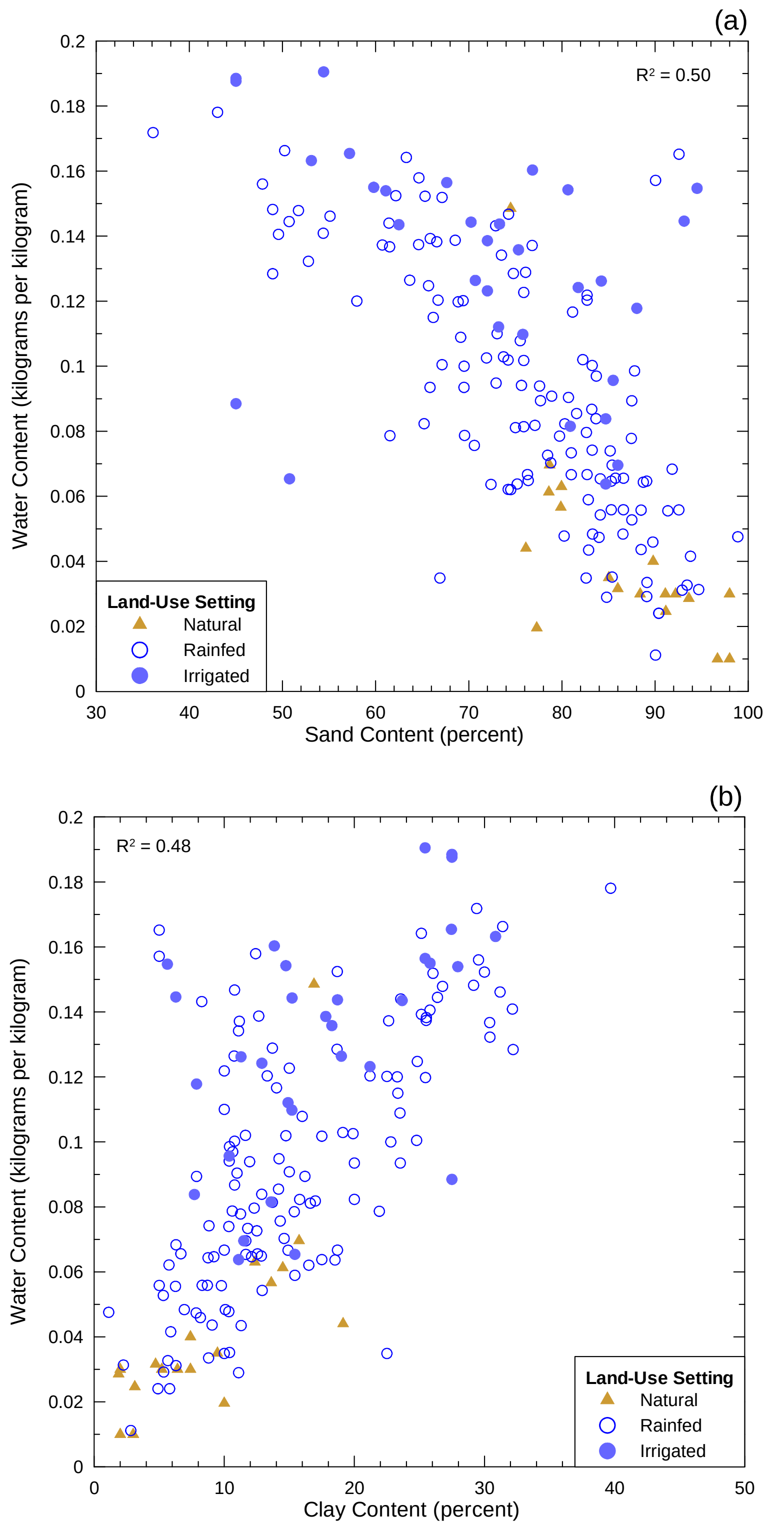

Figure 4.4.5 Relationship between (a) water content and sand content and (b) water content and clay content for boreholes in the unsaturated zone studies in the Seymour Aquifer.

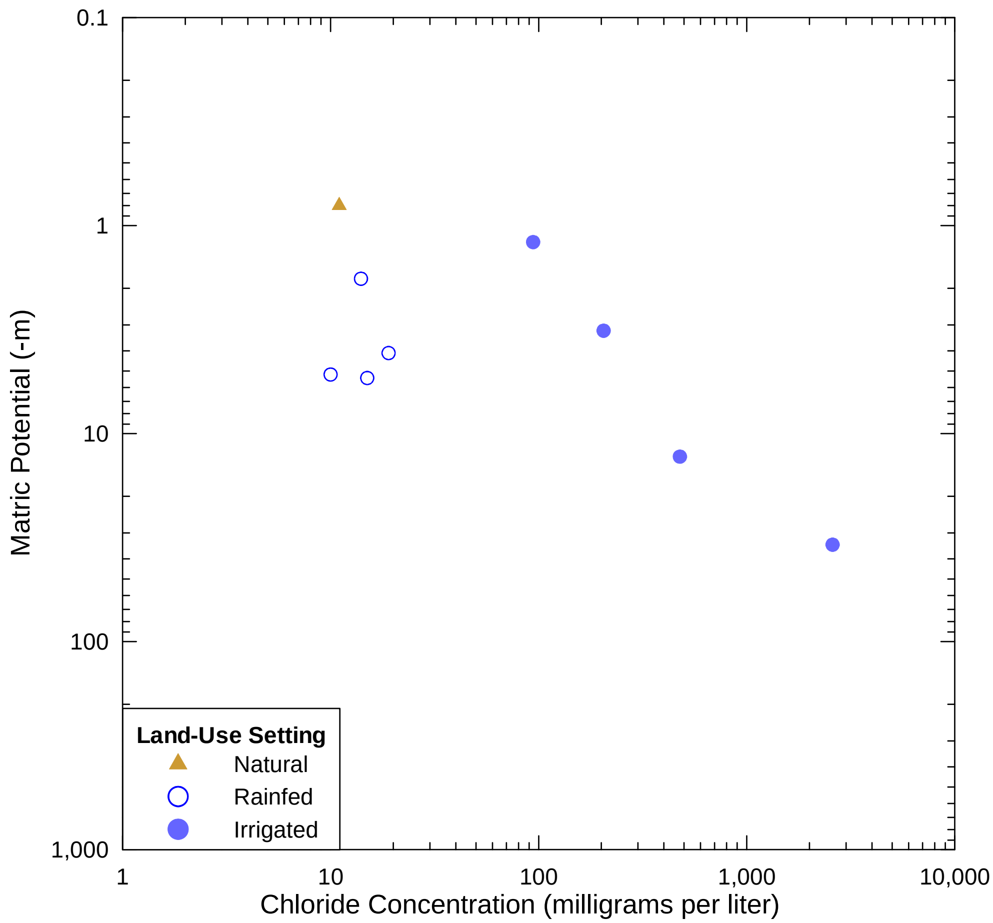

Figure 4.4.6 **Relationship between matric potential and chloride concentration for boreholes in the unsaturated zone studies in the Seymour Aquifer.**

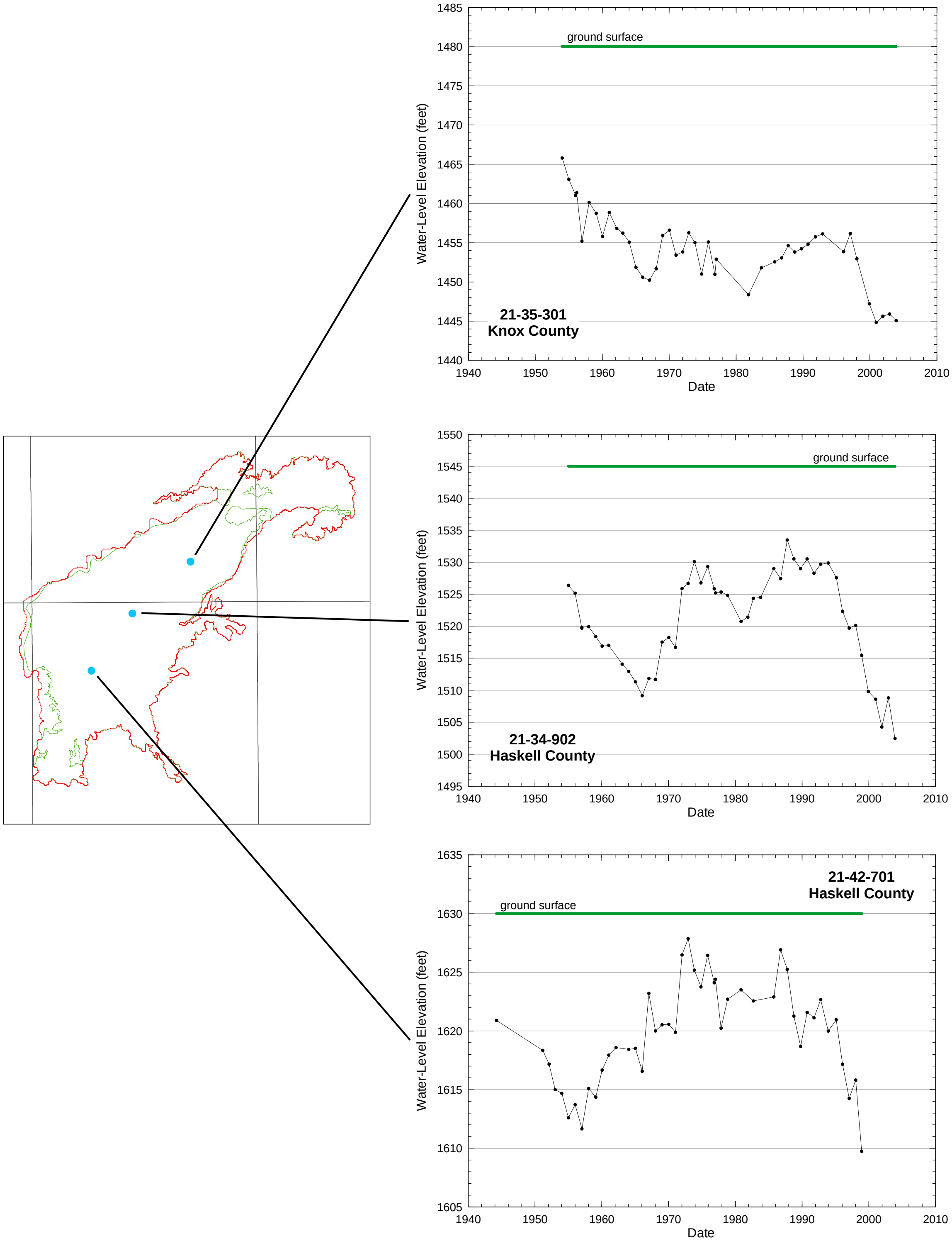

Figure 4.4.7 Long-term water-level data used to estimate recharge rates for the Seymour Aquifer using the water-table fluctuation method.

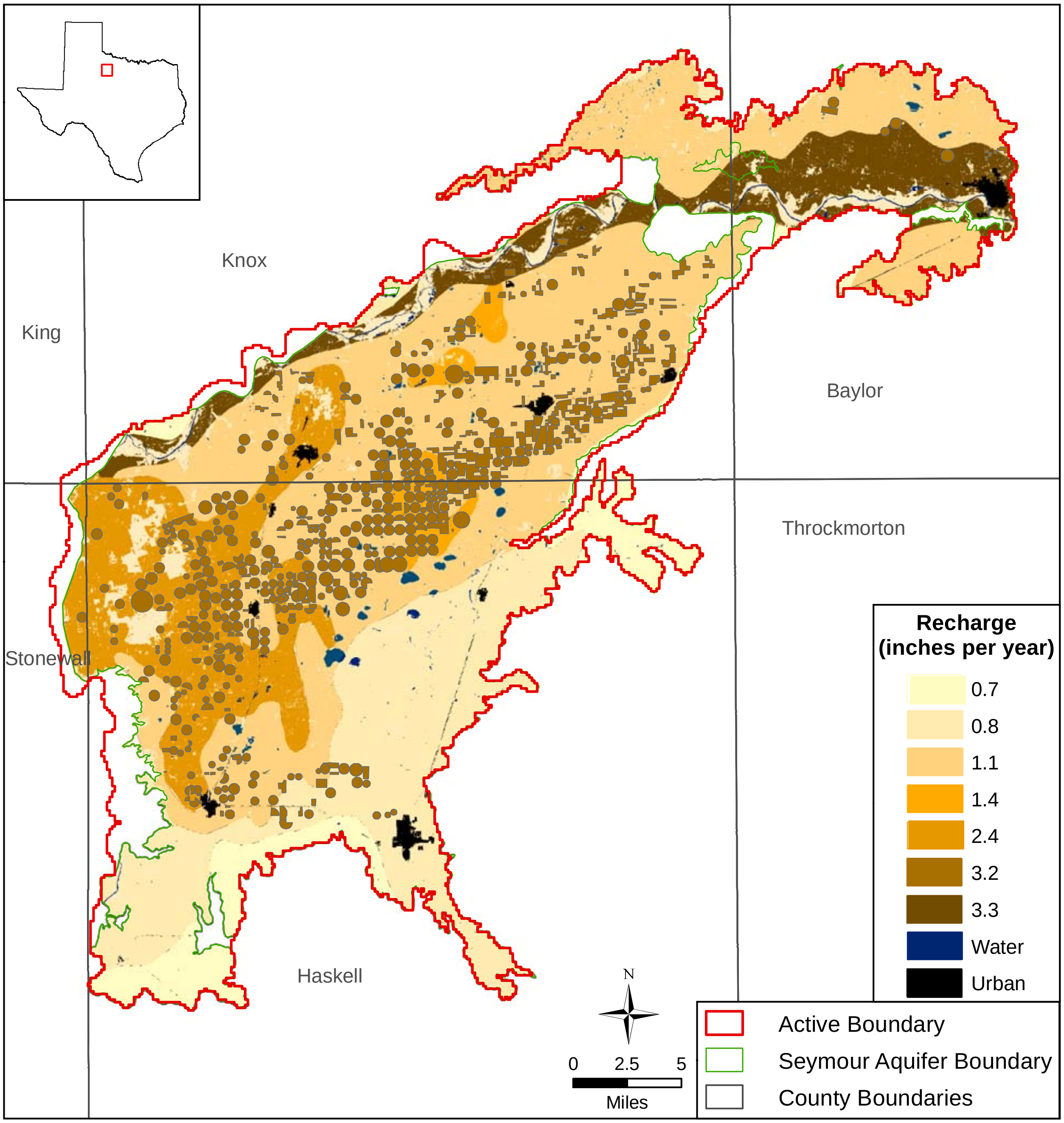

Figure 4.4.8 Estimated spatial distribution of modern recharge for the Seymour Aquifer.

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4.5 Rivers, Streams, Springs, and Lakes

Interaction between groundwater and surface water occurs at the location of rivers, streams, springs, and lakes. Rivers and streams can either lose water to the underlying aquifer, resulting in aquifer recharge, or gain water from the underlying aquifer, resulting in aquifer discharge. Discharge from an aquifer also occurs where the water table intersects the ground surface at springs or seeps. Lakes can provide a potential site of focused recharge.

4.5.1 Rivers and Streams

Base flow in a river or stream is the contribution of groundwater to gaining reaches of a stream. After runoff from storm events has drained away, the natural surface-water flow that continues is predominately base flow from groundwater. Streams can have an intermittent base flow with flow during wet periods and low or no flow during dry periods. Larger streams and rivers might have a perennial base flow. Direct exchange between surface water and groundwater is limited to the outcrop.

One major river, two large creeks, and four small creeks intersect the study area (Figure 4.5.1). The locations of the major river and two large creeks were obtained from the United States Environmental Protection Agency reach file 1 for the conterminous United States (Alexander and others, 1999), clipped to the active model area, and the locations for the four small creeks were digitized from a scanned image of a United States Geological Survey topographic map obtained from the Texas Natural Resources Information System website (TWDB, 2005). The names for these four small creeks were taken from R.W. Harden and Associates (1978). Because the locations of the four small creeks were digitized from a figure, they are less certain than the locations of the major river and two large creeks.

Also shown on Figure 4.5.1 is the location of the one stream gage, where stream-flow data are collected, available for the river in the study area. This gage is located on the Brazos River in Baylor County. Figure 4.5.2 shows a hydrograph of the yearly average stream flow at this gage over the period of record from 1924 through 2008. This yearly average stream flow was calculated from daily stream flow data obtained from the United States Geological Survey website of surface water data for the nation (United States Geological Survey, 2009b). The yearly average has ranged from a low of 48 cubic feet per second in 1952 to a high of 1,786 cubic feet per second in 1941. During the transient model calibration period of 1980 through 1997, the yearly average ranged from a low of 92 cubic feet per second in 1984 to a high of 632 cubic feet per second in 1992. A pattern of relatively low stream flow for one or two years followed by significantly higher flow for the next two or three years occurs three times during the transient model calibration period of 1980 through 1997. However, stream flow was continually low from 1993 through 1997. Figure 4.5.3 shows the daily and monthly average stream flow at the gage during the transient model calibration period. The grid lines on the monthly average figure indicate the month of January in each year. A comparison of this grid line to the data does not show a consistent seasonal trend in the monthly average stream flow. Although the lowest stream flows occurred in the summer months of 1983, 1984, and 1996, several of the highest streams flows also occurred in summer months (i.e., 1982, 1990, 1991, and 1992).

Stream interaction with underlying aquifers can be quantified through stream gain/loss studies that determine the rate of water exchange between a stream and the adjacent aquifers. A low-flow gain/loss study was conducted in February 1970 on the Brazos River from the Knox-Baylor county line to the bridge over the river at the city of Seymour in Baylor County (Preston, 1978). Gains/losses in stream flow were measured at five sites along this portion of the river. The approximate locations of measurements sites 2, 3, 4, and 5 are shown in Figure 4.5.1. The location of measurement site 1 is not shown on this figure because it was not given in Preston (1978). Table 4.5.1 summarizes the stream flow measured at each site, the net gain, and the yearly discharge from the Seymour Aquifer represented by the gain. The study showed that this portion of the Brazos River is gaining, with the net gain ranging from 0.1 to 2.6 cubic feet per second (Table 4.5.1). The gains observed along the river indicate discharge from the Seymour Aquifer to the river. Preston (1978) calculated the magnitude of this discharge to range from 72.4 to 1,882.5 acre-feet per year (Table 4.5.1). Note that along this portion of the Brazos River, the Seymour Aquifer includes groundwater in the Seymour Formation as well as groundwater in the recent alluvium sediments located adjacent to the river. The majority of the groundwater discharging to the river comes from the Seymour Formation and travels through the recent alluvial deposits to the river (Preston, 1978). The Slade and others (2002) report on gains from and losses to major and minor aquifers in Texas does not include stream gain/loss study data for the Seymour Aquifer.

4.5.2 Springs

In unconfined aquifers, springs are locations where the water table intersects the ground surface. Springs typically occur in topographically low areas in river valleys or in areas of the outcrop where hydrogeologic conditions preferentially reject recharge. Four sources were used to find spring data for the Seymour Aquifer; the TWDB website (TWDB, 2008c), a database of Texas springs compiled by the United States Geological Survey and reported in Heitmuller and Reece (2003), a report on the springs of Texas by Brune (2002), and the R.W. Harden and Associates (1978) report on the availability and quality of groundwater in the Seymour Aquifer in Haskell and Knox counties. Note that all of the springs identified in the report in the occurrence and quality of groundwater in Baylor County by Preston (1978) are included in TWDB (2008c). All of the springs found in Heitmuller and Reece (2003) were also found on the TWDB website (TWDB, 2008c).

The TWDB website and Heitmuller and Reece (2003) provide coordinates for springs but Brune (2002) does not. An exercise was conducted to try to determine the locations of the springs given in Brune (2002) by first looking at the discharge rates from the springs. If the rate was low, those springs were considered to be unimportant and not evaluated further. For springs with high discharge rates, an attempt was made to match the spring with a spring found in TWDB (2008c). For three springs this was easily done because the name of the spring in Brune (2002) matched the name of the spring in TWDB (2008c) and/or Heitmuller and Reece (2003). Several other springs were matched to a spring in TWDB (2008c) based on the description of the spring location given in Brune (2002) and/or based on the flow measurements given in Brune (2002) and TWDB (2008c). The certainty of this match is high for some springs but low for others. Six of the springs in Brune (2002) had a high discharge rate but could not be matched to a spring in TWDB (2008c). For those springs, an approximate location was estimated based on the location description given in Brune (2002).

Figure 4.5.4 shows the locations of springs flowing from the Seymour Aquifer obtained from the TWDB website (TWDB, 2008c), Heitmuller and Reece (2003), and Brune (2002). The springs are predominately located along the Brazos River in Baylor County and along the western edge of the Seymour Aquifer in Knox and Haskell counties. Table 4.5.2 provides a summary of flow from Seymour Aquifer springs. A flow rate is not available for several of the springs and only one flow rate is available for many of the springs. For the springs with more than one measurement, spring discharge has generally declined over time. Brune (2002) attributes this decline primarily to pumping of the Seymour Aquifer for irrigation purposes. More than two discharge measurements are available for only three of the springs. A plot of discharge for those three springs is provided in Figure 4.5.5.

R.W. Harden and Associates (1978) provide a figure showing areas of natural discharge from the Seymour Aquifer. That figure, reproduced as Figure 4.5.6, shows the locations of springs and zones of springs and seeps in creeks. A comparison of Figures 4.5.4 and 4.5.6 shows that the location for some, but not all, of the springs on the R.W. Harden and Associates (1978) figure match locations for springs found in TWDB (2008c). Volume II of the R.W. Harden and Associates (1978) report also contains a table with a record of wells, which includes springs. All of the springs in that table are included in TWDB (2008c). Coordinate and discharge data for springs shown on their figure but not included in their record of wells table are not provided by R.W. Harden and Associates (1978).

Brune (2002) reports that buffalo bones and Indian artifacts were found at several Seymour Aquifer springs in Baylor, Haskell, and Knox counties. He also found evidence of camp sites for buffalo hunters and Indians near several springs. Brune (2002) states that Rice Springs near the city of Haskell was flowing in 1867, 1875, and 1881 and that a spring in Baylor County fed a pool used for baptisms in the 1880s. This information indicates that that the Seymour Aquifer contained some water in the steady-state period prior to about 1880.

4.5.3 Lakes and Reservoirs

Figure 4.5.7 shows reservoirs located within the study area. None of these reservoirs lie on the Seymour Aquifer. Although it is difficult to see in Figure 4.5.7, a portion of Lake Davis falls within the active model area, but the boundary of the Seymour Aquifer does not include the lake. Figure 4.5.7 also shows the locations of several playas on the Seymour Aquifer. These playas contain water intermittently based on rainfall (McGuire, 2009). Most of the playas are located over the portion of the aquifer that is dry. The playas on the portion of the aquifer that contains water may be a source of focused recharge. However, their impact is expected to be insignificant.

Table 4.5.1 Summary of the February 1970 gain/loss study on the Brazos River in Baylor County (after Preston, 1978).

Measurement Site	Flow (cubic feet per second)	Net Gain (cubic feet per second)	Yearly Discharge Represented by Net Gain (acre-feet)
1	34.6	-	-
2	34.7	0.1	72.4
3	35.2	0.5	362.5
4	37.8	2.6	1,882.5
5	38.7	0.9	651.6

Table 4.5.2 Summary of springs flowing from the Seymour Aquifer in the study area.

Spring Number/ Name	Possible Spring in Brune (2002)	County	Elevation (feet)	Max Flow (gpm)	Max Flow (lps)	Date of Max	Min Flow (gpm)	Min Flow (lps)	Date of Min	Number of Measure-ments	Source
21-21-703	Soap Springs	Baylor	1388	30	**1.9**	10/1969	16	**1.0**	7/21/1979	3	TWDB (2008c), Brune (2002)
21-22-406	Dead Man Springs	Baylor	1280	10	**0.63**	10/1969	5.5	**0.35**	7/21/1979	2	TWDB (2008c), Brune (2002)
21-22-407		Baylor	1285	**15**	0.95	nr				1	TWDB (2008c)
21-22-408		Baylor	1285	**15**	0.95	nr				1	TWDB (2008c)
21-22-910		Baylor	1346	**2**	0.1	nr				1	TWDB (2008c), Heitmuller and Reece (2003)
21-29-317		Baylor	1300	**5**	0.3	nr				1	TWDB (2008c)
21-29-701		Baylor	1385							0	TWDB (2008c)
21-30-201		Baylor	1290	**10-15**	0.63-0.95	nr				1	TWDB (2008c)
21-30-214/ Buffalo Springs	Buffalo Springs	Baylor	1268	44	**2.8**	8/7/1925	12	**0.75**	1/22/1969	3	TWDB (2008c), Heitmuller and Reece (2003), Brune (2002)
21-30-262		Baylor	1267	**15**	0.95	nr				1	TWDB (2008c)
21-30-263		Baylor	1290	**15**	0.95	nr				1	TWDB (2008c)
21-30-383		Baylor	1303	**10**	0.63	nr				1	TWDB (2008c)
21-30-384		Baylor	1280	**5**	0.3	nr				1	TWDB (2008c)
21-30-603		Baylor	1332							0	TWDB (2008c)
21-39-604		Baylor	1260	**15**	0.95					1	TWDB (2008c)
21-30-393		Baylor		**67.32**	4.247	8/7/1925				1	TWDB (2008c), Heitmuller and Reece (2003)
Cottonwood Holes		Baylor		12	**0.75**	7/21/1979				1	Brune (2002)

Table 4.5.2, continued

Spring Number/ Name	Possible Spring in Brune (2002)	County	Elevation (feet)	Max Flow (gpm)	Max Flow (lps)	Date of Max	Min Flow (gpm)	Min Flow (lps)	Date of Min	Number of Measure-ments	Source
21-41-131	McGregor Springs	Haskell	1495	27	**1.7**	9/9/1979				1	TWDB (2008c), Heitmuller and Reece (2003), Brune (2002)
21-49-505	nr	Haskell	1650	**25**	1.6	3/20/1944	10	**0.61**	9/8/1979	2	TWDB (2008c), Heitmuller and Reece (2003), Brune (2002)
21-50-639		Haskell	1582							0	TWDB (2008c), Heitmuller and Reece (2003)
21-51-717/ Rice Spring	Rice Springs	Haskell	1560	55	**3.5**	9/7/1979	**dry**		8/6/1975	4	TWDB (2008c), Heitmuller and Reece (2003), Brune (2002)
Cook Springs		Haskell		41	**2.6**	9/9/1979				1	Brune (2002)
21-27-921	Redder Springs	Knox	1375	8.7	**0.55**	9/2/1979				1	TWDB (2008c), Heitmuller and Reece (2003), Brune (2002)
21-27-922		Knox	1365							0	TWDB (2008c), Heitmuller and Reece (2003)
21-28-601		Knox	1390	**1**	0.1	11/5/1975				1	TWDB (2008c), Heitmuller and Reece (2003)
21-28-602		Knox	1400							0	TWDB (2008c), Heitmuller and Reece (2003)
21-34-323	Mansfield Springs	Knox	1405	**100**	6.31	2/10/1957	**seeps**		9/1/1979	2	TWDB (2008c), Heitmuller and Reece (2003), Brune (2002)

Table 4.5.2, continued

Spring Number/ Name	Possible Spring in Brune (2002)	County	Elevation (feet)	Max Flow (gpm)	Max Flow (lps)	Date of Max	Min Flow (gpm)	Min Flow (lps)	Date of Min	Number of Measure-ments	Source
21-34-445/ Chalk Springs	Chalk springs	Knox	1445	**75**	4.73	3/1957	15	**0.95**	8/31/1979	3	TWDB (2008c), Heitmuller and Reece (2003), Brune (2002)
21-35-105		Knox	1405							0	TWDB (2008c), Heitmuller and Reece (2003)
21-35-106		Knox	1415							0	TWDB (2008c), Heitmuller and Reece (2003)
21-36-602		Knox	1412	**0.125**	0.008	11/6/1975				1	TWDB (2008c), Heitmuller and Reece (2003)
Bluff Springs		Knox		9.8	**0.62**	9/1/1979				1	Brune (2002)
Mockingbird Springs		Knox		21	**1.3**	9/3/1979				1	Brune (2002)
W Cross Springs		Knox		5.5	**0.35**	9/3/1979				1	Brune (2002)
Wild Horse Springs		Knox		81	**5.1**	9/3/1979				1	Brune (2002)

Note: Bold information reflects values and text given in the data source.
gpm = gallons per minute
lps = liters per second
TWDB = Texas Water Development Board

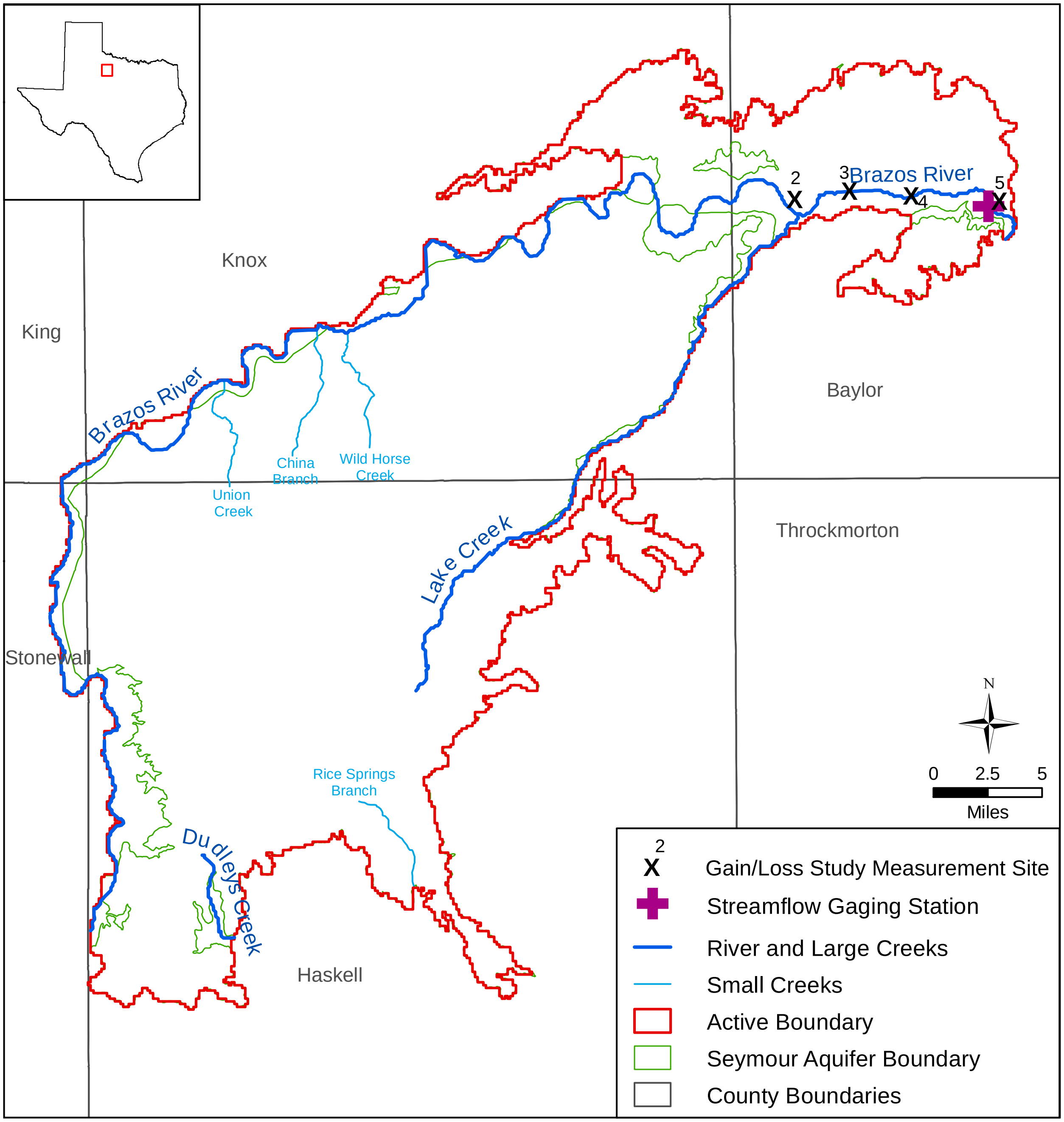


Figure 4.5.1 Locations of major river, large creeks, and small creeks in the model area.

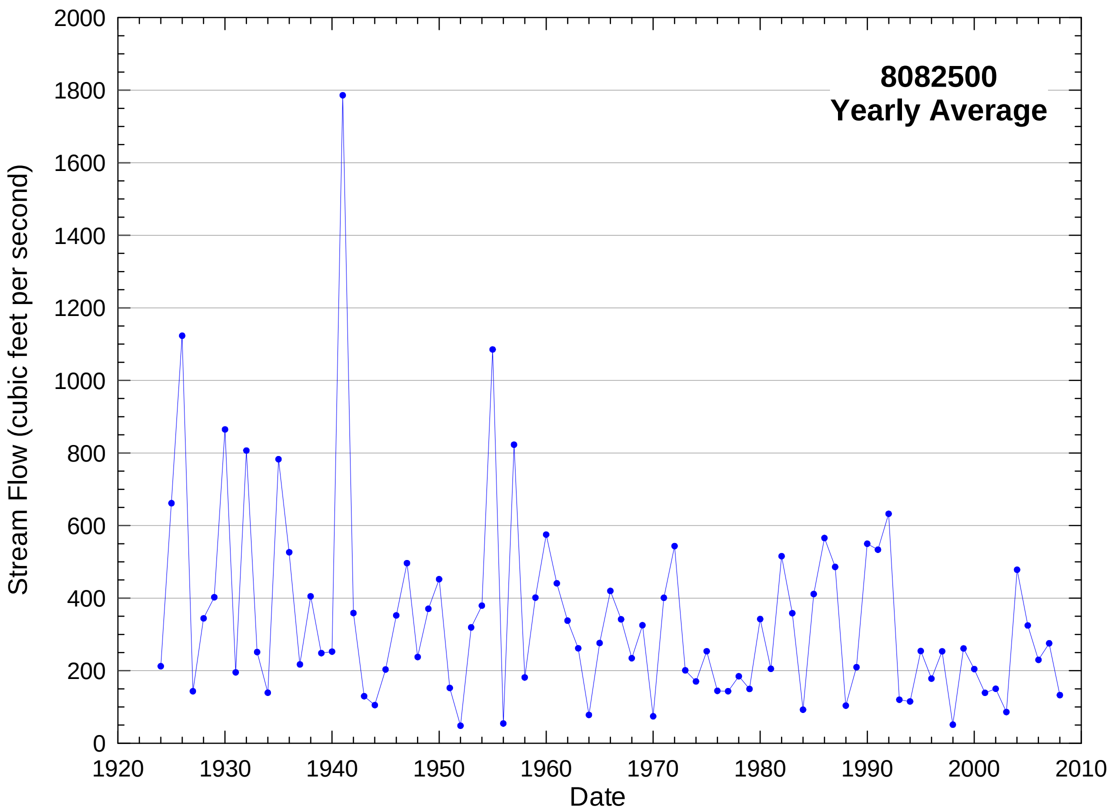
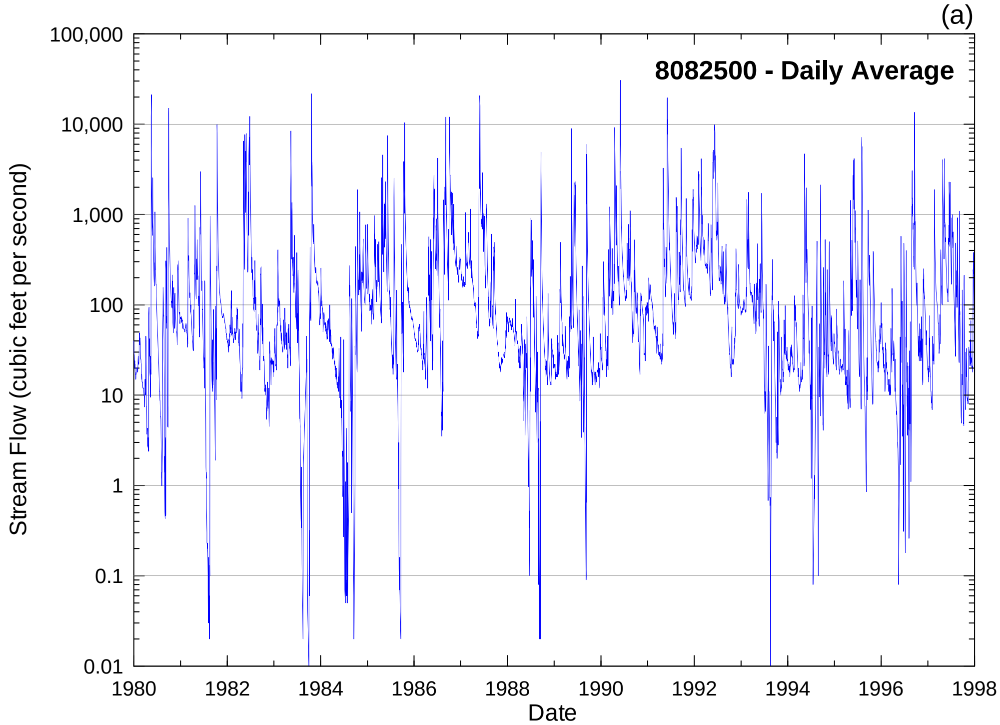


Figure 4.5.2 Hydrograph of yearly average stream flow for the gage on the Brazos River in Baylor County.



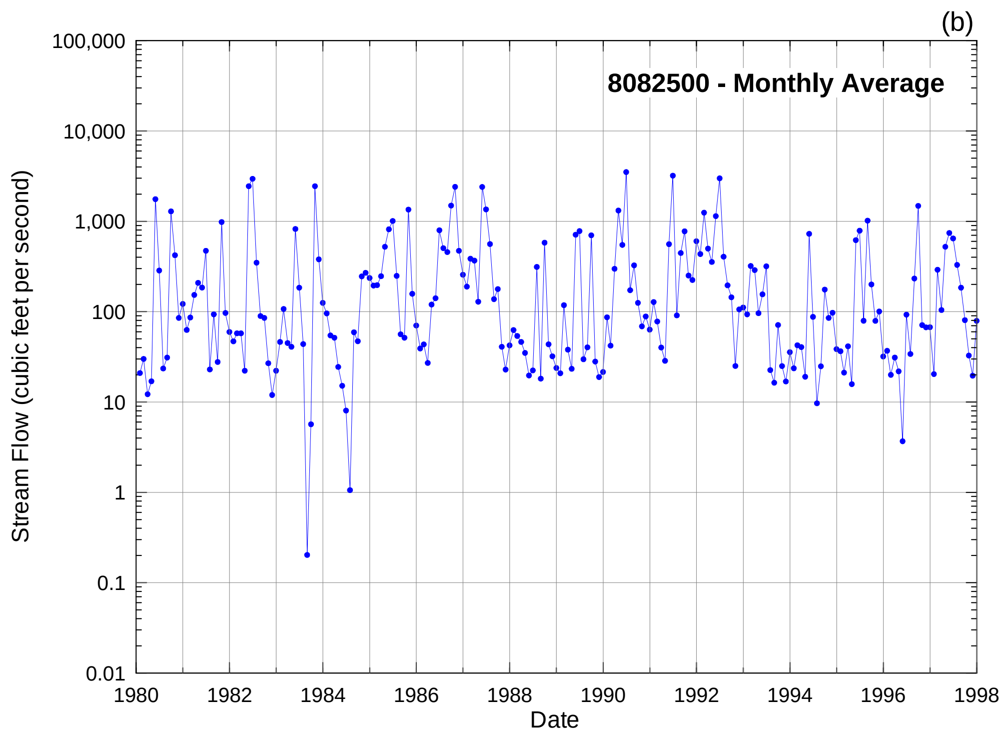


Figure 4.5.3 Hydrograph of (a) daily and (b) monthly average stream flow for the gage on the Brazos River in Baylor County during the calibration period (1980 to 1997).

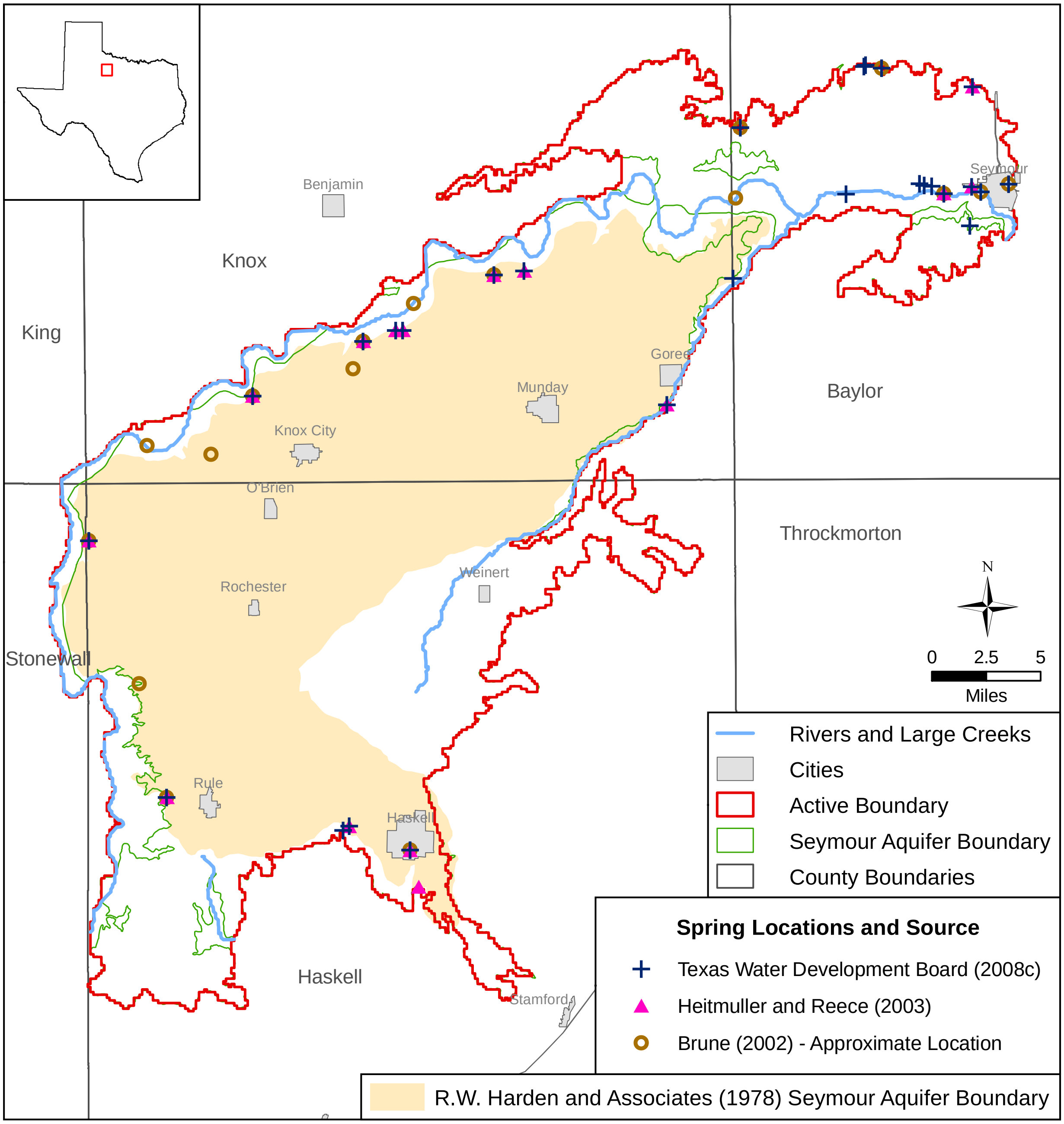


Figure 4.5.4 Locations of springs flowing from the Seymour Aquifer in the study area.

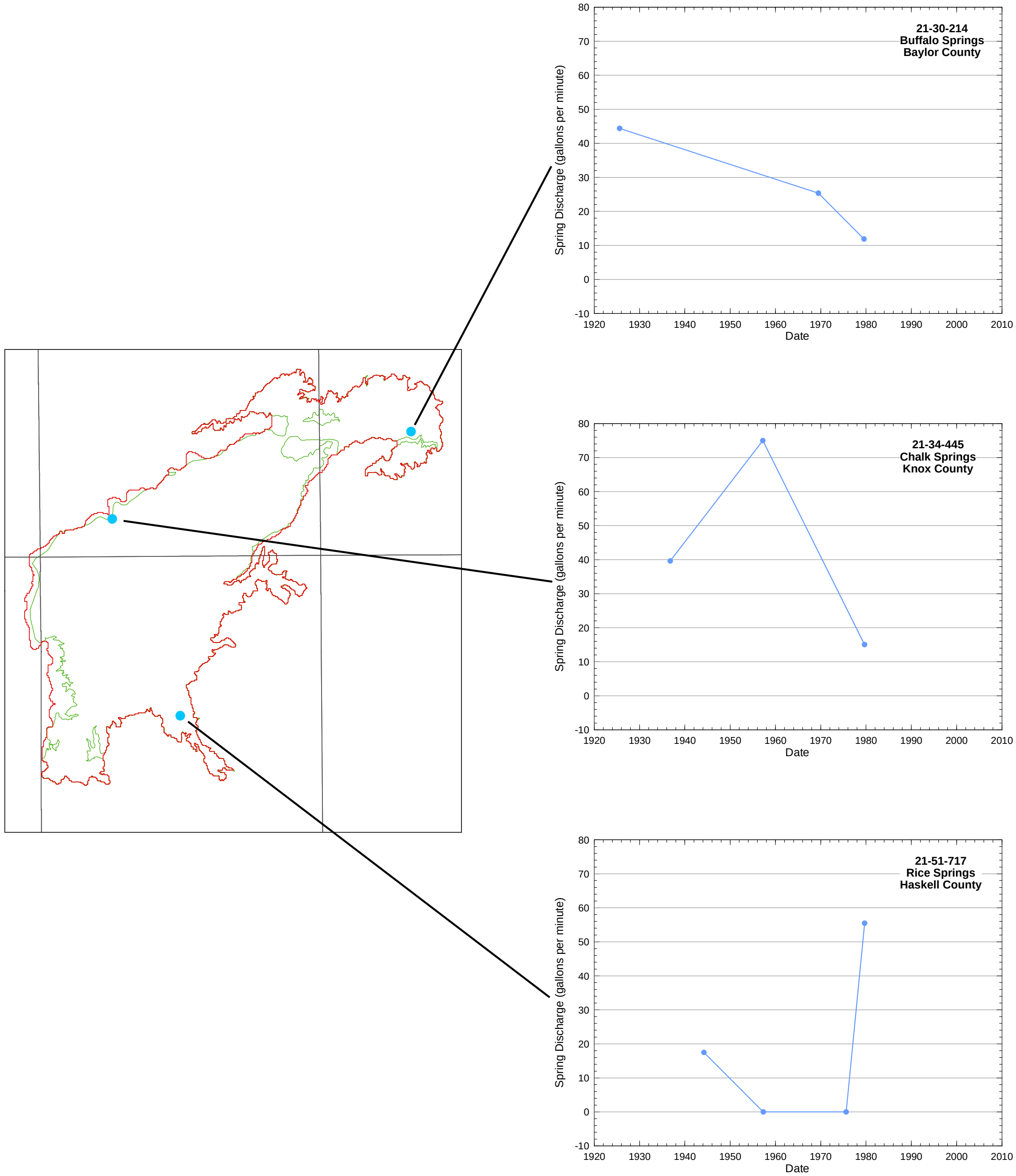


Figure 4.5.5 Hydrographs of discharge for selected springs flowing from the Seymour Aquifer.

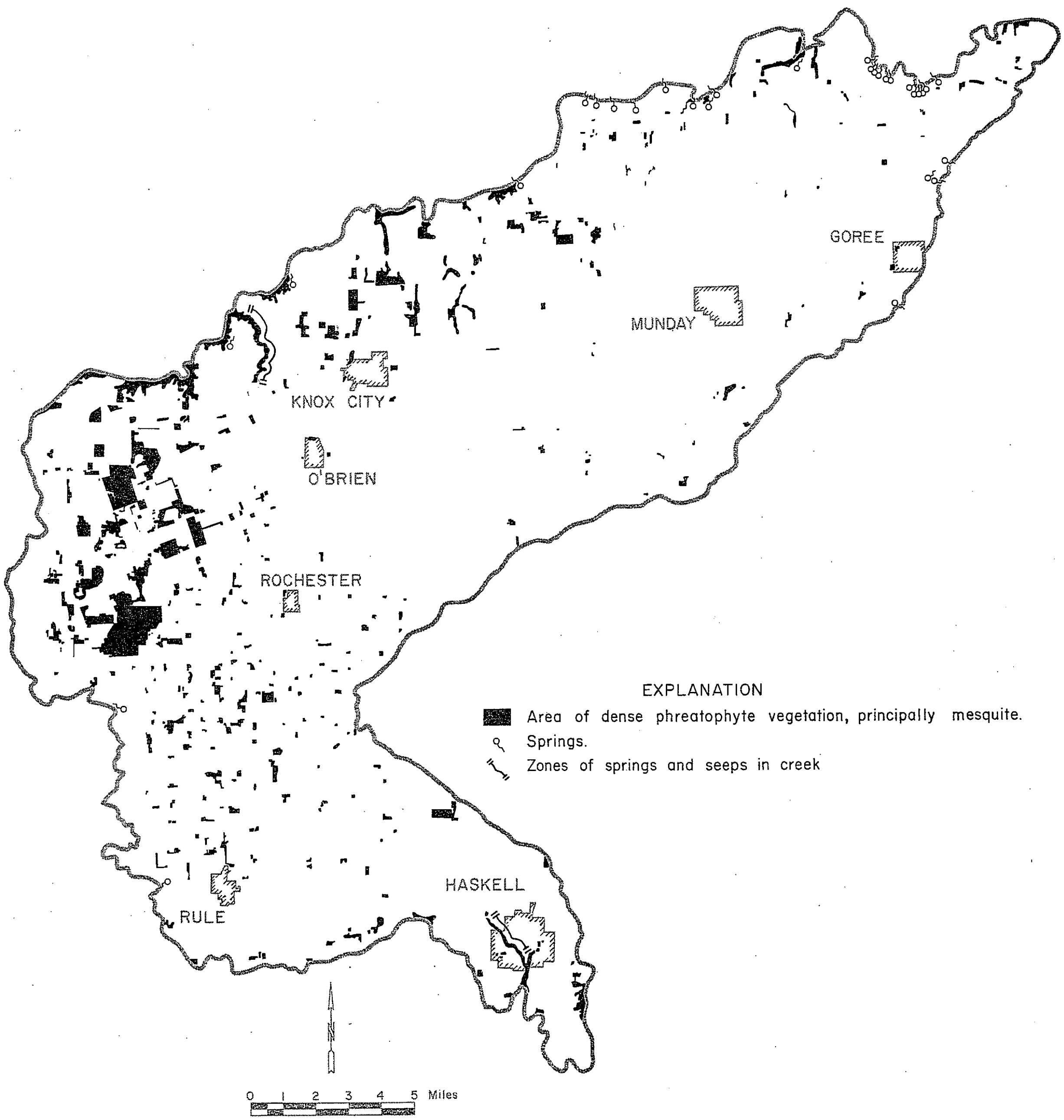


Figure 4.5.6 Locations of springs and zones of springs and seeps given in R.W. Harden and Associates (1978).

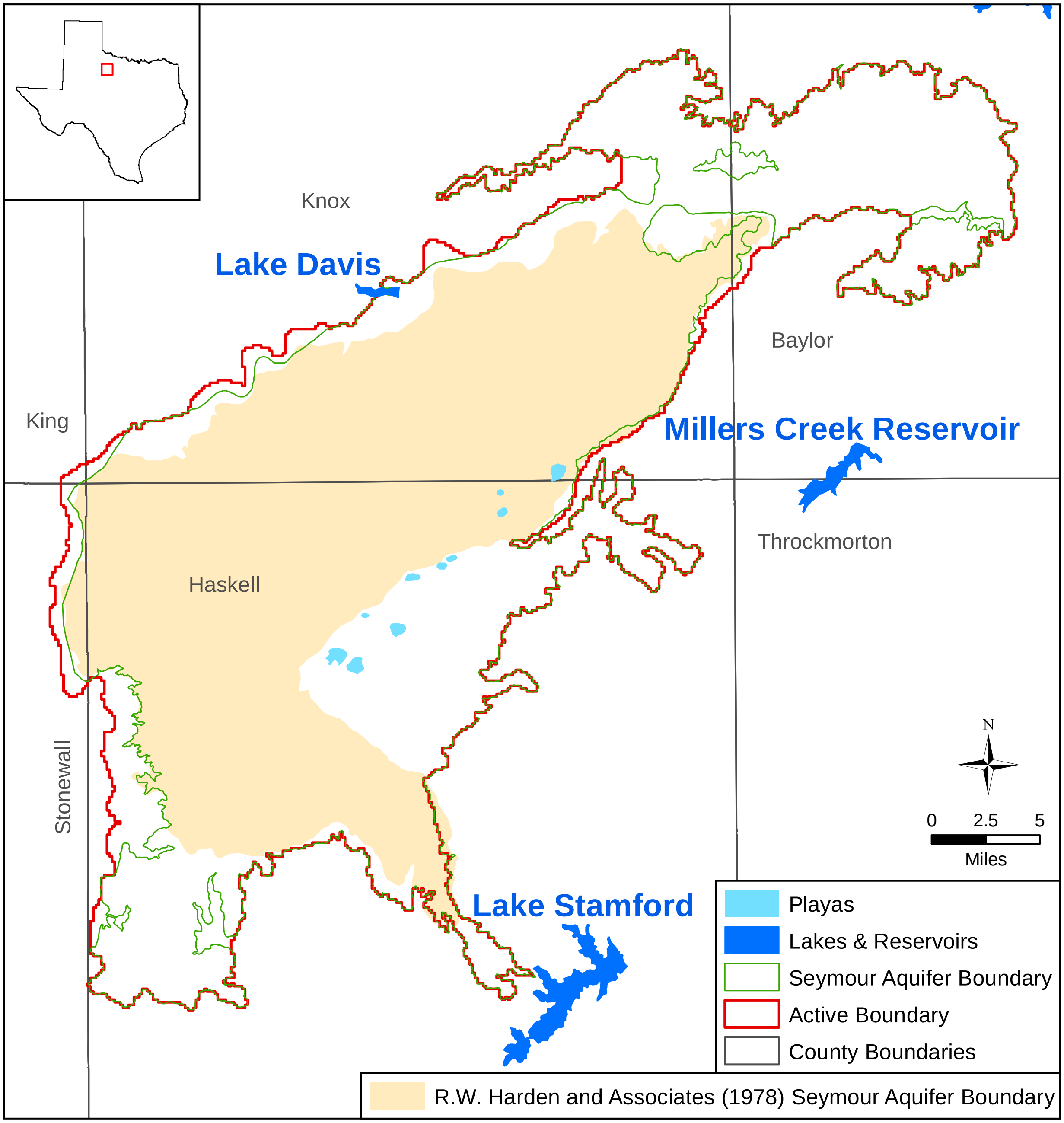


Figure 4.5.7 Locations of reservoirs and playas in the study area.

4.6 Hydraulic Properties

The Seymour Aquifer in Haskell, Knox, and Baylor counties includes the Seymour Formation and other Quaternary-age alluvium. The Seymour Formation generally consists of fluvial sheet deposits of clays, silts, sands, gravels and conglomerates, and some caliche and volcanic ash, that are isolated by incised river valleys. The Quaternary-age alluvium, which was deposited by the Brazos River, consists of silt, sand, and gravel derived primarily from the Seymour Formation. A fairly consistent deposit of sands and gravels is present near the base of the Seymour Formation over much of the model domain resulting in reasonably high permeabilities. The underlying Permian System, which includes the Clear Fork Group and a very small portion of the Wichita Group in the active model domain, consists of generally low-permeability rocks with poor water transmitting characteristics.

4.6.1 Data Sources

Development of hydraulic properties for the Seymour Aquifer considered transmissivity, hydraulic conductivity, specific capacity, and storage values reported in various TWDB reports, from the TWDB website (TWDB, 2008c), and from Texas Commission on Environmental Quality and Rolling Plains Groundwater Conservation District well records. Hydraulic properties for the Clear Fork Group were developed using specific capacity data from Texas Commission on Environmental Quality well records. The locations and sources of the hydraulic property data for the Seymour Aquifer are given in Figure 4.6.1.

4.6.2 Calculation of Hydraulic Conductivity from Specific Capacity

Because specific capacity is relatively easy to measure, requiring knowledge of only the pumping rate and drawdown, it is commonly reported in well records. However, hydraulic conductivity is a more useful parameter than specific capacity for regional groundwater modeling. The methodologies presented in Mace (2001) were used in an attempt to estimate hydraulic conductivity from specific capacity.

For the Seymour Aquifer, transmissivity and specific capacity were measured at 32 coincident locations (R.W. Harden and Associates, 1978; Myers, 1969). From these paired values, an attempt at an empirical correlation relating transmissivity to specific capacity was made as depicted in Figure 4.6.2. The low coefficient of determination of 0.3282 implies a very weak correlation between the two properties. In other words, only approximately 30 percent of the variability in transmissivity can be explained by specific capacity alone. For this reason, specific capacity measurements were not used to augment the hydraulic properties for the Seymour Aquifer. For each of the well tests reported by R.W. Harden and Associates (1978), the saturated thickness of the aquifer at the location was noted and used to calculate hydraulic conductivity from transmissivity.

No transmissivity measurements are available for the Clear Fork Group, so no empirical relationship could be developed to estimate transmissivity from the specific capacity measurements. Instead, the analytical methodology presented in Mace (2001) was used to estimate transmissivity for these units. Specifically, the analytical method of Theis and others (1963) was used. The empirical correction for well loss according to Equation 64 of Mace (2001) was applied to the drawdowns; however, the low conductivity of the Clear Fork Group sediments and the correspondingly low pumping rates resulted in negligible well losses (average of 1 percent) in most cases. Hydraulic conductivity was calculated from transmissivity using well screen length for these data. No transmissivity or specific capacity measurements were available for the Wichita Group.

4.6.3 Analysis of the Hydraulic Property Data

Figure 4.6.3 shows a histogram of the hydraulic conductivity data for the Seymour Aquifer. This figure indicates that the data are closer to being lognormally distributed than being normally distributed. Summary statistics of the hydraulic conductivity data for the Seymour Aquifer and Clear Fork Group are presented in Table 4.6.1. The similarity between the geometric mean and median for both formations indicates that the distribution of hydraulic conductivity is approximately lognormal. While the Clear Fork Group exhibits low mean hydraulic conductivity values, the actual value may be still lower than that presented. This is because wells in the Clear Fork Group are necessarily located in the highest conductivity portions of the formation and, therefore, biased high.

4.6.4 Variogram Analysis of Hydraulic Conductivity

The spatial distribution of hydraulic properties can be characterized by a variogram analysis. A variogram analysis quantifies gross spatial correlation and variability (for detailed background information on geostatistics, refer to Isaaks and Srivastava, 1989). Typical hydrogeologic properties show some spatial correlation indicated by lower variance for nearby measurements. As the distance between measurements increases, variance increases until it becomes constant. That constant value corresponds to the ensemble variance of the entire dataset. At the separation distance where the variance becomes constant, no correlation between measurements exists. The variogram describes the degree of spatial variability between observation points as a function of distance. Spatial variability is described in terms of the nugget (variance at zero separation), range (correlation length), and the sill (ensemble variance). The variogram can also be used as a tool to characterize horizontal anisotropy in hydraulic conductivity. In an aquifer with horizontal anisotropy, hydraulic conductivity is a function of horizontal direction. For a detailed explanation of directional variogram terminology and calculation, see Deutsch and Journel (1992).

The variogram analysis was completed on logarithmically transformed hydraulic conductivity data. Directional variograms were calculated along 10 degree increments and compared to an omnidirectional variogram of the data to help delineate any directional trends. A lag width of 20,000 feet (3.8 miles) and a total lag of 120,000 feet (22.7 miles) were used. The data exhibited no distinct directional trends. Although the variogram changed with direction, closer analysis revealed that these differences were likely due to the geometry of the data, rather than any data trend. In the end, an omnidirectional variogram was retained.

Figure 4.6.4 shows the experimental variogram calculated for the Haskell-Knox-Baylor pod of the Seymour Aquifer. The range for the variogram is between 10 and 15 miles. The initial slope of the variogram appears almost linear, although this may be an artifact of the data spacing. Figure 4.6.4 also shows the model variogram fit of the data using a spherical variogram model. The equation for the spherical model is:

$$\gamma(h) = \begin{cases} C_0 + C_1\left(1.5\dfrac{h}{A} - 0.5\left(\dfrac{h}{A}\right)^3\right) & h < A \\ C_0 + C_1 & h \geq A \end{cases} \qquad (4.6.1)$$

where C_0 is the nugget, C_1 is the scale (sill minus nugget), A is the range parameter, and h is the lag distance. For the model variogram shown in Figure 4.6.4, a nugget of 0.018, a scale of 0.112, and a range of 12 miles were fit to the data.

4.6.5 Spatial Distribution of Hydraulic Conductivity

The hydraulic conductivity data for the Seymour Aquifer were kriged using the variogram model described above. The resulting spatial distribution of hydraulic conductivity within the Seymour Aquifer is depicted in Figure 4.6.5. Although the kriging tends to smooth the irregularities in the sampled data, hydraulic conductivity varies approximately one order of magnitude (from 150 to 1,500 ft per day) over the aquifer.

A small topographic break which separates the Seymour Aquifer into two sections of older and younger deposits was noted by R.W. Harden and Associates (1978). They also reported that the steepest gradients in water levels were observed across this break indicating that the two units are poorly connected. Figure 4.6.6 depicts the location of the topographic break. The location was estimated using the 30 meter digital elevation map and a map depicting the approximate location of the two units in R.W. Harden and Associates (1978). A significance test was conducted to investigate whether hydraulic conductivities differ between the older and younger sections. That test indicates that hydraulic conductivities in the two sections are significantly different, with the younger units exhibiting higher hydraulic conductivities. However, only five measurements are available within the younger section, so the associated statistics are somewhat suspect.

4.6.6 Vertical Hydraulic Conductivity

No vertical hydraulic conductivity data for the hydrogeologic units in the study area were found in the literature review. The stratified nature of sediments will likely result in some degree of anisotropy in hydraulic conductivity. While horizontal hydraulic conductivity is dominated by the higher permeability sediments, vertical hydraulic conductivity will be dominated by the lower permeability strata and will tend to be lower than the horizontal hydraulic conductivity. Domenico and Schwartz (1998) list values of horizontal to vertical hydraulic conductivity ratios that range from 2 to 10 for materials similar to sediments in the study area. At the scale of the Haskell-Knox-Baylor pod of the Seymour Aquifer, higher anisotropy ratios may exist.

4.6.7 Storativity

For unconfined aquifers, the applicable storage coefficient is the specific yield which is defined as the volume of water an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline in the water table (Freeze and Cherry, 1979). A literature review was conducted for specific yield of the Seymour Aquifer (Table 4.6.2). Specific yield ranged from 0.03 to 0.30 and the arithmetic means reported for two studies ranged from 0.11 to 0.15. Figure 4.6.1 shows the locations of specific yield estimates. Domenico and Schwartz (1998) list values of specific yield that range from 0.03 to 0.28 for materials similar to the sediments of the Seymour Aquifer in the active model area. Lohman (1972) gives 0.1 and 0.3 and Freeze and Cherry (1979) give 0.01 to 0.3 as general limits for the specific yield of unconfined aquifers. Originally, augmenting specific capacity values with inferred porosity data was considered. This idea was later deemed inferior to using measured data for the Seymour Aquifer and was dismissed. Specific yields were assumed to be approximately 0.15 for both of the Clear Fork and Wichita groups, which is about the middle of the values given in Freeze and Cherry (1979) for unconfined aquifers.

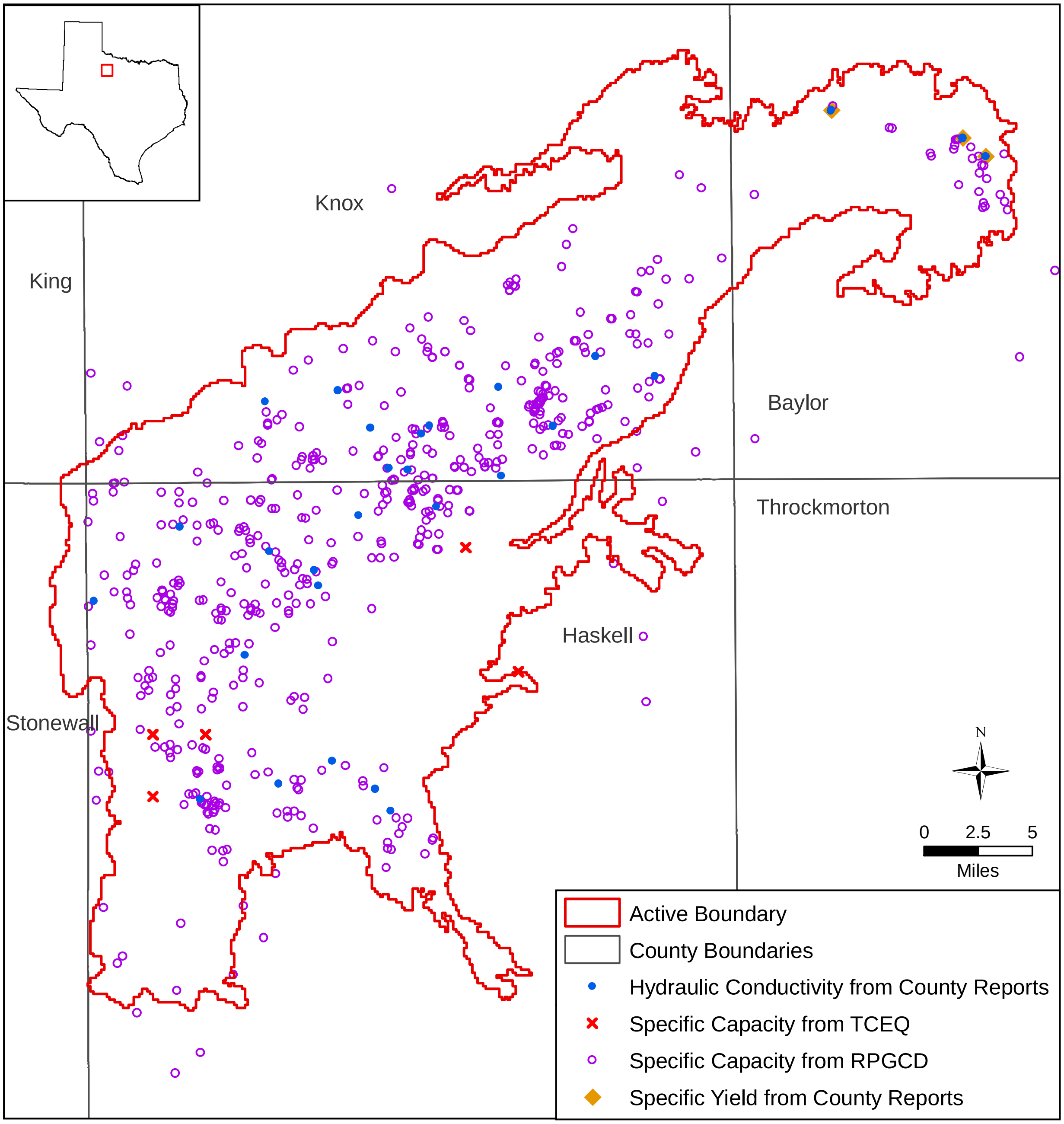
Table 4.6.1 Summary statistics for hydraulic conductivity data (feet per day) for the Seymour Aquifer and Clear Fork Formation.

Statistic	Seymour Aquifer	Clear Fork Group
Number of Samples	44	19
Arithmetic Mean	564.8	6.0
Median	342.6	2.3
Geometric Mean	386.0	2.6
Standard Deviation K	549.8	8.9
Standard Deviation Log10(K)	0.37	0.71

K = hydraulic conductivity

Table 4.6.2 Specific yield values for the Seymour Aquifer from the literature.

County	State Well Number	Specific Yield		Reference
		Point	Average	
Baylor	21-30-387	0.03	0.11	Preston (1978)
Baylor	21-30-385	0.04		
Baylor	21-22-911	0.04		
Baylor	21-22-912	0.06		
Baylor	21-22-913	0.08		
Baylor	21-21-941	0.16		
Baylor	21-21-940	0.18		
Baylor	21-30-386	0.30		
Haskell-Knox			0.15	R.W. Harden & Associates (1978)



TCEQ = Texas Commission on Environmental Quality
RPGCD = Rolling Plains Groundwater Conservation District

Figure 4.6.1 Locations and sources of hydraulic property data for the Seymour Aquifer.

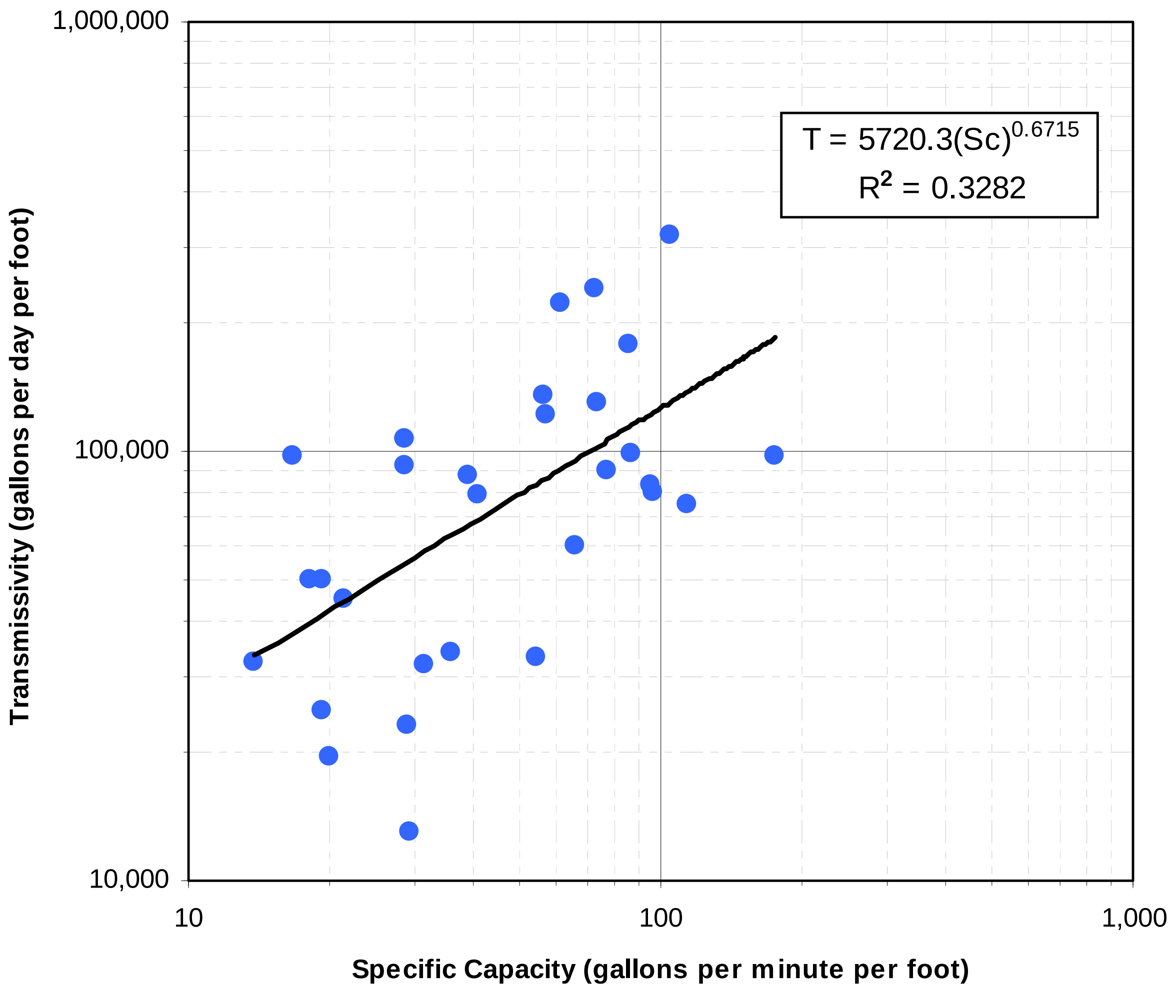


Figure 4.6.2 Empirical correlation between transmissivity (T) and specific capacity (Sc) for the Seymour Aquifer.
Note: (R^2 = coefficient of determination).

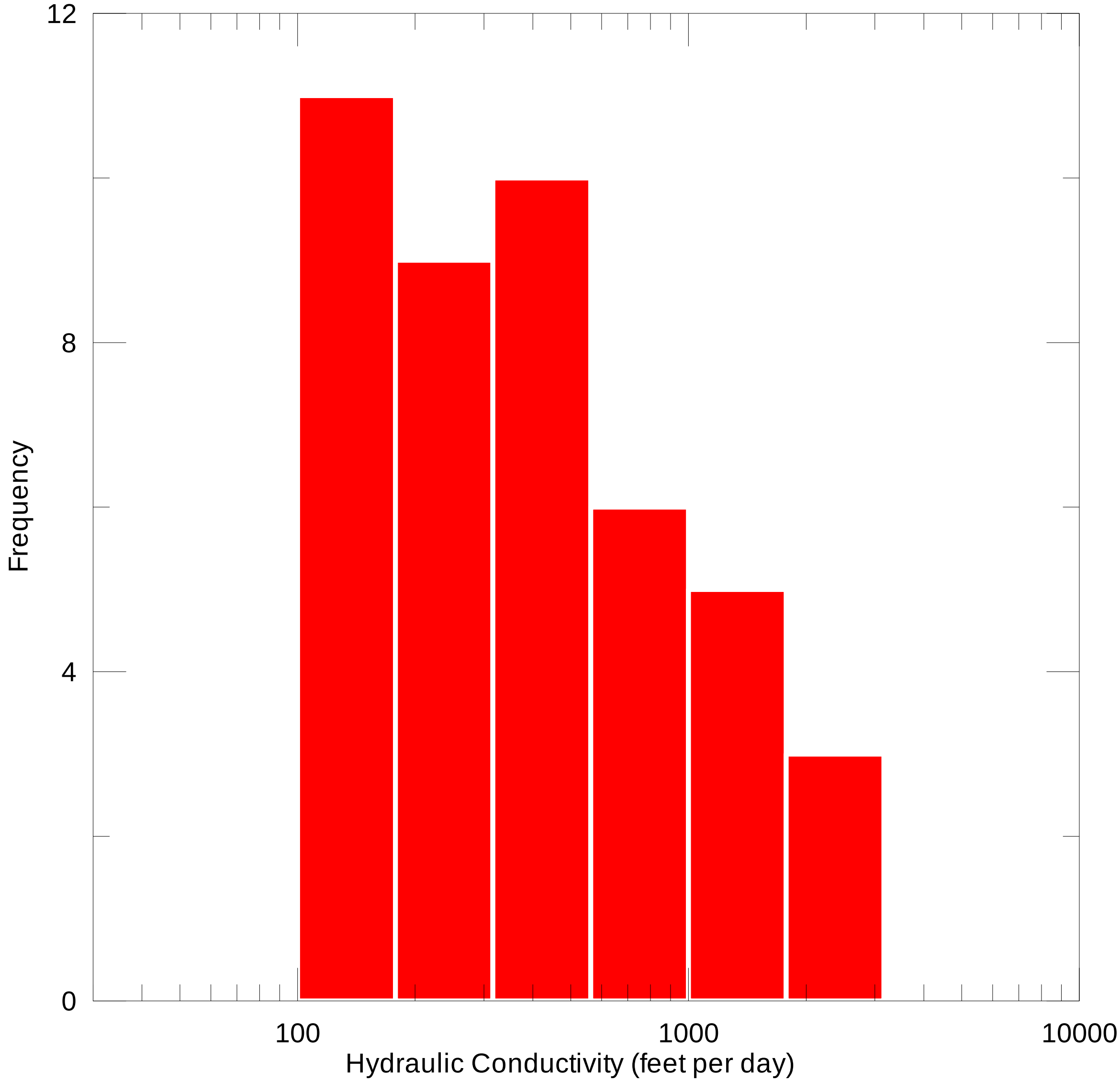


Figure 4.6.3 Histogram of hydraulic conductivity data for the Seymour Aquifer.

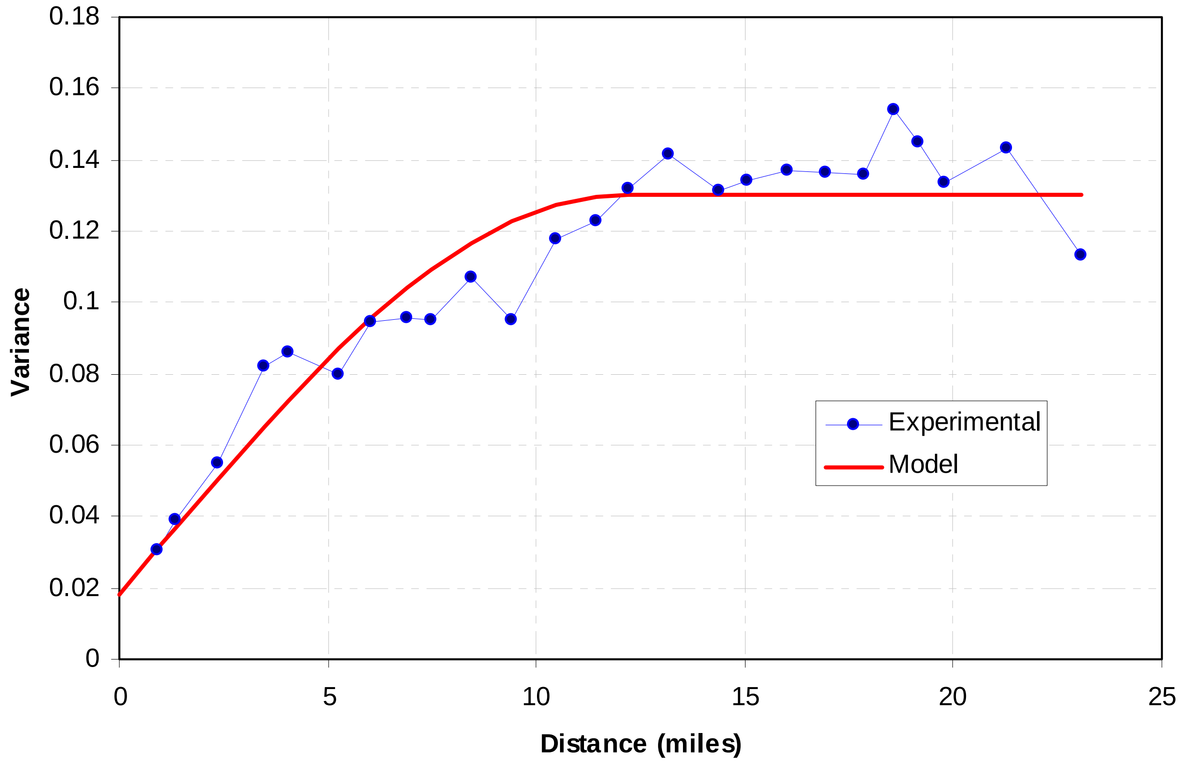


Figure 4.6.4 Experimental variogram of log10 of hydraulic conductivity for the Seymour Aquifer.

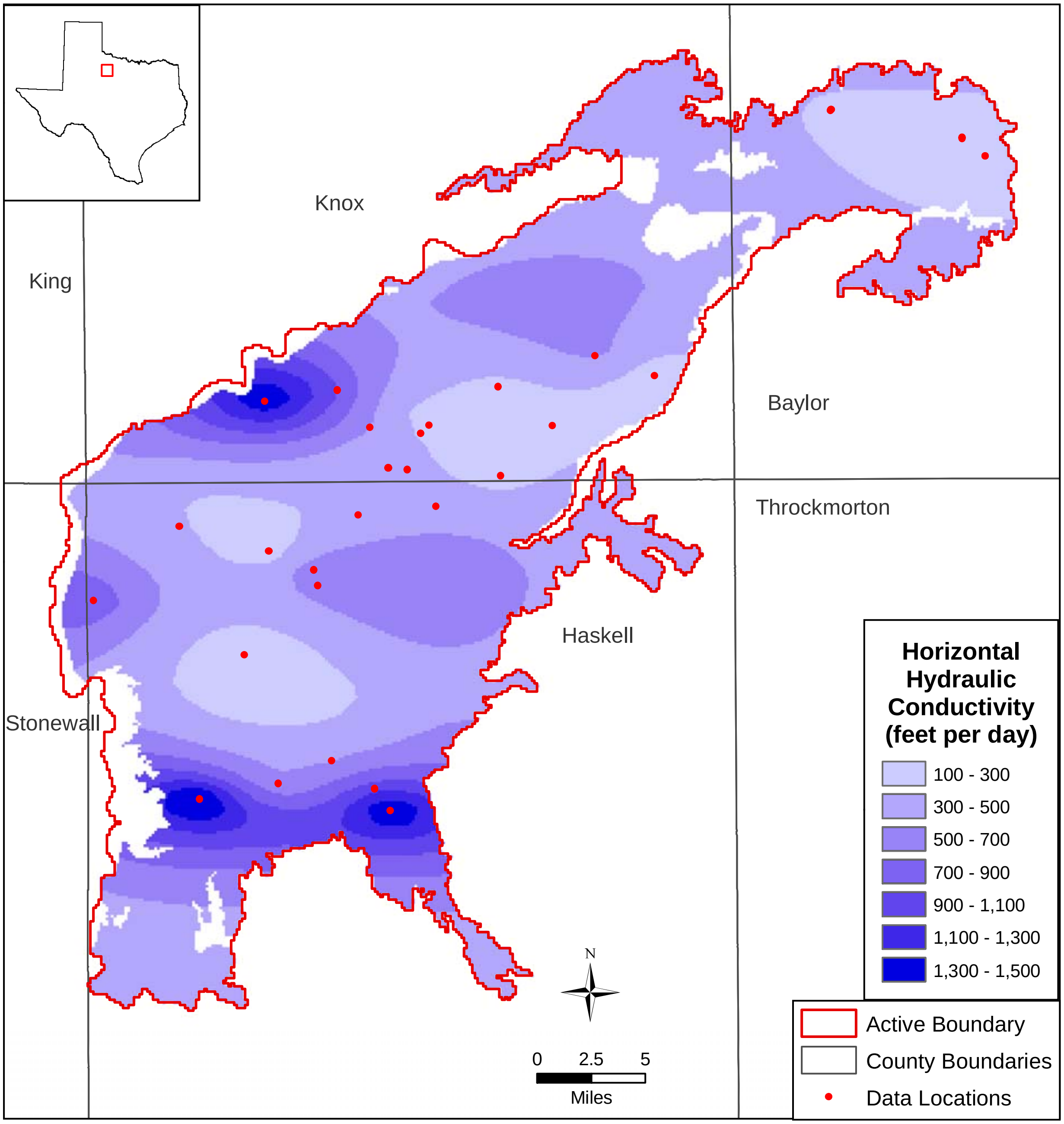


Figure 4.6.5 Kriged map of hydraulic conductivity for the Seymour Aquifer.

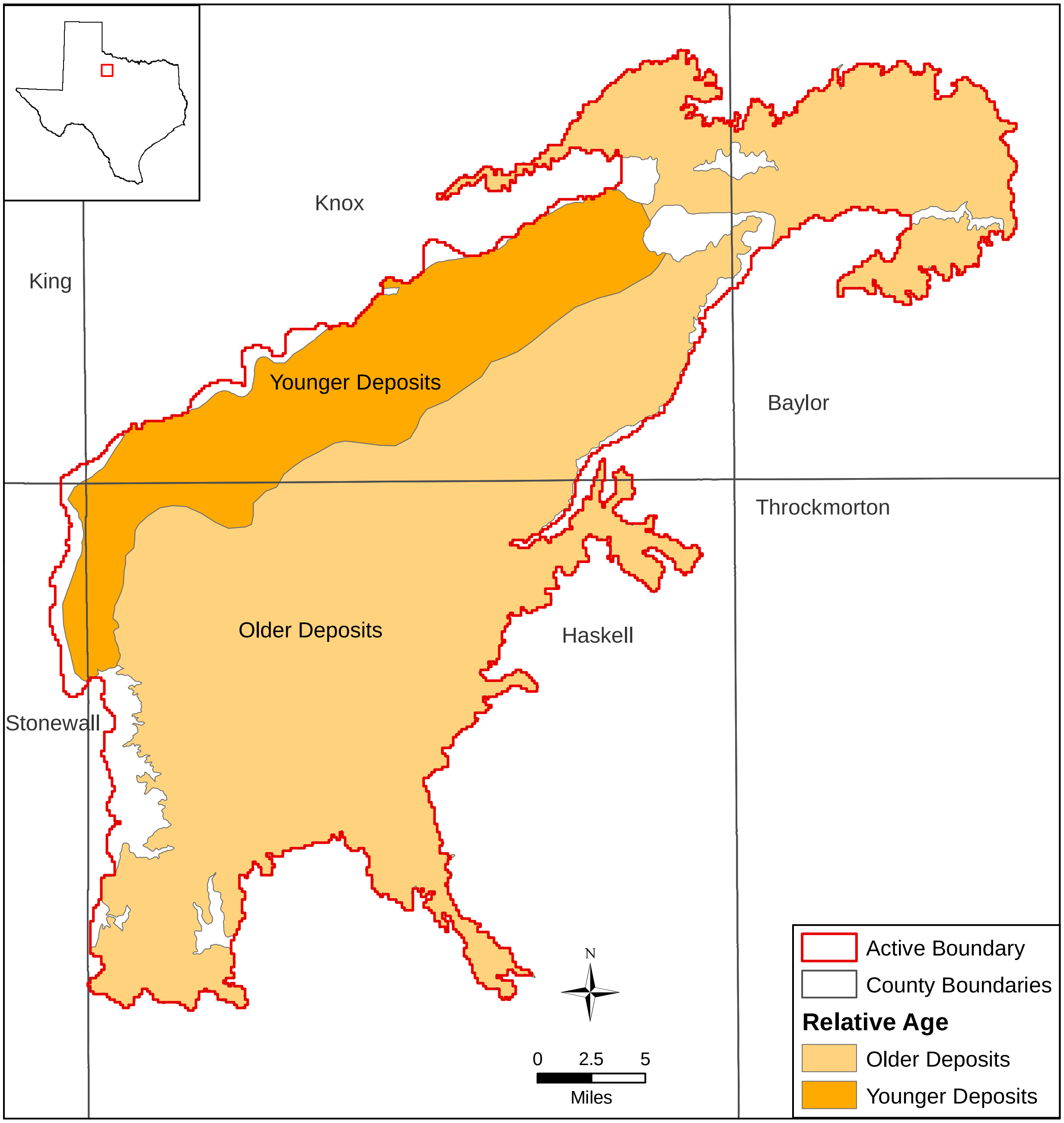


Figure 4.6.6 Location of older and younger deposits within the Seymour Aquifer.

4.7 Aquifer Discharge

Discharge from an aquifer can occur through either natural or man-made processes, both of which are discussed in the following sections.

4.7.1 Natural Discharge

Natural discharge from an aquifer can occur as cross-formational flow, discharge to rivers, streams, and springs, and evapotranspiration. Each of these mechanisms of natural discharge is discussed below.

The Seymour Aquifer provides baseflow to the Brazos River in Baylor County and is expected to provide baseflow to the river to some extent in western Knox and Haskell counties. In Baylor County, the Seymour Formation is connected to the Brazos River through recent alluvial deposits along the river, which are also part of the Seymour Aquifer (see Figure 2.2.2). Preston (1978) estimated discharge from the Seymour Aquifer to the Brazos River based on net gain in the river measured during a gain/loss study conducted in February 1970 (see Section 4.5.1). He calculated that the amount of yearly discharge represented by the observed gains ranged from 72.4 to 1,882.5 acre-feet (see Table 4.5.1). In western Knox and Haskell counties, the Seymour Aquifer most likely discharges directly to the Brazos River in some areas and indirectly through the Permian in other areas due to the aquifer being at a higher elevation than the river. Discharge from the Seymour Aquifer consists of groundwater flowing from the Seymour Formation to the recent alluvial sediments located along the river which then discharge to the river. In areas where the Brazos River lies below the recent alluvial deposits and, thus, the Seymour Aquifer, the aquifer does not directly provide baseflow to the river.

Although leakage from the Seymour Aquifer to the underlying Clear Fork Group is considered to be small locally, it could be significant when considered over the entire extent of the aquifer. The Clear Fork Group consists primarily of shale that has a low permeability which impedes flow. The small amount of local discharge from the Seymour Aquifer into the Clear Fork Group is supported by the difference in the chemistry between the fresh water in the Seymour Aquifer and the slightly saline water in the Clear Fork Group, however, the chemistry in the Clear Fork

Group may be more indicative of pre-development conditions than of more recent (since 1910) conditions in which recharge is considered to have increased. A discussion of cross-formational flow between the Seymour Aquifer and the Clear Fork Group is provided in Section 4.3.5.

Seeps and springs occur predominantly along the edges of the Seymour Aquifer and along the Brazos River, however, several are located a few miles from the edge, such as Rice Springs near the city of Haskell (see Section 4.5.2). Historical discharge from the springs has ranged from as high as 100 gallons per minute at a couple of springs to less than 1 gallon per minute. Most of the springs have historical discharge of between 10 and 30 gallons per minute. In general, spring discharge has declined over time.

A significant amount of natural discharge from the Seymour Aquifer occurs by evapotranspiration. R.W. Harden and Associates (1978) estimate that discharge via evapotranspiration is considerably larger than discharge via springs and seeps. They considered the areas containing dense phreatophytes as the main areas where natural discharge by evapotranspiration occurs. The figure in R.W. Harden and Associates (1978) showing areas of natural discharge from the Seymour Aquifer is reproduced as Figure 4.5.6. That figure shows areas on the Seymour Aquifer that contain dense phreatophytes.

Direct evaporation from the water table is a function of the depth of the water table, the type of material in the unsaturated zone, the type of climate, and the coverage of the ground surface. Evaporation increases with decreasing depth to the water table, homogeneous coarse-grain sediments, hotter and drier climates, and bare soil. White (1932) conducted a field experiment in Escalante Valley, Utah to measure groundwater evaporation from bare soils consisting of clay, clay loam, and loam during the months of April through October. He found evaporation rates ranging from 0.1 to 1.3 feet per year for water-table depths ranging from 2 to 6.8 feet for the clay and clay loam soils and evaporation rates ranging from 0.9 to 3.4 feet per year for water-table depths ranging from 2.4 to 3.6 feet for the loam soil. White (1932) indicates that the high evaporation rates observed for the loam soil may have been due to a problem with the experimental set up for that soil. Preliminary data on water-table evaporation at a field site in the Middle Rio Grande bosque in New Mexico indicates evaporation on the order of 1 to 3 feet per year for water-table depths of 1 to 1.5 feet, respectively (Stormont and Coonrod, 2004). Rose and others (2005) obtained steady-state evaporation rates of 1.6 to 0.4 feet per year for water-table depths of 1 to 2.3 feet, respectively. They conducted their experiment on a bare sandy loam soil with a shallow saline water table under high isothermal evaporative demand. Evaporation from the Seymour Aquifer is expected to be less than that measured for bare soils since it is covered by vegetation during the hottest months of the year. In addition, the soil in the upper portion of the Seymour Aquifer is typically fine grained and heterogeneous, which also reduces groundwater evaporation. Evaporation from the Seymour Aquifer is expected to be small relative to transpiration by plants.

In summary, significant avenues for outflow include baseflow into streams, cross-formational discharge to the Clear Fork Group. Evapotranspiration and spring discharge together are expected to constitute a significant amount of outflow in riparian areas, from the edges of the Seymour aquifer, and from areas with dense phreatophyte growth.

4.7.2 Aquifer Discharge through Pumping

Pumping discharge for each county in the active model area was developed for the transient model. Pumping during the transient model calibration period of 1980 through 1997 was obtained from the TWDB pumping database. Pumping data for the time period prior to 1980 were found in Ogilbee and Osborne (1962), Preston (1978), R.W. Harden and Associates (1978), and TWDB (1981).

4.7.2.1 Methodology

The methodologies used to estimate pumping during the transient model calibration period and prior to 1980 are described in the following sections.

Transient Model Calibration Period Pumping

Estimates of groundwater pumping for the transient model calibration period (1980 through 1997) are provided by the TWDB as master pumpage tables contained in a pumpage geodatabase. The six water use categories defined in the TWDB database are municipal, manufacturing, power generation, mining, livestock, and irrigation. Each water use record in the database carries an aquifer identifier that was used to select pumping records for the Seymour

Aquifer. Rural domestic pumping, which consists primarily of unreported domestic water use, was estimated based on population density data provided by the TWDB.

The TWDB municipal, manufacturing, mining, and power pumping estimates are based on actual water use records reported by the water users. The pumpage geodatabase also includes historical annual pumping estimates for livestock and irrigation for each county-basin. A county-basin is a geographic unit created by the intersection of county and river basin boundaries. For example, Baylor County, which is intersected by both the Brazos River basin and the Red River basin, contains two county-basins.

Reported pumping for municipal, manufacturing, mining, and power water uses was matched to the specific wells from which it was pumped to identify the withdrawal location in the aquifer (latitude, longitude, and depth above mean sea level) based on the well's reported properties. When more than one well is associated with a given water user, groundwater withdrawals were divided evenly among those wells.

Livestock pumping totals within each county-basin was distributed uniformly over the rangeland within the county-basin, based on land use maps, using the categories "shrubland", "grassland/herbaceous", and "pasture/hay". Irrigation pumping within each county-basin was distributed between wells in the TWDB database (TWDB, 2008c) identified as having a primary use of irrigation.

Rural domestic pumping was distributed based on United States census block population density (Figure 4.7.1) in non-urban areas. The TWDB has provided a polygon feature class of census blocks, based on the 1990 United States census, and a table of factors for converting rural population density into annual groundwater use. Although these rural domestic use factors are uncertain, this uncertainty is not significant since rural domestic pumping accounts for less than one-half a percent of total Seymour Aquifer pumping. Urban areas were excluded from rural population calculations and groundwater pumpage.

Pre-1980 Pumping

Because detailed pumping data are not available prior to the transient model calibration period, a literature search was conducted to obtain historical pumping data. Those data are summarized in Table 4.7.1.

Groundwater from the Seymour Aquifer was predominately used for municipal, domestic, and livestock purposes prior to 1950 (Ogilbee and Osborne, 1962; R.W. Harden and Associates, 1978). R.W. Harden and Associates (1978) provide an estimate of total pumpage from the Seymour Aquifer in Haskell and Knox counties every 10 years between 1900 and 1940. They also provide estimates for municipal and irrigation pumpage every year from 1950 through 1976. Their estimates of irrigation pumpage were developed based on records of electricity use for irrigation and an approximation of the number of gallons pumped per kilowatt hour for sprinkler systems and open discharge wells and the historical use of sprinklers in the counties. For irrigation wells powered by butane and natural gas during the time period from 1950 through 1976, R.W. Harden and Associates (1978) estimated their pumpage based on the number of wells. Their estimates of municipal pumpage for 1950 through 1976 were developed using data from individual towns and records from the Texas Department of Water Resources (former name for the TWDB). The historical pumpage data obtained from R.W. Harden and Associates (1978) is summarized in Table 4.7.1.

Ogilbee and Osborne (1962) estimate that irrigation pumpage from the Seymour Aquifer in Haskell and Knox counties was less than 500 acre-feet per year from 1938, when three irrigation wells were dug, through 1951. Using a duty-of-water figure obtained in 1956, they estimated irrigation pumping for 1952 to 1955. They estimated irrigation pumpage for the year 1956 based on estimates of water pumped per unit power consumed for selected wells powered by electricity. They also provide an estimate of pumpage for purposes other than irrigation for the year 1956. The historical pumpage data obtained from Ogilbee and Osborne (1962) are summarized in Table 4.7.1.

Preston (1978) calculated irrigation pumping from the Seymour Formation in western Baylor County from the city of Seymour westward to the Baylor-Knox county line for the years 1952 through 1969 "by applying production figures from power-yield tests ". Estimates of municipal pumpage for 1955 through 1969 and estimates for industrial and rural domestic/livestock pumpage for 1969 are also provided by Preston (1978). The historical pumpage data obtained from Preston (1978) are summarized in Table 4.7.1.

In 1958, a cooperative agreement was made between the Soil Conservation Service of the United States Department of Agriculture, the Texas State Soil and Water Conservation Board, and the TWDB and its predecessor agencies to inventory irrigation in Texas. Since that time, irrigation in Texas has been inventoried on a county-by-county basis about every five years. The inventories include a break down of irrigation with surface water and with groundwater and are obtained through inventory forms and local field data gathering. TWDB (1981) provides the inventory summary for the years 1958, 1964, 1969, 1974, and 1979. Field personnel from the Soil Conservation Service involved with the irrigation inventories on the local level in 1979 estimate that the accuracy of their estimates is within 5 to 10 percent (TWDB, 1981). Irrigation by groundwater for these years in Haskell, Knox, and Baylor counties is summarized in Table 4.7.1. TWDB (1981) reports irrigation pumpage for entire counties and does not indicate which aquifer(s) supply the irrigation water. For Haskell and Knox counties, all groundwater used for irrigation purposes likely comes from the portion of the Seymour Aquifer included in the study area. All of the Seymour Aquifer in Haskell County is included in this study, and irrigation pumpage in the small portion of the Seymour Aquifer in northern Knox County not included in this study is likely small. This assumption is considered to be reasonable by the Rolling Plains Groundwater Conservation District because the quality of water in the small pod of the Seymour Aquifer in northern Knox County is poor (McGuire, 2009). For Baylor County, however, it is likely that some irrigation occurs in portions of the Seymour Aquifer not included in this model.

The historical pumpage data presented above and summarized in Table 4.7.1 was used to estimate pumpage for Haskell, Knox, and Baylor counties for the years prior to 1980.

4.7.2.2 Pumping Plots and Tables

Table 4.7.2 provides the total groundwater withdrawals by county for the Haskell-Knox-Baylor pod of the Seymour Aquifer for the years 1980, 1985, 1990, 1995, and 1997. A bar chart of total pumping by category from 1980 through 1997 is provided in Figure 4.7.2. In 1997, about

97.1 percent of pumpage from the Seymour Aquifer was used for irrigation purposes, about 2.0 percent was used for municipal purposes, about 0.36 percent was used for rural domestic purposes, about 0.45 percent was used for livestock purposes, and none was used for mining purposes. Groundwater from this pod of the Seymour Aquifer is not used for manufacturing or power purposes. Total pumpage from the Seymour Aquifer shows a steady declined from a high of 94,701 acre-feet per year in 1980 to 32,653 acre-feet per year in 1987. Pumpage was also low in 1988 with 34,841 acre-feet per year and then jumped significantly to 64,177 acre-feet per year in 1989. Another steady decline is observed between 1989 and 1993. Pumpage was steady in 1994, 1995, and 1996 at a little over 60,000 acre-feet per year and then decreased to 44,945 acre-feet per year in 1997. Figure 4.7.3 shows the 1980 through 1997 average pumping demands by county for the Haskell-Knox-Baylor pod of the Seymour Aquifer. This figure shows that pumpage in Baylor County is significantly less than that in Haskell and Knox counties. Pumpage in Stonewall County is the least among the four counties due to its relatively small area in the model.

Tables 4.7.3 through 4.7.7 summarize pumping for each county by category for the years 1980, 1985, 1990, 1995, and 1997. Notice that a table for manufacturing and power pumping is not provided since groundwater from this portion of the aquifer was not used for those purposes during this time period. Irrigation pumpage is significantly higher in Haskell and Knox counties than in Baylor and Stonewall counties (Table 4.7.3). The highest pumpage for municipal purposes is in Baylor County (Table 4.7.4). Rural domestic pumpage is higher in Baylor and Knox counties than in Haskell and Stonewall counties (Table 4.7.5). The amount of groundwater pumped for livestock is about the same for Baylor, Haskell and Knox counties and lower in Stonewall County (Table 4.7.6). Pumpage for mining occurred only in Stonewall County (Table 4.7.7). Figures 4.7.4 through 4.7.7 show pumpage by category from 1980 through 1997 for Baylor, Haskell, Knox and Stonewall counties, respectively. As previously stated, pumpage for irrigation purposes dominates in Haskell and Knox counties and is a large percentage of total pumping in Baylor and Stonewall counties.

Table 4.7.1 Available data on historical pumpage from the Seymour Aquifer between 1900 and 1979.

Year	Baylor County					Haskell and Knox Counties					Haskell County	Knox County
	Preston (1978)				TWDB (1981)	Ogilbee and Osborne (1962)		R.W. Harden and Associates (1978)			TWDB (1981)	TWDB (1981)
	portion of the Seymour Formation located west of the city of Seymour to the Knox-Baylor county line (i.e., portion of Seymour Aquifer considered by this study)				entire county	portion of Seymour Aquifer considered by this study		portion of Seymour Aquifer considered by this study			entire county	entire county
	Estimated Irrigation Pumpage (AF)	Estimated Municipal Pumpage (AF)	Estimated Industrial (AFY)	Estimated Rural Domestic and Livestock (AFY)	Irrigation Pumpage (AF)	Estimated Irrigation Pumpage (AF)	Estimated Pumpage for Other Purposes (AF)	Estimated Irrigation Pumpage (AF)	Estimated Public Supply Pumpage (AF)	Estimated Total Pumpage (AF)	Irrigation (AF)	Irrigation (AF)
1900										200		
1910										400		
1920										400		
1930										900		
1940						<500				1,200		
1950						<500		100	1,200	1,300		
1951						<500		900	1,200	2,100		
1952	60					9,000		6,700	1,200	7,900		
1953	390					13,000		9,900	1,200	11,100		
1954	650					22,000		16,800	1,200	18,000		
1955	880	450				45,000		34,800	1,200	36,000		
1956	3,130	820				76,500	2,900	63,800	1,200	65,000		
1957	2,180	640						46,800	1,300	48,100		
1958	1,380	610			3,371			34,500	1,800	36,300	29,533	19,276
1959	2,750	500						17,900	1,600	19,500		
1960	2,740	670						54,600	1,800	56,400		
1961	1,550	580						36,200	1,600	37,800		
1962	2,990	590						60,200	1,900	62,100		
1963	3,580	640						56,800	1,800	58,600		
1964	5,060	680			6,039			64,400	1,500	65,900	66,075	34,894
1965	4,990	680						53,000	2,100	55,100		
1966	4,850	630						51,100	2,000	53,100		
1967	3,850	660						51,600	1,900	53,500		
1968	2,100	670						26,500	1,700	28,200		
Jan-69	3,770	42.4	150	350	6,108			32,000	1,700	33,700	37,696	49,874
Feb-69		37.4										
Mar-69		36.5										
Apr-69		51.4										

Table 4.7.1, continued

Year	Baylor County					Haskell and Knox Counties					Haskell County	Knox County
	Preston (1978)				TWDB (1981)	Ogilbee and Osborne (1962)		R.W. Harden and Associates (1978)			TWDB (1981)	TWDB (1981)
	portion of the Seymour Formation located west of the city of Seymour to the Knox-Baylor county line (i.e., portion of Seymour Aquifer considered by this study)				entire county	portion of Seymour Aquifer considered by this study		portion of Seymour Aquifer considered by this study			entire county	entire county
	Estimated Irrigation Pumpage (AF)	Estimated Municipal Pumpage (AF)	Estimated Industrial (AFY)	Estimated Rural Domestic and Livestock (AFY)	Irrigation Pumpage (AF)	Estimated Irrigation Pumpage (AF)	Estimated Pumpage for Other Purposes (AF)	Estimated Irrigation Pumpage (AF)	Estimated Public Supply Pumpage (AF)	Estimated Total Pumpage (AF)	Irrigation (AF)	Irrigation (AF)
May-69		56.3										
Jun-69		71.5										
Jul-69		133.4										
Aug-69		128.4										
Sep-69		43.1										
Oct-69		39.5										
Nov-69		51.7										
Dec-69		36.4										
1970								41,900	1,900	43,800		
1971								51,200	1,700	52,900		
1972								34,800	1,500	36,300		
1973								24,000	1,600	25,600		
1974					5,364			63,600	1,600	65,200	41,639	44,705
1975								25,100	1,600	26,700		
1976								39,100	1,700	40,800		
1977												
1978												
1979					794						38,013	51,283

AF = acre-feet
AFY = acre-feet per year
TWDB = Texas Water Development Board

Table 4.7.2 Total pumping in acre-feet per year by county for 1980, 1985, 1990, 1995, and 1997.

County	Year				
	1980	1985	1990	1995	1997
Baylor	6,705	2,444	2,395	1,337	1,091
Haskell	39,391	11,074	22,211	32,528	26,658
Knox	48,538	30,910	32,490	31,598	17,002
Stonewall	67	95	146	392	193
Total	94,701	44,524	57,242	65,855	44,945

Table 4.7.3 Irrigation pumping in acre-feet per year by county for 1980, 1985, 1990, 1995, and 1997.

County	Year				
	1980	1985	1990	1995	1997
Baylor	5,748	1,479	1,574	457	389
Haskell	38,906	10,697	21,873	32,190	26,297
Knox	48,349	30,695	32,323	31,365	16,795
Stonewall	53	80	137	379	182
Total Irrigation	93,056	42,951	55,907	64,391	43,663

Table 4.7.4 Municipal pumping in acre-feet per year by county for 1980, 1985, 1990, 1995, and 1997.

County	Year				
	1980	1985	1990	1995	1997
Baylor	786	846	690	734	622
Haskell	429	332	275	247	239
Knox	39	46	0	44	57
Stonewall	0	0	0	0	0
Total Municipal	1,254	1,224	965	1,024	917

Table 4.7.5 Rural domestic pumping in acre-feet per year by county for 1980, 1985, 1990, 1995, and 1997.

County	Year				
	1980	1985	1990	1995	1997
Baylor	108	41	39	36	34
Haskell	18	21	20	21	15
Knox	121	129	122	115	112
Stonewall	1	1	1	1	0
Total Rural Domestic	248	192	182	173	161

Table 4.7.6 Livestock pumping in acre-feet per year by county for 1980, 1985, 1990, 1995, and 1997.

County	Year				
	1980	1985	1990	1995	1997
Baylor	64	78	93	110	46
Haskell	38	24	43	70	108
Knox	29	41	45	74	38
Stonewall	8	12	8	13	11
Total Livestock	139	155	189	267	203

Table 4.7.7 Mining pumping in acre-feet per year by county for 1980, 1985, 1990, 1995, and 1997.

County	Year				
	1980	1985	1990	1995	1997
Baylor	0	0	0	0	0
Haskell	0	0	0	0	0
Knox	0	0	0	0	0
Stonewall	4	3	0	0	0
Total Mining	4	3	0	0	0

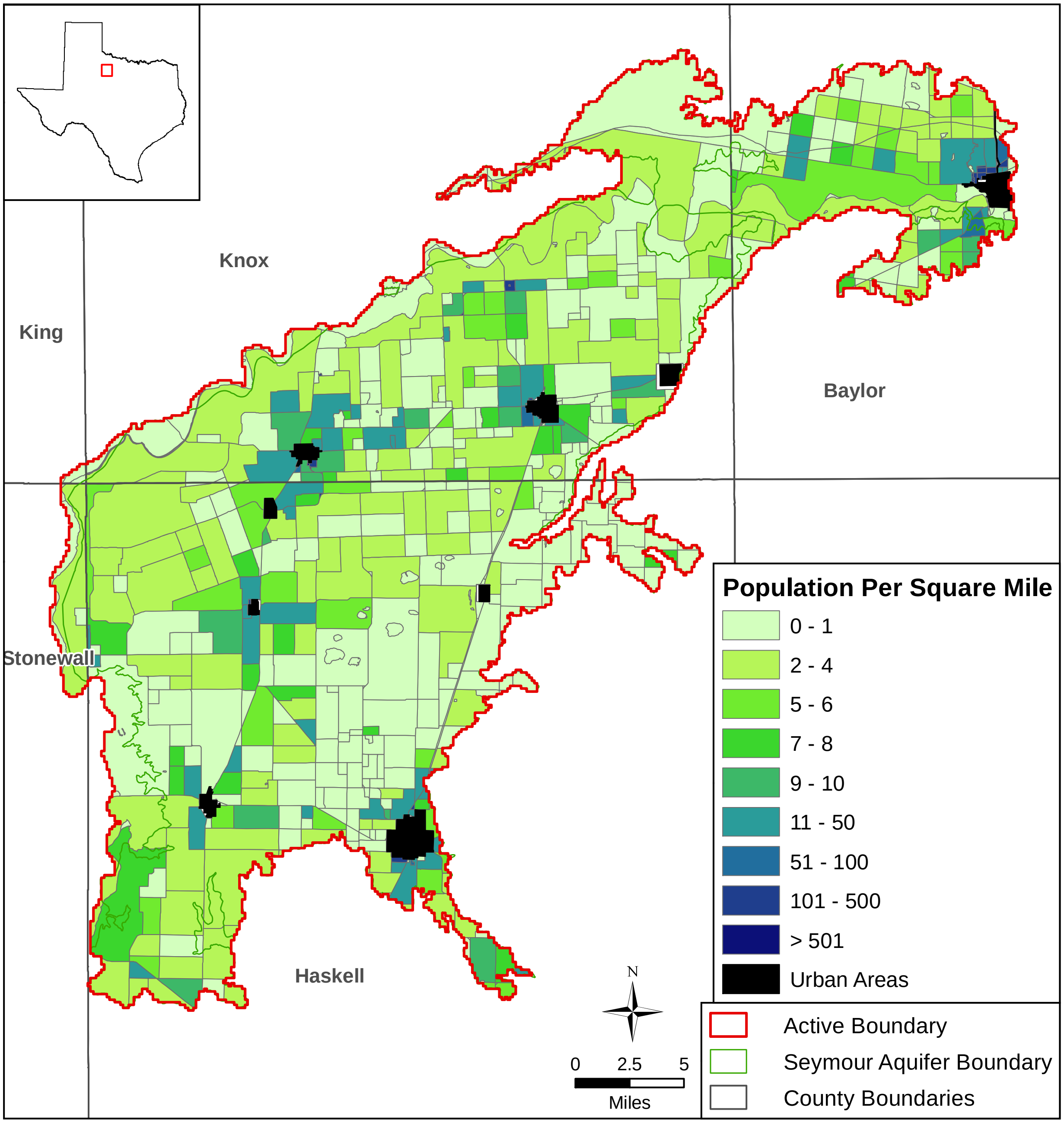


Figure 4.7.1 Population density for the model area.

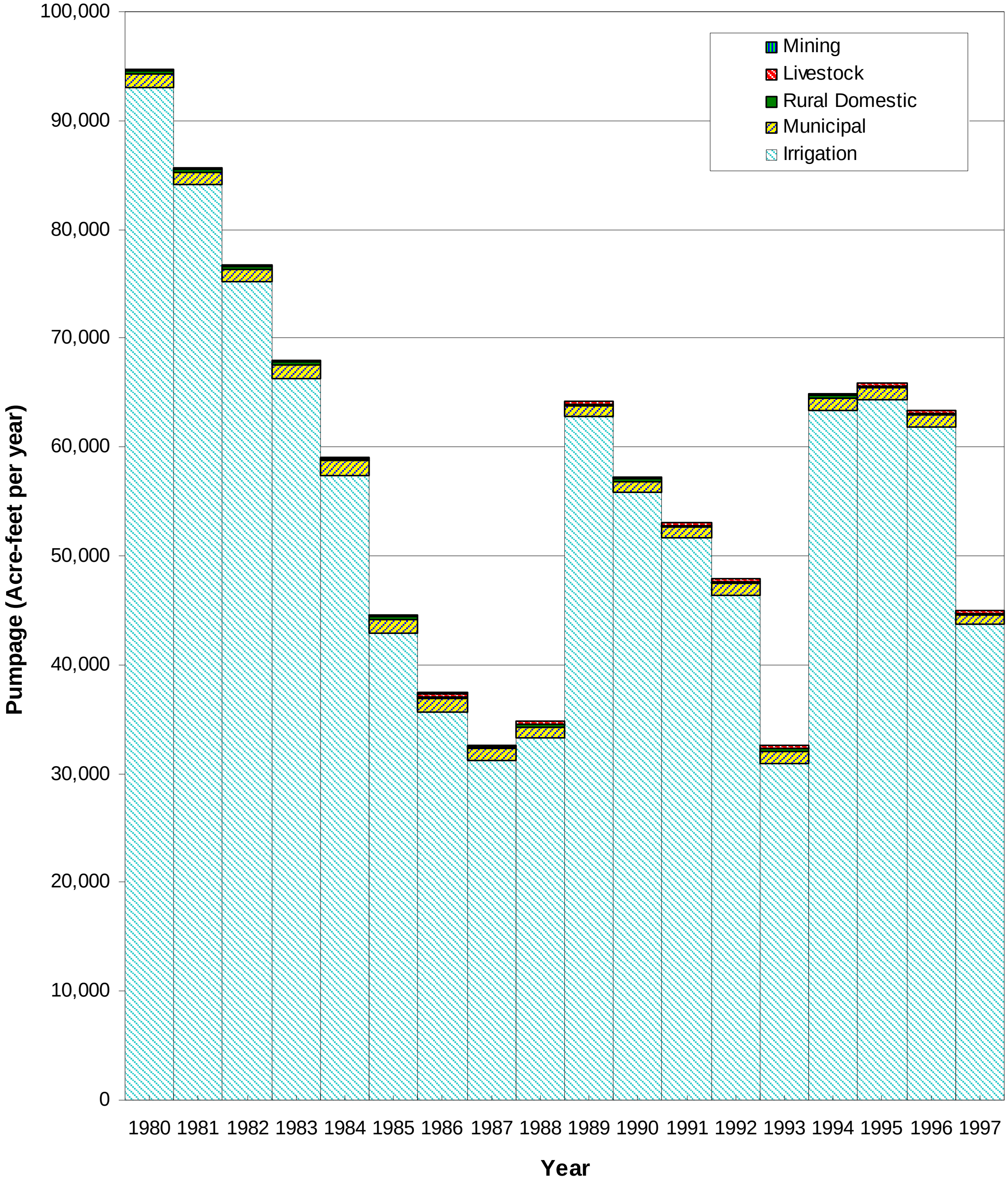


Figure 4.7.2 Total groundwater withdrawals from the Haskell-Knox-Baylor pod of the Seymour Aquifer by category.

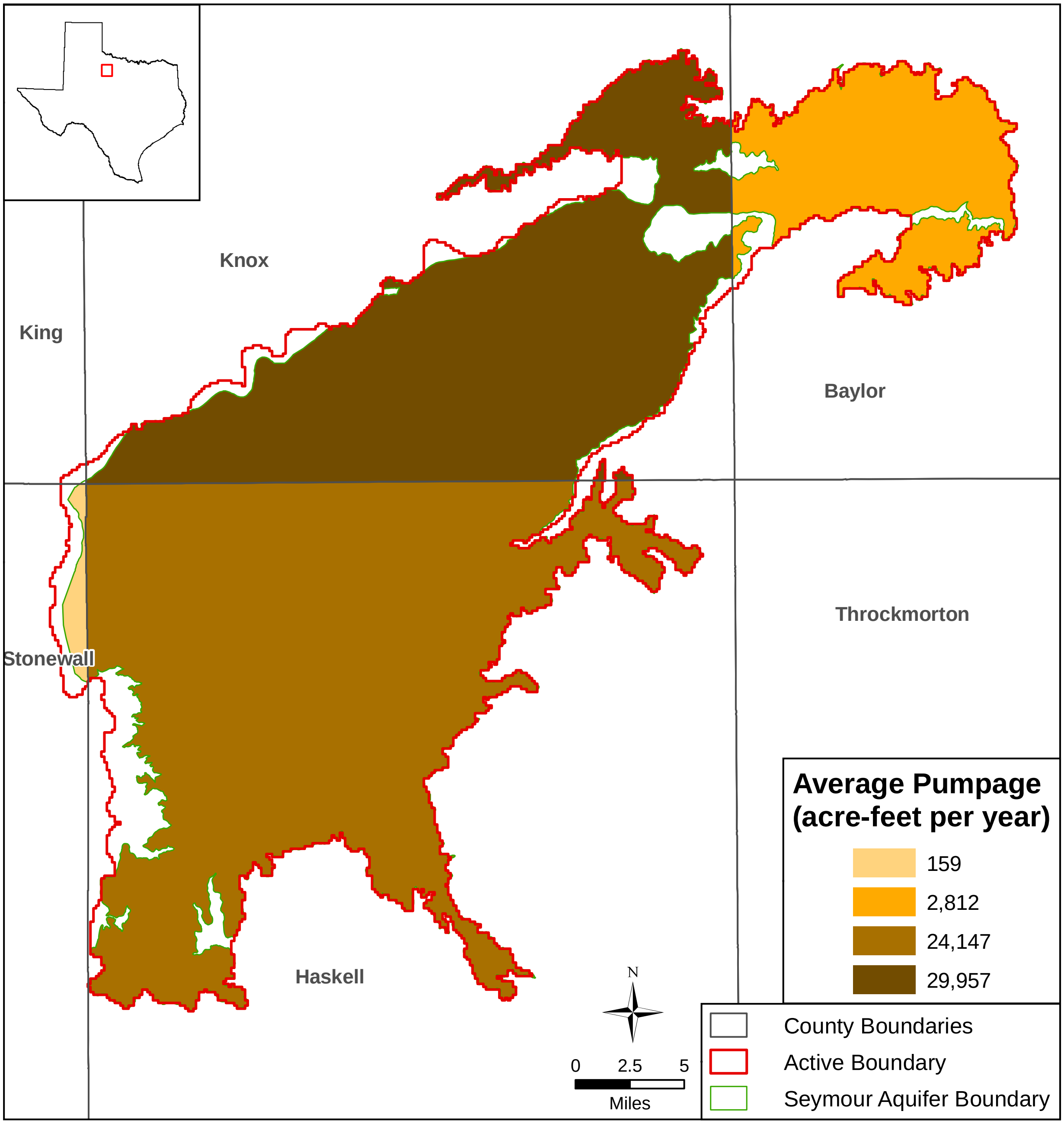


Figure 4.7.3 Yearly average pumpage from the Haskell-Knox-Baylor pod of the Seymour Aquifer for 1980 through 1997.

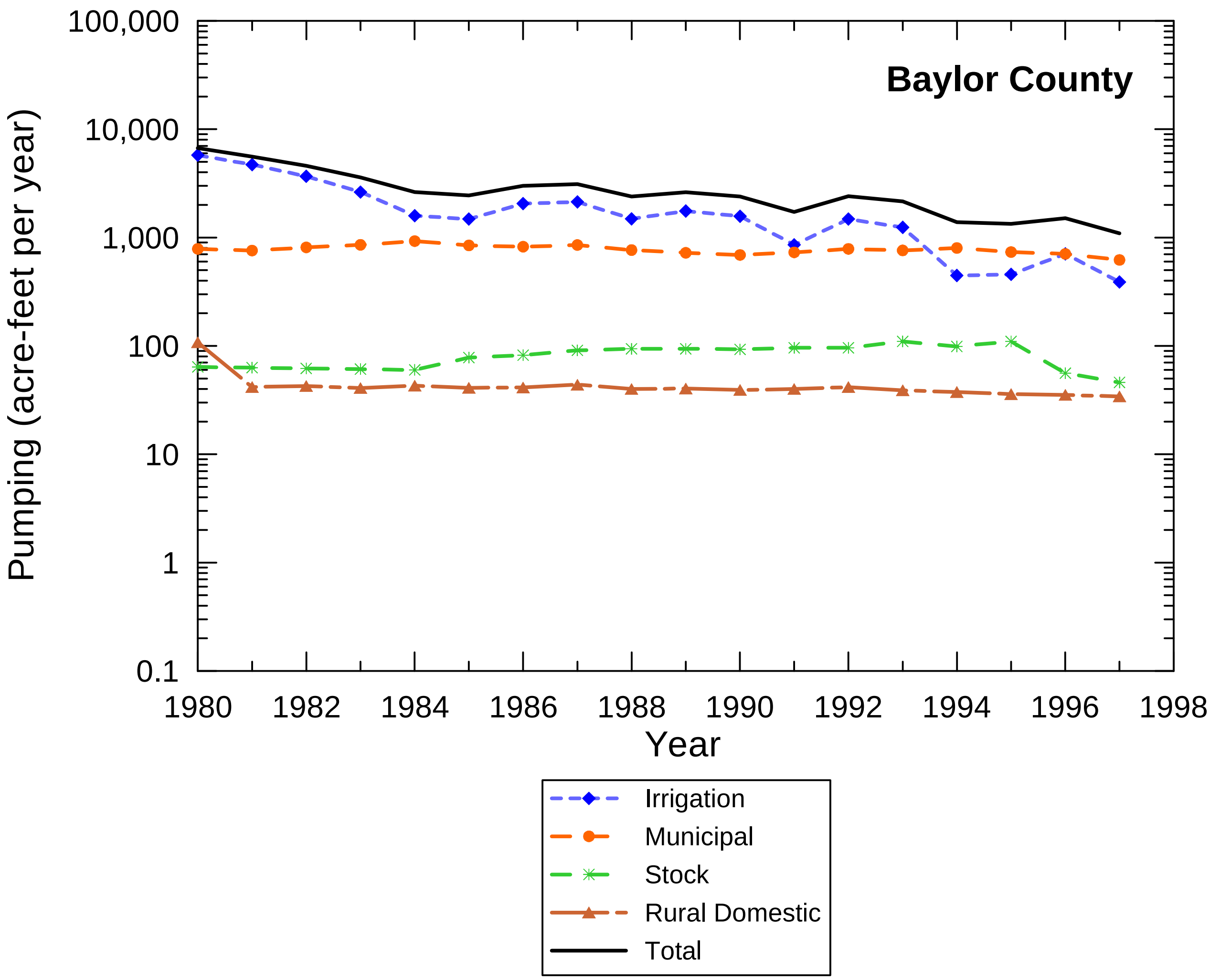


Figure 4.7.4 Groundwater withdrawals from 1980 through 1997 for the portion of the Seymour Aquifer in Baylor County considered by this study.

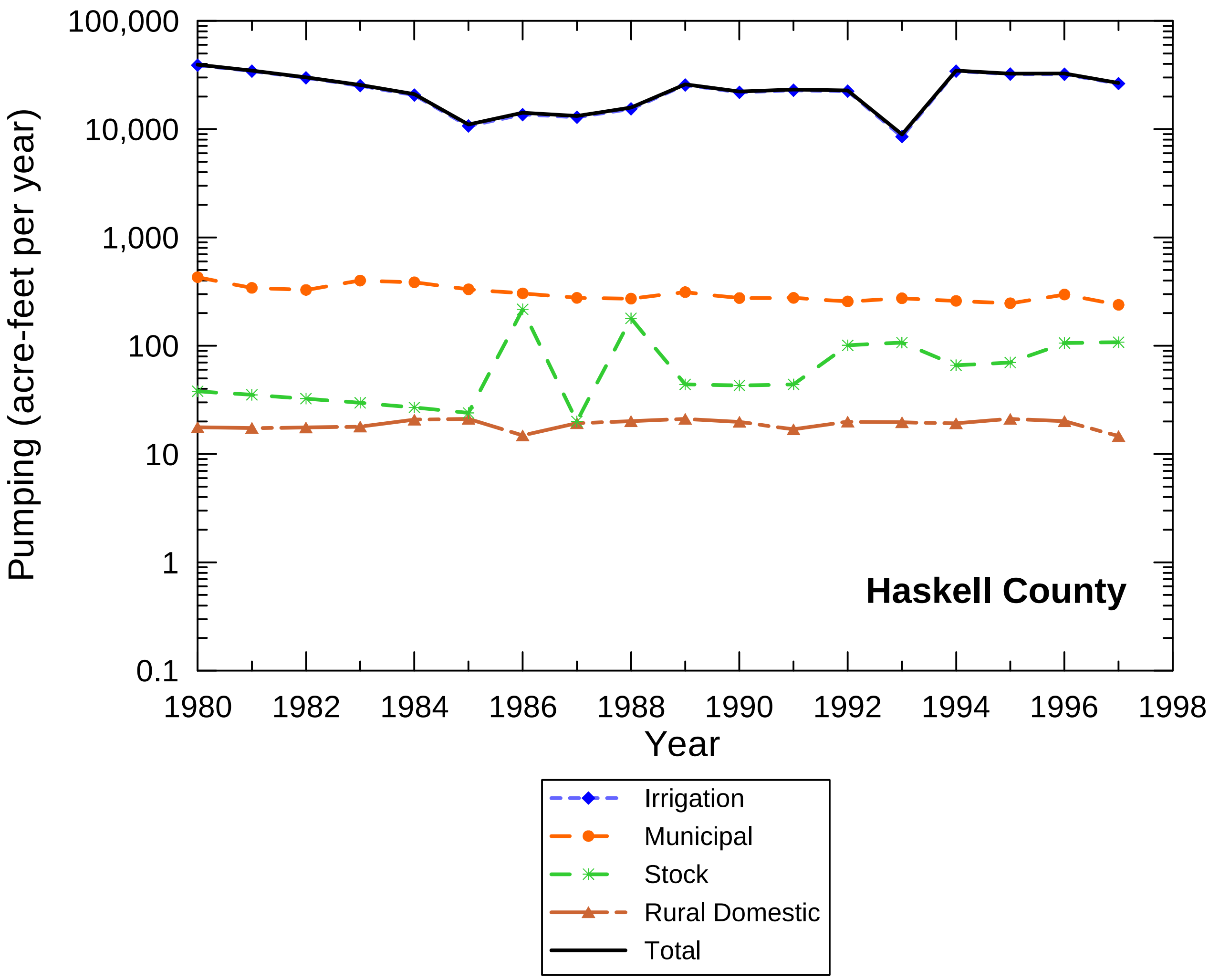


Figure 4.7.5 Groundwater withdrawals from 1980 through 1997 for the Seymour Aquifer in Haskell County.

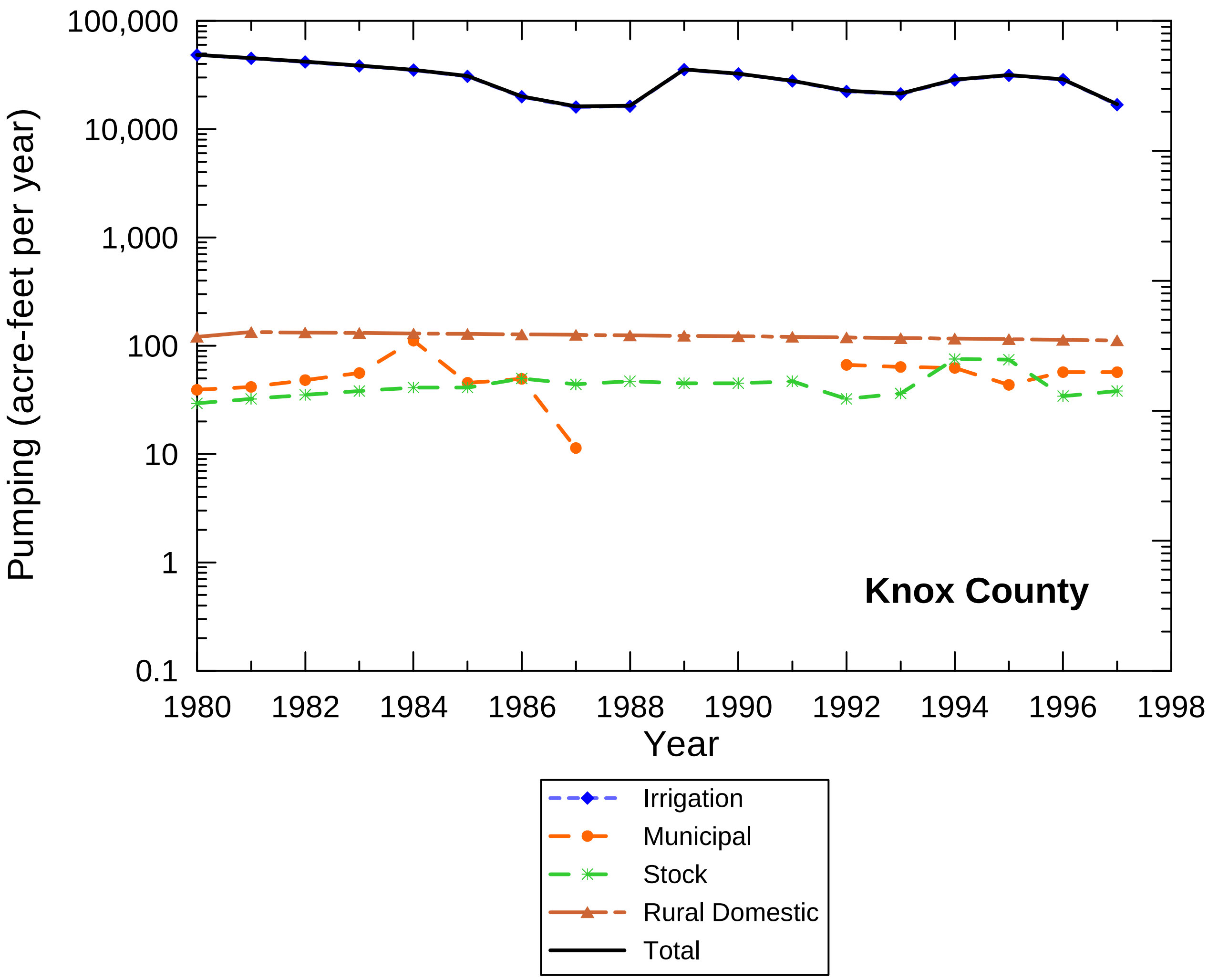


Figure 4.7.6 Groundwater withdrawals from 1980 through 1997 for the portion of the Seymour Aquifer in Knox County considered by this study.

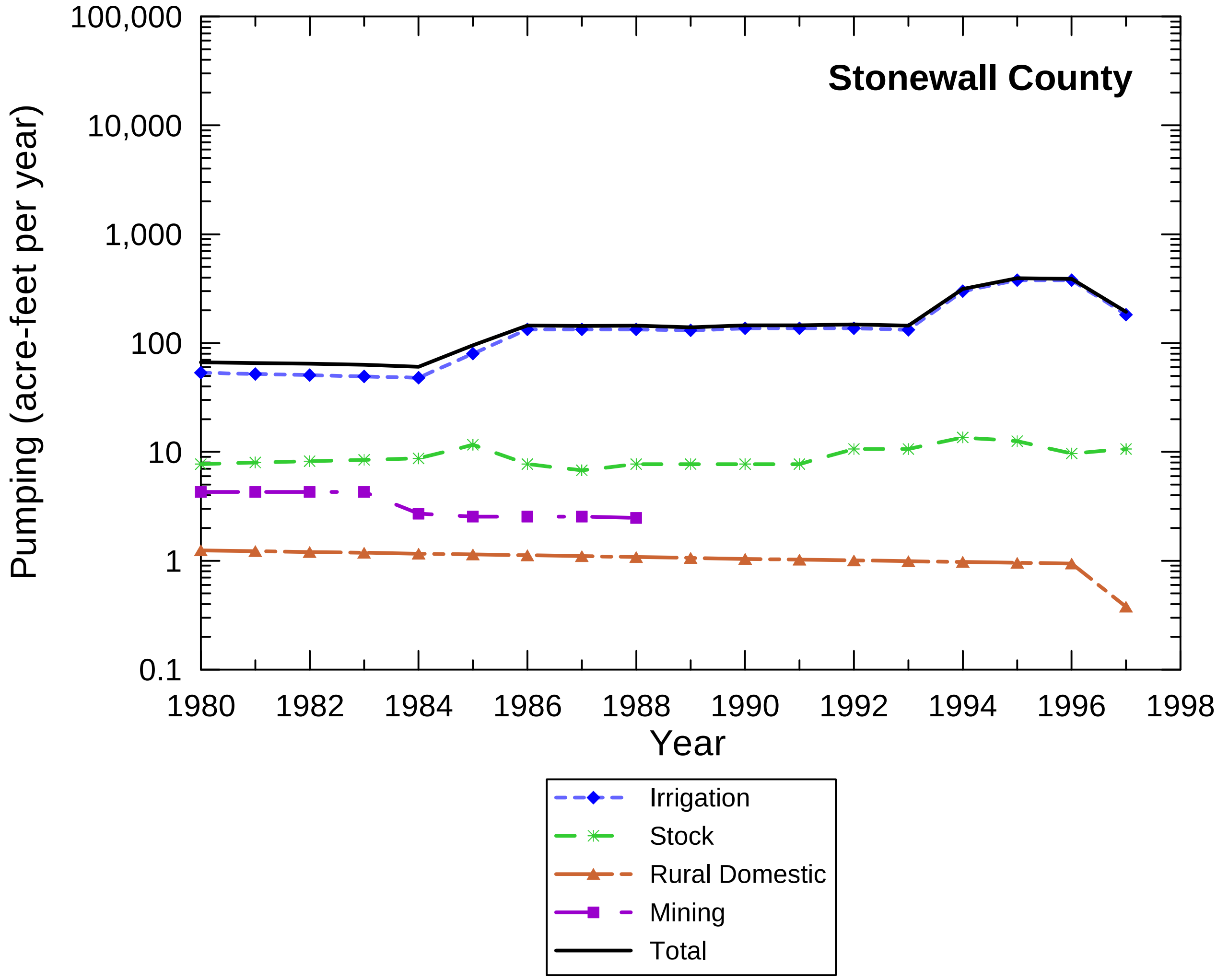


Figure 4.7.7 Groundwater withdrawals from 1980 through 1997 for the portion of the Seymour Aquifer in Stonewall County considered by this study.

4.8 Water Quality in the Seymour Aquifer

Groundwater in the Haskell-Knox-Baylor pod of the Seymour Aquifer was evaluated for its quality as a drinking water supply and for irrigation of crops by comparing the measured chemical and physical properties of the water to screening levels. Water quality measurements were retrieved for the entire available historical record, 1906 through 2006, from the TWDB groundwater database (TWDB, 2009c).

4.8.1 Previous Studies

The quality of groundwater in the Seymour Aquifer is discussed briefly by Ogilbee and Osborne (1962) in their report on groundwater resources in Haskell and Knox counties. Preston (1978) provides a discussion on water quality and possible sources of contamination of groundwater in the Seymour Aquifer in his report on the occurrence and quality of groundwater in Baylor County. R.W. Harden and Associates (1978) provide a comprehensive look at the quality of groundwater in the Seymour Aquifer in Haskell and Knox counties and pollution or the potential for pollution of groundwater in the aquifer due to oil field activities, septic tanks and cesspools, sewage treatment plant discharge, landfills and dumps, and agricultural operations. They estimated that, as of 1977, about 2 percent of the groundwater in the Seymour Aquifer was polluted. The majority of this pollution was the result of historical practices and not due to significant, current sources of pollution. Of the polluted groundwater, R.W. Harden and Associates (1978) estimated that 75 percent was polluted by oil field disposal pits, 20 percent by injection wells or unplugged holes, 4 percent by septic tanks, and 1 percent by all other sources.

4.8.2 Data Sources and Methods of Analysis

The TWDB groundwater database (TWDB, 2009c) is the source of water-quality data for groundwater in the Seymour Aquifer. Chemical analyses of groundwater samples from 1,472 Seymour Aquifer wells are on record in the database. For the purpose of statistical evaluation and mapping, only the most recent sampling event for a given parameter was chosen for each well. The most recent data were used in order to assess the current status of the quality of groundwater in the Seymour Aquifer.

4.8.3 Results

The following sections discuss the results of the water-quality analysis conducted for groundwater in the Seymour Aquifer. A comparison of the chemistry of the groundwater in the aquifer to drinking water standards is provided in the first section and the quality of groundwater in the Seymour Aquifer for irrigation purposes is provided in the second section. A comparison of groundwater quality in the Seymour Aquifer to drinking water and irrigation standards considering only the most recent chemical analysis for each constituent is provided in Table 4.8.1.

4.8.3.1 Drinking Water Quality

Screening levels for drinking water supply are based on the maximum contaminant levels established in the Texas Administrative Code (Title 30 Chapter 290). Primary maximum contaminant levels are legally enforceable standards that apply to public water systems to protect human health from contaminants in drinking water. Secondary maximum contaminant levels are non-enforceable guidelines for drinking water contaminants that may cause aesthetic effects (taste, color, odor, foaming), cosmetic effects (skin or tooth discoloration), and technical effects (e.g., corrosivity, expensive water treatment, plumbing fixture staining, scaling, and sediment).

High levels of nitrate are common in the Seymour Aquifer, with the concentration in 69 percent of the sampled wells exceeding the primary maximum contaminant level of 10 milligrams per liter. Figure 4.8.1 shows that nitrate concentrations exceed the primary maximum contaminant level throughout the extent of the aquifer. High concentrations of nitrate can cause serious illness in infants younger than 6 months old. These high nitrate levels may be due in part to domestic sewage contamination, the use of nitrate fertilizers on croplands, or leaching from soil following conversion of former grasslands and mesquite groves to cropland, coupled with the shallow and permeable nature of the Seymour Aquifer (Price, 1979). Measurements of nitrate concentrations at multiple times are plotted, along with the screening level (i.e., the primary maximum contaminant level), for several wells in Figure 4.8.2. These plots indicate that concentrations have varied significantly over time at some locations and have remained fairly stable at other locations. At all but one of the selected locations, the nitrate concentration exceeded the screening level at some point in time. The nitrate concentration in well 21-26-711 located in Knox County has significantly exceeded the screening level in all samples.

Fluoride is a naturally occurring element found in most rocks. At very low concentrations, fluoride is a beneficial nutrient. At a concentration of 1 milligram per liter, fluoride helps to prevent dental cavities. However, at concentrations above the secondary maximum contaminant level of 2 milligrams per liter, fluoride can stain children's teeth. Approximately 14 percent of the sampled wells have exceeded this level. At concentrations above the primary maximum contaminant level of 4 milligrams per liter, fluoride can cause a type of bone disease. About 1.5 percent of the sampled wells have exceeded this level. Fluoride concentrations in groundwater in the Seymour Aquifer relative to these two screening levels are shown in Figure 4.8.3.

Total dissolved solids, a measure of water salinity, is the sum of concentrations of all dissolved ions (such as sodium, calcium, magnesium, potassium, chloride, sulfate, carbonates) plus silica. Some dissolved solids, such as calcium, give water a pleasant taste, but most make water taste salty, bitter, or metallic. Dissolved solids can also increase the corrosiveness of water. Total dissolved solids have exceeded the Texas secondary maximum contaminant level of 1,000 milligrams per liter in approximately 40 percent of the sampled wells (Figure 4.8.4). Time series of total dissolved solids concentrations for several wells, along with the screening level of 1,000 milligrams per liter, are shown in Figure 4.8.5. The concentration temporarily exceeded the screening level in the 1970 to 1990 time frame in well 21-28-711 located in Knox County and in the 1990s in well 21-41-407 located in Haskell County.

Concentrations of sulfate, a major component of total dissolved solids, have exceeded the secondary maximum contaminant level of 300 milligrams per liter in 14 percent of the sampled wells. Concentrations of chloride, another major component of total dissolved solids, have exceeded the secondary maximum contaminant level of 300 milligrams per liter in 24 percent of the sampled wells (Figure 4.8.6). Time series plots of chloride concentrations for several wells, along with the screening level of 300 milligrams per liter, are shown in Figure 4.8.7. Also included on these plots are chloride to sulfate ratios. This ratio is useful for identifying contamination from oil field brines which have a very high chloride content relative to their sulfate content (R.W. Harden and Associates, 1978). A large spike in chloride concentration occurred in several of the wells. For wells with data to calculate the chloride to sulfate ratio, the spike in chloride concentration is accompanied by a spike in the chloride to sulfate ratio, indicating possible contamination by oil field brines. The chloride to sulfate ratio in groundwater in the Seymour Aquifer is plotted in Figure 4.8.8. A ratio of greater than 1 can be an indication of contamination by oil field brines.

In summary, the utility of water from the Seymour Aquifer as a drinking water supply is limited in some areas for health reasons, primarily due to elevated nitrate concentrations and for taste reasons due to saltiness.

4.8.3.2 Irrigation Water Quality

The utility of groundwater from the Seymour Aquifer for crop irrigation was evaluated based on its salinity hazard, sodium hazard, and concentrations of chloride. The results of this evaluation are presented below.

Saline irrigation waters limit the ability of plants to take up water from soils. Various crops differ in their tolerance of high salinity. Salinity is often measured by the total dissolved solids content or electrical conductivity of the water. The salinity hazard classification system of the United States Salinity Laboratory (1954) indicates that waters with an electrical conductivity over 750 micromhos present a high salinity hazard, and those with electrical conductivity over 2250 micromhos present a very high salinity hazard. Of the sampled Seymour Aquifer wells, 95 percent have exhibited a high salinity hazard and 25 percent have exhibited a very high salinity hazard (Figure 4.8.9).

Irrigation water containing large amounts of sodium causes a breakdown in the physical structure of soil such that movement of water and air through the soil is restricted. A sodium hazard condition generally results when the sodium concentration in water is in excess of 60 percent of total cations and is widely measured in terms of sodium adsorption ratio (United States Salinity Laboratory, 1954):

$$\text{Sodium Adsorption Ratio} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca} + \text{Mg}}{2}}} \tag{4.8.1}$$

where the sodium (Na), calcium (Ca), and magnesium (Mg) concentrations are expressed in milliequivalents per liter. Waters with a sodium absorption ratio above 18 are considered to present a high sodium hazard, generally considered unsuitable for continuous use for irrigation. Waters with a sodium absorption ratio above 26 are considered to represent a very high sodium hazard. Less than 1 percent of the sampled Seymour Aquifer wells exhibit a high sodium hazard and none exhibit a very high sodium hazard (Figure 4.8.10).

Most crops cannot tolerate chloride levels above 1,000 milligrams per liter for an extended period of time (Tanji, 1990). This level has been exceeded in about 2.4 percent of sampled Seymour Aquifer wells (see Figure 4.8.6).

Table 4.8.1 Occurrence and levels of some commonly measured groundwater quality constituents in the Haskell-Knox-Baylor pod of the Seymour Aquifer.

Constituent	Type of Standard	Screening Level	Number of Results	Number of Results Exceeding Screening Level	Percentage of Results Exceeding Screening Level
Fluoride	primary maximum contaminant level[1]	4 mg/L	1,030	15	1.5%
Nitrate	primary maximum contaminant level[1]	10 mg/L	1,123	780	69%
Chloride	secondary maximum contaminant level[1]	300 mg/L	1,326	324	24%
Fluoride	secondary maximum contaminant level[1]	2 mg/L	1,030	145	14%
Sulfate	secondary maximum contaminant level[1]	300 mg/L	1,180	160	14%
Total Dissolved Solids	secondary maximum contaminant level[1]	1,000 mg/L	977	388	40%
Specific Conductance	Irrigation Salinity Hazard - High[2]	750 µmhos/cm	1,056	1,003	95%
Specific Conductance	Irrigation Salinity Hazard - Very High[2]	2,250 µmhos/cm	1,056	261	25%
Sodium Absorption Ratio	Irrigation Sodium Hazard -High[2]	18	970	3	0.3%
Sodium Adsorption Ratio	Irrigation Sodium Hazard - Very High[2]	26	970	0	0%
Chloride	Irrigation Hazard[3]	1,000 mg/L	1,326	32	2.4%

[1] 30 Texas Administrative Code, Chapter 290, Subchapter F
[2] United States Salinity Laboratory (1954)
[3] Tanji (1990)

mg/L = milligrams per liter
µmhos/cm = micromhos per centimeter
% = percent

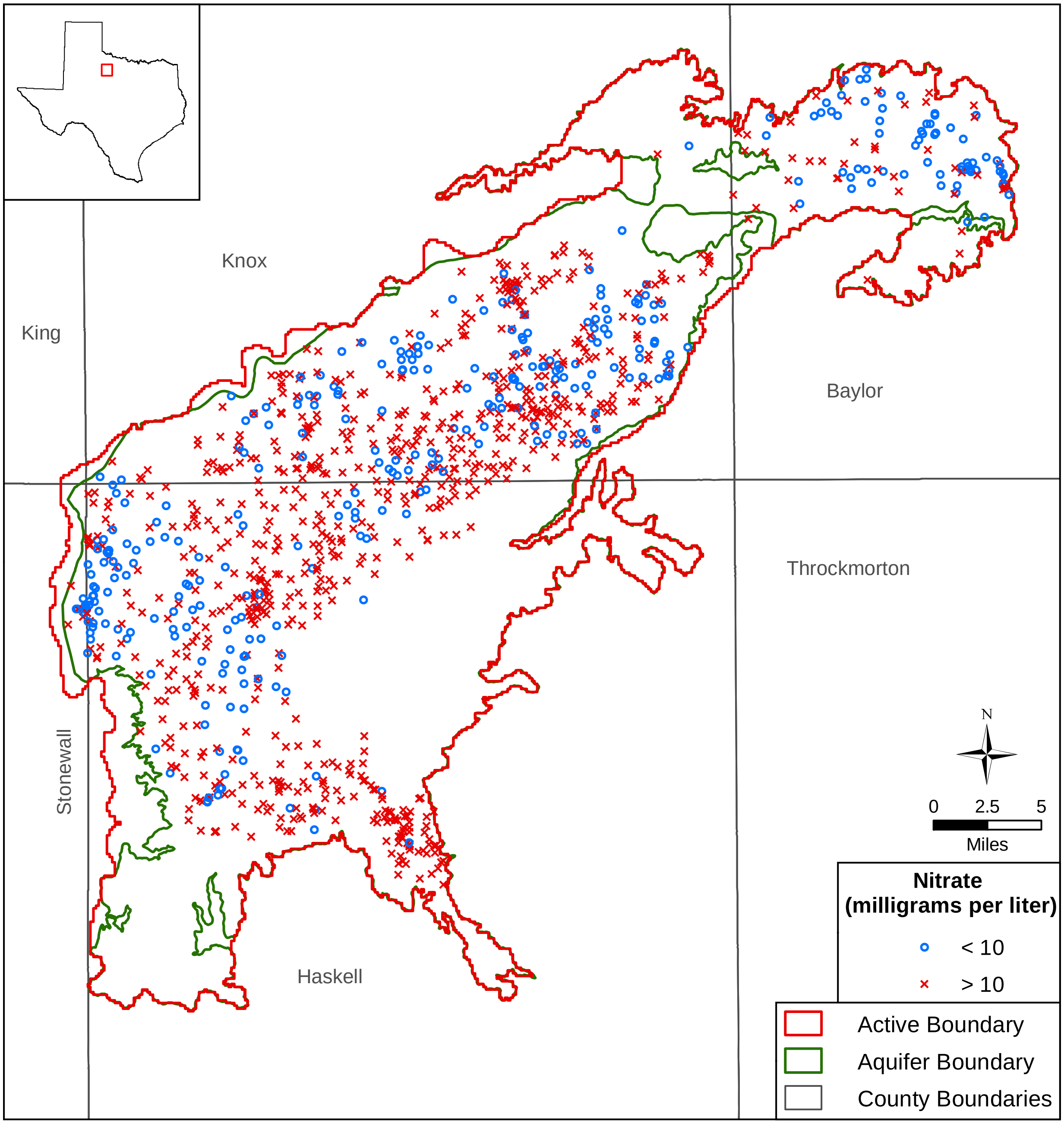


Figure 4.8.1 Nitrate concentrations in the groundwater in the Seymour Aquifer.

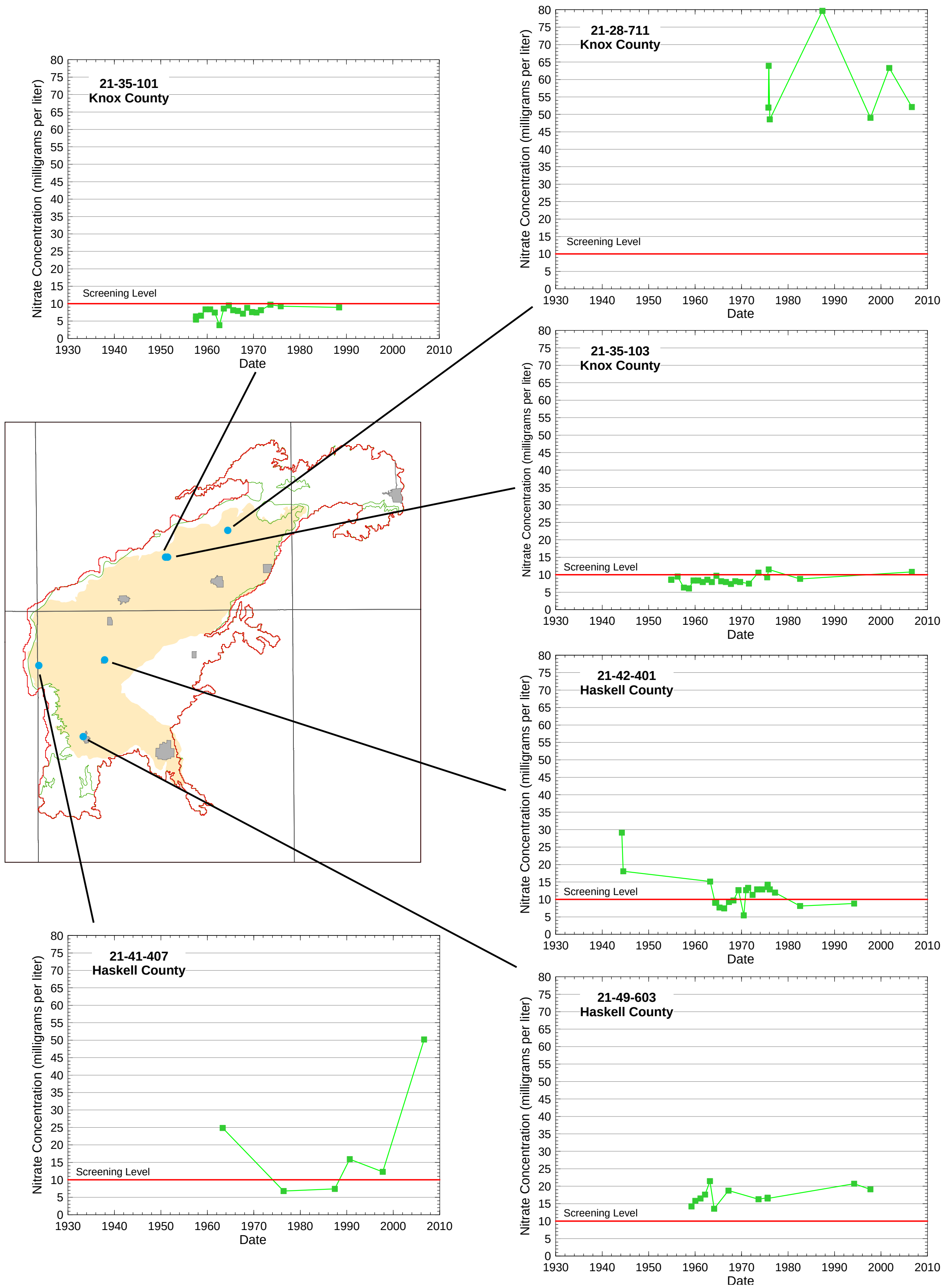


Figure 4.8.2 Time series of nitrate concentrations in the Seymour Aquifer at selected wells.

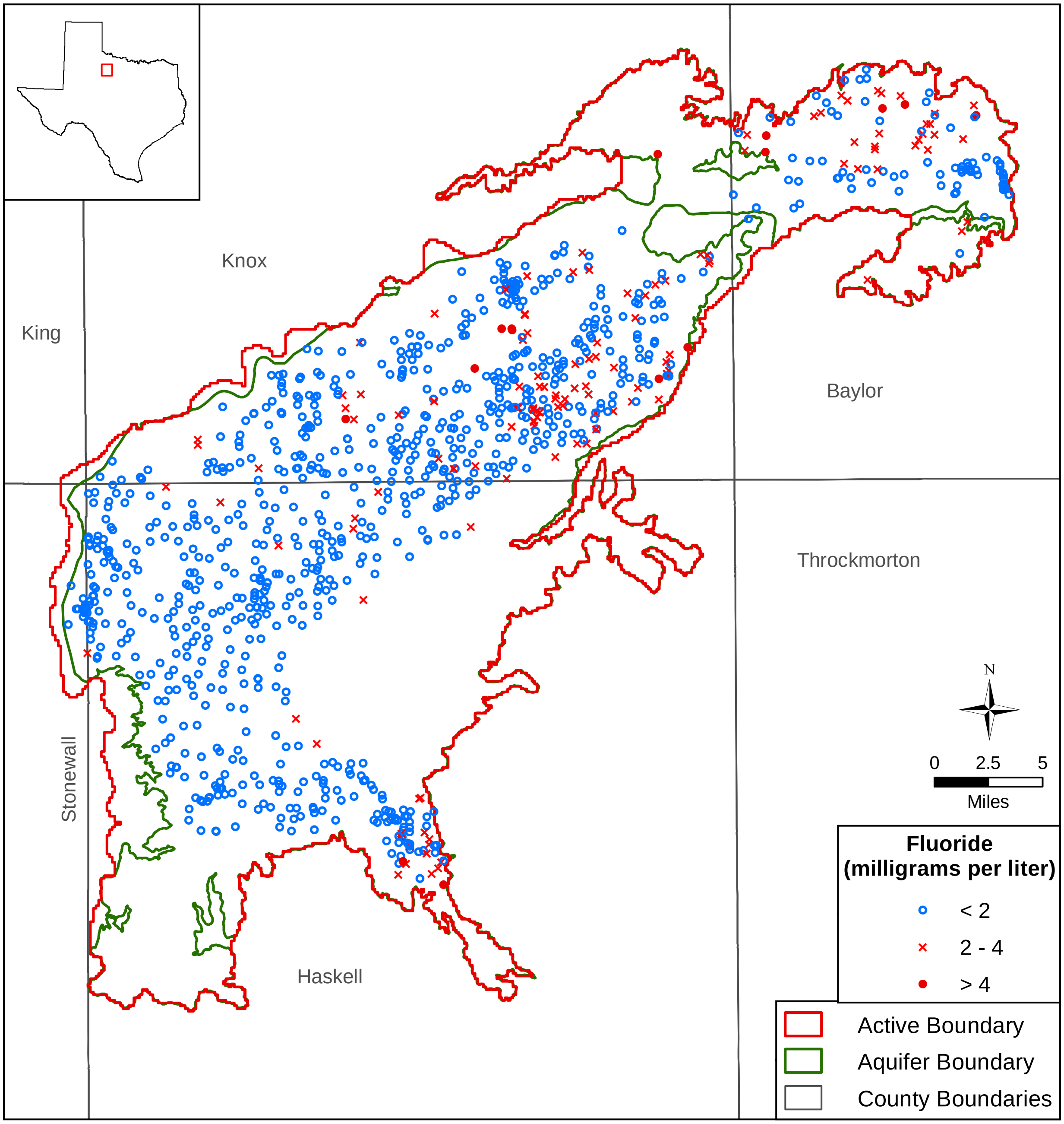


Figure 4.8.3 Fluoride concentrations in the Seymour Aquifer.

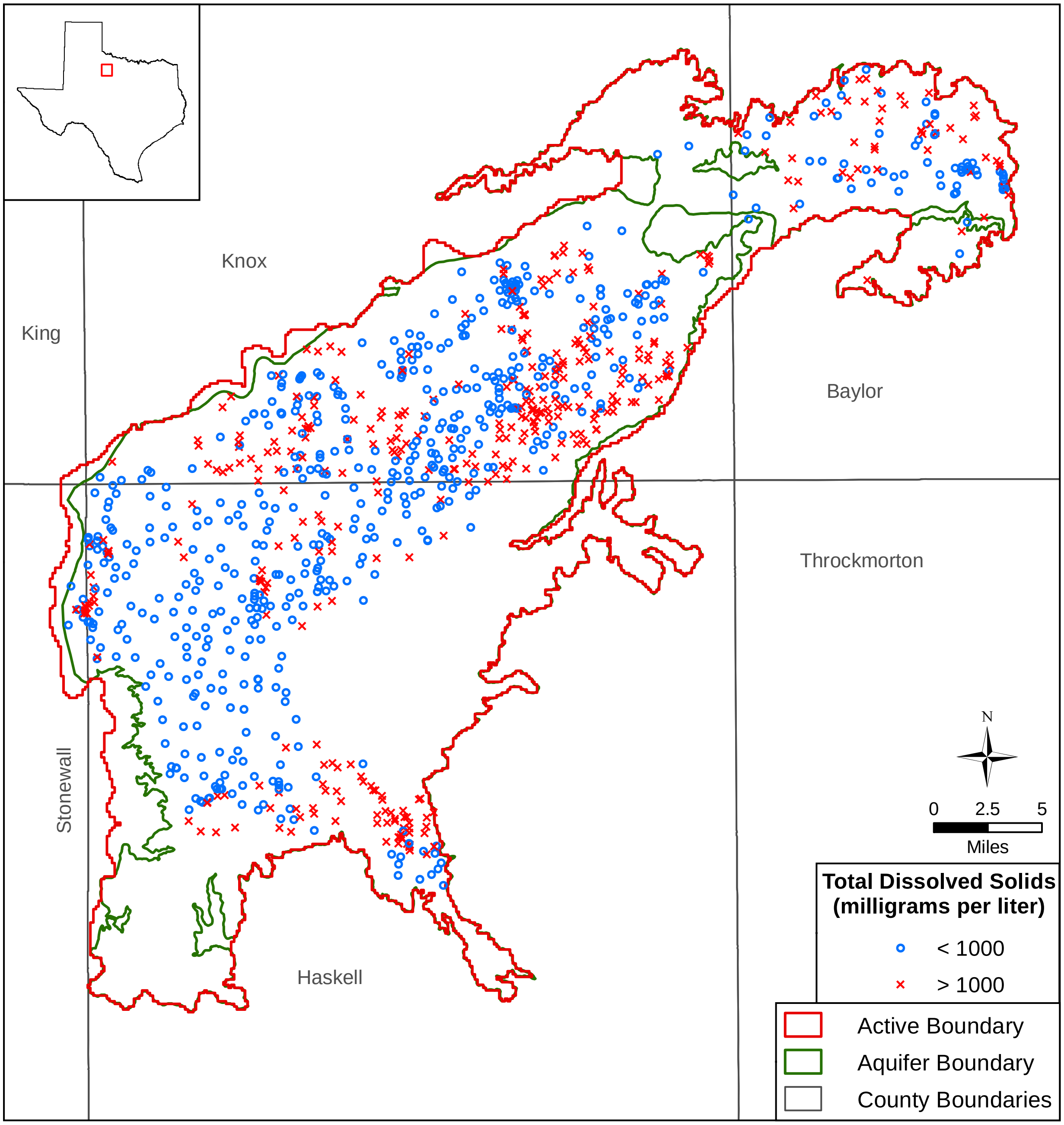


Figure 4.8.4 Total dissolved solids concentrations in the Seymour Aquifer.

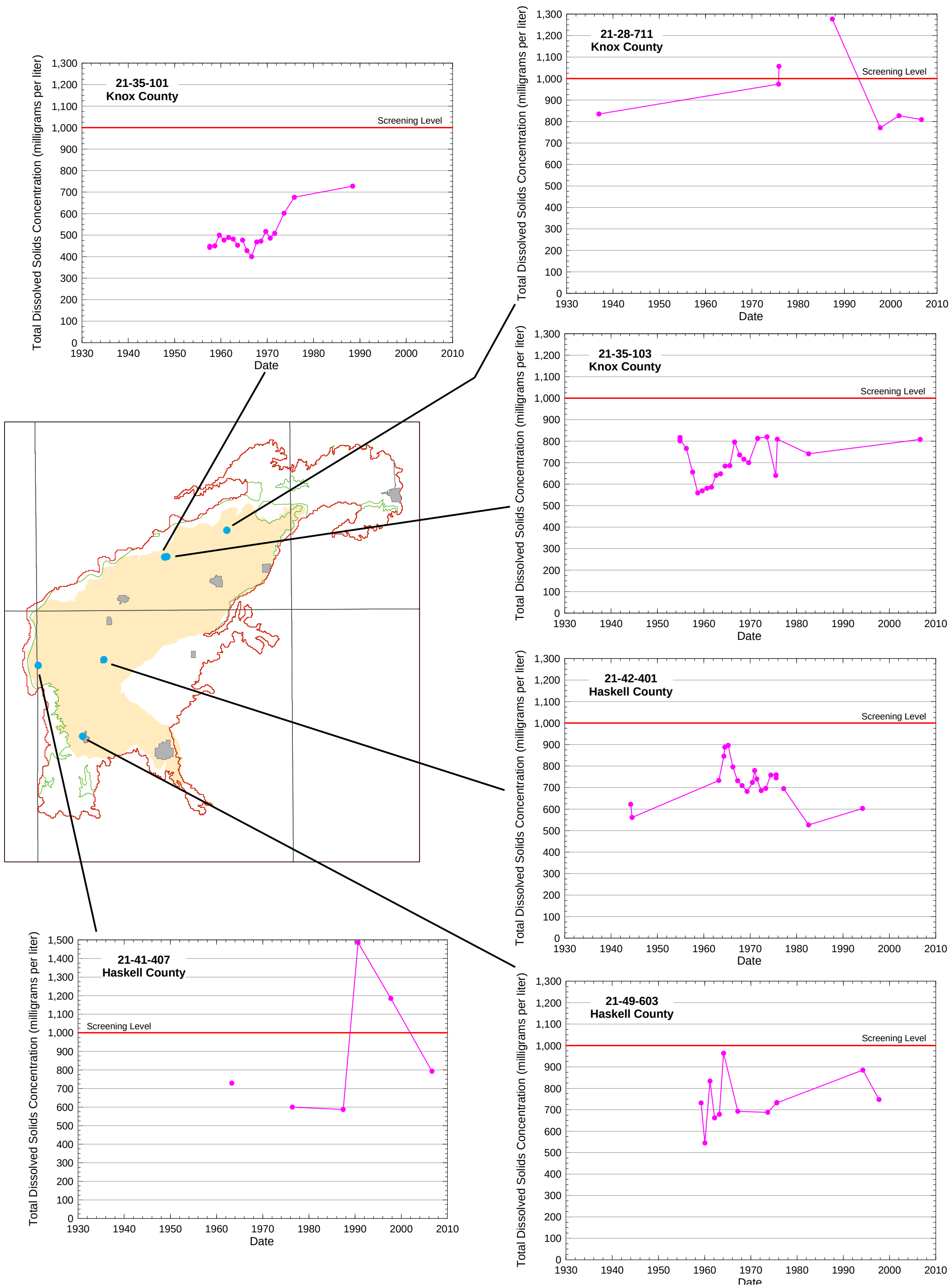


Figure 4.8.5 Time series of total dissolved solids concentrations in the Seymour Aquifer for selected wells.

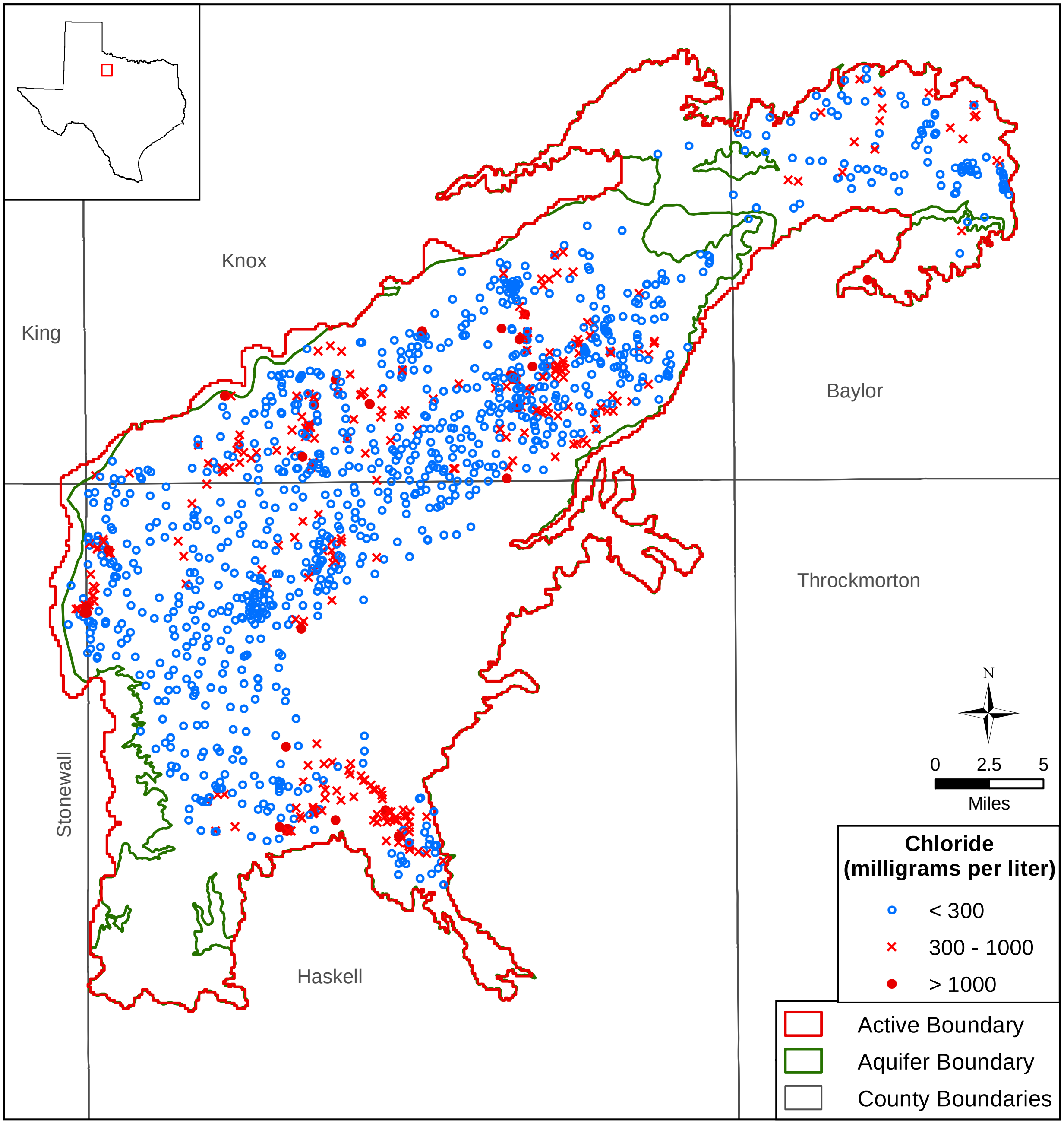


Figure 4.8.6 Chloride concentrations in the Seymour Aquifer.

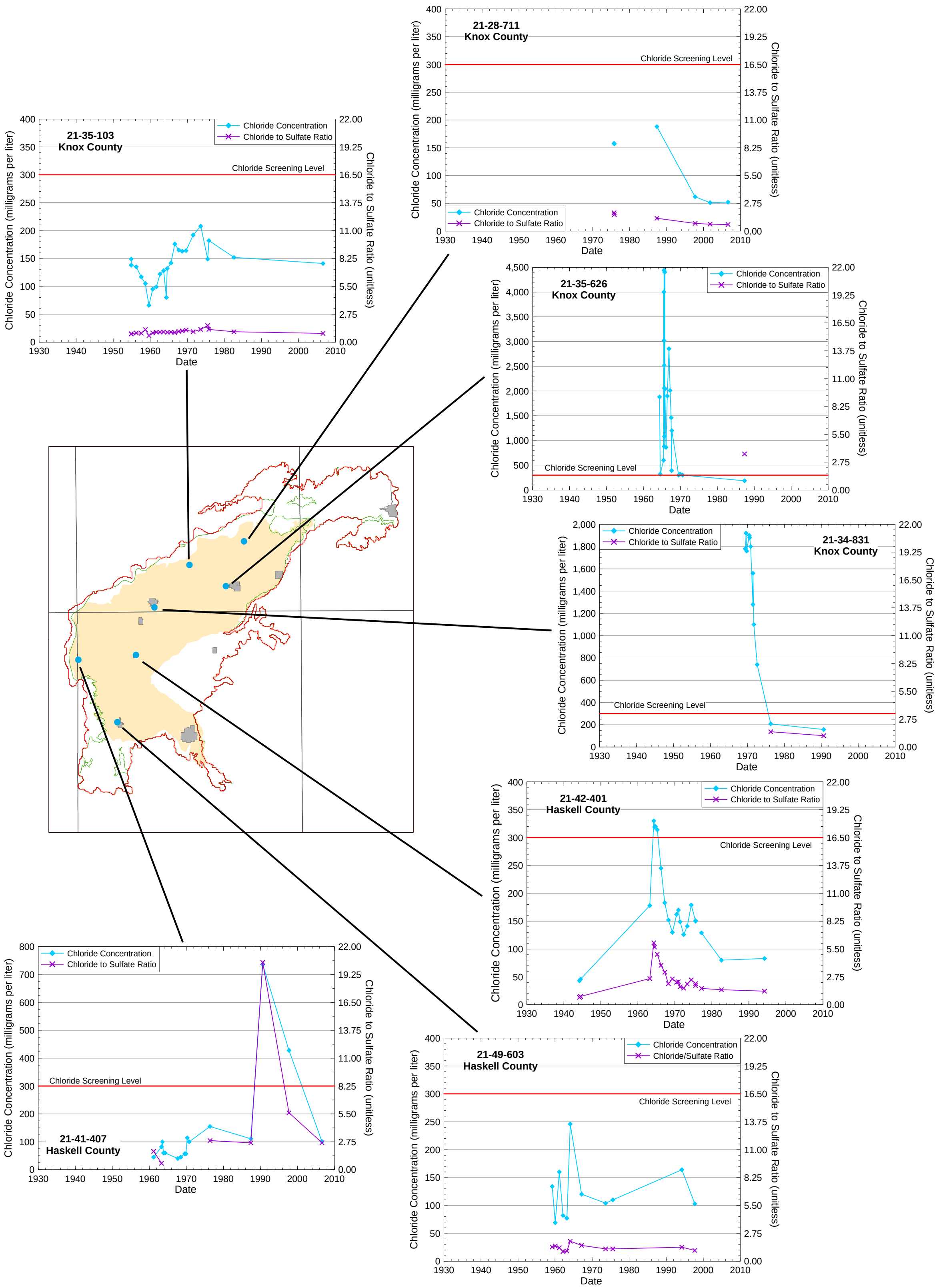


Figure 4.8.7 Time series of chloride concentration and chloride/sulfate ratio for selected wells.

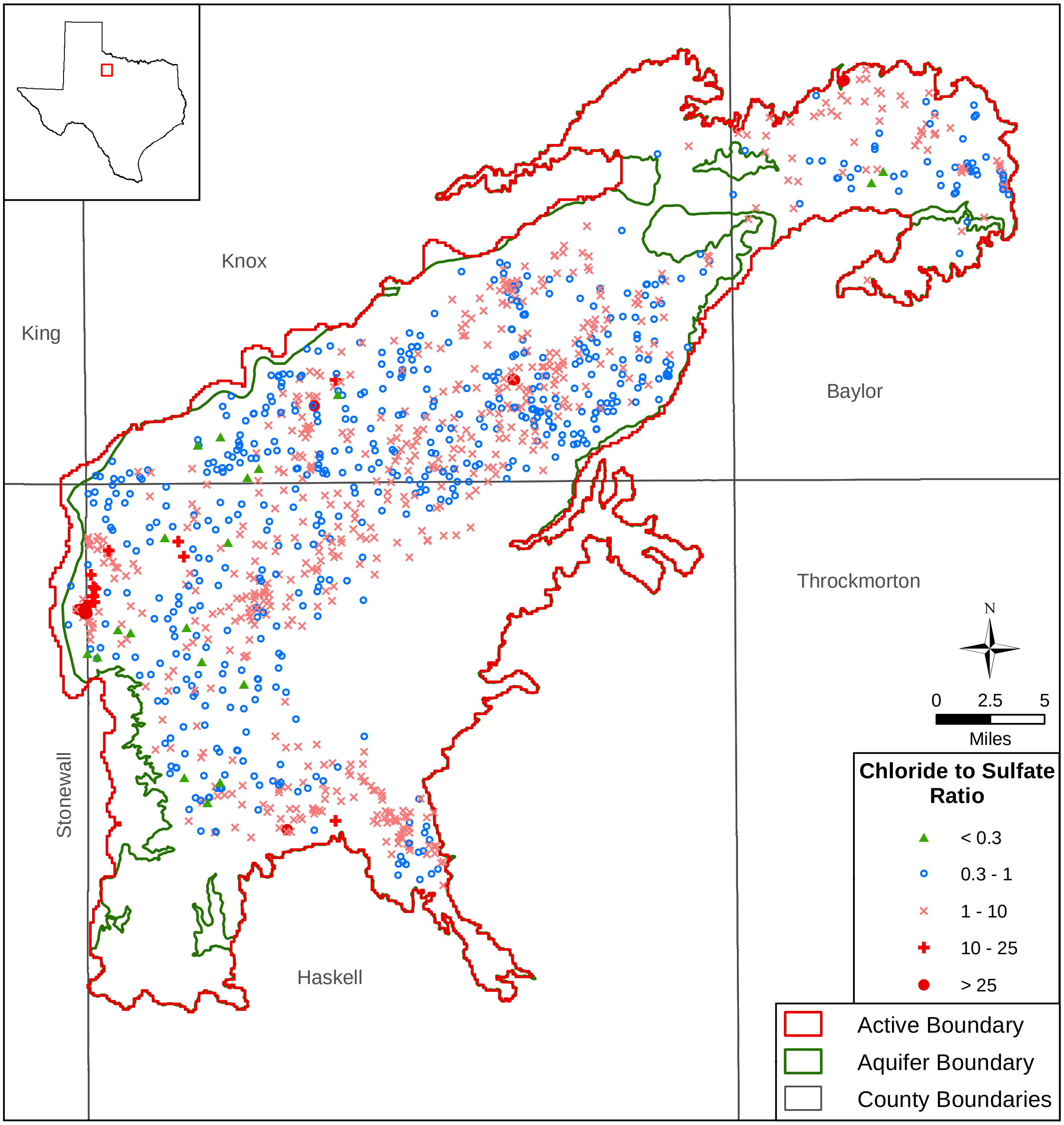


Figure 4.8.8 Chloride to sulfate ratios in the Seymour Aquifer.

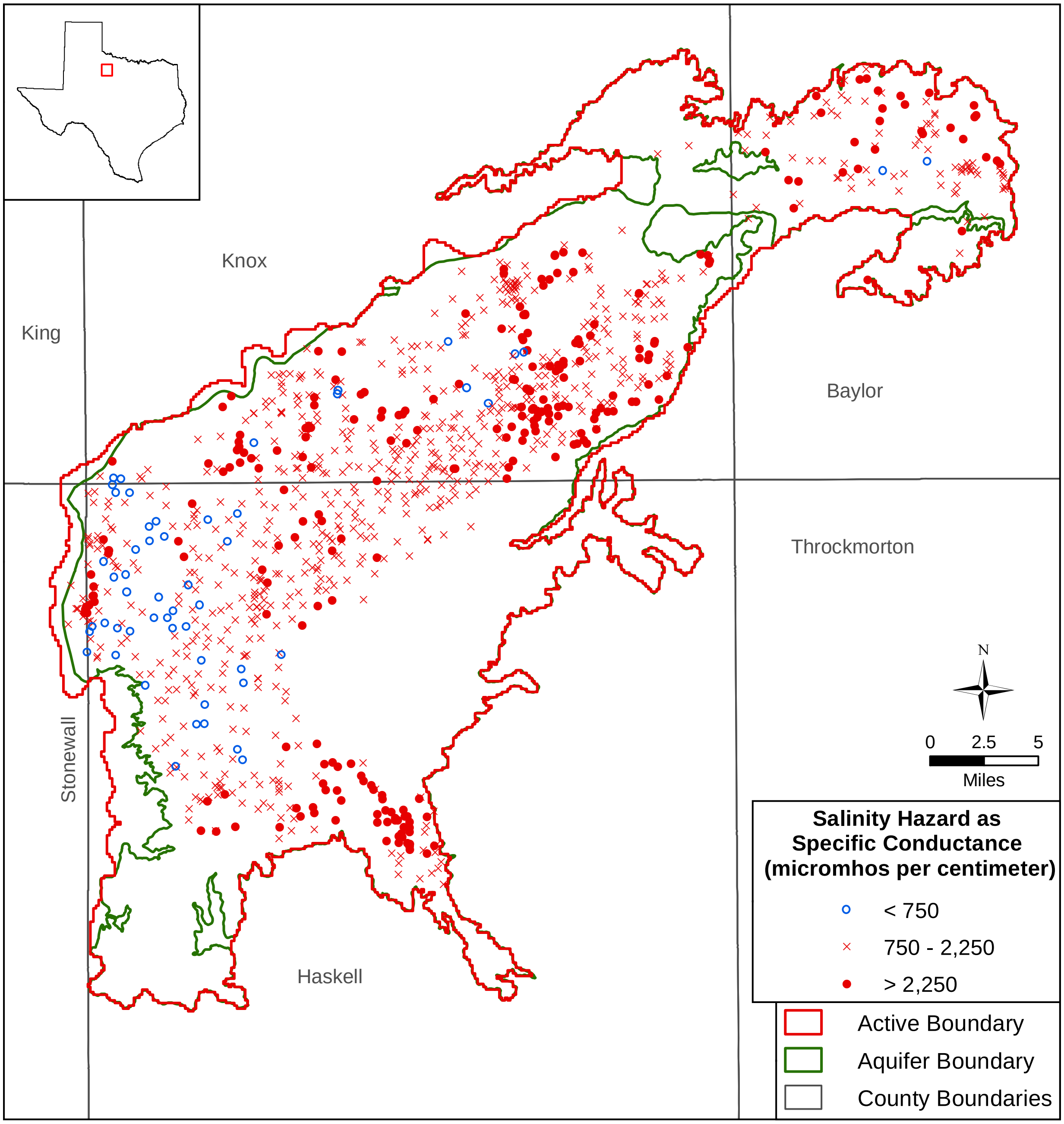


Figure 4.8.9 Salinity hazard of groundwater in the Seymour Aquifer.

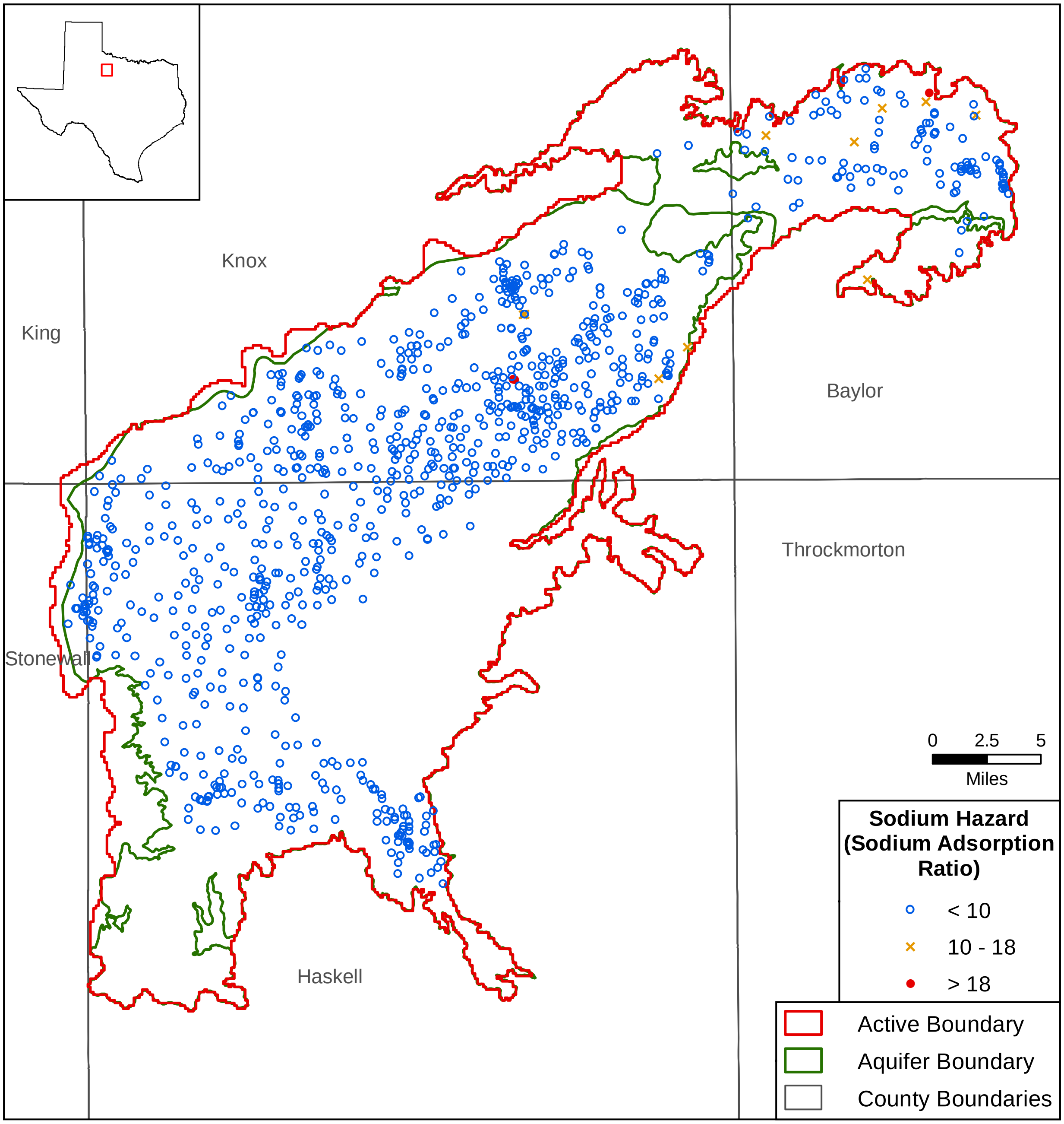


Figure 4.8.10 Sodium hazard (sodium adsorption ratio) of groundwater in the Seymour Aquifer.

5.0 Conceptual Model of Groundwater Flow for the refined Seymour Aquifer Groundwater Availability Model

The conceptual model for groundwater flow in the Haskell-Knox-Baylor pod of the Seymour Aquifer is based on the hydrogeologic setting, described in Section 4.0. The conceptual model is a simplified representation of the hydrogeologic features which govern groundwater flow in the aquifer. These include the hydrostratigraphy, hydraulic properties, hydraulic boundaries, recharge and natural discharge, and anthropogenic stresses from land use changes and pumping. Each element of the conceptual model is described below. The schematic diagram in Figure 5.0.1 depicts a simplified, cross-section conceptualization of the hydrogeologic model describing inflow to and outflow from the Haskell-Knox-Baylor pod of the Seymour Aquifer.

The conceptual model for the refined groundwater availability model for the Haskell-Knox-Baylor pod of the Seymour Aquifer includes two layers. The upper layer represents the Seymour Aquifer and the lower layer represents the upper portion of the Permian-age sediments that underlie and are in hydrologic communication with the Seymour Aquifer. The Seymour Aquifer is the most productive groundwater zone in the model. The Permian-age sediments locally supply small quantities of saline water. The upper portion of the Permian-age sediments is included in the model to allow for cross-formational flow between the Seymour Aquifer and the Permian-age formations and to allow for groundwater flow from the Seymour Aquifer through the Permian-age formations to the Brazos River along the western edge of the Seymour Aquifer in Haskell and Knox counties. In addition to identifying the hydrostratigraphic layers of the groundwater system, the conceptual model defines the mechanisms of recharge and discharge, historical changes in recharge and discharge and their effect on the aquifer, and groundwater flow through the aquifer.

Recharge is a complex function of precipitation, soil type, geology, land cover, water level and soil moisture, topography, and evapotranspiration. Precipitation, land cover, evapotranspiration, water-table elevation, and soil moisture vary spatially and temporally, whereas soil type, geology, and topography vary spatially. Precipitation that falls on the land surface is lost by runoff to streams and rivers and evapotranspiration, which leaves only a small fraction of the precipitation to recharge the aquifer.

Diffuse recharge occurs preferentially in topographically higher interstream areas. Focused recharge along streams can occur when the water table in the aquifer is below the stream-level elevation. If stream levels are lower than surrounding groundwater levels, groundwater discharges to streams resulting in gaining streams. Direct precipitation is the dominate recharge mechanism occurring in the Seymour aquifer. There is some very small potential for focused recharge from the Brazos River only in Baylor County. This focused recharge is expected to be periodic and occur predominantly during flood events.

Under undisturbed conditions, groundwater recharge is balanced by natural groundwater discharge. For a typical aquifer, undisturbed conditions coincide with the time period prior to pumping. For the Seymour aquifer, however, undisturbed conditions were disrupted by land use changes many years prior to the advent of significant pumping. The Seymour Formation and alluvial sediments that make up the Seymour Aquifer have experienced several land use changes as described in Section 2.3. Those changes and the resulting conceptualization of the aquifer are discussed below.

The original condition of the land overlying the Seymour Aquifer was that of native grassland or savannah plant communities prior to any disturbance by Anglos (Texas Parks and Wildlife, 2007). This land coverage was in existence until about 1880 when all nomadic Indians and buffalo were driven off the land (Texas State Historical Association, 2008). During this time, aquifer recharge and natural aquifer discharge would have been balanced. The condition of the Seymour Aquifer under these conditions is unknown. Although the native grasses would have required significant water, it is likely that some precipitation infiltrated to the groundwater and recharged the aquifer resulting in some saturated thickness. This assumption is supported by the existence of historical springs flowing from the aquifer (see Section 4.5.2). This time period is considered to be the only time period in recent history when the Seymour Aquifer was at true steady-state conditions.

The introduction of the first Anglo residents to the three counties in about 1880 brought with it livestock (Texas State Historical Association, 2008), which resulted in a significant change in the land coverage. Livestock were allowed to overgraze the land, which resulted in a depletion of the native grasses and the expansion of phreatophytes, particularly mesquite (Texas Parks and

Wildlife, 2007). It is very likely that evapotranspiration from the water table significantly increased when the land coverage changed from grassland or savannah plant communities to more brushland or woodland habitats due to overgrazing of the land. In addition, the damaged surface soil from overgrazing results in higher runoff and, consequently, lower infiltration of precipitation. These increases in evapotranspiration and runoff may have resulted in an increase in natural aquifer discharge and a decrease in aquifer recharge resulting in an overall decrease in water in storage in the aquifer. Early records indicate that little to no water was available over large portions of the Seymour Aquifer in Haskell and Knox counties in about 1905/1906 (Gordon, 1913).

The land use once again changed in the early 1900s when agricultural activity significantly increased in the three counties. The Texas State Historical Association (2008) indicates that farming was beginning to dominate ranching in the area in about 1910. The surge in farming continued, with a short lull following World War I, until about 1930 and was a result largely of the cotton boom from about 1900 to 1910 and then again from about 1920 to 1930. The advent of farming brought the clearing and plowing of land for crops. In addition, terracing of the land began in about 1928 (Sherrill, 1965). Replacing some of the brushland and woodland habitats with crops resulted in a reduction in water-table evapotranspiration. This, plus loosening the soil with plows, the presence of bare soil between crops, and the collection of rainfall with terraces, caused in an increase in aquifer recharge. This increase in recharge and decrease in natural aquifer discharge created an imbalance that resulted in increased water in storage in the aquifer. Bandy (1934) found that many portions of the Seymour Formation in Haskell County began filling with groundwater between the early 1900s and 1934 resulting in rising water levels and the development of water-logged areas. The existence of water-logged areas indicates that aquifer recharge exceeded natural aquifer discharge in these areas. In addition, groundwater was found in areas of the aquifer that were dry in the early 1900s as reported by Gordon (1913).

The 1930s were economically hard on these three counties due to the Great Depression and the Dust Bowl (Texas State Historical Association, 2008). It is likely that some of the land previously planted with crops was left uncultivated during the 1930s. Ogilbee and Osborne (1962) estimate an end to the rise in water levels in the Seymour Formation in about 1940.

Information regarding land use and aquifer conditions during the 1940s could not be found in the literature.

Although a general history of land use for the Seymour Aquifer from about 1910 to about 1940 was found, there is very little water-level data for the aquifer during this period (see Figure 4.3.2). Therefore, the amount of water in the aquifer and the location of the water table are unknown. One well located near the city of Rochester in Haskell County shows a rise in water level of 31 feet between 1926 and 1944. These observed water levels support the theory that the Seymour Aquifer experienced a significant rise in water level in some areas of Haskell County between about 1900 and 1934. Several wells in Haskell and Knox counties have an early water level measurement from 1936, 1937, or 1944 and then measurements at later times. For these wells, there is not a consistent trend in water level. Therefore, there are not enough data to support the hypothesis that the Seymour Aquifer experienced maximum water levels in about 1940.

Haskell, Knox, and Baylor counties, along with much of the state of Texas, experienced a severe drought from about 1951 through about 1957. The use of groundwater for irrigation purposes also exploded during this time. Ogilbee and Osborne (1962) state that there were 25 irrigation wells in Haskell and Knox counties in 1951 and 1,100 in 1956. In response to the drought and increased pumpage for irrigation purposes, water levels in the Seymour Aquifer generally fell during the 1950s. Since the late 1950s, water levels in the Seymour Aquifer have fluctuated due to changes in precipitation and pumping but have, in general, remained relatively stable (i.e., no significant permanent drawdown and no significant, permanent gains in storage). Table 5.0.1 summarizes conditions in the Seymour Aquifer over time.

Water removed from an aquifer by pumping is supplied through decreased groundwater storage (i.e., decreased water levels), reduced groundwater discharge, and sometimes increased aquifer recharge. If pumping stays relatively constant, a new steady-state condition will be established. In this new equilibrium, the source of pumped water will be drawn completely from either reduced discharge or increased recharge, with the latter component usually being relatively small. Bredehoeft (2002) terms these two volumes as capture. He also defines sustainable yield (pumped flow rate that is sustainable) as being equal to the rate of capture. For a given production volume to be sustainable (i.e., groundwater levels reach a new steady state), there must be enough groundwater capture volume to balance the pumping volume. If pumping exceeds the potential available capture volume for a basin, that basin will experience water-level declines until there are no recoverable groundwater reserves. This is equivalent to the "unstable" basin concept discussed in Freeze (1971).

The sources of capture as a result of pumping the Seymour Aquifer are expected to be primarily from capture of aquifer discharge with little to no potential for capture of additional recharge. Because the majority of the Brazos River in the active model area lies at an elevation beneath the Seymour Aquifer, little increased recharge potential from the river can be expected as a result of pumping. However, additional capture through reduced stream discharge is likely. Lowering the water table, as a result of pumping, beneath the extinction depth of phreatophyte and crop root systems may lead to discharge capture through the reduction of groundwater evapotranspiration. The distribution of rooting depths throughout the Seymour Aquifer is not well characterized and difficult to define, however. Additional capture through reduced flow to springs and seeps is also likely.

The conceptual model of the Seymour Aquifer since about 1957 is that of a stable groundwater aquifer where historical groundwater pumping values can be satisfied by groundwater capture over long-time periods (i.e., decades). Groundwater from the Seymour Aquifer is predominately used for irrigation purposes. Consequently, the aquifer is doubly stressed during periods of low precipitation because recharge is low and pumpage is high. Therefore, declines in water levels are observed for periods of little rainfall, but then the aquifer recovers during periods of abundant rainfall. However, when averaged since about 1957, water levels in the Seymour Aquifer have been fairly stable. The potential for capture of additional recharge as a result of pumping the Seymour Aquifer is expected to be low because the areas of high recharge (i.e., sandy soils in topographic highs) are generally distant from areas of natural discharge (i.e., topographic lows at the edge of the formation.

Groundwater from the Seymour Aquifer discharges to springs and seeps, local creeks, and the Brazos River, predominately in Baylor County. Springs and seeps occur along much of the boundary of the Seymour Aquifer. Some discharge from the Seymour Aquifer occurs by cross-formational flow to the underlying Permian-age sediments. Although the rates of cross-formational flow are expected to be low, when aggregated over the entire aquifer, they may amount to a significant portion of the Seymour Aquifer water budget. A large fraction of natural discharge is anticipated to be evapotranspiration, due to the shallow nature of the water table and the existence of phreatophytes throughout portions of the aquifer (R.W. Harden and Associates, 1978). This is expected to be especially important where the water table is shallowest and phreatophyte density is highest.

Groundwater flow within the Seymour Aquifer is controlled by topography, structure, and permeability variations. A map showing the inferred groundwater flow pattern is shown in Figure 4.3.4. This figure shows a major recharge area in the topographically high, sand hills region in the southwestern portion of the aquifer. Groundwater flow generally follows the topographical gradient along the major axis of the aquifer and discharges laterally to springs and seeps and the Brazos River and Lake Creek.

The boundaries for the refined groundwater availability model for the Haskell-Knox-Baylor pod of the Seymour Aquifer are represented conceptually in Figure 5.0.1. The boundary beneath the Seymour Aquifer is the erosion surface of the Permian-age sediments through which some groundwater discharges.

The vast majority of the inflow into the Seymour Aquifer occurs through recharge from precipitation. Recharge under pre-development conditions is expected to be lower than that estimated for modern conditions. A much lesser amount of inflow may occur from cross-formational flow from the Clear Fork Group, with only minimal inflows possible from losing streams into the alluvium of the Seymour Aquifer. Significant avenues for outflow include baseflow into streams and cross-formational discharge to the Clear Fork Group. Evapotranspiration and spring discharge together are expected to constitute a significant amount of outflow in riparian areas, from the edges of the Seymour aquifer, and from areas with dense phreatophyte growth. Under modern transient conditions, pumping is expected to be the largest discharge mechanism.

Table 5.0.1 Summary of conditions in the Seymour Aquifer.

Time Period	Description	Condition of Aquifer
prior to 1880	undisturbed; aquifer recharge equal to natural aquifer discharge	unknown, but some saturated thickness as indicated by flow in historical springs
1880-1900	increasing natural aquifer discharge through evapotranspiration due to replacement of native grassland and savannahs with brushlands and woodlands and decreased infiltration of precipitation due to damaged surface soil; natural aquifer discharge exceeds aquifer recharge	groundwater found in some areas but not in others; portions of aquifer dry
1900-1940	increasing aquifer recharge and decreased natural aquifer discharge due to development of agriculture; aquifer recharge exceeds natural aquifer discharge	aquifer fills with water, water-logged conditions in some areas
1940-1950	unknown	unknown
1950-1957	significant increase in pumping, for irrigation purposes; drawdown of groundwater over large portions of the aquifer; elimination of water-logged areas; aquifer discharge through pumping exceeds aquifer recharge	declining water levels
1957-1997	aquifer recharge about equal to aquifer discharge (natural and via pumping) over long time periods (i.e., decades)	stable groundwater aquifer with long-term water level fluctuations a function of precipitation and pumping

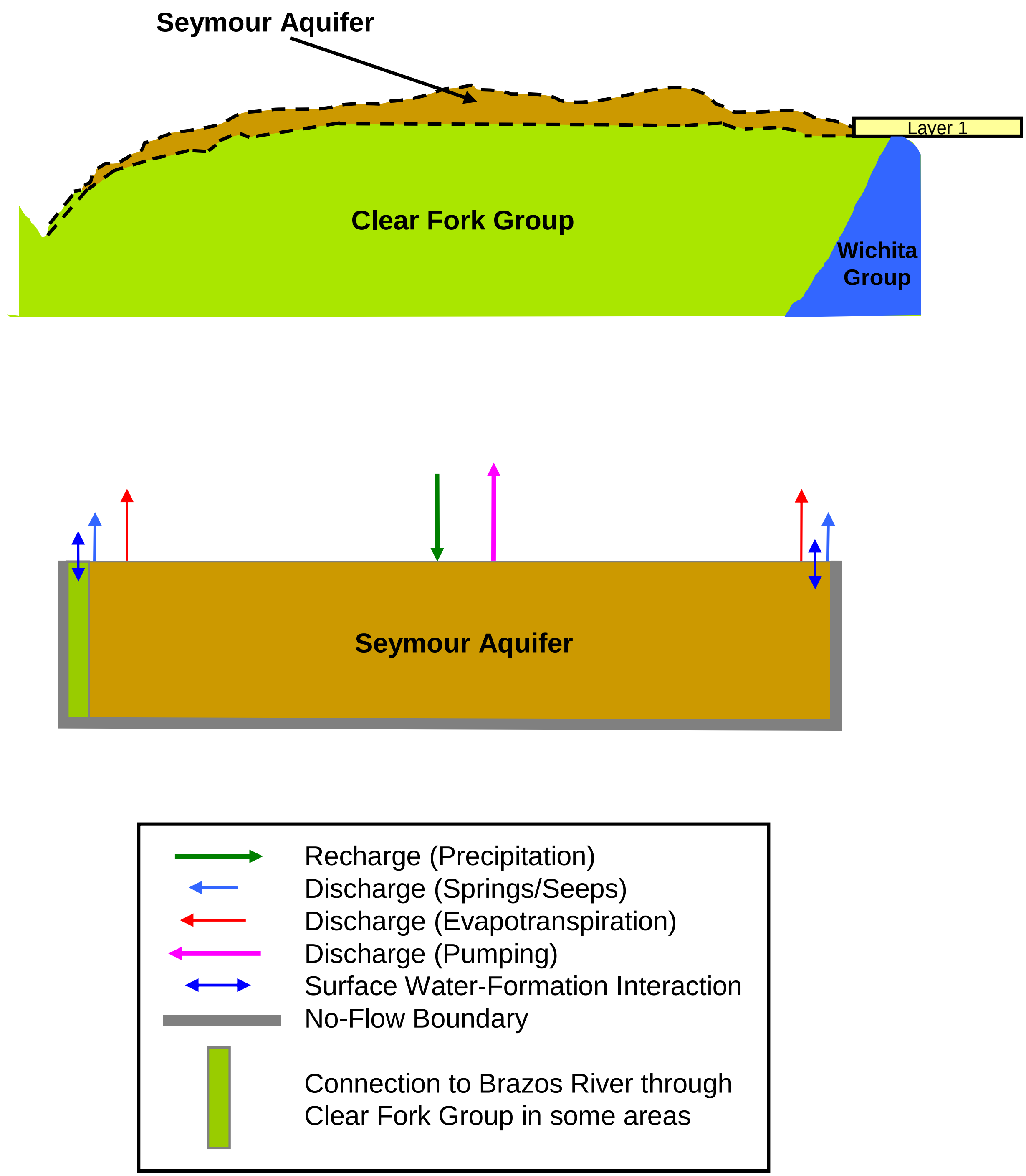


Figure 5.0.1 **Conceptual groundwater flow model (cross-sectional view) for the refined groundwater availability model for the Haskell-Knox-Baylor pod of the Seymour Aquifer.**

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APPENDIX A

Results of Investigation of Likely Completion of UNKNOWN wells located in the Seymour Aquifer

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Appendix A Results of Investigation of Likely Completion of UNKNOWN wells located in the Seymour Aquifer

State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2122813	Baylor	UNKNOWN	112SYMR	NA	Seymour Aquifer well because Preston (1978) states it produced 230 gallons per minute in 1969
2122910	Baylor	UNKNOWN	112SYMR	NA	Seymour Aquifer spring because Preston (1978) states it flows from Permian sandstone but source is Seymour alluvium
2129320	Baylor	UNKNOWN	112SYMR	NA	no information; not used
2129409	Baylor	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2130214	Baylor	UNKNOWN	112SYMR	NA	Seymour Aquifer spring because Preston (1978) states it flowed 25 gallons per minute in 1969 and owner reports it has never stopped flowing and Preston (1978) lists the Seymour Formation as the water bearing unit
2130801	Baylor	UNKNOWN	112SYMR	NA	not located in the pod
2141710	Haskell	110ALVM	112SCFX	S,P	Seymour Aquifer well (5)
2133704	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2133717	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2133719	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2133720	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2133801	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2133915	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2133916	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134704	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134710	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134730	Haskell	UNKNOWN	112SYMR	NA	no information; not used
2134827	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134851	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134926	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134946	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

Appendix A, continued

State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2135719	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135722	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135723	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135724	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135729	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135732	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135820	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135835	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141103	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141106	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141108	Haskell	110ALVM	112SYMR	S,P	Seymour Aquifer well (5)
2141110	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141116	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141117	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141119	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141120	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141121	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141122	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141124	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141126	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141128	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141129	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141130	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141131	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2141132	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

Appendix A, continued

State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2141133	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141134	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141135	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141136	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141138	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141141	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141201	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141205	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141206	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141207	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141208	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141209	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141306	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141309	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141312	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141313	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141315	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141316	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141320	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141322	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141323	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141403	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141408	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141409	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141412	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2141414	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141415	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141418	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141424	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141428	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141501	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141506	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141507	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141508	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141509	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141513	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141514	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141601	Haskell	110ALVM	112SYMR	S,P	Seymour Aquifer well (5)
2141602	Haskell	110ALVM	112SYMR	P	Seymour Aquifer well (5)
2141603	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141604	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141605	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141607	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141608	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141609	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141611	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141612	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141613	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141614	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141616	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2141620	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141701	Haskell	110ALVM	112SYMR	S,P	Seymour Aquifer well (5)
2141704	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141709	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141804	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141806	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141812	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141816	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141817	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141905	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141906	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141907	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141909	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141911	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141914	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141916	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142106	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142108	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142109	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142112	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142114	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142117	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142130	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142131	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142204	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

Appendix A, continued

State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2142216	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142218	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142222	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142227	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142228	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142229	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142255	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142257	Haskell	UNKNOWN	112SYMR	NA	no information; not used
2142305	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142331	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142334	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142335	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142336	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142340	Haskell	UNKNOWN	112SYMR	NA	no information; not used
2142414	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142416	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142420	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142421	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142423	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142424	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142425	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142426	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142427	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142437	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142442	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2142452	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142453	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142503	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142507	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142508	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142509	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142510	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142511	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142513	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142514	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142515	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142516	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142517	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142518	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142602	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142603	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142705	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142706	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142707	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142712	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142803	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2143108	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2143109	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2143110	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2143202	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2143203	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2149204	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2149205	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2149209	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2149302	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2149303	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2149304	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2149305	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2149307	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2149308	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2149313	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2149314	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2149403	Haskell	UNKNOWN	112SYMR	P	Permian well (7)
2149403	Haskell	UNKNOWN	112SYMR	P	Permian well (9)
2149505	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2149903	Haskell	112SYMR	112SYMR	S,P	Seymour Aquifer well (5)
2149906	Haskell	112SYMR	112SYMR	S,P	Seymour Aquifer well (5)
2149908	Haskell	112SYMR	112SYMR	S,P	Seymour Aquifer well (5)
2150104	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150106	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150107	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150108	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150109	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150111	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150112	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2150206	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150301	Haskell	112SYMR	112SYMR	P	Permian well (7)
2150302	Haskell	112SYMR	112SYMR	P	Seymour Aquifer well (5)
2150415	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150443	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150506	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150512	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150514	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150515	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150530	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150531	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150555	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150556	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150557	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150558	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150559	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150639	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2150651	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150652	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150654	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150703	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2150804	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151407	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151411	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151413	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2151418	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151420	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151421	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151714	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151715	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151717	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2151723	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151725	Haskell	110ALVM	112SYMR	P	Seymour Aquifer well (5)
2151729	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151730	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151733	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151735	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151737	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151738	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2151739	Haskell	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2142901	Haskell	310PRMN	310PRMN	P	Permian well (3)
2151301	Haskell	310PRMN	310PRMN	P	Permian well (3)
2136702	Haskell	318CLFK	318CLFK	P	Permian well (3)
2141706	Haskell	318CLFK	318CLFK	P	Permian well (3)
2143901	Haskell	318CLFK	318CLFK	P	Permian well (3)
2143902	Haskell	318CLFK	318CLFK	P	Permian well (3)
2144201	Haskell	318CLFK	318CLFK	P	Permian well (3)
2144202	Haskell	318CLFK	318CLFK	P	Permian well (3)
2144203	Haskell	318CLFK	318CLFK	P	Permian well (3)
2144501	Haskell	318CLFK	318CLFK	P	Permian well (3)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2144601	Haskell	318CLFK	318CLFK	P	Permian well [3]
2144701	Haskell	318CLFK	318CLFK	P	Permian well [3]
2144801	Haskell	318CLFK	318CLFK	P	Permian well [3]
2149622	Haskell	318CLFK	318CLFK	P	Permian well [3]
2149801	Haskell	318CLFK	318CLFK	P	Permian well [3]
2149901	Haskell	318CLFK	318CLFK	P	Permian well [3]
2149902	Haskell	318CLFK	318CLFK	P	Permian well [3]
2149905	Haskell	318CLFK	318CLFK	P	Permian well [3]
2150803	Haskell	318CLFK	318CLFK	P	Permian well [3]
2150811	Haskell	318CLFK	318CLFK	P	Permian well [3]
2150903	Haskell	318CLFK	318CLFK	P	Permian spring [4]
2151601	Haskell	318CLFK	318CLFK	P	Permian well [3]
2151901	Haskell	318CLFK	318CLFK	P	Permian well [3]
2152101	Haskell	318CLFK	318CLFK	P	Permian well [3]
2152402	Haskell	318CLFK	318CLFK	P	Permian well [3]
2157201	Haskell	318CLFK	318CLFK	P	Permian well [3]
2157202	Haskell	318CLFK	318CLFK	P	Permian well [3]
2157301	Haskell	318CLFK	318CLFK	P	Permian well [3]
2157302	Haskell	318CLFK	318CLFK	P	Permian well [3]
2157303	Haskell	318CLFK	318CLFK	P	Permian well [3]
2157401	Haskell	318CLFK	318CLFK	P	Permian well [3]
2157701	Haskell	318CLFK	318CLFK	P	Permian well [3]
2157801	Haskell	318CLFK	318CLFK	P	Permian well [3]
2157802	Haskell	318CLFK	318CLFK	P	Permian well [3]
2157901	Haskell	318CLFK	318CLFK	P	Permian well [3]

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2157902	Haskell	318CLFK	318CLFK	P	Permian well (3)
2158101	Haskell	318CLFK	318CLFK	P	Permian well (3)
2158102	Haskell	318CLFK	318CLFK	P	Permian well (3)
2158301	Haskell	318CLFK	318CLFK	P	Permian well (3)
2158302	Haskell	318CLFK	318CLFK	P	Permian well (3)
2158501	Haskell	318CLFK	318CLFK	P	Permian well (3)
2158601	Haskell	318CLFK	318CLFK	P	Permian well (3)
2159201	Haskell	318CLFK	318CLFK	P	Permian well (3)
2159202	Haskell	318CLFK	318CLFK	P	Permian well (3)
2159601	Haskell	318CLFK	318CLFK	P	Permian well (3)
2159602	Haskell	318CLFK	318CLFK	P	Permian well (3)
2159603	Haskell	318CLFK	318CLFK	P	Permian well (3)
2159801	Haskell	318CLFK	318CLFK	P	Permian well (3)
2159901	Haskell	318CLFK	318CLFK	P	Permian well (3)
2133710	Knox	100ALVM	100ALVM	S,P	Seymour Aquifer well (5)
2133807	Knox	110ALVM	112SCFX	S,P	Seymour Aquifer well (5)
2133809	Knox	110ALVM	112SCFX	S,P	Seymour Aquifer well (5)
2119101	Knox	UNKNOWN	112SYMR	NA	not located in the pod
2119213	Knox	UNKNOWN	112SYMR	NA	not located in the pod
2119215	Knox	UNKNOWN	112SYMR	NA	not located in the pod
2119317	Knox	UNKNOWN	112SYMR	NA	not located in the pod
2119318	Knox	UNKNOWN	112SYMR	NA	not located in the pod
2119322	Knox	UNKNOWN	112SYMR	NA	not located in the pod
2127808	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2127810	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2127901	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2127907	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2127912	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2127915	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2127918	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2127919	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2127921	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2127922	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2127942	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128302	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128406	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128408	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128409	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128503	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128601	Knox	UNKNOWN	112SYMR	P	Permian spring (8)
2128601	Knox	UNKNOWN	112SYMR	P	Permian spring based on the water bearing unit identified as the Permian in R.W. Harden and Associations (1978)
2128602	Knox	UNKNOWN	112SYMR	P	Permian spring (8)
2128602	Knox	UNKNOWN	112SYMR	P	Permian spring based on the water bearing unit identified as the Permian in R.W. Harden and Associations (1978)
2128702	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128706	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128707	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128708	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128712	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128714	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2128716	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128721	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128722	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128804	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128806	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128807	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128810	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128812	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128819	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128820	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128824	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128826	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128827	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128828	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128833	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128904	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128905	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128908	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128909	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2128910	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2129408	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2129702	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2133601	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2133607	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2133611	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2133705	Knox	110ALVM	112SYMR	S,P	Seymour Aquifer well (5)
2133711	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2133806	Knox	110ALVM	112SYMR	S,P	Seymour Aquifer well (5)
2133808	Knox	110ALVM	112SYMR	S,P	Seymour Aquifer well (5)
2133811	Knox	110ALVM	112SYMR	S,P	Seymour Aquifer well (5)
2133908	Knox	110ALVM	112SYMR	S,P	Seymour Aquifer well (5)
2134208	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134225	Knox	UNKNOWN	112SYMR	NA	no information; not used
2134226	Knox	UNKNOWN	112SYMR	NA	no information; not used
2134303	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134313	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134314	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134317	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134318	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134322	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134323	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2134326	Knox	UNKNOWN	112SYMR	NA	no information; not used
2134406	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134428	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134434	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134443	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134445	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2134446	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134508	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134510	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2134517	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134520	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134521	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134524	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134525	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134526	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134533	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134536	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134549	Knox	UNKNOWN	112SYMR	NA	no information; not used
2134607	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134611	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134617	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134621	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134622	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134626	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134646	Knox	UNKNOWN	112SYMR	NA	no information; not used
2134705	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134712	Knox	110ALVM	112SYMR	S,P	Seymour Aquifer well (5)
2134713	Knox	110ALVM	112SYMR	S,P	Permian well (7)
2134716	Knox	110ALVM	112SYMR	S,P	Seymour Aquifer spring (6)
2134721	Knox	110ALVM	112SYMR	S,P	Seymour Aquifer well (5)
2134724	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134806	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134807	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134828	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2134836	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134846	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134847	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2134920	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135105	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2135106	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2135127	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135128	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135130	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135136	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135137	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135138	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135139	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135140	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135142	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135143	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135214	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135218	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135219	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135316	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135319	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135322	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135323	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135324	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135339	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2135340	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135342	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135343	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135344	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135345	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135346	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135347	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135348	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135349	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135350	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135351	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135353	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135354	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135355	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135356	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135357	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135358	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135359	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135360	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135363	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135365	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135366	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135368	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135420	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135433	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2135445	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135447	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135458	Knox	UNKNOWN	112SYMR	NA	no information; not used
2135506	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135517	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135540	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135541	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135542	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135610	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135615	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135616	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135623	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135625	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135626	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135627	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135629	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135631	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135632	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135633	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135634	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135635	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135636	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135637	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135639	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135640	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2135645	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135646	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135647	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135649	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135656	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135657	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135668	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135708	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135709	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135710	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135802	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135812	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135828	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135831	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2135901	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136106	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136108	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136117	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136126	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136128	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136129	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136130	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136135	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136136	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136137	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

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State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2136138	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136139	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136140	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136141	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136142	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136143	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136144	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136147	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136148	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136149	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136150	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136151	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136152	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136212	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136213	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136215	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136217	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136218	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136219	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136221	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136223	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136233	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136234	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136235	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136236	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

Appendix A, continued

State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2136237	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136238	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136239	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136240	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136241	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136305	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136316	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136318	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136409	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136411	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136412	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136414	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136416	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136418	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136421	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136422	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136423	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136424	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136425	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136433	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136434	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136437	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136439	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136446	Knox	UNKNOWN	112SYMR	NA	no information; not used
2136507	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

Appendix A, continued

State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2136511	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136601	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2136602	Knox	UNKNOWN	112SYMR	S	Seymour Aquifer spring (2)
2127301	Knox	310PRMN	310PRMN	P	Permian well (3)
2126101	Knox	318CLFK	318CLFK	P	Permian well (3)
2126301	Knox	318CLFK	318CLFK	P	Permian well (3)
2126302	Knox	318CLFK	318CLFK	P	Permian well (3)
2126303	Knox	318CLFK	318CLFK	P	Permian well (3)
2126304	Knox	318CLFK	318CLFK	P	Permian well (3)
2126402	Knox	318CLFK	318CLFK	P	Permian well (3)
2126502	Knox	318CLFK	318CLFK	P	Permian well (3)
2126503	Knox	318CLFK	318CLFK	P	Permian well (3)
2126504	Knox	318CLFK	318CLFK	P	Permian well (3)
2126601	Knox	318CLFK	318CLFK	P	Permian well (3)
2126701	Knox	318CLFK	318CLFK	P	Permian well (3)
2127101	Knox	318CLFK	318CLFK	P	Permian well (3)
2127102	Knox	318CLFK	318CLFK	P	Permian well (3)
2127103	Knox	318CLFK	318CLFK	P	Permian well (3)
2128101	Knox	318CLFK	318CLFK	P	Permian well (3)
2128201	Knox	318CLFK	318CLFK	P	Permian well (3)
2133201	Knox	318CLFK	318CLFK	P	Permian well (3)
2133401	Knox	318CLFK	318CLFK	P	Permian well (3)
2133501	Knox	NOT_APPL	NOT_APPL	P	Permian well (9)
2141405	Stonewall	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141420	Stonewall	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)

Appendix A, continued

State Well Number	County	Aquifer Code Assigned in August 2008	Previous Aquifer Code	Water Bearing Unit in R.W. Harden and Associates (1978)	Comments
2141422	Stonewall	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141425	Stonewall	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141427	Stonewall	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2141705	Stonewall	UNKNOWN	112SYMR	S	Seymour Aquifer well (1)
2248601	Stonewall	UNKNOWN	112SYMR	S,P	Seymour Aquifer well (5)

NA - not included in R.W. Harden and Associations (1978)
P - water bearing unit identified as Permian by R.W. Harden and Associates (1978)
S - water bearing unit identified as Seymour by R.W. Harden and Associates (1978)
(1) considered to be a Seymour Aquifer well based on the water bearing unit identified as the Seymour Formation in R.W. Harden and Associates (1978)
(2) considered to be a Seymour Aquifer spring based on the water bearing unit identified as the Seymour Formation in R.W. Harden and Associates (1978)
(3) considered to be a Permian well based on aquifer code
(4) considered to be a Permian spring based on aquifer code
(5) considered to be a Seymour Aquifer well based on water chemistry
(6) considered to be a Seymour Aquifer spring based on water chemistry
(7) considered to be a Permian well based on water chemistry
(8) considered to be a Permian spring based on water chemistry
(9) considered to be a Permian well based on water bearing unit identified as Permian in R.W. Harden and Associates (1978) and location outside of the Seymour Aquifer

APPENDIX B

Draft Conceptual Model Report Comments and Responses

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Seymour Conceptual Report to the Texas Water Development Board

REQUIRED CHANGES

Conceptual Report Comments:

General Comments:

General:

In general the report is very well written and thoroughly addresses the requirements for the development of the conceptual model

When referencing the Texas Water Development Board in the text, please either universally abbreviate to "TWDB" or spell out as "Texas Water Development Board." The text currently contains a mixture of these reference styles.

Completed.

In the final report we suggest adding a comparison table or section to indicate differences and similarities between this refined portion and the original Seymour Groundwater Availability Model, as well as implications for anyone using the original model results for one of the other pods.

No change. A table of this type should be included in the model report rather than the conceptual model report.

Specific Comments:

Introduction.

1. Page 1-3, last paragraph, last sentence. Please use a different term other than "intersects" such as overlaps, or overlays, or falls within.

    Completed. See Section 1.0 last paragraph.

Chapter 2.

2. Figure 2.0.6, Page 2-8, per Exhibit B, Attachment 1 page 19 of 24 of contract please include the date of the Groundwater Conservation District map on the Figure.

    Completed. See Figure 2.0.6 title.

3. Sect. 2.0, Pg. 2-1, Para. 2: The last sentence references that depth of lower model boundary will be determined based on model behavior. Please explain what behavior(s) and how the behavior(s) will determine the lower model boundary.

   Completed. Statement removed from text.

4. Sect. 2.0, Pg. 2-2, Para. 1: Please use a different term other than "intersects" such as is contained within or lies within.

   Completed. See Section 2.0, last paragraph.

5. Figure 2.0.5, page 2-7, Please rename "Regional Water Planning Group" to Regional Water Planning Area. Please check GIS Regional Water Planning Area boundary files and make certain they are correct since they do not appear to coincide with county boundaries.

   Completed. See Figure 2.0.5. County boundaries updated using TWDB county shapefile dated 8-12-08.

6. Figure 2.0.6, page 2-8, Please check GIS Groundwater Conservation District boundary files and make certain they are correct since they do not appear to coincide with county boundaries.

   Completed. See Figure 2.0.6. County boundaries updated using TWDB county shapefile dated 8-12-08.

7. Sect. 2.1, Pg. 2-13, Para. 2: The first sentence references Texas Parks and Wildlife, 2009 which is not in the references section. Figure 2.1.2 references Texas Parks and Wildlife, 2006 for ecological regions. Please add or correct as needed.

   Completed. See Figure 2.1.2 and Reference Section.

8. Sect. 2.0, Pg. 2-14, Para. 2: Please correct grammar for last sentence and remove "average".

   Completed. Removed sentence, see Section 2.1, paragraph 5.

9. Sect. 2.0, Pg. 2-14, Para. 3: Last sentence states a high of 27 inches per year in the east whereas Figure 2.1.9 shows 27.5 inches per year in the east.

   Completed. See Section 2.1, paragraph 6.

10. Physiography and climate section 2.1, per Exhibit B, Attachment 1 page 2 of 24 of contract please include some discussion of evapotranspiration in the study area.

    Completed. See Section 2.1, last paragraph and Figure 2.1.12.

11. Sect. 2.1, Pg. 2-14, Para. 2: Please reference Texas A&M University (2002) in the text as the source of the mean annual temperature information.

    Completed. See Section 2.1, paragraph 5.

12. Sect. 2.1, Pg. 2-14, Para. 3: The text states that 12 precipitation gages are in the study area while Figure 2.17 shows 13. Please correct text or figure as needed. Also, please reference National Climate Data Center (2001) in the text as the source of precipitation gage data.

    Completed. See Section 2.1, paragraph 6.

13. Figure 2.1.9, page 2-24, Please use a monochromatic color scale for ratio data types.

    Completed. See Figure 2.1.9.

14. Figure 2.2.1, page 2-31, Structural syncline shows blue boundary. Please label blue edge of syncline with anticline symbol if it is indeed an anticline as most synclines are adjacent to anticlines.

    No change. There is an anticline to the north of this feature outside of the study area but not one to the south of the feature per the original source (i.e., Price, 1979).

15. Figure 2.2.2, page 2-32, Please list rock units for legend with youngest on top and oldest on bottom.

    Complete. See Figure 2.2.2.

16. Figure 2.2.3, page 2-33, Please revise schematic of generalized stratigraphy so that stratigraphic units correlate with geochronologic units or correct figure such that the Seymour does not appear to be of Permian age.

    Completed. See Figure 2.2.3

Chapter 4.

17. Section 4.0, please consider moving the five paragraph discussion of change in aquifer codes to Section 4.3 Water Levels and Regional Groundwater Flow.

    No change. Since the discussion of changes in aquifer code includes a discussion of springs, which are addressed in Section 4.5, as well as wells no change was made.

18. Sect. 4.0, Pg. 4-2, Para. 1: Though I think the inclusion of the 455 wells in R.W. Harden and Associates is important, the logic behind their use described here could be clearer. Suggest adding that it is unlikely that these wells in the study area were drilled past the

relatively high quality water of the Seymour Aquifer into the lower quality water of the Permian units.

Completed. See Section 4.0, paragraph 3.

19. Sect. 4.0, Pg. 4-3, Para. 3: This paragraph references Figure 4.0.1, which is not included at the end of this section. Suggest moving Figure 4.0.1 to this section instead of sect. 4.1.

    Completed. See end of Section 4.0.

20. Please provide more detailed discussion regarding the resolution used to interpolate the structural surfaces.

    Completed. See Section 4.2, paragraph 4.

21. Please provide a more detailed discussion of the hydrostratigraphy of the Clear Fork Group formations.

    Completed. See Section 4.1, paragraph 4.

22. Section 4.1 It's not clear why the active area extends past the aquifer boundary mostly on the western side of the aquifer. Please explain.

    Completed. See Section 4.1, last paragraph.

23. Sect. 4.1, Pg. 4-5, Para. 2: This paragraph references "volcanic ash" as a constituent of the Seymour Aquifer. Nowhere else is this mentioned within the report. Please check for accuracy of this statement or be consistent throughout the report when discussing sediment composition of the Seymour Aquifer.

    Completed. See Section 2.2, paragraph 5, Section 4.1, paragraph 2, and Section 4.6, first paragraph.

24. Sect. 4.1, There is no detailed discussion of the formations within the Clear Fork Group. Please provide more discussion of the formations within the Clear Fork Group regarding lithology, hydraulic characteristics of the Choza, Vale, and Arroya formations.

    Completed. See Section 4.1, paragraph 4.

25. Sect. 4.2, Pg. 4-9, Para. 3: The report states that "These values [Avg. value of contour surface at 1 mile grid scale] were then merged with the other point data." Was this merge an average of the contour value with zero or more drillers logs or was a different method used? Please clarify how the merge took place.

    Completed. See Section 4.2, paragraph 3.

26. Sect. 4.2, Pg. 4-15, Fig. 4.2.4: The text on page 4-10 states that a minimum thickness of 20 feet was assumed for the structure. However, Fig. 4.2.4 shows many areas with a thickness of less than 20 feet. Please revise text and/or figure as needed.

    Completed. See Figure 4.2.4.

27. Sect. 4.2, Pg. 4-10, Para. 3: please state what constant thickness value will be assigned for model layer 2.

    Completed. Statement regarding layer 2 thickness was removed from the text.

28. Please discuss methodology to estimate the recharge for the Permian outcrops.

    Completed. See Section 4.4, first paragraph.

29. Sect. 4.4, Pg. 4-65, Para. 3: There are two references here for Sherrill (1956) that should most likely be Sherrill (1965). Please correct as needed.

    Completed. See Section 4.4, paragraph 3.

30. Sect. 4.4.2.1, Pg. 4-71, Para. 1: Please spell out "Texas Water Development Board" in the reference for consistency with other references.

    Completed. See Section 4.4.2.1, paragraph 1. The abbreviation TWDB is used throughout the document, except for the first time it is used where Texas Water Development board is spelled out and the abbreviation is given.

31. Sect. 4.4.1.2, Pg. 4-70, Para. 2: The last sentence in this paragraph states that "This method…can be used as a regional estimate for recharge because water levels measured in a well should be representative of water levels in a large area around the well." This seems to me to be an overly general statement that may give the wrong impression about the potential for water level variability in the aquifer. Please add clarification, justification, and/or qualification as necessary.

    Completed. See Section 4.4.1.2, first paragraph.

32. Sect. 4.4.2.1, Pg. 4-71, Para. 1: Please provide units for water content in the text "0.04 to 0.06."

    Completed. See Section 4.4.2.1, paragraph 2.

33. Sect. 4.4.1 – 4.4.3: Suggest moving these sections to an appendix and briefly summarizing the methods and results here (or using most of the summary in Sect. 4.4.3). the format of methods, results and discussion, and summary and recommendations does not seem to fit well into the overall scheme of the report.

    No change.

34. Sect. 4.5.1, Pg. 4-91, Para 1: Please spell out “Texas Water Development Board” in the reference for consistency with other references and with the references section. This occurs many times in the report.

    Completed. The abbreviation TWDB is used throughout the document, except for the first time it is used where Texas Water Development board is spelled out and the abbreviation is given.

35. Sect. 4.5.2, Pg. 4-93, Para.1: Please change “where” to “were” in the last sentence.

    Completed. See Section 4.5.2, first paragraph.

36. Sect. 4.5.1, Pg. 4-93: Please add discussion on how the information needed for the streamflow-routing package will be collected (e.g. streambed top and bottom, channel width and slope, Manning’s roughness coefficient).

    No change. Information of this type belongs in the model report not the conceptual model report.

37. Sect. 4.6.2, Pg. 4-108, Para. 2: Please add Theis and others (1963) to references section.

    Completed. See Section 6.

38. Sect. 4.6.7, Pg. 4-111, Para. 1: The last sentence states that the specific yield for the Clear Fork and Wichita groups was “assumed to be approximately 0.15.” Please provide a source or support for this assumption.

    Completed. See Section 4.6.7.

39. Section 4.7 Are there any estimates of pumping in the Clear Fork Group? Will pumping be included in the Clear Fork Group? If so, per Exhibit B, Attachment 1 page 5 of 24 of contract, please include that information in Section 4.7.

    No change.

40. Figure 4.7.2, page 4-131, Legend – two items are labeled as Municipal, please clarify which is Municipal and which is Rural domestic.

    Completed. See Figure 4.7.2.

Chapter 5.

41. Figure 5.0.1, Pg. 5-8: Please add a line to delineate boundary between Seymour (Layer 1) and Permian (Layer 2) to the upper part of the figure.

    Completed. See Figure 5.0.1.

42. The report states that evapotranspiration is expected to be a very significant portion of the water budget. Please provide detailed discussion regarding evapotranspiration and how it will be implemented in the model.

    No change. Information of this type belongs in the model report not the conceptual model report.

43. Please explain how recharge will be implemented for the both the steady-state and transient periods. Will there be a relationship to precipitation or will recharge be constant and the same for both steady-state and transient periods?

    No change. Information of this type belongs in the model report not the conceptual model report.

Chapter 6.

44. Sect. 6.0, Pg. 6-5: The two Texas Parks and Wildlife (2006 and 2007) references are in the wrong order. Please correct.

    Completed. Texas Parks and Wildlife (2006) should be Texas Parks and Wildlife (2009). Correction made in Section 6.

Source Geodatabase and Figures Comments:

45. Please update the county boundary layer and revise all figures where county boundaries are present.

    Completed. See "counties_SY" feature class and all figures.

46. Please remove duplicate features from the RA_Seymour_Study_Area feature class.

    Completed. See "RA_Seymour _Study_Area" feature class.

47. Figure 2.0.8: Please revise this figure to include a hatched area for the overlap between the two river authorities and add the word "River" after Brazos in the legend.

    Completed. See Figure 2.0.8.

48. Figure 2.1.4: Please include a climate classification feature class. (per Exhibit B Attachment 1, Section 4.2)

    Completed. See "Climate_Class" feature class.

49. Figure 2.1.5: Please add the temperature attribute to the "ave_temp_tx_Griffiths_SY" feature class.

Completed. See feature class ‘avg_temp_tx_Griffiths_SY’.

50. Figure 2.1.6: Please add time series data for this figure. (per Exhibit B Attachment 1, Section 4.2)

    Completed. See “Avg_Monthly_Temp” table.

51. Figure 2.1.8: Please add time series data for this figure. (per Exhibit B Attachment 1, Section 4.2)

    Completed. See “Station_Prec_Time_Series” table.

52. Figure 2.1.11: Please add time series data for this figure. (per Exhibit B Attachment 1, Section 4.2)

    Completed. See “Average_Monthly_Lake_Evaporation” table.

53. Figure 2.2.1: Please include a feature class for the Baylor syncline. (per Exhibit B Attachment 1, Section 4.2)

    Completed. See “Baylor_Syn_Poly” feature class.

54. Figure 2.2.4: Please include the high resolution (300 dpi) image used in this figure.

    Completed. See Figure 2.2.4.

55. Figure 4.2.1: Driller’s logs from RPGCD seems to be using “sey_base_McGuire” feature class. Please rename feature class in a manner consistent with its representation.

    Completed. See “sey_base_RPGCD_logs” feature class.

56. Figures 4.2.2 through 4.2.5: Data associated with these figures need to be revised because:
    a. The base of the Seymour is above the top in several locations
    b. Raster grids have different resolutions (200 or 660); you should match the model grid cell size since this information will make its way into the model
    c. Raster grids are not aligned to the model grid, or not even aligned with each other; please use the snap raster option when generating these surfaces

    Completed. See “model_grid_update” feature class.

57. Figures 4.3.8 through 4.3.10: The point feature classes: “Seymour_1980”, “Seymour_1990”, and “Seymour_1997” have corrupted/inaccessible attribute tables. Please revise these feature classes.

    Completed. See “Seymour_1980_Rev”, “Seymour_1990_Rev”, and “Seymour_1997_Rev” feature classes.

58. Figure 4.4.1: The land use raster dataset should probably be found in the ConservationLandUse raster catalog. The raster dataset does not match this figure. Please add a field with nominal values to describe your reclassification and revise the data to include the missing class.

    Partially completed. The land use raster shown on this figure represents combined National Land Cover Dataset classes as they apply to the evaluation of recharge. Therefore, the raster was not moved from the RechargeGrids raster catalog. A field was added to the land use raster to include the description of the combined land use. The raster data in this figure just applies to the land cover. The irrigated agriculture shown on this figure is a polygon feature class that is separate from the land cover and consists of irrigated areas. Therefore, the irrigated agriculture coverage was not added to the raster. The figure was modified to show that the land use and irrigated agriculture are different. Text was also added to Section 4.4, paragraph six to clarify the content of Figure 4.4.1.

59. Figure 4.4.3: Please include time series data for this figure. (per Exhibit B Attachment 1, Section 4.2)

    Completed. See "haskell_prec_data" table.

60. Figure 4.4.5: Please add tabular data to support these figures. (per Exhibit B Attachment 1, Section 4.2)

    Completed. See "WC_Soil_Type_Comp" table.

61. Figure 4.6.1: The TCEQ feature class has no specific capacity values and we could not locate a feature class for specific yield from county reports. Please revise.

    Completed. See "SC_values_RPBGC_logs", "SC_values_TCEQ_logs", and "Storage_locations" feature classes

62. Figure 4.6.2: Please provide data for this figure. (per Exhibit B Attachment 1, Section 4.2)

    Completed. See "SC_vs_T" table.

63. Figure 4.6.5: It is not clear what data you used to interpolate. The Kh_data_points feature class has duplicate entries for some wells, and the high values in the attribute table were not honored or closely reproduced.

    No change. The duplicate points were counted twice because the represent multiple measurements rather than the same measurement counted twice. The fact that the high values were not (closely) honored has to do with the fact that kriging was used to interpolate the data. Kriging, by definition, has a nugget effect whereby local anomalies will not be honored locally beyond the nugget and not honored elsewhere beyond the scale (1/8 mile by 1/8 mile in the final case) in

any case. Text was added to Section 4.6.5, first paragraph to indicate where the discussion of implementation of hydraulic conductivity in the model can be found in the text.

64. Please include the arbitrary bottom of the Permian-age formations in the geodatabase, provide explanations in the metadata, and include appropriate figures in the report. (per Exhibit B Attachment 1, Section 4.2)

    No change. The bottom of the Permian-age formations is not presented in the report.

65. Per Exhibit B, Attachment 1 page 15 of 24 of contract, please provide tabular data for hydraulic properties and GIS locations of point data. The information shown on Figures 4.6.1 though 4.6.5 is not provided in the geodatabase.

    Completed. See "Hydraulic_Property_Data" table.

SUGGESTIONS

66. Page 1-3, first paragraph, third line, suggest changing "<u>This</u> involves …" to "<u>It</u> involves…"

    Completed with alternative wording. See Section 1.0, paragraph 7.

67. Page 2-1, last paragraph, suggest changing both occurrences of Regional Water Planning Group to Regional Water Planning Area.

    Completed. See Section 1.0, last paragraph, Section 2.0, paragraph 3, and Figure 2.0.5.

68. Page 3-1, 1st paragraph, line 5, suggest changing "(1978) <u>is</u> his report ..." to "(1978) <u>in</u> his report .."

    Completed. See Section 3.0, first paragraph.

69. Page 4-21, suggest removing paragraph six "The probability ….ago", because this was already stated on page 4-19 at the end of the last paragraph.

    Completed. See Section 4.3.1.

70. Page 4-67, 1st paragraph, line 6 , suggest changing "Table 4.1.1" to "Table 4.4.1".

    Completed. See Section 4.4, paragraph 6.

71. Page 4-67, 2nd paragraph, line 7, suggest breaking paragraph at "The long-term mean annual…", since it is a new topic.

Completed. See Section 4.4, paragraph 8.

72. Page 4-95, section 4.5.3: Lake Davis might not overlay the aquifer boundary, but it does overlay your active area boundary. Please clarify.

    Completed. See Section 4.5.3, first paragraph

73. Page 4-119, section 4.7.1: You state that in western Knox and Haskell counties the Seymour Aquifer discharges to the Brazos River. In Haskell County the aquifer rarely approaches the river. And the only study that quantifies discharge was where the river runs across the aquifer beginning at the border of Knox and Baylor counties. Please provide data/studies to support the statement?

    Completed. Added wording indicting that the aquifer most likely discharges to the Brazos River due to the higher elevation of the aquifer than of the river channel. See Section 4.7.1, paragraph 2.

74. Page 4-71, 1st paragraph, last line, suggest changing “range” to “ranging”.

    Completed. See Section 4.4.2.1, first paragraph.

75. Page 5-1, last paragraph, last sentence, suggest changing “small <u>faction</u>...” to “small <u>fraction</u> …”.

    Completed. See Section 5.0, paragraph 3.

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