Final Report

Brazos River Alluvium Aquifer Quantity and Quality Assessment Of McLennan County, Texas

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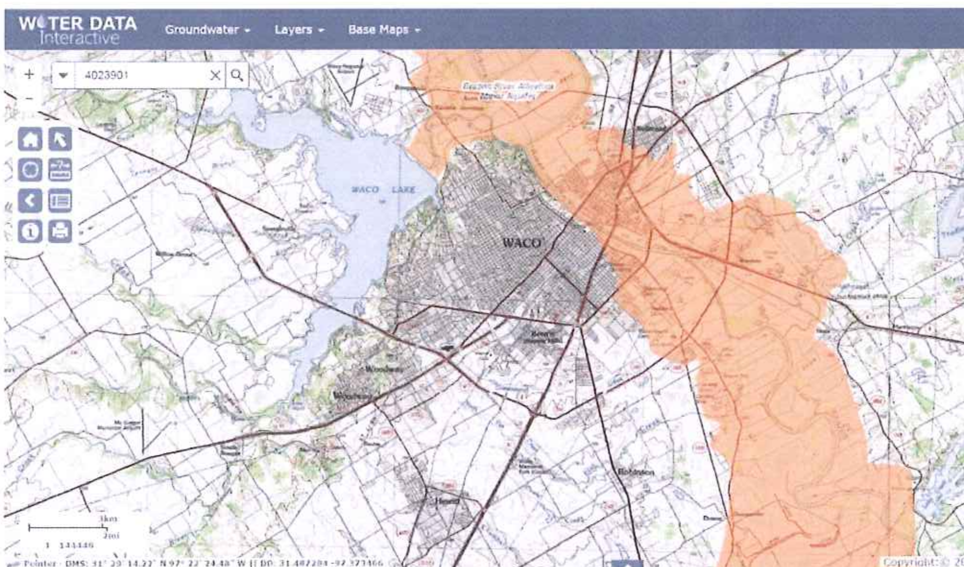
Tuesday, September 12, 2017



Brazos River Alluvium Aquifer in McLennan County

Key Report Findings

- Quantity: 14,000 acre-feet of practical production with deductions and static interpretation of current DFC.
- Quality: 556 mg/l median and 668 mg/l mean Total Dissolved Solids, fresh water, useable for irrigation and non-potable uses. Drinking water may need treatment.
- Sustainable aquifer recharged by rainfall.
- Saturated thickness (volume) fluctuates seasonally and due to droughts.
- Highly variable production by location.

Contents

Executive Summary

The quantity of groundwater in the Brazos River alluvium aquifer is about 14,000 acre-feet with landuse and low water yielding sediment deductions plus current static interpretation of the desired future condition. The groundwater quality as determined with total dissolved solids is fresh water, useable for irrigation and non-potable uses whereas, drinking water use may need treatment. The quantity of groundwater is sustainable due to rainfall recharging the unconfined aquifer. However, the aquifer saturated thickness and volume does fluctuate due to low rainfall periods during seasons or droughts. The groundwater production varies greatly from site-to-site across the alluvium aquifer. Hence the only way to verify local groundwater production is by pumping and measuring well yields. The results and conclusions of this report were based primarily on Texas Water Development Board wells and geotechnical borings.

Introduction

Acknowledgements

Many people assisted in the development of this research. The following people were instrumental in supporting this work: Jim Forte, with Brazos River Authority, Scooter Radcliffe with the Southern Trinity Groundwater Conservation District (STGCD), and landowners. Without Mr. Forte, Mr. Radcliffe and landowner interest and assistance this work would have not been possible. Also, the STGCD Board was key in supporting this research to assess a possibly under-utilized water resource of McLennan County.

Bob Wallace, of Wallace Engineering, provide some of the earliest encouragement to develop the Brazos River Alluvium (BRAA). Mr. Wallace's support included the first financial assistance to start the BRAA research. Also when interviewed about possible research topics that needed to be addressed, Johnny Tabor encouraged Baylor researchers to take another look at the BRAA as an underutilized water resource. Furthermore, Dr. Joe Yelderman with Baylor University, supervised student research which played a role in providing a foundation for this work.

The research was conducted under contract with the Southern Trinity Groundwater Conservation District. The Brazos River Authority provided matching funding to provide significant funding for the project.

Background

This report focuses on the BRAA of McLennan County that contains groundwater managed by the STGCD.

The purpose of the report is to assess the quantity and quality of the Brazos River Alluvium Aquifer groundwater in McLennan County. This is a simple work scope but providing scientific based answers to the quantity and quality of this aquifer is a technical challenge.

The primary data source was the Texas Water Development Board's web-based data. Additional data and aquifer understanding were obtained from the Southern Trinity Groundwater Conservation District and Baylor's MS theses.

Previous Works

One of the earliest and seminal works of the Brazos River Alluvium aquifer was conducted by Cronin and Wilson (1967). Their report includes the entire alluvial aquifer from the Whitney Dam to Richmond, Texas. Cronin and Wilson (1967) provide well-documented baseline hydrogeological data and understanding.

Epps (1973) utilized field data, flow records and topographic map analysis that described the depositional history and composition of the floodplain plus terrace sediments associated with the entire Brazos River basin. Epps (1973) is an important resource to understand sedimentary environments providing groundwater movement insight.

Harlan (1985) conducted a study of the BRAA from Waco to Marlin and described groundwater in the Brazos River alluvium flow toward the river and slightly down river. He also evaluated several well hydrographs in relation to rainfall with data from 1960 to 1980 and concluded the water level fluctuated but showed no trends of declining.

An overview of the alluvial basin aquifer hydrogeochemistry is Harlan (1990). Harlan's study area was from Waco's low water dam to the Falls of The Brazos State Park near Marlin. This work provides a summary of the alluvium hydrogeology with an emphasis on groundwater chemistry. Harlan (1990) noted the water to be predominately calcium bicarbonate with quality variability due to mineralogical differences and possibly residence time.

Pinkus (1987) evaluated the contamination potential at three solid waste disposal sites. The groundwater chemistry in up-gradient and down-gradient wells at Brazos Alluvium waste disposal sites suggest the water quality down-gradient may have been affected.

Wong (2012) studied the Brazos River Alluvium Aquifer in Bosque, Hill, McLennan and Falls counties. Aquifer thickness was determined from wells and borehole data where well depth was considered to be a proxy for aquifer thickness.

Ju (2014) studied the effects of native and foreign materials used to fill mining pits occurring in the BRAA. Ju (2014) characterized the fill materials by identifying their physical and chemical properties and how they may affect the aquifer. Results indicated that native fill materials are usually less hydraulically conductive than the original sediments.

Ewing and others (2016) prepared the current BRAA Groundwater Availability Model (GAM). The GAM correlates a compilation of studies that describe the aquifer's stratigraphy, measured water levels, groundwater flow, recharge and discharge dynamics, and water quality. Ewing and others (2016) provide modeled estimates of groundwater availability for the BRAA on a per county basis and aquifer recharge calculations pre- and post-1950.

Hydrogeology

The Brazos River Alluvium aquifer is comprised of gravel-sand-silt-and clay-sized sediments deposited by the Brazos River. Generally, the coarser sediments (sands and gravel) are near the bottom of the alluvium and the finer sediments (silts and clays) are near the top. However, coarse sediments are not found in all areas of the alluvium. Throughout McLennan County the alluvial sediments are underlain by Cretaceous aged bedrock formations that act as a confining layer at the bottom of BRAA. The top of the alluvium is the land surface and alluvial thickness varies throughout the county but is commonly 20-50 feet thick. The lower portion (roughly about half) of the alluvium is saturated forming an unconfined aquifer or water table aquifer. The water table is the top of the saturated zone and also the top of the aquifer. The bottom of the aquifer is fixed but the top of the aquifer (the water table) fluctuates with wet and dry periods. The "seasonal" fluctuations are due to areal recharge from local rainfall and discharge to the Brazos River and some of the major tributaries. Other forms of recharge, may include overbank flow during floods and lateral flow from fractured bedrock along the alluvium boundaries. Additional discharge occurs from pumping, transpiration from plants, and evaporation from pit lakes that intersect the water table. The groundwater in the BRAA generally flows toward the Brazos River and slightly downstream (Cronin and Wilson 1967, Harlan 1986). The dynamics of the temporal and spatial processes in the BRAA are not well documented at this time.

Quantity

The Groundwater Availability Model (GAM) by Shi and others (2014) and TWDB Report 41 by Cronin and Wilson (1967) contain estimates of groundwater quantity in the BRAA. In addition, to these two reports Baylor calculated the volume of groundwater using ArcMap independently, a Geographic Information System. The three volume methods were compared to obtain a better understanding of available groundwater quantity (Figure 1).

Figure 1. Diagram illustrates the process used to estimate groundwater quantity in the BRAA in McLennan County.

GAM

This section describes the GAM Task 13-031 (Shi, and others, 2014) to estimate the total recoverable storage for aquifers in Groundwater Management Area 8. The Texas Water Code 36.108 requires that the TWDB provide the total estimated recoverable storage (TERS) for all aquifers in a groundwater management area to aid in the groundwater conservation district efforts to develop Desired Future Conditions (DFC). The GAM Task 13-031 includes total estimated recoverable storage for the Brazos River Alluvium aquifer in McLennan County.

To estimate the recoverable aquifer storage, the total storage of the aquifer within the official aquifer boundary is calculated first. This total storage is the groundwater volume that would be removed by completely draining the aquifer.

The equation used to calculate total storage is:

Total Storage = Official aquifer area x Saturated Thickness x Specific Yield

The GAM methodology is:

- BRAA is at water table or unconfined conditions at most places (George and others 2011)
- The aquifer thickness was obtained from Shah and Houston (2007)
- The average depth to water was from the TWDB groundwater database

- Alluvium thickness averages were calculated using zonal statistics from Esri ArcGIS 10.1
- Average saturated thickness was determined by ArcGIS from average alluvium thickness subtracting the average water depth
- The specific yield of 0.15 was obtained from Cronin and Wilson (1967)

Table 1. GAM Task 13-031 showing total storage, 25 percent and 75 percent of total storage.

County	Total Storage (acre-feet)	25 percent of Total Storage (acre-feet)	75 percent of Total Storage (acre-feet)
McLennan	90,000	22,500	67,500

Report 41

This portion of the report describes the Cronin and Wilson (1967) estimate of the BRAA in McLennan County. On pages 70 and 71 the estimated the ground water stored in the floodplain alluvium in the spring of 1963 is shown. The report methodology used to estimate floodplain alluvium groundwater was based on an assumed specific yield of 15 percent and saturated thickness from individual wells or test holes in McLennan County. Cronin and Wilson (1967) reported the following volume of water in storage for McLennan County:

Table 2. Cronin and Wilson, (1967) reported volume of water in storage for BRAA in McLennan County.

County	Total Storage (acre-feet)
McLennan	112,000

Baylor GIS

Baylor used ArcMap 10.3, a Geographic Information System (GIS), to determine the volume of water in the aquifer. The first task was to determine the bottom and top of the alluvium aquifer. Different datasets were evaluated that are found on the TWDB web site. Data from TWDB Groundwater Database was determined to be the most complete with lithology and/or water level measurements. The elevation of the bottom and top of the aquifer was determined for each location. The point data were used to generate inverse distance interpolated elevation surfaces of the bottom and top of aquifer. The aquifer bottom and top elevation surfaces plus the side edge boundary were used to calculate the total volume. Once the total aquifer volume was determined the alluvium specific yield and desired future conditions were used to refine the available groundwater volume.

All well and borehole data from TWDB database were used in order to have adequate spatial data to contour the water table and bottom of aquifer surfaces. No seasonality was selected. Where multiple readings were available, the first reading was used. The reason of using all the data no matter the season was to have adequate spatial data to contour the water table and bottom of aquifer surfaces so volume calculations be made. The 130 data points use to calculate the volume of groundwater are shown spatially in Figure 2.

Figure three is an isopach map of saturated thickness in the BRAA in McLennan County. The map shows the saturated thickness is generally greater in southern McLennan County. Also for the northern portion of the county, the northeast side of the alluvial valley is thicker than the southwest side.

Table 3. Baylor GIS calculated total water storage.

Total Saturated Volume (Cubic Feet)	Specific Yield (dimensionless)	Total Recoverable/Production Volume (Acre-Feet)
4.266×10^{10}	**0.15**	**149,577**

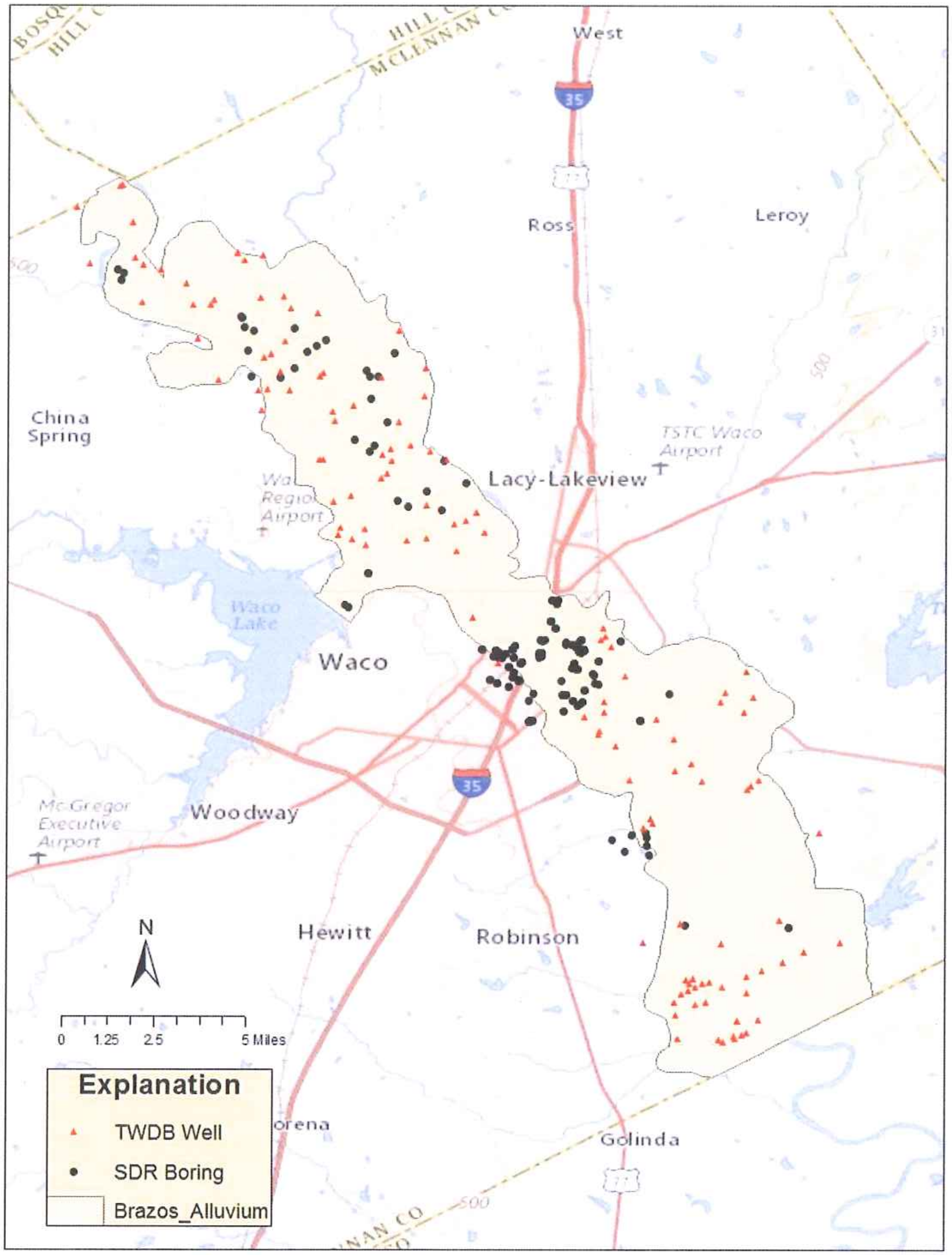


Figure 2. TWDB wells and borings used to calculate the groundwater volume.

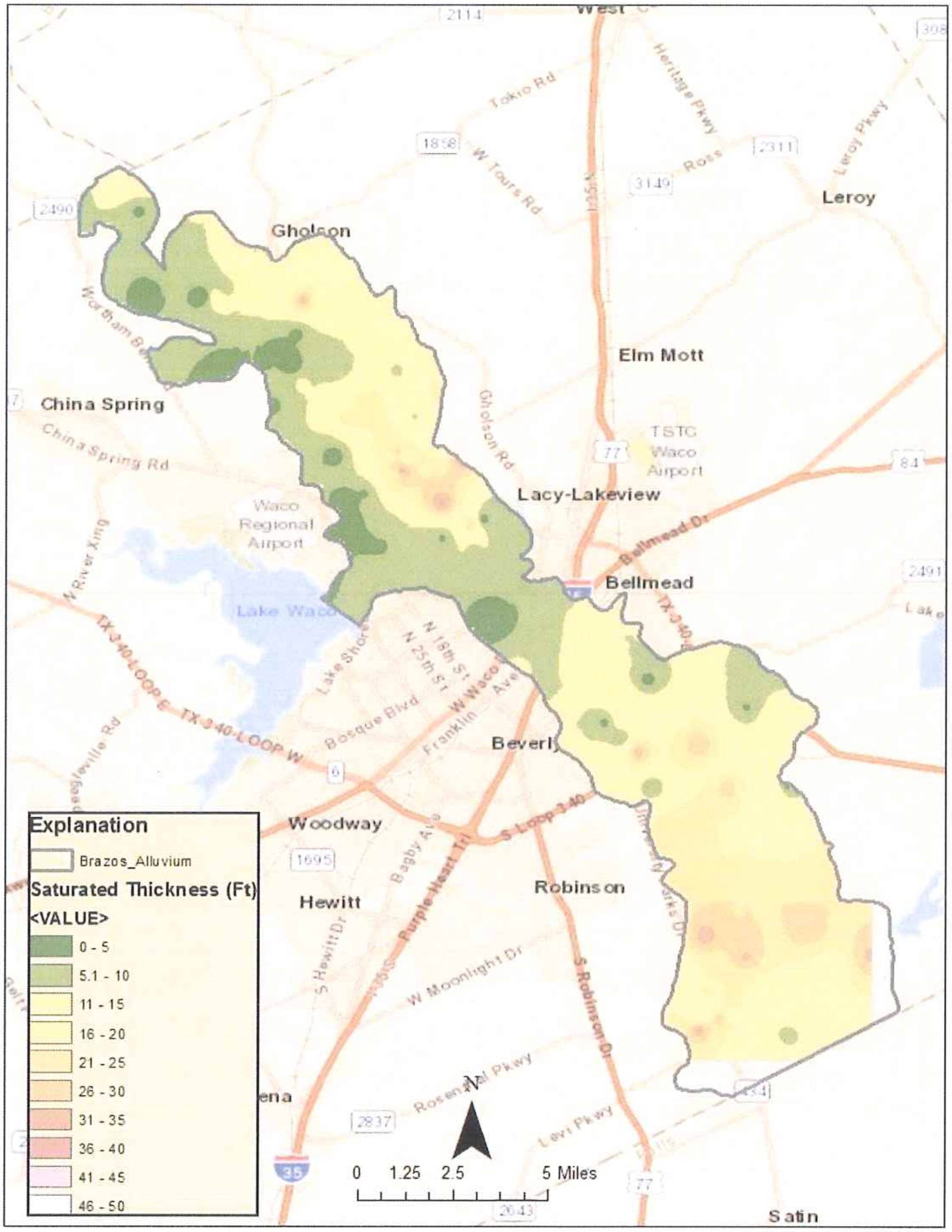


Figure 3. Saturated thickness map.

Figure 4 is a hydrograph for an alluvial well showing the range of saturated thickness measured annually for over 50 years. The range in saturated thickness coupled with variability measured in a long range hydrograph provides an understanding of the potential variability in the total volume calculations. The last value in the hydrograph shows how the aquifer can recover quickly when recharged. Note this is only one well.

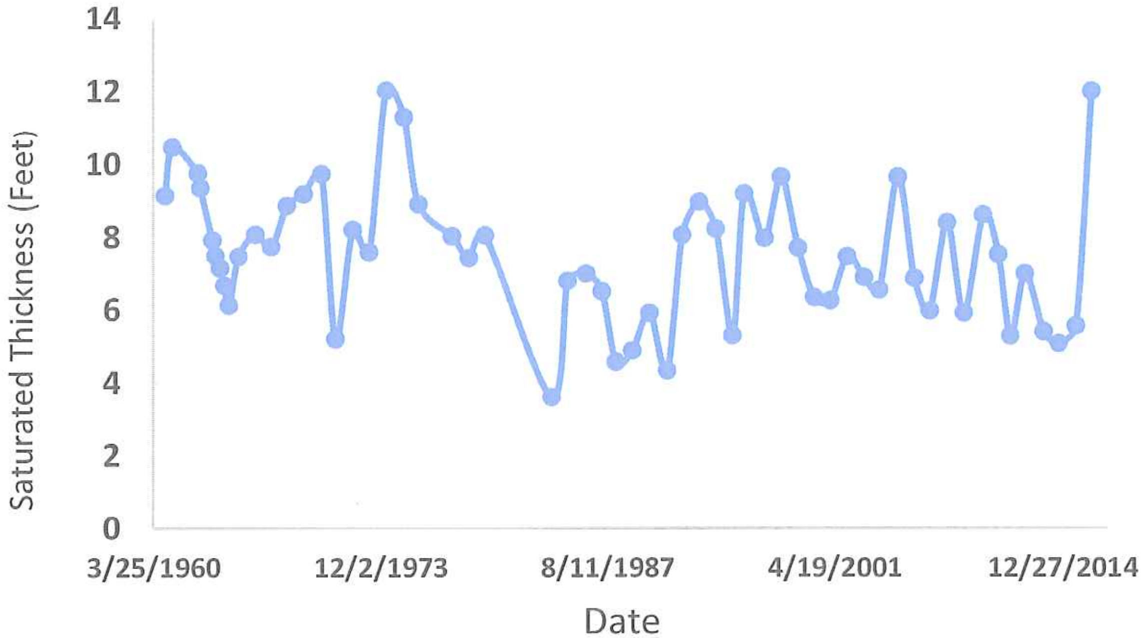


Figure 4. Saturated thickness variability in Well 40-23-801 from 1960 to 2016.

Deductions

Introduction

This section describes the conceptual basis for removing portions of the aquifer volume in order to achieve a more practical or useable volume. Although there may be 149,000 acre-feet of saturated section in the McLennan County Brazos River alluvium, not all of the aquifer is readily usable. In order to assess the practical or feasible potential of the aquifer it is necessary to reduce the total volume to a more practical number that represents the usable portion. There were three major categories used to reduce the total aquifer volume to a more practical aquifer volume. One category was based on the "landuse" where conditions or activities could affect use of the entire aquifer thickness and these areas were totally removed from volume calculation using their surface area footprint. The other category was "production potential" which affected a portion of the vertically oriented saturated thickness and was based on sediment grain size and its anticipated effect to produce water using a well transmissivity. Once the non-productive and the practically unusable portions were removed from the total volume, the remaining is the usable quantity. The BRAA is managed by STGCD therefore the current DFC was the final volume deduction.

Figures 5a and 5b depicts the methodology to reduce the total storage and calculate a practical storage. This approach provides a logical approach to volume reductions, instead of using total storage or arbitrary reduction percentages.

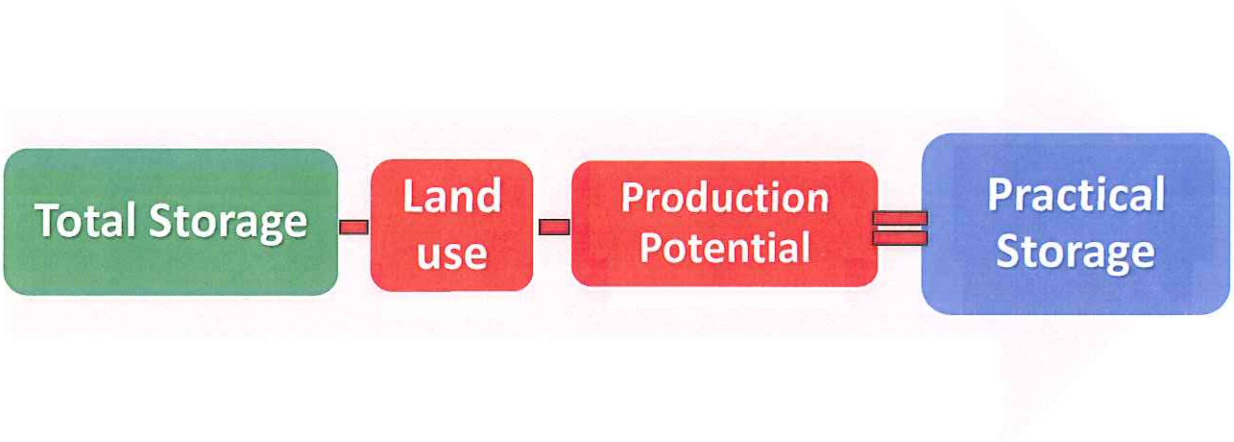


Figure 5a

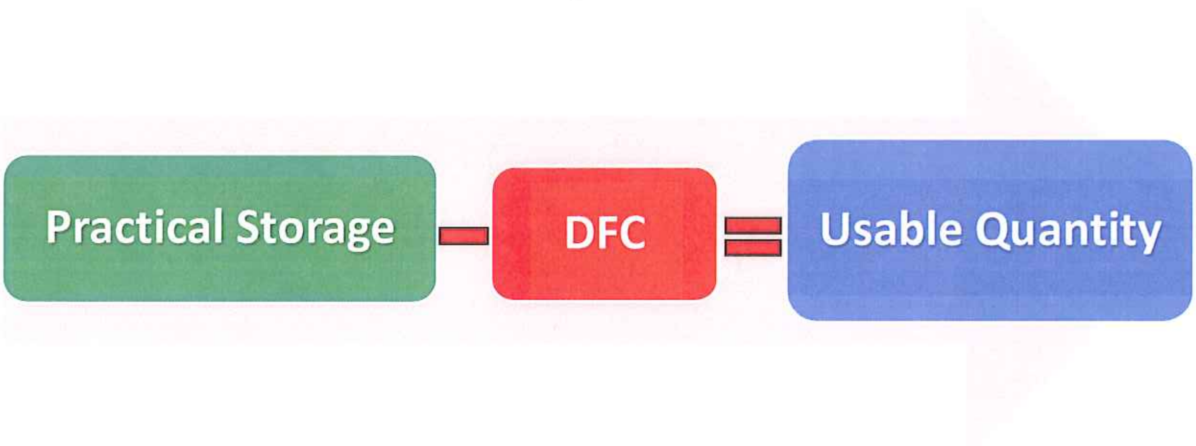


Figure 5b

Figure 5a and 5b. Practical storage and useable quantity: total storage minus landuse and production potential. Then practical storage minus DFC to equal usable quantity.

Landuse

The USGS landuse classifications were used as the data source for landuse. The following classifications were considered unusable; water, wetlands, and developed land. In addition, areas where solid waste was known to be buried were designated as "landfills" and removed along with additional acreage immediately around the landfill as a buffer or precautionary zone. The reasons for eliminating these areas are as follows.

Wetlands – wetlands are not a practical location to drill or maintain a well. Wetlands are usually located in low areas that can be inundated and the inundation could cause contamination to wells. Also wetlands are often affected by legal complications which make them unattractive for groundwater extraction. Therefore, the area represented by wetlands was removed from the aquifer volume calculation.

Developed land – Although there are potential locations that would be appropriate to drill in some of the developed land, there are some areas that one would not want to develop. Cemeteries, roadways, athletic fields and many other areas come to mind. In addition, there are many industrial and commercial activities that could potentially contaminate shallow groundwater and it would not be prudent to locate wells near these areas. Transportation corridors and adjacent lands along the right-of-way have practical deterrents to groundwater development such as surface traffic and buried utilities. Transportation corridors often attract commercial and industrial landuse activities that could potentially contaminate shallow groundwater. Therefore, the area represented by developed land was removed from the aquifer volume calculation.

Landfills – there are a number of landfills located in the Brazos River Alluvium aquifer in McLennan County. Some of the landfills were filled with burned material and others contain unburned material. Some of the landfills were lined with clay and others were not. Although no contamination has been documented officially, concerns exist regarding potential contamination of the surrounding aquifer. Because the cone of depression from pumping nearby wells may intercept a landfill area, a buffer was extended around each landfill. These areas of landfill and buffer were removed from the aquifer volume calculations.

The following section describes the method used to deduct land-use classification from the aquifer area. Table 4 depicts landuse classification as practical and non-practical aquifer productive areas.

Table 4. McLennan County landuse classification for practical and non-practical aquifer productive areas.

FID	Gridcode	Non-Practical Aquifer Landuse	F-Area (Meter^2)	F-Area (Acres)
0	11	Open Water	12,405,647	3,065
1	21	Low Intensity Residential	19,368,467	4,786
2	22	High Intensity Residential	5,662,664	1,399
3	23	Commercial / Industrial / Transportation	5,014,510	1,239
4	24	Developed high Intensity	2,081,190	514
13	95	Emergent Herbaceous Wetlands	437,745	108
12	90	Woody Wetlands	16,009,961	3,956
			No Access Area	15,069
			% No Access Area	**23%**

FID	Gridcode	Practical Aquifer Landuse	F-Area (Meter^2)	F-Area (Acres)
5	31	Bare Rock / Sand / Clay	344,360	85
6	41	Deciduous Forest	11,440,359	2,827
7	42	Evergreen Forest	9,537,615	2,357
8	43	Mixed Forest	19,800	5
9	71	Grasslands / Herbaceous	40,686,777	10,054
10	81	Pasture / Hay	83,372,999	20,602
11	82	Row Crops	58,688,415	14,502
			Accessible Area	50,432
			% Accessible Area	**77%**

Open Water – open water is not a practical location to drill or maintain a well. The water present may act as a water resource but by being exposed to the surface it is exposed directly to potential contamination and does not receive the protection of filtration through soils and sediments that is characteristic of the groundwater. If the open water body is connected to the aquifer and it becomes contaminated it may contaminate the groundwater nearby. Therefore, the area represented by open water bodies was removed from the aquifer volume calculation.

Figure 6 shows the practical and non-practical productivity aquifer areas in the BRAA in McLennan County. This map shows the areal extent of the two landuse divisions as shown in Table 4.

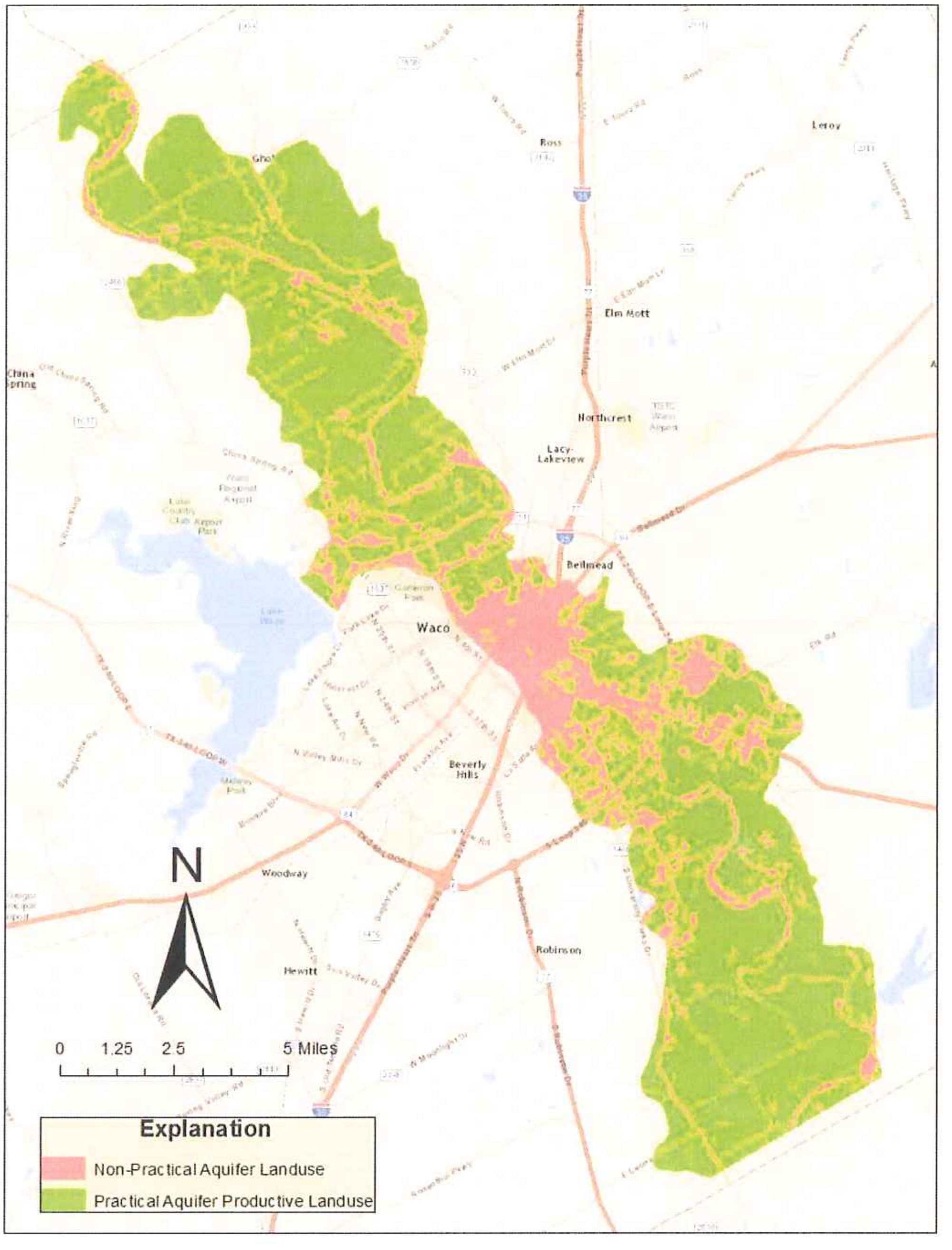


Figure 6. USGS landuse map with interpreted practical and non-practical aquifer areas.

Production Potential

The ability of an aquifer to transmit water is based in part on the ease with which water can flow through the pore spaces. To some extent, the bigger the pore spaces, the easier the water can move through the material and the more productive the aquifer would be. In other words, a well can be pumped at a higher rate (gallons per minute) if the aquifer has a high transmissivity. The pore size is related to the sediment size. Clays are small particles that have small pores and water cannot move through them easily. Gravels have large pores and can transmit water easily. Therefore, the portion of the vertical saturated section that contained clay or silt was removed from the volume and the portion composed of sand and gravel remained as the usable volume of the aquifer.

This section documents an approach to estimate the percentage of area that has aquifer sediments (sand/gravel) and non-aquifer sediments (silt/clay). The TWDB database has lithology description, but the sediments are not described consistently. The water-well database information is biased toward wells completed in permeable sediments. In other words, a driller would not complete a well with limited water yield. Therefore, a series of borings that were drilled for a non-production purpose were selected for this assessment to avoid the water well bias.

Hence to maximize sediment logging consistency and eliminate water-well bias, a Geotechnical Investigation entitled *WMARSS Transfer Lift Station and Force Main, Waco, Texas, LFE Project No. W16-004, July 8, 2016* and a USGS study along Steiner Road in 1963. The Waco Metropolitan Area Regional Sewerage System (WMARSS) study approximated a longitude study parallel to the river while the USGS study approximated a transverse study perpendicular to the river. Although both studies consisted of a transect of borings they were separated by several miles and represent two different areas of the aquifer. Only the borings that penetrated the complete aquifer were used in this calculation. Below is a summary of the percent determination of low and high permeable sediments.

Table 5. Geotechnical soil borings from the WMARSS study lithology classification and measured lengths.

Boring No.	Depth to Water (Feet)	Silt/Clay Length (Feet)	Sand/Gravel Length (Feet)	Shale Depth (Feet)
B-1	12	12	22	46
B-2	14	23	12	49
B-5	8	27	0	35
B-6	7	27	4	38
B-8	27	1	26	54
B-15	18	30	4	52
B-28	17	8	28	53
B-29	18	0	25	43
B-30	15	0	28	43
Average	15	14	17	45
Summed Length		128	149	
		46%	**54%**	

Table 6. Geotechnical soil boring lithology classification and measured lengths from the USGS Study.

State Well Number	Depth to Water (Feet)	Silt/Clay Length (Feet)	Sand/Gravel Length (Feet)	Shale Depth (Feet)
4040515	19	2	10	31
4040516	13	0	17	30
4040606	15	11	4	30
4040607	13.5	6.5	10	30
4040608	15	3	14	32
4040609	18	8	9	35
4040401	23	0	31	54
Average	17	4	14	35
Summed Length		30.5	95	
		24%	**76%**	

The assumption is that the borings in Tables 5 and 6 are each representative and applicable to the entire Brazos River Alluvial aquifer in McLennan County. However the area of the USGS study appears to be more productive than the area encountered in the WMARRS study. If both the WMARSS study and the USGS study are considered, there is approximately 158.5 feet of silt and clay and 244 feet of sand and gravel in the saturated sections of both studies. These numbers result in approximately 40% of the saturated section in the boring study area containing silt and clay and approximately 60% containing sand and gravel.

Referring to Tables 5 and 6, and estimate was made using the length of the sand and gravel in each boring to determine the potential for developing a well at that boring location. The determination criteria used was a minimum of 5 feet of saturated section as the amount of sand or gravel needed to develop a feasible well. Using that criteria borings B5, B6, and B15 in Table 5 and boring 4040606 in Table 6 would not be feasible for well development. Therefore, 6 of the 9 borings in the WMARSS study and 7 of 8 borings in the USGS study are potentially feasible well locations. If these study areas are representative then 76% (13 of 17) of the BRAA may be potentially productive. It is possible that the area of the USGS study is potentially more productive than most areas in the BRAA because there is an active sand and gravel mining operation in the area. In order to ensure the estimated productive area is not too optimistic, the potentially productive percentage was estimated using 0.66 or two thirds because that number falls between the two estimates of 60% (WMARSS study) and 76% (USGS study)

DFC

The Desired Future Condition (DFC) for the Brazos River Alluvium Aquifer is defined in Section 8.8.3 on page 16 or the STGCD Management Plan (2015) as:

The average DFC of the Brazos River Alluvium Aquifer is to maintain 82% of estimated saturated thickness after 50 years in McLennan County. The District will limit the total amount of groundwater produced or withdrawn from the portion of the Brazos River Alluvium Aquifer as necessary to meet the DFCs.

In order to meet this goal, the District has established the following <u>Management Objective:</u>

> *The District will annually measure the water level in one or more wells open, perforated, or screened in the portion of the Brazos River Alluvium within the District and shall calculate the annual and cumulative draw down and provide such information to the District's Board of Directors.*

In order to assess the progress of the objectives listed above, the District has designated the following Performance Standard: The District will provide an analysis report of the effects from pumping on groundwater levels, including the annual and cumulative draw down statistics, in the annual report to the District's Board of Directors.

Therefore, the practical storage determined after considering landuse and production potential was further modified using the 18% of storage available that would not reduce the saturated section below the DFC objective. This last modification does not take into consideration all the dynamic water level fluctuations of an unconfined aquifer but is used as a guide. Table 7 shows the DFC total storage available.

Quantity Summary

Table 7 contains the process used in applying all three deductions. Although the reduction result is approximately 14,000 acre-feet available, this amount is available theoretically or on average every year because it is an unconfined aquifer that can be managed sustainably as it is recharged by local rainfall. The DFC may need to be revisited.

Table 7. Volume calculations for practical storage.

Category	Volume (Acre-Feet)	Comments
Total Storage	149,577	Table 3 GIS calculated total water storage
Landuse Deduction	115,174	77% landuse assessable to groundwater development
Productive Aquifer Area Factor	76,015	66% land with sand & gravel that yield groundwater
DFC deduction with static recoverable storage	13,682 (Rounded to 14,000)	The DFC is defined as 18% of useable storage.

Quality

Total Dissolved Solids

This study reviewed the TWDB Total Dissolved Solids (TDS) data for McLennan County. An overview of the TDS data is found in Table 8. These data are information available from 1955 to 2016. Figure 7 shows the location of wells in the BRAA in McLennan County that contained TDS values. In addition, to the general TDS values (Figure 8), limits recommended for drinking water and irrigation are shown in Figure 9 and hardness values are show in Figure 10.

Table 8. All TWDB TDS water quality information for McLennan County.

Number of Wells	19
Number of TDS Samples	27
Minimum	301 ppm
Maximum	1802 ppm
Median	556 ppm
Mean	668 ppm
Standard Deviation	318 ppm

Figure 7 depicts the TWDB data spatially. At this map scale, the data appear to be provide broad even distribution of TDS data, however, the straight line distance from northwest to southeast county border is about 27 miles. The well density is not adequate to develop a contour map of TDS in the aquifer. When wells contained more than one sample data, the last sample event were used. The median maybe the most representative value.

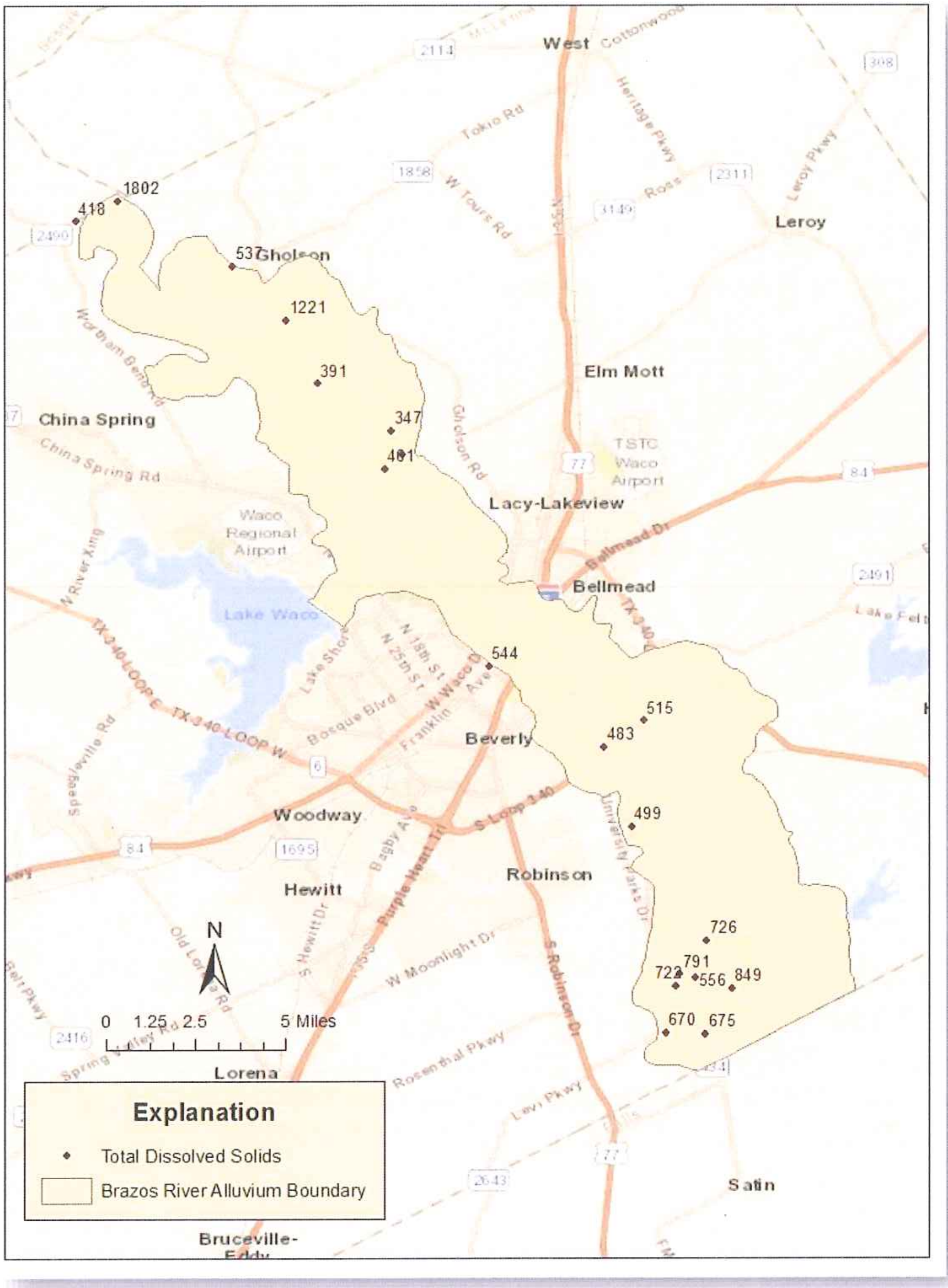


Figure 7. TWDB TDS data.

About 85 percent of the TDS results are below 1000 parts per million (ppm). The remaining 15 percent is defined as slightly saline with four samples between 1000 to 2000 ppm TDS (Figure 8).

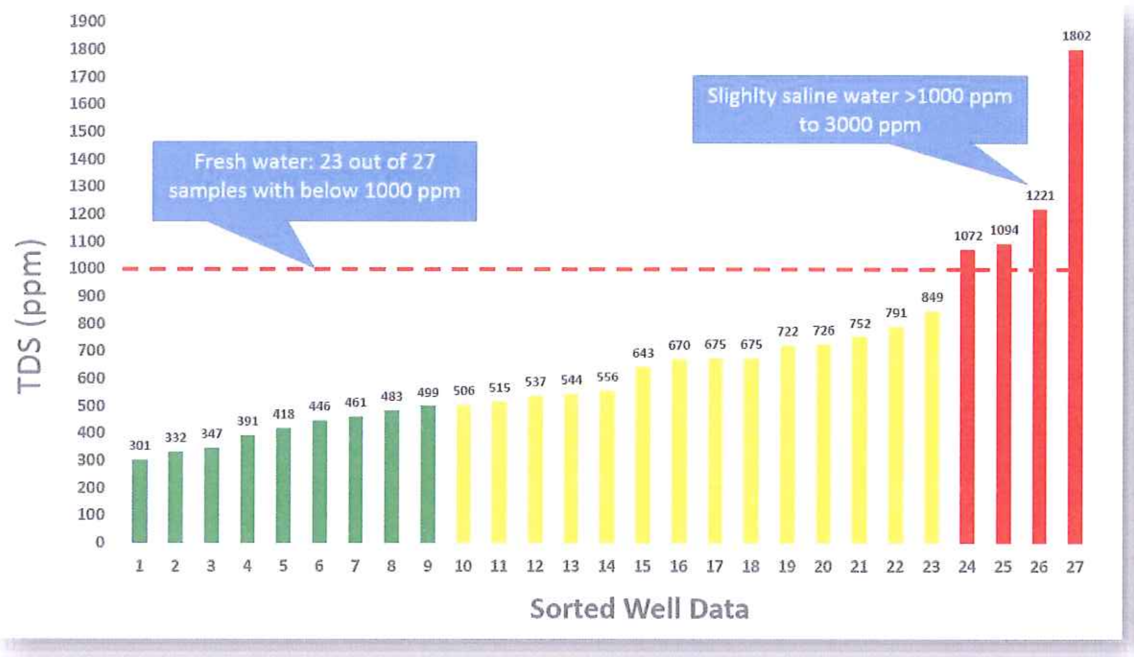


Figure 8. Water quality as defined by total dissolved solids and sorted from lowest to highest values.

Figure 9 indicates 9 of 27 samples are below drinking water standards. TDS and Sodium Adsorption Ratio (SAR) are normally used to classify irrigation water. The mean SAR is 1.20 with a range of 0.13 to 3.18 for 26 samples.

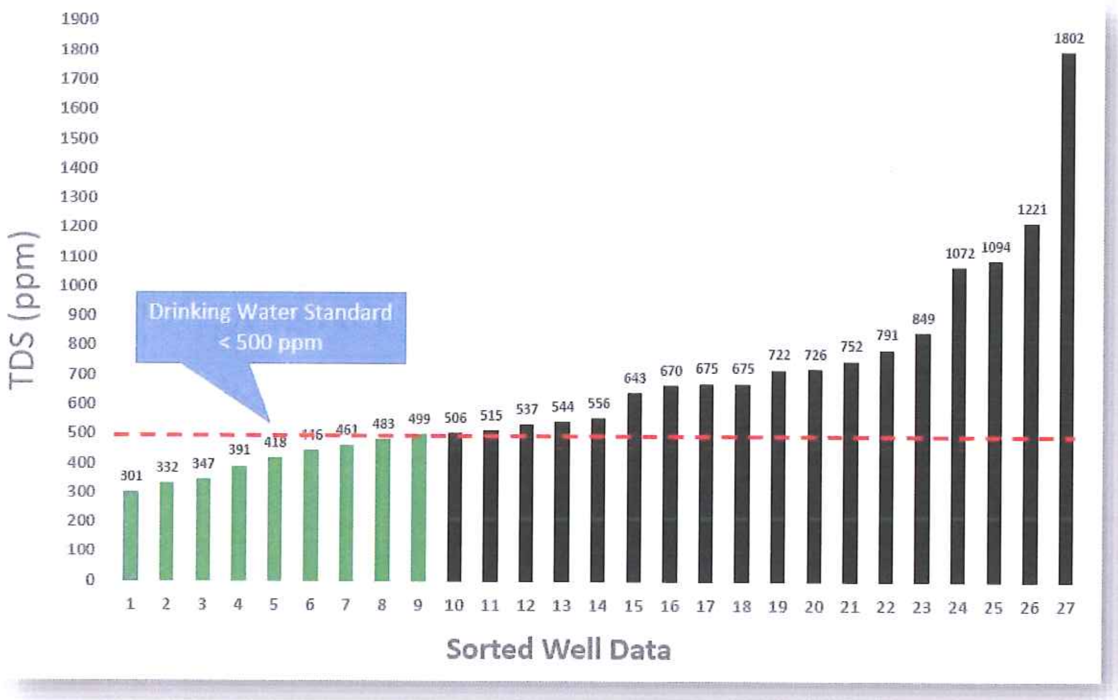


Figure 9. Sorted low to high TDS data.

Hardness

Water hardness data are presented in figure 10 for all wells in the county. In all 27 samples, the water is above the defined hardness concentration of 180 ppm.

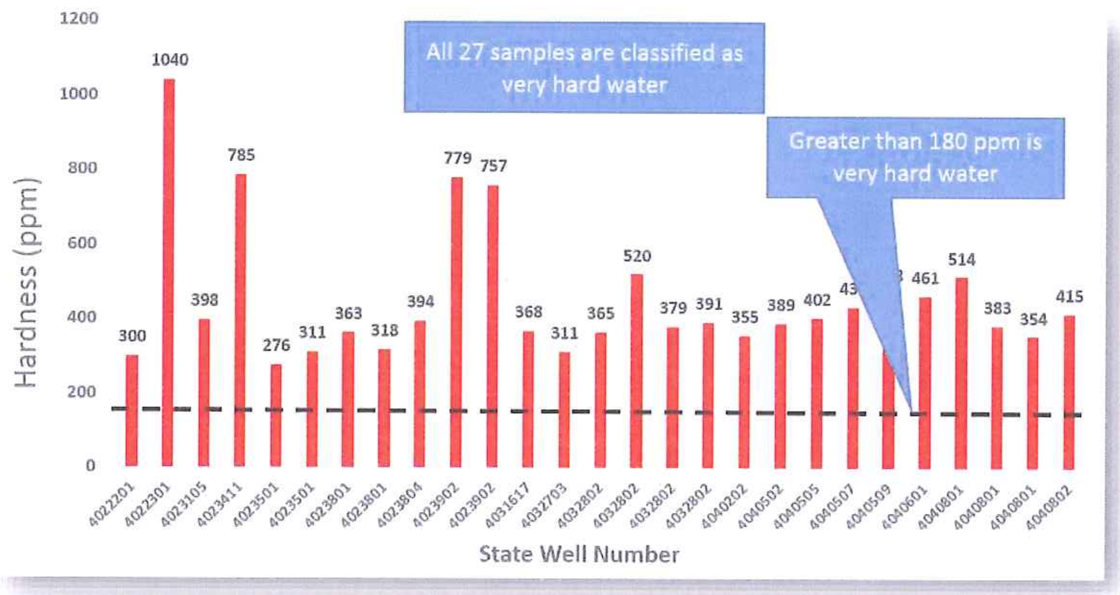


Figure 10. Water hardness of all data.

Water Quality Summary

Water quality was assessed from 19 wells in an aquifer that has an area of about 100 square miles. Therefore, this is a crude county-wide water quality assessment and local water values quality could be quite different. A site-specific water quality assessment will be necessary prior to water development and use. Although most of the water quality values were indicative of fresh water, a more complete analysis of ions and parameters of specific concern should be investigated.

Summary

The quantity reported in this study, 14,000 acre-feet, is conservative for the entire aquifer. However, the amount is an annual volume available using a static interpretation of the current DFC. Some areas within the boundaries of the BRAA may not have an adequate groundwater supply and other areas may have plenty of groundwater available. Because the BRAA volume varies with wet and dry periods, it is probably not prudent to apply an annual measure to a long-term (50 years) goal or to use a singular well to monitor aquifer level. As a more detailed delineation of the aquifer is developed and the recharge dynamics become better understood a new DFC may need to be considered.

The quality assessment in this report was limited to the values of TDS available. More detailed chemistry should be conducted to include the common anions and cations as well as nutrients and microbiological quality. This report represents the most recent understanding of the BRAA in McLennan County and can be used as the basis for future studies.

The four most common questions asked about the alluvium were:

1. How much recharge does the aquifer received annually?
2. What is the interaction with the river?
3. What is the water quality in the BRAA?
4. How much water can be produced?

Future studies should consider focusing on these questions.

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