Garber-Wellington Groundwater Basin Staff Report

Hydrologic Survey and Simulation of Water Available in Storage

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Introduction

Oklahoma groundwater law requires the Oklahoma Water Resources Board (OWRB) to conduct a hydrologic survey for each major groundwater basin from which the OWRB must determine the maximum annual yield of fresh water to be produced.

A major groundwater basin is a distinct underground body of water overlain by contiguous land and having substantially the same geological and hydrological characteristics. Groundwater wells yield at least fifty (50) gallons per minute, on the average, if from a bedrock aquifer and at least one hundred fifty (150) gallons per minute on the average if from an alluvium and terrace aquifer.

The Maximum Annual Yield (MAY) is to be based on the following:

1. The total land area overlying the basin;
2. The amount of water in storage in the basin;
3. The rate of recharge to and total discharge from the basin;
4. Transmissivity of the basin; and
5. The possibility of pollution of the basin from natural sources.

The U.S. Geological Survey (USGS), in cooperation with the OWRB, investigated the hydrogeology and simulated groundwater flow in the Central Oklahoma (Garber-Wellington) aquifer using a numerical groundwater-flow model. This model was used to simulate groundwater levels, to analyze water budgets and to test water management scenarios. The results of this study are published in the USGS Scientific Investigations Report 2013-5219: *Hydrogeology and Simulation of Groundwater Flow in the Central Oklahoma (Garber-Wellington) Aquifer, Oklahoma, 1987 to 2009, and Simulation of Available Water in Storage 2010-2059* by Shana L. Mashburn, Derek W. Ryter, Christopher R. Neel, S. Jerrod Smith, and Jessica S. Magers.

The purpose of this report is to provide information from the USGS and OWRB necessary to make a determination of the Maximum Annual Yield and Equal Proportionate Share (EPS) for the Garber-Wellington Groundwater Basin.

Groundwater Basin Boundaries and Hydrogeology

The Garber-Wellington Groundwater Basin underlies 2,891 square miles of central Oklahoma including all or parts of Cleveland, Logan, Lincoln, Oklahoma, Payne, and Pottawatomie Counties. The aquifer consists of Permian-age Garber Sandstone; Wellington Formation; and Chase, Council Grove, and Admire Groups as well as Quaternary-age alluvium and terrace deposits. The basin is 17% confined on the western edge by the Permian-age Hennessey Group. Groundwater can flow between most of these geologic units and many wells are completed in both Quaternary-age and Permian-age units. Water in the Quaternary-age alluvium and terrace is, volumetrically, a small fraction compared to the Permian-age units.

Mean annual precipitation for the basin, based on data from 1893-2009, is 34.27 inches. Groundwater in the shallow, local flow systems discharge to nearby streams and the rate of flow and flux of water are greatest in these local flow systems. Flow in the deeper part of the aquifer is slower and flowlines are longer than in the shallow, local flow systems. In the deeper flow system, groundwater flows under small streams to discharge primarily to the Deep Fork and Little rivers. Flow in the Garber-Wellington Groundwater Basin is slowest in the confined area to the west and in the less transmissive geologic units of the unconfined flow system, which includes part of the Chase, Council Grove, and Admire Groups.

Saturated thickness in the eastern part of the aquifer, in Lincoln and Pottawatomie counties, is relatively thin, 200-300 feet. Thinner geologic units in the area are caused by the formation dip and erosion. The thickest zone of saturation is about 920 feet, located near Tinker Air Force Base along the eastern extent of the Hennessey Group confining unit. The thickest portion coincides with the deepest part of the base of freshwater and the areas of higher percent sand in the aquifer. Saturated thickness in the northwest portion of Lincoln County is also relatively thick at 650 feet. Storage in the basin was determined to be 98,676,000 acre-feet based on the groundwater flow model in 2009. The aquifer has a mean saturated thickness of 392.5 feet and a specific yield of 0.13.

Groundwater Contamination Concerns

Water quality concerns include elevated concentrations of metals and trace elements (arsenic, uranium, selenium, and chromium), mineral constituents (chloride, fluoride, and sulfate), nitrate, and total dissolved solids. As reported in OWRB’s *2013 Oklahoma Groundwater Report: Beneficial Use Monitoring Program*, 47 wells were tested for water quality. Nitrate, Arsenic, and Uranium were each found to exceed EPA drinking water maximum contaminant levels (MCL) in single instances. Chloride and sulfate exceeded EPA secondary maximum contaminant levels (SMCL) in two instances, while Manganese exceeded SMCL at one site. Samples from nine sites exceeded SMCL for total dissolved solids (OWRB, 2014) (Appendix, Table 1-1). An earlier study from OWRB, which included samples from deeper municipal wells, reported that fifteen percent of sampled wells exceeded MCL for arsenic, two percent exceeded MCL for chromium, seven and a half percent exceeded MCL for selenium, and eleven percent exceeded MCL for uranium (OWRB, 2011) (Appendix, Table 1-2).

In the 1998 *USGS National Water Quality Assessment Water-Supply Paper 2357-A: Ground-Water-Quality Assessment of the Central Oklahoma Aquifer, Oklahoma: Results of Investigations*, sample concentrations were reported for the Garber-Wellington Groundwater Basin. For samples from 42 wells completed in alluvium and terrace, the maximum concentration of uranium exceeded the MCL and the maximum concentration of fluoride exceeded the SMCL (Christenson and Havens, 1998).

Samples taken from wells completed in Permian units were separated into shallow wells less than 98.4 feet (30 meters) deep, intermediate wells less than 298.5 feet (91 meters) and greater than 98.4 feet, and deep wells greater than 298.5 feet. For shallow wells, the 95th percentile of samples exceeded the MCL for uranium and SMCL for fluoride. For intermediate wells, the 95th percentile exceeded the MCL for uranium, the maximum concentration of selenium exceeded the MCL, and the 95th percentile exceeded the SMCL for fluoride. For deep wells, the 75th percentile exceeded the MCL for arsenic, the 95th percentile exceeded MCLs for uranium and selenium, and the maximum chromium concentration was equal to the MCL (Christenson and Havens, 1998) (Appendix, Table 1-3).

USGS Scientific Investigations Report 2010-5047: Arsenic-Related Water Quality with Depth and Water Quality of Well-Head Samples from Production Wells, Oklahoma, 2008, also reported elevated levels of arsenic and uranium in samples from wells within the Garber-Wellington aquifer. Arsenic concentrations exceeded the drinking water MCL of 10 ug/L in six of the seven wells tested in the Garber-Wellington Groundwater Basin (all historically high in arsenic), with samples ranging from 18.5 to 124 ug/L. Uranium concentrations of 30.2 - 99 ug/L, exceeding the MCL of 30 ug/L, occurred in samples from the four wells with the largest arsenic concentrations (30 - 124 ug/L). Additionally, arsenic concentrations were found to increase with depth (Becker and others, 2010).

Arsenic, chromium, selenium, and uranium are found in solid phase materials throughout the aquifer. At elevated pH levels, which typically increase with depth, these elements desorb from the parent materials. Spatial distribution of mudstone, containing clay rich in alkalizing sodium, within the aquifer determines where these trace element concentrations are elevated. The portion of the aquifer confined by the Hennessey group exhibits longer residence times and as water is exposed to alkaline conditions for longer periods of time, concentrations increase (Christenson and Havens, 1998).

The saline water underlying the Garber-Wellington Groundwater Basin's base of freshwater is another potential source of pollution. These brines have concentrations of chloride up to 240,000 mg/L. Brines mix in the transition zone at the freshwater base and may incorporate through dead-end pores or fluid inclusions (Parkhurst et al, 1996).

Simulation of Available Water in Storage

A numerical MODFLOW groundwater-flow model was developed to simulate groundwater flow; build water budgets; and use 20, 40, and 50-year predictive models to estimate the effects of different pumping scenarios on available water storage in the Garber-Wellington Groundwater Basin. A long-term transient model that spanned wet and dry periods as well as periods of different pumping rates because two synoptic water-level measurement events were available for 1987 and 2009. Pumping rates increased slightly during this 23-year period, therefore this period was selected for the transient model. The year 1987 was used as an initial quasi-steady-state calibration time period, and the transient model included 1987 and continued through 2009.

Mean annual recharge from the Soil-Water Balance code, during the 1987-2009 period, was 4.6 inches per year. The Soil-Water Balance method was used to estimate initial recharge because this method estimates spatial distribution of recharge for the aquifer area. During model calibration, a scaling factor of 0.4 was applied to the Soil-Water Balance recharge value, resulting in 1.84 inches per year of mean annual recharge for the aquifer area during the 1987-2009 period. This rescaled recharge value is consistent with recharge estimates from previous studies (Christenson, 1998; Pettyjohn and Miller, 1982; Wood and Burton, 1968).

Mean transmissivity from the groundwater-flow model was 1,057 square feet per day based on a mean saturated thickness of 392.5 feet and a hydraulic conductivity of 2.69 feet per day. A previous study indicated that median transmissivity was between 290 to 350 square feet per day (Parkhurst and others, 1996). Another reported a range of values from 20 to 900 square feet per day, with a median value of 400 square feet per day (Gates and others, 1983). Wood and Burton (1968) found transmissivity from aquifer tests to be between 400 to 700 square feet per day in Norman, 900 square feet per day in Edmond, and 500 square feet per day in Nichols Hills.

The aquifer was simulated using a grid comprised of 3,280-feet by 3,280-feet (1-kilometer by 1-kilometer) cells and 11 horizontal layers, each 100-feet thick (30.48 meters). The quasi-steady-state model was run to simulate the 1987 calendar year with equilibrium in flow and minimal changes in storage. Initial hydraulic conductivity used for the groundwater-flow model ranged from 0.33 to 3.3 feet per day and was estimated for each model cell using the percent sand from the hydrogeologic framework. The quasi-steady-state model calibration included hydraulic conductivity, vertical anisotropy, and recharge. There was no apparent horizontal or vertical spatial bias to model error and the residuals indicated that the simulated hydraulic heads were near zero. These results indicate that there was random error in the model, a large component of which is related to the discretization that could not accommodate local variation. Hydraulic heads in the aquifer have been well simulated using the spatial distribution of percent sand.

In the transient, 1987-2009 groundwater-flow model, each year was chosen as a stress period because pumping rates for permitted groundwater use are only available on annual intervals. The transient model was calibrated to all available water-level measurements for the aquifer during the period of the simulation. Parameters adjusted during the transient calibration process included the specific yield and specific storage of the aquifer as well as the recharge. Annual recharge was scaled by a factor of 0.4 and is the largest flux in the model, with water removed from storage, seepage from reservoirs, and water lost from the aquifer to streams being lesser amounts. Outflow is dominated by base flow to streams and pumping from wells. Water was removed from storage to meet the total outflow which indicates the aquifer was in deficit (losing water) during the transient period.

Maximum Annual Yield Scenarios

Continuous pumping rates resulting in fifty percent of the basin reaching less than or equal to 15 feet of saturated thickness were determined for 20-, 40- and 50-year life of basin scenarios. Maximum annual yield must maintain an average saturated thickness of five feet for alluvium and terrace aquifers and fifteen feet for bedrock aquifers, such as the Garber-Wellington Groundwater Basin. Because this study did not attempt to simulate effects from a predictive climate model, recharge was held constant at the average flux for each cell that was specified for the 1987-2009 time period. For the 20 year life-of-basin scenario, a continuous pumping rate of 3.8-5.4 (acre-feet/acre)/year exceeded the requirements for saturated thickness of the aquifer. A continuous pumping rate of 1.1-1.5 (acre-feet/acre)/year over a 50 year life-of-basin scenario resulted in less than or equal to fifteen feet of saturated thickness for fifty percent of the aquifer. A pumping scenario of 2.0 (acre-feet/acre)/year resulted in saturated thickness depletion after 37-41 years. Storage was adjusted +/- 10 percent in each scenario and continuous pumping rates reflect this range. Analysis indicated that the temporary state-apportioned pumping rate of 2.0 (acre-feet/acre)/year is not sustainable for more than 41 years if every landowner with a potential well in each acre of the Garber-Wellington Groundwater Basin exercised their temporary right to pump at that rate. The average maximum annual yield is 3,700,480 acre-feet per year and the equal proportionate share is 2.0 (acre-feet/acre)/year.

Summary

1. The total land overlying the basin is 2,891 square miles, or 1,850,240 acres.
2. Estimated storage of groundwater in the basin in 2009 was about 98,676,000 acre-feet.
3. The rate of natural recharge to the basin is 1.84 inches/year.
4. Water rights were established prior to July 1, 1973 for 94,764 acre-feet/year. Total discharge (prior rights) over the 20-year life-of-the-basin is 1,895,280 acre-feet of water.
5. The mean transmissivity of the basin is 1,057 square feet per day.
6. Potential for pollution in the basin includes elevated concentrations of arsenic, chromium, selenium, and uranium due to desorption from solid phase aquifer materials under alkaline conditions. Elevated levels of chloride, fluoride, nitrate, manganese, sulfate and total dissolved solids may also be of concern. Additionally, intrusion of saltwater underlying the aquifer's base of freshwater could pollute the basin.
7. The equal proportionate share ranges from 1.1-5.4 (acre-feet/acre)/year.

References

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Appendix

Parameter	Sample Size	Number of Samples Exceeding MCL	Number of Samples Exceeding SMCL	Number of Samples Exceeding Health Advisory Level	EPA Maximum Contaminant Level (Secondary Maximum Contaminant Level) Health Advisory*
Nitrate	47	1			10 mg/L
Chloride	47		2		(250 mg/L)
Sulfate	47		2		(250 mg/L)
Total Dissolved Solids	47		9		(500 mg/L)
Arsenic	47	1			10 ug/L
Manganese	47		1	1	(50 ug/L) 300 ug/L*
Uranium	47	1			30 ug/L

Table 1-1. Constituents Exceeding EPA Drinking Water Standards from OWRB's *2013 Oklahoma Groundwater Report: Beneficial Use Monitoring Program* (OWRB, 2014)

Metal	Sample Size	Number of Samples Exceeding MCL	Percentage of Samples Exceeding MCL	EPA Maximum Contaminant Level (MCL)
Arsenic	1,495	219	15%	10 ug/L
Chromium	1,373	22	2 %	100 ug/L
Selenium	1,281	96	7.5 %	50 ug/L
Uranium	900	97	11 %	30 ug/L

Table 1-2. Metals Exceeding EPA Drinking Water Standards from OWRB's *Assessment of Distribution of Arsenic, Chromium, Selenium, and Uranium, in Groundwater in the Garber-Wellington Aquifer – Central Oklahoma* (OWRB, 2011)

Physical properties and constituents	Sample Size	Minimum	Percentiles					Maximum	EPA Maximum Contaminant Level (Secondary Maximum Contaminant Level)
			5	25	50	75	95		
Alluvium and Terrace									
Fluoride (mg/L)	42	.10	.10	.20	.30	.50	1.2	3.0	4 mg/L (2 mg/L)
Uranium (ug/L)	42	<.20	.09	.38	1.4	5.2	12	40	30 ug/L
Permian, Shallow Wells (less than 30 meters deep)									
Fluoride (mg/L)	25	<.10	.10	.20	.30	.40	2.2	2.9	4 mg/L (2 mg/L)
Uranium (ug/L)	25	<.20	.02	.21	1.1	8.6	60	69	30 ug/L
Permian, Intermediate Wells (less than 91 meters and greater than 30 meters)									
Fluoride (mg/L)	35	.10	.10	.30	.30	.5	2.9	3.9	4 mg/L (2 mg/L)
Selenium (ug/L)	35	<1	.05	.25	.80	2	29	75	50 ug/L
Uranium (ug/L)	35	<.20	.05	.5	1.0	7.1	130	220	30 ug/L
Permian, Deep Wells (greater than 91 meters)									
Arsenic (ug/L)	27	<1	.11	.71	2	14	86	110	10 ug/L
Chromium (ug/L)	27	<5	1.36	4.11	8	23	84	100	100 ug/L
Selenium (ug/L)	27	<1	.12	.85	3	20	120	150	50 ug/L
Uranium (ug/L)	27	1.0	1.1	2.2	11	25	120	130	30 ug/L

Table 1-3. Constituents Exceeding EPA Drinking Water Standards from USGS Water Supply Paper 2357-A: *Ground-Water-Quality Assessment of the Central Oklahoma Aquifer, Oklahoma: Results of Investigations* (Christensen and Havens, 1998)