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Joe C. Yelderman Jr.
Hydrogeologist,
Ph. D.
Baylor University

Hydrogeology of the Northern Segment of the Edwards Balcones Fault Zone Aquifer in the Salado Creek Basin and Environs

a current understanding

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Introduction

Purpose

The Northern Segment of the Edwards Balcones Fault Zone aquifer is the least studied and therefore probably the least understood portion of the Edwards Balcones Fault Zone aquifer. Even though it is less prolific than the San Antonio segment, it is the primary water supply to much of the population in and around the Salado Creek basin in Bell County. In addition, the aquifer is connected to important springs in the area that are an attraction to visitors in Salado Village and the aquifer and its springs provide habitat to organisms such as the Salado Salamander which is proposed to be listed as an endangered species. In order to provide an adequate quantity and quality of water to satisfy human consumption, maintain creek aesthetics, and provide suitable habitat for organisms such as the Salado Salamander, it is critical to understand the hydrogeology, especially the recharge, in the this portion of the aquifer. It is important for man to strive to live "in harmony" with karst rather than just live "on karst" (Brinkman and Parize, 2012). This study summarizes our current understanding of the karst hydrogeology in the Northern Segment of the Edwards Balcones Fault Zone aquifer and recommends where more data and research are preferred.

Methods

The methods used in this study included a literature review, data collection, interviews, and field observations. The literature review included references in three major categories.

1. General karst hydrogeology literature that was deemed directly relevant to the study area.
2. Literature regarding recharge processes applicable to the study area.
3. Hydrogeology literature specific to the study area.
    a. Published in refereed journals
    b. Unpublished but in reports, theses, and retrievable documents

Data that were gathered by other entities such as the Texas Water Development Board, Texas Commission on Environmental Quality, and the Clearwater Underground Water Conservation District were also included in the assessment.

Interviews with local inhabitants that live in the area provided information on important locations to investigate and historical context.

Field observations were made in as many areas as practical to view potential recharge features and understand the local hydrogeology.

Location

The study area is defined as the Salado Creek basin and surrounding areas (figure 1). This area encompasses most of Bell County and portions of Williamson County, central Texas.

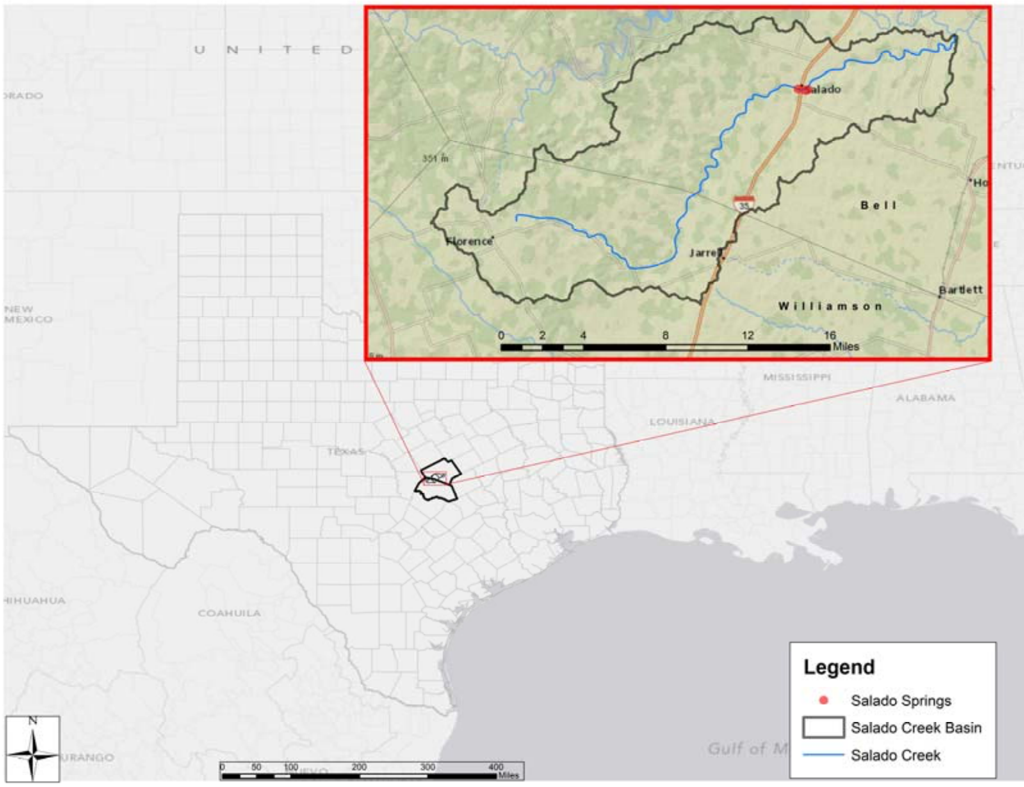

Figure 1. Location of Salado Creek basin and environs.

Acknowledgements

I would like to thank all those who helped in this effort. Particularly those who accompanied me in the field; Tim Brown, Dirk Aaron, Toby Hibbits, Andrew Worsley, Stephanie Wong, and students in several of my classes. Most of all I would like to thank the land owners who allowed me to access their property to make many of the important observations.

Geologic Framework

There are three formations that comprise the Northern Segment of the Edwards Balcones Fault Zone aquifer. They are in ascending order; the Comanche Peak Formation, the Edwards Formation and the Georgetown Formation. All of these units are sedimentary rocks, Cretaceous in age, and comprised mainly of carbonate (limestones). The Edwards and Comanche Peak formations are part of the Fredricksburg Group and the Georgetown is part of the Washita Group. They are fairly well connected hydraulically and considered as one hydrostratigraphic unit referred to as the Edwards aquifer; specifically the Northern Segment of the Edwards Balcones Fault Zone aquifer. The underlying confining unit is the uppermost member of the Walnut Formation, the Keys Valley member. It is comprised of carbonaceous clay material and referred to as a marl. The overlying confining unit is the Del Rio Formation (sometimes referred to as the Grayson Formation). The Del Rio is a carbonaceous clay-rich unit and often referred to as the Del Rio Clay. Upper Cretaceous units overlying the Del Rio Formation that crop out in the Salado Creek basin include the Buda Formation, Eagle Ford Group and the Austin Chalk. None of these are considered aquifers in this area. Figure 2 shows a map of the geologic units in the Salado Creek basin and environs.

Geology of Northern Edwards Aquifer and Salado Creek Basin

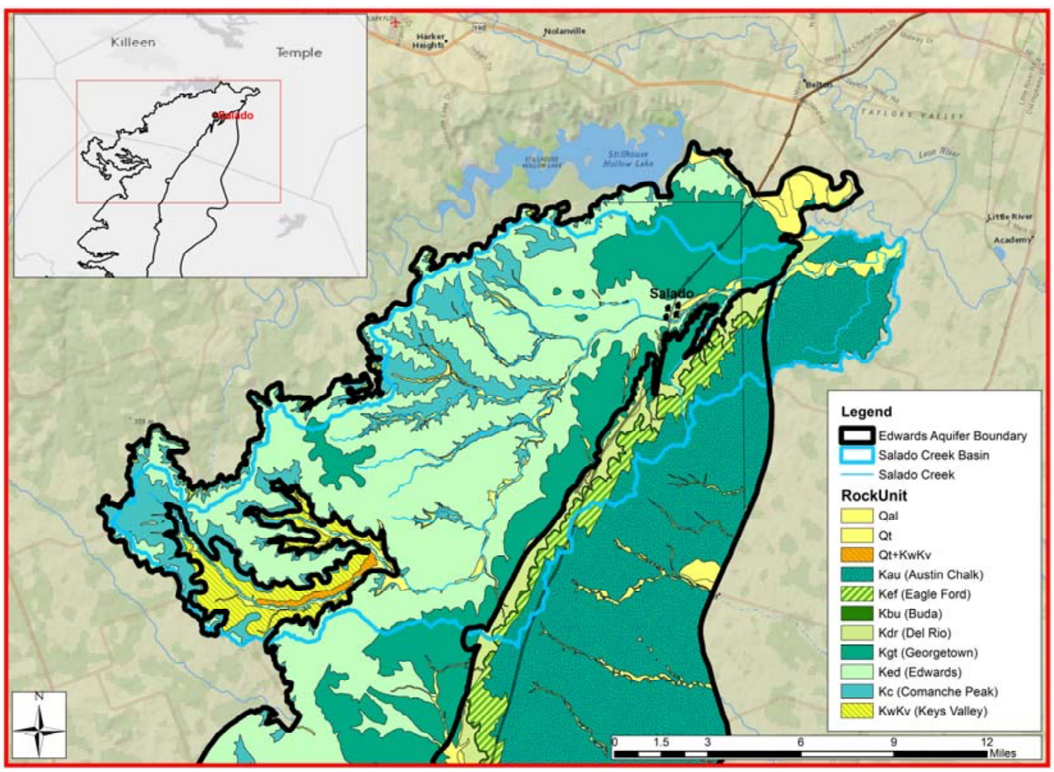

Figure 2. Geologic map of the Northern Segment of the Edwards Balcones Fault Zone aquifer in the Salado Creek basin and environs. Modified from Bureau of Economic Geology, 2007. Geologic Database of Texas. Texas Water Development Board, U.S. Geological Survey. Original Projection: Albers Conical Equal Area

A short description of each of the units is included in the text that follows.

The Austin Chalk (Kau) is an interbedded chalk and marl formation approximately 300-400 feet thick that caps the hills to the east of Interstate Highway-35 (Barnes, 1974). It is an overlying unit that could be considered a confining bed and may contribute runoff to losing streams that flow onto the Northern Segment of the Edwards Balcones Fault Zone aquifer.

The Eagle Ford Group (Kef) is an upper Cretaceous shale unit that contains flaggy siltstones and limestones in the middle section. This unit crops out in a N.E.-S.W. trending linear band on slopes below the Kau (Barnes, 1974). This unit is also a confining unit and only contributes runoff to the Salado Creek basin.

The Buda Formation (Kbu) is a fine-grained, hard limestone that is poorly bedded to nodular in nature and up to 45 feet thick but locally absent to the north (Barnes, 1974).

The Del Rio Formation (Kdr) is a calcareous, fossiliferous, clay approximately 60-70 feet thick (Barnes, 1974).

The Georgetown Formation (Kgt) is a bedded, fine-grained, nodular limestone with marl beds and it is approximately 80-100 feet thick. It occurs as a few outliers in the western portion of Salado Creek basin (Figure 2) and as a N.E.-S.W. trending linear outcrop along Interstate Highway-35 (I-35) on the eastern edge of the basin (Barnes, 1974).

Figure 3. The Georgetown Formation exposed in an outcrop within Salado Creek basin showing the nodular characteristics of the limestone and the fine grained beds between the limestones.

The Edwards Formation (Ked) is sometimes divided into the Kainer and Pearson members but in the northernmost portion of the Northern Segment of the Edwards Balcones

Fault Zone aquifer the upper Pearson unit grades into the Georgetown Formation. For purposes of this report the Edwards Formation will be considered one unit without subdivision into members and the Georgetown will be distinguished as the overlying formation. The lower part of the Edwards Formation in the Northern Segment of the Edwards Balcones Fault Zone aquifer is a porous dolostone and nodular limestone that has experienced significant dissolutioning (Rose, 1972; Woodruff and others, 1985). The Edwards Formation is about 100 feet thick in the Salado Creek basin area (Dahl, 1990).


Figure 4. The Edwards Formation with a typical karst dissolution feature.

The Comanche Peak Formation (Kcp) is a fine-grained, hard, marly limestone. It is about 50-60 feet thick in the study area and thins to the south. The Kcp is exposed in the Salado Creek basin primarily along stream scarps beneath the Edwards Formation (Barnes, 1974; Dahl, 1990).


Figure 5. The Comanche Peak Formation with fractures.

The Keys Valley member (Kkv) of the Walnut Formation (Kwa) is a soft fossiliferous marl approximately 30 feet thick (Barnes, 1974). Its clay content contributes to its function as a confining unit to the Northern Segment of the Edwards Balcones Fault Zone aquifer.

Hydrogeology

Porosity

Limestone is the dominant lithology that makes up the Northern Segment of the Edwards Balcones Fault Zone aquifer and although it contains a certain amount of matrix porosity, the important porosity is the secondary porosity that has developed as a result of fracturing and dissolutioning (Abbot, 1975; Kreitler and others, 1987). Generally the fracture openings in the Comanche Peak and Georgetown formations are narrower than the openings in the Edwards because the Edwards has experienced more dissolutioning (Abbott, 1975; Collins, 1987). Dahl (1990) measured fracture porosity following the methods suggested by Kovacs (1983) in outcrops of the Georgetown, Edwards, and Comanche Peak formations both near faults and away from faults. Dahl (1990) found that the effective porosity was greater near faults in all three of the formations and that the Comanche Peak had the highest porosity range while the Georgetown had the lowest porosity range. The Edwards Formation porosity did not include the cavernous porosity but only fracture porosity in Dahl (1990). Table 1 shows the porosity values Dahl (1990) observed.

Table 1. Percent porosity ranges in outcrops near faulting and away from faulting in the Northern Segment of the Edwards Balcones Fault Zone aquifer near the Salado Creek basin (from Dahl, 1990).

	Georgetown	Edwards	Comanche Peak
Near faults			
high	2.89	3.25	4.25
low	1.50	2.46	3.45
away from faults			
high	1.35	2.12	2.40
low	1.17	0.41	0.64

Hydraulic Conductivity

The hydraulic conductivity is primarily controlled by the fracturing; either near-vertical fractures associated with faulting or horizontal fractures associated with bedding plane separations. Many of the fractures have been widened or enhanced by dissolutioning. Hydraulic conductivity values calculated from pumping tests conducted on 4 wells August 26 and 27, 2012, by Bar W Groundwater Exploration and Clearwater Underground Water

Conservation District ranged over almost two orders of magnitude from .87 feet per day to 83.2 feet per day. This heterogeneity is the result of fractures and dissolutioning.

Transmissivity

The transmissivity is a product of the hydraulic conductivity times the saturated thickness. It is greatest in the thicker sections of the aquifer near the confined portion of the aquifer and near densely fractured zones associated with faults. Transmissivity values calculated from pumping tests conducted on 4 wells August 26 and 27, 2012, by Bar W Groundwater Exploration and Clearwater Underground Water Conservation District in Bell County ranged over almost two orders of magnitude from 34.6 feet squared per day to 3300 feet squared per day. This heterogeneity is the result of fractures and dissolutioning. Dahl (1990) reported transmissivity values that ranged from 1 feet squared per day to over 30,000 feet squared per day in the Salado Creek basin area. Dahl (1990) also noticed that the highest values occurred where the highest fracture densities occurred. Dahl (1990) obtained data from Slade (1987) where he used specific capacity data to estimate transmissivity values because in 1987 there were no pumping test data for the Northern Segment of the Edwards Balcones Fault Zone aquifer. Slade studied the entire Northern Segment of the Edwards Balcones Fault Zone aquifer and did not focus on the Salado Creek basin area. When one selects the data from Slade (1987) for the Salado Creek basin area the range remains the same (1feet squared per day – 32,165 feet squared per day) but the mean value is 1258 feet squared per day and the median value is 40 feet squared per day. De La Garza and Slade (1987) also looked at transmissivity in relation to lineation density and did not see any obvious trends. De La Garza and Slade (1987) included the entire Northern Segment of the Edwards Balcones fault Zone aquifer and this may have blurred local trends. Dahl (1990) observed the highest transmissivity values occurred where the highest lineation densities occurred in the Salado Creek basin area and that extremely high transmissivities were not found in areas with low lineation densities.

Flow

Flow in the Northern Segment of the Edwards Balcones Fault Zone aquifer is affected naturally by geomorphology and structure. Pumping also affects the aquifer. With respect to geomorphology the groundwater flows to springs, local streams, or to regional streams. Another effect of the geomorphology is that perennial streams act as groundwater divides under normal flow conditions. The perennial stream section that includes the major springs in downtown Salado is an example of a groundwater divide. Groundwater flow is from the south to the major springs and Salado Creek and also from the north to Salado Creek but flow from the north does not appear to cross the creek and become part of the springs on the south side (Figure 6).

Structure affects the flow in two ways. Structural dip aligns horizontal fractures (bedding plane separations) toward the southeast and near vertical fractures can align and enhance flow in the directions parallel or subparallel to the fracture lineations.

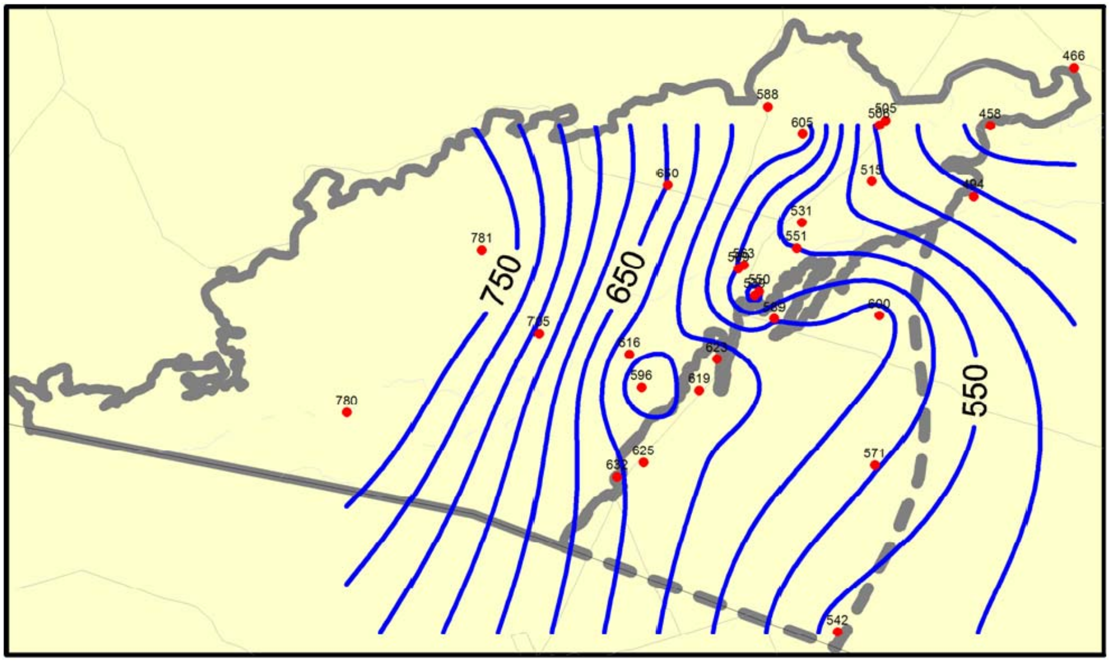

Figure 6. Groundwater contours drawn by Bar W Groundwater Exploration from water levels measured July 6 and 7, 2010. Notice the general flow direction to the east-southeast, the diversion northward toward the major springs in downtown Salado Village and the localized effects of pumping. Also notice that the flow does not appear to cross the creek valley in the northern portion of the basin.

Springsheds

Springsheds are the areas where the groundwater flows to the spring discharge point similar to that of a watershed for a stream. These may include areas that do not receive precipitation recharge and may include areas beyond the outcrop. Springsheds also may be only subsets of the aquifer recharge area (Figure7). Finally, springsheds may encompass different areas under different flow conditions. The springshed drawn in figure 7 is a preliminary interpretation based on the water level data from July 2010. More detailed water level data may move the boundaries. Different flow conditions may move the boundaries but the general flow pattern should be useful in identifying the area for most of the spring recharge. The springshed in figure 7 is also affected by pumping in 2010 as seen in figure 6.

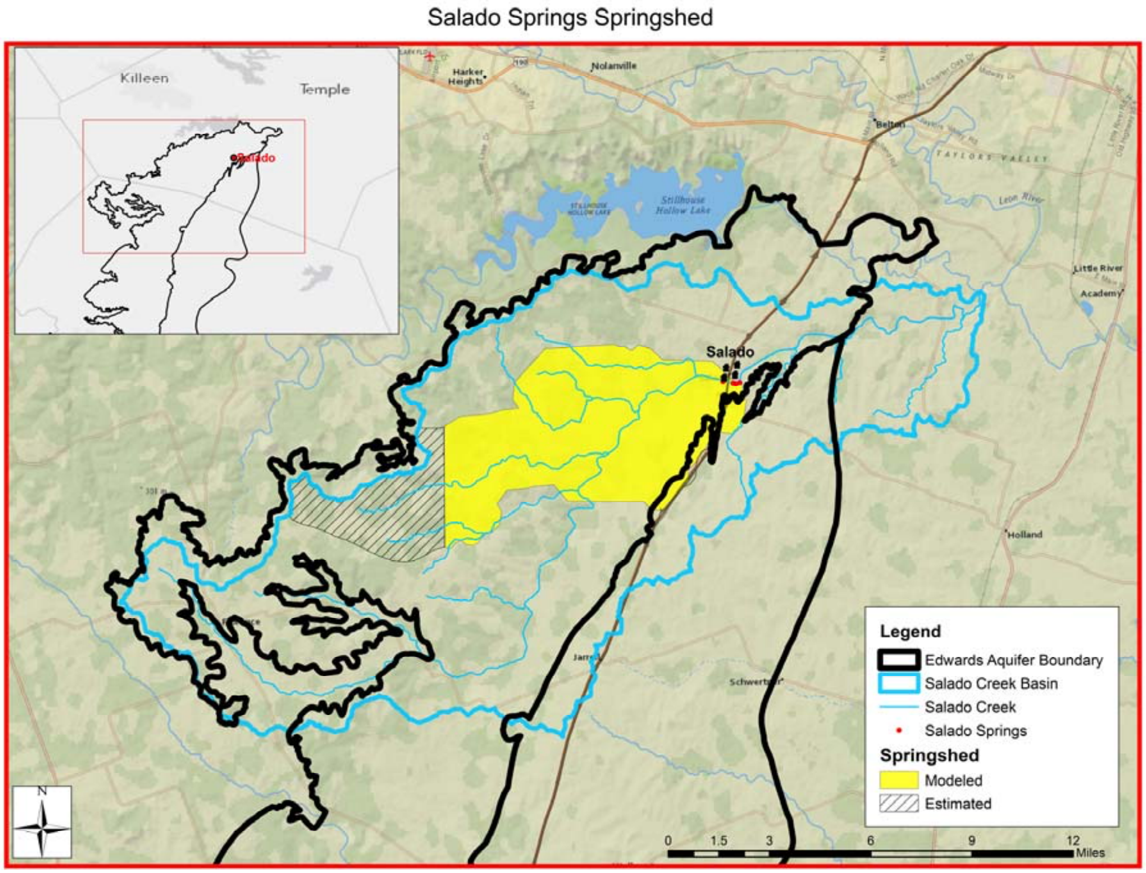

Figure 7. A preliminary springshed drawn from the groundwater contours shown in Figure 6. The general idea is that water recharging the aquifer within the springshed should flow to the springs and water outside the springshed would not flow to the springs. The accuracy of the springshed boundaries is directly related to the density and quality of the groundwater level data available.

Recharge

Recharge to the Northern Segment of the Edwards Balcones Fault Zone aquifer in the Salado Creek basin has been described fairly simply as direct precipitation recharge on the aquifer outcrop supplemented by a "transition zone" where runoff from overlying units flows across the outcrop and may infiltrate through losing streams. However, my investigation has revealed a much more complex recharge system that includes the following observations.

1. Although precipitation on the outcrop can infiltrate into the bedrock and recharge the Northern Segment of the Edwards Balcones Fault Zone aquifer, it is not uniform over the outcrop.
    a. Soils vary in texture, thickness and permeability (figures 8 and 9).
    b. Outcrops are not all connected directly to the portion of the aquifer that supplies groundwater to the springs in the downtown area of Salado Village (Figure 6).
    c. Recharge features such as sinkholes and losing stream sections are common and allow recharge to be concentrated in certain areas (figures 10 and 11).

2. All recharge does not originate on the outcrop within the Salado Creek basin.
    a. Runoff from other units can become stream flow that is lost into the aquifer in losing stream segments.
    b. Because some of the outcrops in the upper Salado Creek basin are not directly connected to the rest of the aquifer units, recharge from precipitation on aquifer outcrops in the upper Salado Creek basin may discharge to streams flowing over the underlying confining bed (Kkv) and some of this stream flow may be recharged back into the aquifer when flowing through losing stream segments.
    c. Recharge to the Northern Segment of the Edwards Balcones Fault Zone aquifer can occur outside the Salado Creek basin and become part of a regional flow system that may contribute to the spring flow in the major springs in the downtown area of Salado Village.
3. Some recharge that occurs on the outcrop may become part of the flow system to the confined portion of the Northern Segment of the Edwards Balcones Fault Zone aquifer and not contribute to the major springs in the downtown area of Salado Village (figures 6 and 7).

Soil Permeability in the Northern Edwards Aquifer

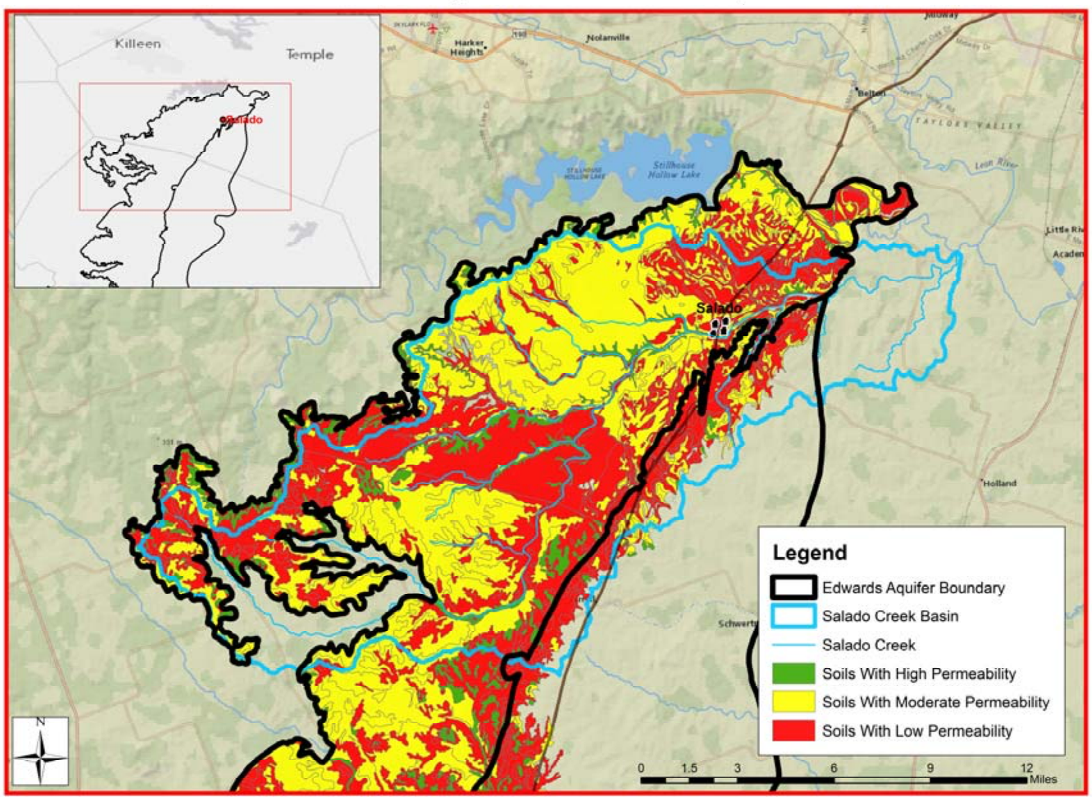

Figure 8. Soil associations based on soil thickness, clay content and permeability. Areal recharge on the aquifer outcrop should be greatest on the soils with the highest permeability and lowest on the soils with the lowest permeability. From U.S. Department of Agriculture, Natural Resources Conservation Service, 2012. Soil Survey Geographic (SSURGO) database for Bell and Williamson counties, Texas. Fort Worth, Texas. http://soildatamart.nrcs.usda.gov . Original Projection: UTM Zone 14, Northern Hemisphere (NAD 83).

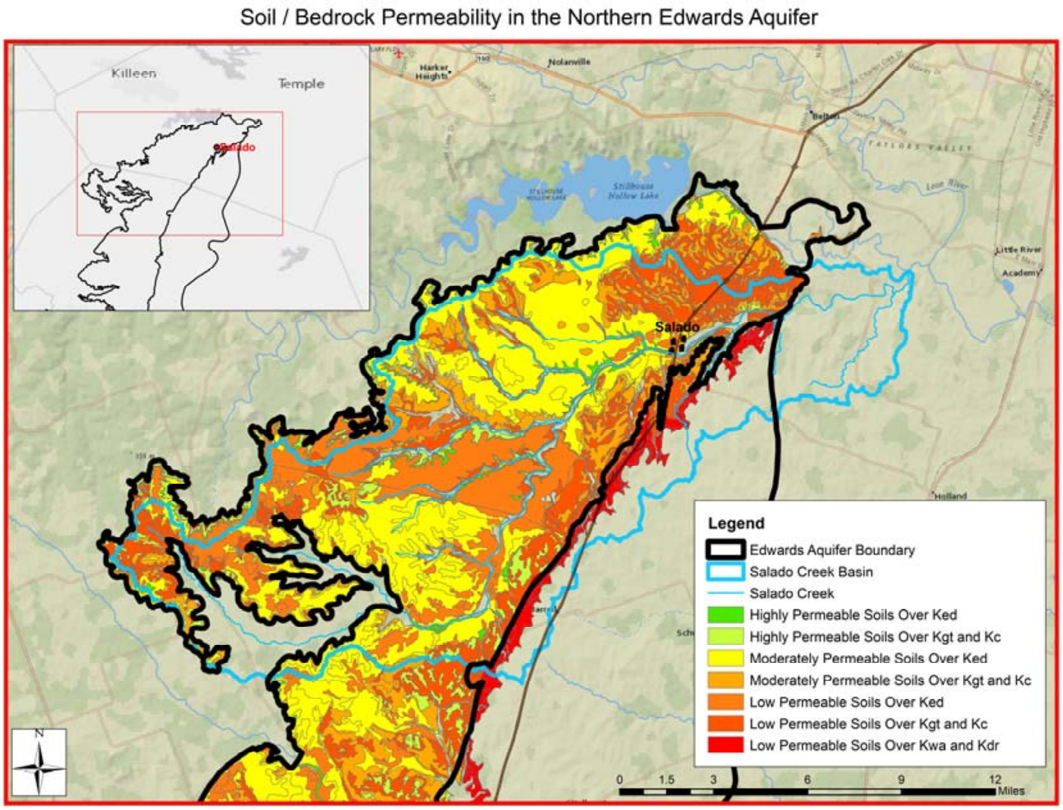

Figure 9. Soil associations coupled with the underlying bedrock formations to show areas with greater and lesser recharge capability. From U.S. Department of Agriculture, Natural Resources Conservation Service, 2012. Soil Survey Geographic (SSURGO) database for Bell and Williamson counties, Texas. Fort Worth, Texas. http://soildatamart.nrcs.usda.gov . Original Projection: UTM Zone 14, Northern Hemisphere (NAD 83).

Figure 10. Losing stream segment in Salado Creek basin.

Figure 11. Sinkhole on hillside in the Salado Creek basin.

Groundwater/Surface Water Interaction

Salado Creek and its tributaries act as gaining and losing streams in different sections throughout the outcrop area. There are many small springs throughout the basin and spring discharge from one spring may become recharge to another spring lower in the basin. Although all springs probably receive recharge from local flow paths near their discharge orifices, the recharge to the major springs in the downtown area of Salado Village is primarily regional in nature, especially during low-flow conditions.

Summary and Conclusions

Research on the Northern Segment of the Edwards Balcones Fault Zone Aquifer needs to continue in order to allow the best decisions to be made regarding groundwater management in the future. This study has confirmed earlier work by Slade (1987) and Dahl (1990) but has also identified a more extensive set of recharge features that need to be investigated with tracers and other quantitative studies. The results of this investigation definitely show there is an incomplete understanding of the location and quantity of recharge that contributes to spring flow throughout the Salado Creek basin area of the Northern Segment of the Edwards Balcones Fault Zone aquifer. What is known about the hydrogeology at this time indicates that the current designated critical habitat appears randomly shaped and is not fully supported by hydrogeological theory or data. The most apparent deficiencies in hydrogeological data for the Northern Segment of the Edwards Balcones Fault Zone aquifer include frequent and extensive water level data and groundwater chemistry data.

Recommendations

Research on the Northern Segment of the Edwards Balcones Fault Zone aquifer needs to continue in order to allow the best decisions to be made regarding groundwater management in the future. This study has summarized the current understanding and identified a number of specific data needs. The needs apparent to me are listed below. This list is not complete, or even exhaustive, but contains some important data voids.

1. Water level data need to be collected more frequently, with greater areal coverage and with greater density.
    a. These data would refine the ability to develop more accurate springsheds and see how springsheds may change under different flow conditions.
    b. These data would allow the development of seasonal and event related hydrographs.
    c. These data would help us understand recharge.
    d. These data would complement chemical data.
2. Tracer tests should be conducted to confirm the interpretations from water level data. This would be especially helpful in regard to recharge features and their relationships to specific springs.
3. Recharge features should be mapped in more detail using field data to calibrate and confirm computer generated data from remote sensing techniques. A combination of LIDAR and Multispectral satellite data appear potentially useful.
4. Modeling of stream flow and groundwater flow may be helpful.
5. Chemical data need to be collected with broad areal coverage and with respect to seasonal and recharge event fluctuations.

Definitions

Aquifer: material that can store and transmit water easily.
Bedding plane: a thin space between two layers of rock.
Carbonaceous: containing calcite ($CaCO_3$).
Chalk: soft, fine-grained limestone.
Confining bed: geological material that confines the flow of water. Usually a clay or shale geologic unit. Also referred to as a “confining unit”.
Dissolution: the process of dissolving rock such as limestone.
Dolostone: a carbonaceous sedimentary rock comprised of the mineral dolomite ($CaMgCO_3$) rather than the mineral calcite ($CaCO_3$).

Fossiliferous: containing fossils
Gaining stream: a stream where groundwater flows into the stream and the stream gains flow from seeps and springs.
Heterogeneity: Spatial variation in characteristics.
Hydraulic conductivity: The ability of a geologic material to conduct water.
Hydrogeology: the study of groundwater
Hydrostratigraphic unit: one or more geologic units with similar hydrologic characteristics and distinct from surrounding geologic units. Examples include aquifers and confining beds.
Karst: material and surface expressions associated with dissolution features and characterized by caves and sinkholes.
Limestone: a sedimentary rock comprised of calcite ($CaCO_3$).
Lithology: the rock type, description or study of rock types.
Losing Stream: a stream where water is "lost" from the stream to the groundwater below.
Marl: a rock comprised of clay and limestone. A clay-rich limestone.
Matrix porosity: the percent of pores or void spaces in a rock where no fractures or dissolution has occurred.
Nodular: having the shape or appearance of nodules.
Outcrop: where the bedrock occurs on the surface (soil is not considered).
Specific Capacity: The quantity of water produced from a well per unit of drawdown. This is usually expressed as gallons per minute per foot of drawdown. It is often the result of a short duration pumping test with only a few measurements. Transmissivity values can be calculated from specific capacity tests but the results are not as accurate as a constant rate pumping test.
Transmissivity: The ability of an aquifer to transmit water. The product of the Hydraulic Conductivity and the thickness of the saturated portion of the aquifer.
Outlier: a surface expression of a geologic unit that is not connected to the main part of the geologic unit outcrop.
Porosity: The volume of voids in a volume of rock expressed as a percentage.
Recharge: the water or processes associated with additions to the aquifer water volume.
Runoff: overland flow or stream flow that resulted from precipitation rate exceeding infiltration rate and causing water to run off.
Scarp: a line of hills or cliffs formed by faulting or erosion.
Secondary porosity; porosity that has developed after a rock formed; usually as a result of dissolution or fractures.
Shale: a sedimentary rock comprised of clay that has been compacted.
Siltstone: a sedimentary rock comprised predominantly of silt sized particles.

Bibliography

Abbott, P. L., 1975, On the hydrology of the Edwards Limestone, south-central Texas, Journal of Hydrology, V. 24, p. 251-269.

Abbott, P.L., and Woodruff, C. M., Jr., 1986, The Balcones Escarpment: geology, hydrology, ecology and social development in central Texas, Guidebook, Geological Society of America, San Antonio, Texas, 200 p.

Barnes, V. E., 1974, Geologic Atlas of Texas, Austin Sheet, Francis Luther Whitney Memorial Edition, Bureau of Economic Geology, University of Texas at Austin,

Brinkman, R. and Parize, M., 2012, Karst environments: problems, management, human impacts and sustainability, Journal of Cave and Karst Studies, Vol. 74, No. 2, p. 135-136.

Collins, E.W., 1987, Characterization of fractures in limestones, northern segment of the Edwards aquifer and the Balcones Fault Zone, central Texas, Gulf Coast Association of Geological Societies Transactions, V. 37, p. 43-54.

Dahl, S. L., 1990, Hydrogeology and Stream Interactions of the Edwards aquifer in the Salado Creek basin, Bell and Williamson Counties, Central Texas, Unpublished Masters Thesis, Baylor University, Waco, Texas, 154 p.

De La Garza, L., and Slade, R. M., Jr., 1987, Relations between areas of high transmissivity and lineaments for part of the Northern Edwards aquifer – a preliminary study, *in* Yelderman (1987), p. 11-18.

Grimshaw, T. W., and C. M. Woodruff, Jr., 1986, Structural style in an en echelon fault system, Balcones Fault Zone, Central Texas: geomorphologic and hydrologic implications, in P. L. Abbott and C. M. Woodruff, Jr., eds., The Balcones Escarpment--geology, hydrology, ecology and social development in Central Texas: Guidebook published for the 1986 Geological Society of America Annual Meeting, San Antonio, Texas, p. 71-75.

Kovacs, J., 1983, Practical application of continuum approach to characterize the porosity of carbonate rocks, *in* methods and instrumentation for the investigation of groundwater systems, Committee for hydrological research, TNO.

Kreitler, C. W., Senger, R. K., and Collins, E. W., 1987, Geology and hydrology of the northern segment of the Edwards aquifer with an emphasis on the recharge zone in the Georgetown, Texas area, Bureau of Economic Geology, unpublished report, contract number IAC (86-87)-1046, 115p.

Rose, P. R., 1972, Edwards Group – Surface and Subsurface, central Texas: Bureau of Economic Geology Report of Investigations no 74, 198 p.

Slade, R. M., Jr., 1987, Transmissivities of the Northern Edwards aquifer, *in* Yelderman (1987), p. 9-10.

Woodruff, C. M., Jr., Snyder, F., De la Garza, L., and Slade, R. M., Jr., 1985, Edwards aquifer - Northern Segment, Travis, Williamson, and Bell Counties, Texas, Austin Geological Society Guidebook #8, p. 1-3.

Yelderman, J. C., Jr., 1987, Hydrogeology of the Edwards aquifer: Northern Balcones and Washita Prairie segments, coordinator, Austin Geological Society, Guidebook #11, 91 p.