Chapter 5

Groundwater is No Longer Secret and Occult – A Historical and Hydrogeologic Analysis of the East case

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Introduction

In 1901, Denison, Texas was a bustling railroad town that served as a retail and shipping center for North Texas and a stopping point for more than 10 railways crossing and intersecting Texas[1] (Figure 1). Twenty-nine years earlier, the Missouri, Kansas and Texas Railroad, affectionately referred to as the K-T or KATY, laid out the town and named it after its vice president, Mr. George Denison.[2] The town quickly grew from 3,000 residents in 1873 to more than 10,000 in 1900.[3]

Running a railroad required water: water for passengers at the station, water for maintaining machine shops, and water for the steam boilers that propelled the locomotives down the tracks. In July of 1901, the Houston and Texas Central Railroad Company sent some of its staff to Denison in search for water for its facilities.[4,5] They started their search near Owings Street and Lamar Avenue and investigated wells that had already been dug in the nearby neighborhood, including a well on property owned by Mr. W. A. East.[6] These household wells were about 5 feet in diameter and 33 ft deep. The railroad men, apparently satisfied with the groundwater-producing abilities in the area, dug a well near the intersection of Owings Street and Lamar Avenue that was 20 ft in diameter and 66 feet deep. Once the well was completed in August of 1901, the railroad installed a steam pump and began producing 25,000 gallons a day.

Sometime after the railroad started pumping its well,[7] wells in the nearby neighborhood started to go dry. This resulted in Mr. East and several of his neighbors[8] filing suit against the railroad, claiming that production from the railroad's well dried up their wells. Mr. East claimed to be damaged in the sum of $1,100 (about $23,000 in 2002 dollars) plus court costs. In December of 1902, the District Court of Grayson County ruled against Mr. East and his neighbors and stated in its conclusion of law that "…no cause of action is shown in behalf of plaintiffs in any sum whatsoever, because I do not believe that any correlative rights exist between the parties as to underground, percolating waters, which do not run in any defined channel." Mr. East then filed for a new trial, claiming that the court erred because "…said finding was contrary to the law and contrary to the

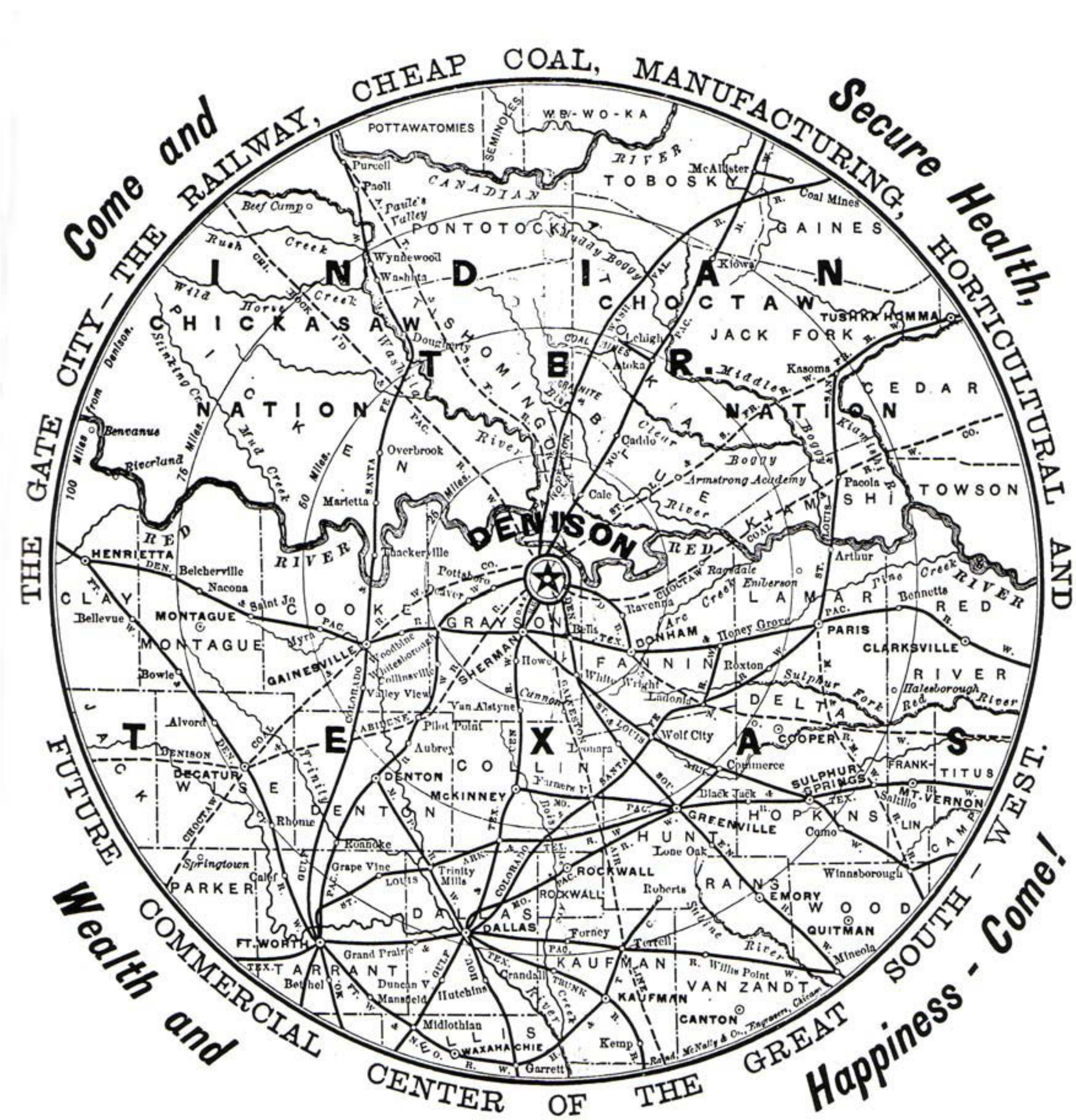

Figure 1: Map showing Denison as a railroad center in northern Texas (from Maguire, 1991).

evidence." The court denied Mr. East's motion for a new trial. Mr. East then filed for appeal, claiming that the court erred in its conclusion of law that the railroad was not liable, erred in overruling the motion for a new trial, and erred in failing to render judgement for the plaintiff.

The Court of Civil Appeals over-ruled the District Court and ruled in favor of Mr. East, awarding him $206.25 (about $4,300 in 2002 dollars). The Court of Civil Appeals found that "…the use to which defendant puts its well was not a reasonable use of their property as land, but was an artificial use of their property, and if the doctrine of reasonable use, as applicable to defined streams to such cases, this was unreasonable.” However, the railroad appealed that decision and the Texas Supreme Court ruled against Mr. East and in favor of the railroad.[9]

In its decision on June 13, 1904, the Texas Supreme Court laid the foundation of Texas groundwater law: the rule of capture. The Texas Supreme Court ruling quotes English doctrine that states: “That the person who owns the surface may dig therein, and apply all that is there found to his own purposes at his free will and pleasure; and that if, in the exercise of such right, he intercepts or drains off the water collected from the underground springs in his neighbor’s well, this inconvenience to his neighbor falls within the description *damnum absque injuria*[[10]], which cannot become the ground of an action.” The Texas Supreme Court made its decision on two public policy rationales, quoting a decision made by the Ohio Supreme Court in 1861 in the case of Frazier vs. Brown:

> “In the absence of express contract and a positive authorized legislation, as between proprietors of adjoining land, the law recognizes no correlative rights[[11]] in respect to underground waters percolating, oozing, or filtrating through the earth; and this mainly from considerations of public policy: (1) Because the existence, origin, movement, and course of such waters, and the causes which govern and direct their movements, are so secret, occult, and concealed that an attempt to administer any set of legal rules in respect to them would be involved in hopeless uncertainty, and would, therefore, be practically impossible. (2) Because any such recognition of correlative rights would interfere, to the material detriment of the commonwealth, with drainage and agriculture, mining, the construction of highways and railroads, with sanitary regulations, building, and the general progress of improvement in works of embellishment and utility.”

Many modern hydrogeologists would agree that the existence, origin, movement, and course of groundwater are no longer “…secret, occult, and concealed…” and would therefore disagree with with item (1) above. That is not to say that hydrogeologists know everything and can predict with absolute certainty how an aquifer will respond to pumping, but the science of hydrogeology has widely accepted theories and concepts that describe the existence, origin, movement, and course of groundwater. Item (2), however, is more directly a policy issue rather than a scientific issue.

The 1904 Texas Supreme Court ruling is only part of the story of water law in Texas. Probably the most important event after the 1904 ruling was the approval by voters in 1917 of a conservation amendment to the State constitution proposed by the Legislature that placed the duty to preserve Texas’ natural resources on the State.[12] This amendment forms the basis and duty for legislative action on groundwater regulation. In 1949, the Legislature used the conservation amendment to pass the Texas Underground Water Conservation Act and allow for the creation of groundwater conservation districts. These districts can adopt rules to conserve, preserve, protect, recharge, and prevent waste of groundwater. At present, there are 80 confirmed groundwater conservation districts that contain within their borders about 88 percent of all the groundwater produced in Texas[13]. Since the 1917 conservation amendment to the Texas constitution, the Texas Supreme Court has recognized that the responsibility for the regulation of groundwater rests in the hands of the Legislature.[14] By 1955, the Texas Supreme Court had recognized that the movement of groundwater was no longer secret and occult.[15]

The 1904 Texas Supreme Court ruling still offers several interesting scientific issues for investigation and discussion. One issue is the level of understanding of hydrogeology at the time of the Ohio Supreme Court decision in 1861 and the Texas Supreme Court decision in 1904. What was known about hydrogeology at those times? Was groundwater, indeed, secret and occult in 1861 and 1904? Another issue is the hydrogeologic details of the East case itself. Is it reasonable, given what is known, that production of the railroad well may have drained Mr. East's well? Finally, another issue is the progress of the science of hydrogeology since 1904. Is enough known now to refute that groundwater is secret and occult? The purpose of this paper is to briefly investigate and discuss these three issues.

A Brief History of Hydrogeology[16]

Based on our review, there have been three major theories of groundwater through the years: the Oceanus theory, the condensation theory, and the percolation theory. Ultimately, it was the percolation theory that withstood the test of time. As Darcy wrote in 1856, "no one would not reply that they [springs] result from the infiltration [percolation] of rain water." However, the resilience and proponents of the other theories make fascinating history.

The Oceanus Theory

The history of hydrogeology begins with the Greek storyteller Homer (~1,000 B.C.) in Book 21 of his Iliad. In this book, Homer writes of "…the deep-flowing Oceanus, from which flow all rivers and every sea and all springs and deep wells." In this theory, which we call the Oceanus theory, water flows from the oceans; into the continents; and to rivers, springs, and wells.

The Oceanus theory had adherents for more than 2,500 years. The Greek philosopher Thales (624–547 B.C.) supported the Oceanus theory. The Roman natural historian and scientist Pliny the Elder (23-79 A.D.) adhered to the Oceanus theory in Chapter LXV, Book 2 of his encyclopedia Natural History, a document that influentially survived through the Middle Ages (350-1450 A.D.). During the Middles Ages, philosophers and interpreters of the Bible taught that springs originated from the oceans. The Italian painter (and scientist) Leonardo Da Vinci (1452-1519 A.D.) adhered to the Oceanus theory and believed that rivers were sourced from underground veins of water from the sea. Several other documents appeared in the 1500s promoting the Oceanus theory of groundwater. In the 1600s, the Oceanus theory had an offshoot theory that held that the Earth was living or behaved like an animal. The German astronomer Johann Kepler (1571-1630 A.D.) thought the Earth imbibed water from the ocean, digested it, and then expelled it through springs. After more than 2,500 years, the Oceanus theory began to fade when the percolation theory took hold in the late 1600s.

The Condensation Theory

In his book *Meterologicia*, the Greek philosopher Aristotle (384-322 B.C.) introduced the condensation theory by stating that "…the air surrounding the earth is turned into water by the cold of the heavens and falls as rain . . . [and]…the air which penetrates and passes the crust of the earth also becomes transformed into water owing to the cold which it encounters there. The water coming from the earth unites with rain water to produce rivers. The rainfall alone is quite insufficient to supply the rivers of the world with water."[17] This theory states that the source of groundwater is air moving into the ground and condensing the water it holds.

The Roman philosopher Seneca (4 B.C. - 65 A.D.) did not believe that rainfall could supply the water in rivers and thought that groundwater could come from three possible sources: (a) the Earth itself containing a lot of moisture that is continually being forced out, (b) air within the Earth is continually being converted into water by the forces of darkness and cold (the condensation theory), and (c) the Earth is simply being converted to water.

The French philosopher and scientist René Descartes (1596-1650 A.D.) revived the condensation theory in the 1600s. He thought that ocean water moved into the earth by underground channels where it was vaporized by the heat of the Earth's interior. This vaporized water then rose through caverns, condensed at a higher level, and flowed out of springs. The condensation theory began to fade when the percolation theory took hold in the late 1600s.

The Percolation Theory

The Roman architect and engineer Vitruvius (~80-20 B.C.) discussed what we call the percolation theory in the eighth volume, Liber Octavus de Aquis et Aquaeductibus (Eighth Book on Water and Aqueducts), of his treatise De Architectura Libri Decem (Ten Books on Architecture). In this volume, Vitruvius discussed the sources and distribution of water and noted that rain and snow fell on the mountains, percolated through the rock strata at the foot of the mountains, and issued forth as streams and springs. Being the first to describe a simple conceptual model of the groundwater component of the hydrologic cycle, Vitruvius set the foundation for modern hydrogeology.[18]

The French potter (and scientist) Bernard Palissy (1509-1590 A.D.) focused on the percolation theory in his book, Discourse Admirables (Admirable Discourse), published in 1580 A.D.. In the book, he states: "…rain water that falls in the winter goes up in summer, to come again in winter. . . And when the winds push these vapors the waters fall on all parts of the land, and when it pleases God that these clouds (which are nothing more than a mass of water) should dissolve, these vapors are turned into rain that falls on the ground….And these waters, falling on these mountains through the ground and cracks, always descend and do not stop until they find some region blocked by stones or rock very close set and condensed. And they rest on such a bottom and having found some channel or other opening, they flow out as fountains or brooks or rivers according to the size of the opening and receptacles…" Palissy's thoughts are similar to those of Vitrivius except that he introduces the concept of an underlying confining layer.

Prior to the latter 1600s, scientists and philosophers assumed that water discharged from springs could not be derived from rainfall because it was thought that there wasn't enough rainfall and that the Earth was too impervious to allow deep infiltration of water. This was, in part, the foundation upon which the Oceanus and Condensation theories rested. However, a number of findings in the late 1600s caused people to question these assumptions. The French scientist Pierre Perrault (1608-1680 A.D.) measured rainfall and observed that the rainfall over a basin was about six times the stream discharge, discrediting a theory that rainfall couldn't possibly account for spring and streamflow. The English astronomer Edmund Halley (1656-1742 A.D.)

made evaporation estimates and calculated that evaporation from the sea would be sufficient to account for all of the water discharged by streams and springs.

The French physicist Edmé Mariotté (1620-1684 A.D.) successfully defended the percolation theory and formed the foundation of modern thought on groundwater. Mariotté discussed how water from rain and snow infiltrates the pores of the Earth and accumulates in wells. He discussed how water percolates down until it hits an impervious layer and then flows laterally in an amount that could supply a spring. He showed that spring flow increased and decreased dependant on rainfall and explained that more constant springs were supplied by larger reservoirs. He used the leaky roof of the cellar of the Paris Observatory to demonstrate that water could percolate through the earth. He also measured this percolation and compared it with rainfall, probably the world's first recharge estimate.

The Beginning of Well Hydraulics

In the beginning of the 1800s, the French took a great interest in groundwater because of the drilling of a number of artesian wells in France. It was during this time that the French engineer Henri Darcy (1803-1858) published his book 'Les Fontaines Publiques de la Ville de Dijon' (Public Foundations of the City of Dijon) in 1856 with an appendix that contained what is now known as Darcy's Law. Just seven years later in 1863, A. J. E. Dupuit (1804-1866) used Darcy’s Law to derive an equation that described the flow of water to a well under equilibrium conditions. In 1870 the German scientist Adolph Thiem modified Dupuit’s formula so that one could calculate the hydraulic properties of an aquifer by pumping a well and observing the resulting decline in the water table in nearby wells under equilibrium conditions. It wasn’t until 1935 that C. V. Theis (1900-1987) developed the non-equilibrium equation and solution for flow to a well.

Early hydrogeology in the United States

There were few hydrogeologic studies in the United States until the 1870s when considerable interest arose in locating artesian water. Several publications documented surveys for artesian prospects across the country, including Texas. A University of Wisconsin professor and United States Geologic Survey (USGS) geologist Thomas Chamberlin (1843-1928 A.D.) published a seminal report on "The requisite and qualifying conditions of artesian flow" in 1885, the first hydrogeologic report published by the USGS. In 1896, William P. Mason of the Rensselaer Polytechnic Institute published a book called “Water Supply” that included two chapters on groundwater and contamination of groundwater by sanitary waste (Mason, 1896). In 1899, the University of Wisconsin professor and USGS geologist Franklin H. King wrote “Principles and Conditions of the Movements of Ground Water” that included a number of important observations concerning groundwater, including:

- groundwater flows according to gravity;
- the water table can be represented using water-level contour maps;
- flow can be indicated on a water-level contour map by showing arrows at right angles to the water-level contours;

- groundwater flow can be shown on a cross-section moving from upland areas to lowland areas; and
- the water table can be a subdued reflection of the surface topography.

Slichter (1899) conducted an electrolytic tracer test to track the movement and velocity of groundwater underflow in river valleys. In Texas, R. T. Hill (1901) published an assessment of the geography, geology, and artesian waters of the Black and Grand Prairies of Texas. Several other USGS geologists published detailed reports of artesian water from around the country through 1904. The advancement of hydrogeology in the United States since 1904 is described by Rosenshein and others (1976).

Was groundwater secret and occult in 1861 and 1904?

At the time of the Ohio Supreme Court decision in 1861, one could argue that groundwater was indeed 'secret and occult'. Although Darcy's law had been established, it was not until 1863 that it was used to describe groundwater flow to a well and 1870 that it was used to characterize aquifer properties and predict water-level declines. However, by 1904, the science of groundwater had progressed considerably. Dupuit and Thiem had developed the aforementioned equations, which recognized that wells interfered with each other, and King had published his book that included many modern concepts about groundwater flow in 1899.

It's unclear how well the knowledge of hydrogeologic principles traveled across the country. However, it seems safe to assume that USGS geologists working in Texas circa 1904 were well aware of King's 1899 book. The propagation of hydrogeologic science to the general public was probably non-existent. Even today, hydrogeologic discoveries rarely make the front page of the local papers.

2004: Groundwater is no longer secret and occult

Groundwater science has progressed considerably since 1904. Besides the C. V. Theis contribution, there has been a considerable amount of research on aquifers and groundwater flow, including research on the hydrologic cycle, measuring hydrologic characteristics, quantifying heterogeneity and anisotropy, evaluating the chemical evolution of groundwater, developing groundwater resources, evaluating the migration of contaminants, and modeling aquifers. There is a long list of books that summarize the state of modern groundwater science (for example, Freeze and Cherry, 1979; Driscoll, 1986; Domenico and Schwartz, 1998; Fetter, 2001; Fitts, 2002).

In addition to basic research on groundwater and aquifers, there has also been a lot of information collected on aquifers. In Texas, the Texas Water Development Board's water well database includes information on 30,000 wells with 650,000 measures of water levels and 103,000 measures of water quality. Through its efforts and those of its cooperators (groundwater conservation districts and the U.S. Geological Survey), the TWDB now collects and compiles 10,000 measurements of water levels each year and 5,000 measurements of water quality over a five year sampling period in a state-wide water well monitoring network.

The TWDB, USGS, and others have developed numerical groundwater flow models of the state's aquifers to understand flow in the aquifers and to make predictions on how drought and pumping might affects water levels, spring flows, and baseflows (Mace, 2001). Since 2001, the TWDB has been developing and overseeing the development of groundwater availability models of the major and minor aquifers of the state as directed by the Legislature (Mace and Mullican, 2000a, b; 2001; Mullican and Mace, 2003; Mace and others, 2004).

The devil is in the details…

Although most (if not all…) modern hydrogeologists would likely agree that groundwater is no longer secret and occult, the devil is in the details. This is because aquifers are generally complex (heterogeneous and anisotropic). This complexity results in variations in the sands, fractures, dissolution conduits, aquifer thickness, water volumes, and other physical parameters from one place to the next. In extreme cases, such as in fractured and karstic aquifers, one well might produce a large amount of water and another well nearby might produce much less depending on whether or not fractures or dissolution features are crossed by the borehole. Other aquifers, such as sandy formations, may be more uniform, but even these aquifers can have lateral and vertical variations over short distances or be affected by faulting. It may even be difficult to predict the long-term response of an area with site-specific information such as pumping tests if those tests were not run for a long period of time. On a regional scale, it can be difficult to estimate recharge and how it relates to groundwater evapotranspiration. Hydrogeologists can still make predictions in areas with little information, but there are always uncertainties associated with predictions.

A technical analysis of the East case

Because the parties involved in the East case did not have an advanced technical understanding of groundwater flow, we decided to investigate, on a technical level, whether or not it was reasonable or possible that the railroad's well caused Mr. East's well to go dry. To do this, we (1) reviewed court and other historical documents for information on the dimensions and locations of the wells, (2) traveled to Denison to inspect the area where the wells were located, (3) ran a model to assess possible interference between wells, and (4) investigated historical rainfall records to determine if a drought may have also occurred at that time.

The study area

Denison, Texas is located in Grayson County near the border with Oklahoma (Figure 2). Located in the Blackland Prairies physiographic subprovince (Wermund, 1996), the northern part of the county is characterized by loamy and sandy soils while the southern part is characterized by blackland soils. The area receives on average 40 to 44 inches per year of precipitation and has an average annual net lake evaporation of 30 to 34 inches (TWDB, 1997, p. 3-11, -12). The Red River forms the northern boundary of the county, most of which is now submerged by Lake Texoma. The surface-water divide between the Red River and Trinity River basins is located in the lower half of the county.

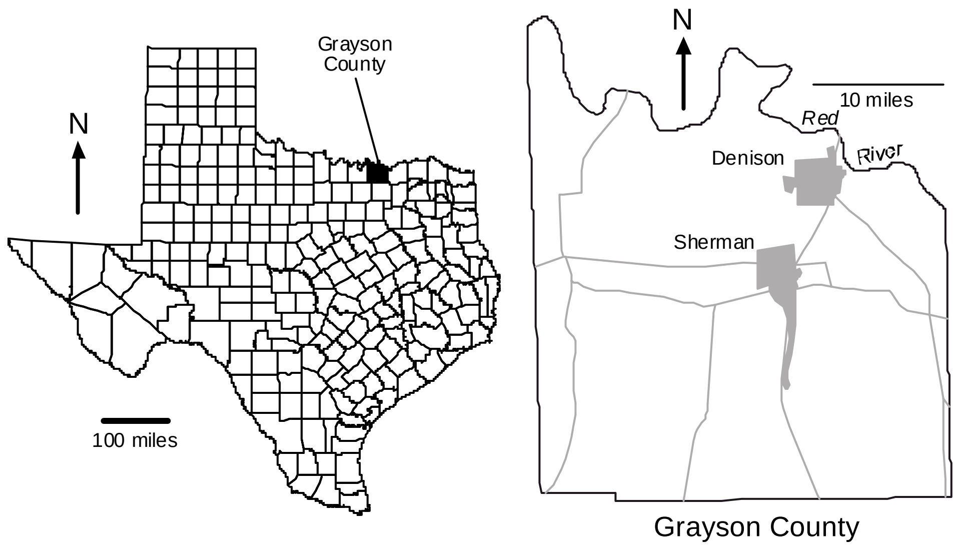

Figure 2: Location of Grayson County in Texas and Denison in Grayson County.

The geometry of the East case

Court documents indicate that the Houston and Texas Central Railroad Company (the Railroad) dug a well near the intersection of Owings Street and Lamar Avenue.[19] An artist's aerial rendition of Denison circa 1886 shows the location of railroad tracks, the location of the Railroad's line, and a number of structures in the area (Figure 3).[20] The 1914 Sanborn Fire Insurance map shows a 'large cistern' next to a structure identified as a pump house located near the intersection of Owings Street and Lamar Avenue (Figure 4). This is the likely location of the Railroad well. Court documents indicate that the Railroad well was 20 feet in diameter and 66 feet deep. The well and the pump house no longer exist at the site, although it appears that there are remnants of the pumphouse foundation (Figure 5a).

Court documents indicate that Mr. W. A. East (East) owned "Two lots and one-half on the corner of Lamar Avenue and Morgan Street, Lots 1 and 2 and one-half of 3, Block 2, Cook's second addition to Denison, Grayson County, Texas." However, this description of East's property appears to be incorrect since the intersection of Lamar Avenue and Morgan Street is in Cook's First Addition and lots 1, 2 and 3 of block 2 are not located near the intersection (Figures 4 and 6).[21] We reviewed deeds at the Grayson County Courthouse and found that East bought lots 5, 6, 7, 8, Block 2, Cook's First Addition to Denison, Texas in September of 1900 "…on the waters of Paw Paw Creek…"[22] which passes through the middle of these lots (Figures 4 and 5b). The 1914 Sanborn fire insurance map shows three dwellings on the northern side of lots 5, 6, and 7 (Figure 4). Therefore, we believe that the East well was located somewhere on these properties, which range from 100 to 250 feet away from the railroad well (Figure 6). The East well is described in court documents as being about 5 feet in diameter and 33 feet deep. Neither the East well nor the houses on the lots exist today.[23] The East well is both shallower and of lesser diameter than the Railroad well (Figure 7a).

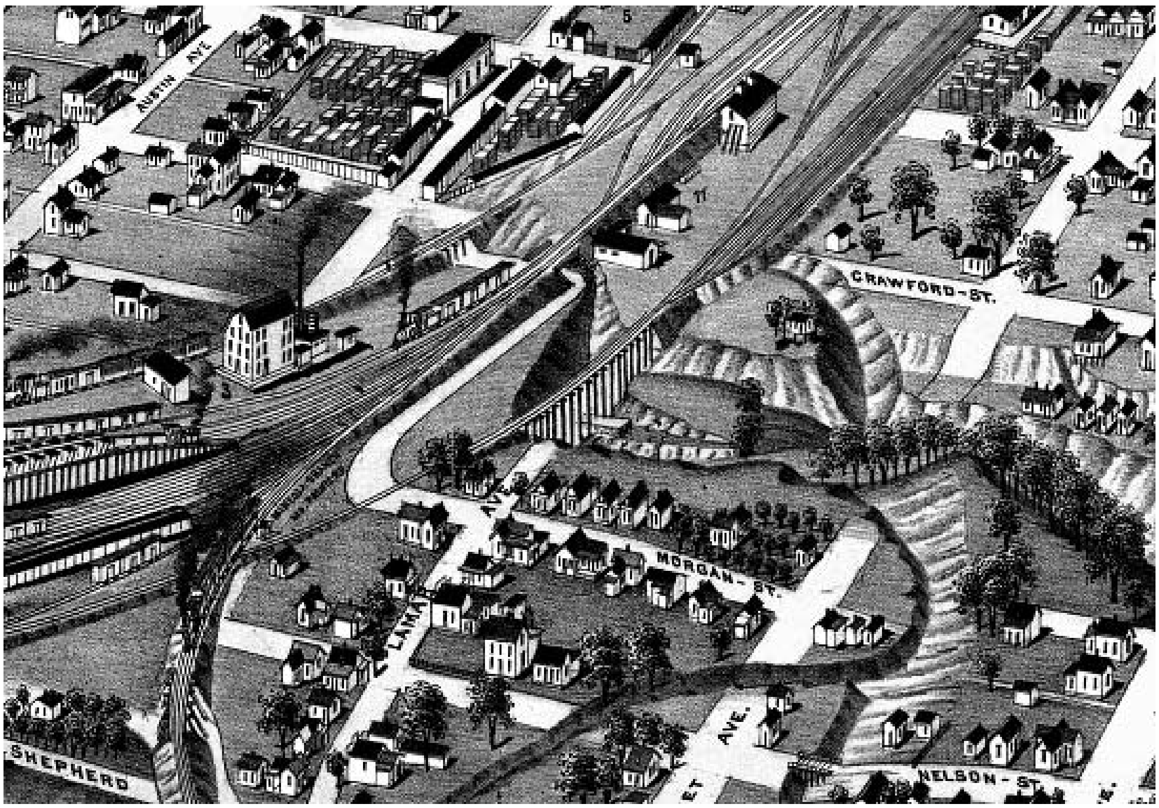

Figure 3: A detail from an artist's rendition of Denison circa 1885 (Beck & Pauli, 1886). Pawpaw Creek is shown in the center of the detail. The Houston and Texas Central Railway line is the railroad that runs over Pawpaw Creek on top of the bridge with trestles. Their station is located near the top right of the figure. Lamar Avenue and Morgan Street are shown in this map. Owings Street is not shown and would be located along the course of Pawpaw Creek North of Morgan Street. The railroad bridge shown on this map was torn down and replaced with a concrete bridge in 1914 (according to the date on the bridge).

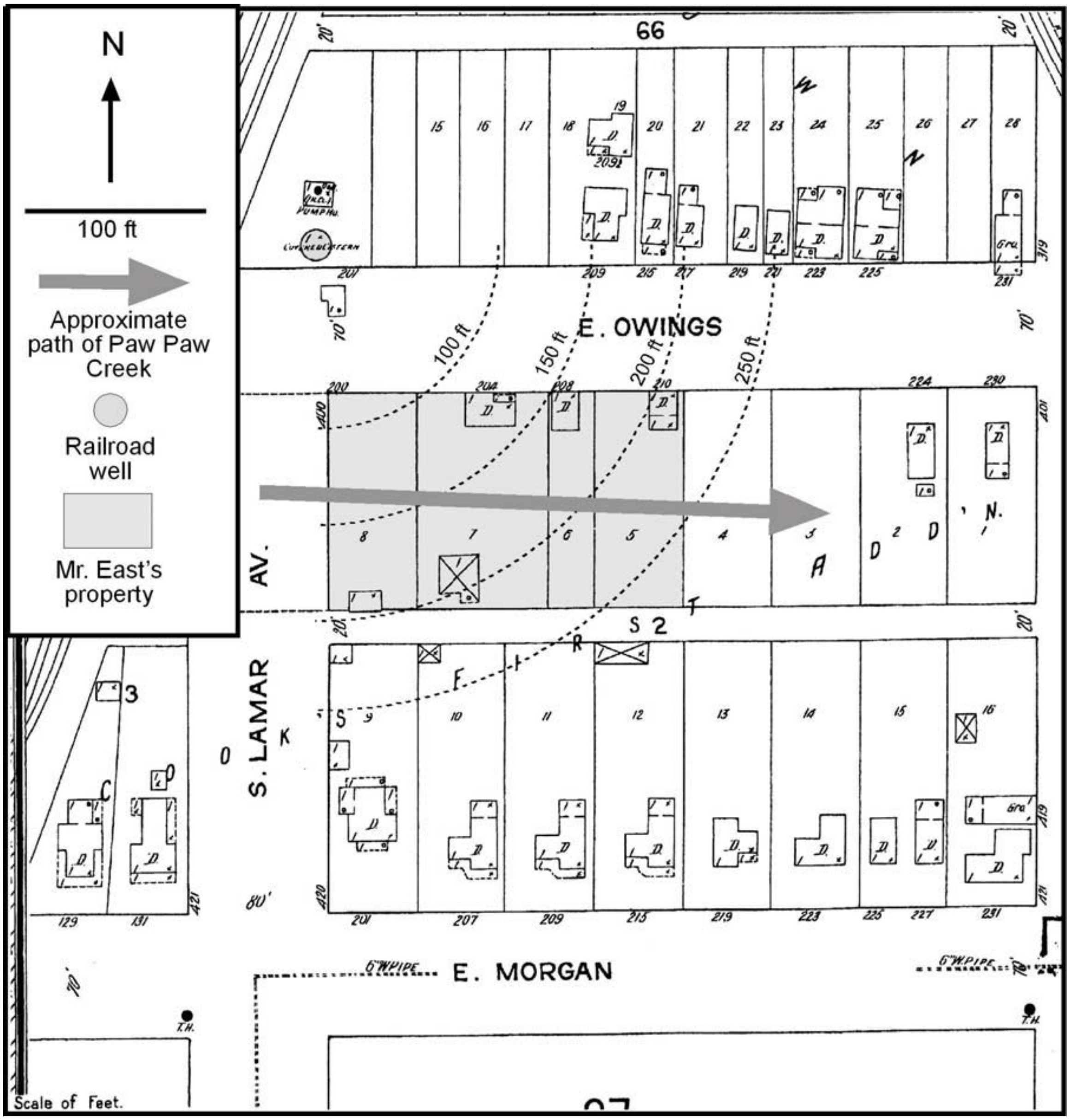

Figure 4: A detail of the 1914 Sanborn fire insurance map of Denison showing the location of the Houston and Texas Central Railroad Company well sunk near the intersection of Owings Street and Lamar Avenue. We have highlighted the location of the well, the properties owned by Mr. East in 1901, the modern approximate location of Paw Paw Creek, and radii of distances from the railroad well.

Figure 5: Photographs taken on January 16, 2004 near Owings Street and Lamar Avenue, including (a) the probable location of the pumphouse for the Railroad well with pieces of foundation cement circled; (b) view to the east while standing on Lamar Avenue, with Pawpaw Creek in the foreground (the creek is channeled beneath Lamar Avenue), Owings Street to the left visible between the trees, and the probable location of the East well between the creek and Owings Street; and (c) looking north at the intersection of Owings Street and Lamar Avenue with the probable location of the Railroad well circled. Photographs by authors.

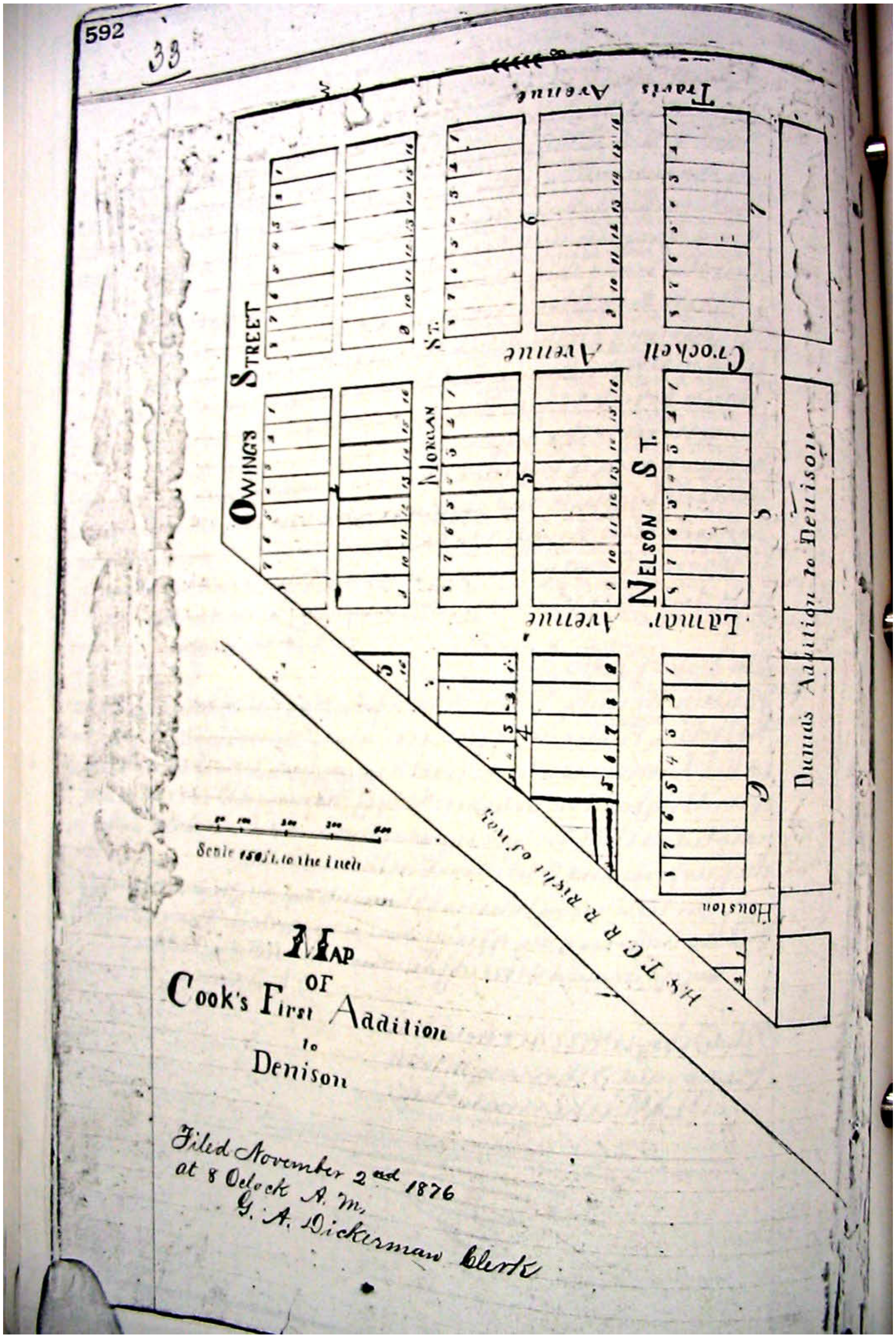

Figure 6: Plat map of Cook's First Addition to Denison as filed in 1876 (from files at the Grayson County Courthouse). Note that north on this map is directed to the left of the page as photographed. Photograph by authors.

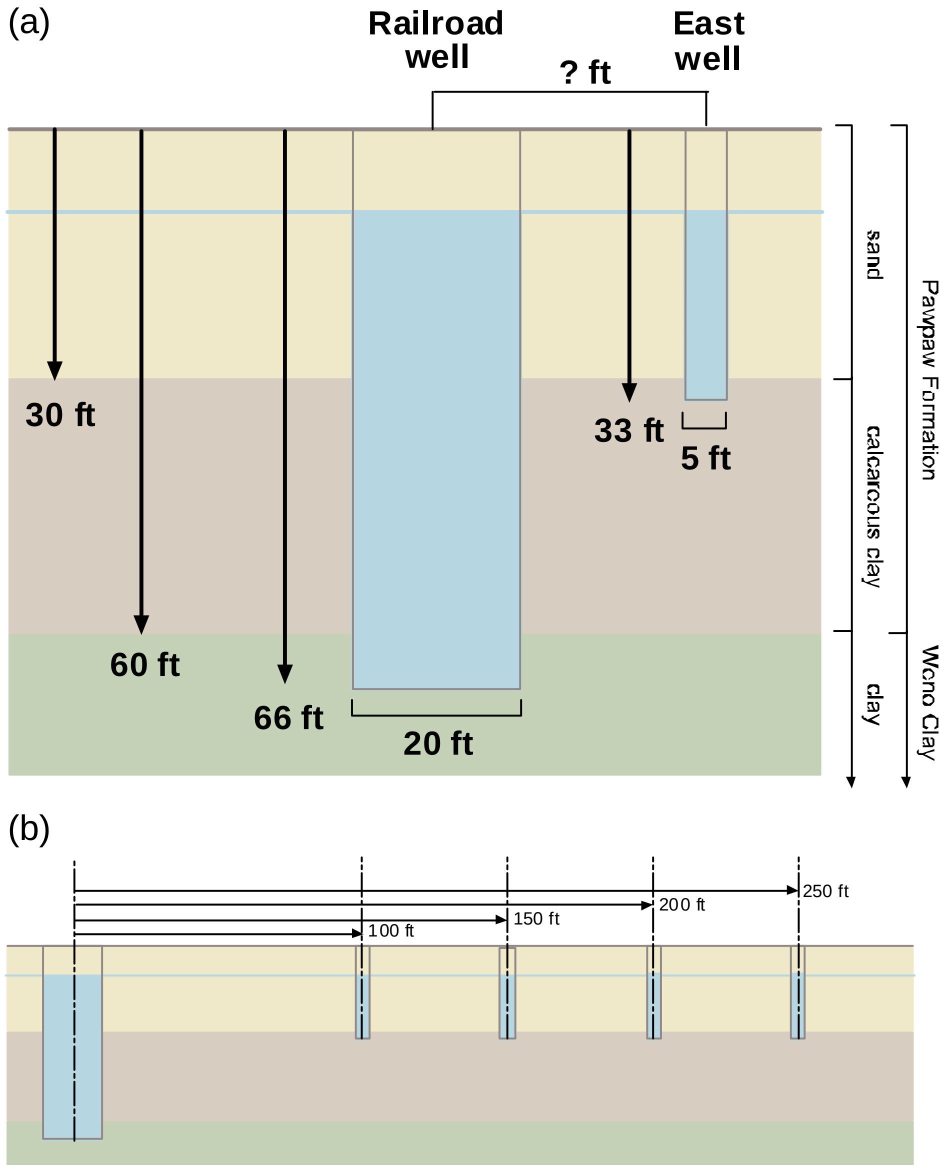

Figure 7: Schematics showing (a) the relative dimensions of the Railroad and East wells and the probable subsurface geology in the area and (b) the same with the East well at likely distances from the Railroad well.

The hydrogeology of the East case

According to the Geologic Atlas of Texas sheet for the area (McGowen and others, 1991), the Railroad and East wells were completed in the Pawpaw Formation (Figure 8). This formation is about 60 feet thick near the outcrop and consists of calcareous clay in the lower part and poorly cemented sand in the upper part which is 20 to 30 feet thick (Baker, 1960). According to Baker (1960), the sand yields small to moderate amounts of water to shallow wells in the outcrop area. Underneath the Pawpaw Formation is the Weno Clay, which is 110 to 135 feet thick of calcareous clay and doesn't produce water (McGowen and others, 1991, refers to the Weno Limestone).[24] The Railroad claimed that water percolated into their well at different depths, including through the bottom. Limited well-log information suggests that different sands exist in the Pawpaw Formation, so the Railroad's claim may be accurate.

The locations of the wells are toward the southern part of the outcrop where the thickness of the Pawpaw Formation is greatest. We were not able to locate any aquifer tests for the Pawpaw Formation in the area. However, the sandy part of the formation would be expected to have hydraulic conductivities[25] between 2 and 20 ft/day (based on the 25th and 75th percentile of the Carrizo-Wilcox aquifer by Mace and Smyth [2003], a sandstone aquifer in the upper coastal plains of Texas).

In 1873, the first city council of Denton had a public well dug in the center of the intersection of Main Street and Austin Avenue (Maguire, 1991, p. 25), about 1,500 ft to the northwest of the intersection of Owings Street and Lamar Avenue. This well was 38 feet deep and held up to 8 feet of water (Maguire, 1991, p. 25). Therefore, the depth to water was about 30 feet at this location. We expect that the depth to water in the Railroad and East wells to be less, perhaps by 5 to 15 feet, because these wells are located close to a creek bed at a lower elevation.[26] We infer that water in the Pawpaw Formation is unconfined (there is no confining layer above the formation) and that the water table would fluctuate with precipitation amount.

Assuming that the full thickness of the Pawpaw Formation is available at the location of the wells, the railroad well fully penetrated the sand and clay in the formation and extended a few feet into the Weno Clay (Figure 7a). Although useable quantities of water are probably only available in the sandy part of the section, there is an advantage in extending a large-diameter well into underlying low-permeability sediments for the storage of water (Mace, 1994; 1998). The East well also would have fully penetrated the

sand in the Pawpaw Formation, but it would have only gone a few feet into the clay in the formation (Figure 7a).

Groundwater flow in the area is probably directed generally toward Pawpaw Creek in a southeasterly direction north of the creek and in a northeasterly direction south of the creek. If this is true, the East well would have been down gradient of the railroad well.

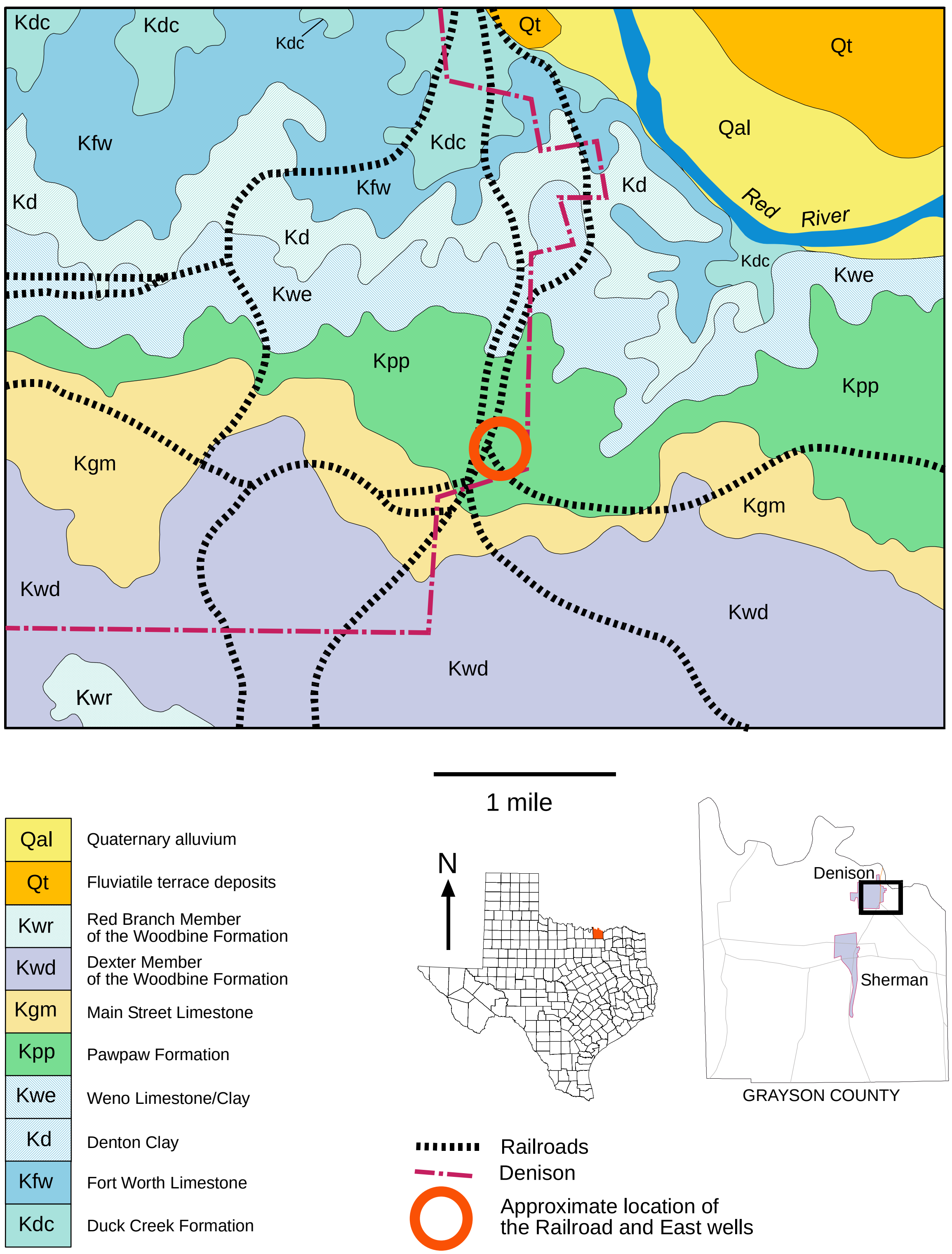

Figure 8: Surface geology in the Denison area (after McGowen and others, 1991).

Possible water-level declines around the railroad well

When a well is pumped, the water level in the well is lowered. This lowered water level induces water to flow from the aquifer into the well. In other words, water flows from a higher water-level elevation or pressure to a lower water-level elevation or pressure. This decline of water levels extends into the aquifer in what is called a cone of depression. The shape and extent of this cone of depression depends on the hydraulic characteristics of the aquifer and the amount of pumping.

There is not enough information about the aquifer to definitively determine whether or not pumping of the railroad well would have dried out the East well. This would require us to drill and test several wells in the area. However, we believe there is enough information to assess whether or not this was a possibility. To do this, we assessed how water levels might have declined around the Railroad well. To estimate the possible effects of pumping the Railroad well might have had on water levels in the Pawpaw Formation, we used a program developed by Barker and Macdonald (2000) that simulates pumping tests in large-diameter wells. We used this program instead of the Theis (1935) equation because pumping a large diameter well can result in less drawdown than in a small diameter well due to the large infiltration face of the well.

Because the drawdown of water levels in the Pawpaw Formation were probable large compared to its thickness, we used an equation developed by Jacob (1944, as reported in Walton, 1970) to calculate the drawdown that would occur in an equivalent nonleaky artesian aquifer, s_a, given the observed drawdowns from a water table (unconfined) aquifer, s_{wt}:

$$s_a = s_{wt} - \frac{s_{wt}^2}{2m} \qquad (1)$$

where m is the initial saturated thickness. The lowering of the water table in a thin aquifer results in greater drawdowns. Solving for s_{wt} using the quadratic formula and using the negative root results in:

$$s_{wt} = m - \sqrt{m^2 - 2ms_a} \qquad (2)$$

For our analysis, we first used the Barker and Macdonald (2000) program to calculate drawdown (s_a) away from the Railroad well. We then used equation 2 to calculate s_{wt} assuming m equaled 30 feet. We chose an initial saturated thickness of 30 feet to represent the maximum thickness of the sand in the Pawpaw Formation.

Assuming that the Railroad was able to rely on their well as a supply at 25,000 gallons per day and knowing the thickness of the aquifer and the pumping rate allowed us to define the lower limit of the hydraulic conductivity of the aquifer. The saturated thickness of the aquifer puts an upper limit on the amount of drawdown. Therefore, we used the Barker and Macdonald (2000) program and the Jacob (1944) correction to calculate this lower limit assuming that there would

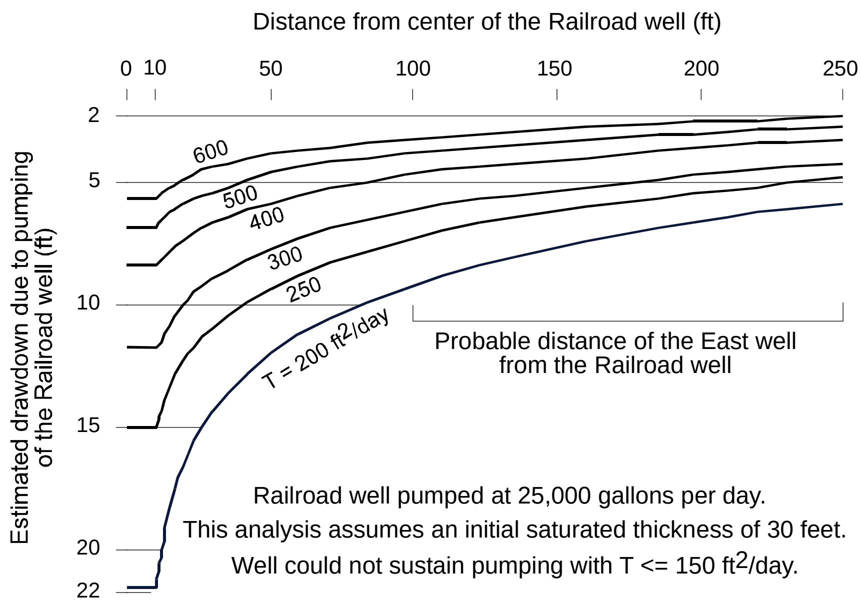

Figure 9: Estimated drawdown around the Railroad well for different transmissivity values (T) and for different distances.

be no more than 30 feet of drawdown. This results in a transmissivity of no lower than about 185 ft^2/day or a hydraulic conductivity of about 6 ft/day (which is within the probable range we mentioned earlier). Because lower transmissivities and hydraulic conductivities result in greater amounts of drawdown, these lower-limit values also represent the greatest amount of drawdown away from the Railroad well (given all of the other assumptions). This lower-limit value results in about 2 to 10 feet of drawdown on the East properties (Figure 9).

This analysis shows, given the various assumptions, that the Railroad well may have had an effect on the East well, but probably not enough to make it go completely dry. If there was a uniform saturated thickness of 30 feet across the site, this amount of drawdown would not have been enough to have dried up the East well. A smaller saturated thickness would result in less drawdown at the possible locations of the East well. A deeper depth to water with the same saturated thickness increases the likelihood that the East well went dry when the Railroad pumped its well. This likelihood also increases as the saturated thickness gets thicker. Any definitive analysis on whether or not the Railroad well dried up or had any effect on the East well would require site-specific analysis of the hydrogeology in the Owings Street and Lamar Avenue area.

Drought in 1901?

When we visited Denison, we looked through microfiche of the local paper at the time of the East case, the Sunday Gazetteer. While we did not find anything concerning the lawsuits against the railroad concerning pumping, we did notice that there were complaints about a drought

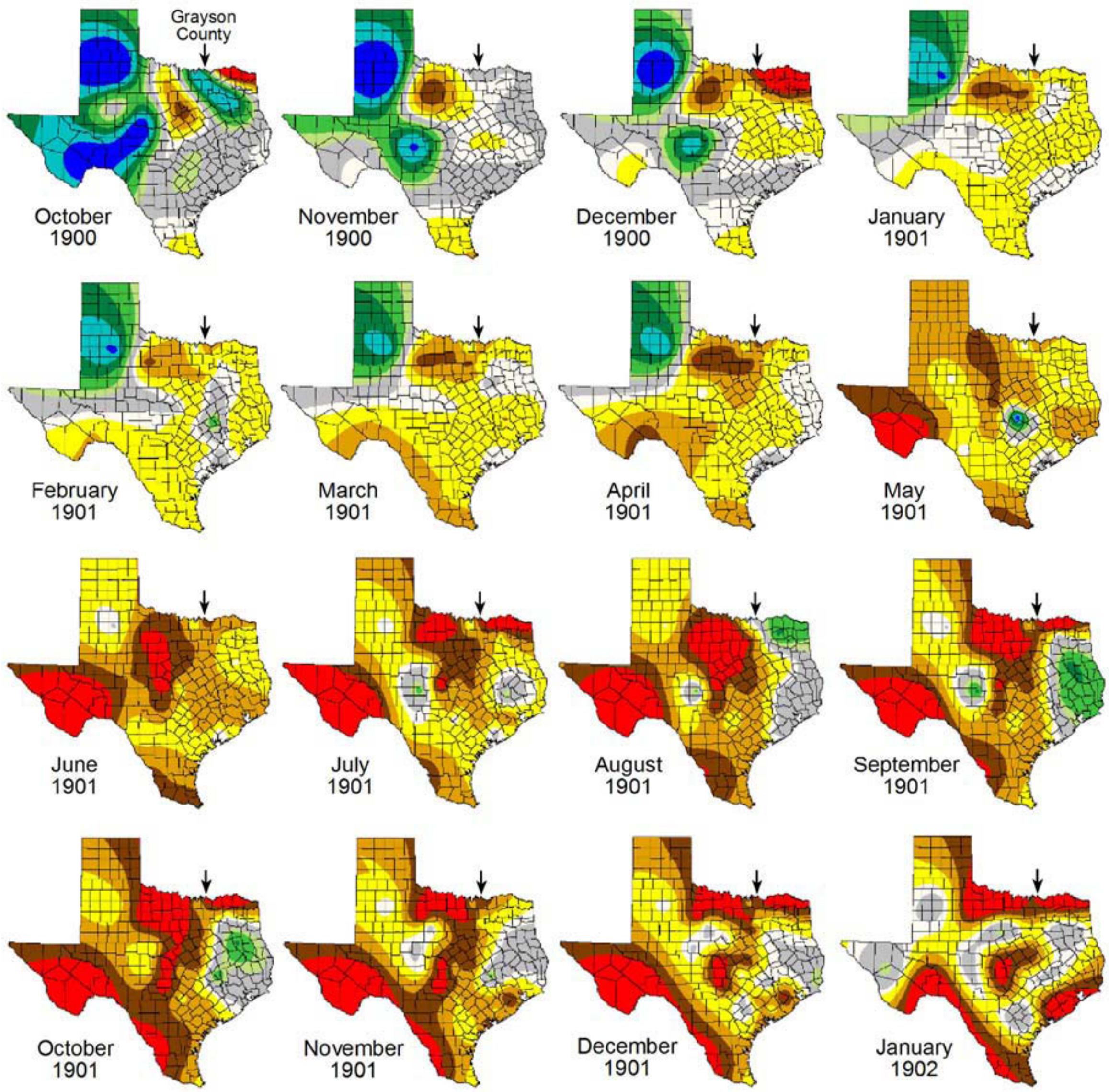

Figure 10: Palmer Drought Severity Index maps of Texas from October 1900 to September 1902 (maps from NADSS, 2004)(Continued on next page).

in the area in 1901. The newspaper refers to the KATY railroad digging a well in the bottoms of the Red River and piping 750,000 gallons a day of water to Denison in support of operations, a distance of about 2.5 miles. Could drought have been a factor in Mr. East's well and his neighbors' wells going dry?

Precipitation was about 10 to 15 percent lower than average for eastern Grayson County for 1896 to 1899 (Lowry, 1959, plate 2). In 1901, rainfall was about 30 percent lower than normal (Lowry, 1959, plate 3). Palmer Drought Severity Indices for the Denison area suggest that Grayson County was in moderate to severe drought conditions from December 1900 through August of 1902 (Figure 10). Although we do not know specifically how water in the Pawpaw

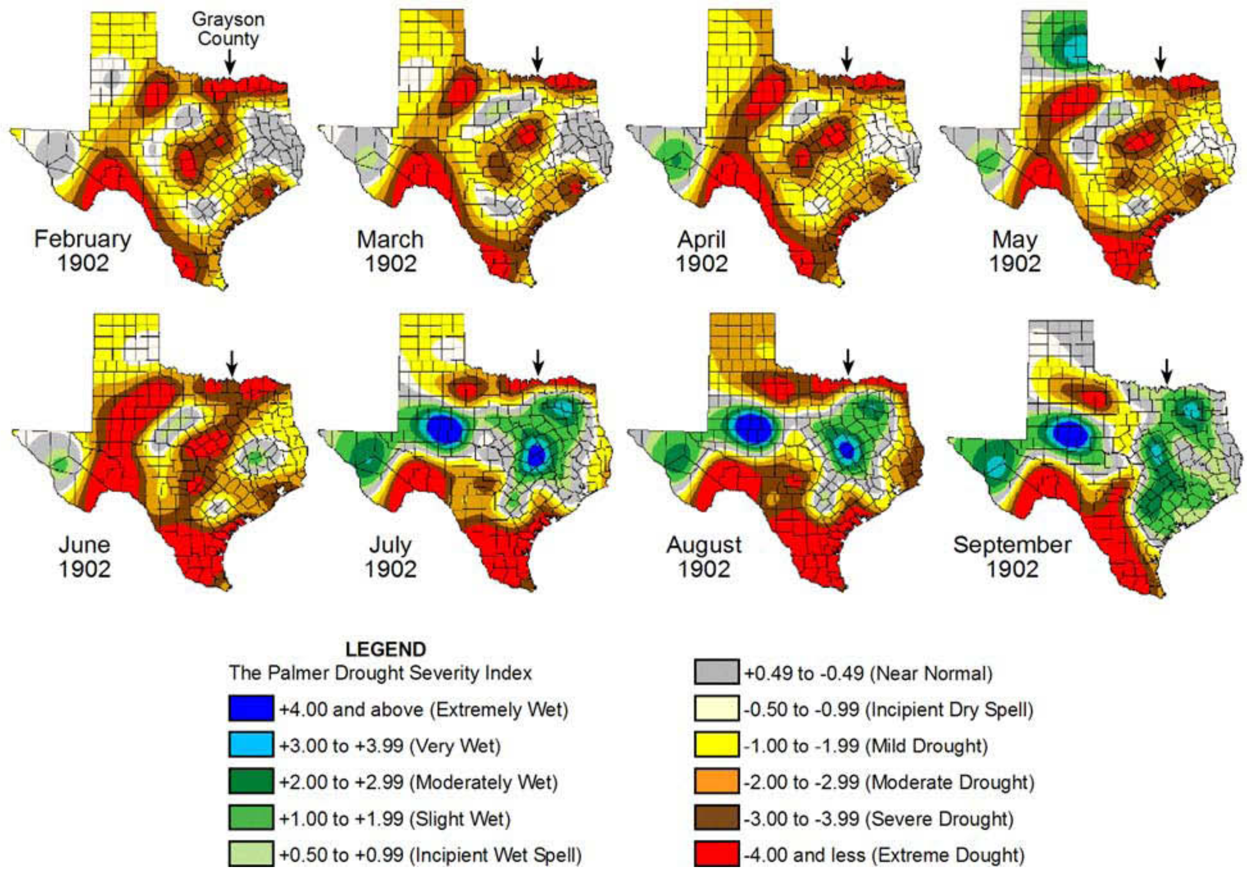

Figure 10: Continued.

Formation responded to this drought, we expect that water levels dropped in response to lower rainfall as is typical of shallow aquifers (for example, see Mace, 1998, and Wickham, 1991). Therefore, it is very likely that drought had an effect on water levels in the Pawpaw Formation and in the East well.

Conclusions

When the Texas Supreme Court ruled against Mr. East in 1904, it referred to language from an 1861 Ohio Supreme Court decision that described groundwater as "…secret, occult, and concealed…" By 1861, most scientists adhered to the percolation theory, which accurately described recharge, flow, and discharge of water in an aquifer. However, although Darcy's law had been established at that time, it was not until 1863 that it was used to describe groundwater flow to a well and 1870 that it was used to characterize aquifer properties and predict water-level declines. By 1904, the science of groundwater had progressed considerably. However, the propagation of hydrogeologic science to the general public was probably non-existent. Although aquifers are no longer secret and occult, they are often complex. Site-specific predictions of aquifer response often require site-specific information and analysis.

Without site-specific information, it is impossible to assess whether or not the well dug by the Houston and Texas Central Railroad caused Mr. East's well to go dry. However, it does appear reasonable that pumping of the Railroad well would have caused water levels to decline in a well on Mr. East's property, although probably not by itself to the level of causing the well to go dry. Water levels in the shallow aquifer probably also declined due to a drought the area experienced from December 1900 through August of 1902.

Acknowledgments

A number of people in Denison were very helpful in our investigations of the Railroad and East wells, including Mr. Kurt Kemp and Ms. Genevieve Hoover at the Eisenhower Birthplace State Historical Park for our initial orientation and viewing of historical maps; Mrs. Robert Riggins at 201 East Morgan, who lived across the street from Mrs. East, for information about the East property; Mr. Chuck Pool, who currently owns the land the Railroad well was located on; Mr. Frank Watkins of Denison for walking the site with us; and staff at the Denison Public Library, Grayson County Courthouse, and Red River Historical Museum for access to materials.

We also thank Mr. Robert Bradley for generating the Palmer Drought Severity Index maps; Mr. Doug Coker for assistance with maps and well files; Mr. Randy Larkin for French translations and discussions; Mr. Richard Preston for discussions on old railroads and books on Denison; staff at the Texas State Library and Archives Commission for assistance with the original East case materials; and Ted Angle, Bill Mullican, and Ruben Ochoa for helpful reviews and comments. We are particularly grateful to Robert Flores and Suzanne Schwartz, both lawyers, for their reviews and discussions of the legal references in this paper.

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Endnotes

[1] The Handbook of Texas

[2] The Handbook of Texas

[3] The Handbook of Texas

[4] Information in this paragraph comes from District Court (Grayson County) documents, including Mr. East's First Amended Original Petition and the Court's Findings of Fact. There are some disagreements between Mr. East's statement and the Findings of Fact. For this paper, we used the information in the Findings of Fact if there was disagreement.

[5] The Houston and Texas Central Railroad had been in Denison since 1873.

[6] Court documents suggest Mr. East owned and rented the property in question. Cemetery records show that Mr. William Alexander East was born on October 3, 1851, died in March of 1933, and married Ms. Dixie Owen.

[7] It is not clear from court documents when the neighborhood wells went dry. Pumping of the railroad well started in August 1901. Court documents filed for the Texas Supreme Court case show that Mr. East's First Amended Original Petition was filed December 16, 1902. However, the railroad's Original answer was filed April 5, 1902. This suggests that Mr. East filed his original petition sometime between August 1901 and April 1902.

[8] Court documents show the Findings of Fact and Conclusions of Law of the District Court referring to "W. A. East, et al," several case numbers, and several landowners and wells.

[9] *Houston & Texas Central Railroad .Company v. East*, 98 Tex. 146, 81 S.W. 279 (Tex.1904).

[10] An injury without a remedy.

[11] Correlative rights hold that when a source of water does not provide enough for all users, the water is reapportioned proportionally on the basis of prior water rights held be each user. The correlative doctrine of ground water rights means that lands overlying an aquifer can rightfully withdraw water from it, as long as similar use by other lands over the same aquifer is not injured.

[12] Tex. Const. Art. XVI, §59.

[13] Based on 2000 water use survey information collected by the Texas Water Development Board.

[14] See, for example, *Sipriano v. Great Springs Water of American, Inc.*, 1 S.W.,3d 75 (Tex. 1999).

[15] *Sipriano v. Great Springs Water of American, Inc.*, 1 S.W.,3d 75 (Tex. 1999) quoting *City of Corpus Christi v. City of Pleasanton*, 276 S.W.2d at 805-806.

[16] This section is based on summaries by Meinzer (1934), Jones and others (1963), Roshenshein and others (1976), Fetter (2003), and research by the authors.

[17] Biswas (1970) as summarized by Fetter (2001).

[18] Vitruvius may not have been the first to do this as some scholars believe he based his work on other work that existed at the time but is now lost. At a minimum, Vitruvius' work is the earliest identified to have survived to modern times.

[19] Court documents suggest that the Houston and Texas Central Railroad owned a "…railway which ran into the City of Denison from a southeasterly direction, crossing Owings Street and Lamar Avenue in a northwesterly direction…" However, the railway actually came into the town from the southwest and heads across town in a northeasterly direction. We believe that the incorrect directions may have been derived from the 1876 plat map which is oriented with north pointing to the left (Figure 6).

[20] Staff at the Red River Historical Center cautioned us that some artistic license was generally used when representing residential structures.

[21] We base this on a 1876 plat map we found at the county courthouse and on the 1914 Sanborn Fire Insurance map. The Sanborn maps suggest there was a Cooks Addition and a Cooks First Addition. Perhaps the Cooks First Addition came after the Cooks Addition and could therefore be interpreted as Cooks Second Addition.

[22] Volume 133, p. 380.

[23] Interestingly, Mr. East and his wife Dixie bought lot 16 on Block 5 of Cooks First Addition in 1904 (Figure 6). Sadly, that house was demolished only a few months before our trip to Denison. Mrs. Robert Riggins, who currently lives on the lot to the east across Lamar Avenue, remembers Mrs. East. She didn't recall Mr. East, but recollected that he worked for the railroad. We can probably safely assume he did not work for the Houston and Texas Central Railroad Company.

[24] McGowen and others (1991) refers to the Weno Limestone.

[25] Hydraulic conductivity is a measaure of how easily an aquifer can transmit water.

[26] Miller's spring, which initially supplied water to Denison in its early days, was located at 1401 West Walker Street (Maguire, 1991, p. 25). This spring likely flowed from the Pawpaw Formation and suggests that the water table could intersect the land surface of the Pawpaw Formation. On our trip to Denison, we noted that Pawpaw Creek was flowing. However, it was unclear if this was natural discharge from the aquifer or anthropogenic flow from the urban landscape.