Characterizing Aquifer Properties Using Base Flow In Streams

Derrick Wagner
Water Resources Geologist

Technical Studies Section
Oklahoma Water Resources Board

April 4, 2019

OWRB
the water agency

What is the purpose of our studies?

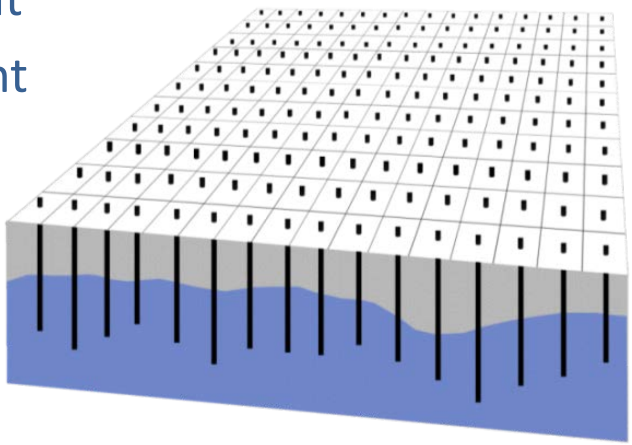
- **1973 Oklahoma Groundwater Law**

  It is declared to be the public policy of the State of Oklahoma, in the interest of the agricultural stability, domestic, municipal, industrial and other beneficial uses, general economy, and health and welfare of the State and its citizens, to utilize the ***groundwater resources*** *of the State, and for that purpose to provide* ***reasonable regulations*** *for the allocation for reasonable use based on* ***hydrologic surveys*** *of fresh groundwater basins or subbasins to* ***determine a restriction on the production*** *based upon the acres overlying the groundwater basin or subbasin.*

- 2012 Comprehensive Water Plan – Directs agency to complete all unstudied basins and complete 20-year reviews/updates.

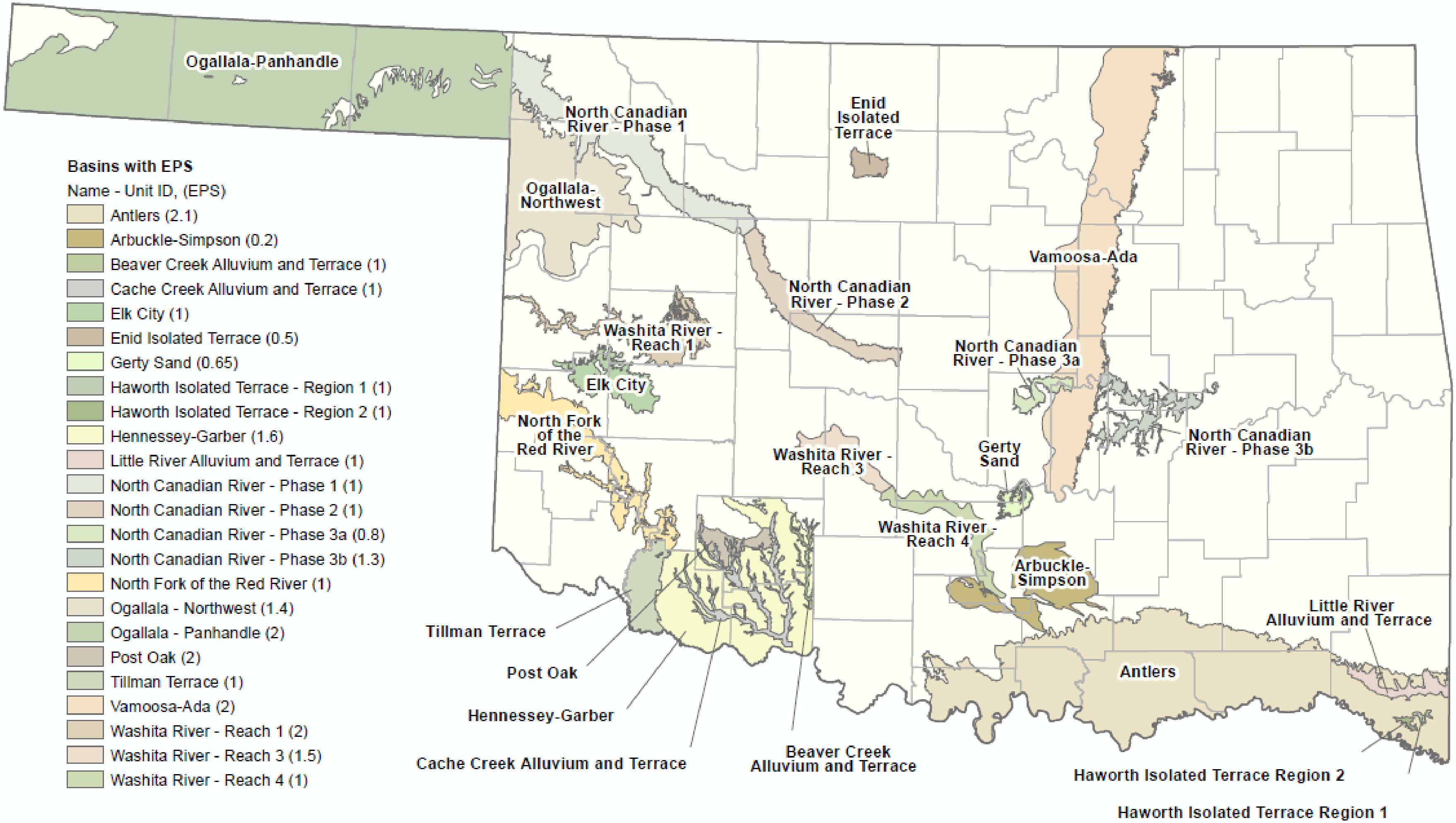
Maximum Annual Yield/Equal Proportionate Share

- Maximum Annual Yield (MAY)
  - The total amount of fresh groundwater that can be withdrawn while allowing a minimum 20-year life of the basin.
- Equal Proportionate Share (EPS)
  - Once the maximum annual yield has been established, the amount of water allocated to each permit applicant will be proportionate to the amount of land owned or leased by that applicant.
  - Each groundwater user is entitled to withdraw an equal share of water proportional to the amount of land owned.



Oklahoma Groundwater Resources

Groundwater Basins with Final Maximum Annual Yield Determination

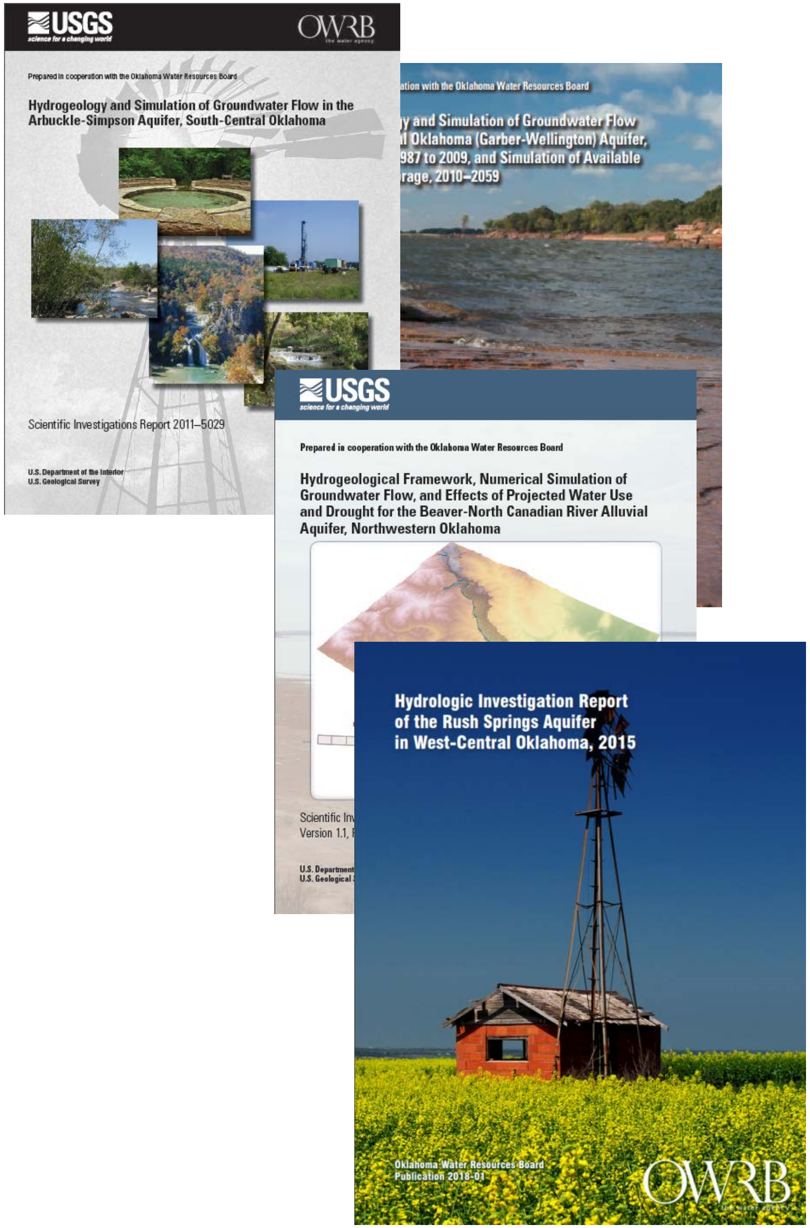


This map represents groundwater basins that have a final maximum annual yield determination by the Oklahoma Water Resources Board. TITLE 785. OKLAHOMA WATER RESOURCES BOARD, CHAPTER 30. TAKING AND USE OF GROUNDWATER, SUBCHAPTER 9. MAXIMUM ANNUAL YIELD DETERMINATIONS.
http://www.owrb.ok.gov 10/18/2017

State of Oklahoma OWRB WATER RESOURCES BOARD the water agency

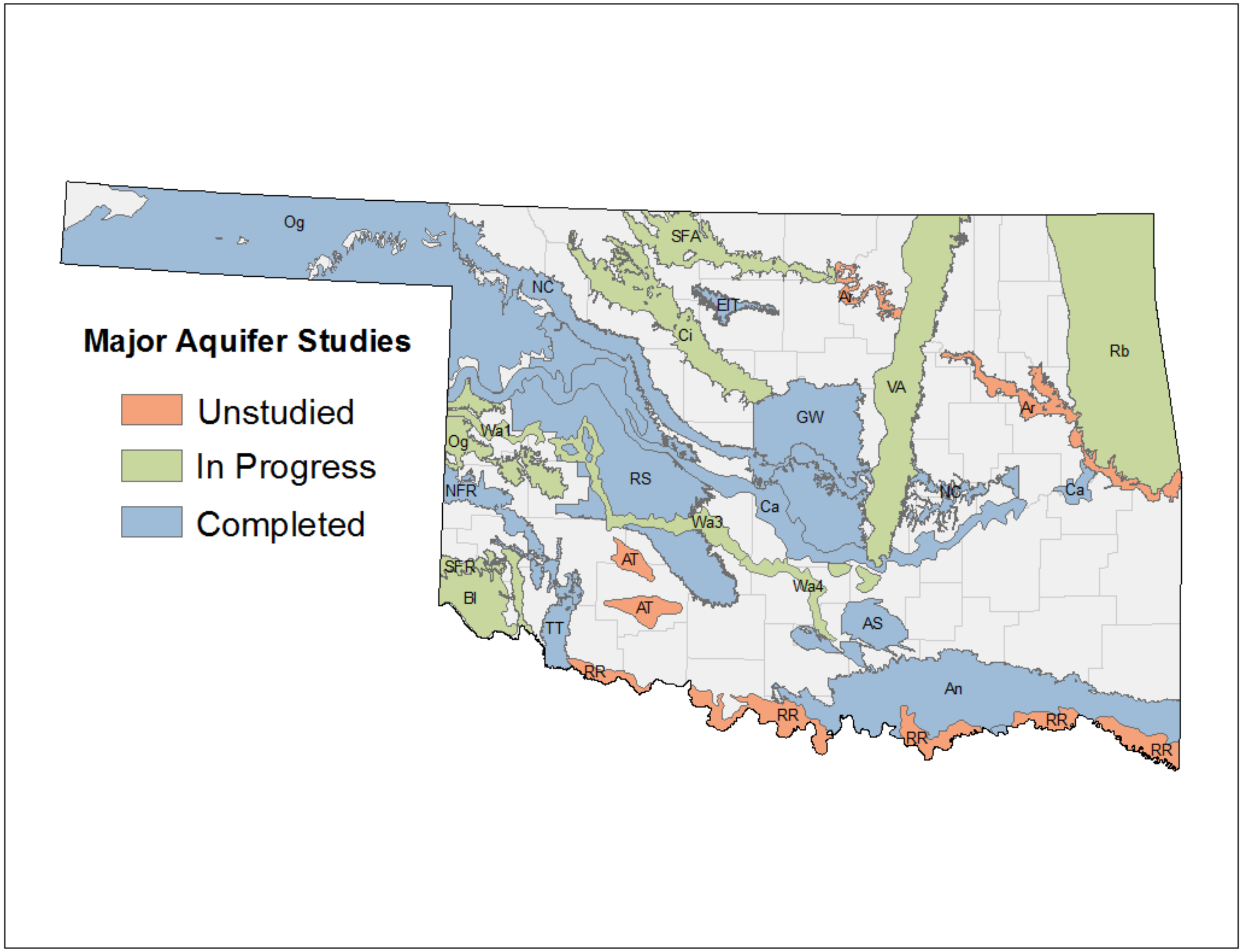
Hydrologic Studies

- Performed by the OWRB or in collaboration with outside agency or institution such as the USGS
- Six ongoing studies by OWRB
  - Cimarron River A&T
  - Elk City Sandstone
  - Blaine Gypsum
  - Vamoosa-Ada
  - Ogallala-Roger Mills
  - Gerty Sand
- Five ongoing studies with USGS
  - Washita River A&T Reach 1
  - Washita River A&T Reaches 3&4
  - Salt Fork of the Red River A&T
  - Boone-Roubidoux
  - Salt Fork of the Arkansas River A&T
- One study completed in 2018
  - Rush Springs



OWRB the water agency

OWRB Hydrologic Investigations



OWRB the water agency

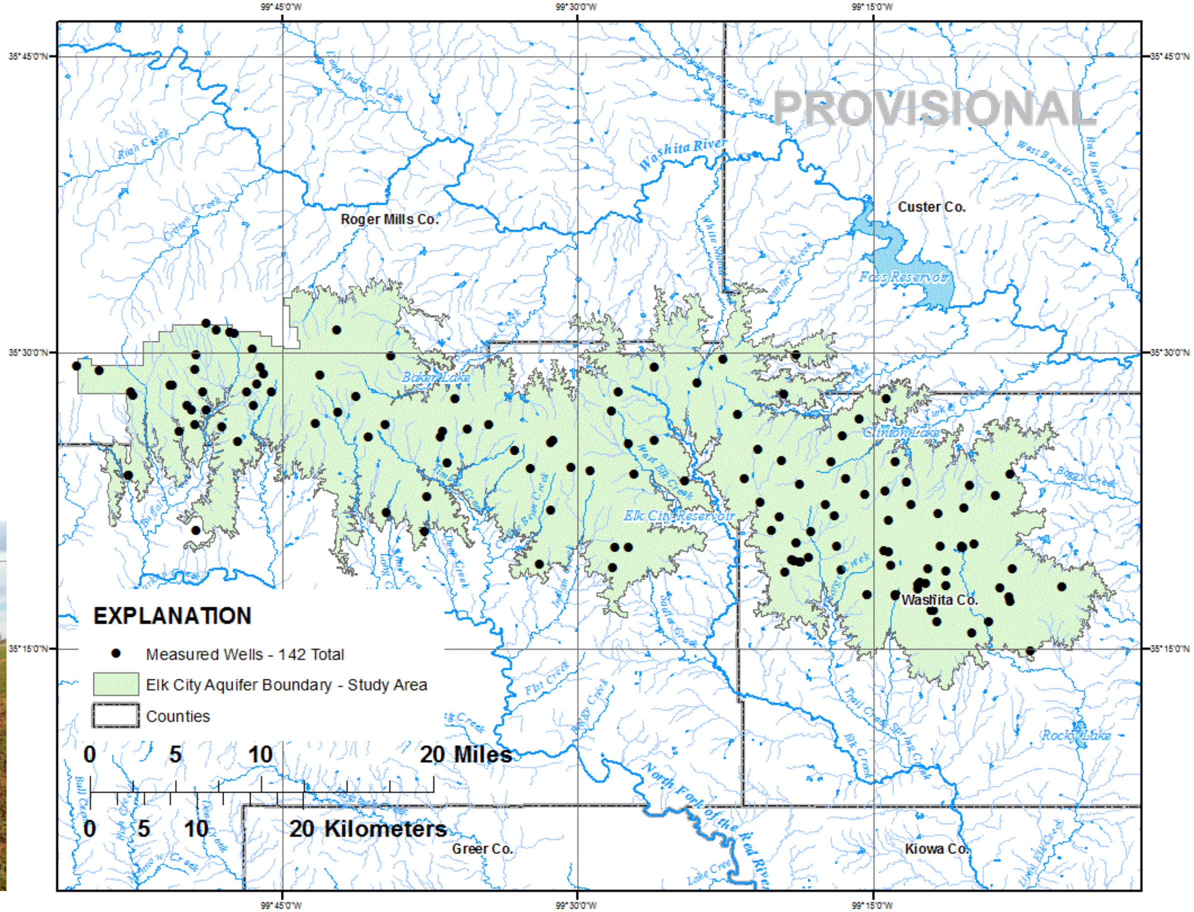
Hydrologic Studies

Study Goals

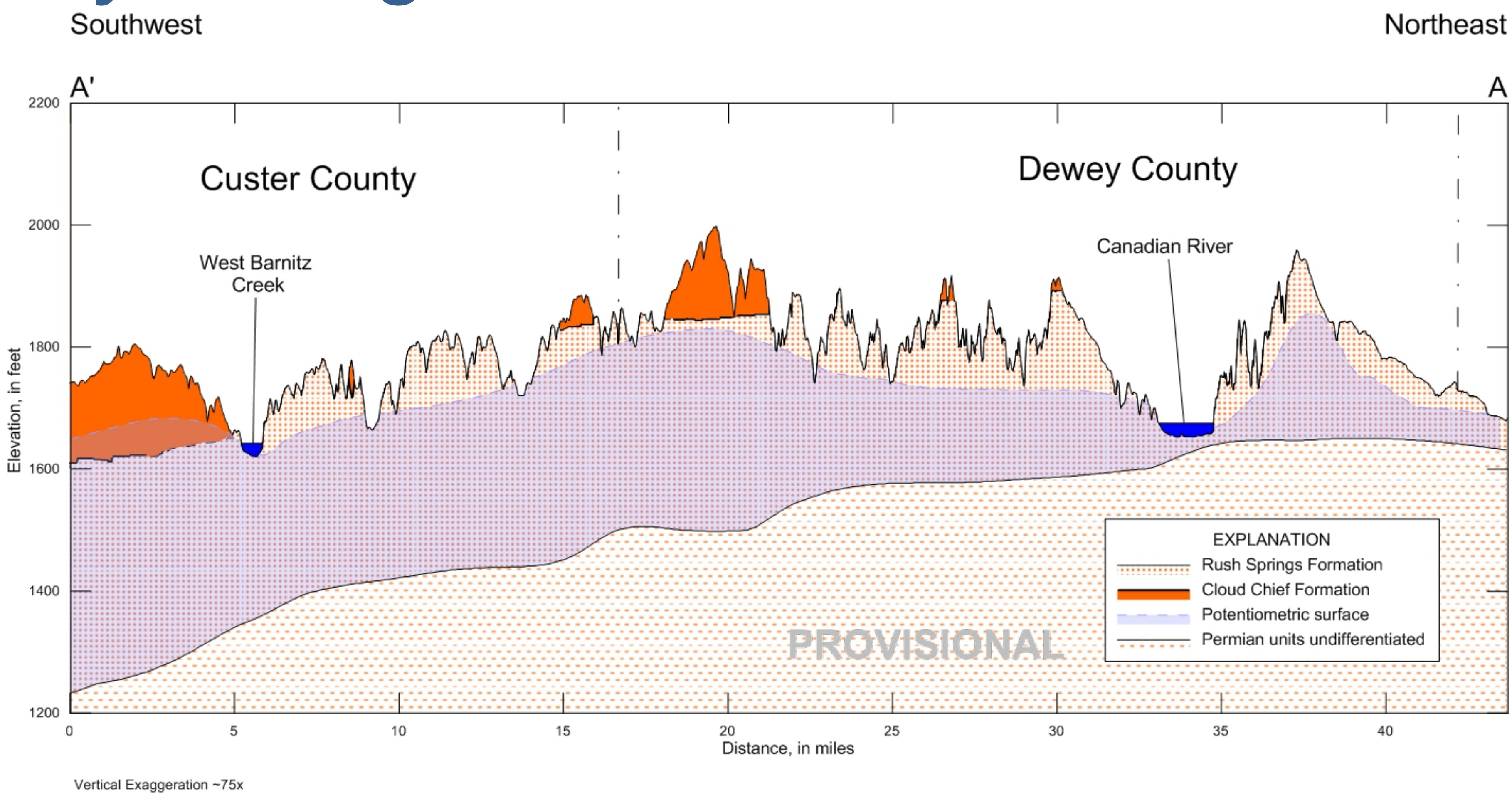
- Define aquifer boundary
- Determine aquifer base
- Measure wells, create water table/potentiometric surface map
- **Hydraulic properties of the aquifer**
  - **Hydraulic conductivity/Transmissivity**
  - **Storativity**
- Analyze permitted groundwater use
- Climate data
- **Estimate aquifer recharge**
  - **RORA**
  - **Soil Water Balance code**
- **Streamflow/baseflow measurements**
  - **Surface water synoptic**
  - **Baseflow separation**
- Groundwater quality

OWRB the water agency

Hydrologic Studies

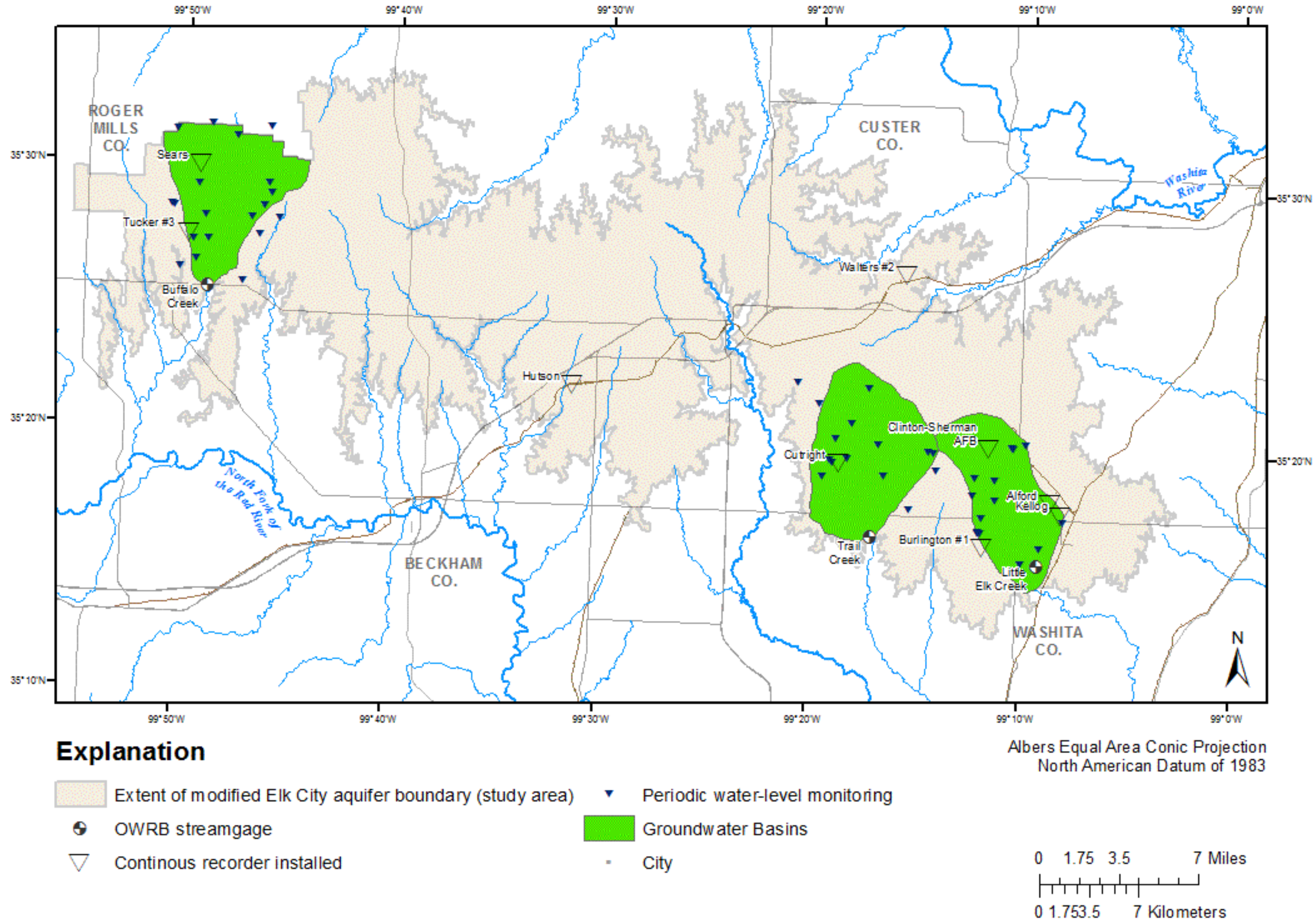


Hydrologic Studies



OWRB the water agency

Determining Aquifer Properties - Storativity



OWRB the water agency

Estimate Storage From Groundwater Levels and Base Flow

The regional method to estimate storage "assumes that if during a specific time an aquifer is not recharged, but is only draining, the ratio of the volume of groundwater discharged to the volume of the aquifer drained is the storage coefficient for that volume of aquifer drained"[1].

$$S = Qb/\Delta DTW$$ [2]

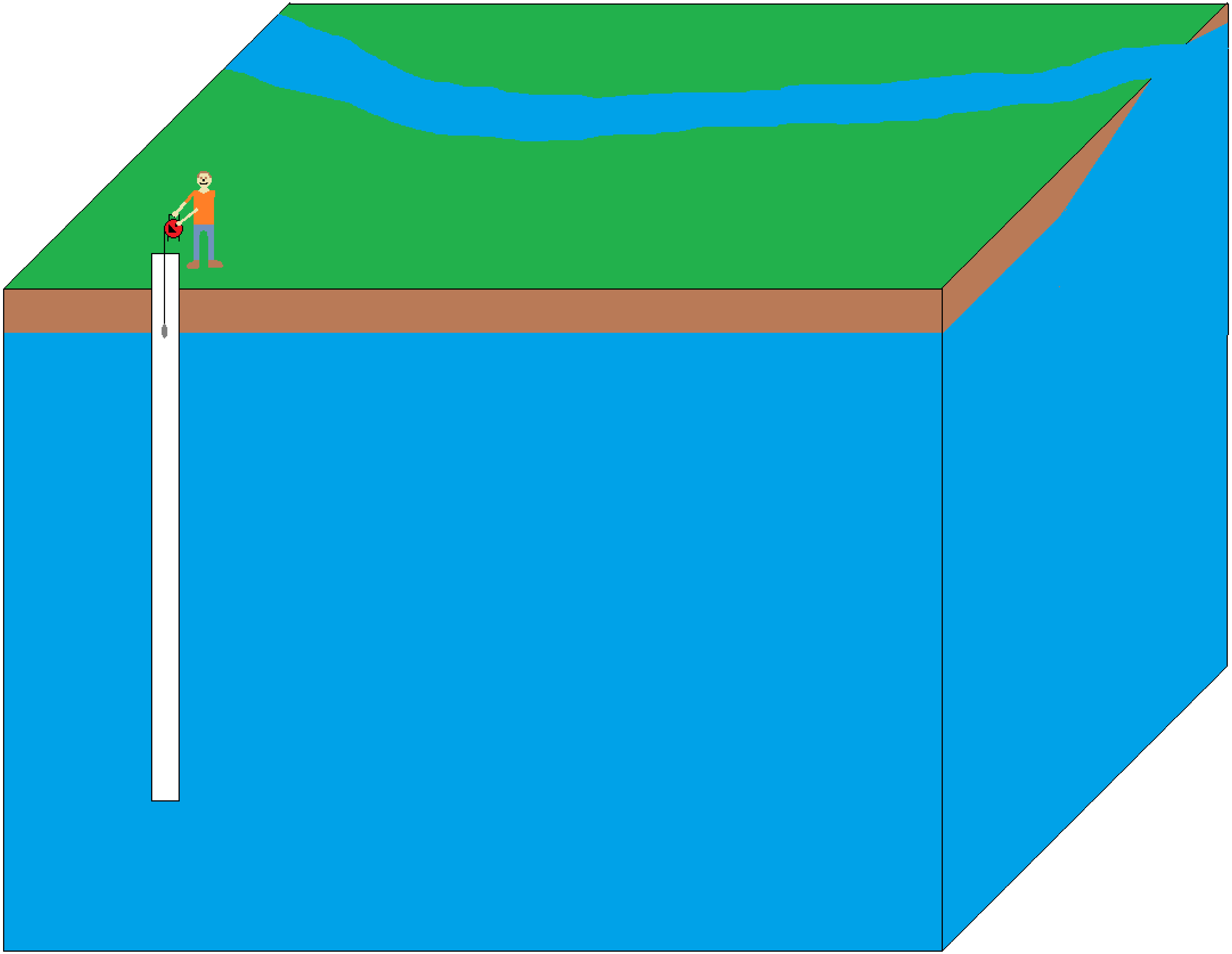
where

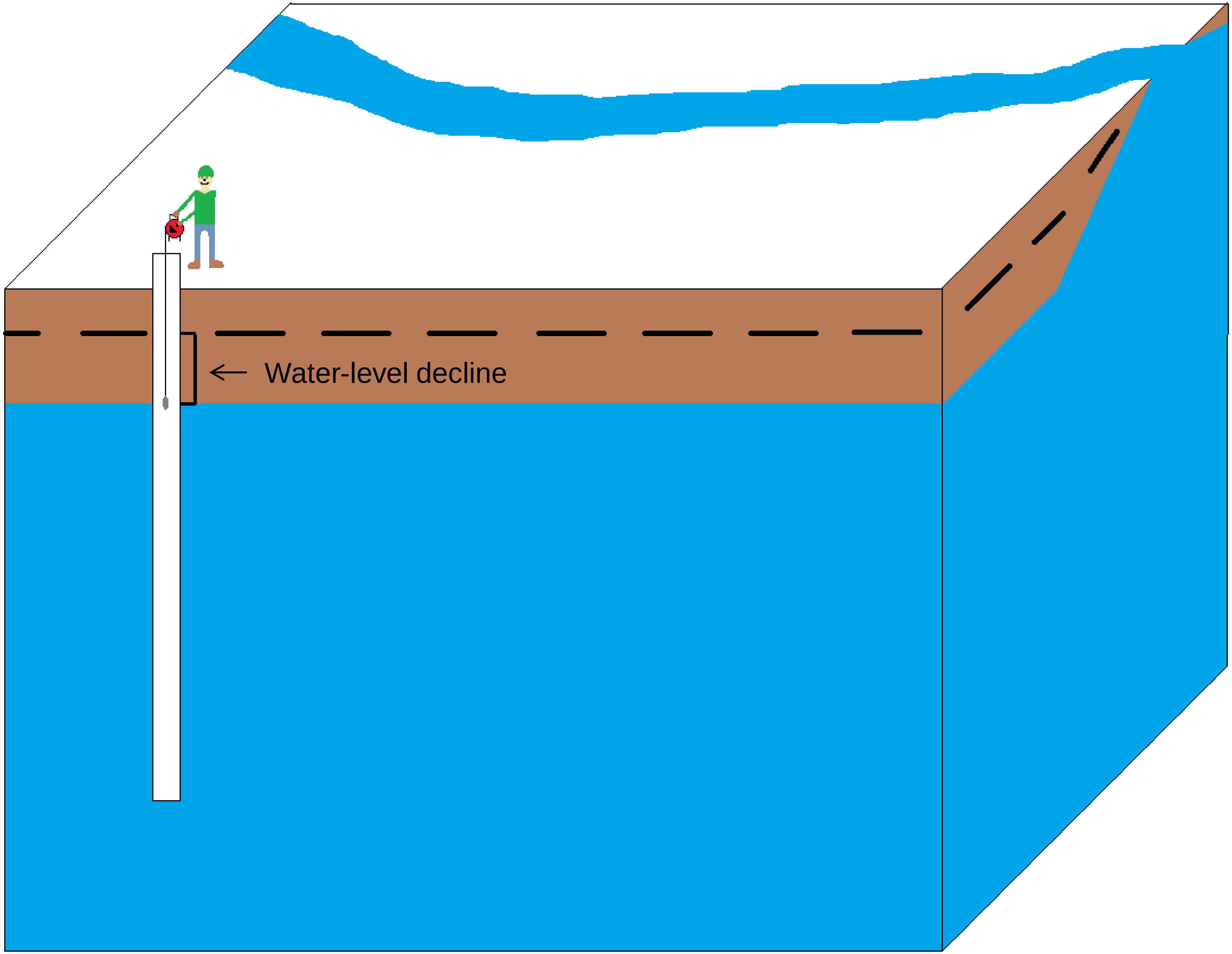
S	is storativity (dimensionless)
Qb	is the amound of base flow during a set period of time
ΔDTW	is the change in the depth to water over a set period of time

[1]Christenson, S., Osborn, N.I., Neel, C.R., Faith, J.R., Blome, C.D., Puckette, J., and Pantea, M.P., 2011, Hydrogeology and simulation of groundwater flow in the Arbuckle-Simpson aquifer, south-central Oklahoma: U.S. Geological Survey Scientific Investigations Reports 2011-5029, 104 p.

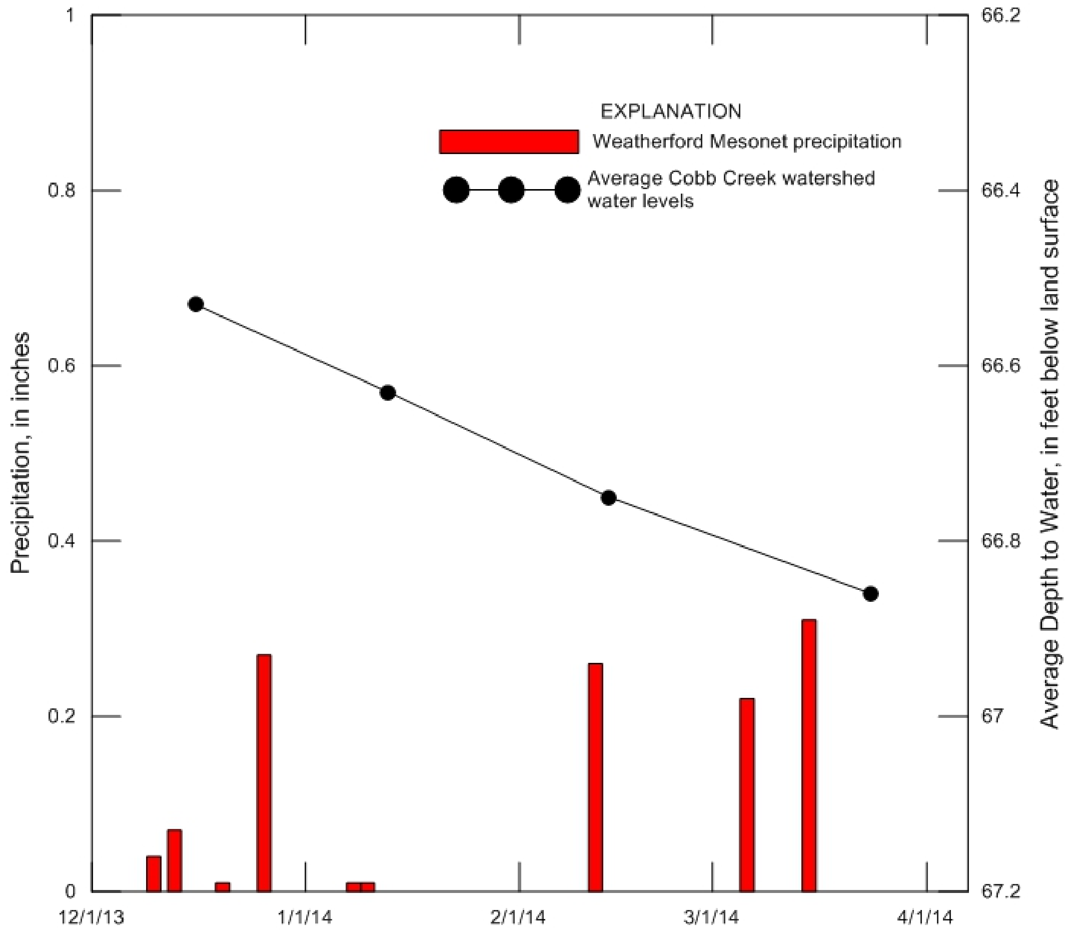
[2]Neel, C.R., Wagner, D.L., Correll, J.S., Sanford, J.E., Hernandez, R.J., Spears, K.W., and Waltman, P.B., 2018, Hydrologic Investigation Report of the Rush Springs aquifer in west-central Oklahoma, 2015: Oklahoma Water Resources Board Publication 2018-01, 61 p.

OWRB the water agency




Water-level decline

Water Levels & Precipitation in Cobb Creek Watershed



OWRB
the water agency

Specific yield calculated from baseflow* and change in water stored in Pennington Creek, Byrd's Mill Spring, and Blue River, Arbuckle-Simpson aquifer.

Table 10. Storage coefficients calculated from streamflows and change in water stored in subsurface watersheds, June 22, 2006, through September 8, 2006.

Subsurface watershed	Volume of aquifer drained in subsurface watersheds (acre-feet)	Total discharge based on daily gaged flow (acre-feet)	Base-flow discharge based on hydrograph separation (acre-feet)	Storage coefficient (dimensionless)
Pennington Creek	335,181	2,834	2,756	0.008
Byrds Mill Spring[1]	248,491	1,990	1,990	0.008
Blue River	454,299	5,187	5,063	0.011

[1]Discharge from Byrds Mill Spring is entirely groundwater.

*baseflow from streams estimated using PART program

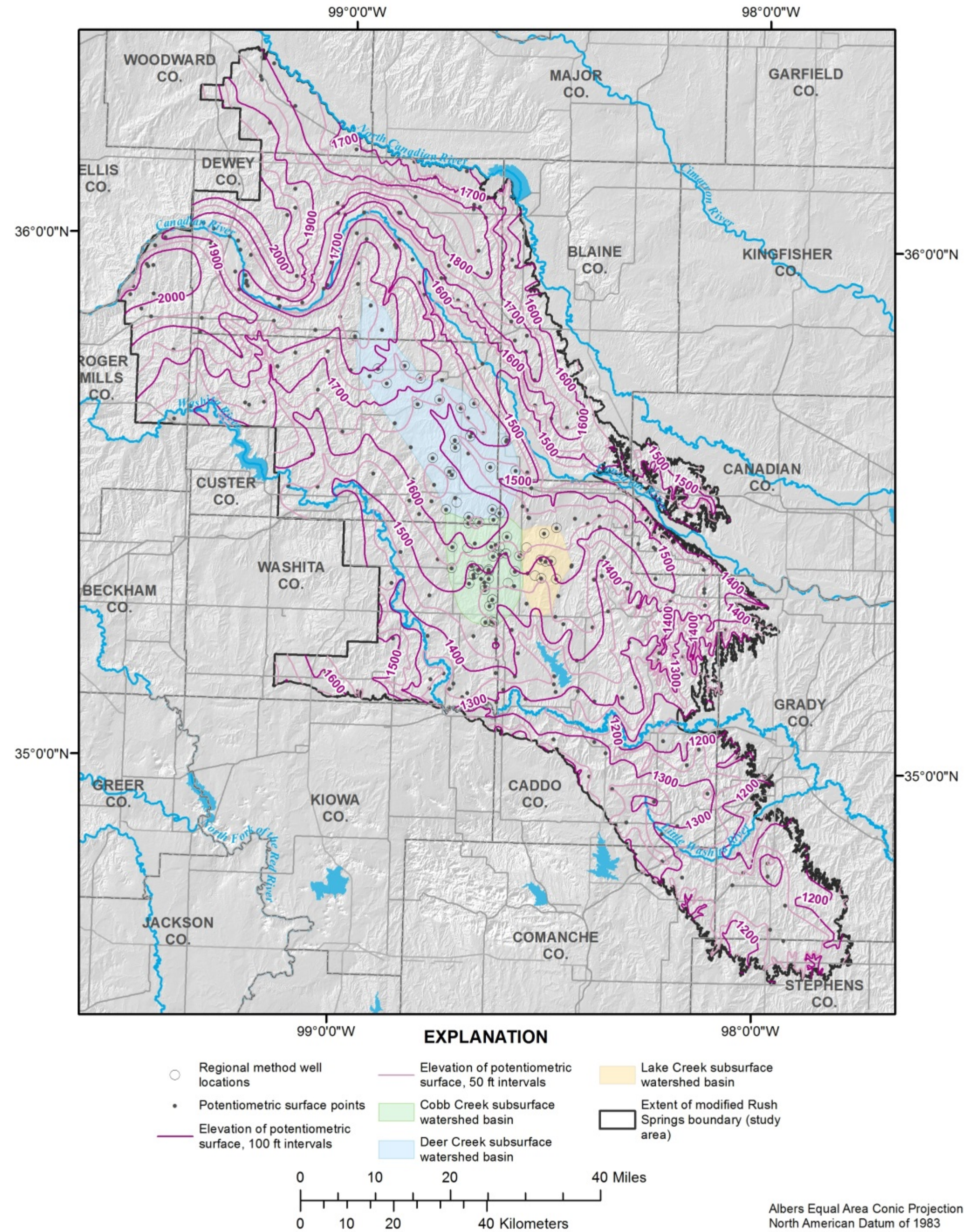
Specific yield calculated from baseflow and change in water stored in Buffalo, Little Elk, and Trail Creek watersheds in the Elk City aquifer.

Subsurface watershed	Basin size (square miles)	Dates Measured	Total discharge based on daily gaged flow (acre-feet)	Volume of aquifer drained in subsurface watersheds (acre-feet)	Average water level decline (feet)	Monthly Storage coefficient (dimensionless)	Total Specific yield (dimensionless)
Buffalo Creek	26.2	January 2016 - February 2016	279	2514	0.15	0.11	0.10
		December 2016 - January 2017	99.5	1173	0.07	0.08	
		January 2017 - February 2017	127	1341	0.08	0.09	
		February 2017 - March 2017	144	1508	0.09	0.10	
Little Elk Creek	24.0	June 2016 - July 2016	107	2301	0.18	0.05	0.07
		October 2016 - November 2016	118	1227	0.08	0.10	
		November 2016 - December 2016	216	3221	0.21	0.07	
Trail Creek	30.5	June 2016 - July 2016	173	2434	0.13	0.07	0.07
		July 2016 - August 2016	204	5067	0.26	0.04	
		November 2016 - December 2016	611	6528	0.34	0.09	

OWRB
the water agency

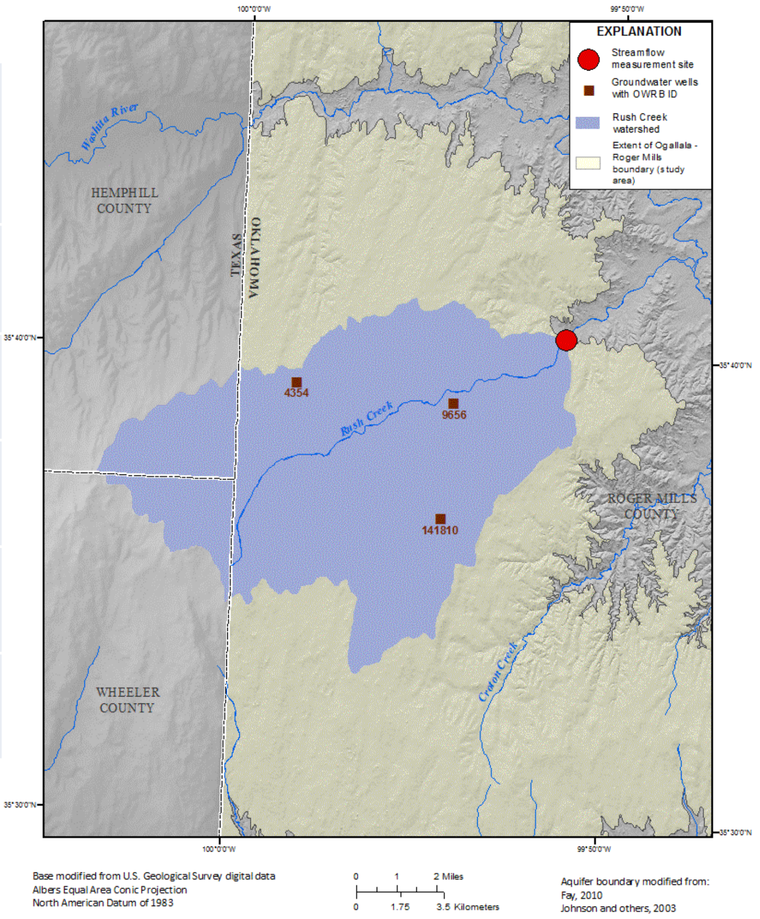
Specific yield calculated from base flow and change in water stored in Cobb, Deer, and Lake Creek subsurface watersheds

Subsurface watershed	Basin size (square miles)	Dates Measured	Total baseflow discharge based on daily gaged flow, (acre-feet)	Volume of aquifer drained in subsurface watersheds (acre-feet)	Storage coefficient (dimensionless)	Combined storage coefficient (dimensionless)	Average water level decline (feet)
Cobb Creek	127.3	December 2013 - January 2014	477	12,932	0.037	0.05	0.16
		January 2014 - February 2014	519	11,042	0.047		0.14
		February 2014 - March 2014	802	12,816	0.063		0.16
Deer Creek	280.1	December 2013 - January 2014	1321	14,620	0.090	0.07	0.08
		January 2014 - February 2014	1537	28,048	0.055		0.16
		February 2014 - March 2014	1652	20,060	0.082		0.11
Lake Creek	58.9	December 2013 - January 2014	115	1,697	0.068	0.07	0.05
		January 2014 - February 2014	143	3,029	0.047		0.08
		February 2014 - March 2014	191	2,176	0.088		0.06


99°0'0"W
98°0'0"W
36°0'0"N
35°0'0"N
WOODWARD CO.
MAJOR CO.
GARFIELD CO.
ELLIS CO.
DEWEY CO.
BLAINE CO.
KINGFISHER CO.
ROGER MILLS CO.
CUSTER CO.
CANADIAN CO.
WASHITA CO.
BECKHAM CO.
GRADY CO.
GREER CO.
KIOWA CO.
CADDO CO.
JACKSON CO.
COMANCHE CO.
STEPHENS CO.
EXPLANATION
Regional method well locations
Potentiometric surface points
Elevation of potentiometric surface, 100 ft intervals
Elevation of potentiometric surface, 50 ft intervals
Cobb Creek subsurface watershed basin
Deer Creek subsurface watershed basin
Lake Creek subsurface watershed basin
Extent of modified Rush Springs boundary (study area)
0 10 20 40 Miles
0 10 20 40 Kilometers
Albers Equal Area Conic Projection
North American Datum of 1983

Specific yield calculated from base flow and change in water stored in Rush Creek, Ogallala-Roger Mills aquifer

Method	Average Transmissivity, ft^2/day	Specific Yield	Average Hydraulic Conductivity, ft/day	Median Hydraulic Conductivity, ft/day
Single Well Pumping Tests	679.25	0.22	11.37	11.10
Percent Coarse	695.10	0.18	12.42	10.00
Slug Tests	1106.86	-	21.31	11.24
Drawdown Tests	1225.45	-	15.97	7.31
Regional Method	-	0.09	-	-



OWRB the water agency

Regional Method Compared to Other Storage Estimation Methods

- Multi-well Pumping Test:
  - Arbuckle-Simpson: One test, storage coefficient of 0.011*, compared to 0.008-0.011 in regional method, another publication estimated 0.008 (Fairchild and others, 1990)[1]
  - Rush Springs: Three tests, specific yields of 0.04, 0.09, and 0.03 compared to 0.05-0.07 for regional method
  - Elk City Sandstone: One test, specific yield of 0.08 compared to 0.07-0.10 for regional method
  - Ogallala-Roger Mills: One test, specific yield of 0.22, compared to 0.09 for regional method
- Percent-Coarse Analysis:
  - Rush Springs: 0.06
  - Elk City Sandstone: 0.08
  - Ogallala-Roger Mills: 0.18

*pumping test was not of sufficient duration to confidently determine storage coefficient

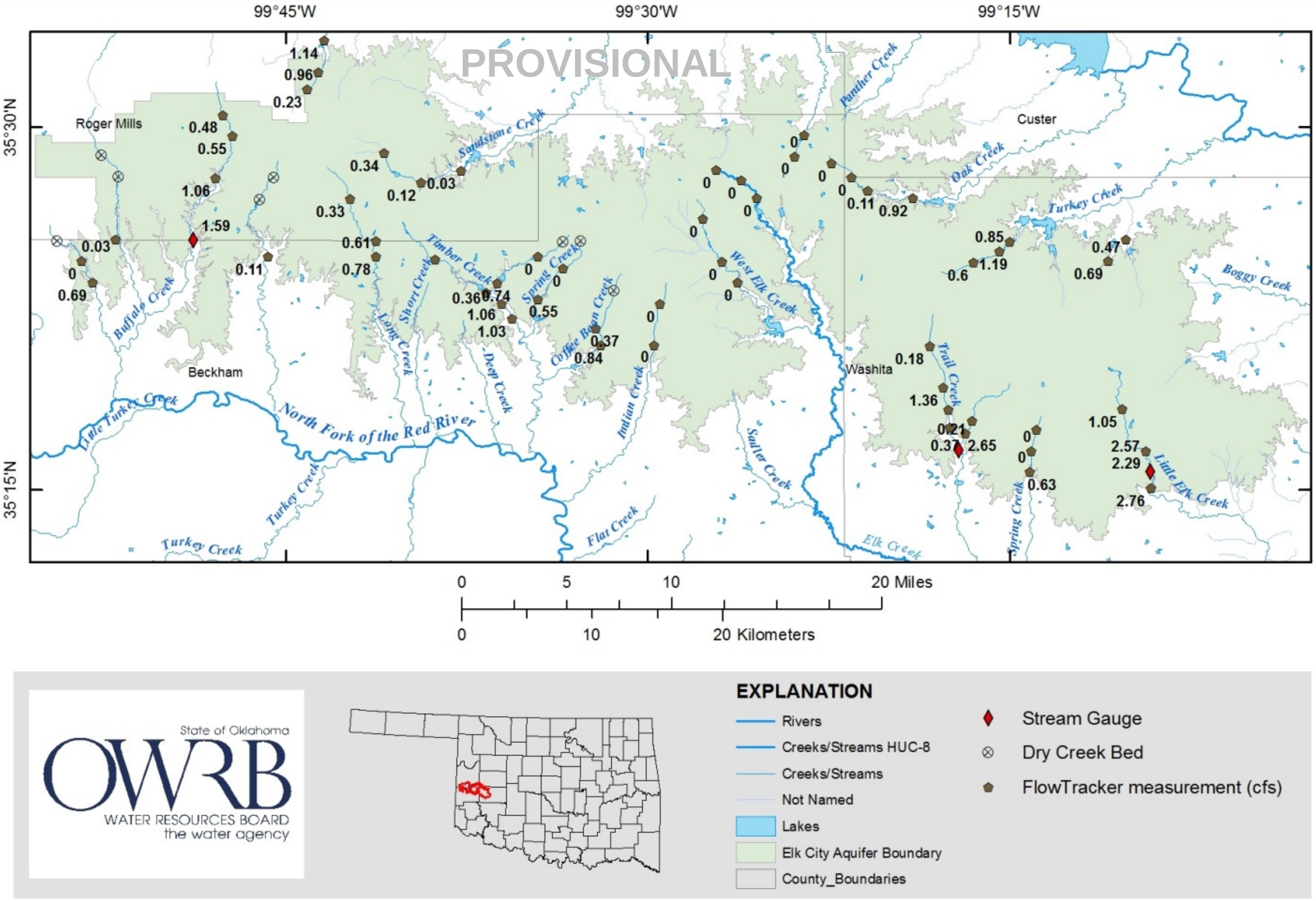
[1]Fairchild, R.W., Hanson, R.L., and Davis, R.E., 1990, Hydrology of the Arbuckle Mountains area, south-central Oklahoma: Oklahoma Geological Survey Circular 91, 112 p., 2 pls., scale 1:100,000.

OWRB
the water agency

Surface Water Synoptic

67 sites on 27 streams measured in Elk City Sandstone aquifer

Elk City Surface Water Measurements



State of Oklahoma OWRB WATER RESOURCES BOARD the water agency

OWRB the water agency

Arbuckle-Simpson aquifer

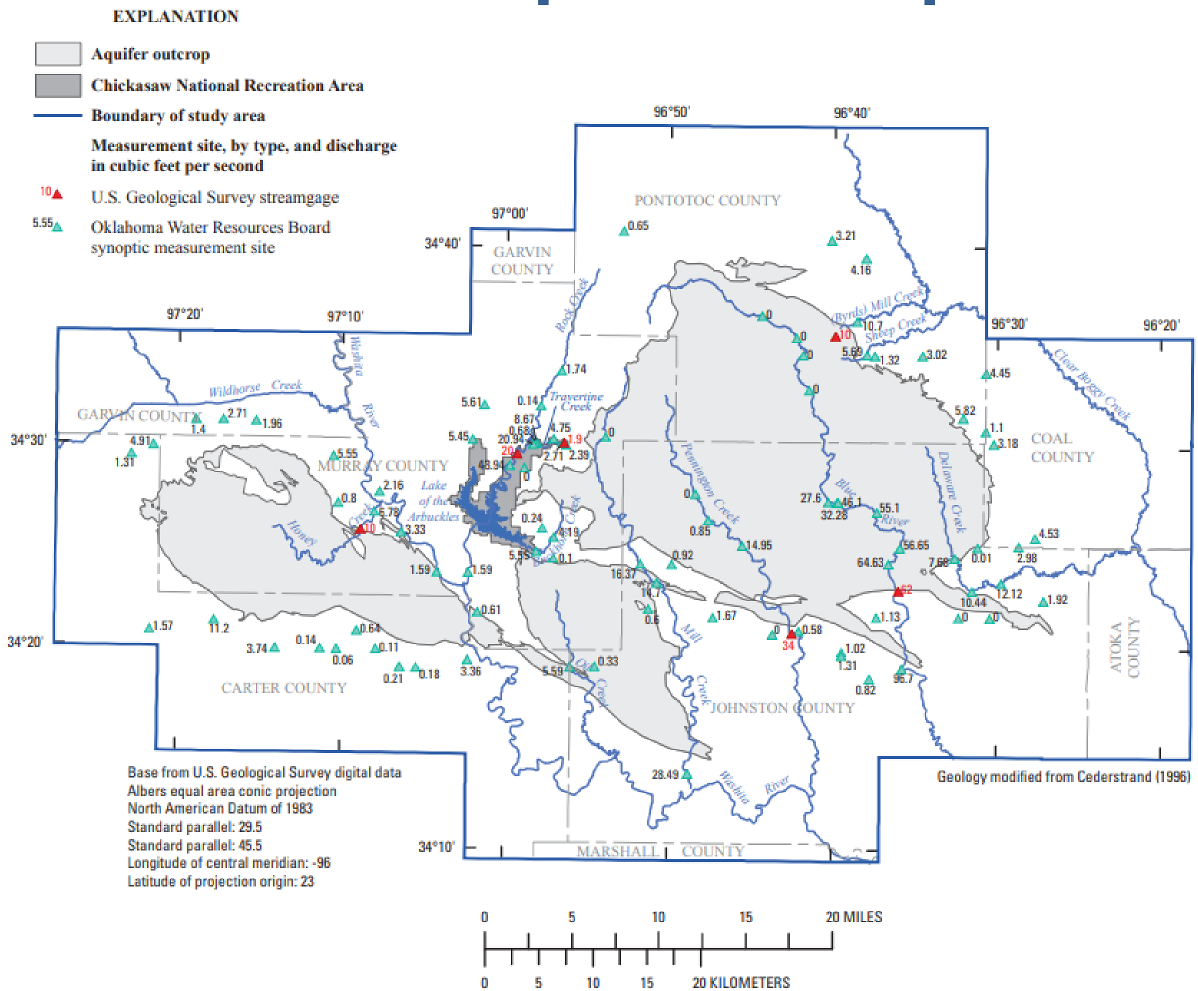
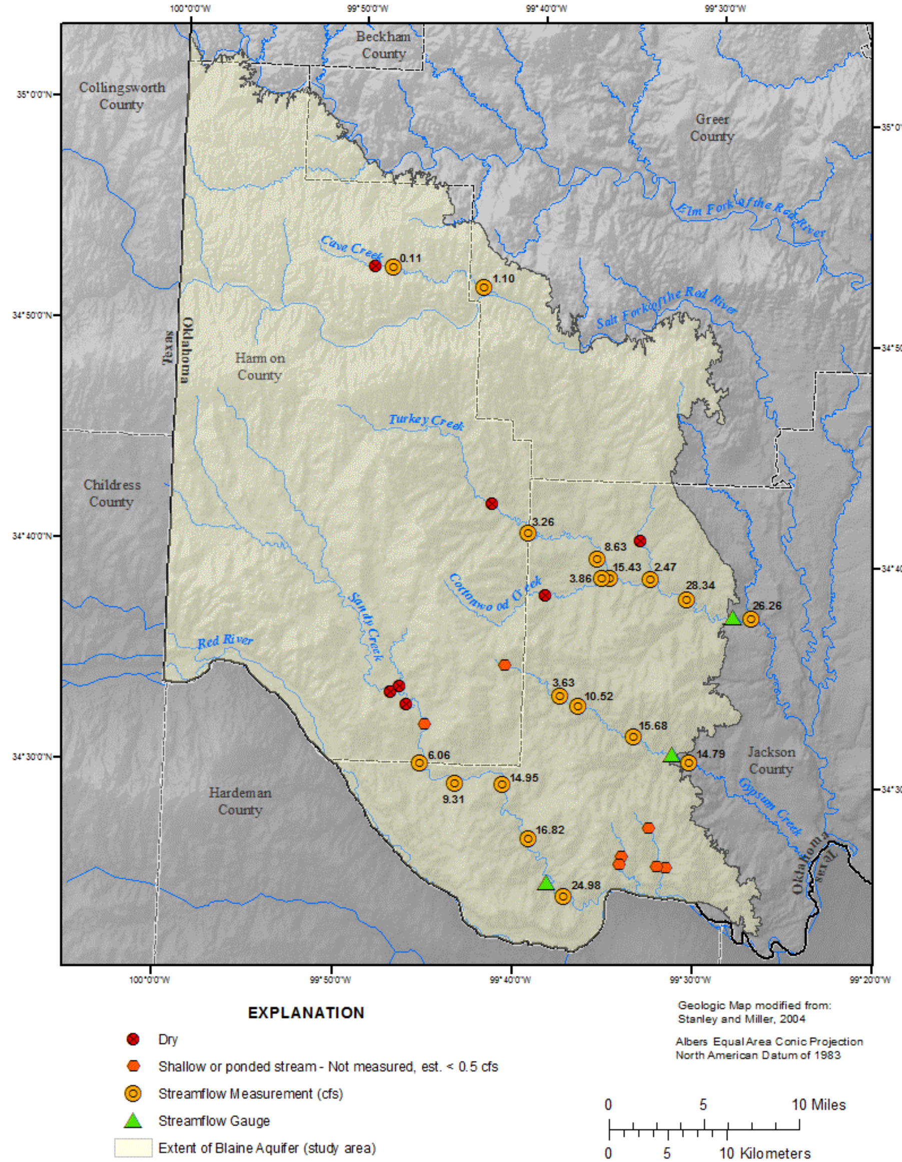


Figure 15. Streamgages, synoptic discharge measurement sites, and streamflow discharge for February 19–22, 2007, for streams on or near the Arbuckle-Simpson aquifer, south-cental Oklahoma.

OWRB the water agency

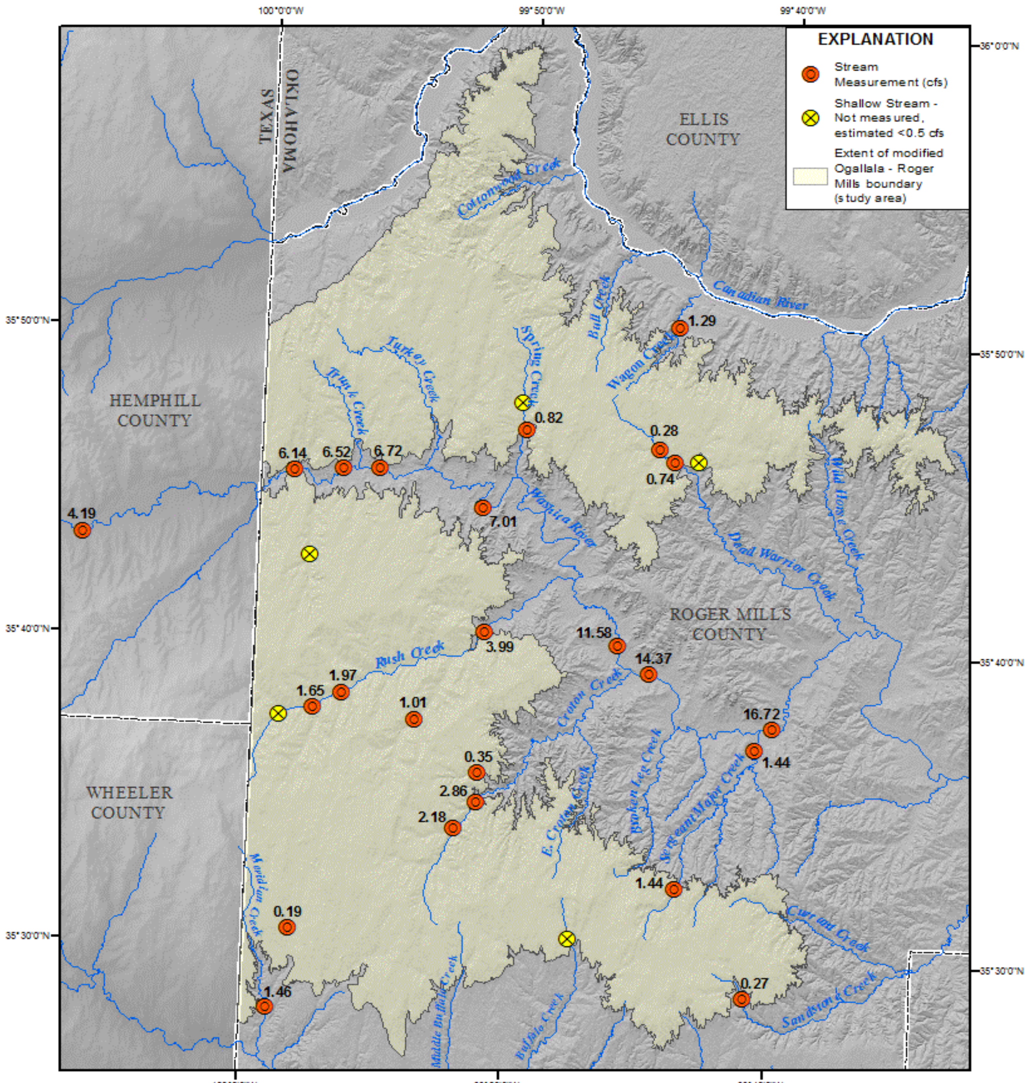
Blaine Gypsum aquifer

- 32 sites on 8 streams measured
- Streams dry in western portion of aquifer
- Streams consistently gaining in eastern portion of the aquifer
- Turkey and Gypsum creeks turn losing upon exiting aquifer.



Ogallala-Roger Mills

- 28 sites on 14 streams measured
- Streamflow gains in Washita River almost entirely from streams draining Ogallala.
- Streams were slightly gaining



Base modified from U.S. Geological Survey digital data
Albers Equal Area Conic Projection
North American Datum of 1983

0 2.5 5 Miles
0 3.5 7 Kilometers

Aquifer boundary modified from:
Fay, 2010
Johnson and others, 2003

Streamflow over the Rush Springs aquifer

Station number	Station name	Drainage area, in square miles	Period of analysis	Mean annual streamflow, in cubic feet per second	Median annual streamflow, in cubic feet per second	Mean annual baseflow, in cubic feet per second	Median annual baseflow, in cubic feet per second
07324500	Barnitz Creek near Arapaho, Okla.	243	1946-1963	14.4	0	1.9	0
07237800	Bent Creek near Seiling, Okla.	139	1967-1970	7.6	2.2	1.8	1.4
07325800	Cobb Creek near Eakly, Okla.	132	1968-2015	28.8	15	14.1	12.3
07228400*	Deer Creek at Hydro, Okla.	274	1961-1962, 1978-1979, 2014-2015	30.50	21.20	16.80	17.20
07325850	Lake Creek near Eakly, Okla.	52.5	1969-1978, 2005-2015	8.1	3.5	3	2.5
07327550	Little Washita East of Ninnekah, Okla.	232	1992-2015	52.20	24.00	24.70	16.20
07327000	Sugar Creek near Gracemont, Okla.	208	1956-1974	14.70	5.30	4.50	2.10
07325860	Willow Creek near Albert, Okla.	28.2	1970-1978, 2005-2015	4.10	1.90	1.60	1.40
07324400	Washita River near Foss, Okla.	1526	1956-1958, 1961-1987,	53.8	7.4	22.3	6.0
07325000	Washita River near Clinton, Okla.	1961	1935-2015	124.3	29.0	52.4	22.0
07325500	Washita River at Carnegie, Okla.	3116	1937-2006	361.5	116.0	148.4	84.1
07326500	Washita River at Anadarko, Okla.	3640	1903-1908, 1935-1937, 1963-2015	484.1	182.0	236.4	142.0
	Washita River gauges common period of record						
07324400	Washita River near Foss, Okla.	1526	1964-1986, 1990-2005	56.1	7.4	24.3	6.2
07325000	Washita River near Clinton, Okla.	1961	1964-1986, 1990-2005	116.6	30.0	63.8	23.6
07325500	Washita River at Carnegie, Okla.	3116	1964-1986, 1990-2005	371.5	127.0	170.8	97.5
07326500	Washita River at Anadarko, Okla.	3640	1964-1986, 1990-2005	439.0	167.0	222.3	132.4

*OWRB stream gauging station number 520620060010-003RS

Recharge Using Base Flow-RORA

RORA can be used to estimate recharge in a basin from analysis of a streamflow record if the system is characterized by diffuse areal recharge to the water table and discharge to a stream

- First determine recession index using RECESS
  - Time required for groundwater discharge to recede by one log cycle after recession becomes linear or near-linear on the semi-log hydrograph
  - Use winter months
  - Find peaks, recession periods that fit minimum days of recession following streamflow peak
  - Select appropriate peaks
- Use recession index in RORA
- Testing shows RORA can yield consistent estimates under conditions that include leakage to or from deeper aquifers and groundwater evapotranspiration
- RORA estimates the net recharge to the water table minus leakage to a deeper aquifer, or recharge minus groundwater evapotranspiration.

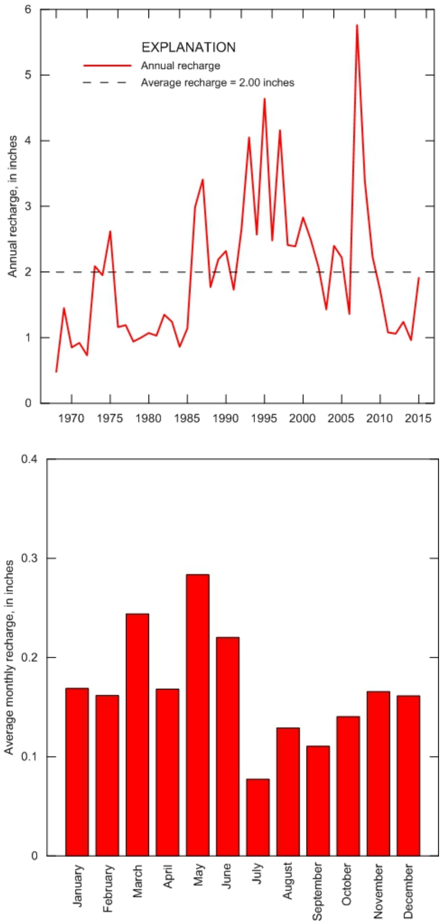
Cobb Creek – Rush Springs Aquifer

Rutledge, A.T., 2000, Considerations for use of the RORA program to estimate ground-water recharge from streamflow records, U.S. Geological Survey Open-File Report 00-156, 52 p.

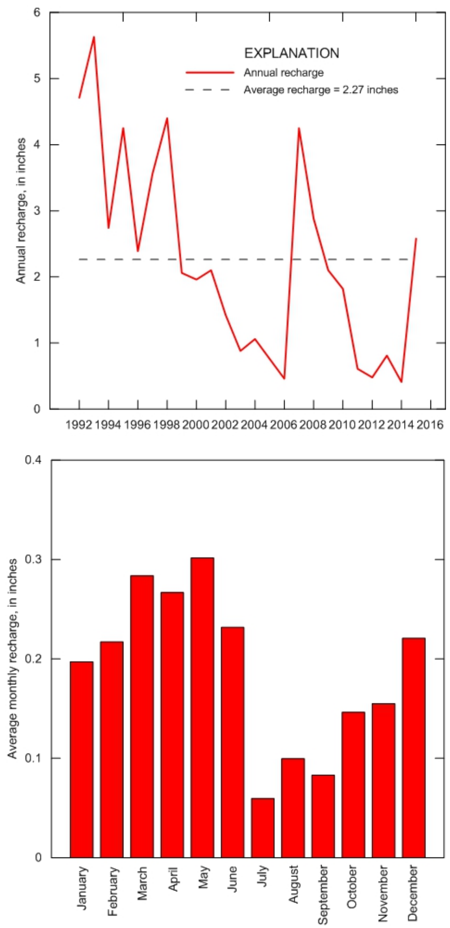
OWRB
the water agency

Recharge – RORA

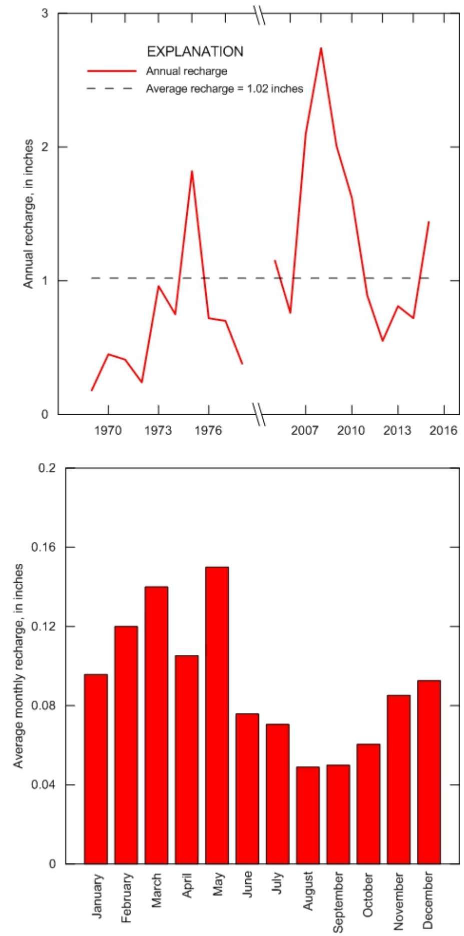
Cobb Creek near Eakly



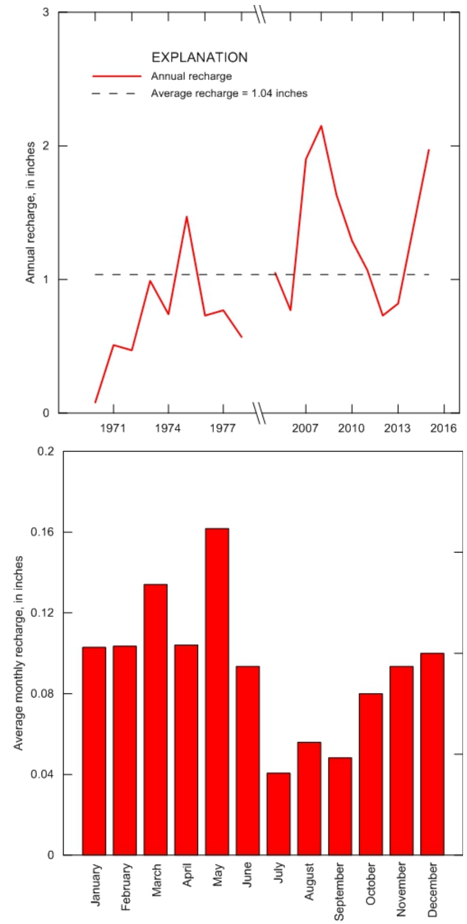
Little Washita River near Ninnekah



Lake Creek near Eakly



Willow Creek near Albert



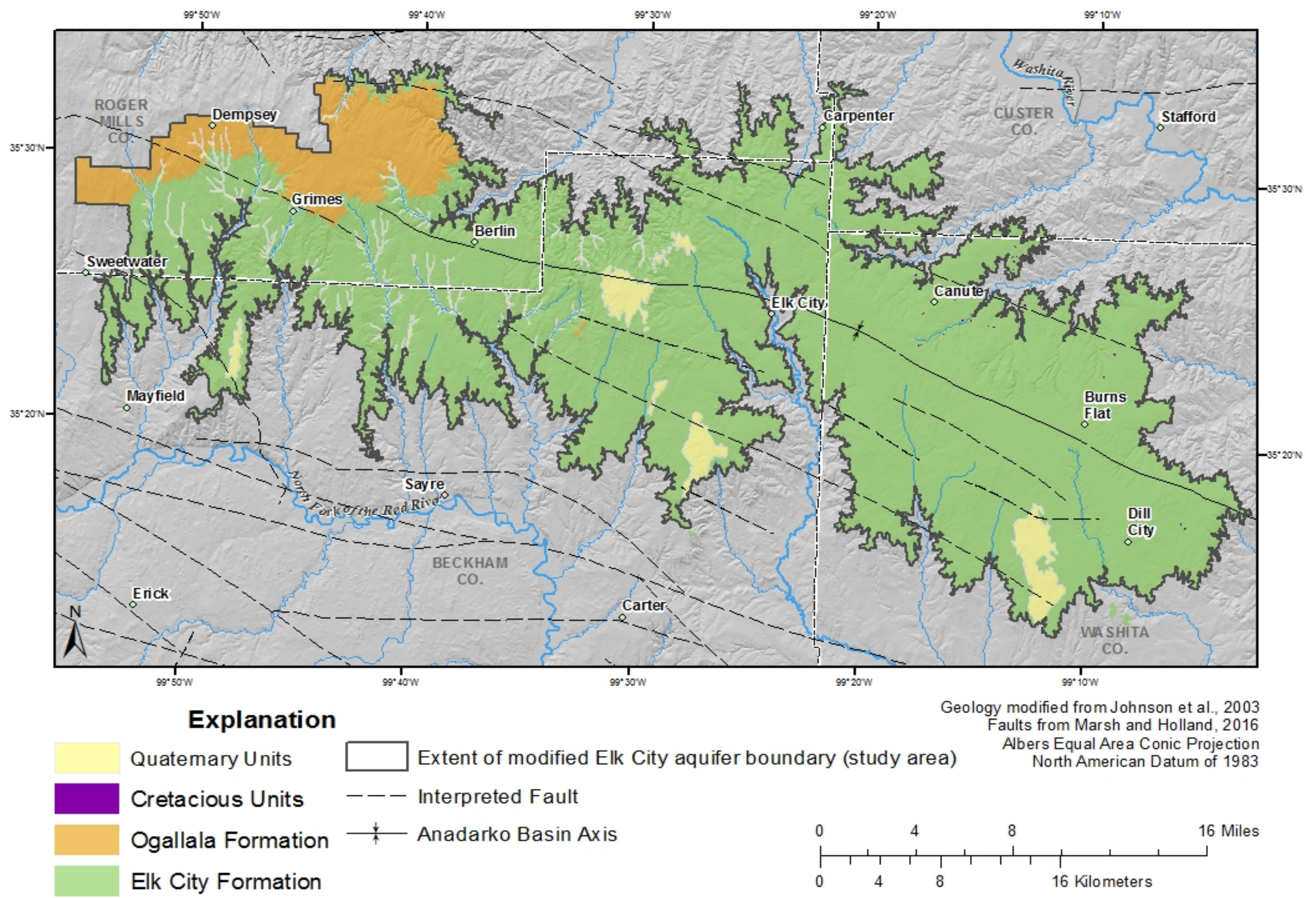
Recharge – RORA & SWB Comparison

Station number	Station name	Drainage area, in square miles	Period of analysis	Minimum annual recharge, in inches	Maximum annual recharge, in inches	Mean annual recharge, in inches
07324500	Barnitz Creek near Arapaho, Okla.	243	1946-1963	0.00	0.74	0.24
07237800	Bent Creek near Seiling, Okla.	139	1967-1970	0.26	0.32	0.29
07325800	Cobb Creek near Eakly, Okla.	132	1968-2015	0.48	5.76	2.00
07228400*	Deer Creek at Hydro, Okla.	274	1961-1962, 1978-1979, 2014-2015	0.94	1.73	1.23
07325850	Lake Creek near Eakly, Okla.	52.5	1969-1978, 2005-2015	0.18	2.74	1.02
07327550	Little Washita East of Ninnekah, Okla.	232	1992-2015	0.41	5.63	2.26
07327000	Sugar Creek near Gracemont, Okla.	208	1956-1974	0.11	1.53	0.58
07325860	Willow Creek near Albert, Okla.	28.2	1970-1978, 2005-2015	0.08	2.15	1.04

*OWRB stream gauging station number 520620060010-003RS

Statistic	Average annual SWB recharge, in inches			
	1950-2015	1950-84	1985-2001	2002-15
Minimum	0.03	0.03	0.76	0.03
Maximum	4.63	3.61	4.15	4.63
Mean	1.40	1.07	2.18	1.30
Median	1.01	0.88	2.00	0.80

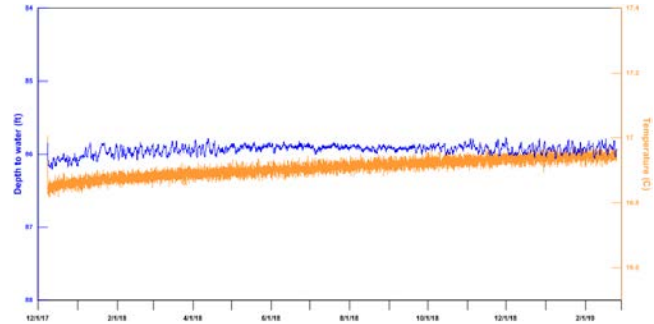
Using Base Flow to Estimate Water Flux Between Units



Base Flow to Estimate Water Flux

- 43 mi^2 of Ogallala Formation overlies the Elk City Sandstone aquifer.
- Create a water budget for Ogallala to estimate flux into Elk City Sandstone.
- Used Ogallala SWB recharge, reported water use, base flow, groundwater levels
- Overlying area had ~3,500 acre-feet of recharge per year, ~100 acre-feet of water use, ~1,700 acre-feet of base flow per year, steady water levels, leaving ~1,700 acre-feet per year into the underlying Elk City, 4.7 acre-feet per day.
- Over the 43 mi^2 of overlap, 4.7 acre-feet per day equals 0.0002 feet per day

Continuous water levels in Ogallala well overlying the Elk City Sandstone



Questions?

Derrick Wagner

derrick.wagner@owrb.ok.gov

Water Resources Geologist

Technical Studies Section

Planning and Management Division

Oklahoma Water Resources Board

3800 North Classen Boulevard

Oklahoma City, OK 73118

Phone: 405.530.8800

Fax: 405.530.8900

OWRB the water agency