Groundwater Database for Kansas, New Mexico, Oklahoma and Texas

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Introduction

A key objective of the USDA funded Ogallala Aquifer CAP project is to integrate hydrologic, crop, soil and climate models across the High Plains (Ogallala) aquifer. A major step of this model building process is compilation of historical groundwater data necessary to calibrate and evaluate models. As Ogallala Aquifer, spans across multiple states, water level information is collected by several local, state and federal agencies. The type of data collected, the frequency of data collection as well as the information reported varies among these state agencies. Therefore, it is necessary that data available in multiple formats and data structures be organized into a consistent format so it can be used and shared with relative ease.

The overall goal of this report is to describe the design and development of a relational database of well information and water level measurements made in the states of Kansas, New Mexico, Oklahoma and Texas. The development of this database is largely to support the development of the southern high plains regional groundwater flow model for the Ogallala Aquifer in the states of New Mexico, Oklahoma and Texas and over smaller areas in Kansas and Colorado to avoid boundary effects. In addition to its use modeling, the data compiled as part of this effort also is useful to understand historical trends in water levels and obtain other insights with regards to the behavior of the aquifer over southern and central high plains regions of the aquifer.

Data Compilation

Raw groundwater level and well data were obtained from the following state agencies - Kansas Geological Survey (KGS), New Mexico Office of State Engineer (NMOSE); Oklahoma Water Resources Board (OWRB) and Texas Water Development Board(TWDB). In addition, well information and water level data from United States Geological Survey (USGS) used for mapping High Plains Aquifer saturated thicknesses (McGuire, 2014) was also downloaded. The sources of data from these agencies are summarized in Table 1 and data compiled is current as of 07/07/2017. As can be seen, different state agencies provide data in using different file formats. In addition, supporting information and meta data provided by each agency varies widely as well.

It is important to note that while data were downloaded from state agency websites, the actual data collection could have been carried out not only by personnel from these agencies, but also their cooperators and other parties. For example, USGS carries out all groundwater monitoring activities for the state of New Mexico Office of State Engineer

Other pertinent information for counties falling within the boundaries of the Ogallala Aquifer within the states of Kansas (KS), Oklahoma (OK), New Mexico (NM) and Texas (TX) such as population, acreages of major crops, and estimated water use were also compiled from various sources (e.g., Maupin et al., 2014; Census, 2017; USDA-NASS, 2016)

Table 1: Summary of Collected well and water level information for the database

State	Data Download Criteria	Data Location	Remarks
Kansas	All data in Kansas	http://www.kgs.ku.edu/Magellan/WaterLevels/index.html	Data Provided by Kansas Geological Survey (KGS)
New Mexico	Local Aquifer = 121OGLL	https://nwis.waterdata.usgs.gov/nm/nwis/gwlevels.	Data Provided by United States Geological Survey (USGS).
Oklahoma	All data in Oklahoma	http://www.owrb.ok.gov/maps/pmg/owrbdata_GW.html	Extracted from Geodatabase provided by the Oklahoma Water Resources Board (OWRB)
Texas	Major Aquifer = Ogallala	http://www.twdb.texas.gov/groundwater/data/gwdbrpt.asp	Data provided by Texas Water Development Board (TWDB)
USGS	Data for all States	https://ne.water.usgs.gov/projects/HPA/data.html	Data provided by High Plains Water-Level Monitoring Study done by USGS

Data Preprocessing

The geographic coordinates of all wells were converted to NAD 1983 projection to ensure consistency among states. NAD 83 datum was used as it has been adopted by USGS and several other state agencies New Mexico, Kansas) for reporting well locations. All downloaded data were converted into comma separated values (CSV) flat file format for further processing. An initial analysis indicated that the land surface elevation data were not reported by some state agencies. Furthermore, the reported elevations came from a variety of sources ranging from topographic maps to field surveys. Elevation data from 10 m National Elevation Dataset (NED) was therefore used to assign the top elevation for each well. This NED based elevation data was used in further calculations to ensure consistency among wells.

The screening intervals for wells, when reported, were not in consistent format across state agencies. Well screening information is not publicly available from KGS and NMOSE. Screening information for wells in New Mexico was obtained from the USGS New Mexico Water Science Center (Lauren Sherson, 2017 Pers. Comm). The USGS dataset (McGuire, 2014) was used to obtain this information for KS. USGS provides the top and bottom elevations of the screens as well as the number of screening intervals. R scripts were written to convert screen information data obtained from TX and OK into the USGS format.

The measurement dates of the downloaded water level measurements were used to create month, day and year fields for each measurement. In some instances, the day of the measurement was not reported and these measurements were arbitrarily assigned a day of 01 to ensure formatting consistency with other reported measurements. Water level measurements with missing day values were also flagged. Certain water wells in Texas are equipped with automated water level loggers which generally report data on an hourly scale. The daily average water level was calculated from hourly measurements for inclusion in the database. A preliminary analysis indicated that diurnal water level variations were generally not

significant and the daily average provided a representative value at a reasonably high resolution while reducing the data storage requirements.

Data Validation

Identification of Wells Tapping the Ogallala Aquifer

Wells identified as belonging to the Ogallala Aquifer (aquifer code 121OGLL) were filtered from downloaded well data tables. To ensure maximal coverage, wells not assigned an aquifer code within each state were also downloaded for further evaluation. This initial compilation resulted in a total of 35347 wells for the study area (see Table 2 for state-wide breakdown).

Table 2: Summary of wells in each State considered in the database creation

State	Aqcode = 121OGLL	Aqcode = Blank	Total
KS	309	6399	6708
NM	5219	0	5219
OK	199	2611	2810
TX	20519	91	20610

Spatial (Areal) Verification of Identified Wells

The initial compilation of wells was overlaid on the Ogallala Aquifer Boundary using the shapefile obtained from USGS (Qi et al., 2009). Wells with unassigned aquifer codes not falling within the aquifer boundaries were excluded from further consideration and only those within the boundaries were retained for further analysis (Figure 1). The spatial analysis indicated that some wells assigned the aquifer code 121OGLL did not fall within the selected aquifer boundaries (see Figure 1). For example, nearly 350 wells in New Mexico did not meet the spatial intersection criterion (see Table 3). As state agency personnel have greater familiarity with local geological conditions, all wells assigned 121OGLL code were retained for further analysis.

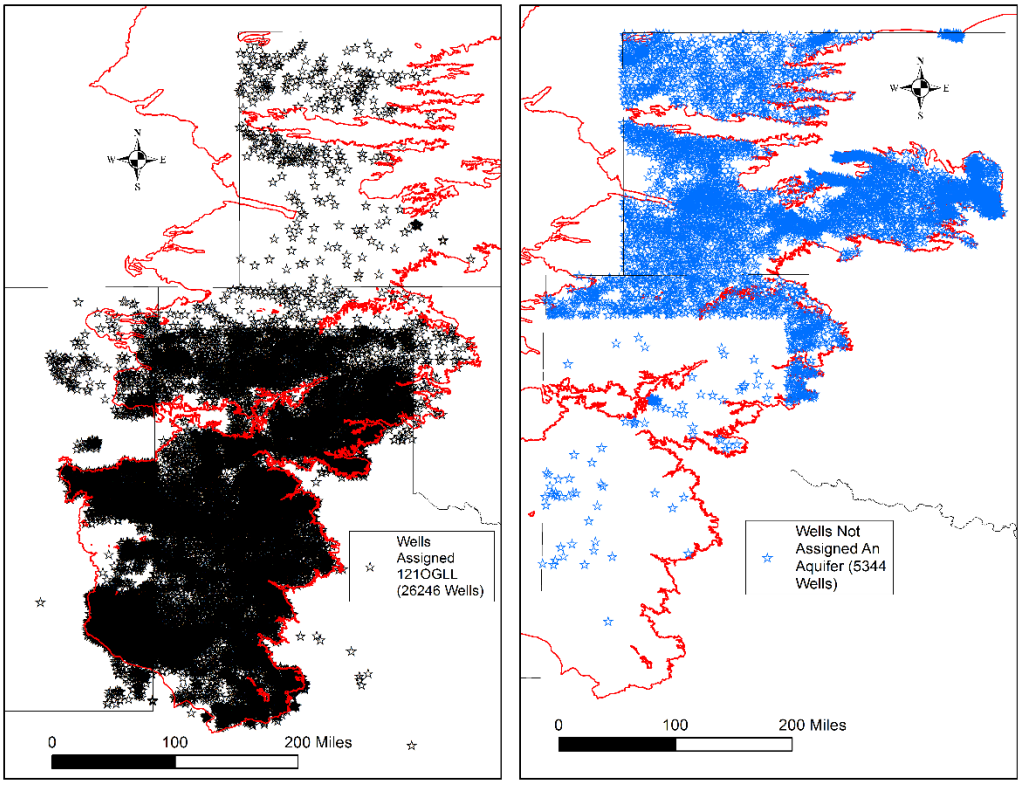

Figure 1: Assessment of spatial locations of all the wells collected in the database

Table 3: Summary splits of All wells included in the wells after spatial check of locations

State	Aquifer Code = 121OGLL		Aquifer Code = Blank		Total
	Outside Aquifer Boundary	Within Aquifer Boundary	Outside Aquifer Boundary	Within Aquifer Boundary	
KS	1	308	1826	4573	6708
NM	338	4881			5219
OK	1	198	1930	681	2810
TX	283	20236	1	90	20610

Vertical Verification of Identified Wells

The High Plains Aquifer system consists of several deeper geological units that are not the focus of this study. Therefore, when a well falls within the areal extent of the Ogallala Aquifer, it is still possible that it may not tap into the upper Ogallala Aquifer formation. The bottom elevations of the Ogallala Aquifer as defined in the Regional Aquifer System Analysis (RASA) model (USGS, 2015) as well as more recent modeling efforts from state agencies (Wilson et al., 2009, Deeds et al., 2015) were extracted for all the 31950 wells that were retained after performing the areal spatial checks.

The bottom elevation of wells from the mean sea level were computed and compared to the estimated bottom elevations of the Ogallala Aquifer. As the accuracy of the estimated bottom elevations is not high, wells whose depths fall below the bottom elevations were flagged. It is also important to note that well depths were not known for all wells, therefore the vertical verification could not be performed for all wells. Wells where the vertical verification could not be performed were also flagged.

The vertical verification was also performed on all water level information provided by the state agencies. The hydraulic head measured from mean sea level (MSL) was computed for each water level by subtracting the water table depth from the land surface (WL) from the land surface elevation obtained from NED. Water level measurements whose hydraulic heads were above the land surface datum were flagged. Meta data from state agencies were checked and no mention was made of artesian conditions. Therefore, these measurements likely represent transcription errors, besides computing heads under artesian conditions are likely prone to significant errors, especially when these measurements are made manually.

Flagging of Unreconcilable Wells

Unreconcilable Wells having Aquifer code 121OGLL

Table 5 shows that 623 wells that were assigned an aquifer code of 121OGLL by the reporting state agency do not fall within the Ogallala Aquifer bounds established using the USGS aquifer bounds (Qi, 2010). As the spatial location of all these wells was unreconcilable to the Ogallala Aquifer region, these wells were assigned an UNRECFLG (Unreconcilable Flag) value of 1. Of these 623 wells, 68 wells were very close to the aquifer boundary and it was possible to assign aquifer bottom information from either RASA or more refined regional models.

Unreconcilable Wells – Same Spatial Location

The GIS-based identical operation was performed on the dataset and indicated that several different wells (assigned different well IDs by the state agencies) had the same location information (Latitude and Longitude). This situation arises particularly for older wells as their location information was obtained from either a topographic map or assigned based on a nested grid system that was used to spatially locate wells in the pre-GPS era. The GIS identify analysis identified a total of 783 wells whose geographic locations matched at least one other well in the database. Wells whose geographic locations could not be uniquely defined were assigned an UNRECFLG of 2.

Unreconcilable Wells – Vertical Position

Vertical verification of whether a well was completely within the Ogallala Aquifer formation or was drilled through more than formation was not possible when the well depth information was not available. These wells were assigned a UNRECFLG value of 3. By the same token, wells whose well depths were identified to not be within the Ogallala Aquifer (using either RASA or recent models) were also assigned a UNRECFLG value of 3. A total of 16859 wells were assigned an UNRECFLG of 3 of which 8811 wells did not have depth information and the remaining wells had depths that were below the estimated bottom elevation of the Ogallala Aquifer formation.

Unreconcilable Wells – Negative Water Level Measurements

Preliminary data validation efforts indicated that there were 25 wells in Kansas and 5 wells in Texas that had at least one negative water level measurement. As no additional information regarding those well measurements could be identified from meta data, these wells were assigned a UNRECFLG of 4 to indicate that the water level measurements are suspect.

Unreconcilable Wells – Wells with Multiple Flags

The initial assignment of URECFLG's to each well as detailed above showed that close to 1000 wells had multiple flags associated with them. The combination of individual flags was assigned to the wells to account that the flags are not unique and there are some wells that overlap over multiple flags. For example, 16 wells in New Mexico were identified with an assigned aquifer code of 121OGLL, but were not spatially within the Ogallala border (URECFLG = 1). At least two or more wells in this list had the same spatial location information (URECFLG = 2) and their vertical extent could not be confirmed in the Ogallala aquifer (URECFLG = 3). To account for all these flags, a combination flag of 123 to represent each individual check was added to the existing list. Table 4 summarizes all the well records with their respective flags for all the states.

Table 4: Summary of all the Flags after data validation of well records

Flag	Description	KS	NM	OK	TX	Total
000	Unique Wells with no issues	2584	1860	432	9397	14273
001	Wells assigned 121OGLL but not within the spatial extent of Ogallala	-	15	-	2	17
002	Different Well ID but same Latitude and Longitude	162	61	-	201	424
012	Wells having both flags 1 and 2	-	1	-	-	1
003	Well whose vertical extent to lie within the Ogallala cannot be confirmed	2025	2827	445	10564	15861
013	Wells having both flags 1 and 3	1	306	1	277	585
023	Wells having both flags 2 and 3	85	133	2	159	379
123	Well having flags 1, 2, and 3	-	16	-	4	20
004	Wells having at least one negative value for measured water levels	14	-	-	2	16
034	Wells having both flags 3 and 4	11	-	-	3	14
Total Number of Wells		4882	5219	880	20609	31590

A Well ID (WID) field is created to assign individual id's to each of the wells using the format "OGG-ST-XXXXXXXX". "OGG" portion of the ID indicates that the well is part of the Ogallala aquifer database. The "ST" portion of the ID suggests the State ID that helped obtain the well record. The first three digits in

the ID number portion "XXXXXXXX" indicates the flag associated with the well as illustrated in the Table 4 while last five digits of the ID indicate a serial number. The WID field assignment is done in this fashion to ensure that no two wells have the same value. During the WID assignment process, it was noted that three wells bearing ID's OGG-NM-00001277, OGG-NM-00001789 and OGG-NM-00302702 were part of the New Mexico database but were spatially inside the Texas portion of the Aquifer.

Flagging Water Level Information

Water level information for wells bearing the URECFLG value of 000 were separated to be included in the database. A DAYFLG value of 1 was assigned to water level measurements for which only the month and year were reported. As stated in the data pre-processing section, these sampling events were assigned to the first day of the month to make the data format consistent with other reported measurements. In total, 6412 (out of 385089) water level records were assigned a DAYFLG of 1.

All water level measurements approved for publication by the state agencies were assigned a status code (STSCODE) of 'A'. Water level measurements that have not been validated by the reporting agency have been assigned a code of 'P' indicating that the data is provisional could change in the future. Water level measurements whose validity is questionable based on information provided by the state agencies were assigned a code of 'Q'. Table 5 presents the state wise summary of status codes for water level measurements.

Table 5: Summary of Status Code for the water level measurements in the database

State	Status Code			
	A	P	Q	Total
KS	179041	-	18493	197534
NM	21125	33	-	21158
OK	21809	-	-	21809
TX	141048	70	3470	144588
Total	363023	103	21963	385089

The Texas Water Development Board provides data collected from Automated Groundwater levels loggers. A total of 33 active and inactive sites have such continuously monitored data that are often reported on an hourly basis. One of the wells taps into both Ogallala and the deeper Dockum aquifer and was excluded from further consideration. A total of 21 wells were identified as unique bearing a unreconcilable flag of 000 based on the data validation performed above. Ten wells with automated loggers were flagged with a code of 003, indicating that their vertical extent could not be confirmed within the Ogallala aquifer while one well flagged with code 013 indicating that it was designated the aquifer code 121OGLL by the state agency but did not fall within the aquifer boundary in addition to its vertical

extent could not be confirmed (Figure 2). Wells equipped with automated loggers were assigned a AWL flag (AWLFLG) of 1 in the "WellInfo" table for easy identification.

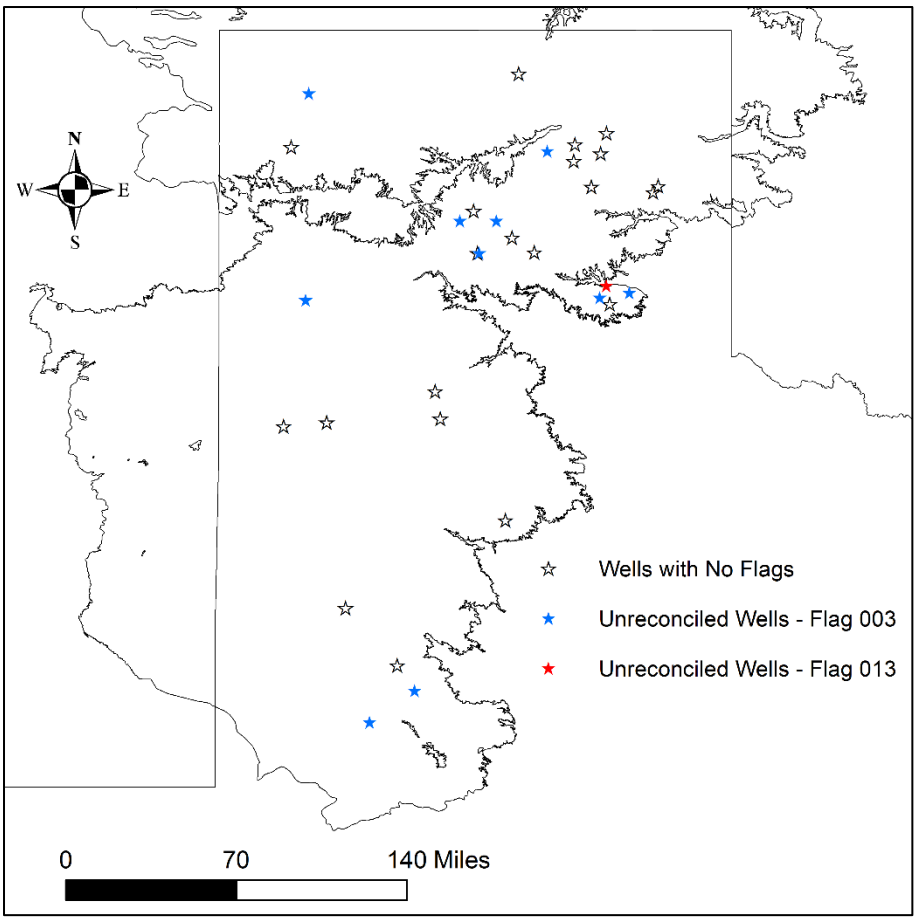

Figure 2: Automated Water Level loggers used in the State of Texas

Database Design

A relational database in MS-Access was designed to store the compiled data into a series of 5 tables as summarized in the Table 6. Each table has been assigned a Primary Key which is a unique value used to connect the other tables in the database. The components of each table have been listed in the Tables A 1 - A 5 in the appendix A. The overall design framework of the relational database is shown in the Figure 3. A variety of queries can be performed using the developed relational database.

Table 6: Summary of Tables created as part of the database design

Table	Primary Key	Remarks
State	STFIPS	State FIPS ID; Information on states of interest
County	GEOID	Combination of State and County FIPS used as primary key. Salient geographic information on the counties.
WellInfo	WID	Unique Well ID Created to identify a Well Record. Information on wells.
WaterLevels	SID	Unique Sample ID Created to identify each Water Level Record. Water levels
AutoLoggerWaterLevels	SID	Unique Sample ID Created to identify each Water Level Record from Continuous Monitoring Loggers

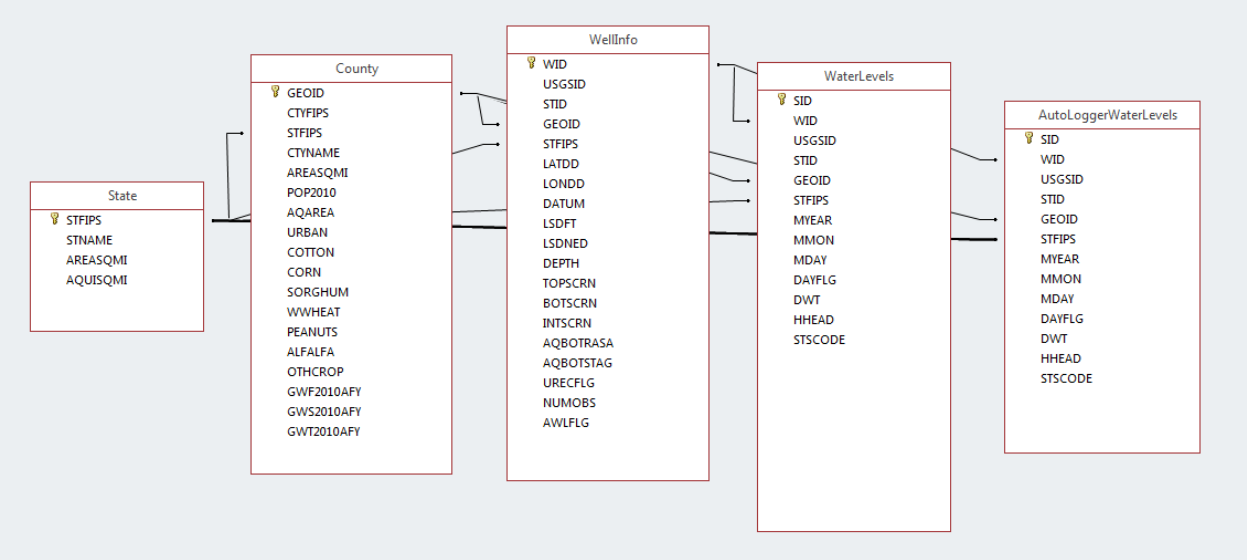

Figure 3: Structure of the relational database to properly organize compiled groundwater data collected from State agencies in Kansas, New Mexico, Oklahoma and Texas

Summary

The overall goal of this study was to develop a database of wells and water level information in the four states of New Mexico, Oklahoma, Texas and Kansas. Data from state agencies were compiled and validated for future use. Ancillary geographic information was compiled as well. The data were arranged in a relational database for future use.

Acknowledgments

The authors thank Mr. Daniel Estrada from the New Mexico Office of the State Engineer and Ms. Lauren Sherson from the USGS who manages the New Mexico Groundwater Level Program for their assistance in obtaining groundwater level data for New Mexico. The staff from KGS, TWDB and OWRB are also thanked for archiving and sharing their data publicly.

Disclaimer

While every effort has been made to ensure the accuracy of the data compiled in this database, no warranties are expressed. This is a secondary compilation that is current as of 07/07/2017. Data obtained from original sources are subject to change and may not be reflected here. It is recommended that the data be checked against original sources prior to use.

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Appendix A: Description of all tables used in the MS-Access database

Table A 1: Meta-data for the "State" table used in the database

Name	Description	Data Type	Remarks
STFIPS	State FIPS ID	Text	**Primary Key** from census.gov
STNAME	Name of the State	Text	census.gov
AREASQMI	Total Area of the State in Sq. Miles	Number	census.gov
AQAREA	Area of Aquifer in the State Sq. Miles	Number	From USGS Ogallala Map

Table A 2: Meta-data for the "County" table used in the database

Name	Description	Data Type	Remarks
GEOID	Combination of State and County FIPS	Text	Primary Key; Data from census.gov
CTYFIPS	County FIPS Code	Text	From census.gov
STFIPS	State FIPS Code	Text	From census.gov
CTYNAME	County Name	Text	From census.gov
AREASQMI	Area of the County in Sq. Miles	Number	From census.gov
POP2010	Population 2010 Census	Number	From census.gov
AQAREA	Aquifer Area in Sq. Miles within the County	Number	From USGS Ogallala Aquifer Map
URBAN	Urban Area in Sq. Miles within the County	Number	From USDA CDL 2016
COTTON	Planted Cotton Area in Sq. Miles within the County	Number	From USDA CDL 2016
CORN	Planted Corn Area in Sq. Miles within the County	Number	From USDA CDL 2016
SORGHUM	Planted Sorghum Area in Sq. Miles within the County	Number	From USDA CDL 2016
WWHEAT	Planted Winter Wheat Area in Sq. Miles within the County	Number	From USDA CDL 2016
PEANUTS	Planted Peanuts Area in Sq. Miles within the County	Number	From USDA CDL 2016
ALFALFA	Planted Alfalfa Area in Sq. Miles within the County	Number	From USDA CDL 2016
OTCROP	Planted Area of Other Crops not considered separately in Sq. Miles within the County	Number	From USDA CDL 2016
GWF2010AFY	Total Fresh Groundwater Use in the County in the Year 2010 in AFY	Number	From USGS Water Use Survey 2014
GWS2010AFY	Total Saline Groundwater Use in the County in the Year 2010 in AFY	Number	From USGS Water Use Survey 2014
GWT2010AFY	Total Groundwater Use in the County in the Year 2010 in AFY	Number	From USGS Water Use Survey 2014

Table A 3: Meta-data for the "WellInfo" table used in the database

Name	Description	Data Type	Remarks
WID	Well ID	Text (Format: OGG-ST-xxxxxxxx)	Primary Key
USGSID	USGS Well ID	Text	Well ID provided by USGS if available
STID	State Well ID	Text	Well ID provided by State Agency if available
GEOID	Combined State and County FIPS	Text	Primary Key of County Table
STFIPS	State FIPS	Text	Primary Key of State Table
LATDD	Latitude in Decimal Degrees	Number	Data provided by state agencies; converted to NAD 83 datum
LONDD	Longitude in Decimal Degrees	Number	Data provided by state agencies; converted to NAD 83 datum
DATUM	Geographic Datum	Text	All data was projected into NAD83
LSDSA	Land Surface Datum in Feet	Number	Data provided by the reporting agency. Kansas Geological Survey (KGS) in Kansas, United States Geological Survey (USGS) in New Mexico, Oklahoma Water Resources Board (OWRB) in Oklahoma and the Texas Water Development Board (TWDB) in Texas
LSDNED	Land Surface Datum in Feet extracted from the National Elevation Dataset (NED)	Number	NED (National Elevation Dataset)
DEPTH	Well Depth in Feet	Number	Data obtained from State agencies
TOPSCRN	Top of the Screen in Feet	Number	
BOTSCRN	Bottom of the Screen in Feet	Number	
INTSCRN	Number of Screened Intervals	Number	
AQBOTRASA	Aquifer Bottom from MSL based on RASA Model in feet	Number	Interpolated Aquifer Bottom at the well using USGS RASA Model
AQBOTSTAG	Aquifer Bottom from MSL based on State Agency Models in Feet	Number	Interpolated Aquifer Bottom at the Well using either TWDB HPAS GAM (TX, OK, NM) or KGS Model in Kansas
CMONFLG	Flag indicating if Station is under continuous monitoring of water levels	Number	Flag = 1 is used for the wells that have been monitored continuously. 32 continuously monitored wells are present in the state of Texas
UNRECFLG	Unreconcilable Well Flag	Text	A three-digit code to suggest the flag assigned to each well during the data

Name	Description	Data Type	Remarks
			validation process. For details, refer to the Table 5 in the main text of this report
NUMOBS	Number of Water Level observations	Number	Field indicating the total number of Water Level measurements available for a well
AWLFLG	Flag indicating if well is under continuous monitoring of water levels	Number	Flag = 1 is used for the wells that have been monitored continuously. 32 continuously monitored wells are present in the state of Texas

Table A 4: Meta-data for the "WaterLevels" table used in the database

Name	Description	Data Type	Remarks
SID	Sample ID	Text	Unique Sample ID; **Primary Key**
WID	Well ID	Text	Primary Key of Well Table
USGSID	Well ID per USGS	Text	
STID	Well ID per State Agency	Text	
GEOID	State + County ID	Text	Primary key of county Table
STFIPS	State FIPS code	Text	Primary key of state Table
MYEAR	Measurement Year	Number	#### format
MMON	Measurement Month	Number	## format
MDAY	Measurement Day	Number	## format
DFLG	Day Flag	Number	1 if measurement day is missing
DWT	Depth to Water Table in Feet	Number	Depth to water table measured from land surface datum
HHEAD	Hydraulic Head in Feet from MSL	Number	
STSCODE	Sample Status	Number	A flag indicating the status of the water level reported by the agency when the database was created. P = Provisional and subjected to change, A = Approved for Publication, Q = Questionable

Table A 5: Meta-data for the "AutoLoggerWaterLevels" table used in the database

Name	Description	Data Type	Remarks
SID	Sample ID	Text	Unique Sample ID; **Primary Key**
WID	Well ID	Text	Primary Key of Well Table
USGSID	Well ID per USGS	Text	
STID	Well ID per State Agency	Text	
GEOID	State + County ID	Text	Primary key of county Table
STFIPS	State FIPS code	Text	Primary key of state Table
MYEAR	Measurement Year	Number	#### format
MMON	Measurement Month	Number	## format
MDAY	Measurement Day	Number	## format
DWT	Depth to Water Table in Feet	Number	Depth to water table measured from land surface datum
HHEAD	Hydraulic Head in Feet from MSL	Number	
STSCODE	Sample Status	Number	All data are provisional and subjected to revision. A code of P has been given to all the records in this file

Appendix B: Methodology to construct the STATE and County Table

STATE Table

From the complete file for all the states in the US including Alaska, Data for the 5 states of interest KS (STATEFP – 20), NM (STATEFP – 35), OK (STATEFP – 40) and TX (STATEFP – 48) were extracted. The data for the five states was then projected using NAD 1983 Albers for area calculations and placed in the field "Area_Sqmi". The High plains aquifer shape file was then used to identify the counties lying over the Ogallala aquifer. The two files were then used to extract the counties that lie within the Ogallala Aquifer region. The corresponding areas for all the counties were calculated and placed in the column "A_Og_Sqmi". The final structure of the table is as shown in the Table A 1.

COUNTY Table

As part of the final database, a comprehensive county table was built to tabulate county wide statistics of various parameters as listed in Table A 2. The current document describes the methodology used to generate information in the fields.

County and Population Information

The database focuses on compiling information for four states: KS (STATEFP – 20), NM (STATEFP – 35), OK (STATEFP – 40) and TX (STATEFP – 48). The spatial processing of the collected data is done using tools provided by the ArcGIS programing software from ESRI. The cartographic county boundaries for all states in the contiguous United States and Alaska is obtained from the Census.gov data portal (Census, 2017). The data obtained from the above portal includes basic county information such as GEOID, State and County FIPS (STFIPS and CTYFIPS respectively). The projections associated with the spatial data are in the Geographic Coordinate System (North American 1983). As the primary objective of the analysis is to calculate areas, this data is then re-projected into Projected Coordinate System (North American 1983) to carry out the calculations with more efficiency. Using the projected coordinate system, total county areas in square miles (AREASQMI) can be calculated. The spatial file for the High Plains Aquifer boundary is obtained from the USGS data portal (Qi, 2010). The two spatial files are used to extract the counties that have the High Plains Aquifer underlaying them and the areas for each county overlaying the High Plains Aquifer are calculated (AQAREA) in the four states of interest. The 2010 county wide population counts (POP2010) obtained from census.gov is then matched and attached to the counties in the four states of interest.

County Level Areas for Major Crops

The High Plains Aquifer boundary is used to extract the 2016 Crop Scape Crop Data Layer from the USDA - NASS data portal (USDA-NASS, 2016). Crop data for the four states (KS, NM, OK and TX) are separated out from the complete file to calculate areas for various major crops (COTTON, CORN, SORGHUM, Winter Wheat (WWHEAT), PEANUTS, ALFALFA and Other Crops (OTCROP)) and total URBAN landcover. Crop data layers for each crop were extracted in the ArcGIS environment to calculate areas of each crop for all the counties of interest.

The complete process is summarized using Corn as an example. The corn data for all the counties is extracted from the crop data layer. To account for complete corn data, Corn as a single and double crop were considered. For the case of Corn, the double crops were identified as Winter Wheat/Corn, Crop Oats/Corn and Barley/Corn. "Zonal Statistics", a tool within the ArcGIS environment was then used to compute the area of corn all the counties within the four states of interest. The same procedure was followed to compute the areas for all remaining major crops and land covers. Crops that were not considered as major crops were analyzed as other crops. The summarized areas for each county were updated to the county table.

County Level Water Use

County level estimated use of water or groundwater withdrawal data is obtained from USGS Circular 1405 for the year 2010 (Maupin et al., 2014). This data is available as a spreadsheet for all the states and counties in the United States. The data was separated for the four states of interest along with the State and County FIPS to aid in updating the county table. The data table computes county wide estimate of surface and groundwater usages for various industries such as irrigation, mining etc. The total fresh (GWF2010AFY) and saline (GWS2010AFY) groundwater data is used in the county table. The total groundwater use (GWT2010AFY) information combines the total fresh and saline water use as documented by USGS.