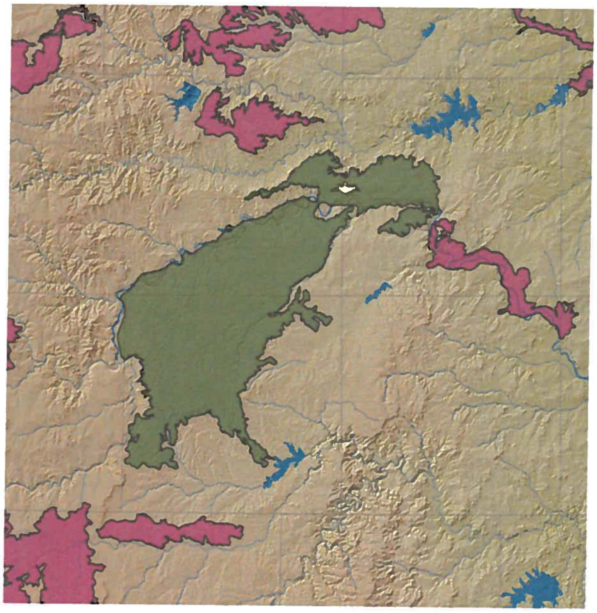
Final Report
Conceptual Model for the Refined Seymour Aquifer Groundwater Availability Model: Haskell, Knox, and Baylor Counties



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:

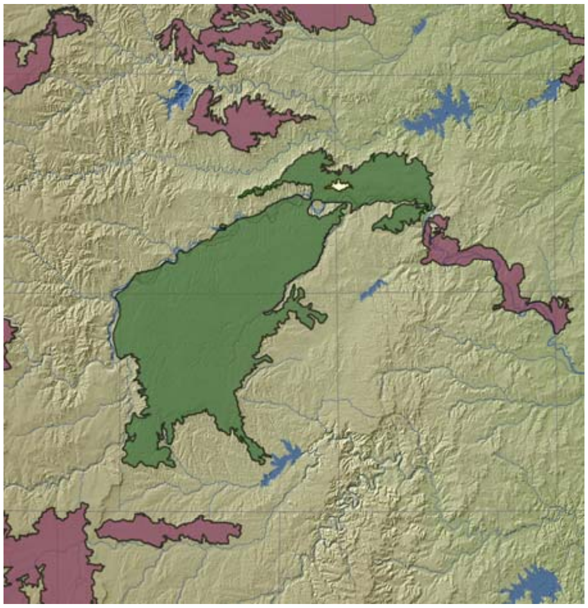
Texas Water Development Board

February 2012

2012 FEB 10 AM 8:55
CONTRACT ADMINISTRATION

0804830796

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

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.
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

Prepared for:

Texas Water Development Board

February 2012

This page is intentionally blank.

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.

JOHN F. PICKENS
GEOLOGY
No. 1962

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.

JOHN E. EWING
92817

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.

TOYA JONES DALE
GEOLOGY
No. 2497

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.

BRIDGET SCANLON
GEOLOGY
NO. 1645

Bridget R Scanlon
Signature

2/8/12
Date

This page intentionally left blank.

Table of Contents

Table of Contents, continued

List of Figures

List of Figures, continued

List of Figures, continued

List of Figures, continued

List of Figures, continued

This page is intentionally blank.

List of Tables

List of Tables, continued

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.

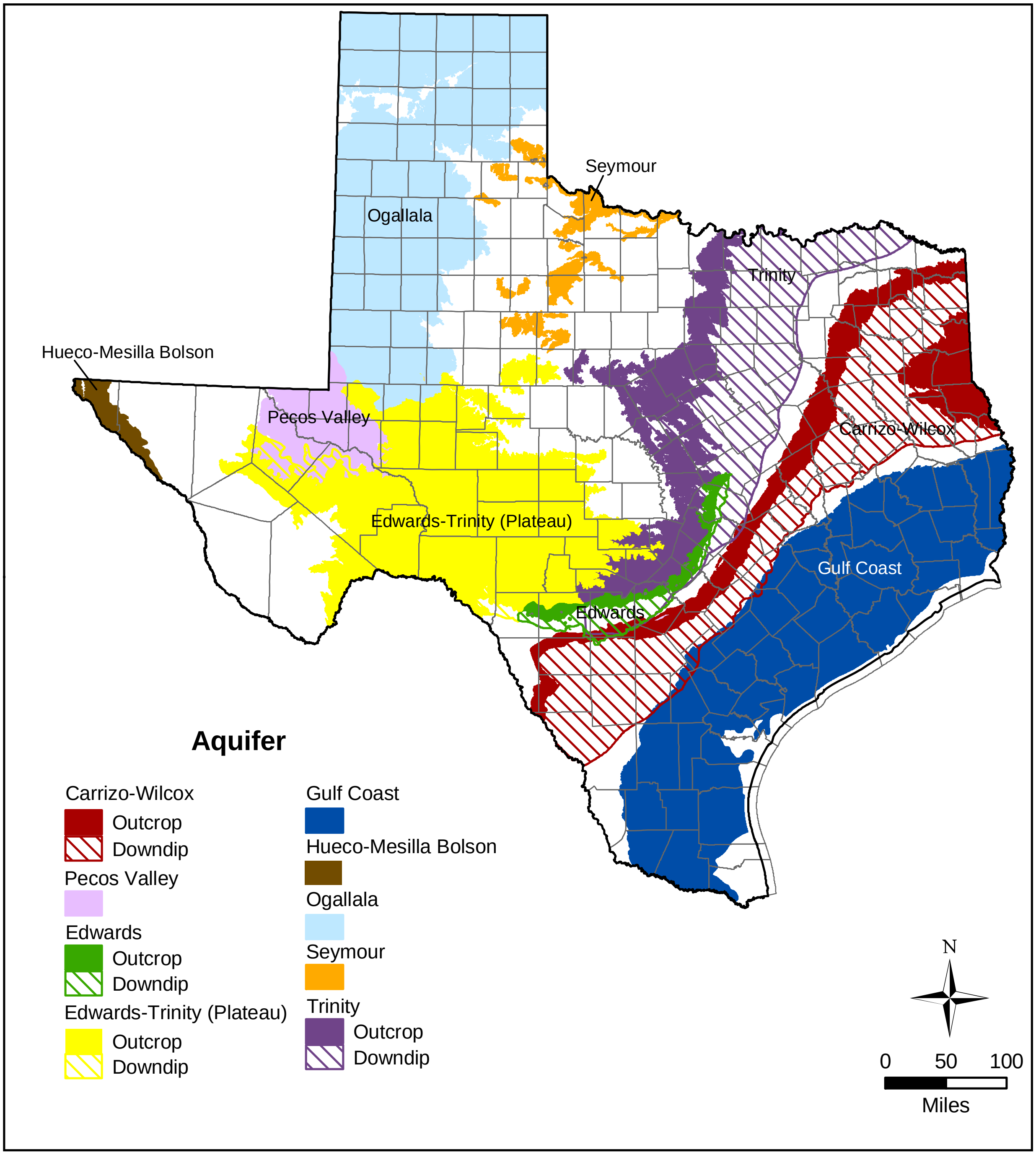


Figure 1.0.1 Locations of major aquifers in Texas (TWDB, 2006a).

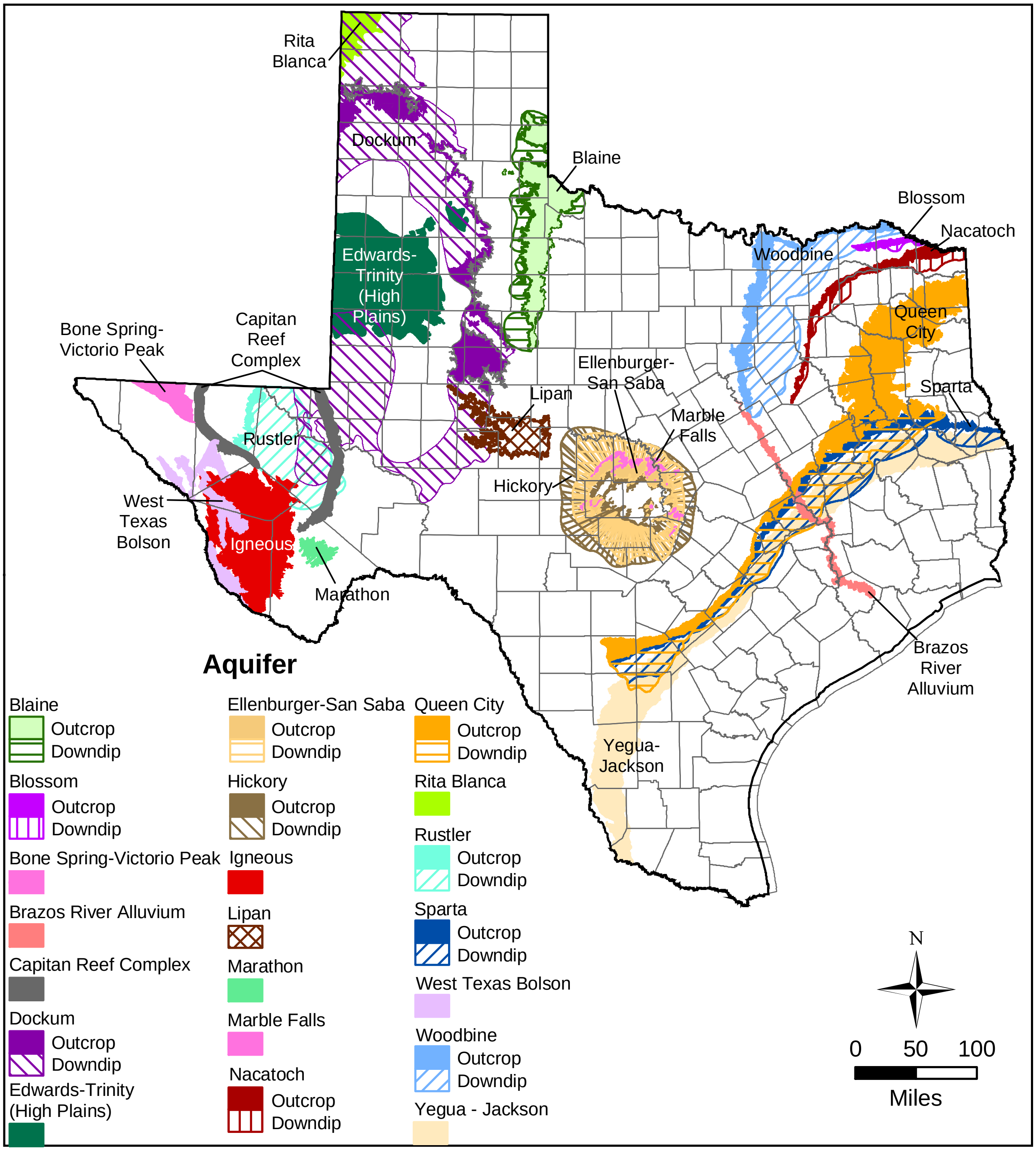


Figure 1.0.2 Locations of minor aquifers in Texas (TWDB, 2006b).

This page is intentionally blank.

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).

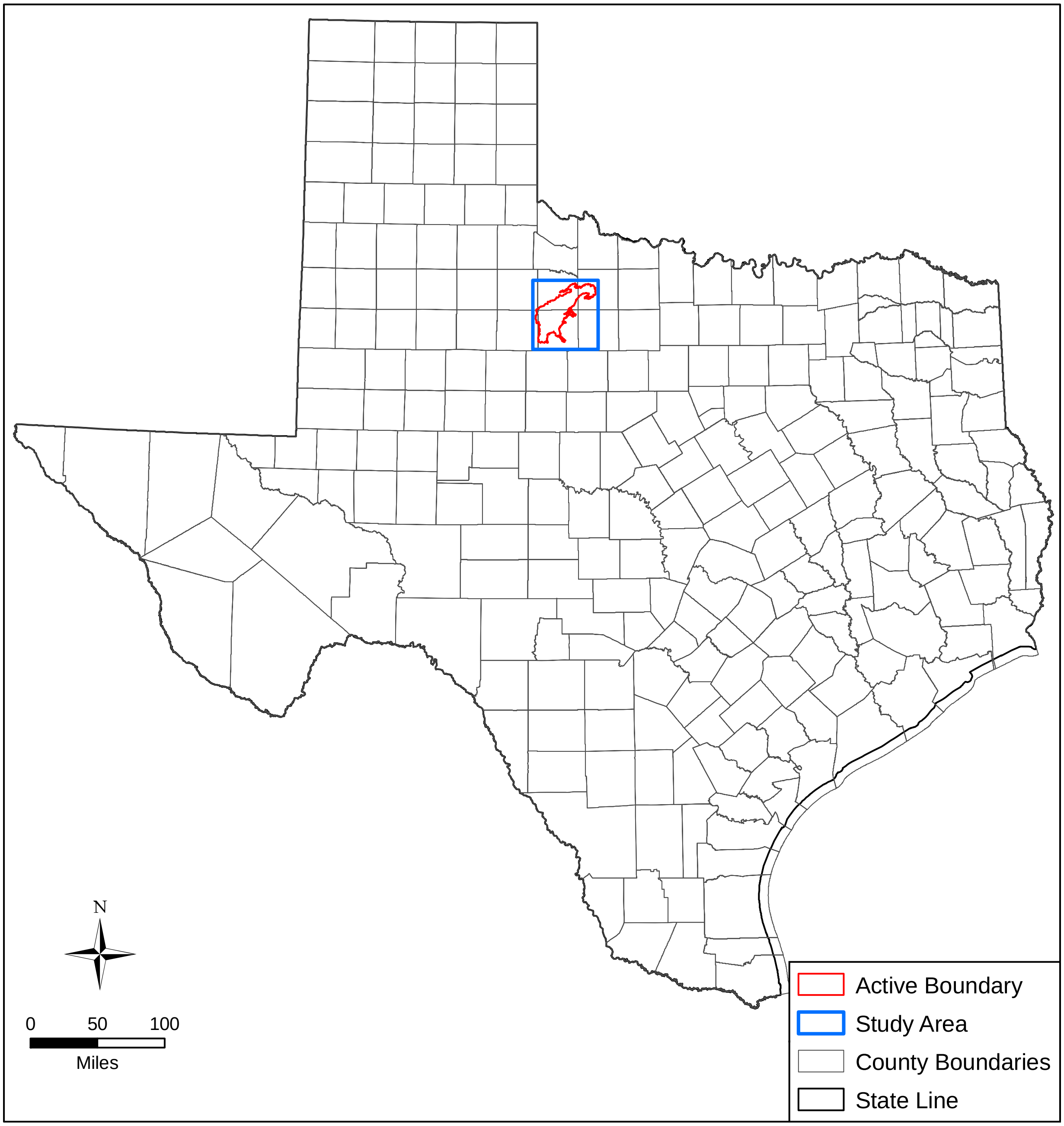


Figure 2.0.1 **Location of study area and model boundary for the refined Seymour Aquifer groundwater availability model.**

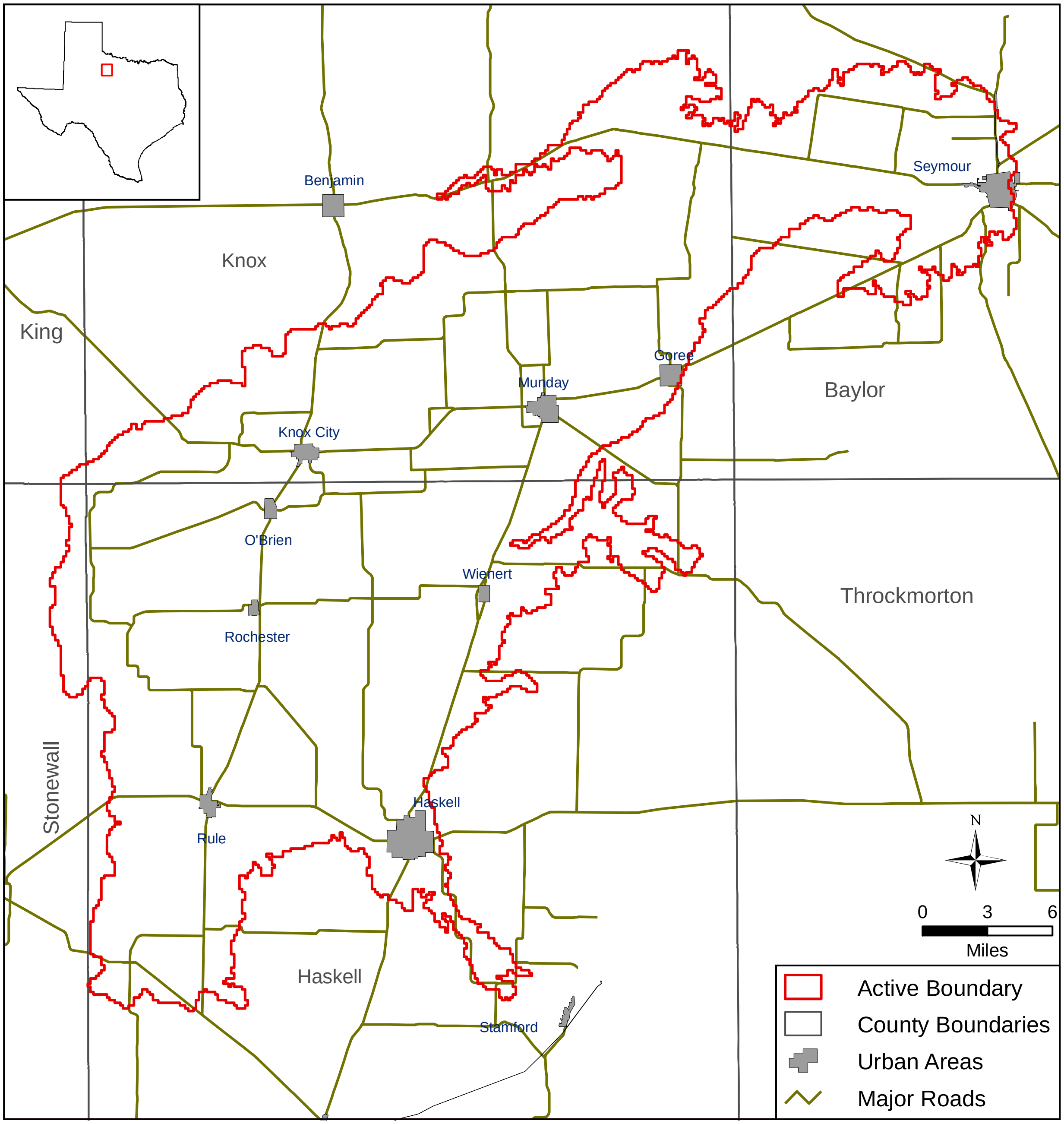


Figure 2.0.2 **Location of study area showing county boundaries, cities, and major roadways (TWDB, 2006c; TWDB, 2006d).**

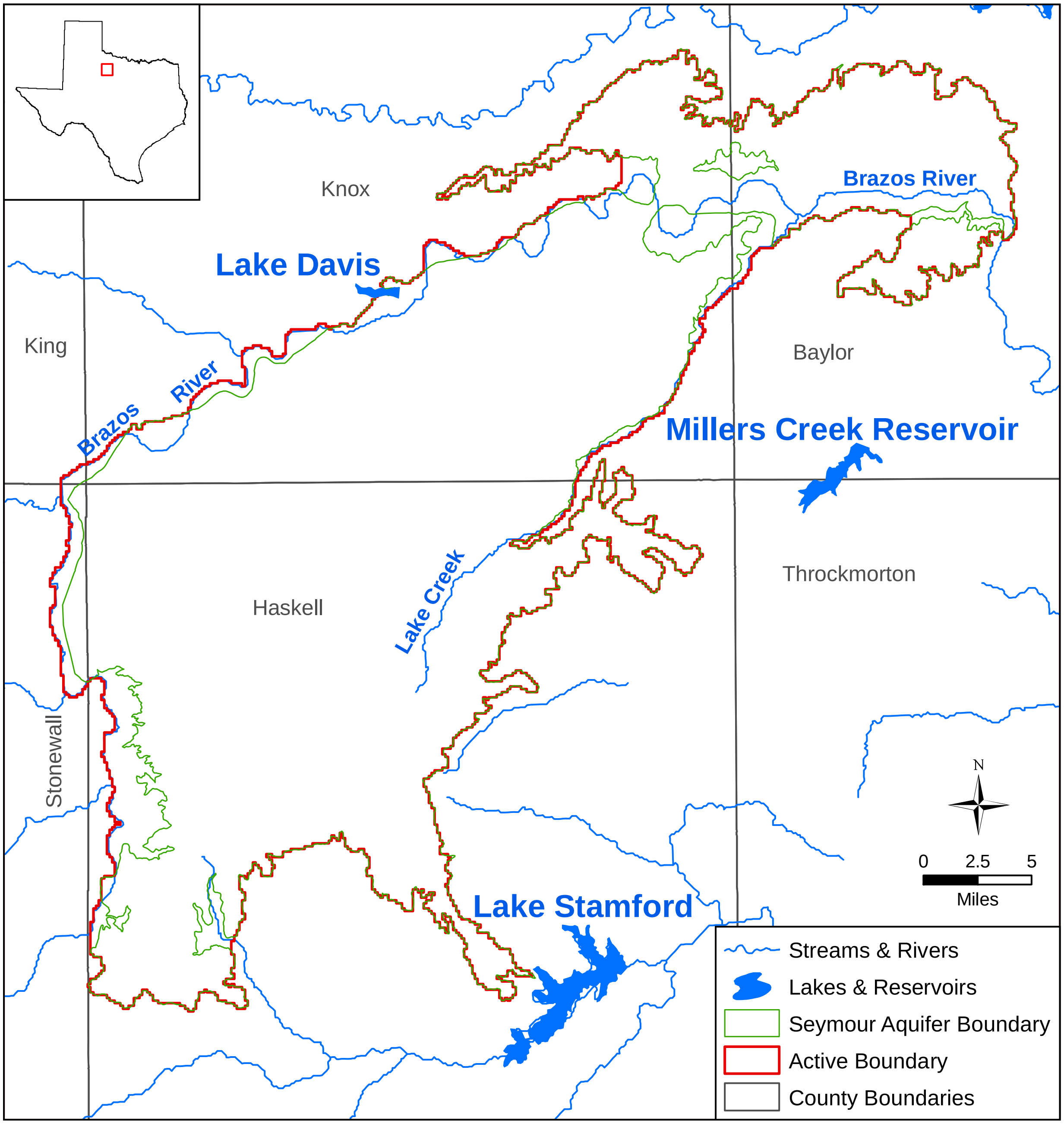


Figure 2.0.3 **Location of study area showing lakes and rivers (TWDB, 2007a; Alexander and others, 1999).**

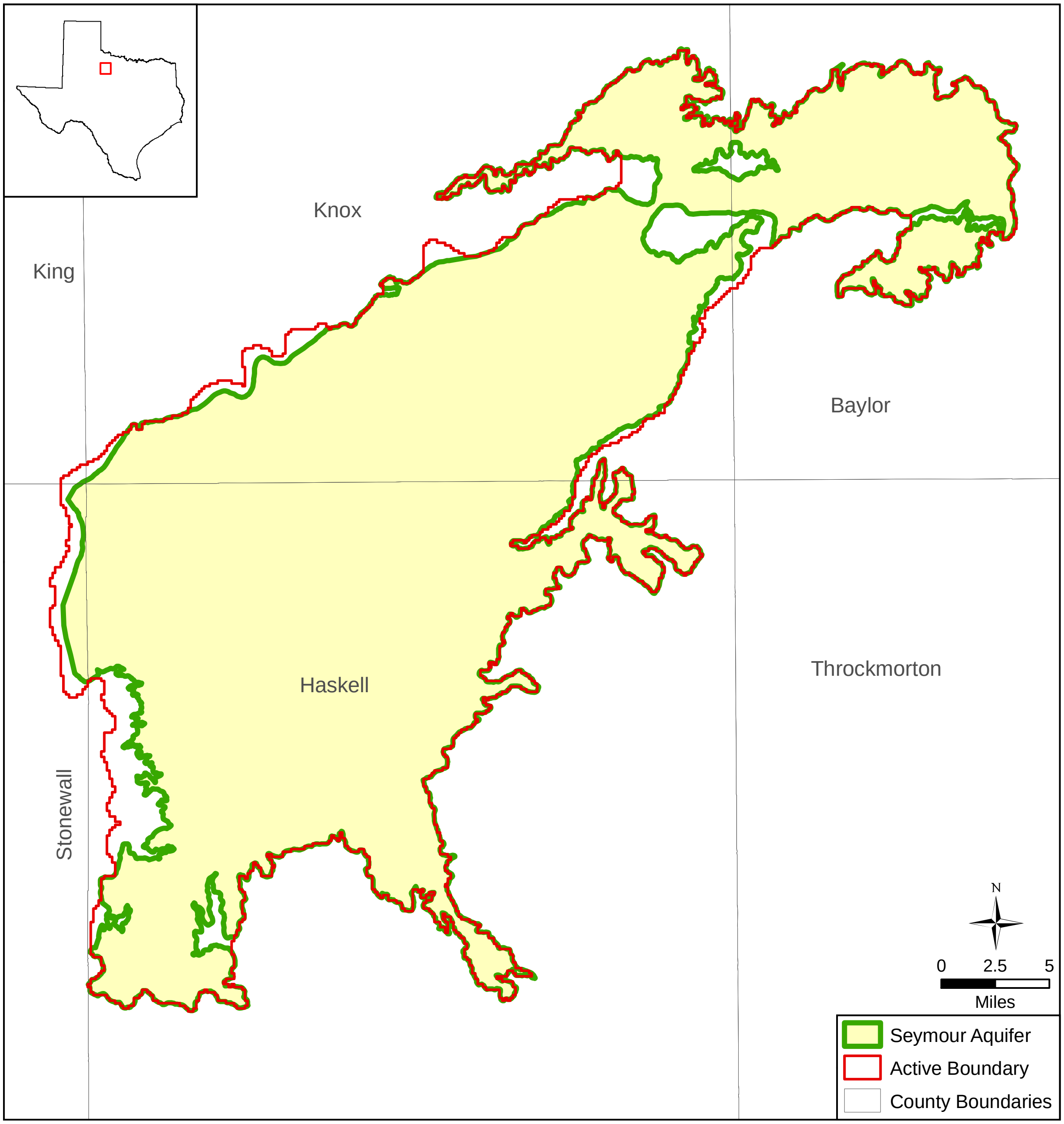


Figure 2.0.4 **Areal extent of major aquifers in the study area (TWDB, 2006a).**

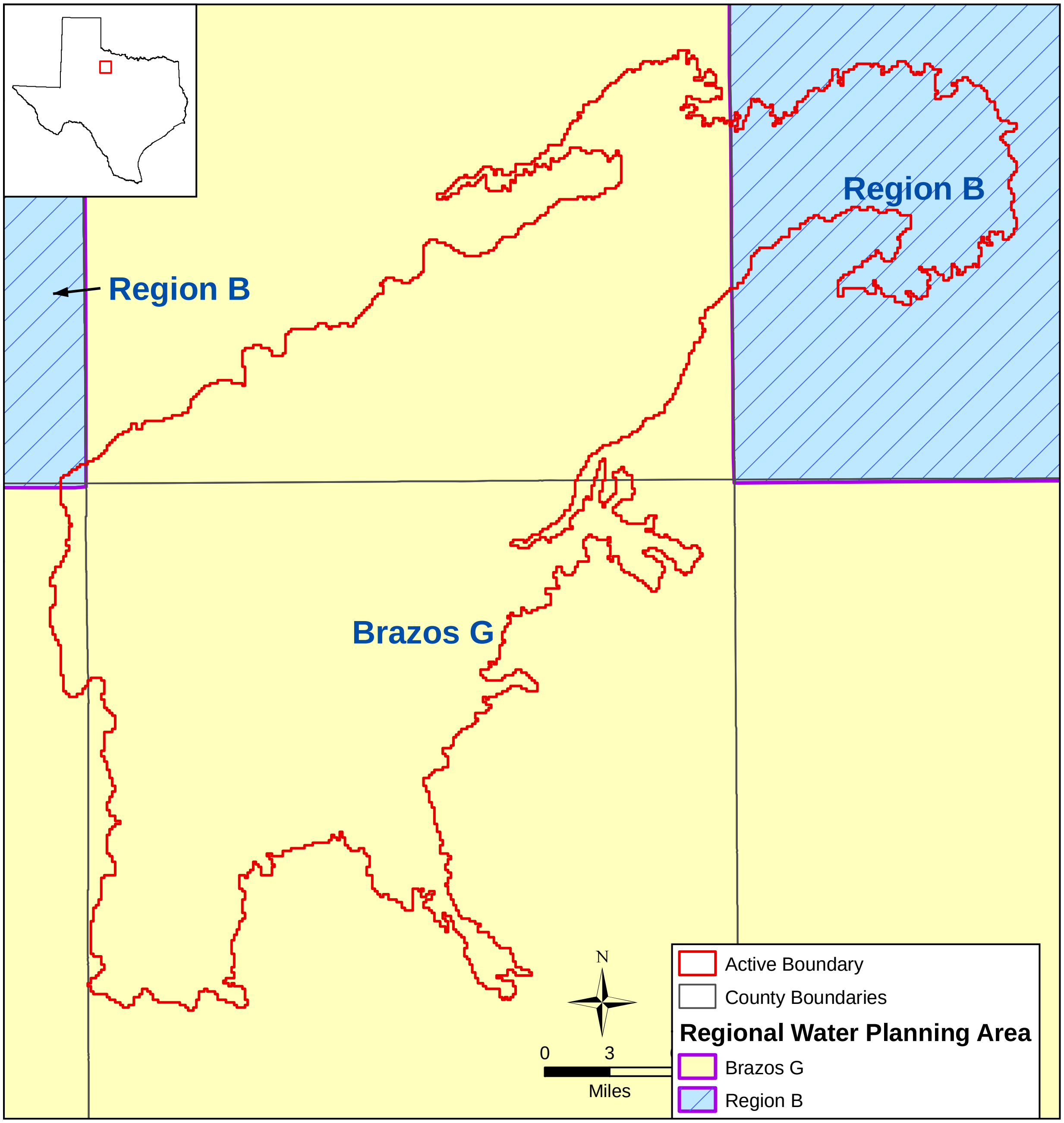


Figure 2.0.5 Locations of Regional Water Planning Areas in the study area (TWDB, 2008a).

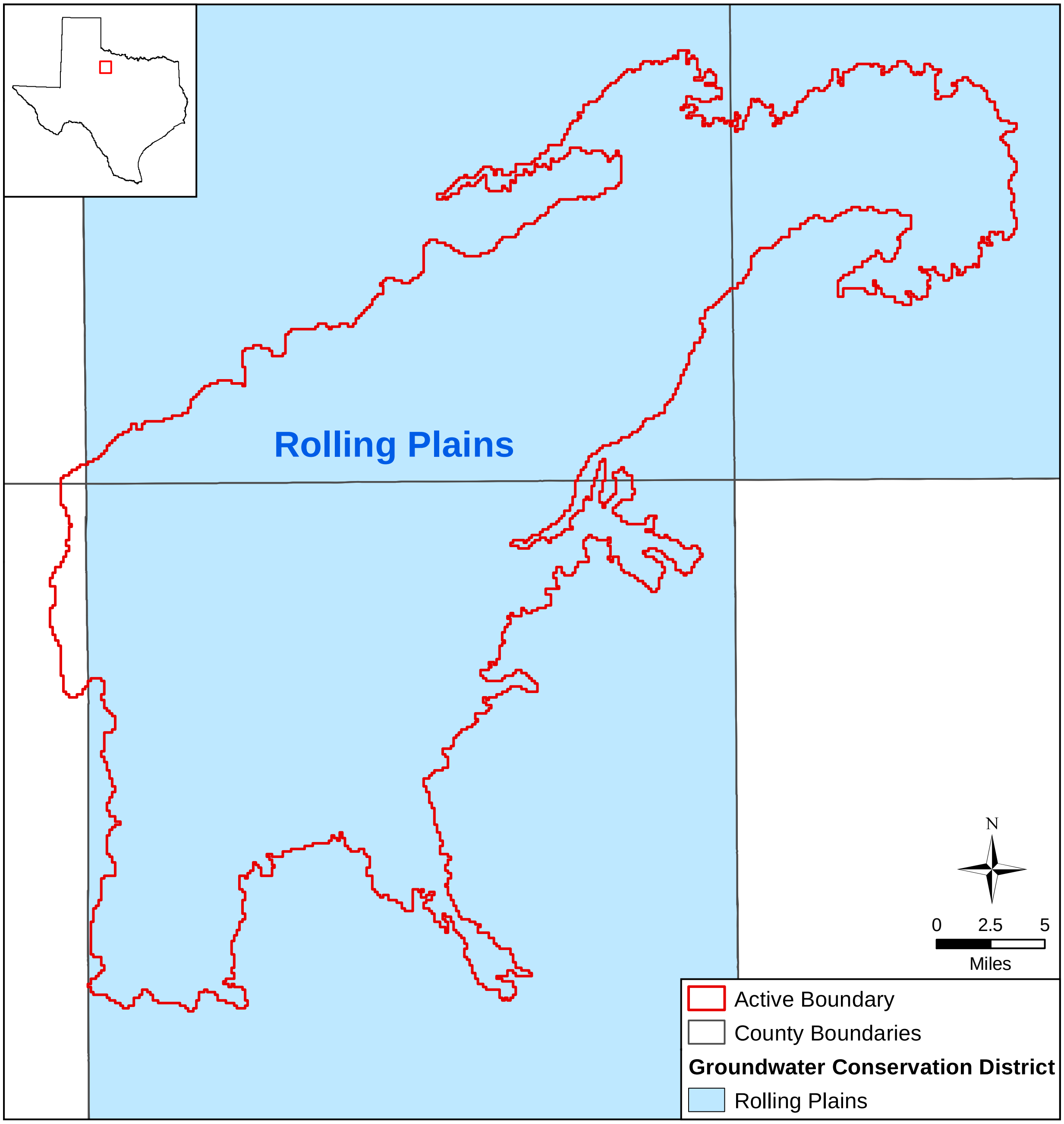


Figure 2.0.6 Location of the Groundwater Conservation District in the study area from the October 2008 Groundwater Conservation District map (TWDB, 2009a).

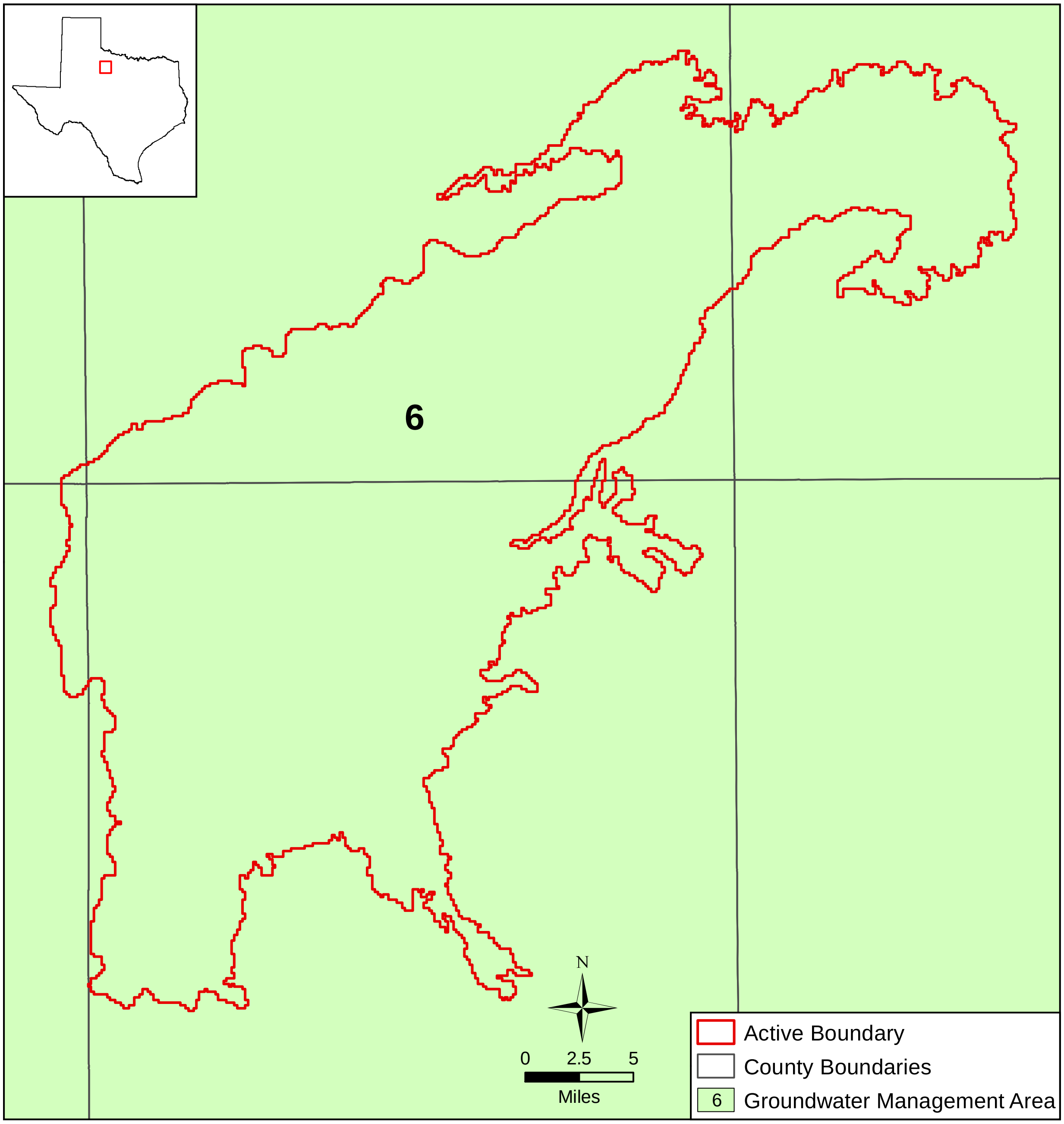


Figure 2.0.7 Location of the Groundwater Management Area in the study area (TWDB, 2007b).

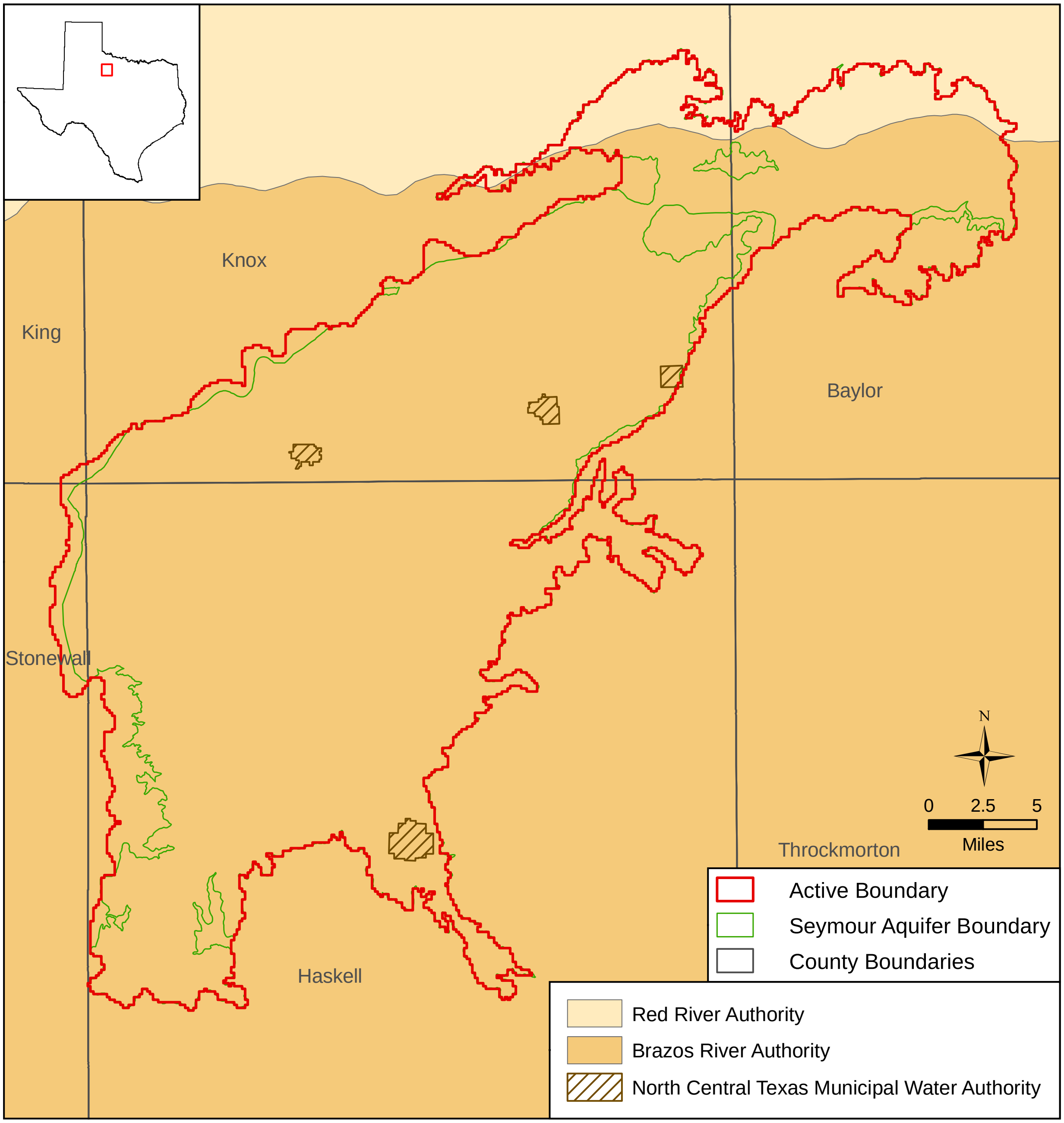


Figure 2.0.8 Location of River Authorities in the study area (TWDB, 1999).

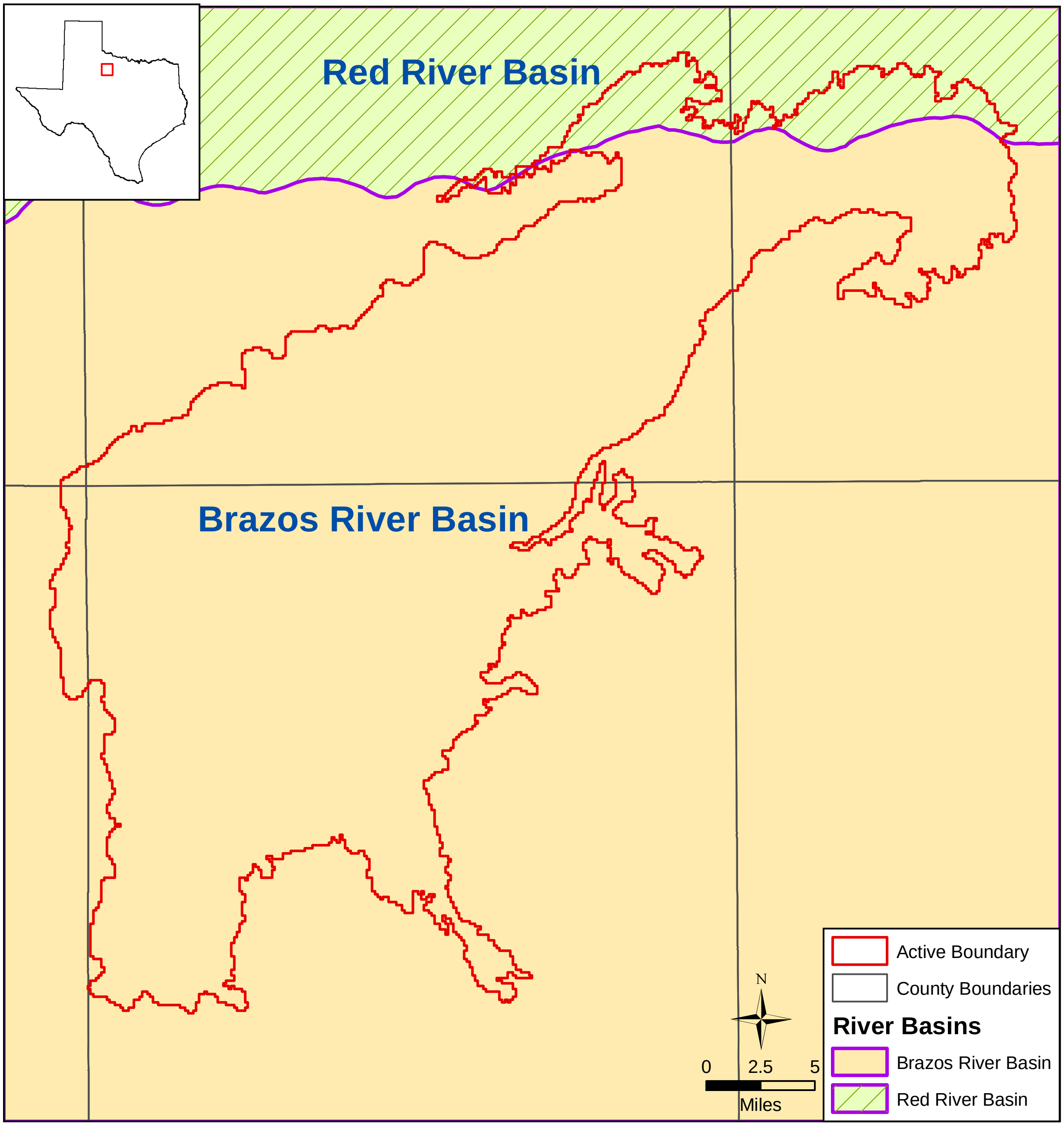


Figure 2.0.9 Major river basins in the study area (TWDB, 2008b).

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).

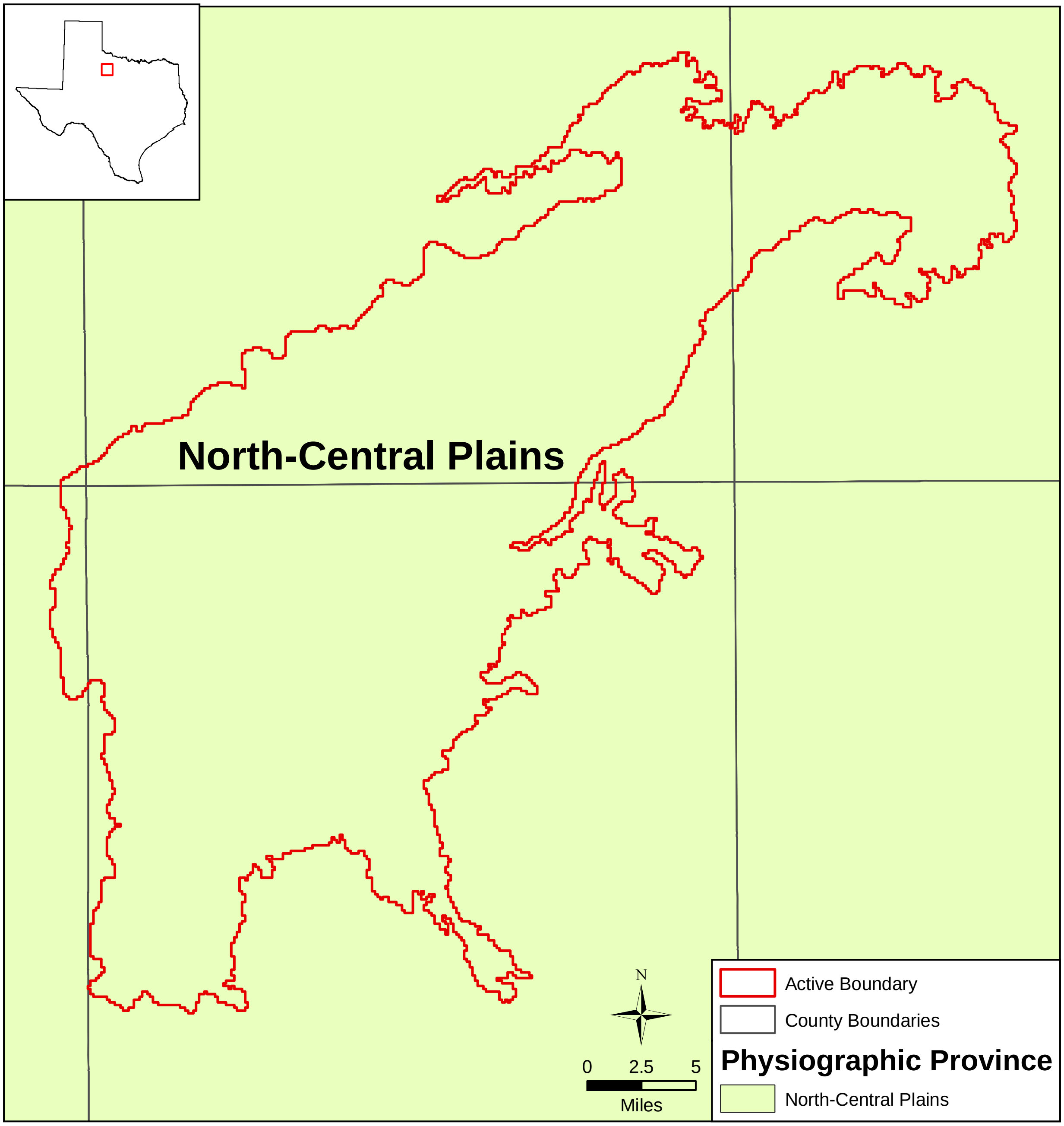


Figure 2.1.1 **Physiographic province in the study area (University of Texas at Austin, Bureau of Economic Geology, 1996).**

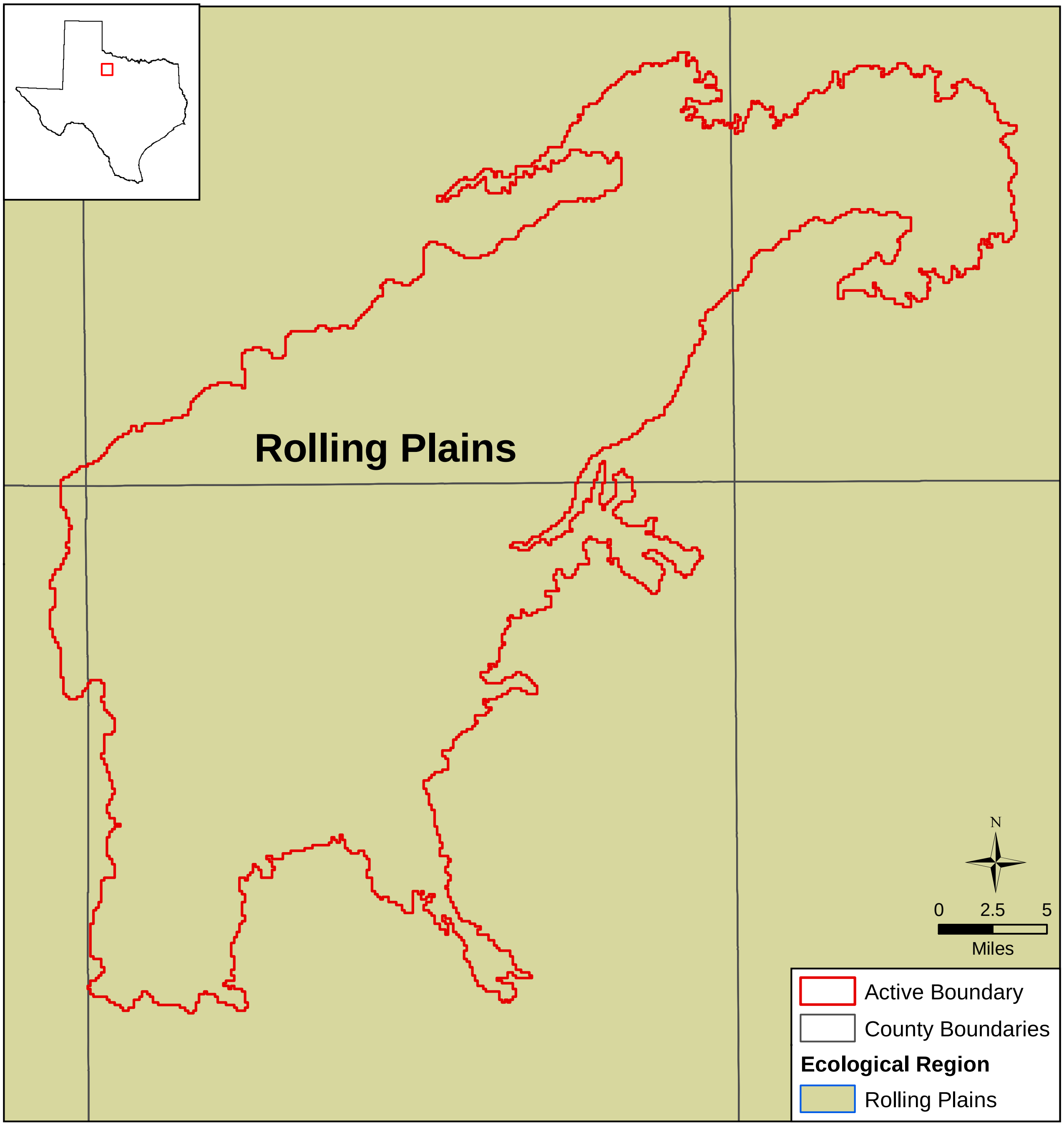


Figure 2.1.2 **Ecological region in the study area (Texas Parks and Wildlife, 2009).**

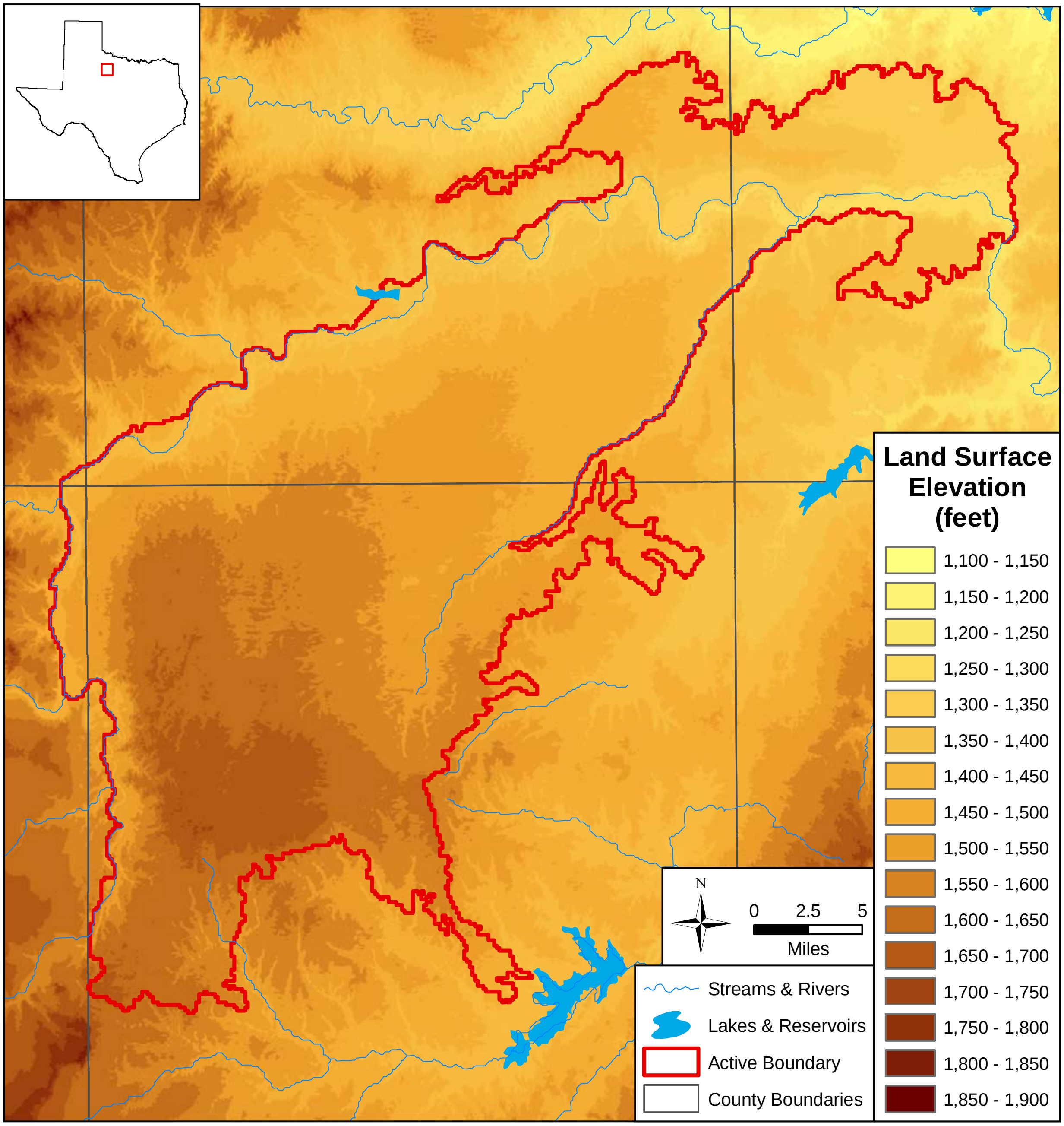


Figure 2.1.3 Topographic map of the study (United States Geological Survey, 2006).

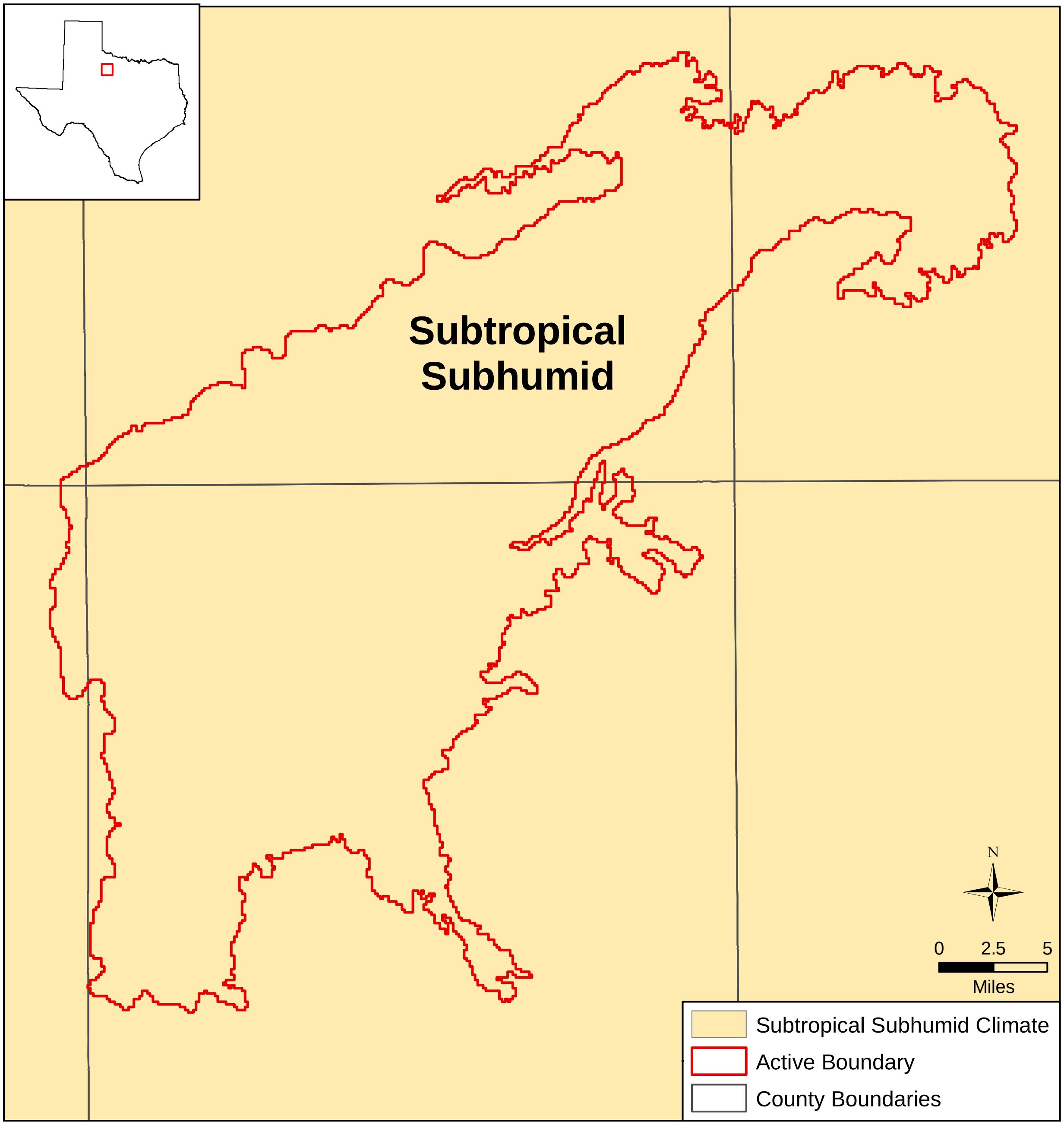


Figure 2.1.4 **Climate classification in the study area (Larkin and Bomar, 1983).**

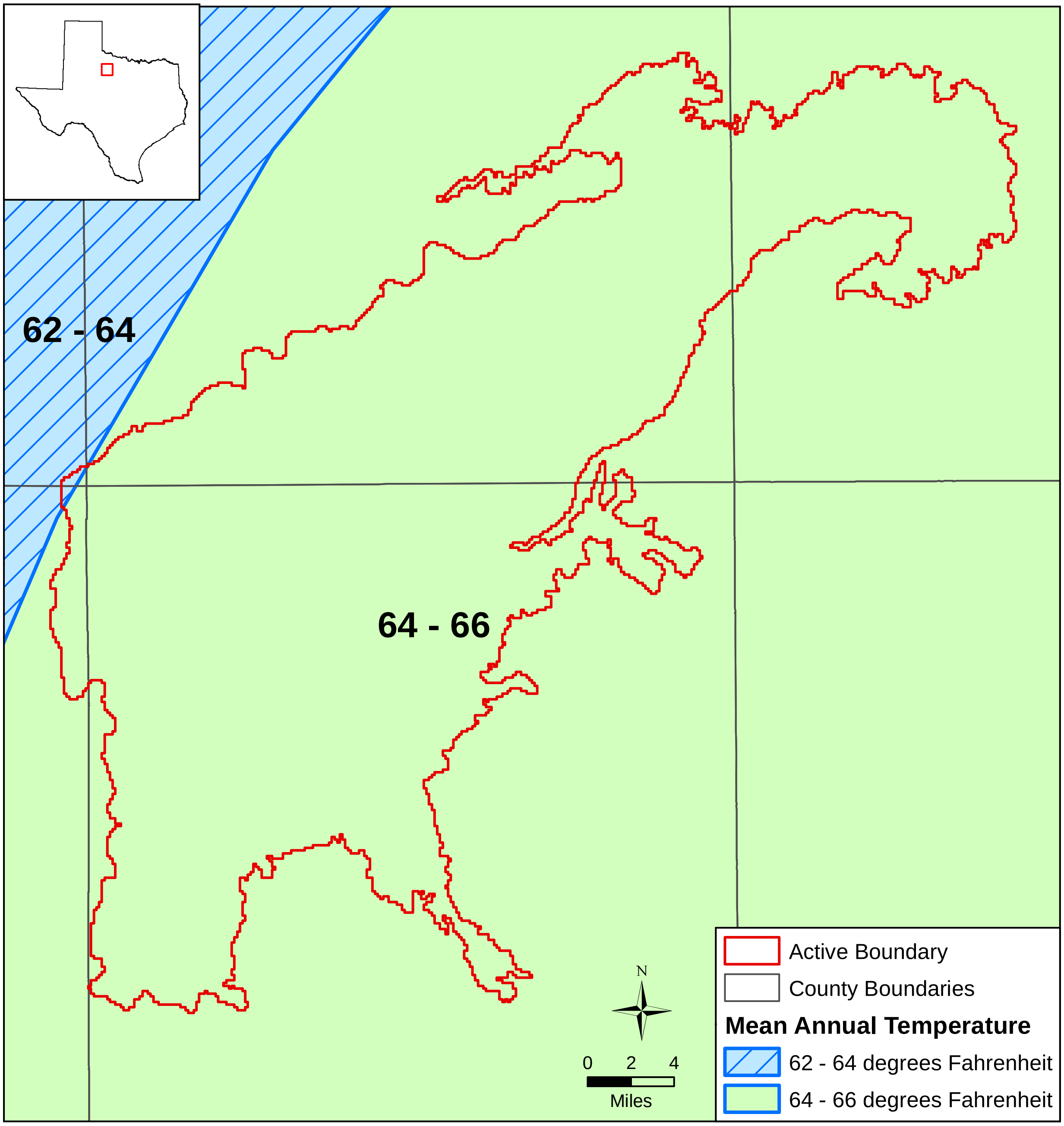


Figure 2.1.5 Average annual air temperature in the study area (Texas A&M University, 2002).

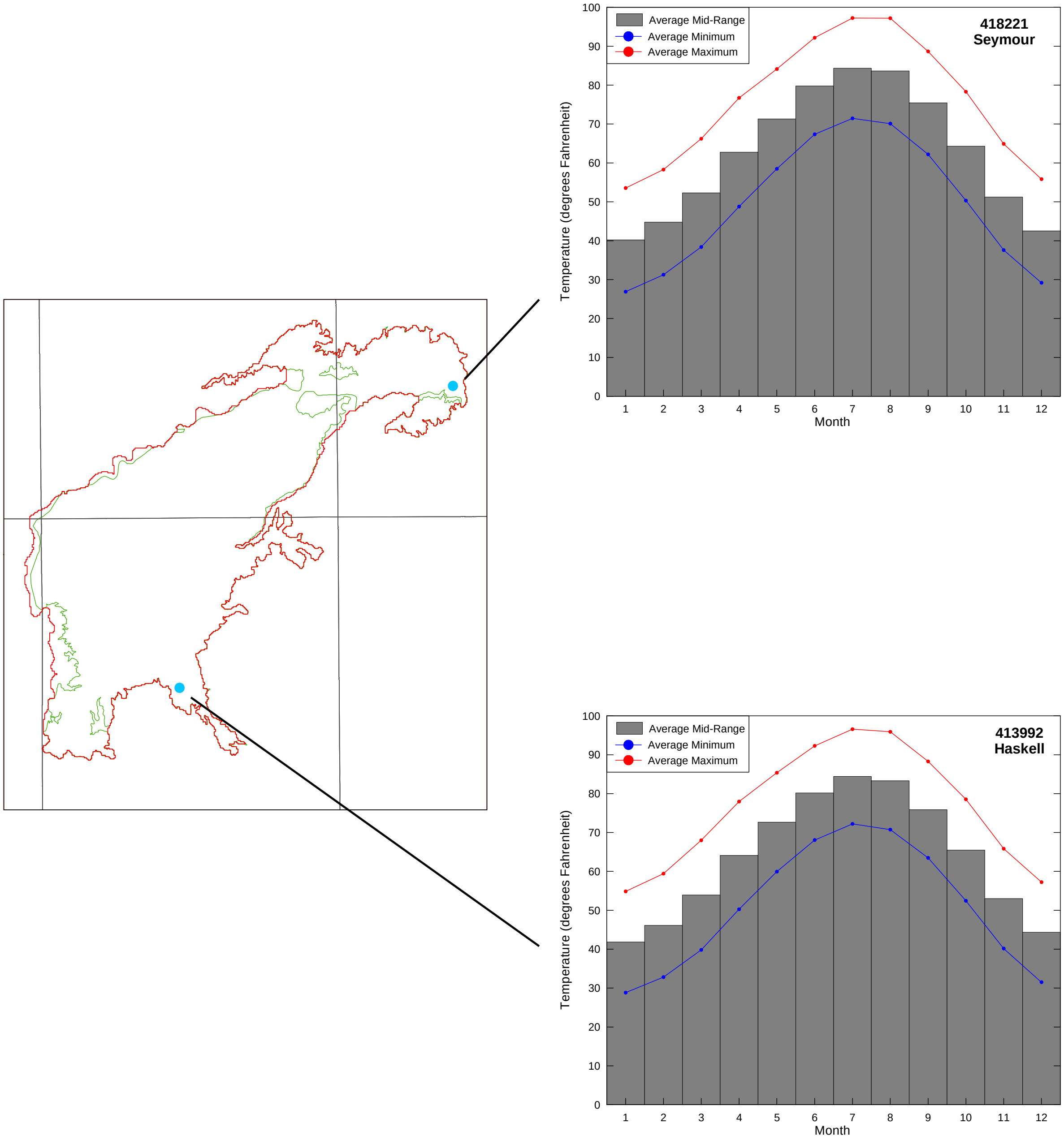


Figure 2.1.6 **Average minimum, mid-range, and maximum monthly temperatures at two locations in the study area (National Climatic Data Center, 2001).**

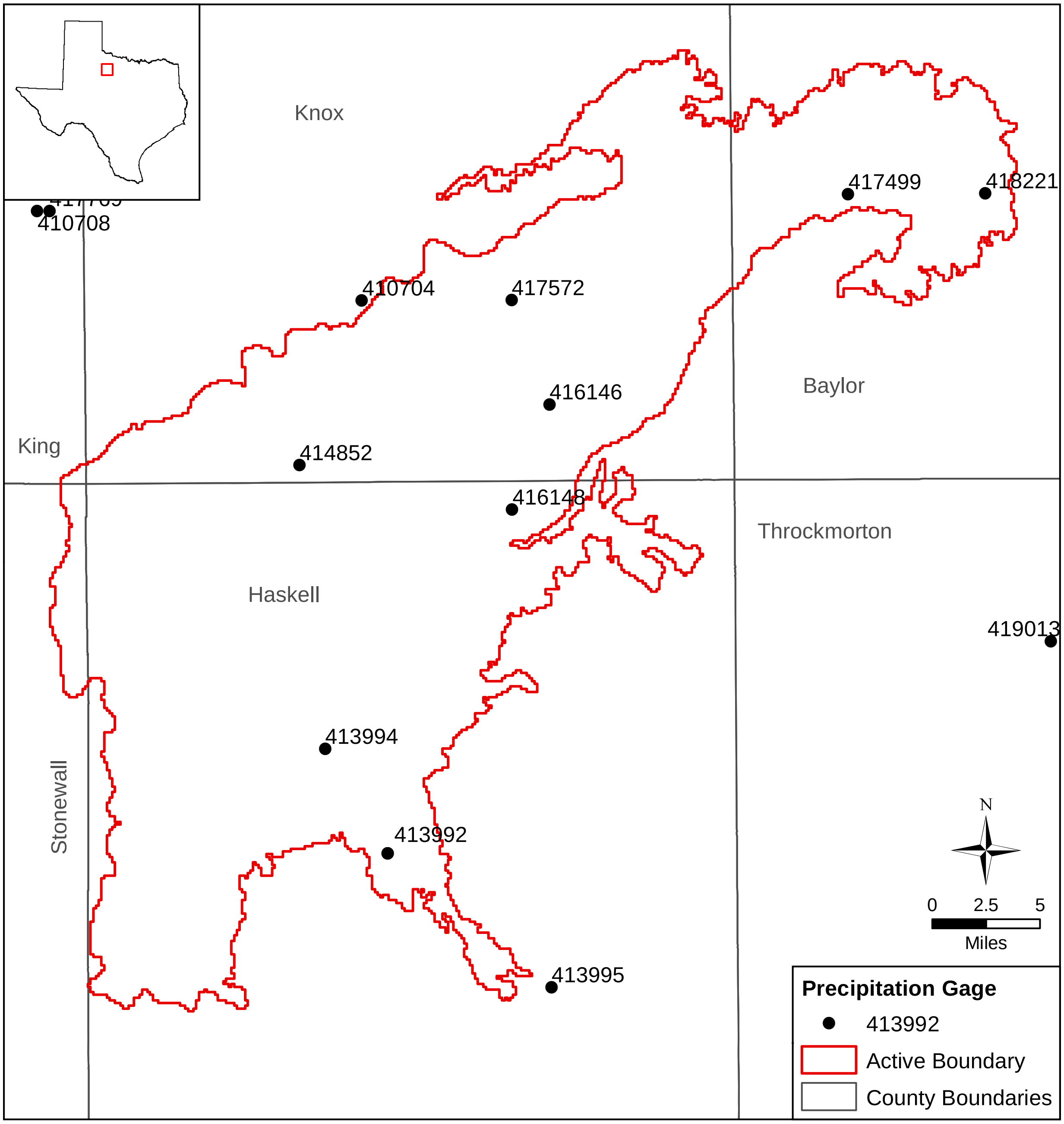


Figure 2.1.7 **Location of precipitation gages in the study area (National Climatic Data Center, 2001).**

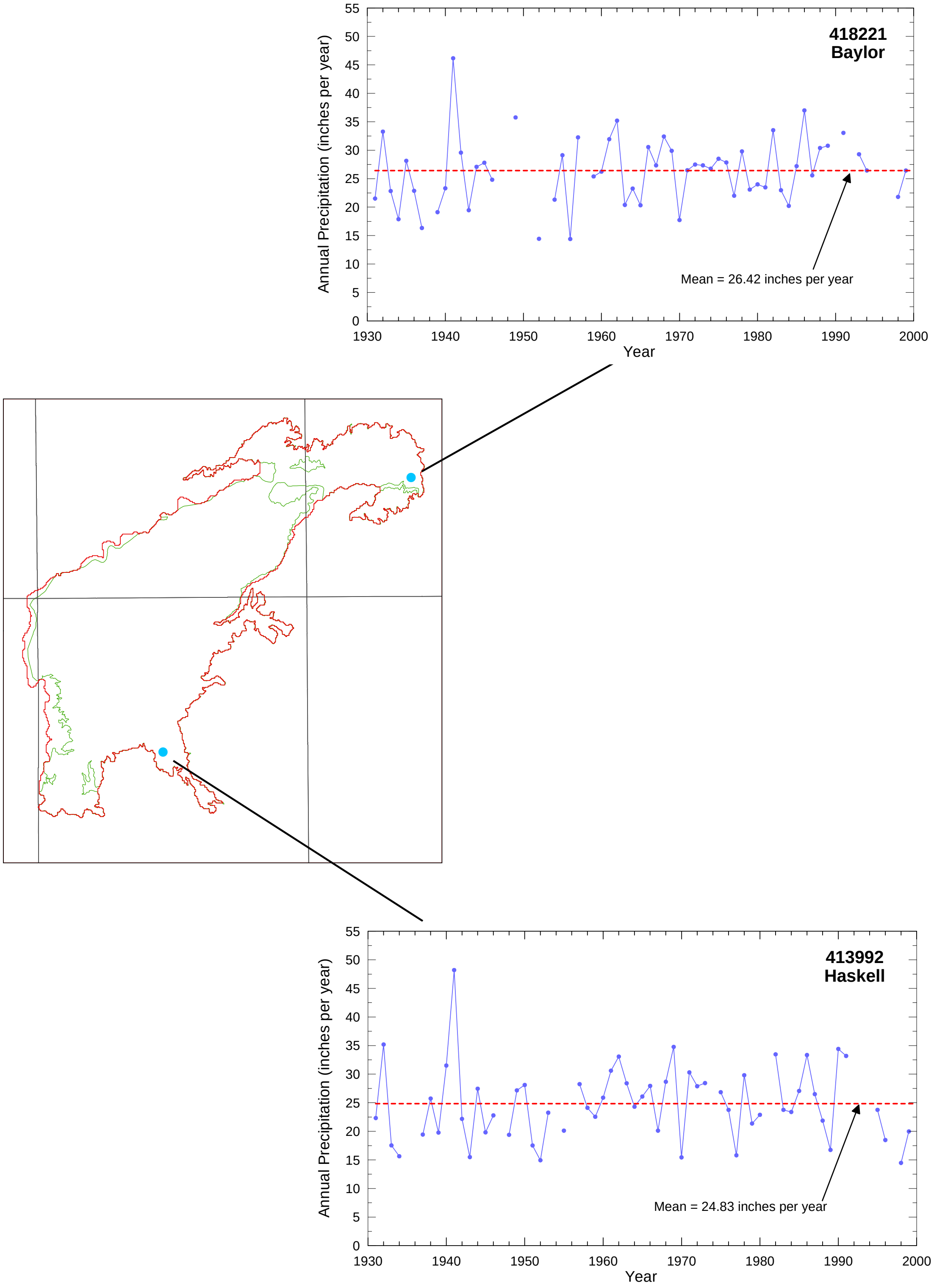


Figure 2.1.8 **Annual precipitation time series at two locations in the study area (National Climatic Data Center, 2001). (A discontinuous line indicates a break in the data. The dashed red line represents the mean annual precipitation.)**

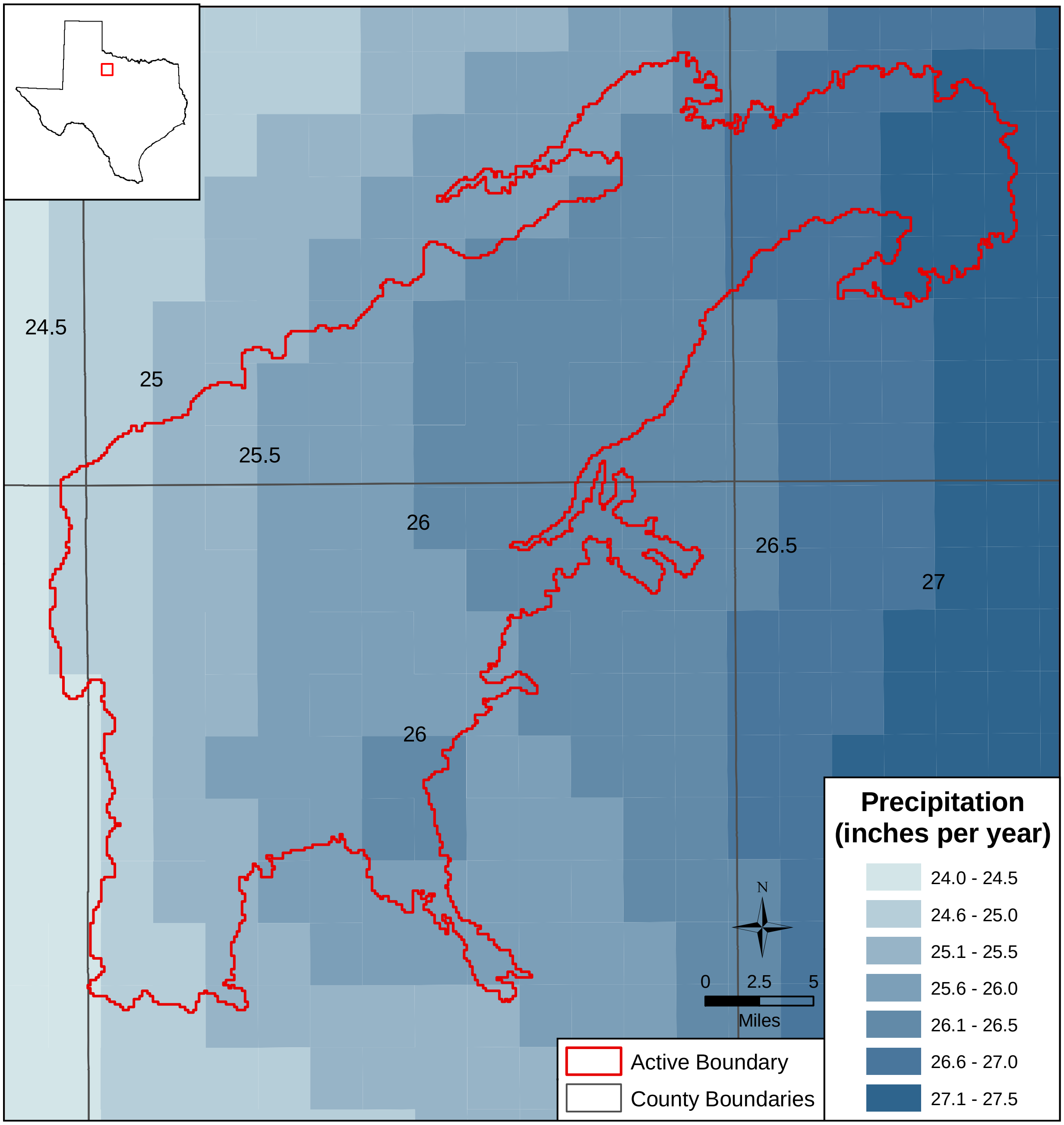


Figure 2.1.9 Average annual precipitation over the study area (Oregon State University, 2002).

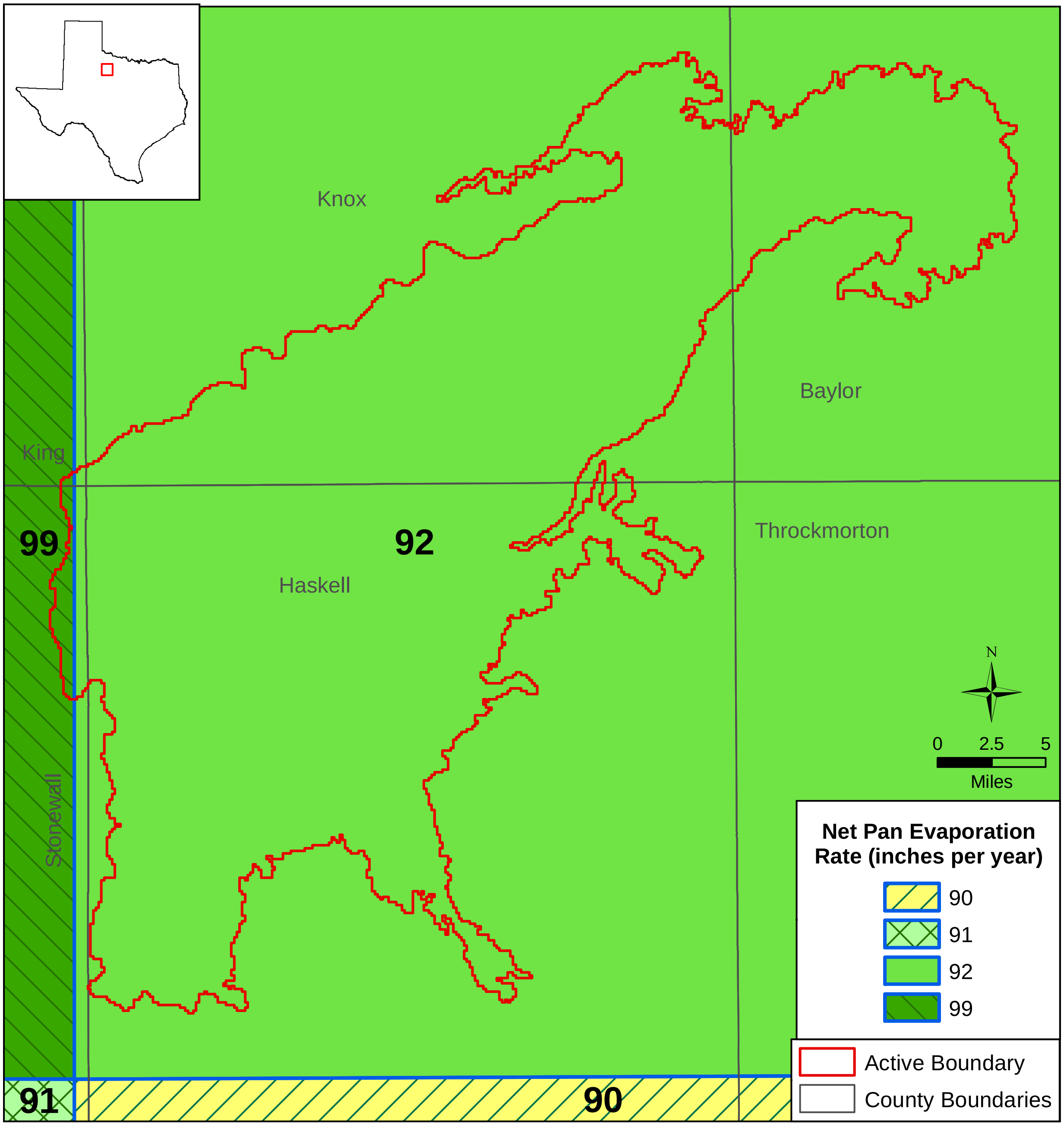


Figure 2.1.10 Average annual net pan evaporation over the study area (TWDB, 2009b).

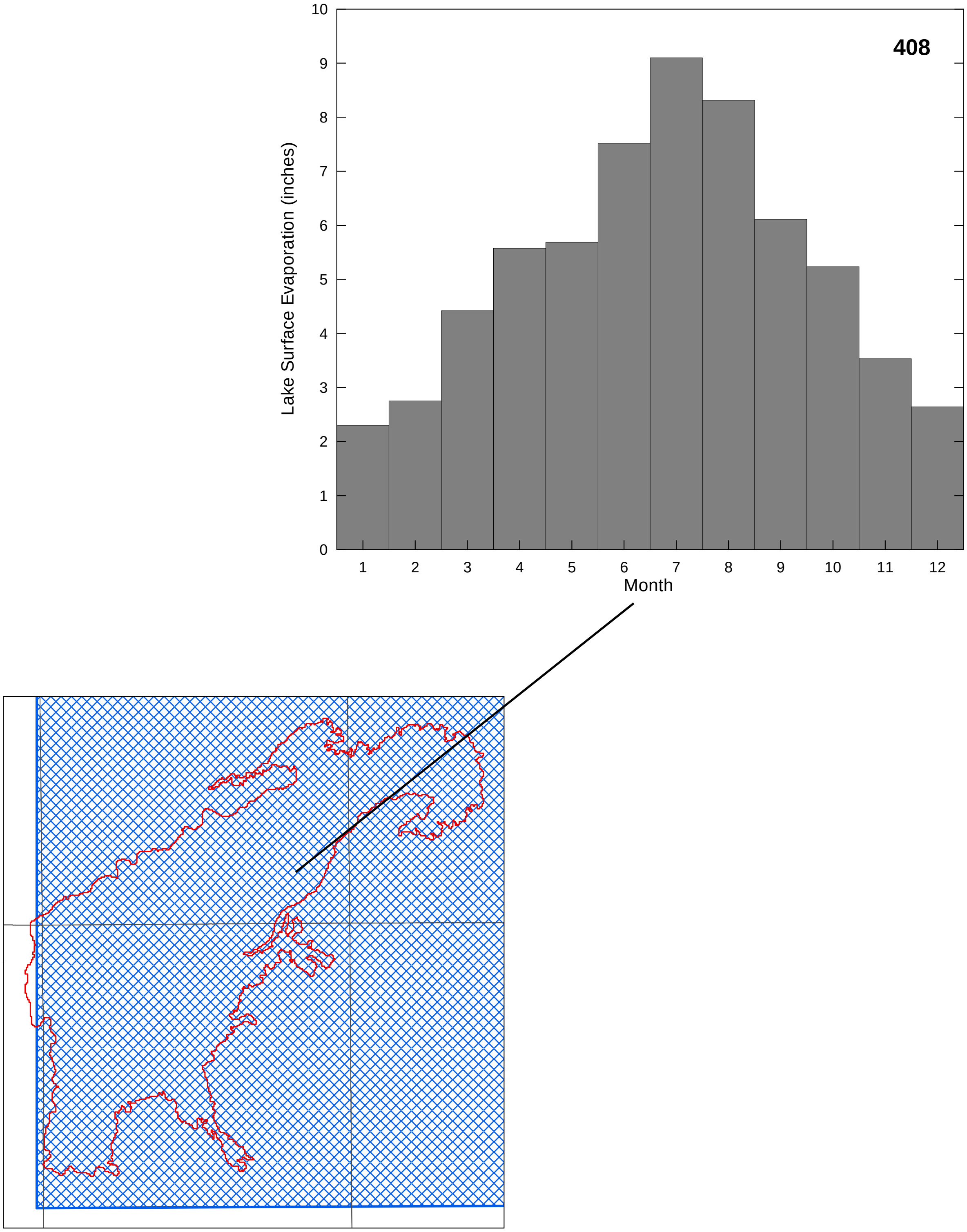


Figure 2.1.11 Average monthly lake surface evaporation for one-degree quadrangle 408 in the study area (TWDB, 2009b).

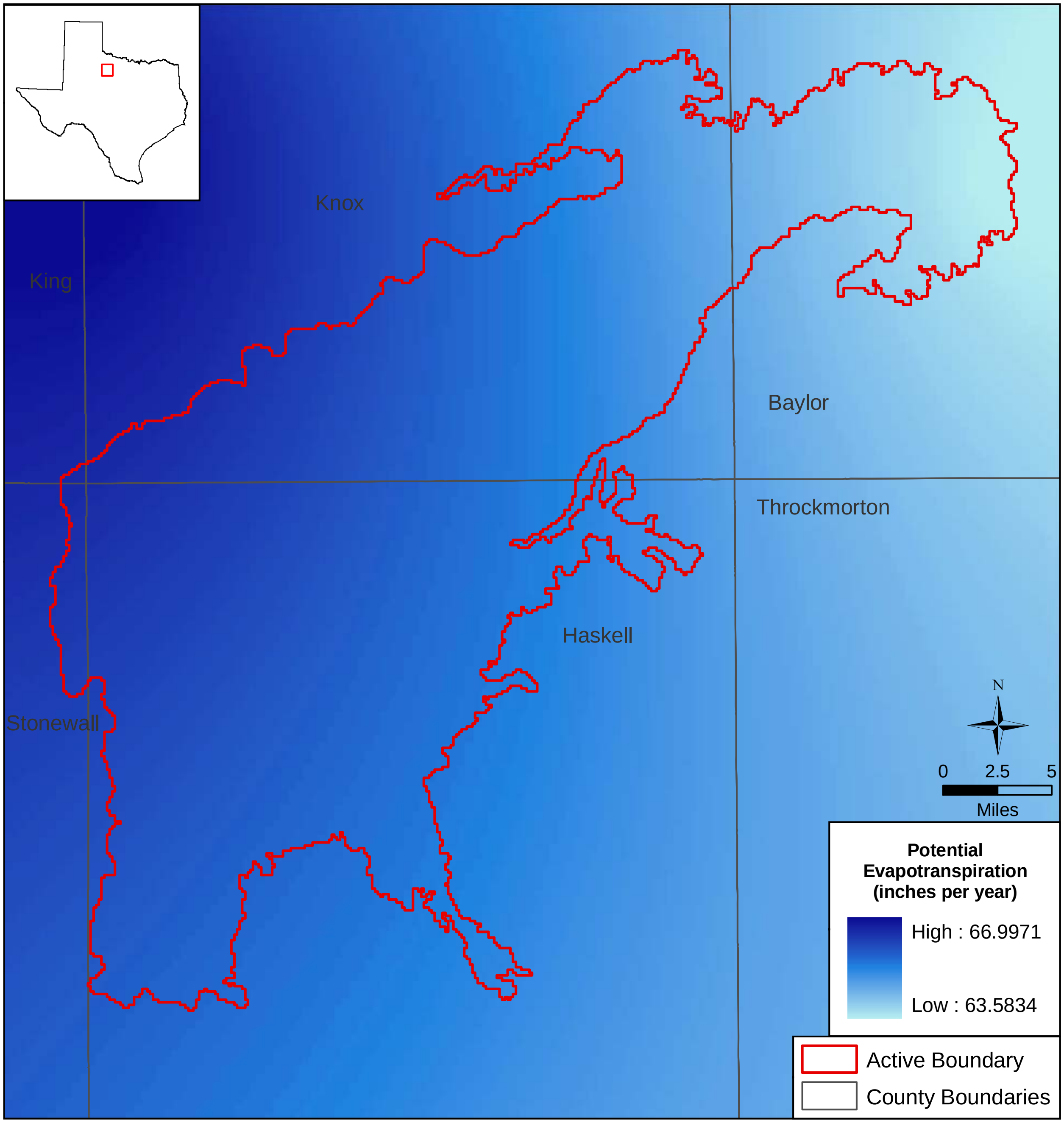


Figure 2.1.12 Potential evapotranspiration in the study area (Borrelli and others, 1998).

This page is intentionally blank.

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

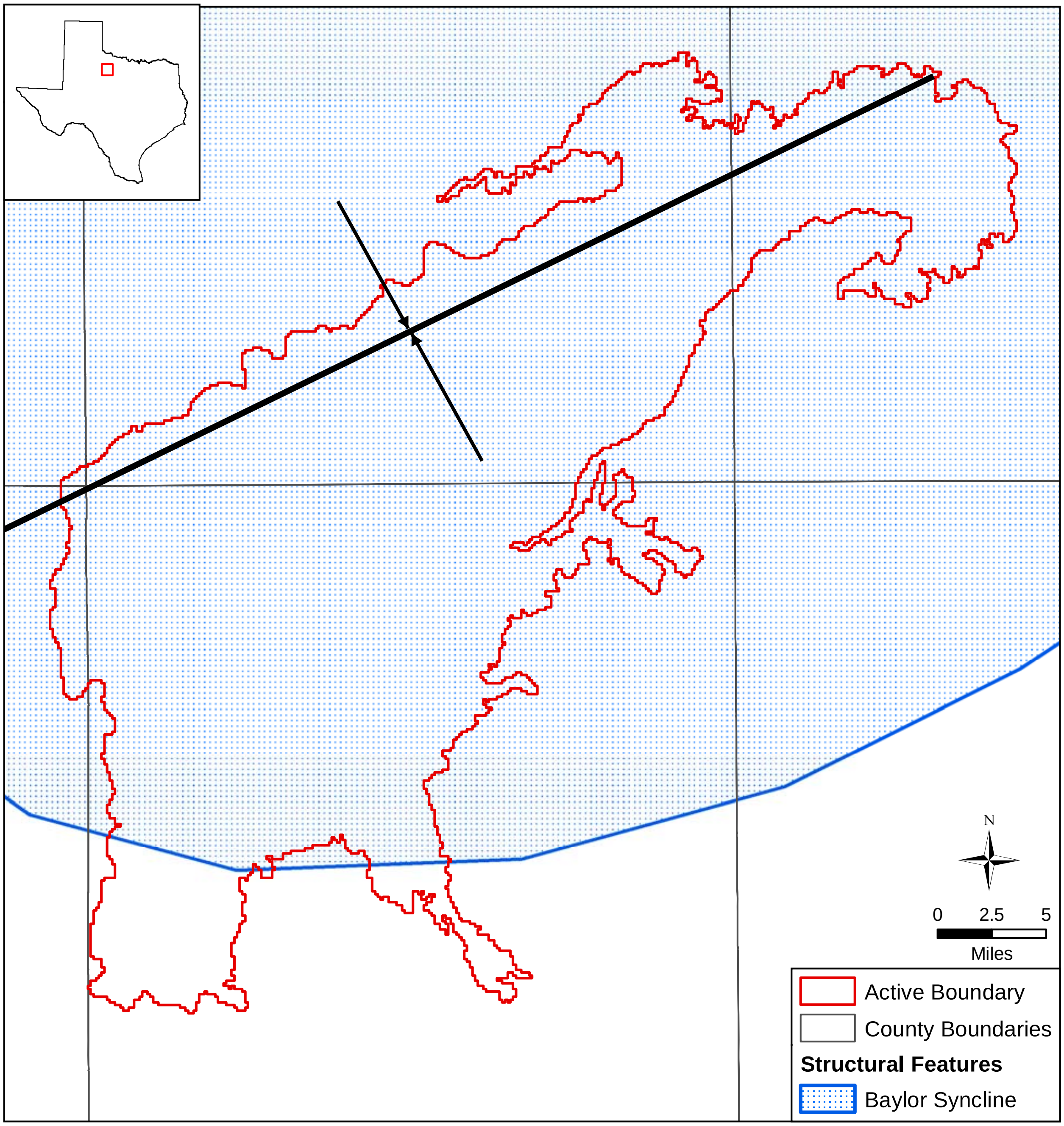


Figure 2.2.1 Major structural features in the study area (Price, 1979).

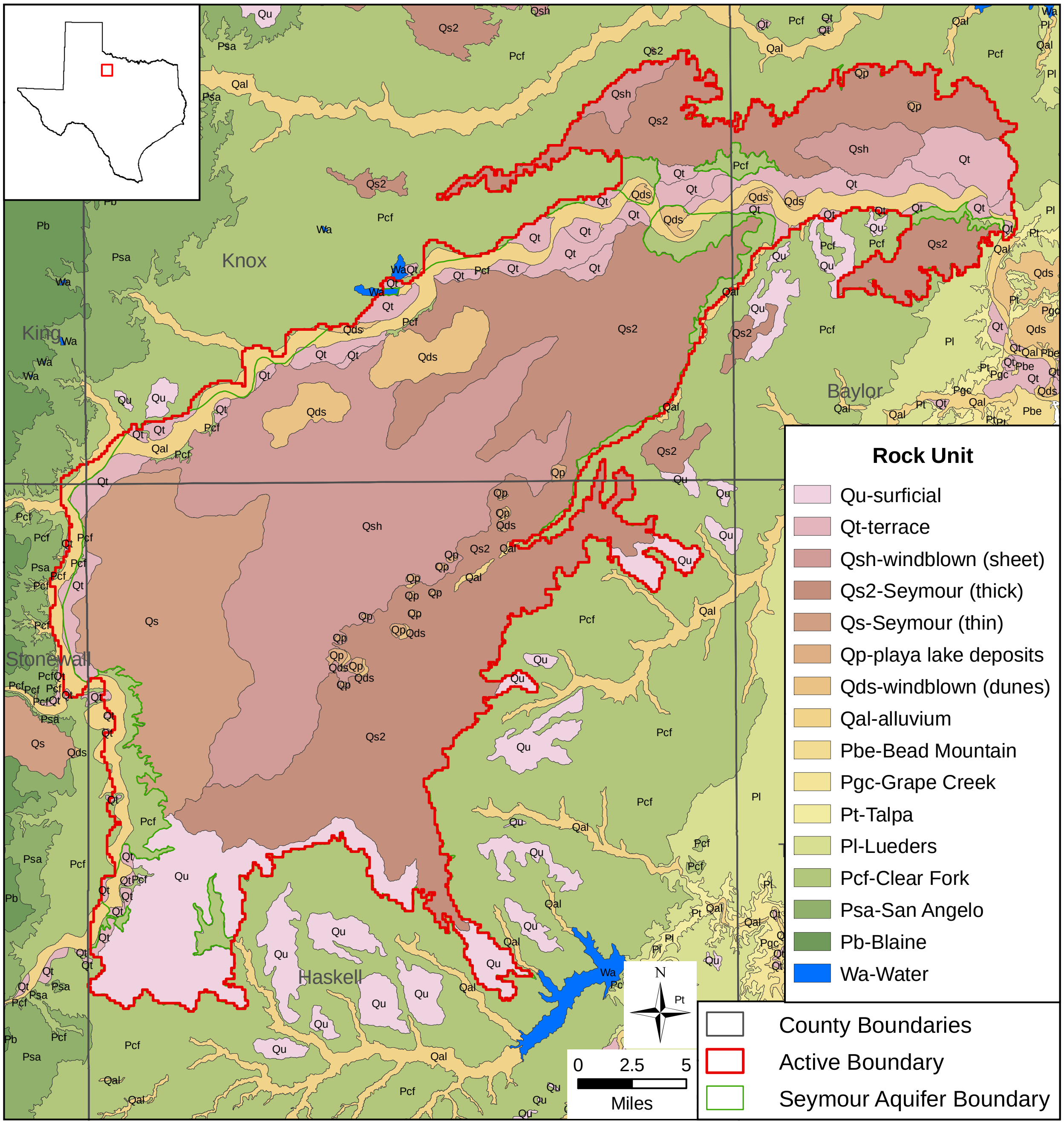


Figure 2.2.2 **Surface geology of the study area (United States Geological Survey-Texas Water Science Center and the Texas Natural Resources Information System, 2004).**

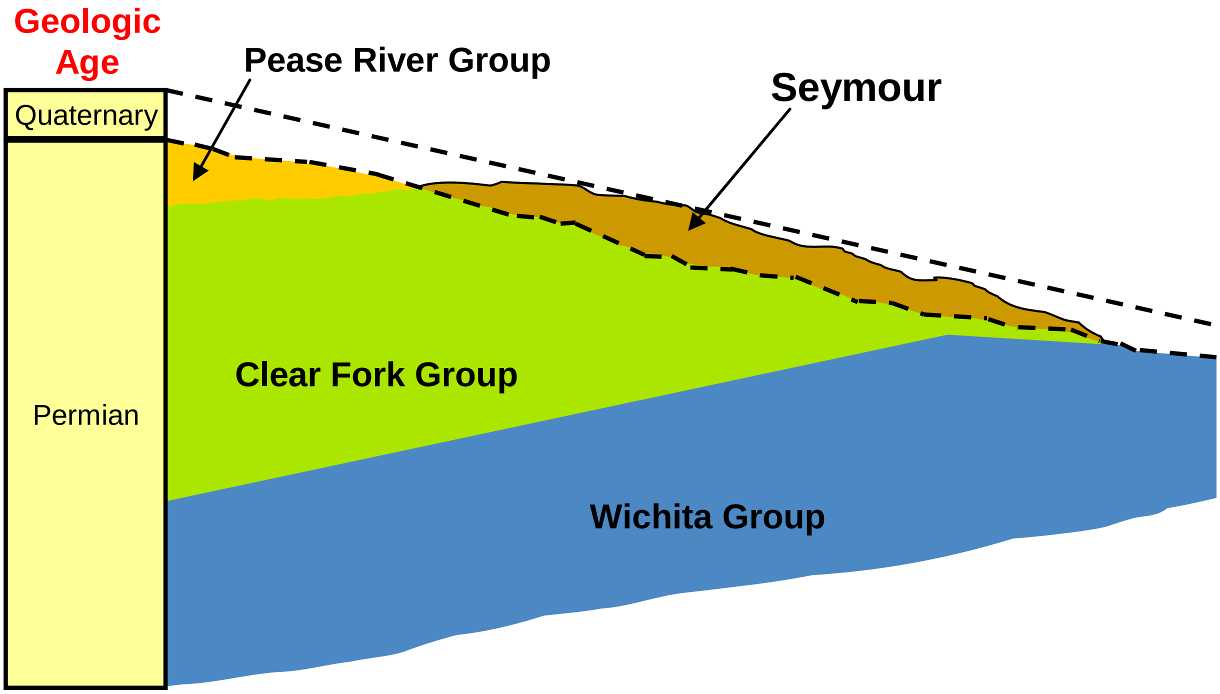


Figure 2.2.3 **Schematic of generalized stratigraphy across the study area.**

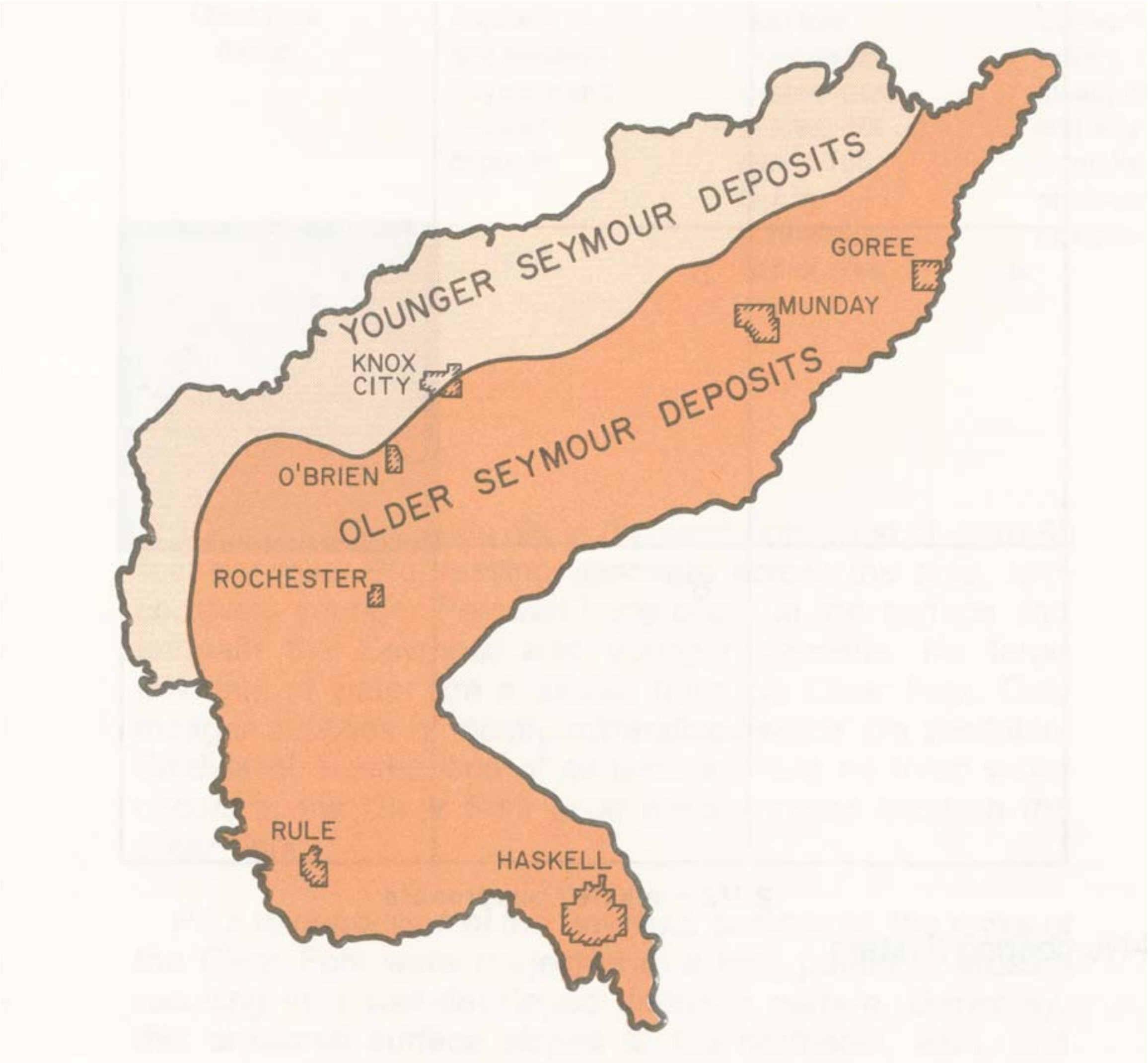


Figure 2.2.4 Location of older and younger Seymour Formation deposits (from R.W. Harden and Associates, 1978).

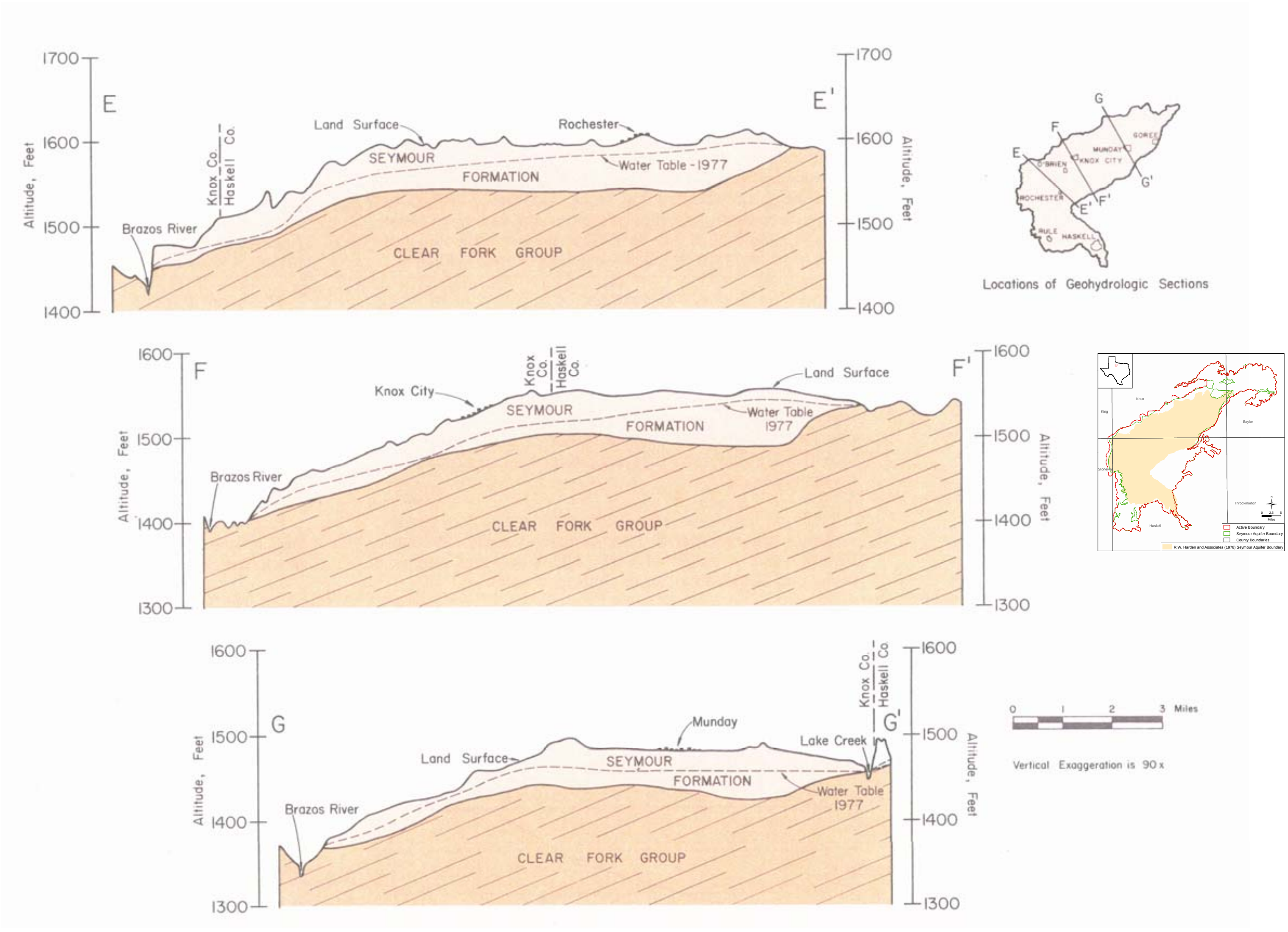


Figure 2.2.5 A-A', B-B', C-C', and D-D' cross-sections from R.W. Harden and Associates (1978) showing the Seymour Formation and Clear Fork Group in Haskell and Knox counties.

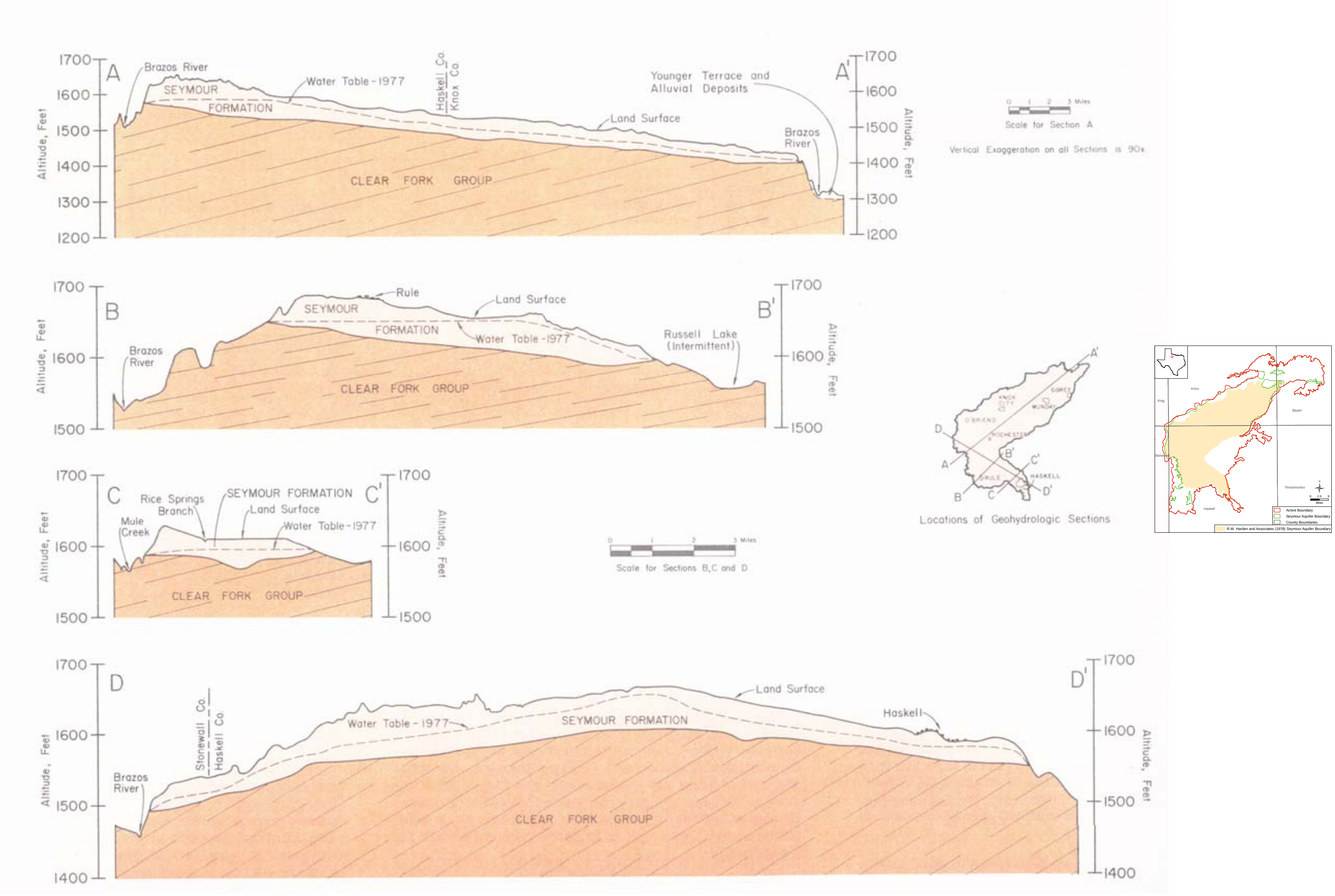


Figure 2.2.6 E-E', F-F', and G-G' cross-sections from R.W. Harden and Associates (1978) showing the Seymour Formation and Clear Fork Group in Haskell and Knox counties.

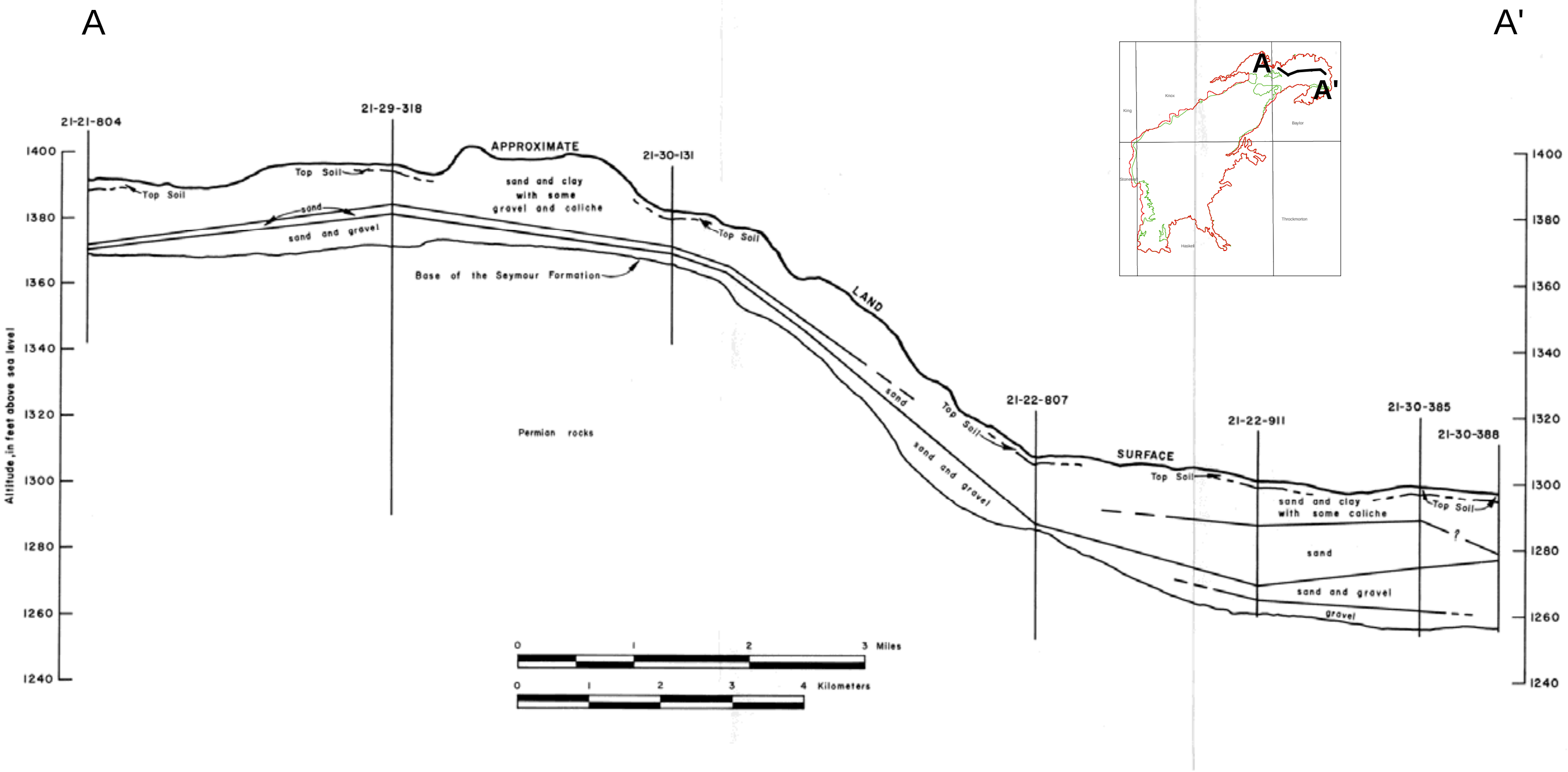


Figure 2.2.7 Geologic cross-section through the Seymour Formation in Baylor County (from Preston, 1978).

This page is intentionally blank.

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.

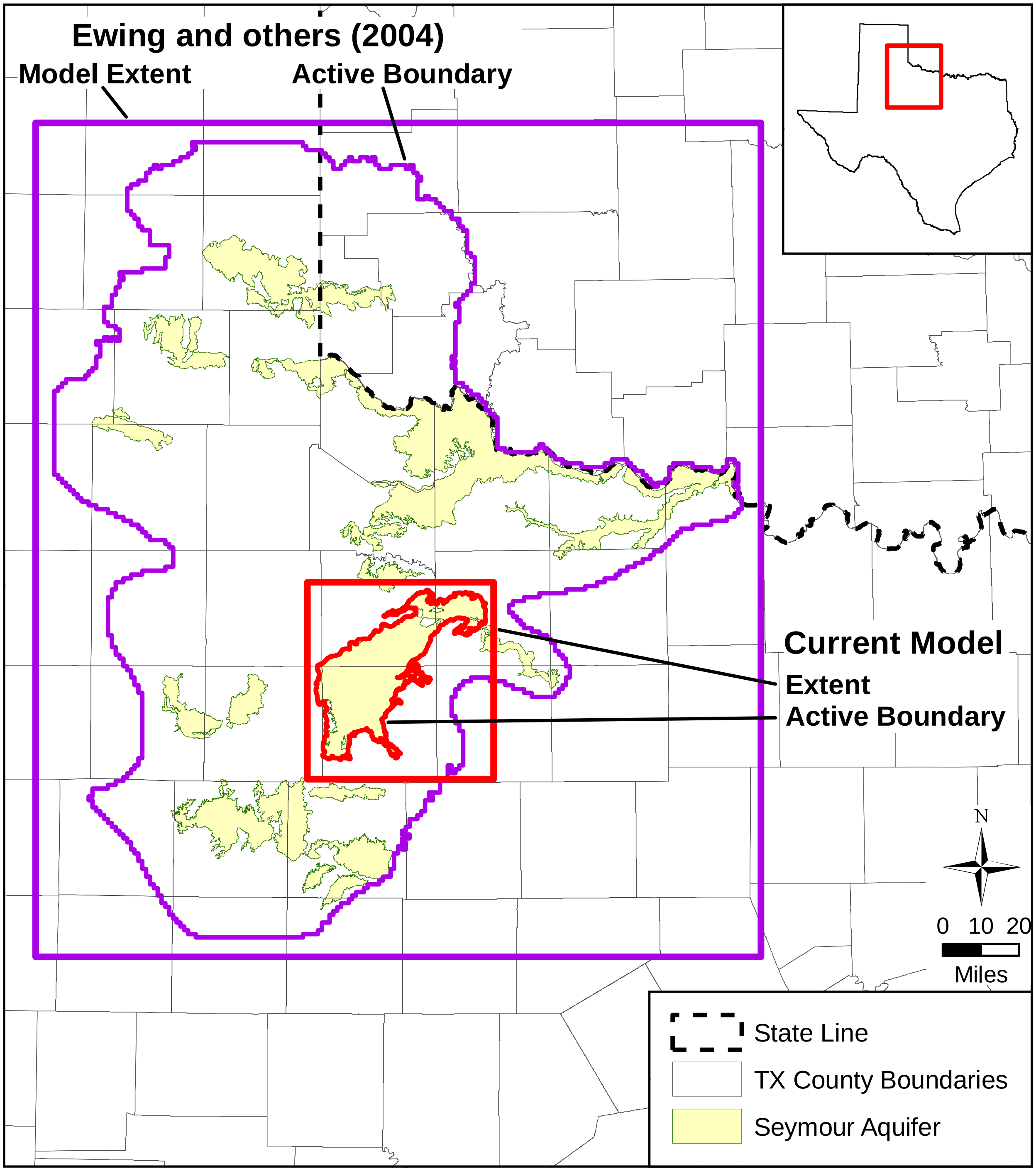


Figure 3.0.1 Location of extent and active area for the Seymour Aquifer groundwater availability model (Ewing and others, 2004) and the refined groundwater availability model for the Haskell-Knox-Baylor pod of the Seymour Aquifer.

This page is intentionally blank.

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.

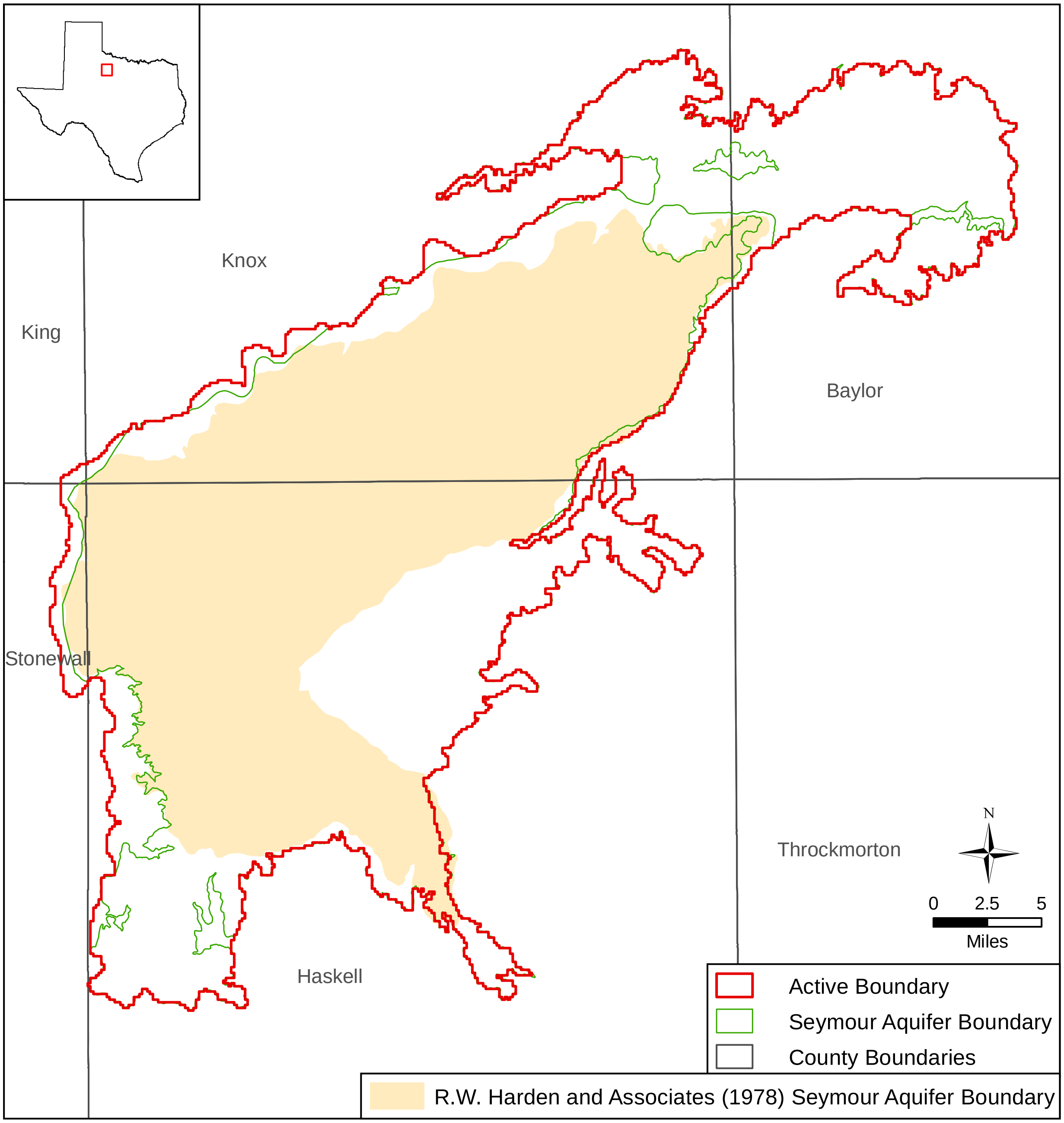


Figure 4.0.1 **Outline of the Seymour Aquifer as defined by the TWDB and of the water-bearing portion of the Seymour Formation as defined by R.W. Harden and Associates (1978).**

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.

System	Series	Group	Formation
Quaternary	Recent to Pleistocene		Alluvium
			Seymour
Tertiary	missing		
Cretaceous			
Jurassic			
Triassic			
Permian	Leonard	Clear Fork	Choza
			Vale
			Arroya
		Wichita (upper portion only)	Lueders

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.

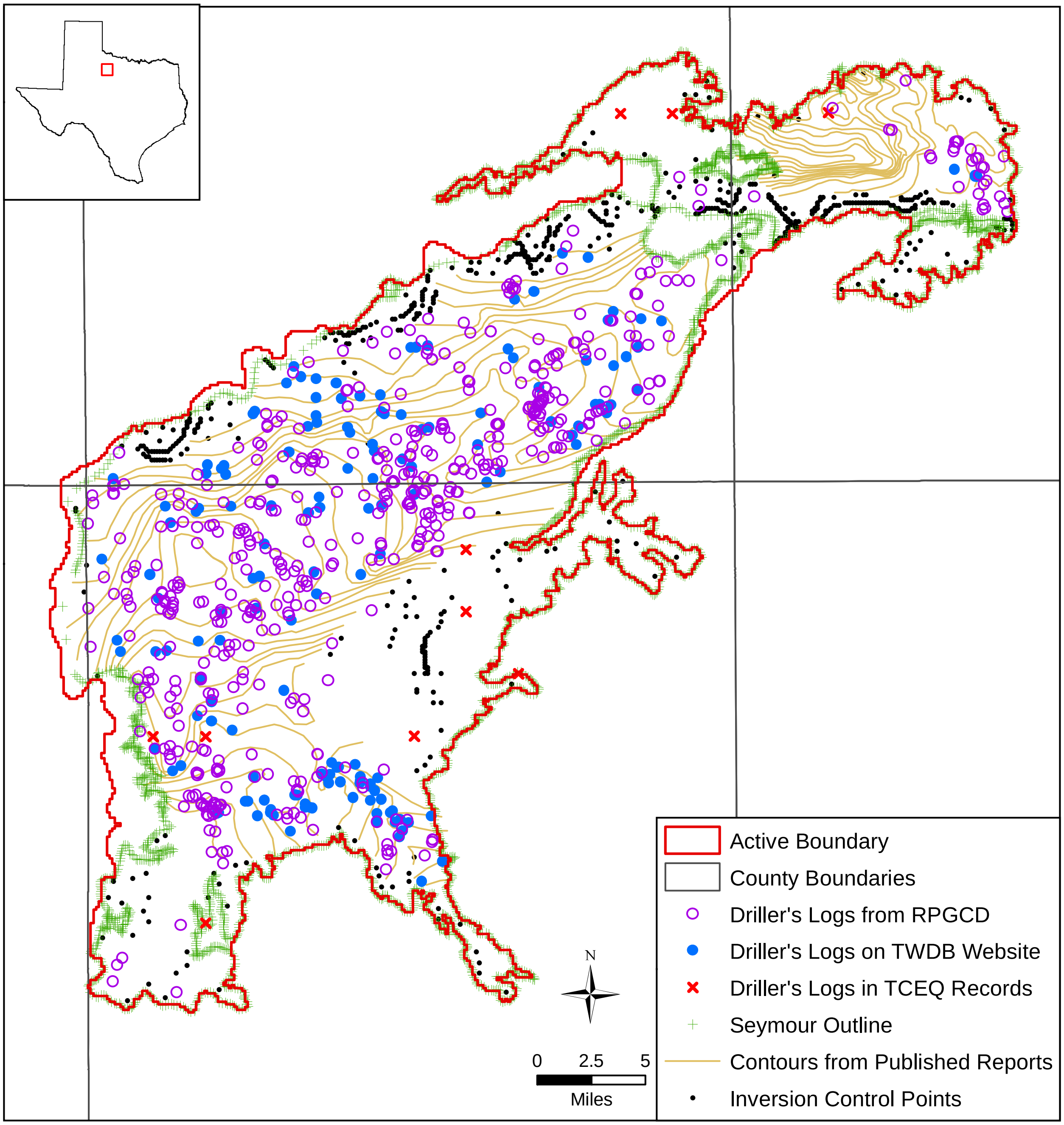
The interpolated surface of the base of the aquifer and the 30-meter digital elevation model (the top of the aquifer) were averaged onto the model grid, which is at a resolution of one-eighth mile by one-eighth mile. Once the model grid had been populated with the structure data, several tests were performed 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.

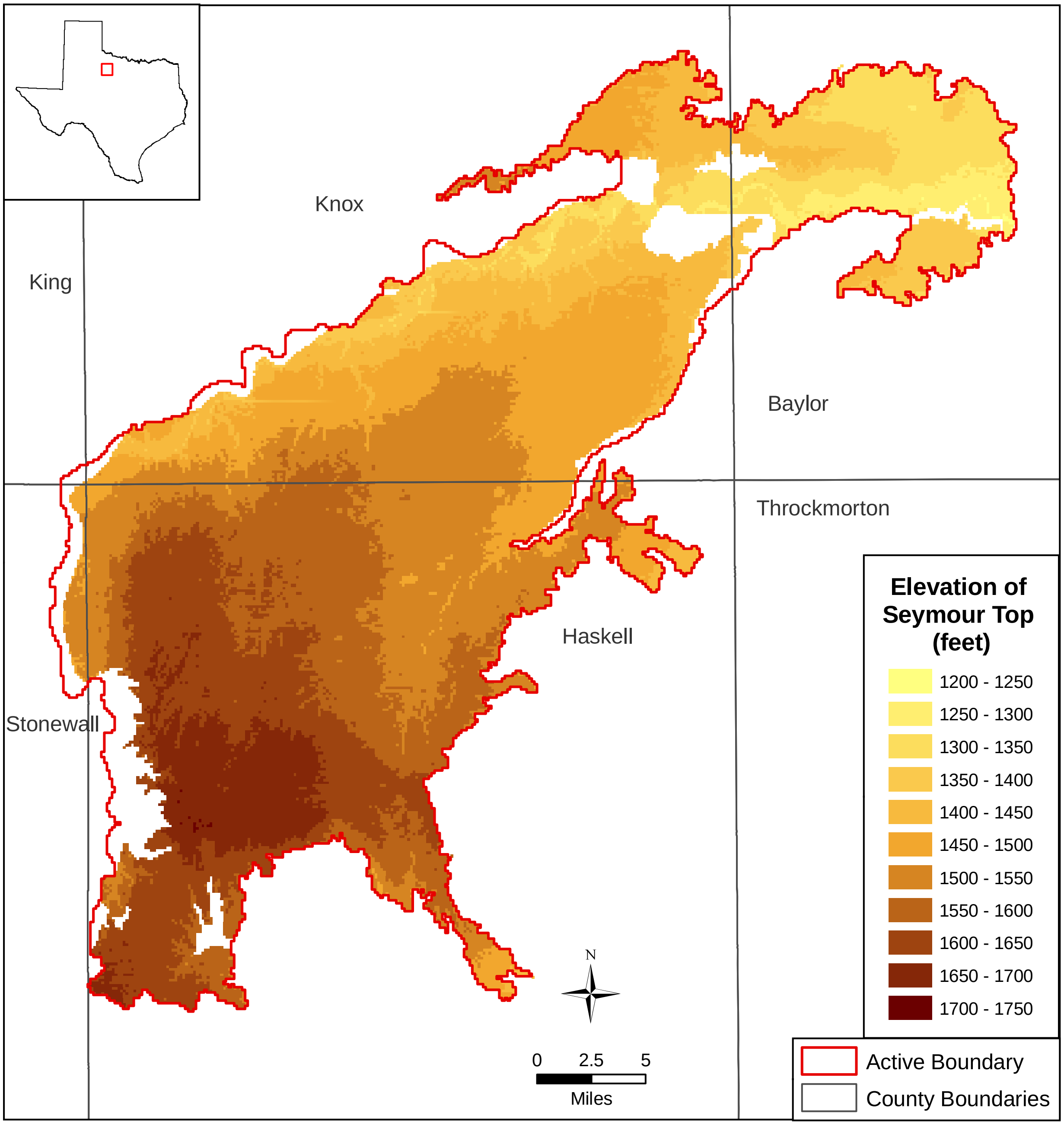


Figure 4.2.2 **Structure map of the top of the Seymour Aquifer.**

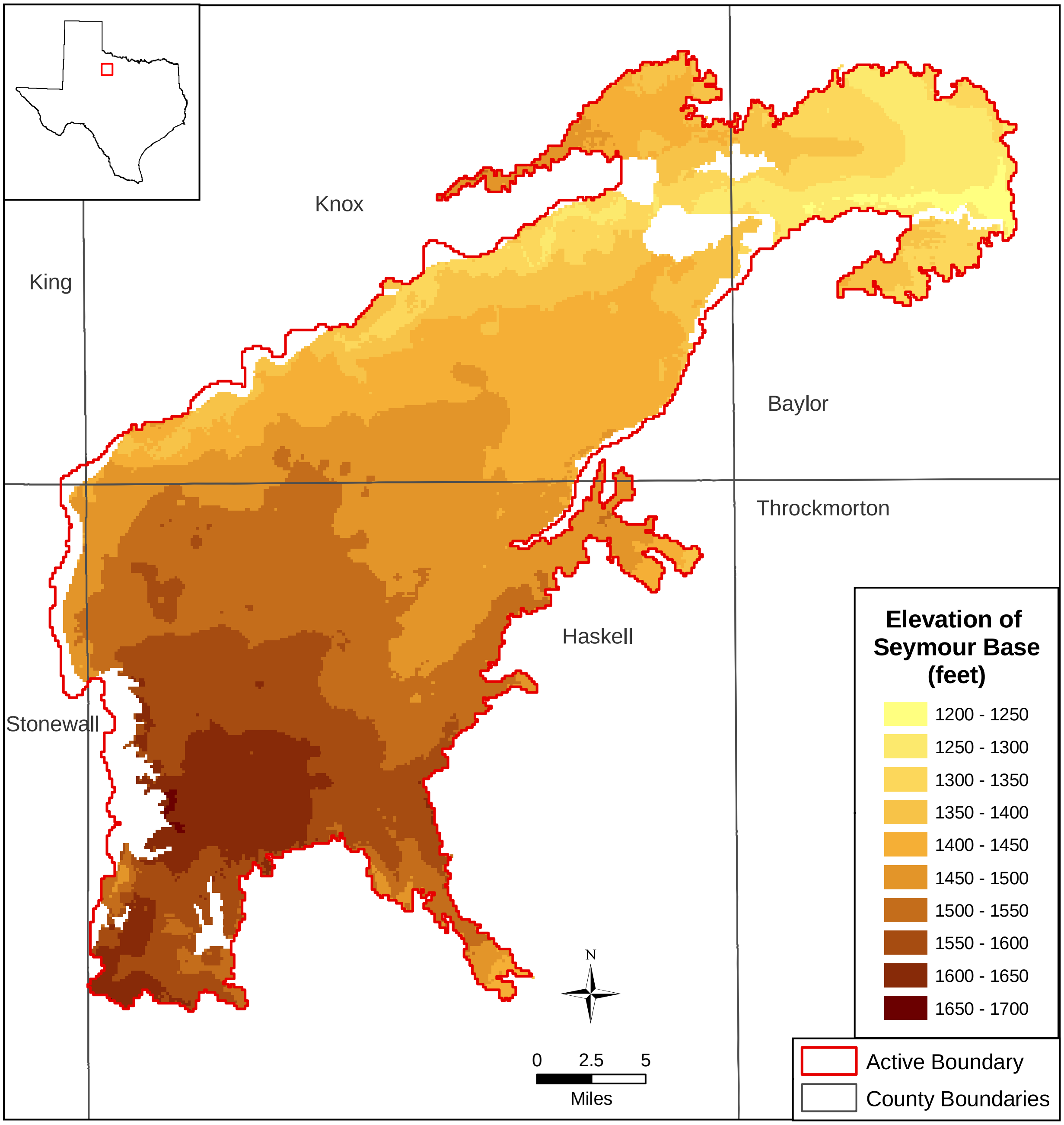


Figure 4.2.3 Structure map of the base of the Seymour Aquifer.

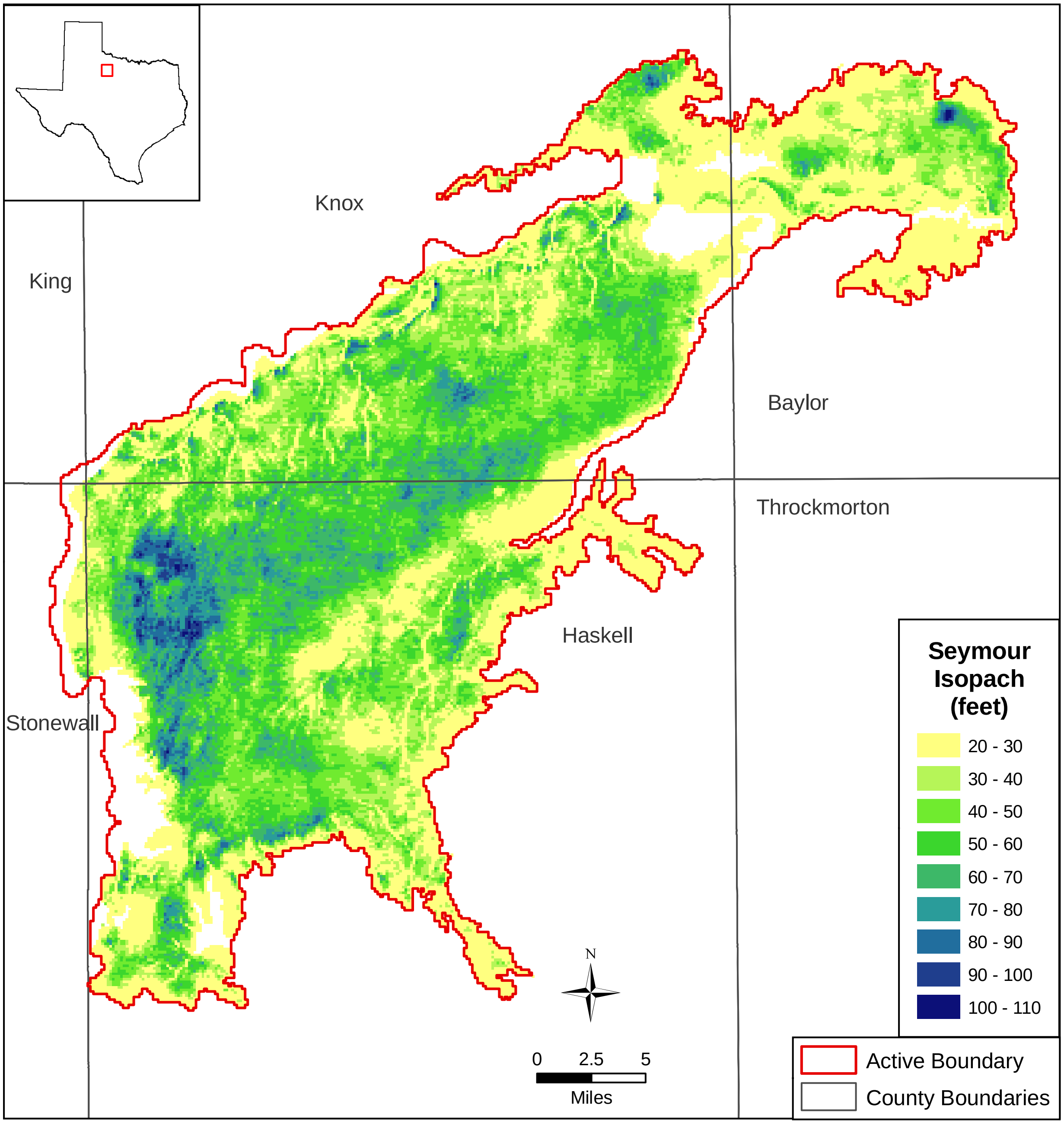


Figure 4.2.4 **Isopach map of the Seymour Aquifer.**

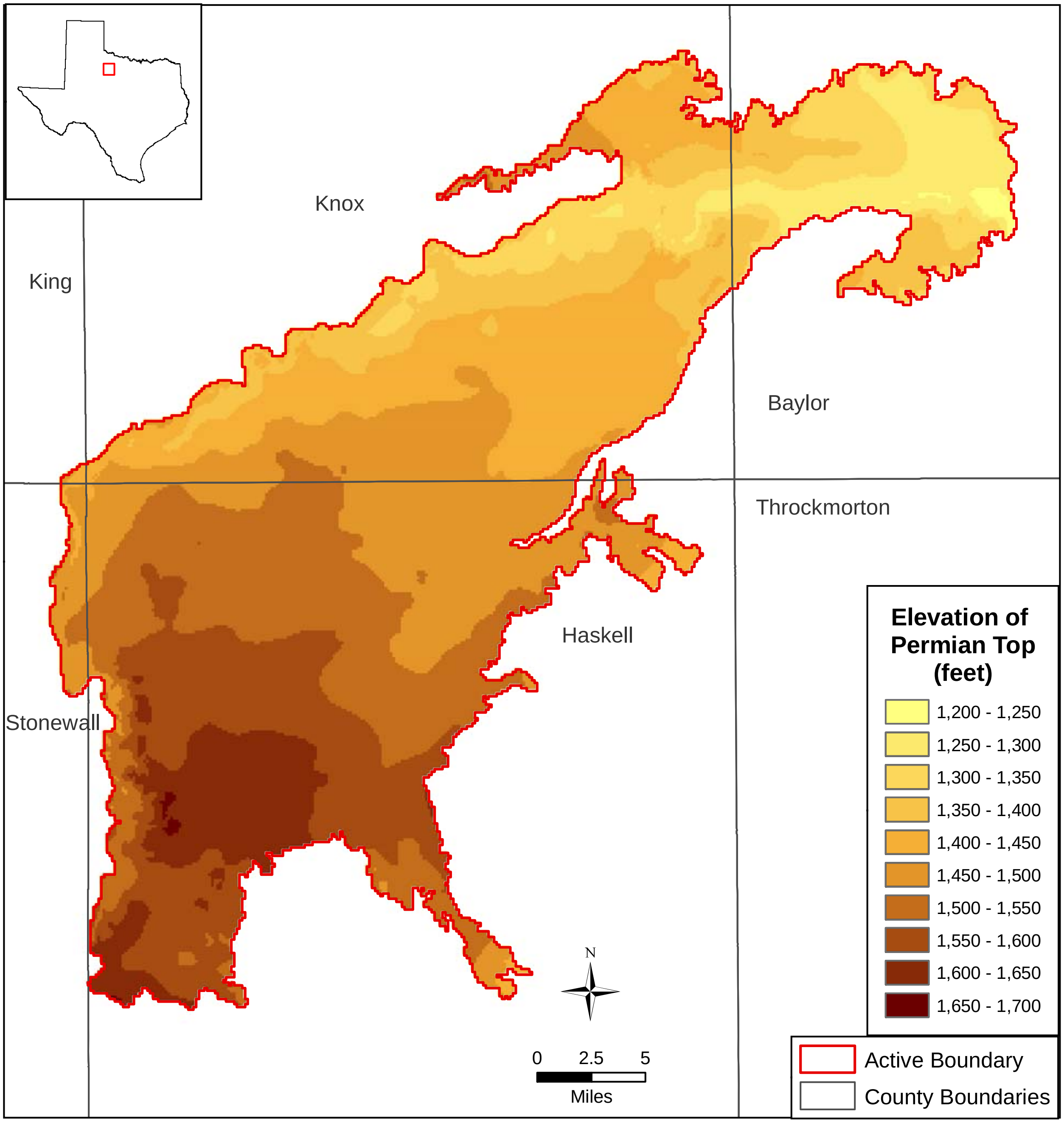


Figure 4.2.5 Structure map of the top of the Clear Fork Group.

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

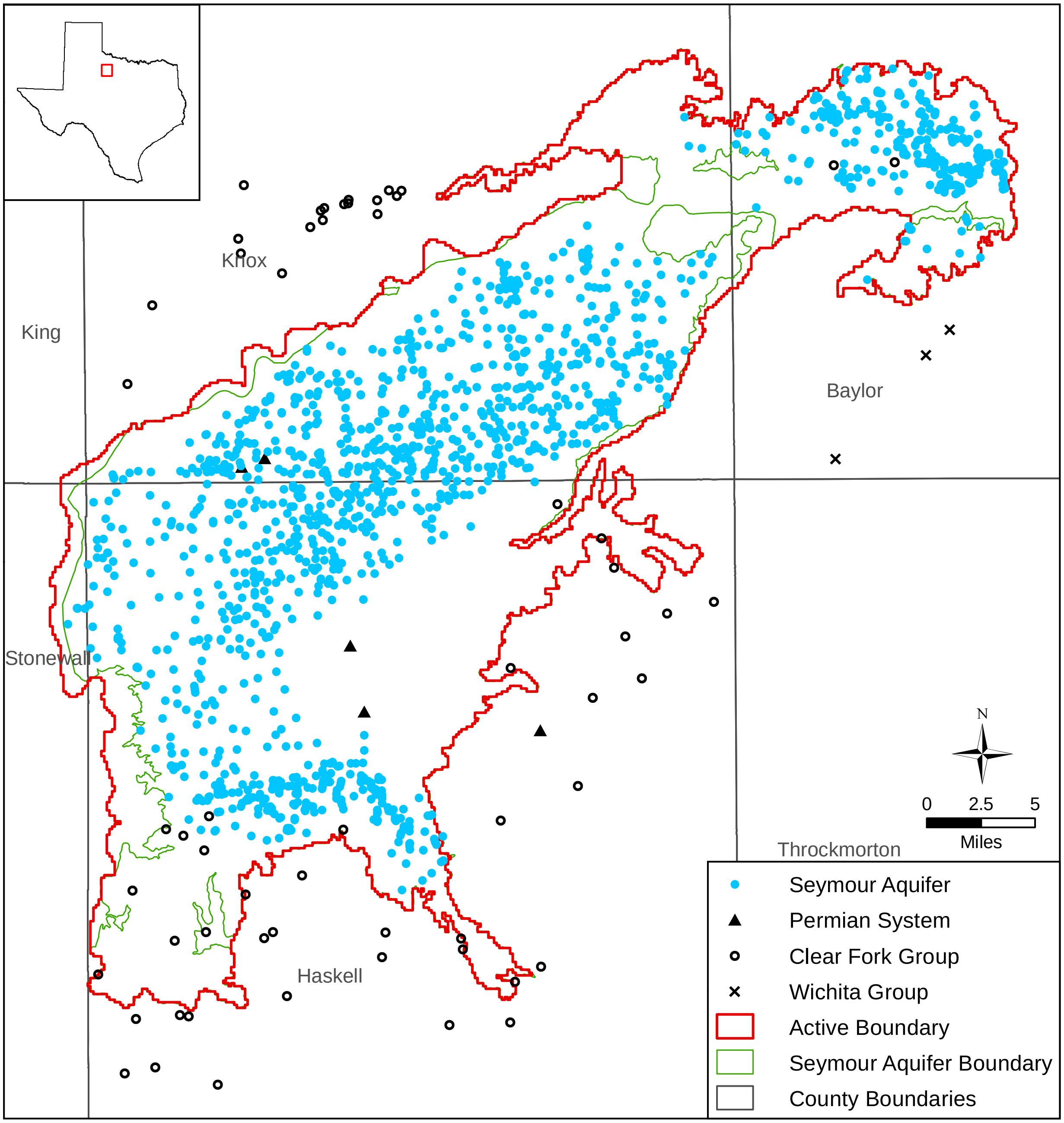


Figure 4.3.1 **Water-level measurement locations for the Seymour Aquifer and Permian-age formations in the study area.**

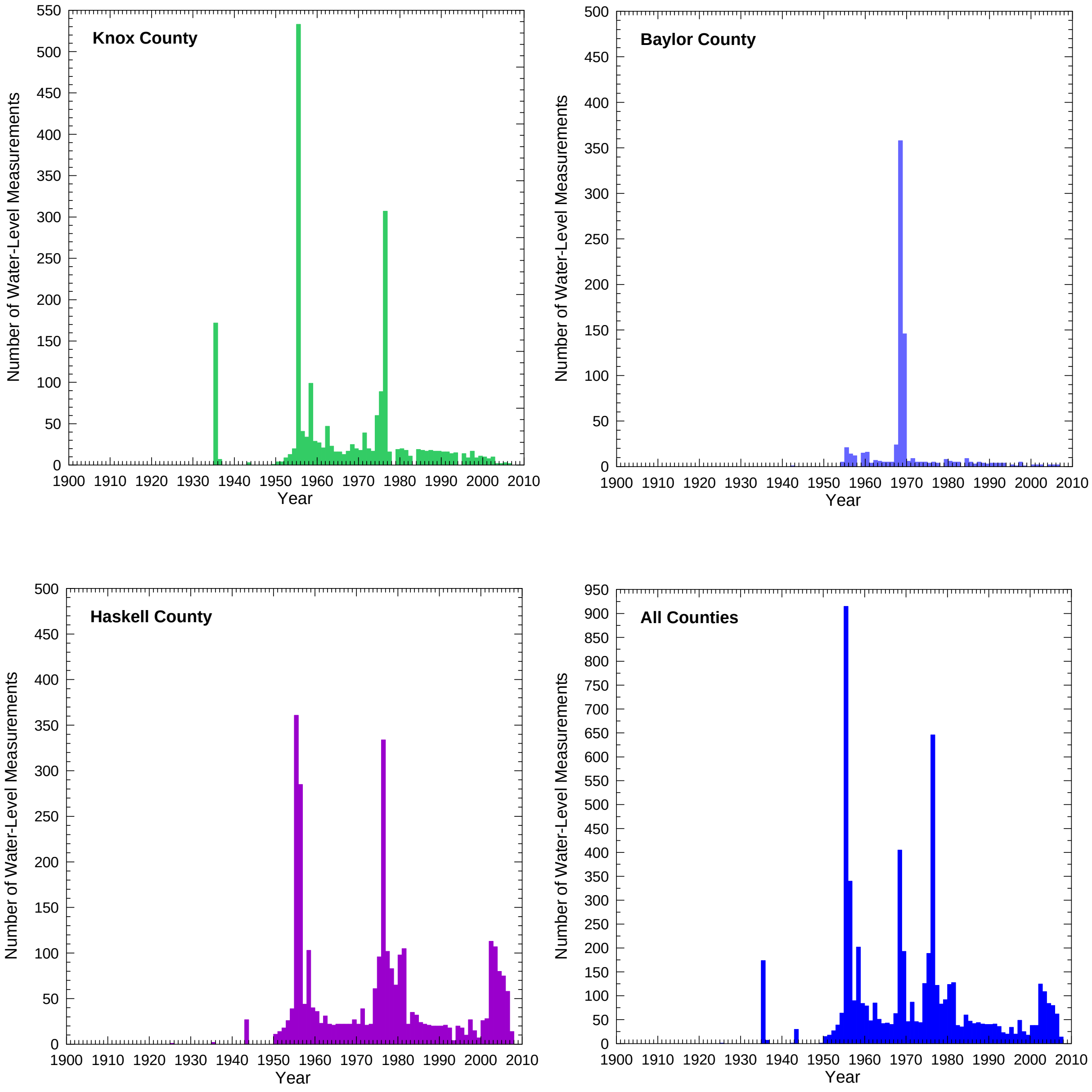


Figure 4.3.2 **Temporal distribution of water-level measurements in the Seymour Aquifer in the study area.**

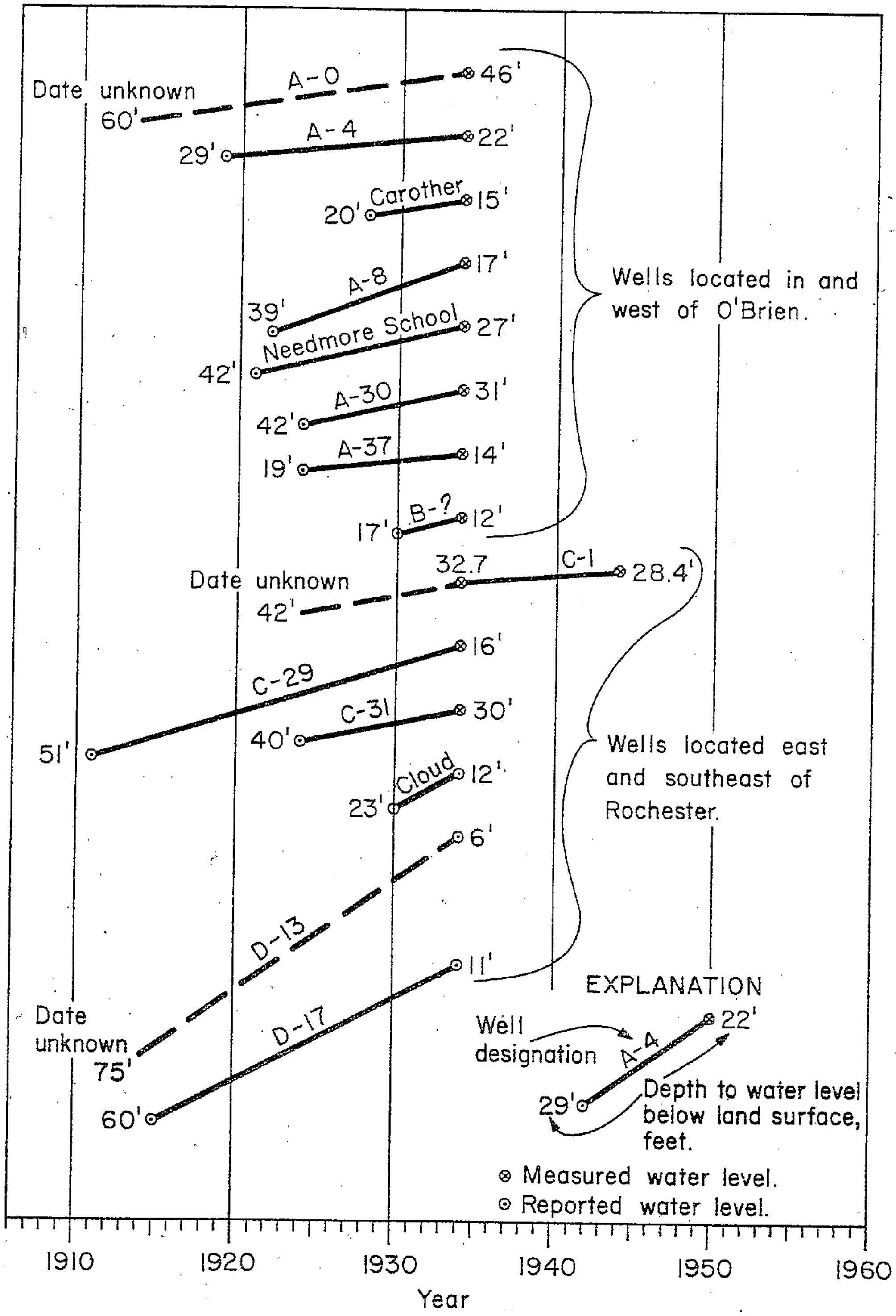


Figure 4.3.3 **Water-level rises reported in the Seymour Formation in western Haskell County by Bandy (1934) (from R.W. Harden and Associates, 1978).**

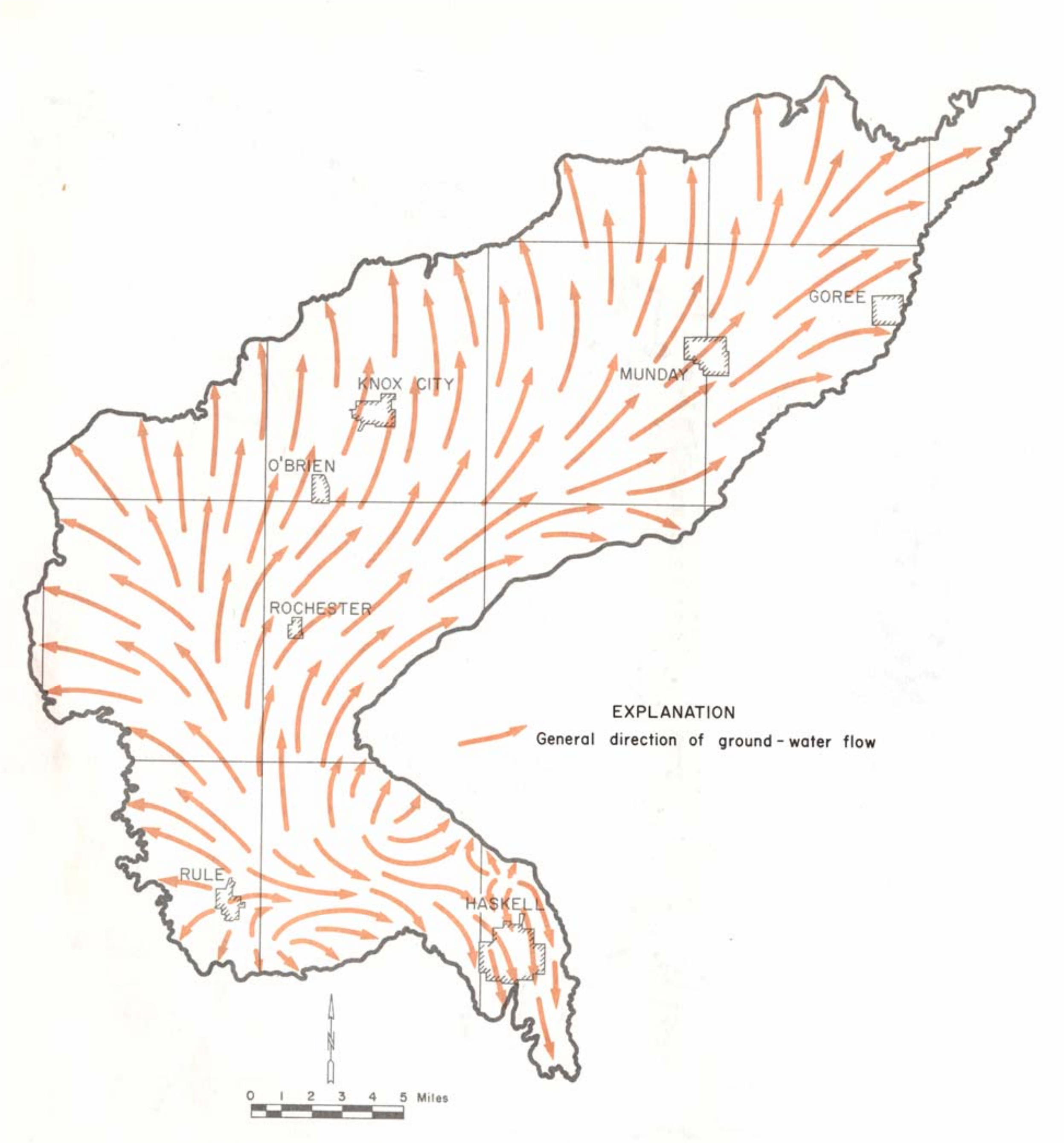


Figure 4.3.4 **Groundwater flow directions in the Seymour Aquifer in Haskell and southern Knox counties (from R.W. Harden and Associates, 1978).**

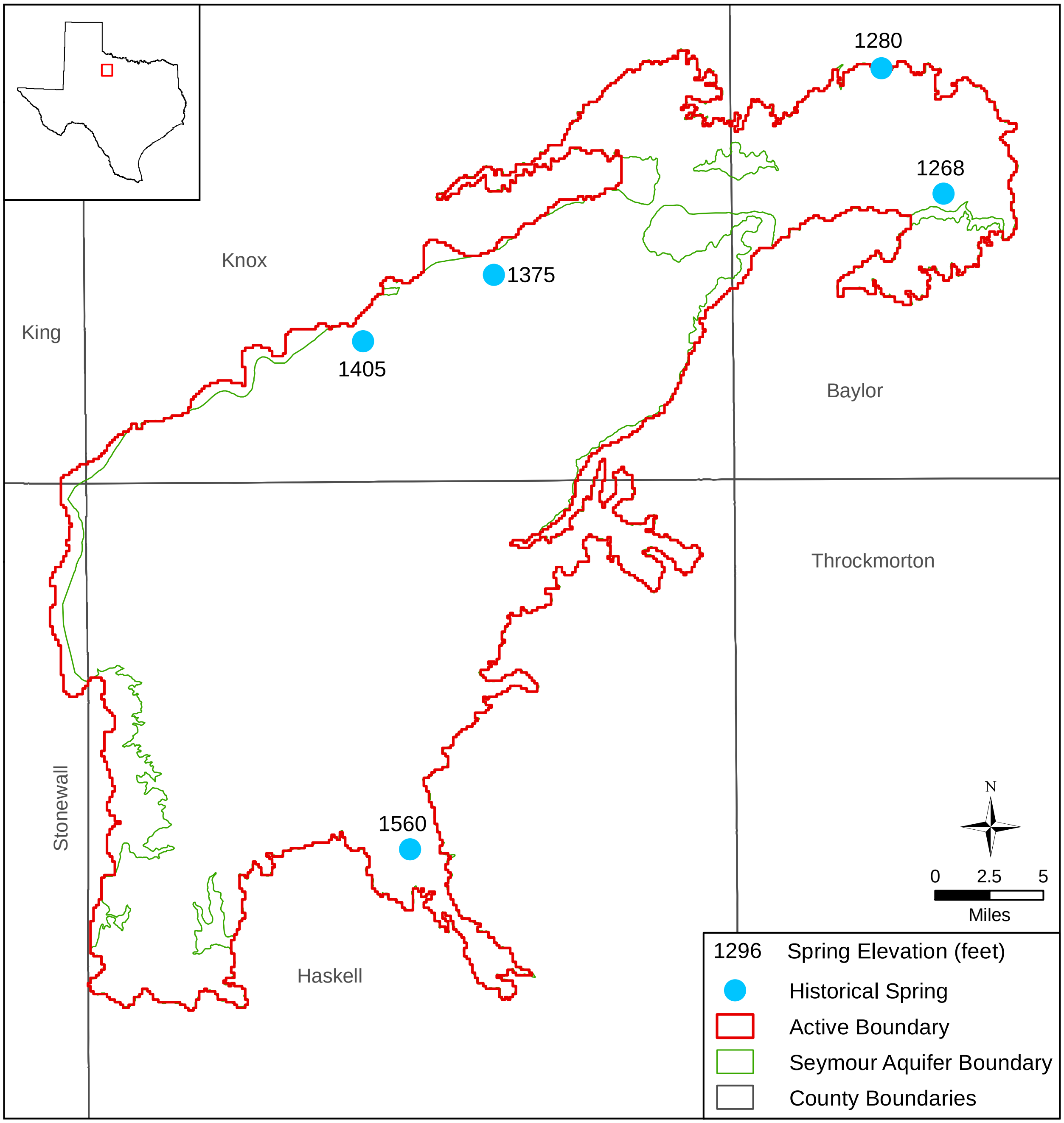


Figure 4.3.5 **Elevations of springs flowing from the Seymour Aquifer under steady-state conditions.**

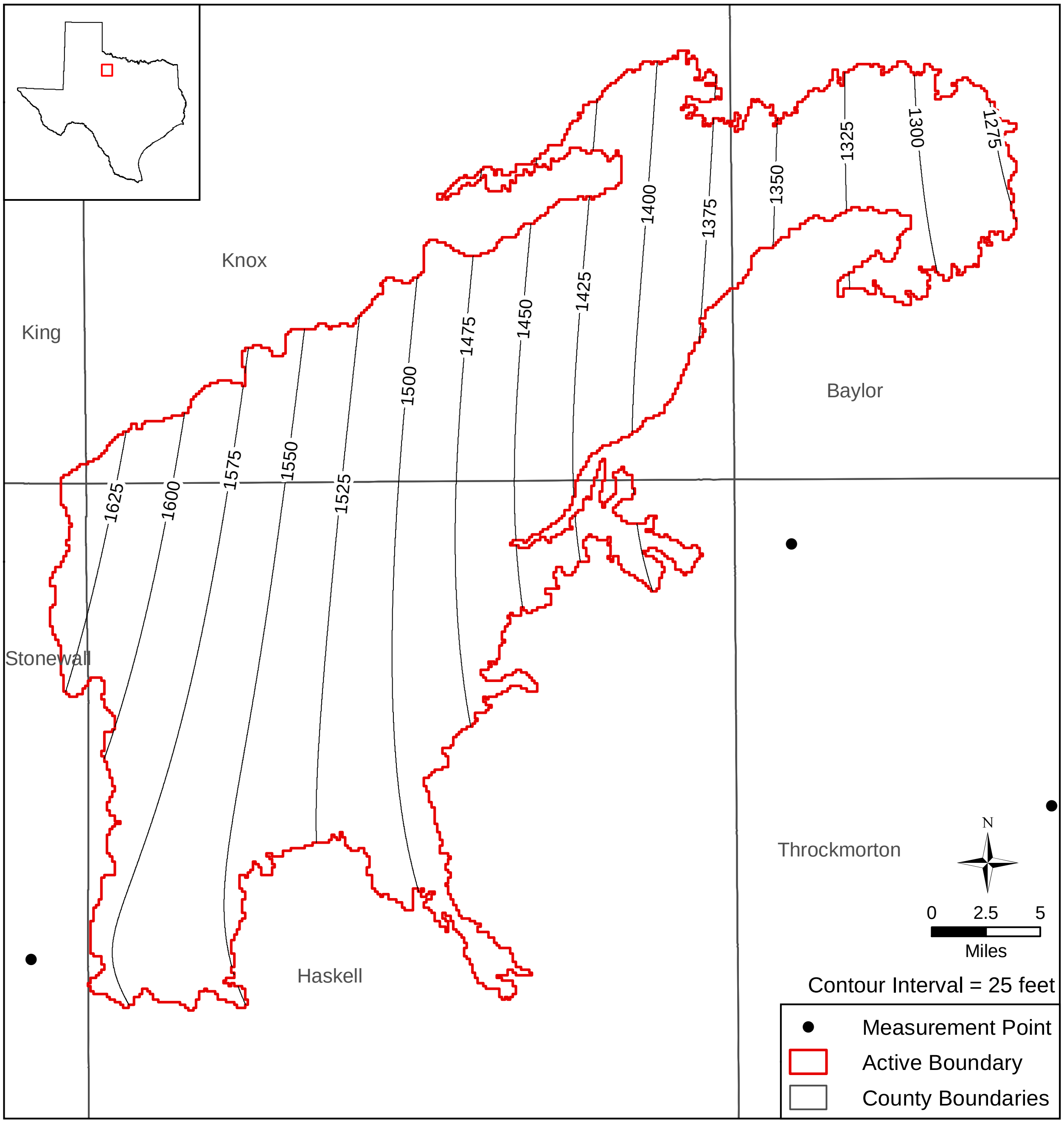


Figure 4.3.6 **Estimated steady-state water-level elevation contours for the Permian-age formations in the study area.**

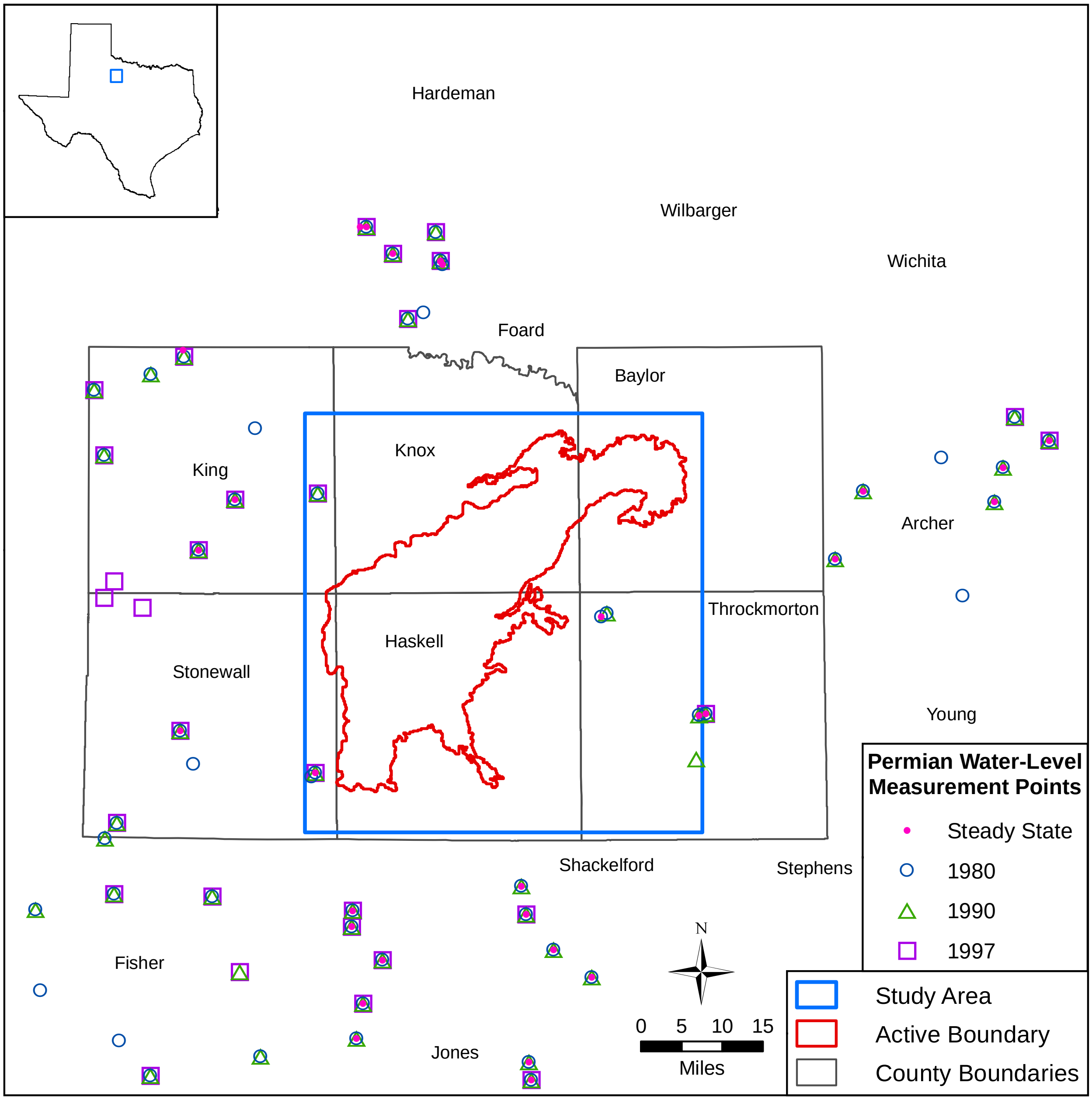


Figure 4.3.7 **Locations of data points used to develop estimated steady-state, 1980, 1990, and 1997 water-level elevation contours for the Permian-age formations.**

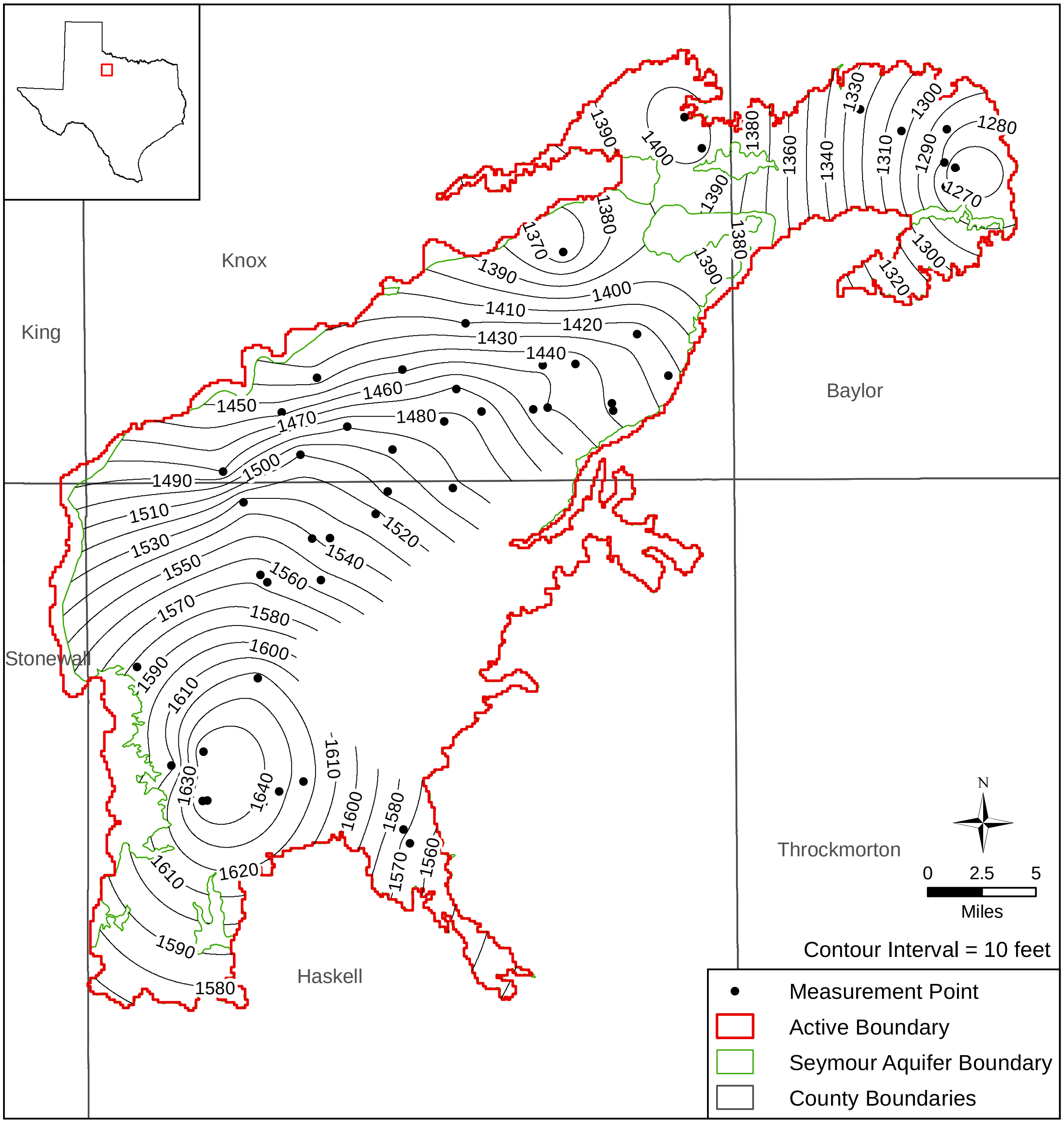


Figure 4.3.8 **Estimated water-level elevation contours in the Seymour Aquifer in the study area at the start of the transient model calibration period (January 1980).**

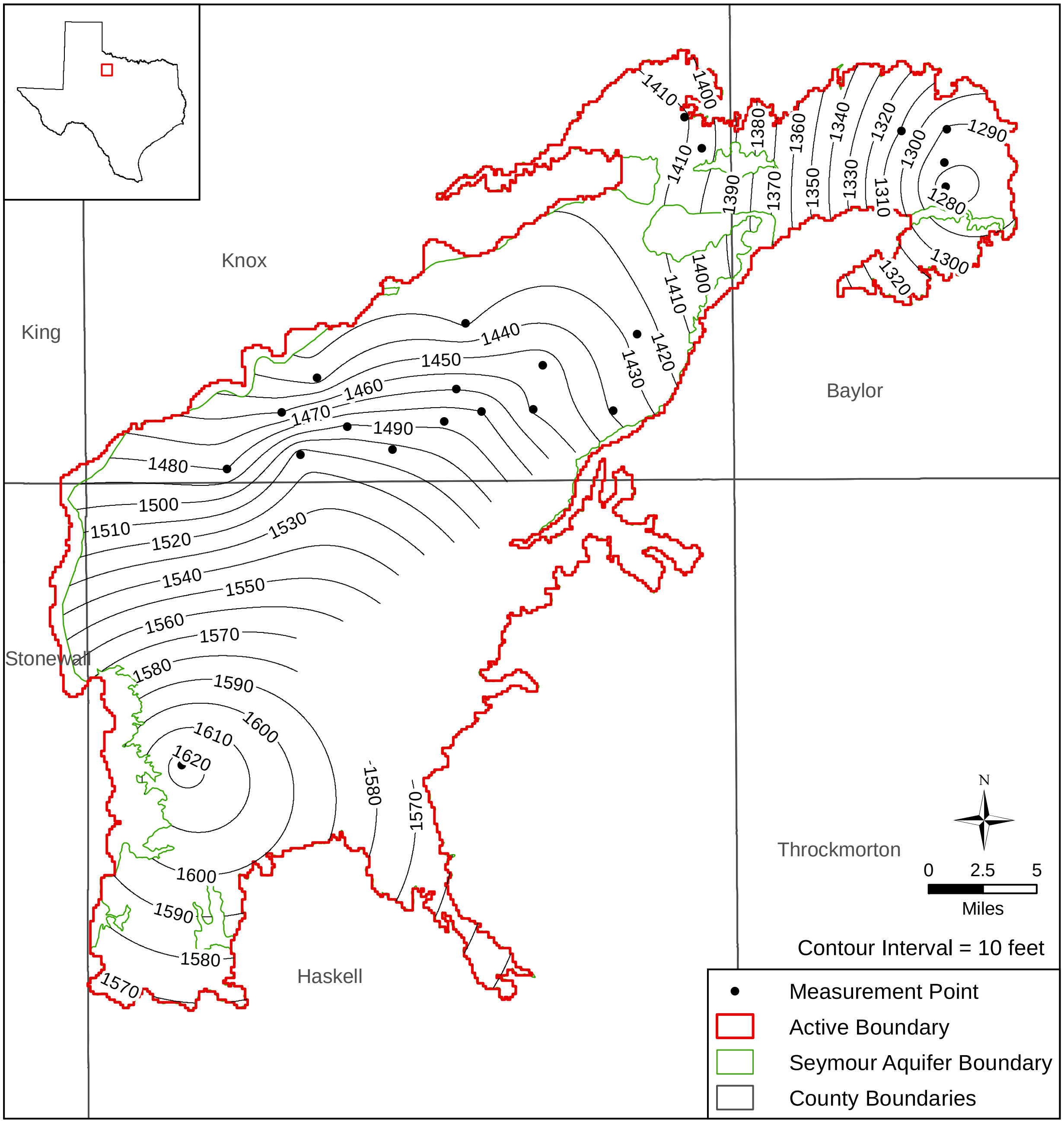


Figure 4.3.9 **Estimated water-level elevation contours in the Seymour Aquifer in the study area at the middle of the transient model calibration period (January 1990).**

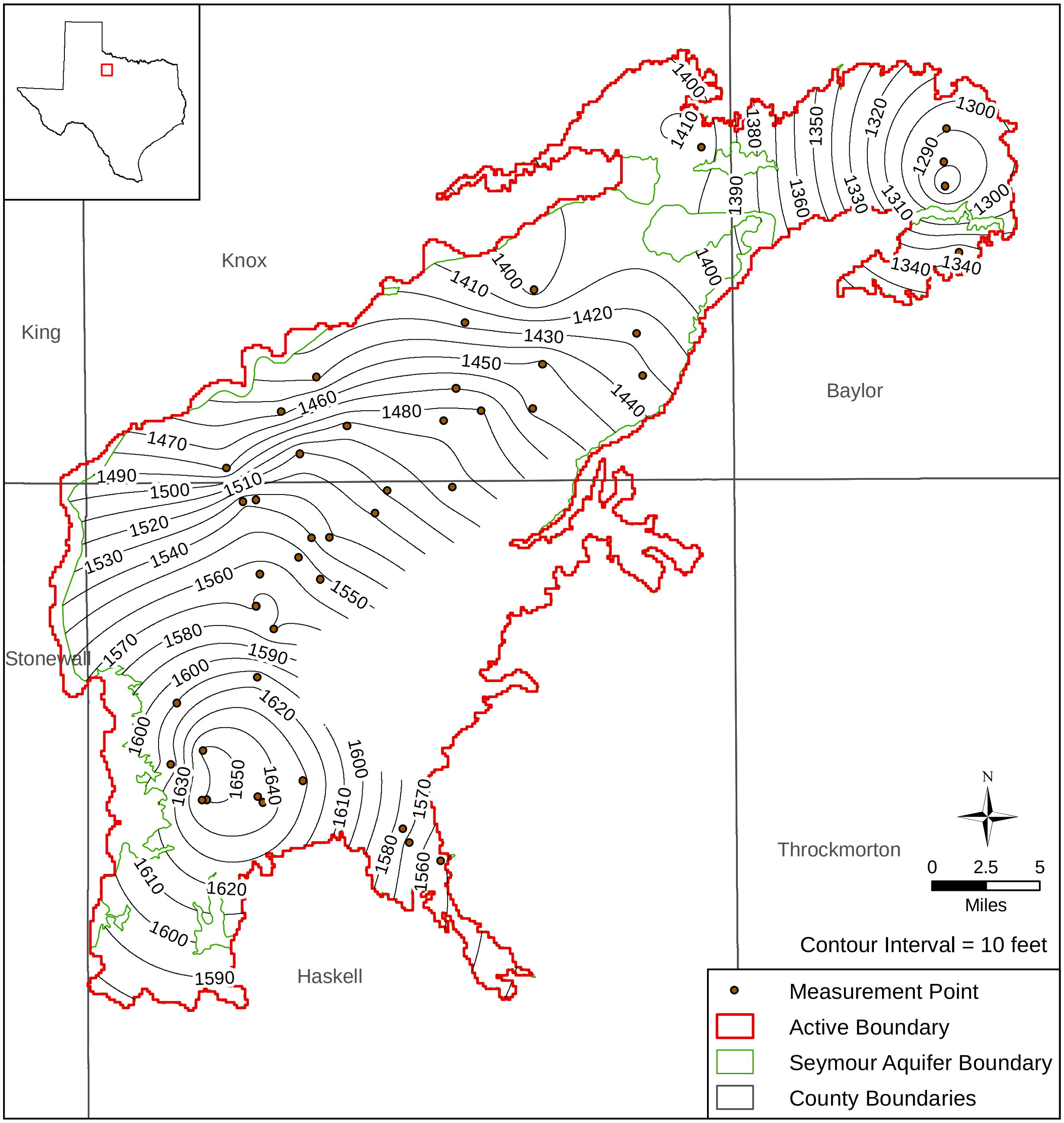


Figure 4.3.10 **Estimated water-level elevation contours in the Seymour Aquifer in the study area at the end of the transient model calibration period (December 1997).**

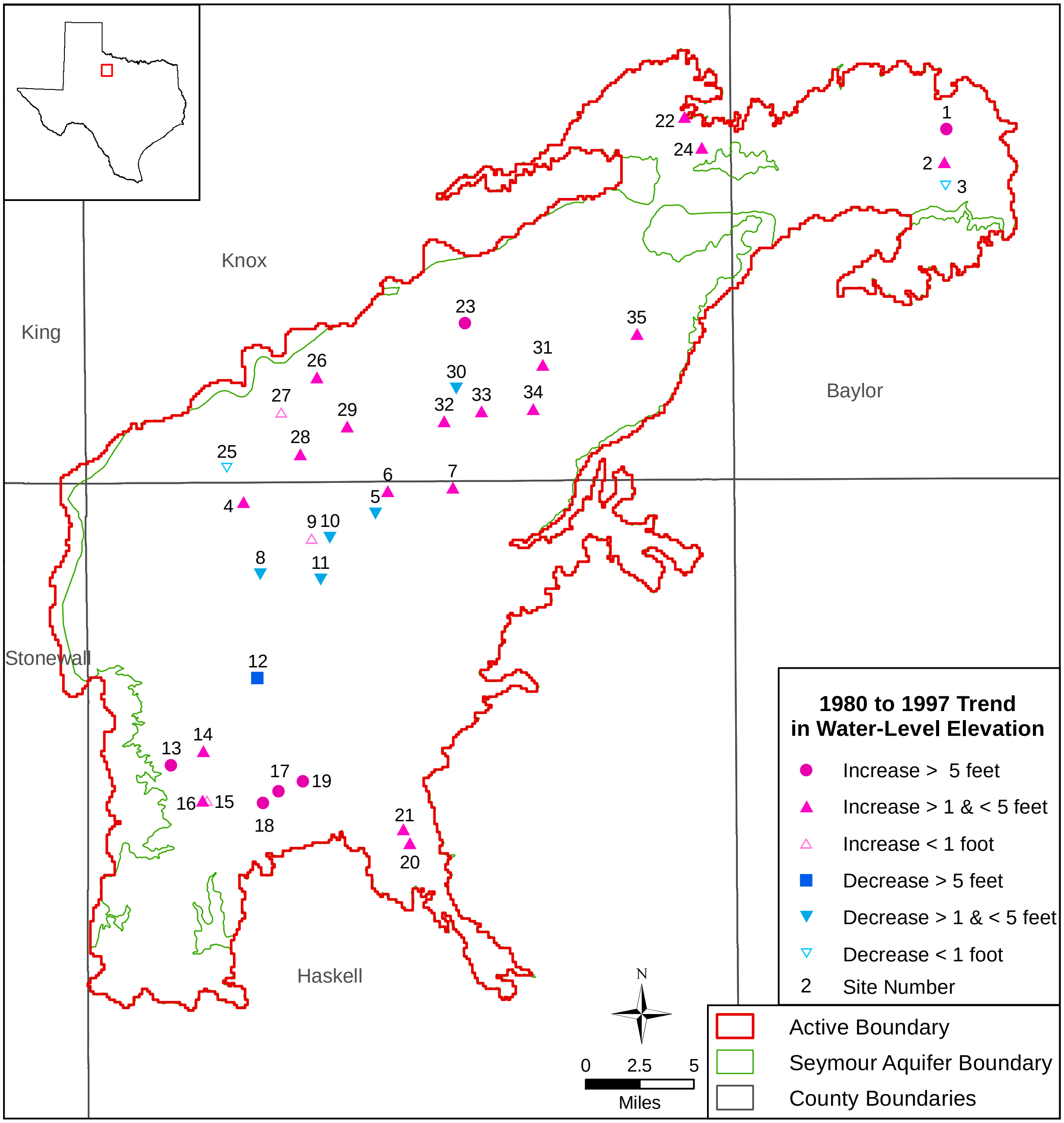


Figure 4.3.11 **Estimated 1980 to 1997 trends in water-level elevations in the Seymour Aquifer in the study area.**

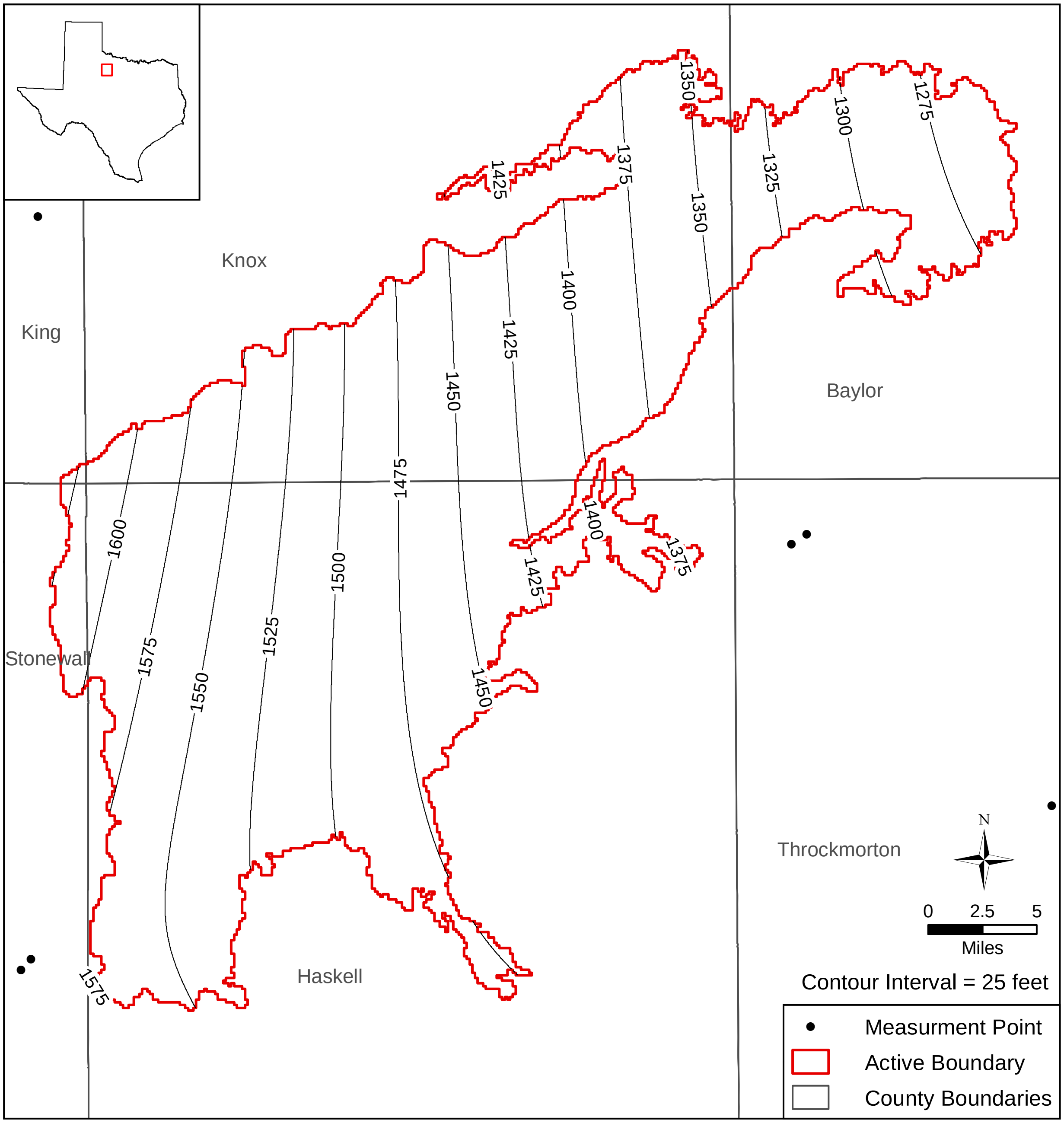


Figure 4.3.12 **Estimated water-level elevation contours in the Permian-age formations in the study area at the start of the transient model calibration period (January 1980).**

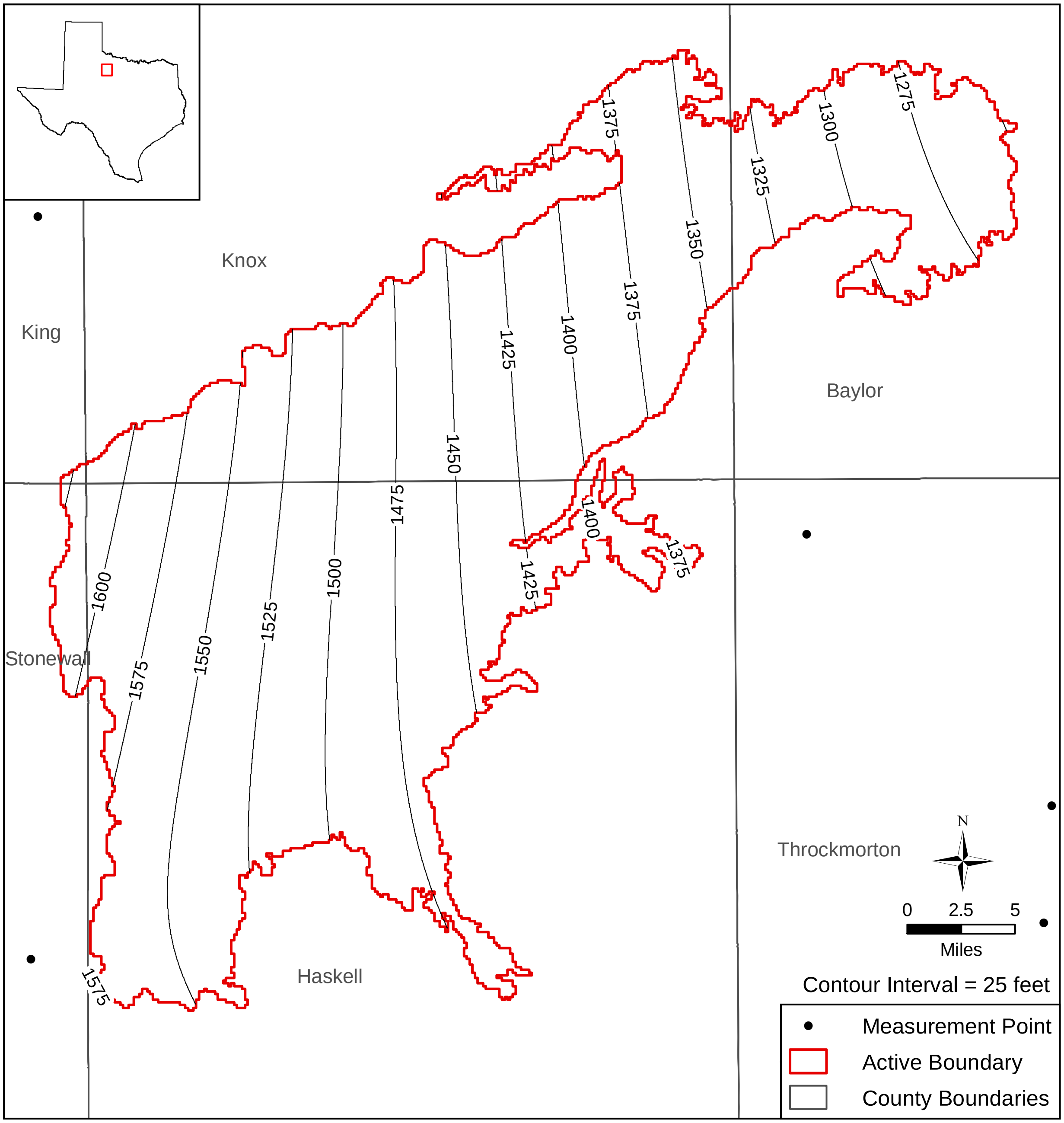


Figure 4.3.13 Estimated water-level elevation contours in the Permian-age formations in the study area at the middle of the transient model calibration period (January 1990).

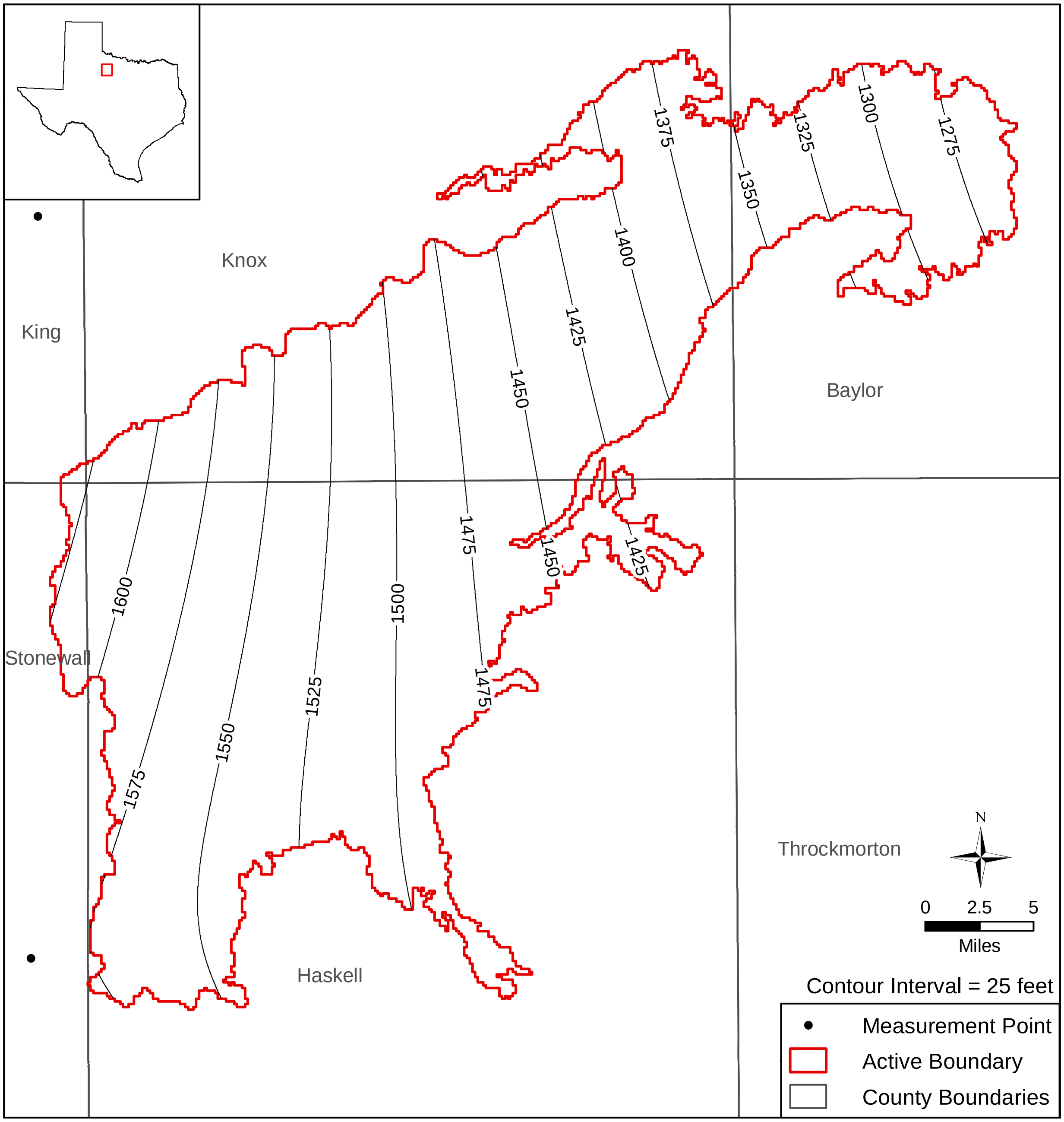


Figure 4.3.14 **Estimated water-level elevation contours in the Permian-age formations in the study area at the end of the transient model calibration period (December 1997).**

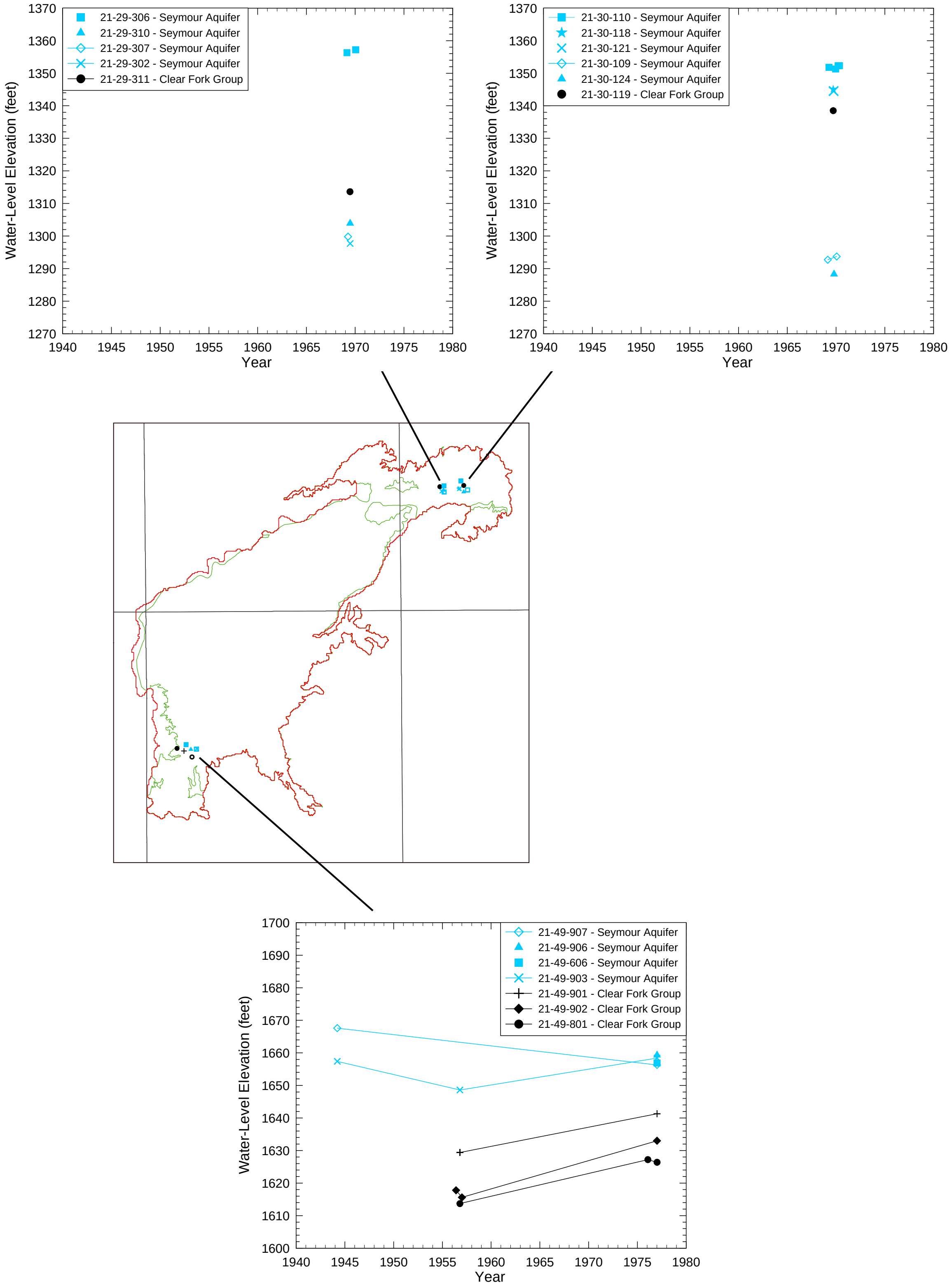


Figure 4.3.15 Comparison of water-level elevations in the Seymour Aquifer and underlying Clear Fork Group in the study area.

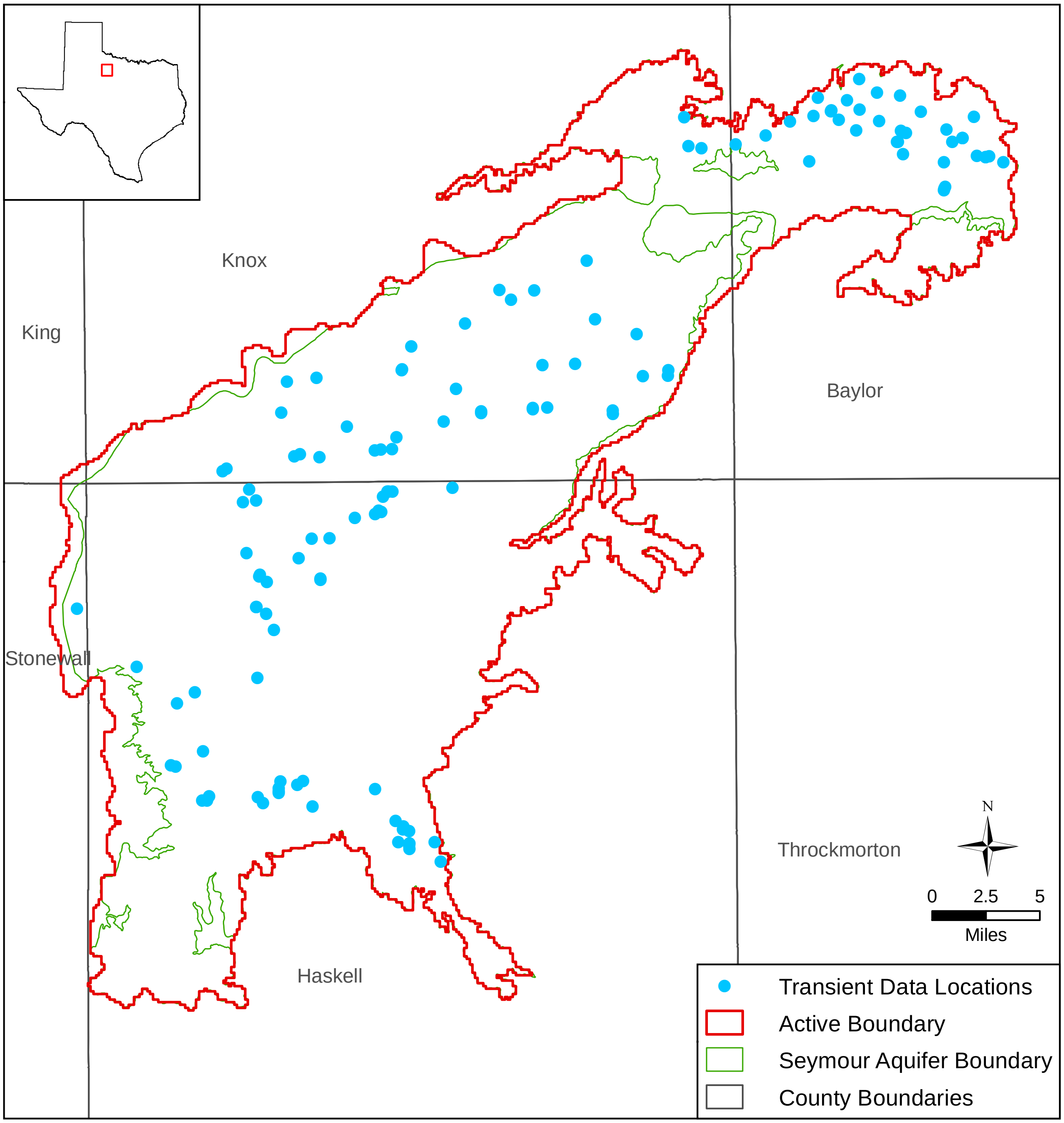


Figure 4.3.16 **Locations of Seymour Aquifer wells in the study area with transient water-level data.**

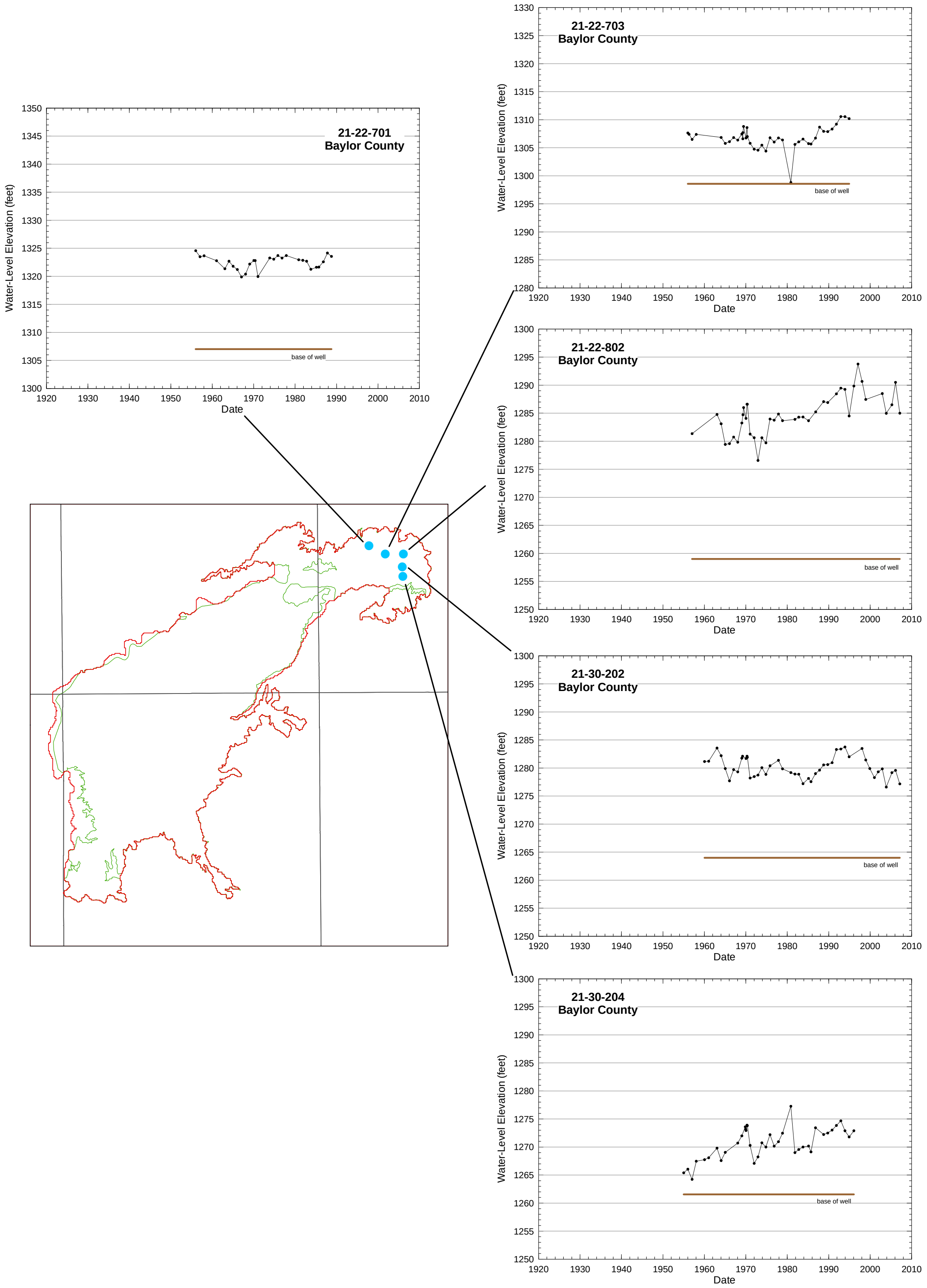


Figure 4.3.17 Hydrographs for the five Seymour Aquifer wells in Baylor County with long-term transient water-level data.

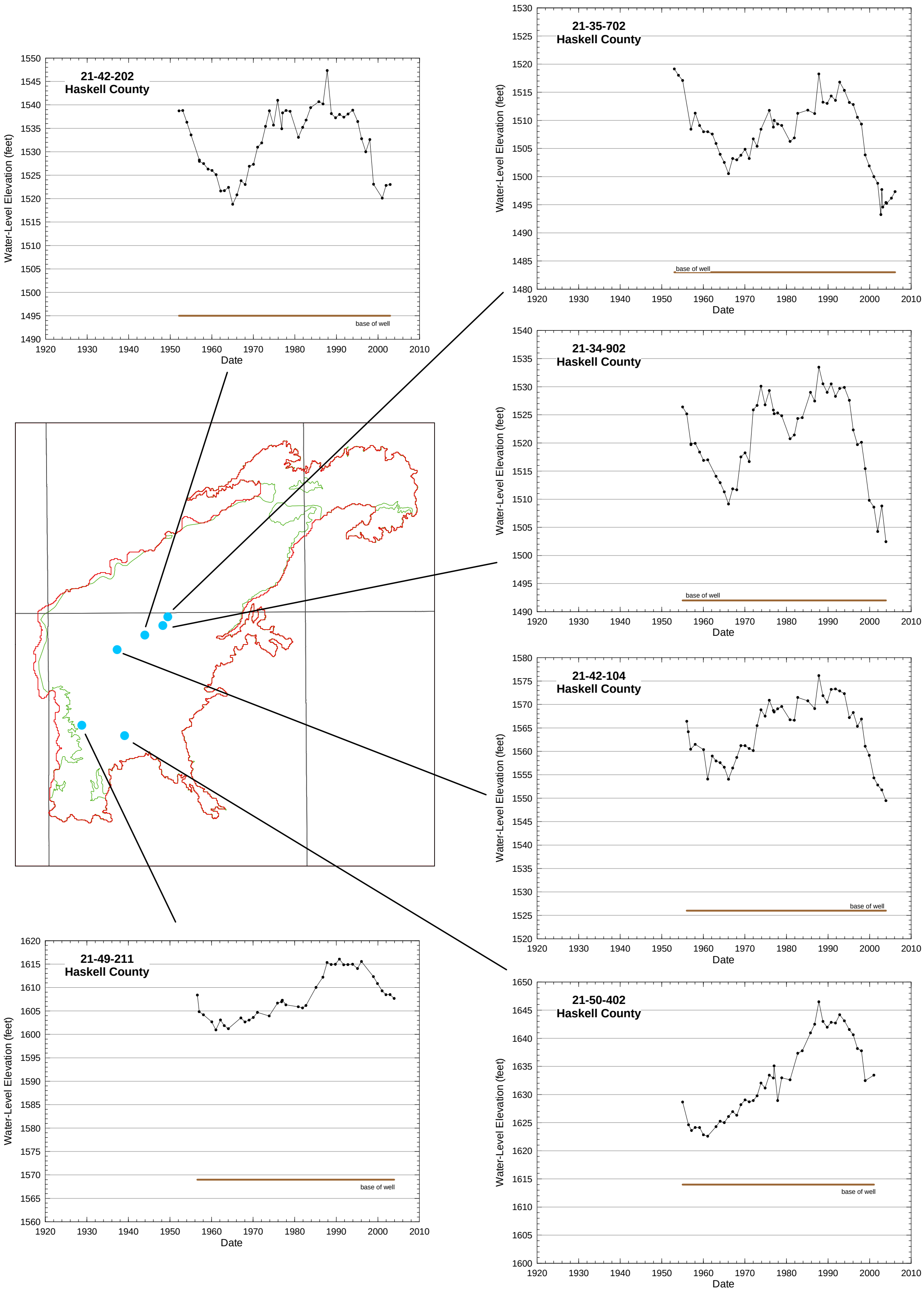


Figure 4.3.18 Example hydrographs showing fluctuating water-level elevations with time in the Seymour Aquifer in Haskell County.

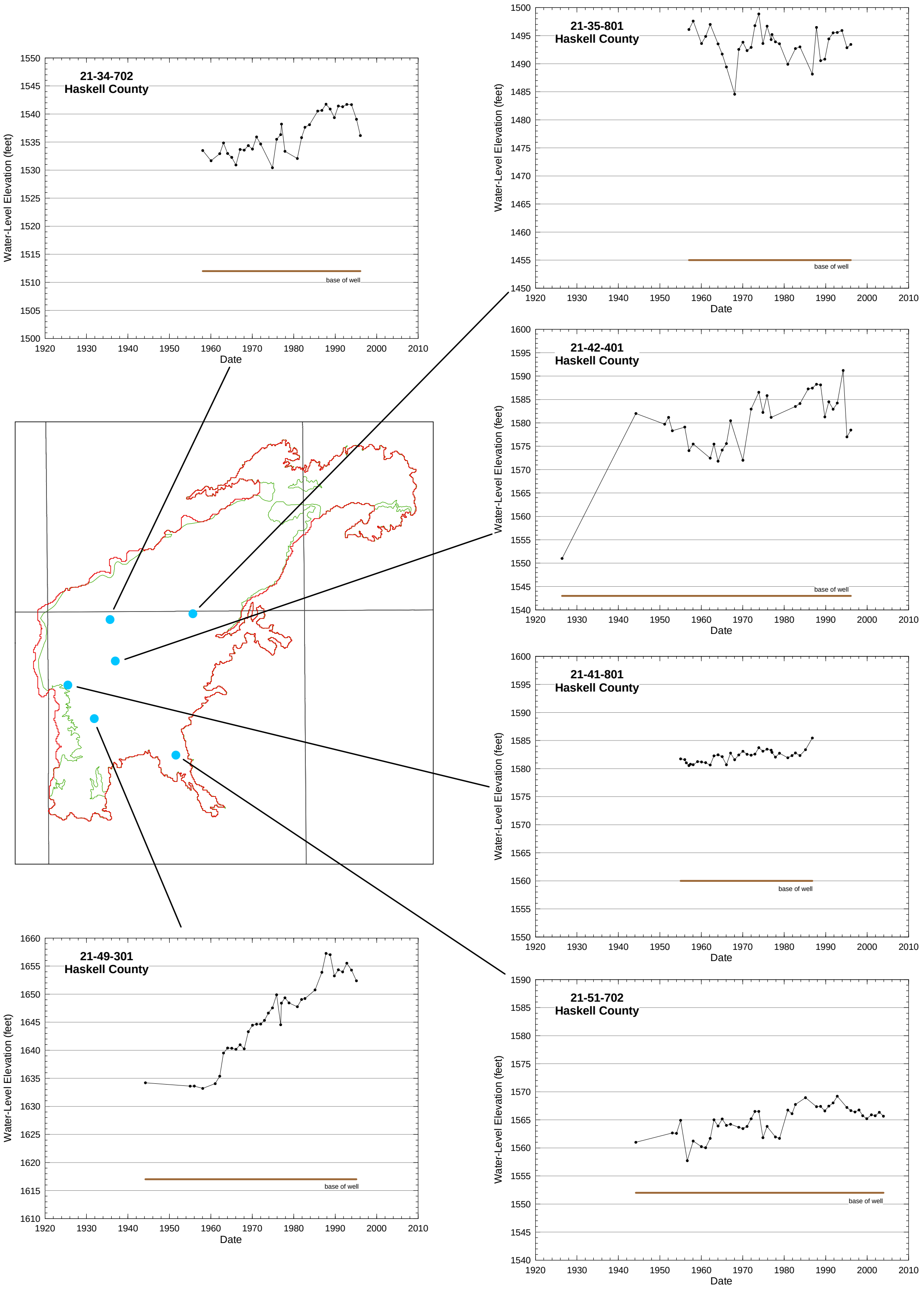


Figure 4.3.19 Example hydrographs showing increasing and stable water-level elevations with time in the Seymour Aquifer in Haskell County.

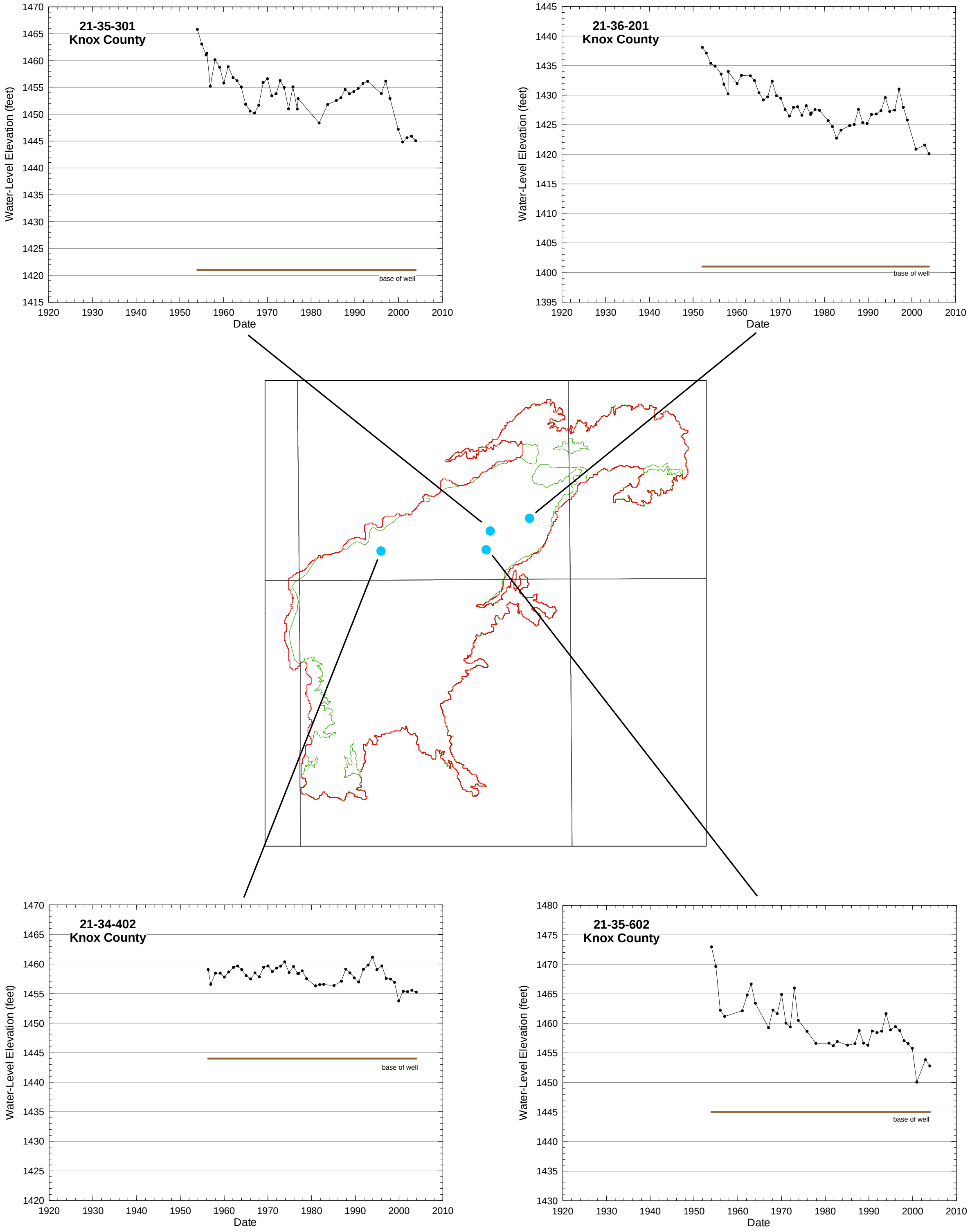


Figure 4.3.20 Hydrographs for the four Seymour Aquifer wells in Knox County with long-term transient water-level data showing a decreasing trend.

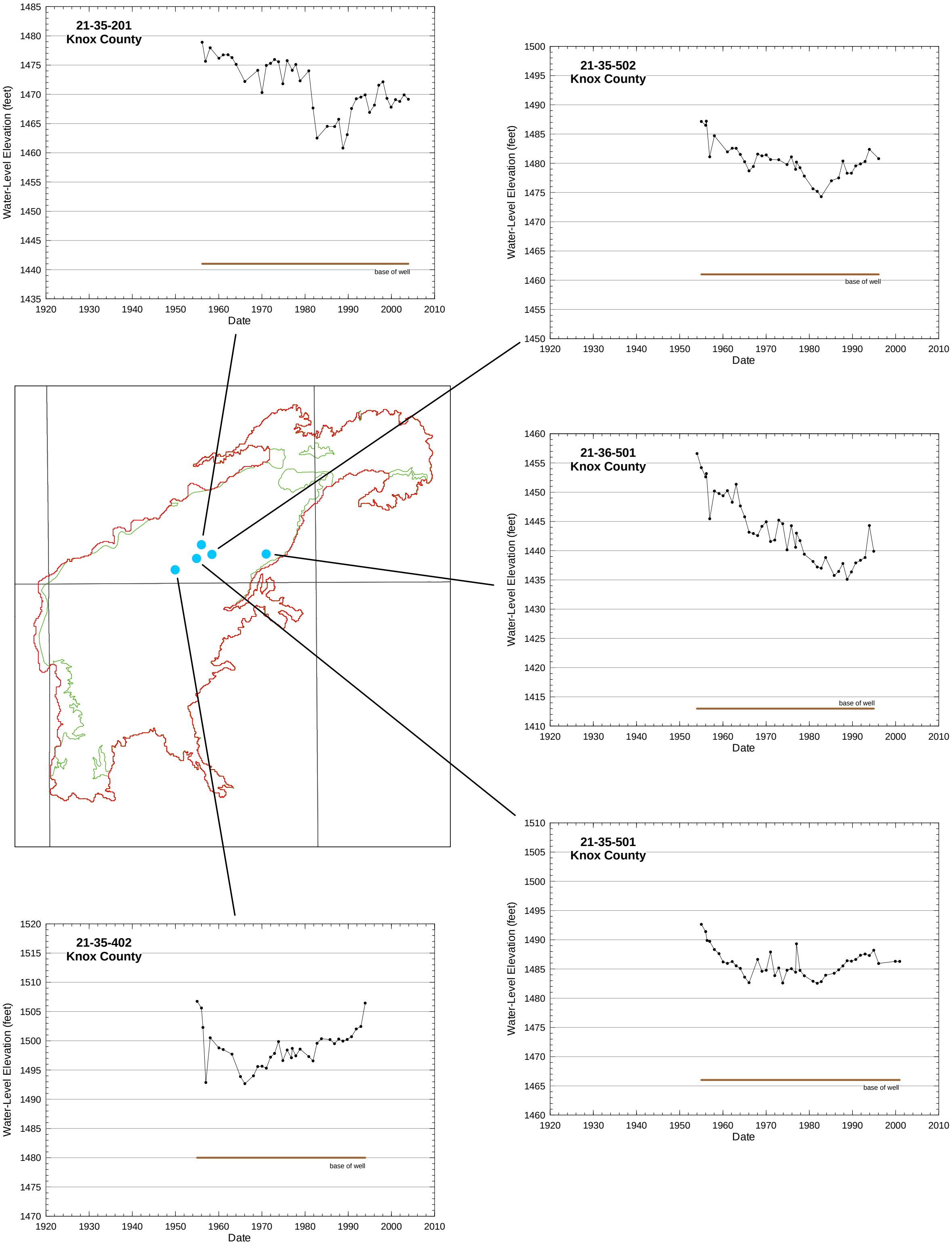


Figure 4.3.21 **Hydrographs for the five Seymour Aquifer wells in Knox County with long-term transient water-level data showing a decreasing and then increasing trend.**

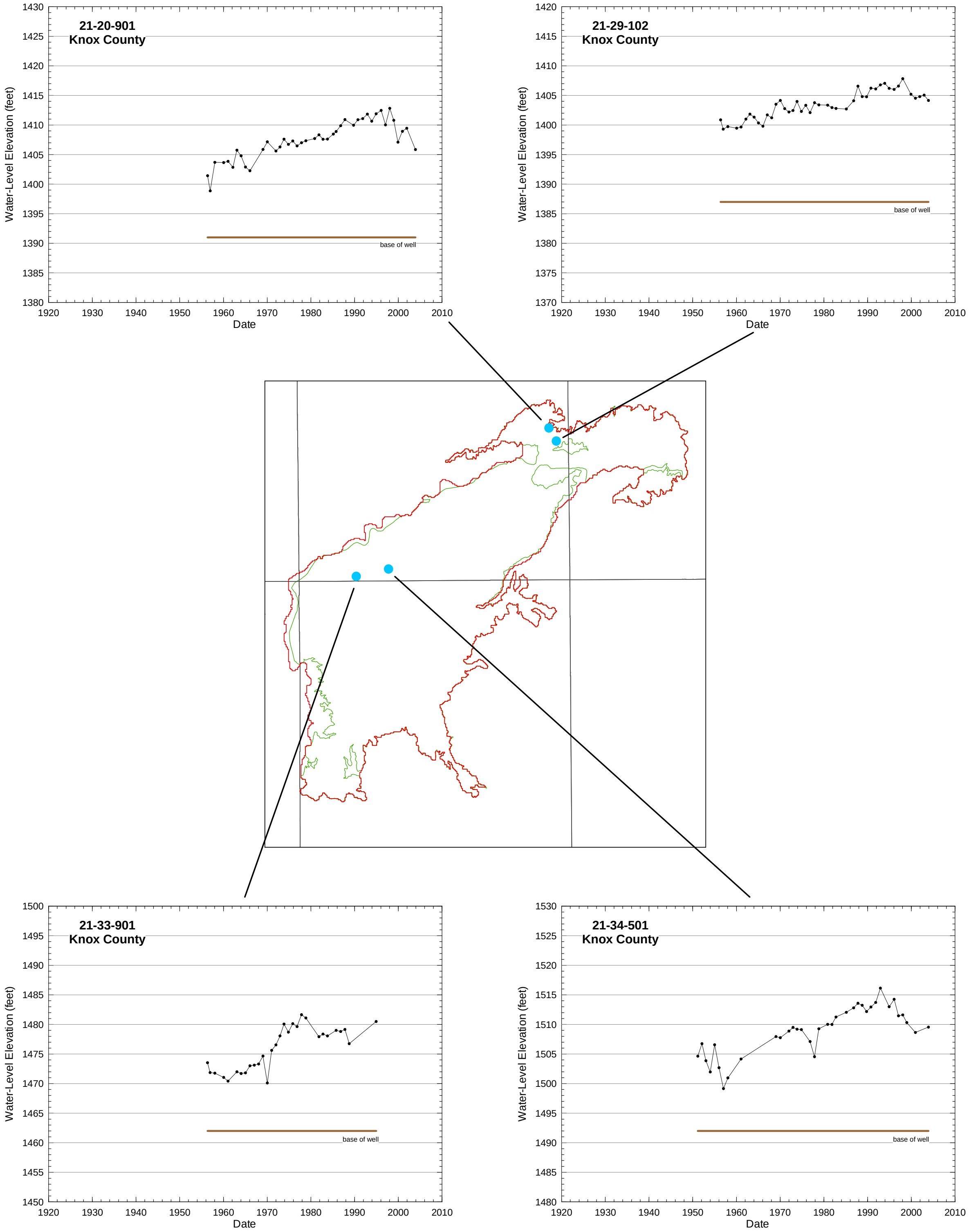


Figure 4.3.22 Hydrographs for the four Seymour Aquifer wells in Knox County with long-term transient water-level data showing an increasing trend.

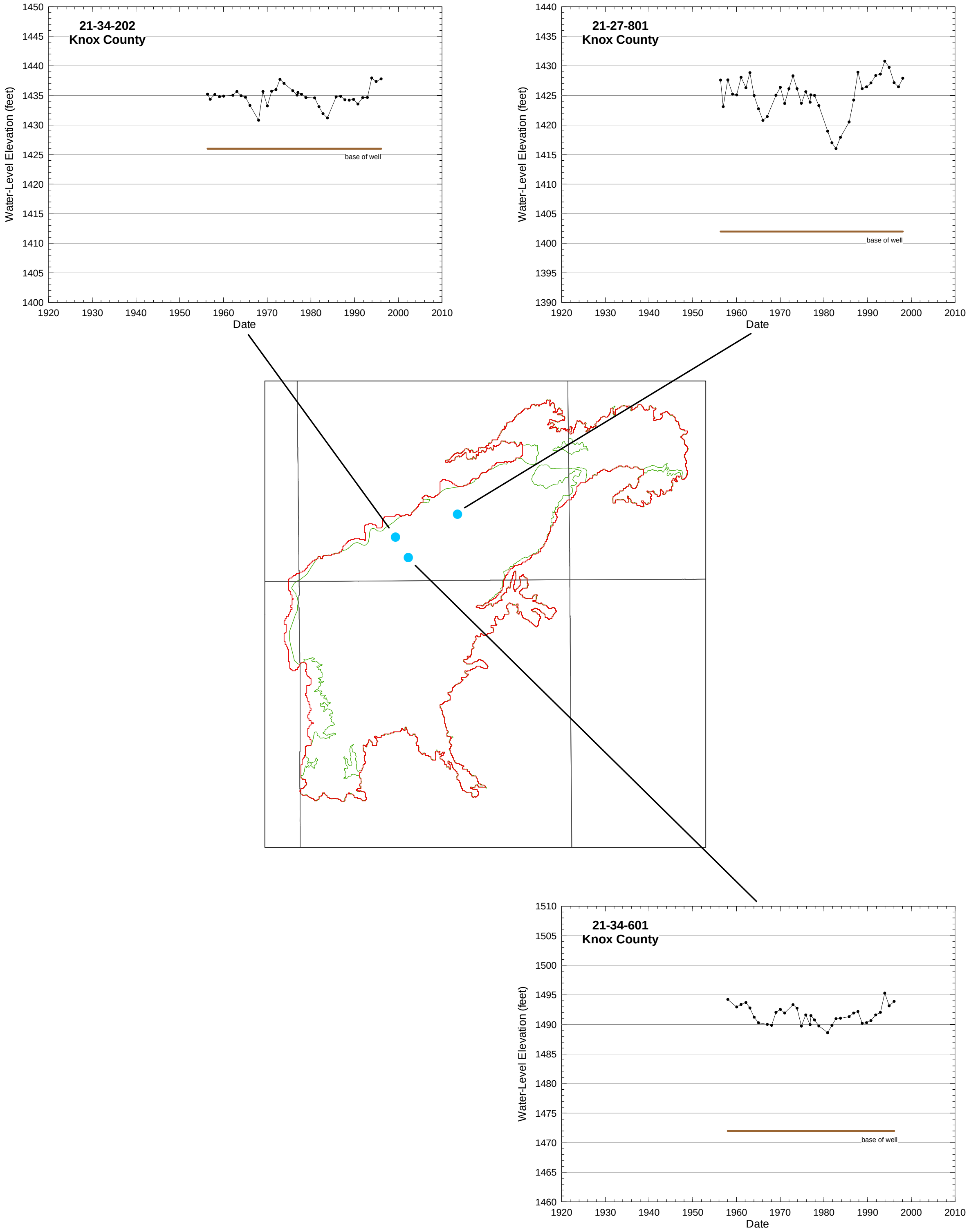


Figure 4.3.23 Hydrographs for the three Seymour Aquifer wells in Knox County with long-term transient water-level data showing a stable trend.

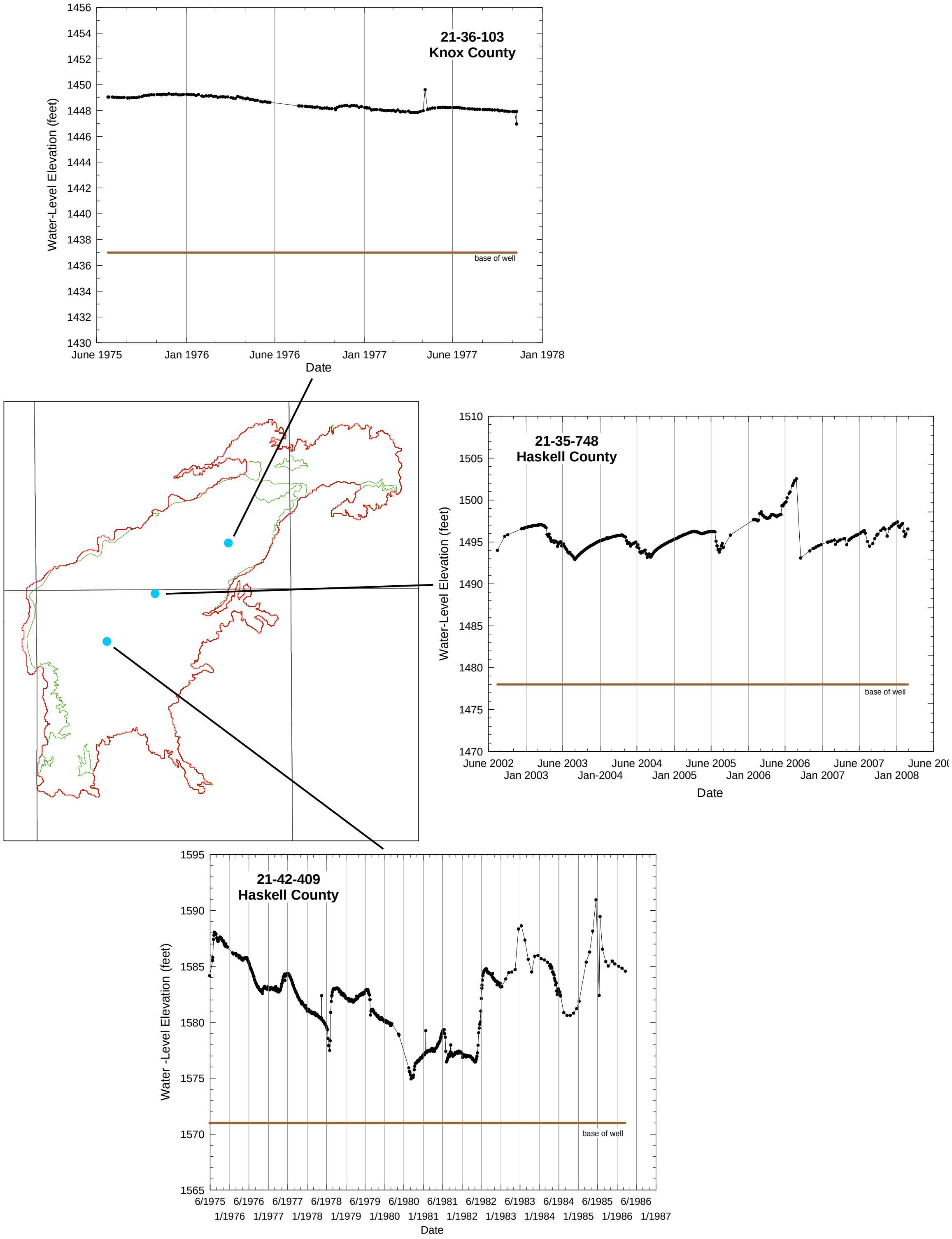


Figure 4.3.24 **Hydrographs for the three Seymour Aquifer wells with sufficient data to evaluate long-term seasonal fluctuations in water-level elevations.**

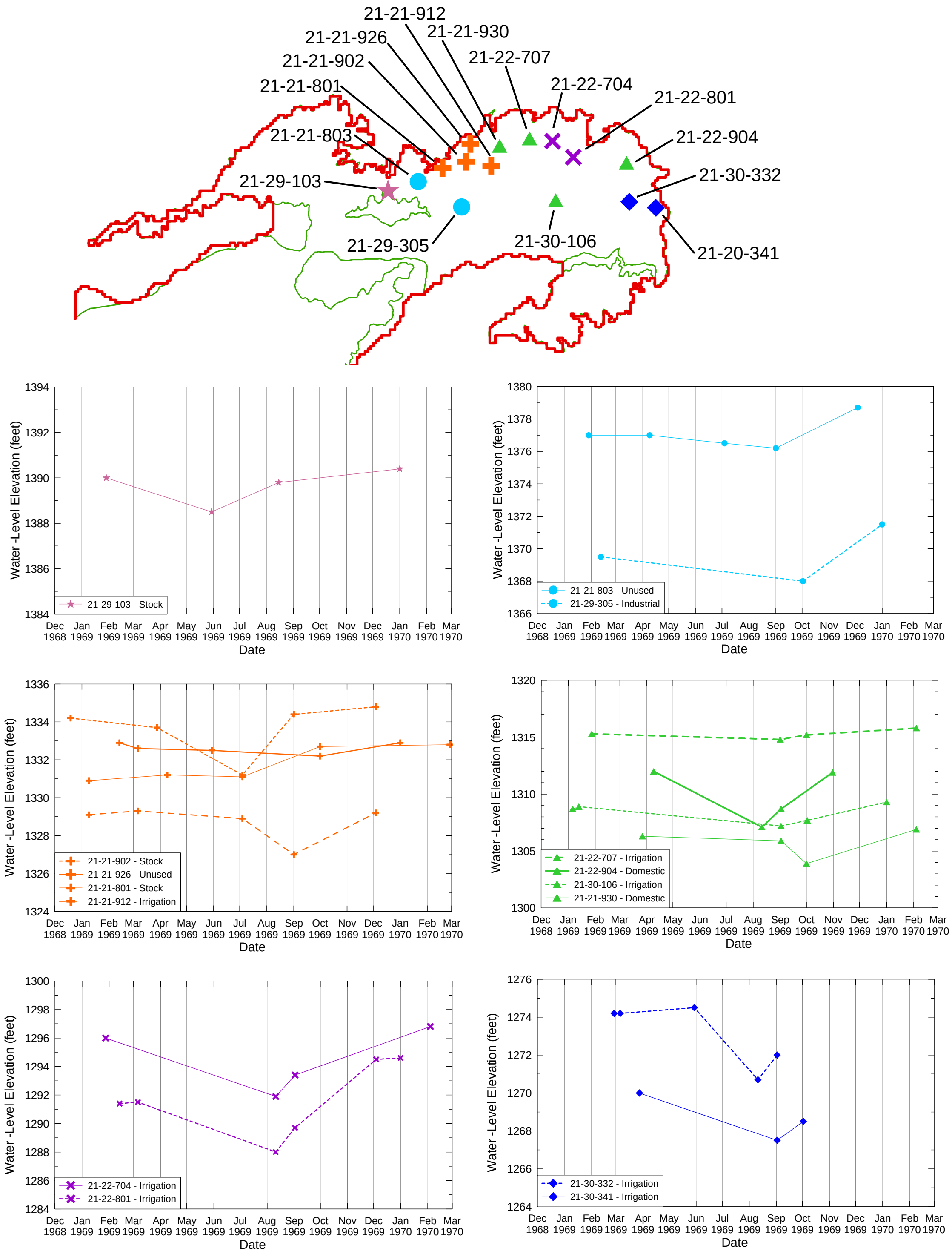


Figure 4.3.25 Hydrographs for the 15 Seymour Aquifer wells in Baylor County with data to evaluate seasonal fluctuations between December 1968 and February 1970.

This page is intentionally blank.