GTA Aquifer Assessment 09-01

by Peter G. George, Ph.D., P.G.
Texas Water Development Board
Groundwater Technical Assistance Section
(512) 475-2136

This document is released for the purpose of interim review under the authority of Peter George, P.G. 10344 on February 4, 2010.

Rick Illgner, on behalf of Groundwater Management Area 10.

DESCRIPTION OF REQUEST:

In an email dated 3/13/2009, Mr. Rick Illgner, administrator for GMA 10, requested the Texas Water Development Board (TWDB) to prepare a draft Managed Available Groundwater (MAG) for the Leona Gravel Aquifer in Medina County utilizing any and all TWDB data and information from the October 2002 Phase I Leona Gravel Aquifer Study (Lowry and Couch, 2002), water level data, and current pumping data provided by the Medina County Groundwater Conservation District. The draft MAG is to be based upon the Desired Future Condition.

DESIRED FUTURE CONDITIONS:

Allow average water-level declines in the Leona Gravel Aquifer of 15, 25, and 35 feet over the next 50 years.

METHODS:

A transient hydrologic budget for the saturated portion of an aquifer is described by Freeze and Cherry (1979, p.365):

$$Q(t) = R(t) - D(t) + \frac{dS}{dt}$$

where Q(t)= total rate of groundwater withdrawal
R(t)= total rate of groundwater recharge to the basin
D(t)= total rate of groundwater discharge from the basin
$\frac{dS}{dt}$ = rate of change of storage in the saturated zone of the basin

For this analysis, it is assumed that

$$R(t) = R(r) + R(e)$$

where R(r) = rejected recharge for the basin
R(e) = effective recharge

Effective recharge is the amount of water that enters an aquifer and is available for development (Muller and Price, 1979, p. 5). Rejected recharge is the amount of total (or potential) recharge that discharges from an aquifer because it is over-full and cannot accept more water (Theis, 1940, p.1).

In addition, it is assumed that

$$R(r) \cong D(t)$$

Therefore, the total rate of groundwater withdrawal equals effective recharge plus the change in storage of the aquifer, or

$$Q(t) = R(e) + \frac{dS}{dt}$$

Using ArcGIS 9.2, the boundary of the Leona Gravel Aquifer was determined using the Digital Geologic Atlas of Texas (USGS and TWDB, 2006). The aquifer was divided into three units (Figure 1); unit 1 is the Leona Formation (Qle), unit 2 includes Quaternary Alluvium (Qal), and unit 3 is terrace deposits (Qt). These units were further subdivided by GMA and river basin boundaries. Map areas were calculated for each subdivision (Figure 2).

The average annual precipitation (1971-2000) for each aquifer outcrop map unit (Qle, Qt, and Qal) was determined from the Texas Climatic Atlas (Narasimhan and others, 2008) using zonal statistics in Spatial Analyst (ArcGIS 9.2). The average annual precipitation values were used to calculate annual effective recharge volumes (Table 1).

To determine the annual volume from storage used, the areas were multiplied by the estimated aquifer specific yield, and then by annual drawdown of 0.3, 0.5, and 0.7 feet.

All calculations were done in a Microsoft Excel worksheet (Tables 2 and 3).

PARAMETERS AND ASSUMPTIONS:

- The Leona Gravel Aquifer in Medina County consists of three units; unit 1 is the Leona Formation (Qle), unit 2 includes fluviatile terrace deposits (Qt), and unit 3 is Quaternary Alluvium (Qt).
- Areas in acres for each unit of the aquifer, after being subdivided by GMA and river basin boundaries, were calculated in ArcGIS 9.2 using the 1:250,000 Digital Geological Atlas of Texas (USGS and TWDB, 2006).
- Annual water level declines of 0.3, 0.5, and 0.7 feet were estimated to be uniform across the aquifer.
- Average annual precipitation was used to calculate effective recharge volumes.
- The average annual precipitation for the aquifer area, based on the period of 1971 to 2000, was determined from the Texas Climatic Atlas (Narasimhan and others, 2008).
- Recharge from precipitation is estimated to be 5.5 percent of annual precipitation (Mace and others, 2000; Lowry and Couch, 2002).

- Well reports submitted to the TWDB by drillers from 2003 to 2009 indicate a mean thickness for Leona Gravel Aquifer of about 60 feet.
- Well reports submitted to the TWDB by drillers from 2001 to 2009 indicate a mean thickness for sand and gravel deposits in the aquifer of about 22 feet, with the remainder being mostly clay, or clay with silt and sand.
- Specific yield of the aquifer is estimated to be 0.15 (Johnson, 1967).
- Discharge from the Leona Gravel Aquifer to streams is assumed to be about 15,000 AFY.
- The draft managed available groundwater volume estimates are the sum of the annual effective recharge amount and the annual volume of water depleted from the aquifer based on the draft desired future condition.
- Annual volumes of groundwater taken from storage are calculated by dividing the total volume of depletion, based on the desired future condition, by 50 years.
- Conditions were assumed to be physically possible in the area of interest. It is assumed that water level declines do not exceed aquifer thickness.

RESULTS:

The annual effective recharge estimate for the Leona Gravel Aquifer in Medina County is 27,607 acre-feet per year (Table 1).

The results (Tables 2 through 7) show the draft managed available groundwater estimates for the Leona Gravel Aquifer in Medina County. A 15-foot decline over 50 years results in an estimated annual total volume of 22,110 acre-feet per year. A 25-foot decline over 50 years results in an estimated annual total volume of 28,445 acre-feet per year. A 35-foot decline over 50 years results in an estimated annual total volume of 34,780 acre-feet per year.

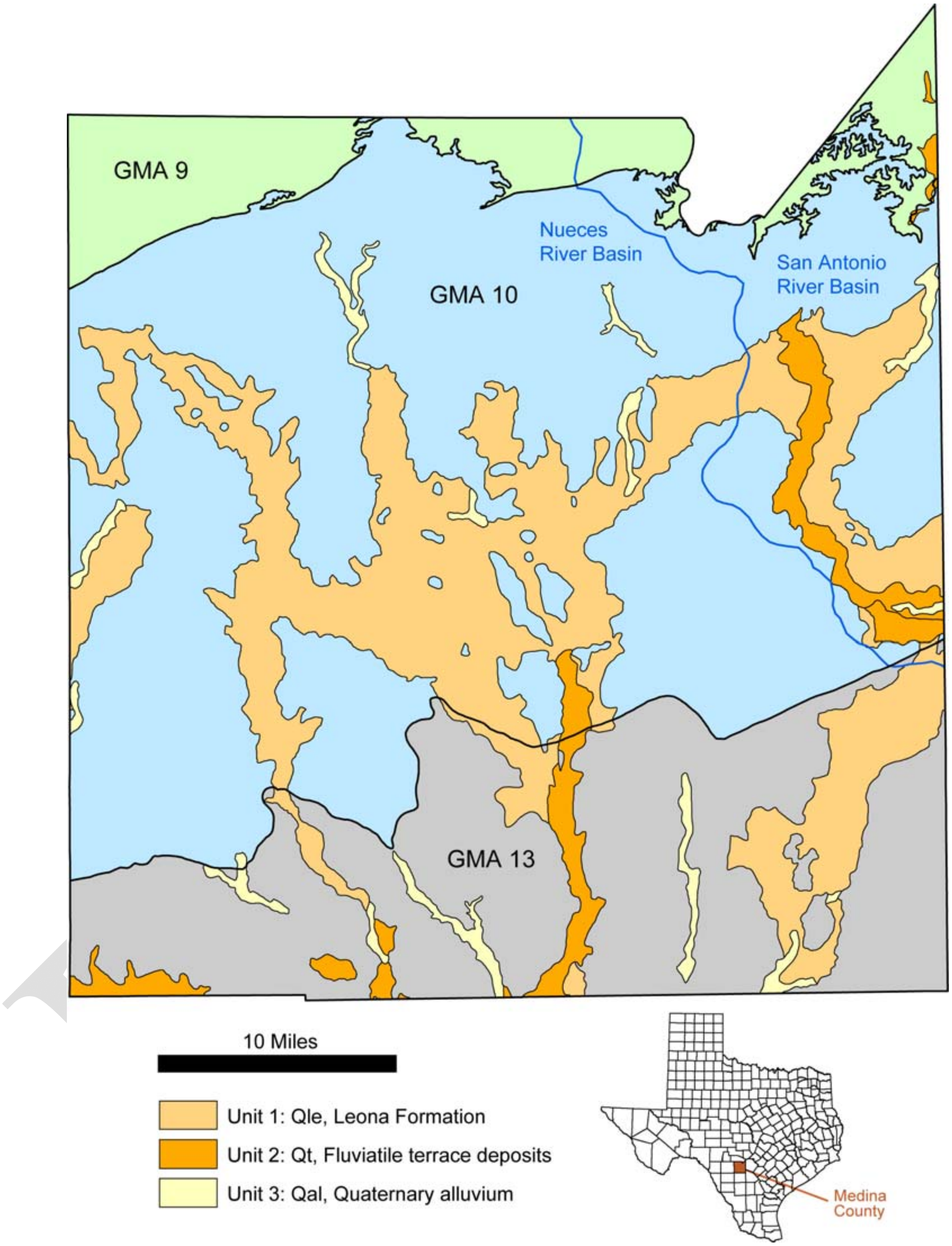

Figure 1. Partial geology of Medina County showing GMA and river basin boundaries.

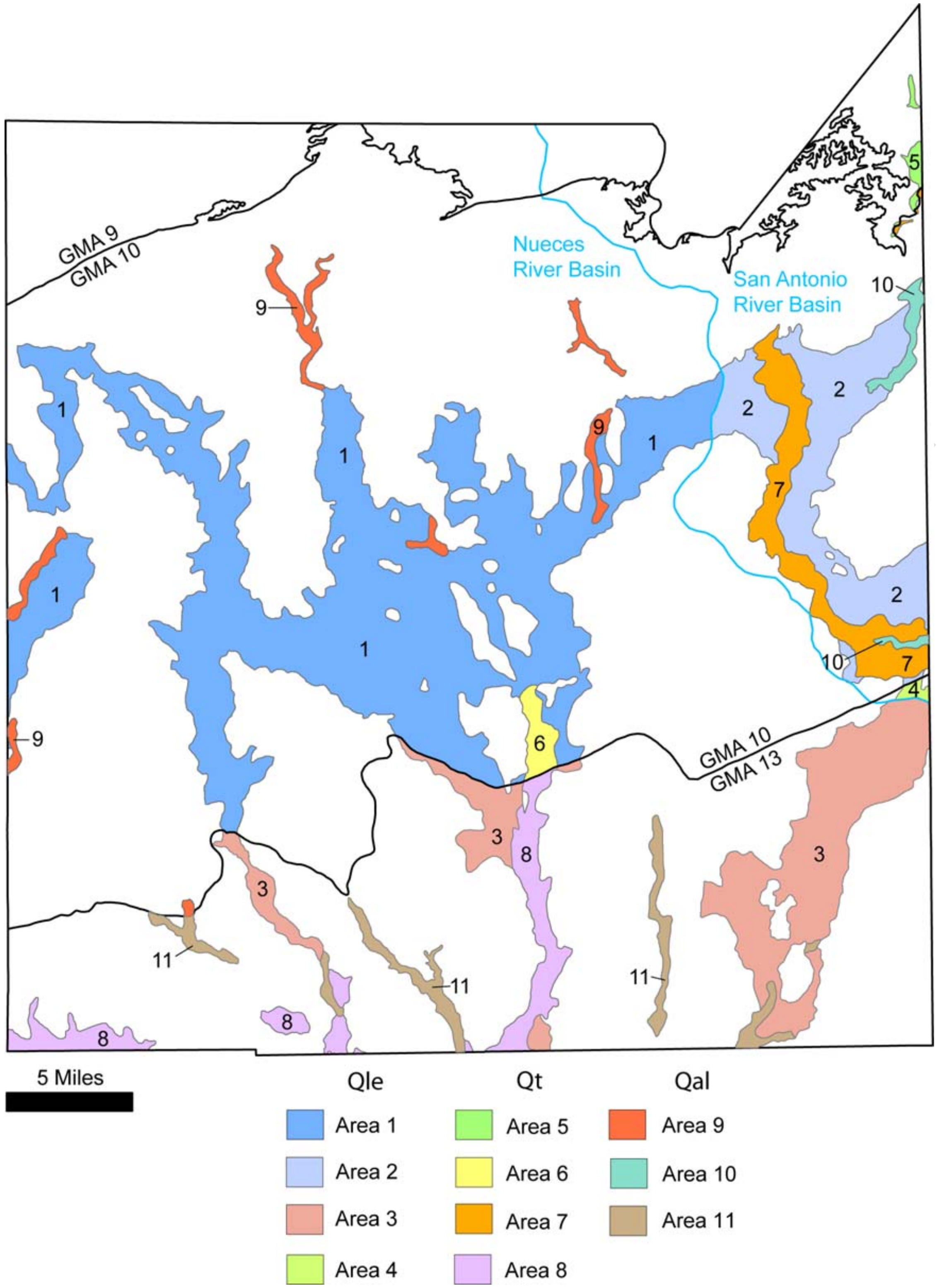

Figure 2. Map areas based on geology, GMA boundaries, and river basins.

Table 1. Estimated total annual recharge volume for the Leona Gravel Aquifer by map area subdivisions (See Figure 2).

GMA	Geologic Unit	County	GCD	River Basin	Map Area	Areal extent (acres)	Average precipitation (inches)	Average precipitation (feet)	Effective recharge rate (percent)	Estimated annual effective recharge (acre-feet)
9	Qle: Leona Fm	Medina	Medina County GCD	N/A	N/A	0	28.55	2.38	5.5	0
10	Qle: Leona Fm	Medina	Medina County GCD	Nueces	1	109896	28.55	2.38	5.5	14,385
10	Qle: Leona Fm	Medina	Medina County GCD	San Antonio	2	24203	28.55	2.38	5.5	3,168
13	Qle: Leona Fm	Medina	Medina County GCD	Nueces	3	34,191	28.55	2.38	5.5	4,476
13	Qle: Leona Fm	Medina	Medina County GCD	San Antonio	4	471	28.55	2.38	5.5	62
9	Qt: Fluviatile terrace deposits	Medina	Medina County GCD	San Antonio	5	882	28.72	2.39	5.5	116
10	Qt: Fluviatile terrace deposits	Medina	Medina County GCD	Nueces	6	2,124	28.72	2.39	5.5	279
10	Qt: Fluviatile terrace deposits	Medina	Medina County GCD	San Antonio	7	12,061	28.72	2.39	5.5	1,585
13	Qt: Fluviatile terrace deposits	Medina	Medina County GCD	Nueces	8	11,869	28.72	2.39	5.5	1,560
9	Qal: Alluvium	Medina	Medina County GCD	N/A	N/A	0	27.81	2.32	5.5	0
10	Qal: Alluvium	Medina	Medina County GCD	Nueces	9	6,102	27.81	2.32	5.5	779
10	Qal: Alluvium	Medina	Medina County GCD	San Antonio	10	2,010	27.81	2.32	5.5	256
13	Qal: Alluvium	Medina	Medina County GCD	Nueces	11	7,369	27.81	2.32	5.5	940
									Total:	**27,607**

Table 2. Estimates of draft managed available groundwater for the Leona Gravel Aquifer by map area subdivisions, based on an annual drawdown of 0.3 feet for 50 years, 15 feet total (see Figure 1).

Geologic Unit	Map Area	GMA	River Basin	Areal extent (acres)	Year	Specfic Yield	Annual Drawdown (feet)	Estimated annual volume from storage (acre-feet)	Estimated annual effective recharge (acre-feet)	Estimated annual discharge to streams (acre-feet)	Estimated annual total volume (acre-feet)*
Qle: Leona Fm	N/A	9	N/A	0	2010	0.15	0.3	0	0	0	0
Qle: Leona Fm	1	10	Nueces	109,896	2010	0.15	0.3	4,945	14,385	7,806	11,525
Qle: Leona Fm	2	10	San Antonio	24,203	2010	0.15	0.3	1,089	3,168	1,719	2,538
Qle: Leona Fm	3	13	Nueces	34,191	2010	0.15	0.3	1,539	4,476	2,429	3,586
Qle: Leona Fm	4	13	San Antonio	471	2010	0.15	0.3	21	62	33	49
Qt: Fluviatile terrace deposits	5	9	San Antonio	882	2010	0.15	0.3	40	116	63	93
Qt: Fluviatile terrace deposits	6	10	Nueces	2,124	2010	0.15	0.3	96	279	151	224
Qt: Fluviatile terrace deposits	7	10	San Antonio	12,061	2010	0.15	0.3	543	1,585	857	1,271
Qt: Fluviatile terrace deposits	8	13	Nueces	11,869	2010	0.15	0.3	534	1,560	843	1,251
Qal: Alluvium	N/A	9	N/A	0	2010	0.15	0.3	0	0	0	0
Qal: Alluvium	9	10	Nueces	6,102	2010	0.15	0.3	275	779	433	620
Qal: Alluvium	10	10	San Antonio	2,010	2010	0.15	0.3	90	256	143	204
Qal: Alluvium	11	13	Nueces	7,369	2010	0.15	0.3	332	940	523	749
								9,503	**27,607**	**15,000**	**22,110**
					(2011 to 2060: same numbers each year)						
* Managed Available Groundwater (MAG)					**50 year period totals:**			**475,148**	**1,380,338**	**750,000**	**1,105,486**

The estimated total annual effective recharge volume for the Leona Gravel Aquifer by map areas is from Table 1. The formulas for this table are: specific yield * areal extent * annual drawdown = estimated annual volume from storage. The estimated annual volume from storage + estimated annual effective recharge – estimated annual discharge to streams = estimated annual total volume.

Table 3. Estimates of draft managed available groundwater for the Leona Gravel Aquifer by GMA for an annual drawdown of 0.3 feet, 15 feet total (see Figure 1).

GMA	River Basin	Geologic Unit	Estimated annual effective recharge (acre-feet)	Estimated annual volume from storage (acre-feet)	Estimated annual discharge to streams (acre-feet)	MAG Estimated annual total volume (acre-feet)*
9	San Antonio	Qt: Fluviatile terrace deposits	116	40	63	93
		Unit Totals:	**116**	**40**	**63**	**93**
10	Nueces	Qle: Leona Fm	14,385	4,945	7,806	11,525
10	San Antonio	Qle: Leona Fm	3,168	1,089	1,719	2,538
10	Nueces	Qt: Fluviatile terrace deposits	279	96	151	224
10	San Antonio	Qt: Fluviatile terrace deposits	1,585	543	857	1,271
10	Nueces	Qal: Alluvium	779	275	433	620
10	San Antonio	Qal: Alluvium	256	90	143	204
		Unit Totals:	**20,453**	**7,038**	**11,109**	**16,382**
13	Nueces	Qle: Leona Fm	4,476	1,539	2,429	3,586
13	San Antonio	Qle: Leona Fm	62	21	33	49
13	Nueces	Qt: Fluviatile terrace deposits	1,560	534	843	1,251
13	Nueces	Qal: Alluvium	940	332	523	749
		Unit Totals:	**7,038**	**2,426**	**3,829**	**5,635**
		Total (All Units):	**27,607**	**9,503**	**15,000**	**22,110**

Table 4. Estimates of draft managed available groundwater for the Leona Gravel Aquifer by map area subdivisions, based on an annual drawdown of 0.5 feet over 50 years, 25 feet total (see Figure 1).

Geologic Unit	Map Area	GMA	River Basin	Areal extent (acres)	Year	Specfic Yield	Annual Drawdown (feet)	Estimated annual volume from storage (acre-feet)	Estimated annual effective recharge (acre-feet)	Estimated annual discharge to streams (acre-feet)	Estimated annual total volume (acre-feet)*
Qle: Leona Fm	N/A	9	N/A	0	2010	0.15	0.5	0	0	0	0
Qle: Leona Fm	1	10	Nueces	109,896	2010	0.15	0.5	8,242	14,385	7,806	14,822
Qle: Leona Fm	2	10	San Antonio	24,203	2010	0.15	0.5	1,815	3,168	1,719	3,264
Qle: Leona Fm	3	13	Nueces	34,191	2010	0.15	0.5	2,564	4,476	2,429	4,611
Qle: Leona Fm	4	13	San Antonio	471	2010	0.15	0.5	35	62	33	64
Qt: Fluviatile terrace deposits	5	9	San Antonio	882	2010	0.15	0.5	66	116	63	119
Qt: Fluviatile terrace deposits	6	10	Nueces	2,124	2010	0.15	0.5	159	279	151	288
Qt: Fluviatile terrace deposits	7	10	San Antonio	12,061	2010	0.15	0.5	905	1,585	857	1,633
Qt: Fluviatile terrace deposits	8	13	Nueces	11,869	2010	0.15	0.5	890	1,560	843	1,607
Qal: Alluvium	N/A	9	N/A	0	2010	0.15	0.5	0	0	0	0
Qal: Alluvium	9	10	Nueces	6,102	2010	0.15	0.5	458	779	433	803
Qal: Alluvium	10	10	San Antonio	2,010	2010	0.15	0.5	151	256	143	264
Qal: Alluvium	11	13	Nueces	7,369	2010	0.15	0.5	553	940	523	970
								15,838	**27,607**	**15,000**	**28,445**
					(2011 to 2060: same numbers each year)						
* Managed Available Groundwater (MAG)					**50 year period totals:**			**791,913**	**1,380,338**	**750,000**	**1,422,251**

The estimated total annual effective recharge volume for the Leona Gravel Aquifer by map areas is from Table 1. The formulas for this table are: specific yield * areal extent * annual drawdown = estimated annual volume from storage. The estimated annual volume from storage + estimated annual effective recharge – estimated annual discharge to streams = estimated annual total volume.

Table 5. Estimates of draft managed available groundwater for the Leona Gravel Aquifer by GMA for an annual drawdown of 0.5 feet, 25 feet total (see Figure 1).

GMA	River Basin	Geologic Unit	Estimated annual effective recharge (acre-feet)	Estimated annual volume from storage (acre-feet)	Estimated annual discharge to streams (acre-feet)	MAG Estimated annual total volume (acre-feet)*
9	San Antonio	Qt: Fluviatile terrace deposits	116	66	63	119
		Unit Totals:	**116**	**66**	**63**	**119**
10	Nueces	Qle: Leona Fm	14,385	8,242	7,806	14,822
10	San Antonio	Qle: Leona Fm	3,168	1,815	1,719	3,264
10	Nueces	Qt: Fluviatile terrace deposits	279	159	151	288
10	San Antonio	Qt: Fluviatile terrace deposits	1,585	905	857	1,633
10	Nueces	Qal: Alluvium	779	458	433	803
10	San Antonio	Qal: Alluvium	256	151	143	264
		Unit Totals:	**20,453**	**11,730**	**11,109**	**21,074**
13	Nueces	Qle: Leona Fm	4,476	2,564	2,429	4,611
13	San Antonio	Qle: Leona Fm	62	35	33	64
13	Nueces	Qt: Fluviatile terrace deposits	1,560	890	843	1,607
13	Nueces	Qal: Alluvium	940	553	523	970
		Unit Totals:	**7,038**	**4,043**	**3,829**	**7,252**
		Total (All Units):	**27,607**	**15,838**	**15,000**	**28,445**

Table 6. Estimates of draft managed available groundwater for the Leona Gravel Aquifer by map area subdivisions, based on an annual drawdown of 0.7 feet over 50 years, 35 feet total (see Figure 1).

Geologic Unit	Map Area	GMA	River Basin	Areal extent (acres)	Year	Specfic Yield	Annual Drawdown (feet)	Estimated annual volume from storage (acre-feet)	Estimated annual effective recharge (acre-feet)	Estimated annual discharge to streams (acre-feet)	Estimated annual total volume (acre-feet)*
Qle: Leona Fm	N/A	9	N/A	0	2010	0.15	0.7	0	0	0	0
Qle: Leona Fm	1	10	Nueces	109,896	2010	0.15	0.7	11,539	14,385	7,806	18,118
Qle: Leona Fm	2	10	San Antonio	24,203	2010	0.15	0.7	2,541	3,168	1,719	3,990
Qle: Leona Fm	3	13	Nueces	34,191	2010	0.15	0.7	3,590	4,476	2,429	5,637
Qle: Leona Fm	4	13	San Antonio	471	2010	0.15	0.7	49	62	33	78
Qt: Fluviatile terrace deposits	5	9	San Antonio	882	2010	0.15	0.7	93	116	63	146
Qt: Fluviatile terrace deposits	6	10	Nueces	2,124	2010	0.15	0.7	223	279	151	351
Qt: Fluviatile terrace deposits	7	10	San Antonio	12,061	2010	0.15	0.7	1,266	1,585	857	1,995
Qt: Fluviatile terrace deposits	8	13	Nueces	11,869	2010	0.15	0.7	1,246	1,560	843	1,963
Qal: Alluvium	N/A	9	N/A	0	2010	0.15	0.7	0	0	0	0
Qal: Alluvium	9	10	Nueces	6,102	2010	0.15	0.7	641	779	433	986
Qal: Alluvium	10	10	San Antonio	2,010	2010	0.15	0.7	211	256	143	325
Qal: Alluvium	11	13	Nueces	7,369	2010	0.15	0.7	774	940	523	1,191
								22,174	**27,607**	**15,000**	**34,780**
					(2011 to 2060: same numbers each year)						
* Managed Available Groundwater (MAG)					**50 year period totals:**			**1,108,678**	**1,380,338**	**750,000**	**1,739,016**

The estimated total annual effective recharge volume for the Leona Gravel Aquifer by map areas is from Table 1. The formulas for this table are: specific yield * areal extent * annual drawdown = estimated annual volume from storage. The estimated annual volume from storage + estimated annual effective recharge – estimated annual discharge to streams = estimated annual total volume.

Table 7. Estimates of draft managed available groundwater for the Leona Gravel Aquifer by GMA for an annual drawdown of 0.7 feet, 35 feet total (see Figure 1).

GMA	River Basin	Geologic Unit	Estimated annual effective recharge (acre-feet)	Estimated annual volume from storage (acre-feet)	Estimated annual discharge to streams (acre-feet)	MAG Estimated annual total volume (acre-feet)*
9	San Antonio	Qt: Fluviatile terrace deposits	116	93	63	146
		Unit Totals:	**116**	**93**	**63**	**146**
10	Nueces	Qle: Leona Fm	14,385	11,539	7,806	18,118
10	San Antonio	Qle: Leona Fm	3,168	2,541	1,719	3,990
10	Nueces	Qt: Fluviatile terrace deposits	279	223	151	351
10	San Antonio	Qt: Fluviatile terrace deposits	1,585	1,266	857	1,995
10	Nueces	Qal: Alluvium	779	641	433	986
10	San Antonio	Qal: Alluvium	256	211	143	325
		Unit Totals:	**20,453**	**16,421**	**11,109**	**25,766**
13	Nueces	Qle: Leona Fm	4,476	3,590	2,429	5,637
13	San Antonio	Qle: Leona Fm	62	49	33	78
13	Nueces	Qt: Fluviatile terrace deposits	1,560	1,246	843	1,963
13	Nueces	Qal: Alluvium	940	774	523	1,191
		Unit Totals:	**7,038**	**5,660**	**3,829**	**8,869**
		Total (All Units):	**27,607**	**22,174**	**15,000**	**34,780**

LIMITATIONS:

Additional data are needed to create improved estimates; these estimates are a basic interpretation of the requested conditions. This analysis assumes homogeneous and isotropic aquifers; however, conditions for the Leona Gravel Aquifer may not behave in a uniform manner. There is uncertainty with respect to the distribution of the sand and gravel in the aquifer (Lowry and Couch, 2002; Green, 2003). The analysis further assumes that precipitation is the only source of aquifer recharge and that lateral inflow to the aquifer is equal to lateral outflow from the aquifer, and that future pumping will not alter this balance.

Discharge and recharge from other aquifers, such as the Edwards BFZ aquifer, are unknown as is recharge from streams. Discharge to streams from the Leona Gravel Aquifer is assumed to be 15,000 acre-feet per year, but this number needs to be investigated with gain-loss streamflow assessment research. The recharge rate is also a rough estimate as is the specific yield.

Note that estimates of managed available groundwater are based on the best available scientific tools that can be used to develop managed available groundwater and that these estimates can be a function of assumptions made on the magnitude and distribution of pumping in the aquifer. Therefore, it is important for groundwater conservation districts to monitor whether or not they are achieving their desired future conditions and to work with the TWDB to refine managed available groundwater given the reality of how the aquifer responds to the actual magnitude and distribution of pumping now and in the future.

REFERENCES:

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice Hall, Inc., 604.

Green, R.T., 2003, Geophysical survey to determine the depth and lateral extent of the Leona Aquifer in the Leona river floodplain, south of Uvalde, Texas: Prepared for the Edwards Aquifer Authority by the Southwest Research Institute, 21 p.

Johnson, A.I. 1967. Specific yield — compilation of specific yields for various materials. U.S. Geological Survey Water Supply Paper 1662-D. 74 p.

Lowry, M.V., and Couch, B. E., 2002, Phase I Leona Gravel Aquifer Study: Prepared for the Medina County Groundwater Conservation District by Turner Collie & Braden Inc., 51 p.

Mace, R.E., Chowdhury, A.H., Anaya, R., and Way, S.-C., 2000, Groundwater availability of the Trinity Aquifer Hill County, Texas: Texas Water Development Board, Report 353, 117 p.

Muller, D. A. and Price, R. D., 1979, Ground-water availability in Texas, estimates and projections through 2030: Texas Department of Water Resources Report 238, 77 p.

Narasimhan, B., Srinivasan, R., Quiring, S., and Nielsen-Gammon, J.W., 2008, Digital Climatic Atlas of Texas: Texas A&M University, Texas Water Development Board Contract, Report 2005-483-5591, 108p.

Theis, C.V., 1940, The source of water derived from wells: Essential factors controlling the response of an aquifer to development: Civil Engineering 10, pp.277-280.

USGS and TWDB, 2006, Digital Geologic Atlas of Texas: U.S. Geological Survey and Texas Water Development Board, available through the Texas Natural Resources Information System.