# HYDROLOGIC INVESTIGATION REPORT

# OF THE

# KIAMICHI, POTATO HILLS, BROKEN BOW, PINE MOUNTAIN AND HOLLY CREEK

# MINOR BEDROCK GROUNDWATER BASINS IN SOUTHEASTERN OKLAHOMA

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## INTRODUCTION

The hydrologic investigation for this report was conducted to provide the public with general information on the minor bedrock aquifers present in Latimer and LeFlore counties and the northern portions of Atoka, Pushmataha, and McCurtain counties located in southeastern Oklahoma. This report will also provide the Oklahoma Water Resources Board (OWRB) with the information needed to allocate the amount of water that can be withdrawn from the basins. The area for the report was selected on the basis of similar groundwater resources and similar geologic deposits and structure.

A total of five minor bedrock groundwater basins were identified within the study area. The basin of greatest areal extent consists of Pennsylvanian and Mississippian aged units and is located north of the Antlers Formation outcrop in the aforementioned counties. This basin has been designated as the Kiamichi Minor Groundwater Basin (KMGB). The remaining minor basins include the Potato Hills Minor Groundwater Basin (PHMGB), located in Latimer and Pushmataha Counties, and the Broken Bow Minor Groundwater Basin (BBMGB), Pine Mountain Minor Groundwater Basin (PMMGB) and the Holly Creek Minor Groundwater Basin (HCMGB), all located in McCurtain County. Figure 1 shows the boundaries of the respective groundwater basins superimposed upon the public land survey.

## PHYSICAL SETTING

### Location

The principal groundwater basin in terms of surface area stretches from Atoka County to McCurtain County along the southern edge of the basin and to LeFlore County in the north. This basin, designated as the KMGB, consists primarily of Pennsylvanian and Mississippian age rocks with some minor Quaternary age alluvium and terrace deposits that occur along the Fouche Maline River, Kiamichi River and the Poteau River. Four smaller groundwater basins were also identified in the overall study area. The Potato Hills Basin is located along the boundary line between Latimer and Pushmataha counties; the Broken Bow and Pine Mountain Basins are located in northern McCurtain County. These three basins consist of Mississippian, Silurian and Ordovician age formations. The Holly Creek Basin is in central McCurtain County and consists of Cretaceous age gravel, clay and silt lenses.

The alluvium and terrace deposits, associated with the Arkansas River system along the northern border of the study area, are a potential major basin and will not be considered in this report. The Antlers Groundwater Basin, which lies south of the study area, is a major groundwater basin and has also been excluded from this report.

Figure 1

## Physiography

The land encompassed by the study area lies primarily within the Quachita Province of Oklahoma with the exception of the southern most portion that lies in the Coastal Plain Province (Marcher etal, 1987). The region slopes gently toward the Red River in the southern portion and towards the Arkansas River in the northern portion. Topographic differences in the study area range from less than 400 feet above sea level in McCurtain County to near 2600 feet above sea level in LeFlore County according to USGS topography maps. Land use varies from farm and rangeland areas to forest areas. Southward dipping sedimentary strata give rise to a cuesta and dip-slope type of topography where the more resistant formations are present (Huffman etal, 1975).

## Climate

The study area has a warm, temperate climate with gradual seasonal changes. The spring and autumn months are mild, with cool nights and warm days. Summers are hot with high humidity. Winters are comparatively mild although an occasional influx of cold air keeps the temperature below freezing several days in most years (Marcher etal, 1987).

The mean annual precipitation ranges from 40 inches per year in Atoka County to near 50 inches in McCurtain County (OWRB 1990). The mean annual precipitation for the study area was determined to be 44 inches. The average yearly precipitation is sufficient for most field crops commonly grown in the area. Rainfall is typically uniformly distributed throughout the year, reaching a slight peak in spring (Marcher etal, 1987).

July and August are the warmest months while December and January are the coldest. Average daily maximum temperatures range from about 50 degrees in January to 95 degrees in July and August. Average daily minimum temperatures range from 28 degrees in January to 70 degrees in July and August (Marcher etal, 1987).

## Land Use

Land use in the study area varies with geology and topography but is predominantly agriculture and forest, with some active mining operations. The dominant agricultural uses are cropland, pasture and confined poultry and swine operations. Forest uses include recreation and commercial production of timber. Coal and sand/gravel mining operations also occur in site specific areas throughout the region.

## Population

Combined population for the study area according to the 1990 Census figures is 60,735. LeFlore County has the largest population with 43,270 people and Latimer County has the second largest population with 10,333 people. The remaining study area consists of the northern portions of Atoka, Pushmataha, and McCurtain Counties which have populations of 1,658, 2,768 and 2,706, respectively.

# HYDROGEOLOGIC SETTING

## Structure

The study area primarily lies within the structural feature known as the Arkoma

Basin. The Arkoma Basin is an elongate structural trough extending from south-central Oklahoma easterly into central Arkansas. The basin is flanked on the south by the Ouachita Mountains and the formations have been moderately folded to form northeast to east trending synclines and anticlines. Dips on the limbs of these structures generally range from 10 to 40 degrees. The crests of some anticlines have been broken by thrust faults with displacements of several hundred feet (Marcher etal, 1987).

**Stratigraphy**

Formations outcropping at the surface range in age from Cretaceous to Ordovician with scattered deposits of alluvium and terrace and of Pleistocene and Holocene age as shown in Table 1 (Marcher and Bergman, 1983). The oldest formation exposed in the study area is the Ordovician Collier Shale. Overlying the Collier Shale is the Crystal Mountain Sandstone, Mazarn Shale, Blakely Sandstone, Womble Formation, Big Fork Chert, and Polk Creek Shale, all of Ordovician age. The Silurian formations present in the area include the Blaylock Sandstone and the Missouri Mountain Shale. The Mississippian/Devonian/Silurian formation outcropping is the Arkansas Novaculite. The Mississippian formation outcropping above the Arkansas Novaculite is the Stanley Group. Overlying the Stanley Group are the Jack Fork, Johns Valley, Union Valley-Cromwell, Wapanucka, Atoka, Hartshorne, McAlester, Savanna, and Boggy formations of Pennsylvanian age. The Cretaceous formation outcropping in the study area is the Holly Creek.

The Pennsylvanian through Ordovician formations generally consist of a sequence of interbedded shale, siltstone, fine to very fine-grained sandstone, chert and thin beds of limestone and coal. Shale and siltstone are the predominant lithologies comprising 60-80 percent of the exposed stratigraphic section (Marcher etal, 1987). The Cretaceous Holly Creek Formation consists of gravel, with clay and silt.

Alluvium and terrace deposits are also present along rivers and tributary streams. The deposits are generally less than 20 feet thick and because of the predominantly shale bedrock, consist mainly of sandy and clayey silt.

**TABLE 1. FORMATIONS WITHIN THE STUDY AREA**

| SYSTEM | SERIES | GROUP | FORMATION | MEMBER |
|---|---|---|---|---|
| Quaternary | Holocene | | | Alluvium |
| | Pleistocene | | | Terrace |
| Cretaceous | Comanchean | Trinity | Holly Creek Formation | |
| Pennsylvanian | Des Moinesian | Krebs | Boggy Formation | |
| | | | Savanna Formation | |
| | | | McAlester Formation | |
| | | | Hartshorne Formation | |

| | | | | |
|---|---|---|---|---|
| | Atokan | Atoka | Atoka Formation | Fanshawe |
| | | | | Red Oak |
| | | | | Spiro |
| | Morrowan | | Wapanucka/Johns Valley | |
| | | | Union Valley-Cromwell | |
| | | | Jackfork | |
| Mississippian | Chesterian | Stanley | Stanley Formation | |
| Mississippian/ Devonian/Silurian | | | Arkansas Novaculite | |
| Silurian | | | Missouri Mountain Shale | |
| | | | Blaylock Sandstone | |
| Ordovician | | | Polk Creek Shale | |
| | | | Bigfork Chert | |
| | | | Womble Formation | |
| | | | Blakely Sandstone | |
| | | | Mazarn Shale | |
| | | | Crystal Mountain Sandstone | |
| | | | Collier Shale | |

Taken from Marcher and Bergman, 1983.

### Groundwater

## WATER RESOURCES OF THE KIAMICHI BASIN

### Basin Description

The KMGB in the five county area is comprised of approximately 3,020,000 acres of Mississippian, Pennsylvanian and Quaternary deposits that occur as shale, sandstone, siltstone, coal, marl, limestone, clay, silt and sand units.

The occurrence, storage, and movement of water in these formations are largely controlled by the lateral and vertical distribution of rock units, the geologic structure, and their physical characteristics, particularly permeability (Marcher et al, 1987). The movement of water can also be governed by the location and altitude of areas of recharge and discharge. The slope of the potentiometric surface can be in the same direction as the land surface and may parallel the geologic structure in some areas, but may cut across the structure in others (Marcher et al, 1987).

The formations in the study area are tilted at the surface exposing bedding plane openings between the layers of sandstone and partings between laminae of shale. These openings are the principal avenues of water entry and movement. Other openings for water movement are fractures and joints formed during folding of the brittle rocks. Faults, where they are present, also may be water conduits. If, however, the rocks are so greatly crushed that the openings are sealed, the faults may act as water barriers. The number and distribution of bedding planes, fractures and joints differ both areally and with depth so that a well of given depth may yield enough water for household use whereas a nearby well of the same depth, or even deeper, may not yield any water (Marcher et al, 1987).

## Aquifer Characteristics

The hydraulic characteristics of an aquifer describe its ability to store and transmit water and can be represented in terms of storage coefficient and transmissivity. Groundwater in the KMGB is generally under confined conditions. Water is typically encountered at approximately 75 feet below land surface and water rises in wells to within 25 feet below the land surface (Marcher et al, 1987 and OWRB, 1999A). Values for coefficient of storage for a confined aquifer generally range from $10^{-5}$ to $10^{-3}$ according to Driscoll, 1986 and a value of 0.005 was estimated for the KMGB.

Review of OWRB Multi-Purpose Completion Reports indicates that fresh water has been encountered in wells within the KMGB at maximum depths ranging from 300 to 400 feet. Based on this data, an average base of the fresh water was estimated at 300 feet. Using an average depth to water of 75 feet and a value of 300 feet for the base of the fresh water zone, the average total saturated thickness for which fresh water could be encountered is 225 feet.

Hydraulic conductivity (K) is estimated for the basin based on the mean K taken from hydrogeologic texts which provide ranges of possible K values for different consolidated aquifers (Heath, 1983). Formations which consist primarily of shale, fine-grained sandstone, and thin limestone beds are reported to have K values ranging from $10 \times 10^{-1}$ ft/day to $10 \times 10^{-3}$ ft/day. For this study, an average K value of 0.055 ft/day was estimated for the basin. Transmissivity, a product of the saturated thickness and K, is estimated to be 12.5 $ft^2$/day.

Recharge to the KMGB can be limited in areas of rugged topography, thin soils and finite bedrock permeability. The amount of annual recharge to the basin ranges from 1 to 5 percent with an average of 2.5 percent of the average annual precipitation which is approximately 1.1 inches per year (Marcher and Bergman, 1983).

## Aquifer Storage and Yield Capabilities

Initial storage for the KMGB is estimated at approximately 3,400,000 acre-feet of groundwater. This value is obtained by multiplying the storage coefficient for the basin, by the estimated saturated thickness, and the area of the basin (3,020,000 acres).

Groundwater availability ranges from extremely limited to readily available. The mean well yield for the basin as determined from OWRB well records is approximately 5 gallons per minute. Locally, yields of 50 to 100 gallons per minute have been obtained from wells penetrating thicker, fractured sandstone units in the area, while other wells yield only a fraction of a gallon (OWRB, 1999A). Table 2 shows a summary of the aquifer parameters and aquifer storage for the basin.

**TABLE 2. Summary of aquifer and storage parameters for the Kiamichi Basin.**

| Area (acres) | Storage Coefficient | Saturated Thickness (ft) | K (ft/day) | T ($ft^2$/day) | Recharge (in/yr) | Storage (acre-ft) |
|---|---|---|---|---|---|---|
| 3,020,000 | 0.005 | 225 | 0.05 | 12.5 | 1.1 | 3,400,000 |

K - Hydraulic Conductivity   T - Transmissivity

## Water Use

Groundwater use in the study area includes household, stock, agriculture and public water supply.  In some parts of the study area, adequate supplies of suitable groundwater are not available and water districts have been established to meet the domestic, commercial, and industrial needs of rural areas.  Farm ponds have also been constructed to provide water for livestock.

OWRB records indicate that 40 permits for a total amount of 1,555.6 acre-feet of groundwater per year have been issued within the KMGB.  Table 3 summarizes the permit data for the basin.

## Prior Groundwater Rights

Prior rights in the amount of 638 acre-feet were established or recognized by the Board within this basin.

**TABLE 3. PERMIT INFORMATION WITHIN THE KMGB BASIN FOR 2000.**

| COUNTY | PURPOSE | NO. OF PERMITS | PERMITTED AMOUNT |
|---|---|---|---|
| Atoka | Public Water Supply | 1 | 504 acre-ft |
| Latimer | Irrigation | 2 | 134 acre-ft |
| | Public Water Supply | 1 | 68  acre-ft |
| | Agriculture | 2 | 115 acre-ft |
| Pushmataha | Public Water Supply | 1 | 86 acre-ft |
| McCurtain | Agriculture | 1 | 15 acre-ft |
| | Public Water Supply | 1 | 2 acre-ft |
| LeFlore | Agriculture | 27 | 430.6 acre-ft |
| | Public Water Supply | 4 | 201 acre-ft |
| TOTALS | | 41 | 1555.6 acre-ft |

Compiled from unpublished OWRB 1999 data

## Future Use of Basin

Future use of the basin will be limited due to the finite availability of water in storage and water quality issues.  Primary uses will continue to be domestic and agricultural.  Growth in those areas is expected to continue, however, rural water districts are increasing coverage to rural areas, which may offset future groundwater usage.

## Potato Hills Minor Groundwater Basin

The PHMGB comprises approximately 20,660 acres of Mississippian, Silurian, and Ordovician deposits that lie along the boundary between Latimer and Pushmataha Counties east of Sardis Lake. The formations in the study area are comprised of shale, sandstone, chert and minor limestone and coal seams. These rocks have been subjected to low-grade dynamic metamorphism that has increased their brittleness so that they have been broken by folding and faulting. The capability of the bedrock to store and transmit water depends almost entirely on fractures formed by folding and faulting. Well yields range from a few gallons per minute to as much as 50 gpm (Marcher and Bergman, 1983).

Formations in the basin include the Ordovician aged Womble Formation and Big Fork Chert. The Silurian formation present in the basin is the Missouri Mountain shale and the Mississippian/Devonian/Silurian formation outcropping is the Arkansas Novaculite. The primary water-yielding formations in the basin are the Bigfork Chert and the Arkansas Novaculite. These formations consist of novaculite and chert with some interbedded shale and sandstone. The highly broken and fractured rocks can potentially yield moderate to large amounts of water. However, because of their remoteness, few wells have been drilled into these formations, and much of their potential can only be inferred (Marcher and Bergman, 1983).

Recharge entering the basin is derived mainly from precipitation falling on the outcrop. Discharge is by evaporation, flow to streams and through pumping of domestic and stock wells.

## Aquifer Parameters

The hydraulic characteristics of an aquifer describe its ability to store and transmit water and can be represented in terms of storage coefficient and transmissivity. Groundwater in the PHMGB is generally encountered within approximately 75 feet below land surface. The upper portion of the basin is generally unconfined while the lower portion is under confined conditions. Water levels in wells generally rise to within 25 feet below the land surface (Marcher et al, 1987 and OWRB, 1999A). Values for coefficient of storage for a confined aquifer generally range from $10^{-5}$ to $10^{-3}$ according to Driscoll, 1987. A storage coefficient value of 0.005 was estimated for the KMGB.

Information regarding the base of the aquifer was obtained from review of the available OWRB Multi-Purpose Completion Reports and from an interview with staff from the Oklahoma Corporation Commission (OCC). OWRB reports indicate that fresh water has been encountered in water wells within the PHMGB at depths ranging from 300 to 400 feet. Staff from the OCC indicated that the base of treatable water had been encountered during the drilling of natural gas wells in the study area from 600 feet to 2700 feet. According to OCC information, the water quality does not degrade dramatically with depth. Surface casing to protect the fresh water is typically set 50 feet below the Big Fork Chert into the Womble Shale.

Based on the available data, the average base of the fresh water is determined to be 450 feet. Using an average depth to water of 75 feet and a value of 450 feet for the base of the fresh water zone, the average total saturated thickness for which fresh water could be expected is 375 feet. Inference should be made that the saturated thickness of the PHMGB may be substantially greater than the 375 feet determined from this study. Re-evaluation of the basin can occur should data become available that substantiates a larger value.

Hydraulic conductivity (K) is estimated for the basin based on the mean K taken from hydrogeologic texts which provide ranges of possible K values for different consolidated aquifers (Heath, 1983). Formations that consist primarily of fractured shale, sandstone, and limestone are reported to have K values ranging from 10 x $10^{-1}$ ft/day to 10 x $10^{-3}$ ft/day. For this study, an average K value of 0.5 ft/day was estimated for the basin. Transmissivity, a product of the saturated thickness and K, is estimated to be 187.5 $ft^2$/day.

Recharge to the PHMGB can be limited in areas of rugged topography, thin soils and finite bedrock permeability, but can be substantial in areas with surface fractures. The amount of annual recharge to the basin ranges from 1 to 5 percent with an average of 2.5 percent of the average annual precipitation which is approximately 1.15 inches per year (Marcher and Bergman, 1983).

## Aquifer Storage and Yield Capabilities

Determination of the initial storage of a groundwater basin is calculated by multiplying the area of the basin by the storage coefficient and saturated thickness. Initial storage calculations for the PHMGB is 39,000 acre-feet. Average well yield in the basin is estimated at 10 gallons per minute (OWRB, 1999A). Table 4 summarizes the aquifer parameters and storage parameters for the PHMGB.

## Water Use

Groundwater use in the study area of the PHMGB currently appears to be primarily limited to domestic and stock water use. No regular or temporary groundwater permits have been issued by the Board in the basin (OWRB, 1999B).

**TABLE 4. SUMMARY OF AQUIFER PARAMETERS AND STORAGE INFORMATION FOR THE PHMGB.**

| Basin | Area (acres) | Specific Yield | Saturated Thickness (ft) | K (ft/day) | T ($ft^2$/day) | Mean Well Yield (gpm) | Storage (ac-ft) |
|---|---|---|---|---|---|---|---|
| PHMGB | 20,660 | 0.005 | 375 | .5 | 187.5 | 10 | 38,700 |

K - Hydraulic Conductivity   T - Transmissivity

## Prior Groundwater Rights

No prior groundwater rights have been established within this basin.

## Future Use of Basin

Future use of the basin will be limited due to the finite availability of water in storage. Primary uses will continue to be domestic and agricultural. Growth in those areas is expected to continue as the remote areas are developed.

## Broken Bow / Pine Mountain Minor Groundwater Basins

The BBMGB and PMMGB encompass approximately 150,000 acres and 19,000 acres, respectively, of Mississippian, Silurian, and Ordivician deposits. The formations are comprised primarily of shale, sandstone, chert, and minor layers of limestone and coal and are tilted at the surface exposing bedding plane openings between the layers of sandstone and partings between laminae of shale. These openings are the principal avenues of water entry and movement. Other openings for water movement are fractures and joints formed during folding of the brittle rocks (Marcher et al, 1987).

The basins are in the Ouachita Mountains geologic province, which is characterized by broad synclines and narrow anticlines separated by steep, southward-dipping thrust faults and broken by many small faults. The Ouachita Mountains have the most rugged topography in Oklahoma, with an average relief of several hundred feet and local relief that exceeds 1,700 feet. The ridges are comprised of hard, resistant sandstones while the valleys are carved into soft, easily eroded shale (Marcher and Bergman, 1983).

Formations in the basins include the Ordovician Collier Shale overlain by the Crystal Mountain Sandstone, Mazarn Shale, Blakely Sandstone, Womble Formation, Big Fork Chert, and Polk Creek Shale of Ordovician age. The Silurian formation present in the basins is the Blaylock Sandstone and the Missouri Mountain Shale. The Mississippian/Devonian/Silurian formation outcropping is the Arkansas Novaculite.

The primary water-yielding formations in both basins are the Bigfork Chert and the Arkansas Novaculite. These formations consist of novaculite and chert with some interbedded shale and sandstone. The highly broken and fractured rocks can potentially yield moderate to large amounts of water (Marcher and Bergman, 1983).

Recharge entering the basins is derived mainly from precipitation falling on the outcrop. Discharge is by evaporation, flow to streams and through pumping of domestic and stock wells.

## Aquifer Parameters

The hydraulic characteristics of an aquifer describe its ability to store and transmit water and can be represented in terms of storage coefficient and transmissivity. Groundwater in the BBMGB and the PMMGB is generally encountered at approximately 75 feet below land surface (OWRB, 1999A). The upper portion of the basins is unconfined while the lower portion is under confined conditions. Water levels are typically within 25 feet below the land surface (Marcher et al, 1987 and OWRB, 1999A). Values for coefficient of storage for a confined aquifer generally range from $10^{-5}$ to $10^{-3}$ according to Driscoll, 1986. A value of 0.005 was estimated for the BBMGB.

OWRB Multi-Purpose Completion Reports indicate that fresh water has been encountered in wells within the BBMGB and the PMMGB at depths ranging from 300 to 400 feet. Based on the available data, the average base of the fresh water is determined to be 350 feet. Using an average depth to water of 75 feet and a value of 350 feet for the base of the fresh water zone, average total saturated thickness for which fresh water could be expected for both basins is 275 feet.

Hydraulic conductivity (K) is estimated for both basins based on the mean K taken from hydrogeologic texts which provide ranges of possible K values for different consolidated aquifers (Heath, 1983). Formations which consist primarily of shale, sandstone, and limestone are reported to have K values ranging from $10 \times 10^{-1}$ ft/day to $10 \times 10^{-3}$ ft/day. For this study, an average K value of 0.5 ft/day was estimated for the basins. Transmissivity, a product of the saturated thickness and K, is estimated to be 140.0 $ft^2$/day.

Recharge to the BBMGB and the PMMGB can be limited in areas of rugged topography, thin soils and finite bedrock permeability. The amount of annual recharge to the basins ranges from 1 to 5 percent with an average of 2.5 percent of the average annual precipitation which is approximately 1.2 inches per year (Marcher and Bergman, 1983).

## Aquifer Storage and Yield Capabilities

Determination of the initial storage of a groundwater basin is calculated by multiplying the area of the basin by the storage coefficient and saturated thickness. Initial storage calculations for the BBMGB and the PMMGB is 206,250 acre-feet and 26,150 acre-feet, respectively. Average well yield for both basins is estimated at 14 gallons per minute (OWRB, 1999A). Well yields have been reported as high as 60 to 100 gallons per minute in area that are highly fractured. Table 5 summarizes the aquifer parameters and storage parameters for the BBMGB and PMMGB.

**TABLE 5. SUMMARY OF AQUIFER PARAMETERS AND STORAGE INFORMATION FOR THE BBMGB AND PMMGB.**

| Basin | Area (acres) | Specific Yield | Saturated Thickness (ft) | K (ft/day) | T ($ft^2$/day) | Mean Well Yield(gpm ) | Storage (ac-ft) |
|---|---|---|---|---|---|---|---|
| BBMGB | 150,000 | 0.005 | 275 | 0.5 | 140.0 | 14 | 206,250 |
| PMMGB | 19,000 | 0.005 | 275 | 0.5 | 140.0 | 14 | 26,125 |

K - Hydraulic Conductivity T - Transmissivity

## Water Use

Groundwater use in the BBMGB and the PMMGB currently appears to be primarily limited to domestic and stock water use. No regular or temporary groundwater permits have been issued by the Board in either basin (OWRB, 1999B).

## Prior Groundwater Rights

No prior groundwater rights have been established within either basin.

## Future Use of Basin

Future use of both basins will be limited due to the finite availability of water in storage and water quality issues. Primary uses will continue to be domestic and agricultural. Growth in those areas is expected to continue, however, the Broken Bow Gravity Flow System is increasing coverage to rural areas, which may offset future usage.

### Holly Creek Minor Groundwater Basin

The HCMGB comprises approximately 18,900 acres of Cretaceous aged deposits, which occur in central McCurtain County. The HCMGB is composed of lenticular beds of gravel, silt, clay and sandy clay (Davis, 1960). About half of the pebbles in the gravel are quartz and the remainder is novaculite (Davis, 1960). Generally they are interbedded with silt and clay. The HCMGB lies unconformably on the Mississippian Stanley Group.

The sediments comprising the HCMGB have a low transmissibility in most places because of the high percentage of silt and clay in the formation (Davis, 1960). Consequently the formation yields little water to wells. The yield of the wells is generally sufficient only for household and stock. Locally however, the percentage of silt and clay decreases and wells in these areas may yield as much as 50 to 75 gallons per minute (Davis, 1960). The Holly

Creek formation in the outcrop area ranges from 30 to 100 feet in thickness according to Davis (1960). Average saturated thickness in the study area, as determined from OWRB well records, was 30 feet.

## Aquifer Parameters

The hydraulic characteristics of an aquifer describe its ability to store and transmit water and can be represented in terms of storage coefficient and transmissivity. Groundwater in the HCMGB is generally encountered at approximately 25 feet below land surface and is unconfined in the outcrop area (OWRB 1999A). For unconfined aquifers, the storage coefficient and specific yield are nearly equivalent. Specific yield for the HCMGB is estimated at 0.10 which is representative of a formation consisting of lenticular beds of gravel, clay and silt according to Driscoll, 1986.
Recharge entering the basin is derived mainly from precipitation falling on the outcrop. Discharge is by evaporation, flow to streams and through pumping of domestic and stock wells.

Hydraulic conductivity (K) is estimated for the basin based on the mean K taken from hydrogeologic texts which provide ranges of possible K values for different consolidated aquifers (Heath, 1983). Formations, which consist primarily of gravel, clay and silt, are reported to have K values ranging from $10 \times 10^{-2}$ ft/day to $10 \times 10^{2}$ ft/day. For this study, an average K value of 10.0 ft/day was estimated for the basin. Transmissivity, a product of the saturated thickness (30 ft) and K, is estimated to be 300 $ft^2$/day.

Annual recharge to the HCMGB ranges from 1 to 5 percent with an average of 2.5 percent of the average annual precipitation which is approximately 1.2 inches per year (Marcher and Bergman, 1983).

## Aquifer Storage and Yield Capabilities

Determination of the initial storage of a groundwater basin is calculated by multiplying the area of the basin by the specific yield and saturated thickness. Initial storage calculations for the HCMGB is 56,700 acre-feet.

Yields of the wells are generally sufficient only for household and stock according to Davis, (1960). Locally however, the percentage of silt and clay decreases and wells in these areas may yield as much as 50 to 75 gallons per minute (Davis, 1960). Average well yield as determined from the available OWRB well records was 25 gallons per minute. However, because of the limited data available, the basinwide average well yield is estimated at a more conservative rate of 12 gallons per minute. Table 6 summarizes the aquifer parameters and storage parameters for the HCMGB.

## Water Use

Groundwater use in the HCMGB currently appears to be primarily limited to domestic and stock water use. No regular or temporary groundwater permits have been issued by the Board in the basin (OWRB, 1999B).

**TABLE 6. SUMMARY OF AQUIFER PARAMETERS AND STORAGE INFORMATION FOR THE HCMGB.**

| Basin | Area (acres) | Specific Yield | Saturated Thickness (ft) | K (ft/day) | T ($ft^2$/day) | Mean Well Yield (gpm) | Storage (ac-ft) |
|---|---|---|---|---|---|---|---|
| HCMGB | 18,900 | 0.10 | 30 | 10.0 | 300 | 12 | 56,700 |

K - Hydraulic Conductivity T - Transmissivity

## Prior Groundwater Rights

No prior groundwater rights have been established within this basin.

## Future Use of Basin

Future use of the basin will be limited due to the finite availability of water in storage. Primary uses will continue to be domestic and agricultural. Growth in those areas is expected to continue, however, the Broken Bow Gravity Flow System is increasing coverage to rural areas, which may offset future usage.

# GROUNDWATER QUALITY

### Kiamichi Minor Groundwater Basin

The chemical quality of water in the Pennsylvanian and Mississippian rocks is extremely variable. No relationship between variations in groundwater chemistry and well depth, geographic distribution, or geologic formation is apparent according to Marcher et al (1987). Typically, groundwater is a sodium bicarbonate type although many variations in water type occur. Concentrations of Dissolved Solids range from 4.9 to 1,690 milligrams per liter (mg/l) and Hardness ranges from 2.0 to 480 mg/l. Table 7 is a summary of selected physical and chemical properties of groundwater sampled from wells within Pennsylvanian and Mississippian age rocks. The table shows the parameter, maximum, median and minimum concentrations for the selected parameters.

**TABLE 7. SUMMARY OF SELECTED CHEMICAL ANALYSES OF WATER FROM WELLS COMPLETED IN PENNSYLVANIAN AND MISSISSIPPIAN FORMATIONS IN THE KMGB.**

| Parameter | Minimum | Median | Maximum |
|---|---|---|---|

| Parameter | Minimum | Median | Maximum |
|---|---|---|---|
| Hardness (mg/l) | 2 | 100 | 480 |
| Sulfate (mg/l) | 1.4 | 15 | 346 |
| Chloride (mg/l) | 1.6 | 36.4 | 615 |
| Nitrate (mg/l) | 0.0 | 0.1 | 51 |
| Dissolved solids mg/l) | 4.9 | 225 | 1,690 |

Compiled from Marcher and Bergman, 1983.

In summary, the water quality of the KMGB is probably suitable for all beneficial uses except in localized areas. The major natural source of pollution in the area that might impact some portions of the basin includes high chlorides and dissolved solids. However, with proper well completion techniques (sealing out lower quality water zones), water treatment techniques, and water quality sampling and analysis, negative health affects can be mitigated.

**Potato Hills Minor Groundwater Basin**

The area within the PHMGB is remote and very few wells have been completed in the basin. Groundwater quality information regarding the PHMGB is extremely limited. The Office of Environmental Health and Engineering of the Choctaw Nation provided analytical data from two wells completed in the study area. Average analytical results from the wells indicate that the groundwater exceeds recommended maximum contaminant level for Total Dissolved Solids, Chloride, and Total Alkalinity. All other constituents are within acceptable ranges. Table 8 shows the combined chemical characteristics of groundwater from the two wells.

**TABLE 8. GENERAL CHEMICAL QUALITY OF WATER FOR POTATO HILLS MINOR GROUNDWATER BASIN.**

| PARAMETER | MINIMUM | MEDIAN | MAXIMUM |
|---|---|---|---|
| Fluoride (mg/l) | 0.61 | 0.65 | 0.69 |
| Total Alkalinity as CaCO3 | 280 | 320 | 360 |
| Total Hardness | 124 | 157 | 190 |
| Sulfate (mg/l) | 0.187 | 22.15 | 44.11 |
| Turbidity (NTU) | 5.6 | 7.0 | 8.4 |
| Chloride (mg/l) | 100 | 530 | 960 |
| Iron (mg/l) | 0.031 | 0.0875 | 0.144 |
| Nitrate (mg/l) | 0.3 | 0.3 | 0.3 |
| pH | 7.58 | 7.79 | 8.0 |
| Total Dissolved Solids | 428 | 866 | 1303 |

Compiled from Office of Environmental Health and Engineering of the Choctaw Nation of Oklahoma, 2000

In summary, the water quality of the PHMGB would to be suitable for most beneficial uses except possibly in localized areas. The major natural sources of pollution in the area that might impact some portions of the basin include Chlorides, total Alkalinity and Total Dissolved Solids. However, with proper well completion techniques (sealing out lower quality water zones), water treatment techniques, and water quality sampling and analysis, negative health effects can be mitigated.

**Broken Bow / Pine Mountain Minor Groundwater Basin**

Groundwater quality information regarding the BBMGB and PMMGB is limited. However, analytical data was obtained from Marcher and Bergman, 1983 for three wells completed in the study area of both basins. Median analytical results from the wells indicate that the groundwater does not exceed the Oklahoma Department of Environmental Quality (ODEQ) recommended maximum contaminant levels for any of the reported parameters. Table 9 shows the combined chemical characteristics of groundwater from the wells.

**TABLE 9. CHEMICAL ANALYSES OF WATER FROM BROKEN BOW / PINE MOUNTAIN MINOR GROUNDWATER BASINS.**

| PARAMETER | MINIMUM | MEDIAN | MAXIMUM |
|---|---|---|---|
| Hardness | 350 | 475 | 600 |
| Sulfate | 48 | 66 | 84 |
| Chloride | 0.0 | 18 | 35 |
| Sodium | 23 | 35 | 46 |
| Bicarbonate as $HCO_3$ | 305 | 397 | 488 |
| Total Dissolved Solids | 181 | 255 | 328 |

Compiled from Marcher and Bergman, 1983 - Results in mg/l

In summary, the water quality of the BBMGB and PMMGB appears to be suitable for most beneficial uses except possibly in localized areas. The major natural source of pollution in the area that might impact some portions of the basin is Hardness. However, with proper well completion techniques (sealing out lower quality water zones), water treatment techniques, and water quality sampling and analysis, negative health effects can be mitigated.

**Holly Creek Minor Groundwater Basin**

Groundwater quality information regarding the HCMGB is very limited. Marcher and

Bergman, 1983 report data for one well completed in the study area. Analytical results from the well indicate that the groundwater does exceed ODEQ recommended maximum contaminant level for Total Dissolved Solids. No other reported parameters are exceeded. Table 10 shows the combined chemical characteristics of groundwater from the well.

**TABLE 10. GENERAL CHEMICAL ANALYSES OF WATER FOR HOLLY CREEK MINOR GROUNDWATER BASIN**

| PARAMETER | MINIMUM | MEDIAN | MAXIMUM |
|---|---|---|---|
| Hardness | 250 | 458 | 625 |
| Sulfate | 72 | 96 | 120 |
| Chloride | 35 | 61 | 87 |
| Sodium | 34 | 46 | 57 |
| Bicarbonate as $HCO_3$ | 305 | 478 | 610 |
| Total Dissolved Solids | 145 | 300 | 400 |

Compiled from Marcher and Bergman, 1983 - Results in mg/l

In summary, the water quality of the HCMGB appears to be suitable for most beneficial uses except possibly in localized areas. The major natural source of pollution in the area that might impact some portions of the basin is Hardness. However, with proper well completion techniques (sealing out lower quality water zones), water treatment techniques, and water quality sampling and analysis, negative health effects can be mitigated.

## SUMMARY

Oklahoma water law requires the OWRB to conduct hydrologic investigations of groundwater basins to characterize the availability, extent, and natural hydrologic conditions of the resource. Upon completion of the hydrologic investigation, the OWRB must determine the maximum annual yield of fresh water to be produced from the basin and the equal proportionate share to be allocated to each acre of land overlying the basin, based on a minimum life of 20 years. The maximum annual yield of a minor groundwater basin shall be based upon present and reasonably foreseeable future use of groundwater from the basin, recharge and total discharge, the geographical region in which the basin is located, and other relevant factors.

Information on the Kiamichi Minor Groundwater Basin, Potato Hills Minor Groundwater Basin, Broken Bow Minor Groundwater Basin, the Pine Mountain Minor Groundwater Basin and the Holly Creek Minor Groundwater Basin that should be considered in determining the maximum annual yield and equal proportionate share are summarized below:

**Kiamichi Minor Groundwater Basin**

1. The total land area overlying the basin is 3,020,000 acres;
2. The amount of water in storage in the basin on January 1, 2000 was determined to be 3,400,000 acre-feet;
3. The average rate of recharge is estimated at 1.1 inches or 2.5 percent of the average annual precipitation (44 inches) and totals approximately 5,537,000 acre-feet, and the total discharge of the basin is 12,760 acre-feet over the life of the basin (20 years);
4. The transmissivity of the basin is estimated to be 12.5 $ft^2$/day;
5. The possibility of pollution of the basin from natural sources such as chlorides and total dissolved solids can be minimized by proper well construction, water treatment, and water quality testing and analysis.

**Potato Hills Minor Groundwater Basin**

1. The total land area overlying the basin is 20,660 acres;
2. The amount of water in storage in the basin on January 1, 2000 was approximately 38,700 acre-feet;
3. The estimated rate of recharge is 1.15 inches per year or 2.5 percent of the average annual precipitation (46 inches) and totals approximately 39,600 acre-feet, and the total discharge of the basin is 0.0 acre-feet over the life of the basin (20 years);
4. The transmissivity of the basin is estimated to be 187.5 $ft^2$/day;
5. The possibility of pollution of the basin from natural sources such as chlorides, total alkalinity and total dissolved solids can be minimized by proper well construction, water treatment, and water quality testing and analysis;

**Broken Bow Minor Groundwater Basin**

1. The total land area overlying the basin is 150,000 acres;
2. The amount of water in storage in the basin on January 1, 2000 was approximately 206,250 acre-feet;
3. The estimated rate of recharge is 1.2 inches per year or 2.5 percent of the average annual precipitation (48 inches) and totals approximately 300,000 acre-feet, and the total discharge of the basin is 0.0 acre-feet over the life of the basin (20 years);
4. The transmissivity of the basin is estimated to be 140 $ft^2$/day;
5. The possibility of pollution of the basin from a natural source such as hardness can be minimized by proper well construction, water treatment, and water quality testing and analysis;

**Pine Mountain Groundwater Basin**

1. The total land area overlying the basin is 19,000 acres;
2. The amount of water in storage in the basin on January 1, 2000 was approximately 26,125 acre-feet;
3. The estimated rate of recharge is 1.2 inches per year or 2.5 percent of the average annual precipitation (48 inches) and totals approximately 38,000 acre-feet, and the total discharge of the basin is 0.0 acre-feet over the life of the basin (20 years);
4. The transmissivity of the basin is estimated to be 140 $ft^2$/day;
5. The possibility of pollution of the basin from a natural source such as hardness can be minimized by proper well construction, water treatment, and water quality testing and analysis;

**Holly Creek Minor Groundwater Basin**

1. The total land area overlying the basin is 18,900 acres;
2. The amount of water in storage in the basin on January 1, 2000 was approximately 57,600 acre-feet;
3. The estimated rate of recharge is 1.2 inches per year or 2.5 percent of the average annual precipitation (49 inches) and totals approximately 37,800 acre-feet, and the total discharge of the basin is 0.0 acre-feet over the life of the basin (20 years);
4. The transmissivity of the basin is estimated to be 300 $ft^2$/day;
5. The possibility of pollution of the basin from a natural source such as hardness can be minimized by proper well construction, water treatment, and water quality testing and analysis.

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## GLOSSARY

Alluvium

A general term for clay, silt, sand, and gravel, or similar unconsolidated material deposited during comparatively recent geologic time by stream or other body of running water as a sorted or partially sorted sediment in the bed of the stream or on its flood plain or delta, or as a cone or fan at the base of a mountain slope.

Aquifer

A formation, group of formations, or a part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Equal Proportionate Share

That portion of the maximum annual yield of water from a groundwater basin which shall be allocated to each acre of land overlying such basin. The percentage of the maximum annual yield is equal to the percentage of the land overlying the fresh groundwater basin which is owned or leased by an applicant for a regular permit.

Fresh Water

Water which has less than five thousand (5,000) parts per million total dissolved solids. All other water is salt water.

Groundwater

Fresh water under the surface of the earth regardless of the geologic structure in which it is standing or moving outside the cut beds or banks of any definite stream.

Groundwater Basin

A distinct underground body of water overlain by contiguous land having substantially the same geological and hydrological characteristics and yield capabilities. The areal boundaries of a basin can be determined by political boundaries, geological, hydrological, or other reasonable physical boundaries.

Hydraulic Conductivity

The volume of water that will move through a medium in a unit of time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow.

Life of a Groundwater Basin

That period of time during which pumping of the maximum annual yield for a minimum twenty-year life of such basin will result in a final basin storage which approaches zero. Fifteen feet of saturated thickness is maintained in bedrock aquifers to provide for domestic use.

Major Groundwater Basin

A distinct underground body of water overlain by contiguous land and having substantially the same geological and hydrological characteristics and from which groundwater wells yield at least fifty gallons per minute on the average basinwide if from a bedrock aquifer and at least one hundred fifty gallons per minute on the average basinwide if from an alluvium and terrace aquifer, or as otherwise designated by the Oklahoma Water Resources Board (Board).

Maximum Annual Yield
: A determination by the Board of the total amount of fresh groundwater that can be produced from each basin allowing a minimum twenty-year life of such basin.

Minor Groundwater Basin
: A distinct underground body of water overlain by contiguous land and having substantially the same geological and hydrological characteristics and from which groundwater wells yield less than fifty gallons per minute on the average basinwide if from a bedrock aquifer and less than one hundred fifty gallons per minute on the average basinwide if from an alluvium and terrace aquifer, or as otherwise designated by the Oklahoma Water Resources Board (Board).

Natural Recharge
: All flow of water into a groundwater basin by natural processes including percolation from irrigation.

Permeability
: The property of a porous medium to transmit fluids under a hydraulic gradient.

Porosity
: The ratio, usually expressed as a percentage, of the total volume of voids of a given porous medium to the total volume of the porous medium.

Prior Groundwater Right
: The right to use groundwater established by compliance with the laws in effect prior to July 1, 1973, the effective date of the Oklahoma Groundwater Act.

Specific Yield
: The ratio of the volume of water which the porous medium after being saturated, will yield by gravity to the volume of the porous medium.

Storage Coefficient
: The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (virtually equal to the specific yield in an unconfined aquifer).

Terrace Deposits
: Deposits of older alluvium which occupy positions topographically higher than recent

alluvium and mark the former position of a stream.

Total Discharge from the Basin

Shall include but may not be limited to the amount of fresh groundwater withdrawn and placed to beneficial use prior to July 1, 1973, which amount shall be determined from the applicable final orders of the Board determining prior groundwater rights.

Transmissivity

The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.