FACING REALITY: AGRICULTURE WITHOUT THE OGALLALA AQUIFER

A COMPARITIVE STUDY:

THE TEXAS PANHANDLE

&

WESTERN AUSTRALIAN WHEATBELT

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– PROBLEM STATEMENT

Agriculture in the Texas Panhandle depends extensively on the Ogallala Aquifer for its water needs and is on path to be completely depleted. Once emptied, hydrogeologists estimate it could take over 6,000 years to fully recharge (Brambila 2014). Parts of the Texas Panhandle have already exhausted the aquifer for irrigation purposes. By 2050 the cost of extracting water from increasing depths could render the entire portion of the aquifer that lays beneath Texas economically exhausted. The high plains of Texas have no alternative aquifer, river, or lake that could provide similar volumes of water without being cost prohibitive. Despite this widely known forecast in and out of the region little research or planning exists for transitioning agriculture away from aquifer water. The only sustainable way forward is to return to "dryland" agriculture that relies natural rainfall swings. This research will contribute to this gap in policy and scholarly analysis through a comparative case study of the Western Australian Wheatbelt (WAW). It will illustrate what future agriculture yields and techniques could resemble in the Texas Panhandle and to suggest specific strategies for adaptation.

– FORWARD

I have a personal connection to both regions. Growing up in a small farming community in Central Texas, naturally I had several family members involved in some way with agriculture. Even though the Panhandle is over six hours away from Williamson County, many people including me would visit several times during the year. Buying or selling equipment or seeing extended family, the region was not the forgotten part of Texas to me. Flash forward more than a decade. I completed my undergraduate majoring in water resources, took a gap year, and very curiously wound up in Western Australia. Shortly after arriving I found work 3 hours outside of Perth on a family farm. I spent the next six months helping with the summer harvest and handling 7,000 head of sheep over 18,000 acres in the Wheatbelt Region. Conditions were harsher than most I had seen in Texas. Labor, material, and fuel costs were double or triple what I knew. The most fascinating part, the area was thriving and with less rainfall, surface water, or a usable aquifer.

After studying the Ogallala Aquifer in college, my outlook on the region was grim. I thought that the area would have a similar repeat to the Dust Bowl after the water was gone. Once I experience the WAW I had hope for the Panhandle and wanted to share my experience with farmers back home.

– INTRODUCTION

The Texas Panhandle Ogallala Region (TPOR) uses 90% of the water from the aquifer for agriculture which helps Texas' farmers produce over two billion dollars' worth of agricultural products every year. In addition, tens of thousands of individuals are directly employed on farms, and there are numerous other economic activities closely dependent on agriculture (Yates 2010). The panhandle also accounts for 15% of the entire United States' beef production from feed lots (Cavazos 2011), and beef production is highly dependent on groundwater. The area's future is not only important to Texas and the United States, but the entire world. If the panhandle was a country it would rank in the top 10 of beef and cotton production (Ernst 2013). It would also be in the top twenty in corn, wheat, and swine output (Colaizzi et al 2009). Scientists and people in the region know the aquifer is a finite resource that is being essentially mined for a one-time use, yet the extraction has not abated. Rates of depletion are at all record highs with no signs of slowing down.

This research has these main goals: Are WAW non-irrigated wheat yields and irrigated wheat yields in the TPOR comparable? If similar, are the two regions' spatial characteristics equivalent? What policy recommendations for adaption can be put forward?

The hypothesis going in is that dryland farming, along with a mixed farming technique will allow the TPOR agricultural economy to survive with some adjustment to current practices. The comparison should fail to reject the null and show that farmers in the panhandle who cannot irrigate in the future should expect similar income to farmers in the WAW.

- BACKGROUND

TEXAS PANHANDLE OGALLALLA REGION

The Texas Panhandle is in the top west part of the State of Texas, and its physical geography is unique to Texas. It has the undisputed north boundary of 36°30’ N. Its east and west boundaries are by most authorities the 100th meridian and the 103rd meridian, respectively (Rathjen 2017). The southern edge does not usually extend below 32° N. Most of the panhandle region is considered cold semi-arid (BSk) and humid subtropical (Cfa) on the Köppen climate classification. The boundary for the TPOR was created for this study using the 49 counties that have at least a portion of the aquifer underneath them. The TPOR defined as such comprised an area of 70,362 square miles or 182,236 square kilometers.

Native Americans inhabited the area for thousands of years before the final United States colonization after the American Civil War in the 1870s. With the country reunified and increasing railroad routes Anglos steadily moved into the area (Rathjen 2017). The discovery of oil in the 1920s enriched the area, but the 1930s Dust Bowl devastated the agriculture of the region. After WWII (1939-1945) new technologies for the first time allowed pumping massive amounts of water from the Ogallala for agriculture (Braxton 2009). In 1930 there were less than a hundred irrigation wells, and by 1954 there were nearly 30,000 wells irrigating over 3 million acres (Colaizzi 2009). The previously marginal farm lands were turned into a fertile oasis. The new-found water source, along with other factors, led to a dramatic increase in cattle feedlots as well (Rathjen 2017). Today, the area has a strong agriculture sector, vibrant business, petroleum industry, wind energy, and huge solar energy potential. However, it does face the same problem of population loss that many rural areas in the United States struggle with. The rapid decline of the Ogallala Aquifer is the existential threat that looms over the region.

Agriculture in the panhandle is heavily reliant on irrigation due to the arid climate receiving around twenty inches of rainfall each year. The lack of major rivers and lakes forces farmers to almost exclusively rely on the aquifer (Cavazos 2011). Farmers in the region earn on average nearly $500 more per acre over ordinary crops relying on rain fall alone (Yates, Smith, and Pate 2010). In 2006 cotton was the most abundant crop using irrigation, with nearly two million acres planted. In second place, winter wheat had around a million acres in irrigated. Other irrigated crops include corn, grain sorghum, peanuts, soybeans, and silage (Colaizzi et al. 2009).

Current Texas law allows owners with water rights to pump as much as they want, when they want (Texas A&M University 2014). As the water table drops, the cost of bringing water to the surface increases in conjunction with a decrease in total water quantity. Usually, irrigation must use extremely inexpensive water for it to be financially viable.

OGALLALA AQUIFER

The Ogallala Aquifer (sometimes called the High Plains Aquifer) is one of the largest bodies of fresh water in the world. As the Rocky Mountains formed toward the west, erosion carried sediment east creating a great plain with loose sand and gravel underneath (Steward and Allen 2016). Ancient rivers then filled the gaps between the sand and gravel creating the Ogallala Aquifer. Most of the water has been undisturbed for the last three million years (Little 2009). Due to surface conditions, climate, and geology, the aquifer overall recharges less than one inch a year (Tidwell et al. 2016). This effectively makes the water a finite source that is non-renewable. When it was first discovered in the United States Geologic Survey near the end of the 19th century, water could only be extracted in small quantities by windmill pumps. The vast quantity was known but the technology to extract it on a large scale was lacking. That technology finally arrived after WWII (1939-1945) in the form of better pumps and center pivot irrigation systems (Tidwell et al. 2016).

The aquifer is split geologically in three areas, the Northern High Plains, the Central High Plains, and the Southern High Plains. While the whole aquifer is connected, it is divided into different formations. The Ogallala section accounts for three quarters of the total area, with several smaller aquifers making up the total (Smidt et al 2016).

The water is accessible from at depths ranging from 100ft to over 1,000 and has an estimated total volume of nearly 3 billion acre-feet of water as of 2011(Tidwell et al. 2016). An acre-foot of water is one acre of land covered in one foot of water or about 326,000 gallons. Three billion acre-feet is roughly the same size as Lake Huron. To put it another way, if the all the water was brought to the surface a foot and half would cover all 50 United States (Little 2009).

The aquifer lies under eight US states Nebraska, Texas, Kansas, Oklahoma, Colorado, Wyoming, New Mexico, and South Dakota (Colaizzi et al. 2009). Figure 1. illustrates the full aquifer boundaries and all eight states that sit above. Underlying over 110 million acres or about 175, 000 square miles (Tidwell et al. 2016) it is an area larger than the state of California. The latest survey of the entire aquifer was performed in 1980 by the USGS. Nebraska has the highest percent of the total aquifer area at 36%, the largest volume of drainable water slightly over 2 billion acre-feet, and the highest saturated thickness of 342 ft. Texas is second in total aquifer area of the eight states at around 20%, and volume of drainable water at 390 million acre-feet. However, Texas comes in sixth in average saturated thickness at 110 ft (Tidwell et al 2016).

Over 15 million acres of cropland were irrigated across the Ogallala Aquifer region in 2007 (Tidwell et al. 2016) with 97% coming from the aquifer (Smidt et al. 2016). The region accounts for around a quarter of the United States' agriculture production, twenty percent of all its irrigated cropland, more than a third of the entire United States feedlot beef production and drinking water to over two million people (Tidwell et al. 2016).

WESTERN AUSTRALIA WHEATBELT (WAW)

Although the Colony of Western Australia was established in 1829, agriculture did not fully develop until after World War I. In fact, colonial records indicate that Western Australia was still importing wheat to feed its population until 1910. Given the difficulties of establishing a distant colony with harsh weather condition, agriculture producers have historically worked cooperatively with government agencies. Railroads, aqueducts, crop research studies, and land development plans were all directed with the intention of fostering agriculture. Today Australia is the 4th largest wheat exporting country in the world. With Western Australia its top wheat producing state, and the majority coming from inside the WAW, it is a breadbasket of the world.

The WAW varies in geographic location slightly depending on which Australian government agency is involved. The general area stretches over 150,000 square kilometers in the south west of the state of Western Australia. For this study the boundary is delineated by the Australian Bureau of Statistics with and exact area of 197,345 square kilometers or 76,195 square miles. In 2013 it had a population of around 75,000 with modest increases projected for the future. The economy is highly mixed with significant employment in forestry, mining, tourism, retail, and agriculture. However, agriculture is the dominate industry, accounting for a quarter of employment and valued over three billion dollars (Government of Western Australia 2014). Figure 2 shows the WAW boundaries used in this report.

– LITERATURE REVIEW

OGALLALA AQUIFER'S DEPLETION AND IMPACTS

Extensive irrigation with water from the aquifer began in the 1950s, and by the 1970s concerns about the sustainability of the resource began. The natural recharge rate was completely outpaced by withdrawals for irrigation. Water level declines over 100ft in Texas, Kansas and Oklahoma were observed by 1980 (Tidwell et al 2016). Some fears subsided when the water level fell at a slower rate in part due to new more efficient irrigation technology. However, at the same time gains were being made in efficiency, more wells were being installed, which caused further declines in water volume (Allen et al. 2007).

The aquifer, managed differently by each state, has different hydraulic characteristics in different locations, and future climate change impacts are unknown. What is certain is substantial areas have seen the aquifer decline so much that irrigation is no longer feasible (Cotterman et al. 2017). Across the aquifer, timelines to depletion vary from 25 years to some areas in the north that might sustainable. One report suggests that the southern and central portions will have less than 50% of their land that can support the irrigation by 2025 and 2065, respectively (Smidt et al 2016).

Groundwater law typically follows the rule of capture, riparian rights, prior appropriation, or a mix of the last two. Riparian rights (aka reasonable rights) follow that only a portion usually corresponding to the size of the surface area owned will be allocated. Many western US states use prior appropriation law to govern groundwater which states that the first person to "beneficially" use the water has the continuing right to that water. The rule of capture/absolute ownership place no restrictions on groundwater pumping (Cech 2010). It is sometimes called the law of the biggest pump. If one neighbor has a larger or deeper well that causes someone adjacent to run out of water, it is perfectly legal. Texas is the only state that uses the rule of capture. A 1904 Texas Supreme Court case made the rule of capture official law and decided that surface water and groundwater are separate. Surface water is the property of the state and groundwater is the property of the individual landowner whose property overlays it. The owner does not need a permit to drill or pump and can use as much water as they deem necessary, even at the expense of their neighbors (Texas A&M University 2014). Some areas in the panhandle still have this completely uncontrolled form of the rule of capture. However, given the problems that arose from the rule of capture the Texas Legislature created locally based groundwater conservation districts GCDs as a way to regulate groundwater. The first GCDs were created over the Ogallala in the panhandle in the 1950s (Texas A&M University 2014). Several GCDs now very lightly regulate the groundwater of the area. However, they each have a different desired future condition that they want for their water and treat the aquifer as independent of the area outside their authority.

By one estimate more than half a billion acre-feet of the aquifer has been pumped out. The same research estimated that more than half of the 3 billion acre-feet left in the aquifer is too deep and has such marginal quality that it will not be used for irrigation (Glennon 2002). Other research states that that less than 10% of the total water has been used from before the advent of modern irrigation to 2011 (Tidwell et al. 2016). Overall the literature is promoting conservation through technology, innovation and crop changes. The reports conflict each other on the total amount of water that has been used, and when it precisely will run out for any given location.

WAW/TPOR COMPARISON & DRYLAND FARMING STRATEGY

There are no known case studies that examine similarities or differences between the TPOR and the WAW. Western Australia agriculture represents only a portion of the total Australian agriculture output which is wrongly considered a minor player when in the global market. The general impressions of the Australian continent being desert like, and the extreme geographic remoteness of the wheatbelt means even its existence is not likely known to many people in the United States.

The few agriculture comparison studies over the Texas Panhandle focus on the potential reduction in irrigation use or a complete switch to dryland farming (Yates, Smith, and Pate 2010). One study examines the possible impacts of using livestock in a more combined manner (Allen et al 2007). It determines that it could increase production over monocropping dryland farming alone. This is like what occurs in Australia, but, again, no other area is referenced or analyzed.

– RESEARCH METHODS

The research only examined the 49 counties that overlay the aquifer completely or partially represented by TPOR, shown in figure 3. The WAW is delineated using the Government of Australia's Bureau of Statistics boundaries. Figure 4 shows an equal scale side by side comparison of the two study areas.

The *Mean Center Analysis* tool in ArcMap was used to generate the geographic center of each area. Next, the nearest town large enough to have accurate weather data was determined. Using weather data from each town provides an extremely basic comparison between each area. See Table 4.

Climate data on the WAW was obtained from the Australian Government Bureau of Meteorology online. A Köppen climate map review found the WAW is comprised of Csb, Csa, BSk, and BSh climates. Using data from the Texas Natural Resource Information System the climate zones for the TOPR showed Cfa, BSk, BSh, and BWh climates.

The Census of Agriculture is a comprehensive report of all agricultural land that has more than $1,000 worth of animal or plant product sold in the United States. The US Department of Agriculture conducts the census once every five years, and, like the US decennial census, responses are required by law. Between reports, less comprehensive annual statistics are also available. The report segments Texas down to the county level. It has irrigated, and non-irrigated acreage planted, and total weight in pounds for every crop produced.

Yearly totals for each county in the TPOR were obtained from the USDA National Agricultural Statistics Service annual reports and entered ArcMap via an Excel spreadsheet. The processes took a considerable amount of time. With out the aid of an advanced search tool on the USDA website or knowledge of Python the values were entered manually. One at a time.

– RESULTS

The numbers show that the TPOR is averaging 2,380 lbs. per acre of wheat harvested under irrigation. The WAW is averaging 1,492 lbs. per acre of wheat harvested land NOT under irrigation. So, the WAW is producing 38% less wheat per acre than the irrigated portions in the TPOR. This is in a range that would suggest a comparison could be drawn from the two areas. A decrease in revenue of 38% would be dramatic for any farmer, but likely survivable with the right planning and support.

The possibility of examining the added economic benefits of livestock in the WAW did not come to fruition. While there are data over livestock, it could not be determined how to analyze it during this research.

Table 4. indicates that spatially the two areas are more similar than dissimilar. Temperature, rainfall, Latitude/Longitude, and elevation of the mean center of the areas are very similar.

– LIMITATIONS

The study relies exclusively on secondary source quantitative data and does not tell the whole story. A survey of some type in conjunction with the hard numbers would help better explain the mentality of the farmers in the TPOR, which would greatly help the policy decision. The averages on irrigated acres of wheat planted sometimes varies from no acres planted to the following year over a hundred thousand acres planted. Why are the fluctuations so extreme? What programs have helped the farmers who have already lost their water supply? The questions go on with no answer. A simple phone interview with local stakeholders in the region could fill the gaps in the vast amount of quantitative data available.

Wheat compared to wheat is a good first comparison, but cotton is the main source of income and most likely water usage in the TPOR. Comparing wheat to cotton and every other crop must be completed to better predict the future. Farm size, demographics, government support, specific wheat varieties used, and climate impacts are critical to understand agriculture. Again, none were accounted for.

– DISCUSSION

The parallels with the WAW should provide clear evidence that the loss groundwater irrigation will not be the end of modern agriculture in the panhandle. For the last seventy years water from the aquifer has provided a cushion from drought and above normal crop yields. Farmers who survive will be the ones who recognize that they are going to have to diversify, work harder, and have some bad years.

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– TABLES

Area (ha) 2011	Area (acres) 2011	Production (t) 2011	Production (lbs) 2011	Yield (t/ha) 2011	Yield (lbs/acre) 2011
3322744	8031238	3016817	6650943004	0.908	828
Area (ha) 2012	Area (acres) 2012	Production (t) 2012	Production (lbs) 2012	Yield (t/ha) 2012	Yield (lbs/acre) 2012
3718425	9188428	7662007	16891836858	2.061	1838
Area (ha) 2013	Area (acres) 2013	Production (t) 2013	Production (lbs) 2013	Yield (t/ha) 2013	Yield (lbs/acre) 2013
3520055	8698245	4612388	10168576669	1.31	1169
Area (ha) 2014	Area (acres) 2014	Production (t) 2014	Production (lbs) 2014	Yield (t/ha) 2014	Yield (lbs/acre) 2014
3587099	8863914	7221214	15920054472	2.013	1796
Area (ha) 2015	Area (acres) 2015	Production (t) 2015	Production (lbs) 2015	Yield (t/ha) 2015	Yield (lbs/acre) 2015
3587724	8865459	6506141	14343588089	1.813	1618
Area (ha) 2016	Area (acres) 2016	Production (t) 2016	Production (lbs) 2016	Yield (t/ha) 2016	Yield (lbs/acre) 2016
3149464	7782495	5464741	12047693697	1.735	1548
Area (ha) 2017	Area (acres) 2017	Production (t) 2017	Production (lbs) 2017	Yield (t/ha) 2017	Yield (lbs/acre) 2017
3144959	7771362	5816540	12823277864	1.849	1650

Table 1

OBJECTID	CNTY_NM	acres_17	acres_16	acres_15	acres_14	acres_13	acres_12	acres_11	acres_10	acres_09	acres_08	bushels_17	bushels_16	bushels_15	bushels_14	bushels_13	bushels_12	bushels_11	bushels_10	bushels_09	bushels_08	average_bushels	total_bushels	average_acres
103	Andrews	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
116	Borden	0	0	0	0	0	0	0	12200	16700	0	0	0	0	0	0	0	0	178000	85000	0	26300	263000	2890
118	Dawson	5000	0	0	0	49000	0	0	11000	19100	19000	61000	0	0	0	813000	0	0	27200	62000	344000	130720	1307200	10310
119	Gaines	21700	0	0	0	106000	0	0	0	0	10400	272700	0	0	0	458000	0	0	0	0	29000	75970	759700	13810
151	Glasscock	10800	8300	0	0	14901	6001	0	12701	23501	0	161000	136000	0	0	42701	28101	0	214101	102201	0	68410	684104	7620
152	Midland	0	0	0	0	0	0	0	11400	0	0	0	0	0	0	0	0	0	95500	0	0	9550	95500	1140
153	Ector	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
155	Winkler	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
174	Howard	0	8400	0	0	0	0	0	0	25800	0	0	33500	0	0	0	0	0	0	19000	0	5250	52500	3420
175	Martin	0	0	0	0	12500	0	0	0	20700	0	0	0	0	0	27000	0	0	0	36700	0	6370	63700	3320
184	Garza	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
185	Lynn	10500	11600	14000	18000	20300	8900	0	11000	27300	4500	55000	166000	180000	85000	155200	36300	0	167000	220000	12000	107650	1076500	12610
187	Hockley	0	14500	0	0	0	0	12000	20900	0	12700	0	53400	0	0	0	0	28900	165000	0	32000	27930	279300	6010
188	Cochran	5200	9100	6500	0	0	0	0	10000	26100	0	27500	72000	95000	0	0	0	0	143000	201600	0	53910	539100	5690
199	Motley	0	0	0	0	0	0	0	13200	0	0	0	0	0	0	0	0	0	34000	0	0	3400	34000	1320
200	Floyd	80000	80000	92500	96000	0	68000	55000	81000	85000	100000	964000	1530000	2287000	213000	0	132000	93500	2053000	480000	1330000	908250	9082500	73750
201	Hale	0	0	0	0	0	27000	16000	32000	41000	34000	0	0	0	0	0	20000	32600	776000	92000	149000	106960	1069600	15000
202	Lamb	0	19000	17700	0	0	40000	16400	60000	27600	72300	0	83000	80000	0	0	551800	40000	1724000	15000	2102000	459580	4595800	25300
203	Bailey	39000	43200	21000	41500	0	51000	0	39000	67200	0	360000	392000	297000	148000	0	151800	0	638000	231700	0	221850	2218500	30190
206	Terry	0	0	0	0	0	0	0	21000	78400	15300	0	0	0	0	0	0	0	362000	457000	82000	90100	901000	11470
207	Yoakum	21800	0	0	0	0	0	39100	0	42800	7300	148000	0	0	0	0	0	234000	0	351900	13000	74690	746900	11100
221	Dickens	8700	0	10900	12000	0	0	23000	23000	26600	18000	58000	0	136800	14500	0	0	18500	117000	106000	36000	48680	486800	12220
223	Crosby	12400	25000	0	0	33400	21200	19600	24000	29500	21900	62000	152000	0	0	31900	125900	25300	332000	56000	87000	87210	872100	18700
224	Lubbock	9800	10000	13200	9000	20800	0	6600	16000	22000	23500	43000	29000	185500	36000	20700	0	1200	131000	45000	69000	56040	560400	13090
228	Carson	56300	82500	97300	85000	69000	91100	63000	85600	75000	71800	1438000	1687000	2384000	870000	294000	2317000	707000	3241000	1199000	724000	1486100	14861000	77660
229	Potter	11600	12600	14900	0	0	14200	12400	14400	15600	13200	157000	287000	242000	0	0	97500	40700	268300	50100	30000	117260	1172600	10890
230	Oldham	40000	40000	42200	0	43700	44000	37400	46000	46300	42200	243500	907000	771500	0	77800	68500	136500	517000	237200	151000	311000	3110000	38180
231	Hemphill	7900	9600	12000	11000	15500	13400	13200	16900	16300	13500	111000	192000	98000	56600	66400	237000	143000	248200	112700	190000	145490	1454900	12930
232	Roberts	0	6500	11200	0	8100	12000	9600	10700	8400	6600	0	102000	135000	0	142800	131000	118500	249800	65000	65000	100910	1009100	7310
233	Hutchinsor	28000	39000	43000	44000	0	63000	51000	59000	61000	56700	257000	495000	128000	84000	0	957000	189000	1109000	870000	153000	424200	4242000	44470
234	Moore	84000	69000	78000	116000	110000	74000	57000	68000	77000	76400	1415000	1220000	800000	1680000	1139000	264000	59000	1417000	890000	288000	917200	9172000	80940
235	Hartley	0	0	0	0	0	22000	17000	77200	28000	27400	0	0	0	0	0	270000	77000	2777000	330000	122000	357600	3576000	17160
237	Hall	17800	0	0	0	0	16000	14100	23000	26700	0	83000	0	0	0	0	60400	30300	275000	160000	0	60870	608700	9760
238	Briscoe	42800	41600	50000	0	44000	40000	32400	47100	42000	44300	484000	371000	512000	0	7000	84000	51800	797000	87000	516000	290980	2909800	38420
239	Swisher	147000	138500	159000	176000	0	148000	123000	146300	123000	127000	2604000	2440000	1651000	637000	0	589000	412000	3875000	116000	332000	1265600	12656000	128780
240	Castro	0	0	128000	0	0	0	71000	86000	78000	78400	0	0	2508000	0	0	0	138000	1357000	82000	210000	429500	4295000	44140
241	Parmer	148000	147500	158000	174000	0	181000	105000	120000	115000	101000	1678000	2006000	2818000	683000	0	735000	193000	1866000	170000	263000	1041200	10412000	124950
242	Collingswo	0	39000	38000	35000	0	43600	29000	47000	42000	52000	0	235000	257500	107000	0	212200	11900	370000	260000	575000	202860	2028600	32560
243	Donley	9400	9700	12000	14200	16900	16900	11100	15900	0	10700	89500	103000	63600	58000	135000	50200	13200	196500	0	126000	83500	835000	11680
244	Armstrong	52400	57000	64000	57000	62000	62000	56000	60000	56600	61100	965500	1040000	1100000	180000	56000	448000	356000	1789000	542100	554000	703060	7030600	58810
245	Randall	97000	93000	105000	109000	107500	100000	94000	100000	95000	93300	1092000	1700000	1903000	77000	134400	486000	291000	2136000	270000	228000	831740	8317400	99380
246	Deaf Smith	145000	140000	170000	225000	226000	180000	128000	158000	145000	125000	1570000	2780000	4595000	1459000	738000	215000	333000	2556000	590000	430000	1526600	15266000	164200
247	Wheeler	14800	19300	25500	20000	21000	21300	18000	22000	20100	20900	135400	99000	184200	40000	85000	209000	44000	313900	65000	196000	137150	1371500	20290
248	Gray	32000	0	0	38000	43000	0	33000	38000	41000	39900	733000	0	0	239000	270000	0	192000	1190000	490000	618000	373200	3732000	26490
249	Sherman	51000	59000	131000	139000	0	79000	60000	74000	80000	68700	618000	1564000	3726000	2306400	0	434000	7200	1650000	1039000	391000	1173560	11735600	74170
250	Dallam	28000	30000	34000	144500	108000	42000	30000	39000	139600	36800	455000	760000	350000	2725000	917000	180000	32000	817000	3410000	107000	975300	9753000	63190
252	Lipscomb	19000	18400	24500	29400	31500	18000	16000	20000	32100	19100	340000	330000	411000	527000	291300	392000	170000	458000	640000	236000	379530	3795300	22800
254	Hansford	0	193000	153000	0	0	145000	115000	145000	154000	144000	0	6295000	751000	0	0	1797000	294000	3584000	3120000	371000	1621200	16212000	104900
253	Ochiltree	108000	110000	138000	130000	133000	140000	119000	138000	145000	28000	2897000	3492000	2450000	980000	650000	3368000	1914000	4308000	3400000	1240000	2469900	24699000	118900

Table 2

OBJECTID	CNTY_NM	acres_17	acres_16	acres_15	acres_14	acres_13	acres_12	acres_11	acres_10	acres_09	acres_08	bushels_17	bushels_16	bushels_15	bushels_14	bushels_13	bushels_12	bushels_11	bushels_10	bushels_09	bushels_08	average_bushels	average_acres	total_bushels
244	Armstrong	0	2400	3000	3900	2300	2600	2400	2800	0	0	0	90000	107000	92000	33000	41500	57200	123000	0	0	54370	1940	543700
203	Bailey	0	0	13200	0	0	0	0	29800	0	0	0	0	190000	0	0	0	0	548000	0	0	73800	4300	738000
238	Briscoe	0	0	3600	0	5400	2600	0	0	4500	0	0	0	75000	0	29900	35500	0	0	107500	0	24790	1610	247900
228	Carson	0	0	0	0	26500	0	9200	0	13000	15700	0	0	0	0	496000	0	234000	0	440000	348000	151800	6440	1518000
240	Castro	0	0	0	0	0	0	58500	70000	82000	84600	0	0	0	0	0	0	990000	2729000	3030000	2615000	936400	29510	9364000
188	Cochran	0	0	2800	0	0	0	0	7800	0	0	0	0	63000	0	0	0	0	209000	0	0	27200	1060	272000
242	Collingsworth	0	0	0	5700	0	0	3200	0	9200	0	0	0	0	21500	0	0	51000	0	380000	0	45250	1810	452500
250	Dallam	71000	97000	93000	0	0	72000	74500	75000	0	91200	3155000	3051000	3682000	0	0	1848000	2060000	2776000	0	3501000	2007300	57370	20073000
118	Dawson	8000	0	0	0	0	0	0	26800	22300	0	264000	0	0	0	0	0	0	393000	380000	0	103700	5710	1037000
246	Deaf Smith	54000	54000	49500	0	0	47000	58000	56000	72000	74000	1041000	3393000	2490000	0	0	995000	814000	2143000	1460000	1726000	1406200	46450	14062000
200	Floyd	8500	0	0	15000	0	17000	10000	13500	20100	0	183000	0	0	110000	0	243000	107000	492000	360000	0	149500	8410	1495000
248	Gray	4900	0	0	6000	6200	0	4000	5400	6700	6300	131000	0	0	186000	113000	0	106000	191000	182000	260000	116900	3950	1169000
201	Hale	0	0	0	0	0	33500	23000	31000	48000	48100	0	0	0	0	0	464000	328000	1113000	970000	2086000	496100	18360	4961000
235	Hartley	0	0	0	0	0	55000	52500	0	57000	65100	0	0	0	0	0	1080000	294000	0	2100000	2273000	574700	22960	5747000
233	Hutchinson	7100	10000	163000	17000	0	0	15000	17100	197000	183000	203000	373000	662000	630000	0	0	214000	690000	780000	564000	411600	60920	4116000
253	Ochiltree	17000	20000	24000	26000	29000	23000	21000	208000	23200	28000	866000	936000	1143000	1125000	968000	1140000	637000	896000	960000	1240000	991100	41920	9911000
245	Randall	7000	7000	6200	6700	0	7600	7400	7800	9000	13200	183000	183000	225000	125000	0	135000	120000	2136000	157800	318000	358280	7190	3582800
249	Sherman	40000	44000	0	0	0	54000	49300	54000	62000	73800	1795000	2290000	0	0	0	2320000	2232000	2585000	3060000	3246000	1752800	37710	17528000
239	Swisher	0	0	0	0	0	0	0	0	30600	30500	0	0	0	0	0	0	0	0	510000	1032000	154200	6110	1542000
206	Terry	0	0	0	0	0	0	0	68000	0	47600	0	0	0	0	0	0	0	693000	0	1303000	199600	11560	1996000
247	Wheeler	0	0	0	3300	2300	0	1600	0	1700	1200	0	0	0	0	0	0	0	0	37500	40000	7750	1010	77500

	harvested_17	harvested_16	harvested_15	harvested_14	harvested_13	harvested_12	harvested_11	harvested_10	harvested_09	harvested_08	yield_17	yield_16	yield_15	yield_14	yield_13	yield_12	yield_11	yield_10	yield_09	yield_08	average_yield
Armstrong	0	2200	2800	2700	1100	1500	2200	2500	0	0	0	40.9	38.2	34.1	30	27.7	26	49.2	0	0	35.15714286
Bailey	0	0	5000	0	0	0	0	13700	0	0	0	0	38	0	0	0	0	40	0	0	39
Briscoe	0	0	3000	0	2300	1700	0	0	3600	0	0	0	25	0	13	20.9	0	0	30	0	22.225
Carson	0	0	0	0	16000	0	9000	0	12000	12500	0	0	0	0	31	0	26	0	36.5	28	30.375
Castro	0	0	0	0	0	0	33000	55700	54200	49900	0	0	0	0	0	0	30	49	56	52.5	46.875
Cochran	0	0	2100	0	0	0	0	5800	0	0	0	0	30	0	0	0	0	36	0	0	33
Collingsworth	0	0	0	700	0	0	2000	0	7200	0	0	0	0	30.7	0	0	25.5	0	53	0	36.4
Dallam	45600	51000	62000	0	0	33000	51500	51400	0	80600	69.2	59.8	59.4	0	0	56	40	54	0	43.5	54.55714286
Dawson	4400	0	0	0	0	0	0	51	49.5	0	60	0	0	0	0	0	0	51	49.5	0	53.5
Deaf Smith	22500	46600	42500	0	0	21000	37000	45600	41900	43800	46.3	72.8	58.6	0	0	47.4	22	47	35	39.5	46.075
Floyd	4800	0	0	4500	0	9500	6300	12000	12700	0	38.1	0	0	24.4	0	25.6	17	41	28.5	0	29.1
Gray	4400	0	0	4600	4500	0	3200	5100	5600	4700	29.8	0	0	40.4	25.1	0	33.1	37.5	32.5	55.5	36.27142857
Hale	0	0	0	0	0	13500	8400	21400	29500	38900	0	0	0	0	0	34.4	39	52	33	53.5	42.38
Hartley	0	0	0	0	0	22500	45000	0	45500	45100	0	0	0	0	0	48	35	0	46	50.5	44.875
Hutchinson	5700	7700	15400	15000	0	0	6900	15000	17400	12800	35.6	48.4	43	42	0	0	31	46	45	44	41.875
Ochiltree	16700	17000	23300	22000	22000	19000	18200	19900	21000	24600	51.9	55.1	49.1	51.1	44	60	35	45	45.5	50.5	48.72
Randall	5000	3600	5500	2800	0	5200	4800	6600	6300	11200	36.6	50.8	40.9	44.6	0	26	25	42	25	28.5	35.48888889
Sherman	33000	33000	0	0	0	40000	37200	47000	59300	65700	54.4	69.4	0	0	0	58	60	55	51.5	49.5	56.82857143
Swisher	0	0	0	0	0	0	0	0	19500	26900	0	0	0	0	0	0	0	0	26	38.5	32.25
Terry	0	0	0	0	0	0	0	19800	0	33900	0	0	0	0	0	0	0	35	0	38.5	36.75
Wheeler	0	0	0	1000	1000	0	1200	0	1100	900	0	0	0	30	32	0	17	0	34	44.5	31.5

Table 3

	City of Tulia	Town of Corrigin
Average Rainfall (inches)	21.59 in.	14.8 in.
Average High in °F	72.3 °F	74.7 °F
Average Low in °F	42.2 °F	50 °F
Latitude/Longitude	34.5269 N, 101.839W	32.33 S, 117.88 E
Elevation (feet)	3,484 ft	968 ft
Average Annual Snowfall (inches)	15 in.	0 in.

Table 4

- FIGURES

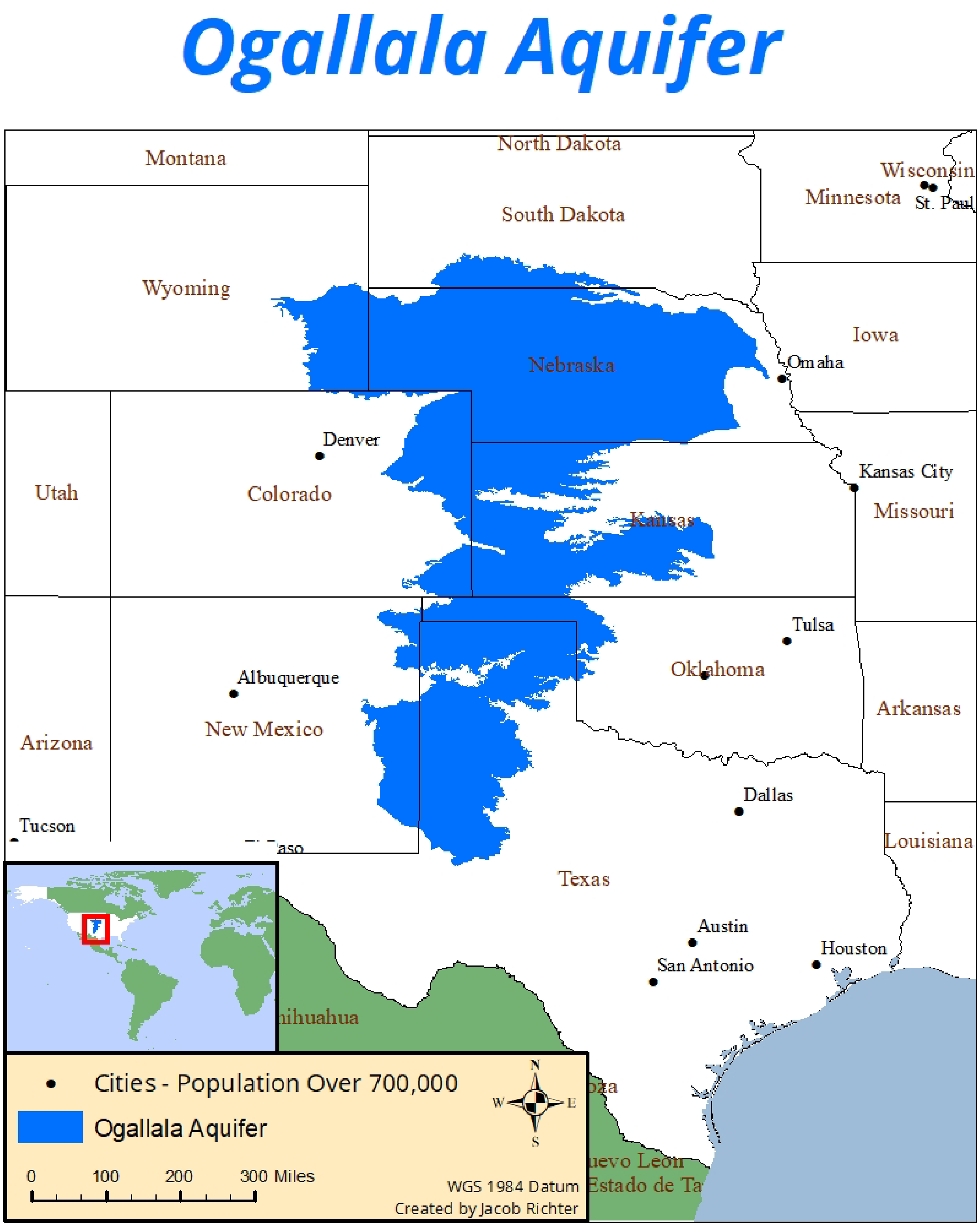


Figure 1

Western Australia - Wheatbelt

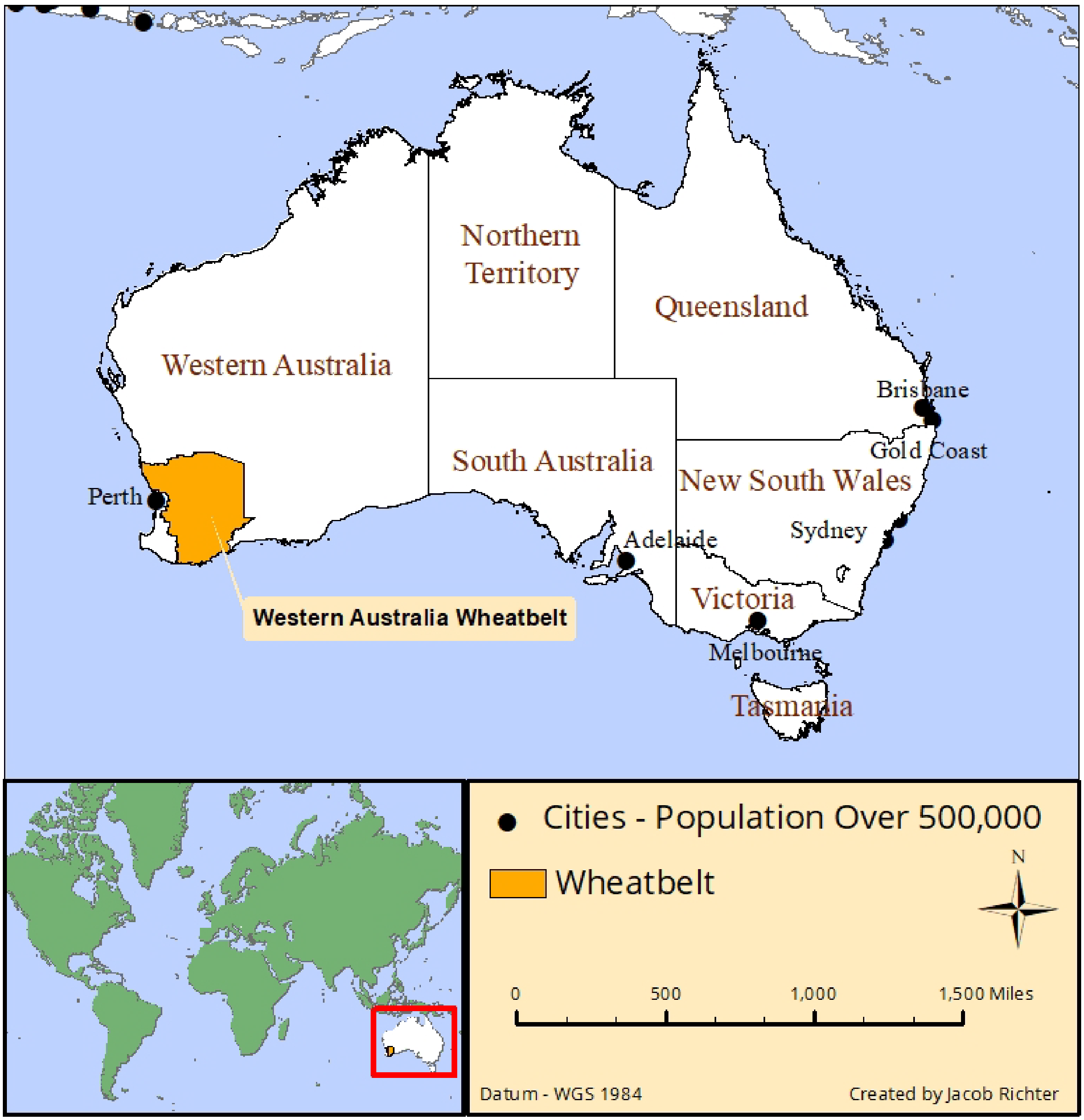


Figure 2

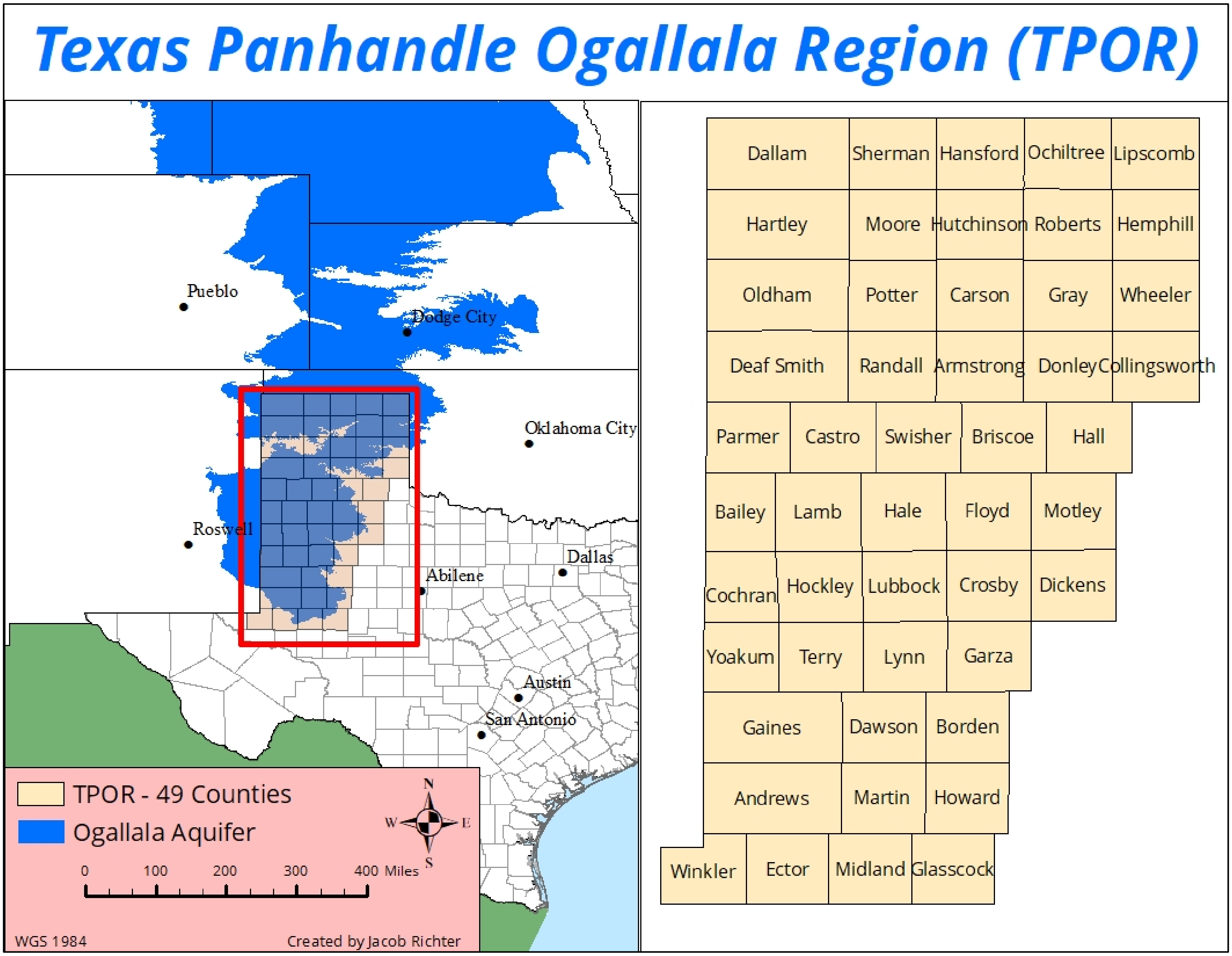

Texas Panhandle Ogallala Region (TPOR)
Pueblo
Dodge City
Oklahoma City
Roswell
Dallas
Abilene
Austin
San Antonio
TPOR - 49 Counties
Ogallala Aquifer
0
100
200
300
400 Miles
N
W
E
S
WGS 1984
Created by Jacob Richter
Dallam
Sherman
Hansford
Ochiltree
Lipscomb
Hartley
Moore
Hutchinson
Roberts
Hemphill
Oldham
Potter
Carson
Gray
Wheeler
Deaf Smith
Randall
Armstrong
Donley
Collingsworth
Parmer
Castro
Swisher
Briscoe
Hall
Bailey
Lamb
Hale
Floyd
Motley
Cochran
Hockley
Lubbock
Crosby
Dickens
Yoakum
Terry
Lynn
Garza
Gaines
Dawson
Borden
Andrews
Martin
Howard
Winkler
Ector
Midland
Glasscock

Figure 3

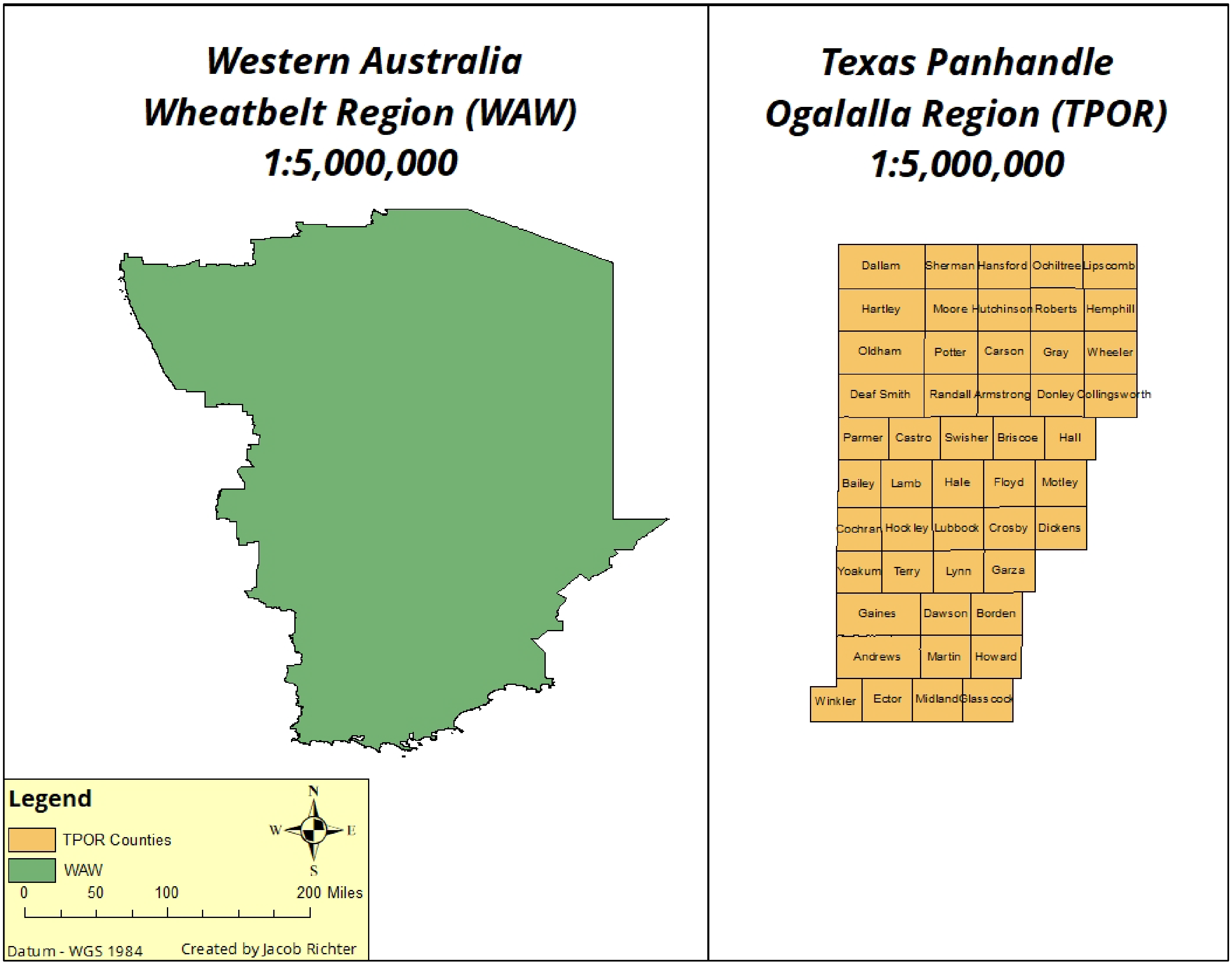

Western Australia
Wheatbelt Region (WAW)
1:5,000,000
Texas Panhandle
Ogalalla Region (TPOR)
1:5,000,000
Dallam
Sherman
Hansford
Ochiltree
Lipscomb
Hartley
Moore
Hutchinson
Roberts
Hemphill
Oldham
Potter
Carson
Gray
Wheeler
Deaf Smith
Randall
Armstrong
Donley
Collingsworth
Parmer
Castro
Swisher
Briscoe
Hall
Bailey
Lamb
Hale
Floyd
Motley
Cochran
Hockley
Lubbock
Crosby
Dickens
Yoakum
Terry
Lynn
Garza
Gaines
Dawson
Borden
Andrews
Martin
Howard
Winkler
Ector
Midland
Glasscock
Legend
TPOR Counties
WAW
N
W
E
S
0
50
100
200 Miles
Datum - WGS 1984
Created by Jacob Richter

Figure 4

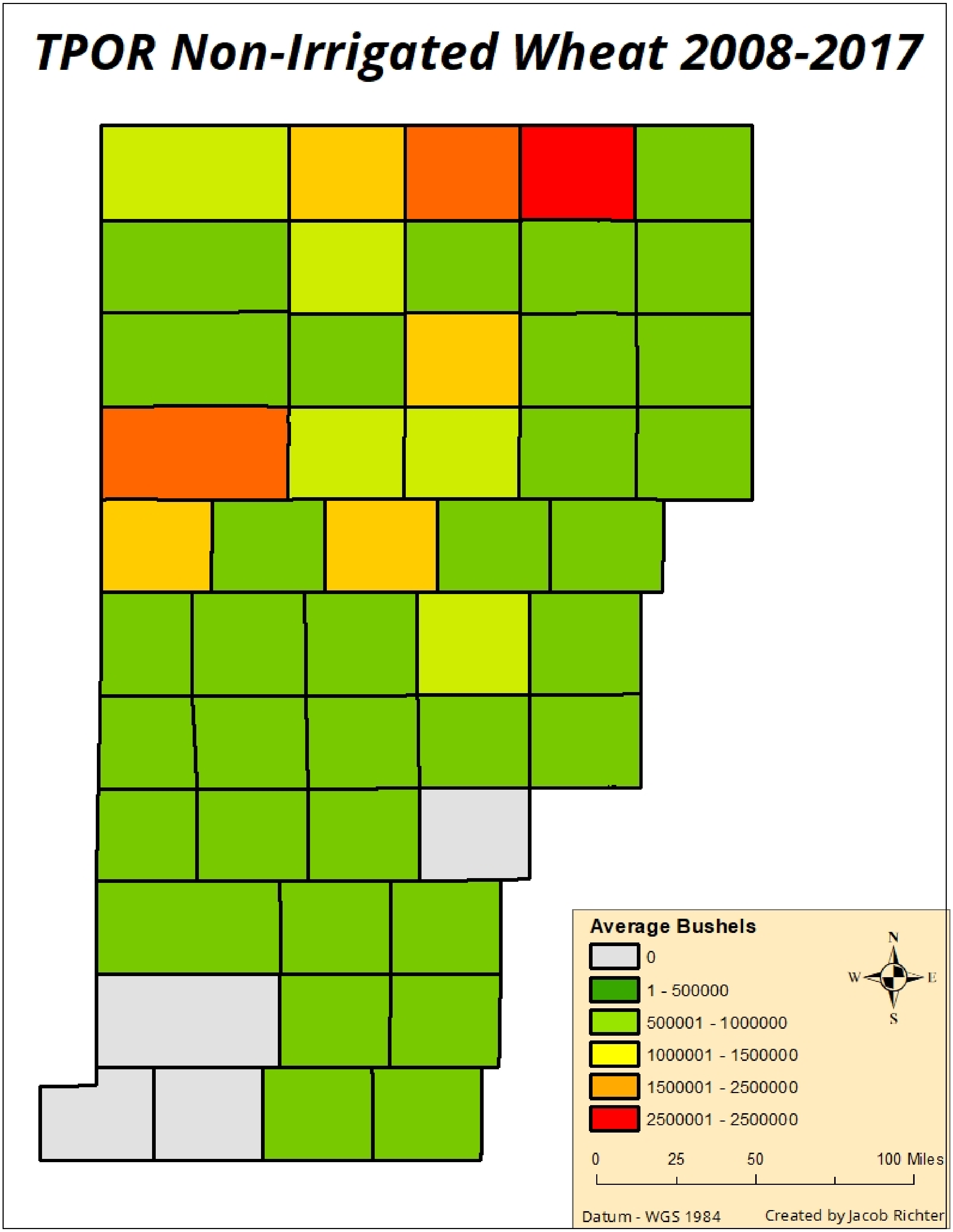

TPOR Non-Irrigated Wheat 2008-2017
Average Bushels
0
1 - 500000
500001 - 1000000
1000001 - 1500000
1500001 - 2500000
2500001 - 2500000
N
W
E
S
0
25
50
100 Miles
Datum - WGS 1984
Created by Jacob Richter

Figure 5

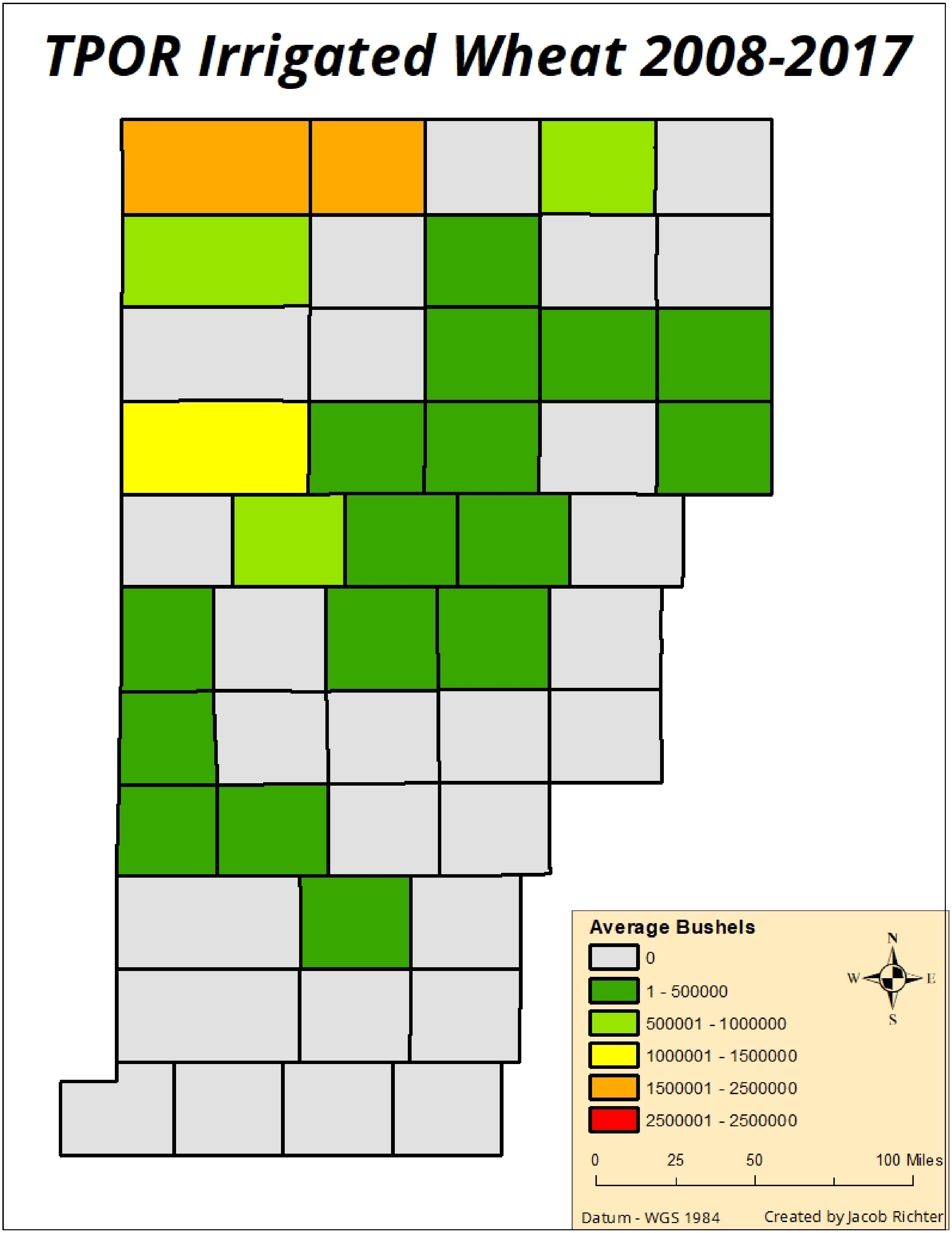
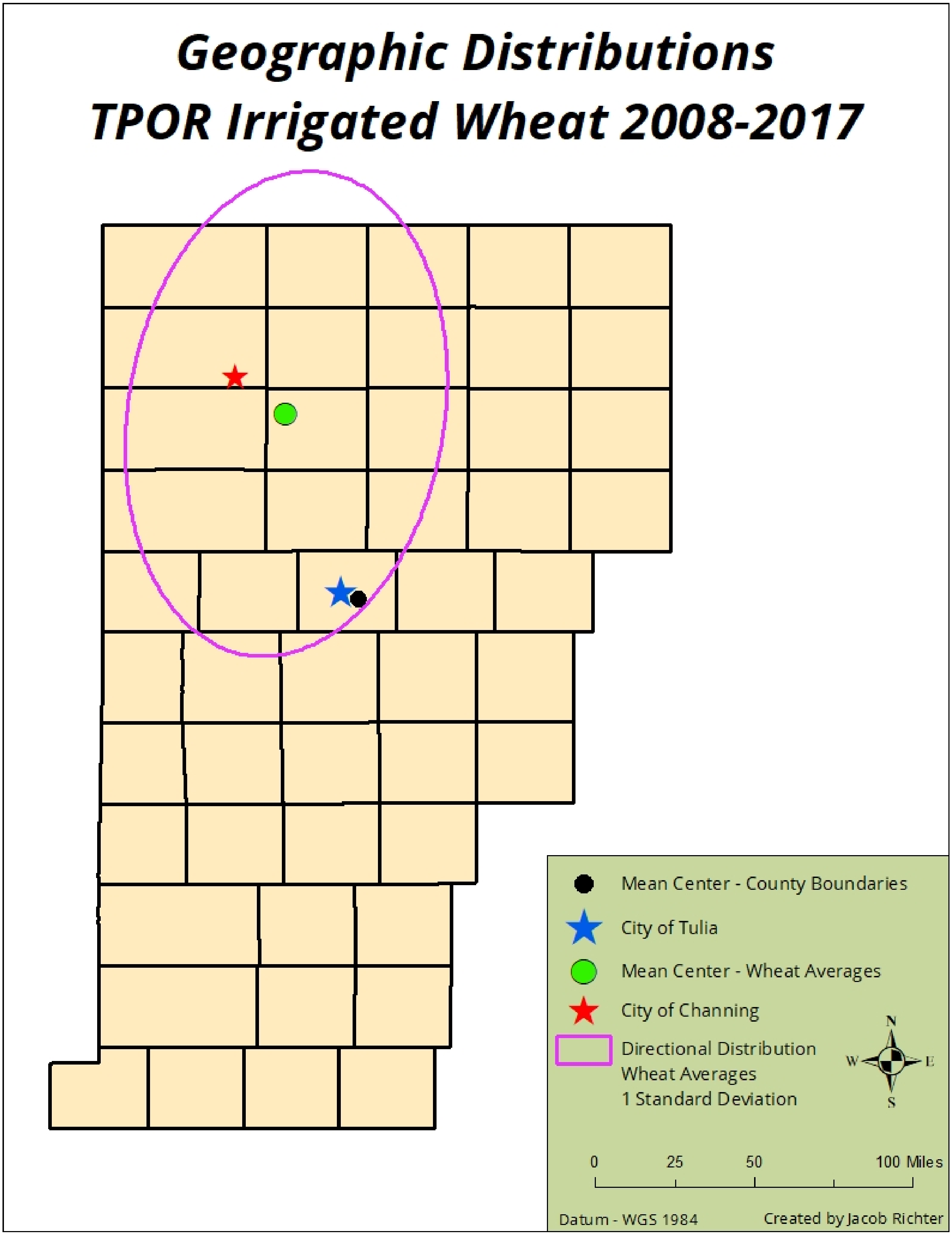

TPOR Irrigated Wheat 2008-2017
Average Bushels
0
1 - 500000
500001 - 1000000
1000001 - 1500000
1500001 - 2500000
2500001 - 2500000
N
W
E
S
0
25
50
100 Miles
Datum - WGS 1984
Created by Jacob Richter

Figure 6



Geographic Distributions
TPOR Irrigated Wheat 2008-2017
Mean Center - County Boundaries
City of Tulia
Mean Center - Wheat Averages
City of Channing
Directional Distribution
Wheat Averages
1 Standard Deviation
N
W
E
S
0
25
50
100 Miles
Datum - WGS 1984
Created by Jacob Richter

Figure 7

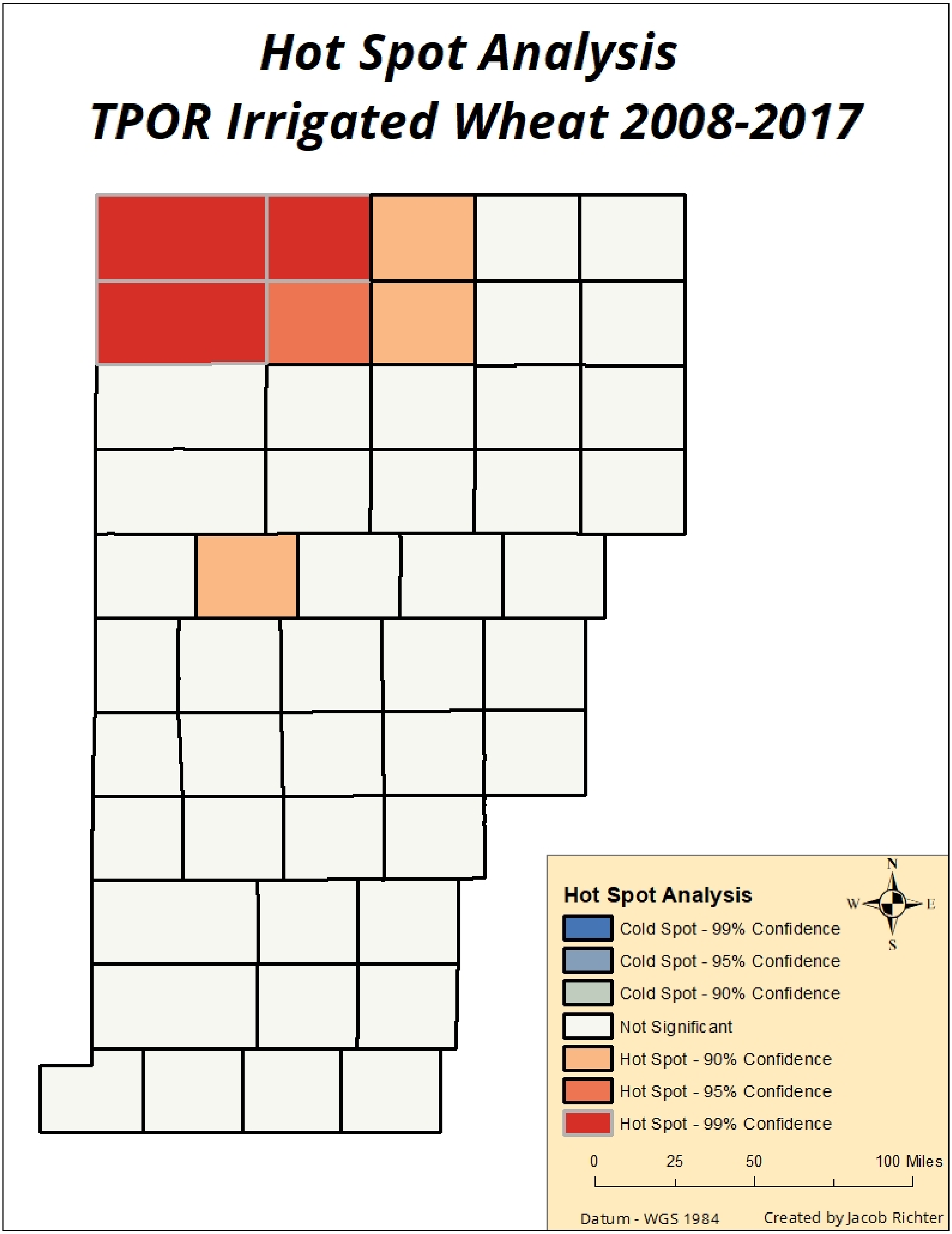

Hot Spot Analysis
TPOR Irrigated Wheat 2008-2017
Hot Spot Analysis
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
N
W
E
S
0
25
50
100 Miles
Datum - WGS 1984
Created by Jacob Richter

Figure 8