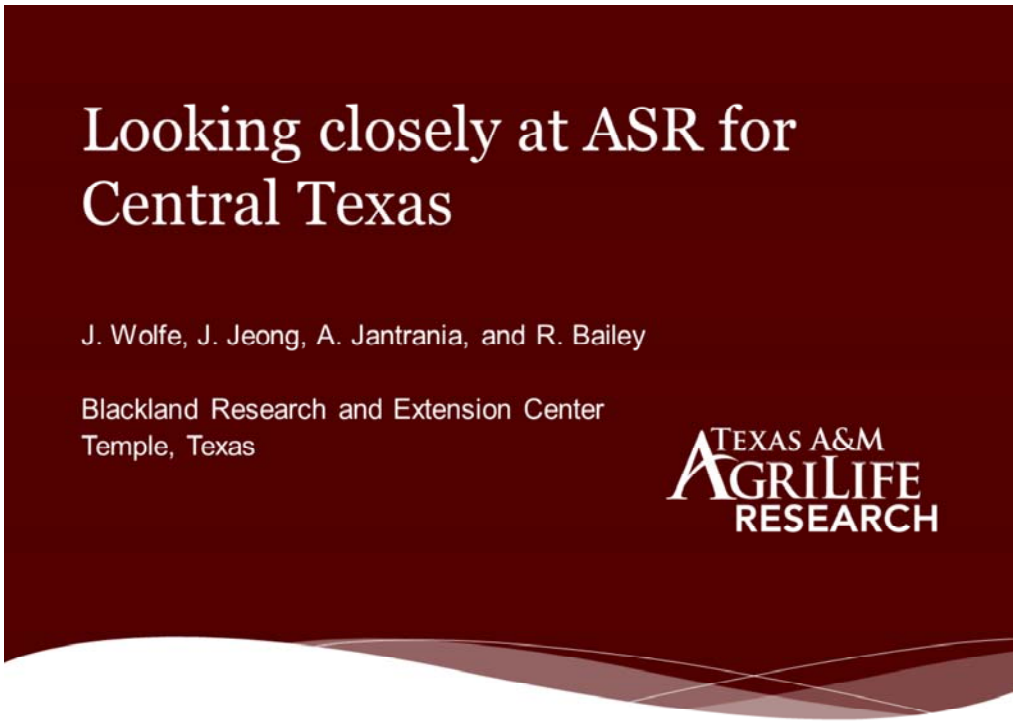


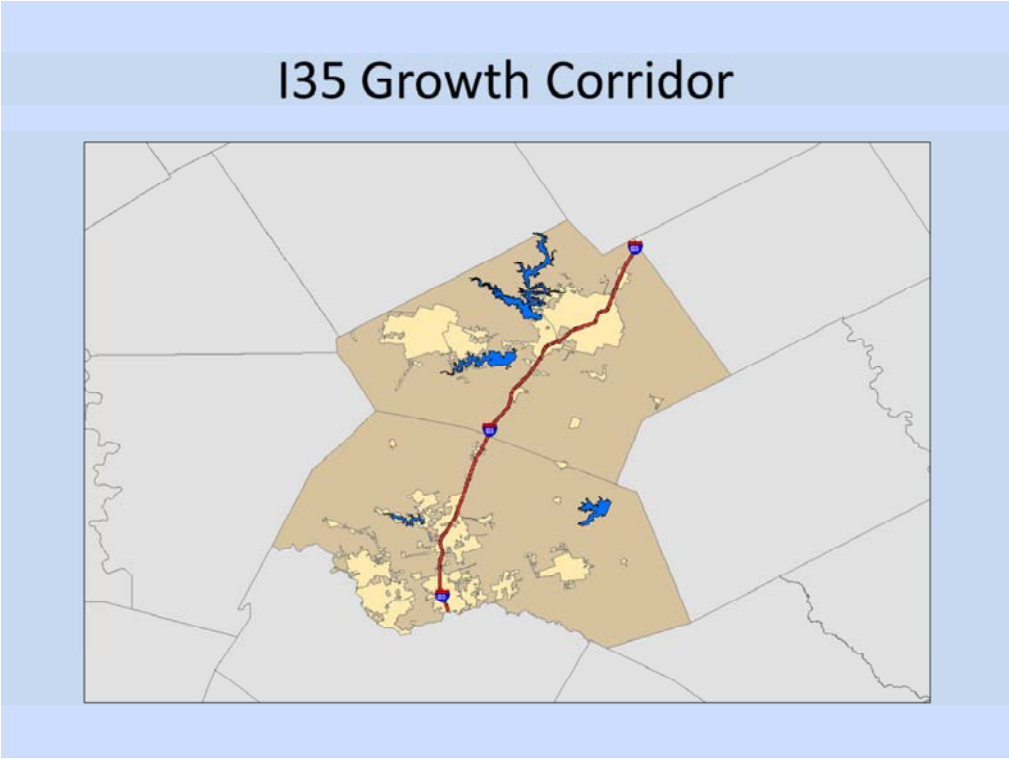
TAMU-BREC is local and therefore works for and with local stakeholders and communities. So, at the request of Clearwater UWCD management BREC is here today to describe how Clearwater and Blackland are proposing to closely examine ASR for Central Texas. We have a lot of questions and issues to examine.

Although they are not here in person, please let me introduce our research team. You already know me, Dr. Jaehak Jeong is an Assistant Professor with a joint appointment in the Department of Agricultural and Biological Engineering and AgriLife, Temple. He develops surface water models for evaluating urban and agricultural watersheds and their management. Dr. Anish Jantrania is the AgriLife Extension state on-site water and wastewater specialist. He holds not only doctoral but, engineering, and business degrees as well and is fine tuned toward water resource management. Dr. Ryan Bailey is an Assistant Professor in the Engineering Department of Colorado State University and is an expert in groundwater modeling. He has worked extensively with Dr. Jeong to develop a coupled surface-ground water tool for evaluating watershed hydrology.

This team provides expertise and leadership in water research by applying basic and applied watershed modeling to understand management consequences upon natural resources.
Blackland scientists do not simply utilize existing models but develop and

implement new code and features to further water management science.

When evaluating ASR feasibility BREC scientists will use these integrated modeling tools to connect the dots between long-term weather variability, surface and subsurface water resources all while considering human aspects.

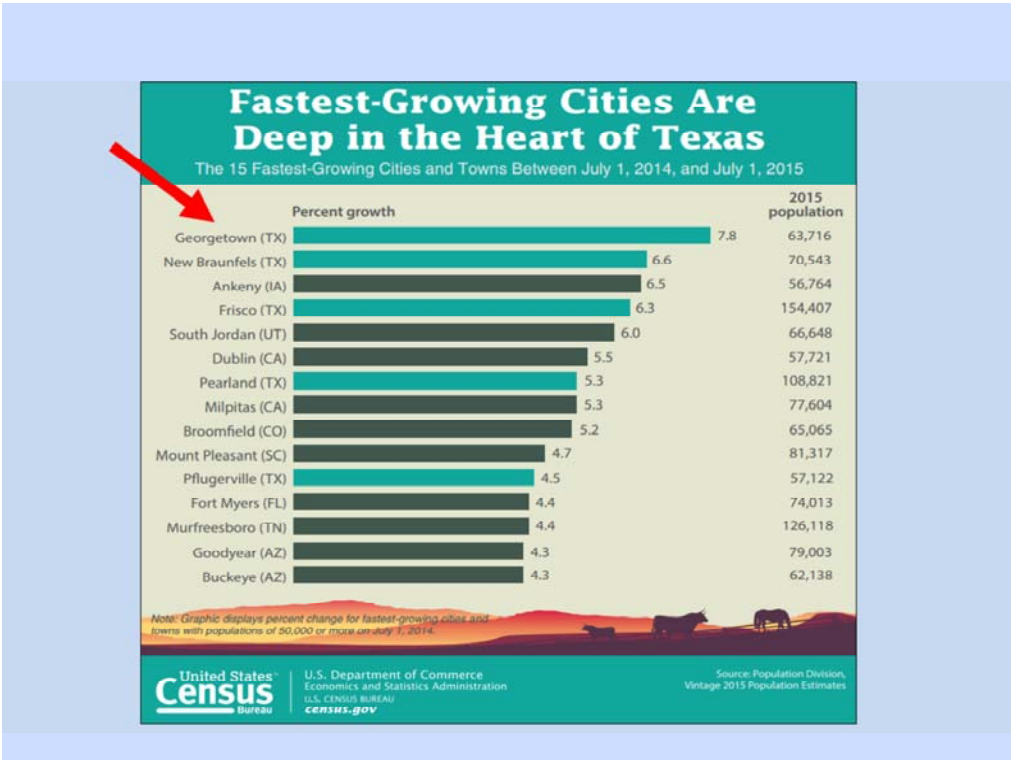


Anyone who has traveled up and down the I35 has observed the massive construction effort required to expand and accommodate the high traffic volume. This is due to the population increases fueling the rapid growth.

Image source Texas Tribune

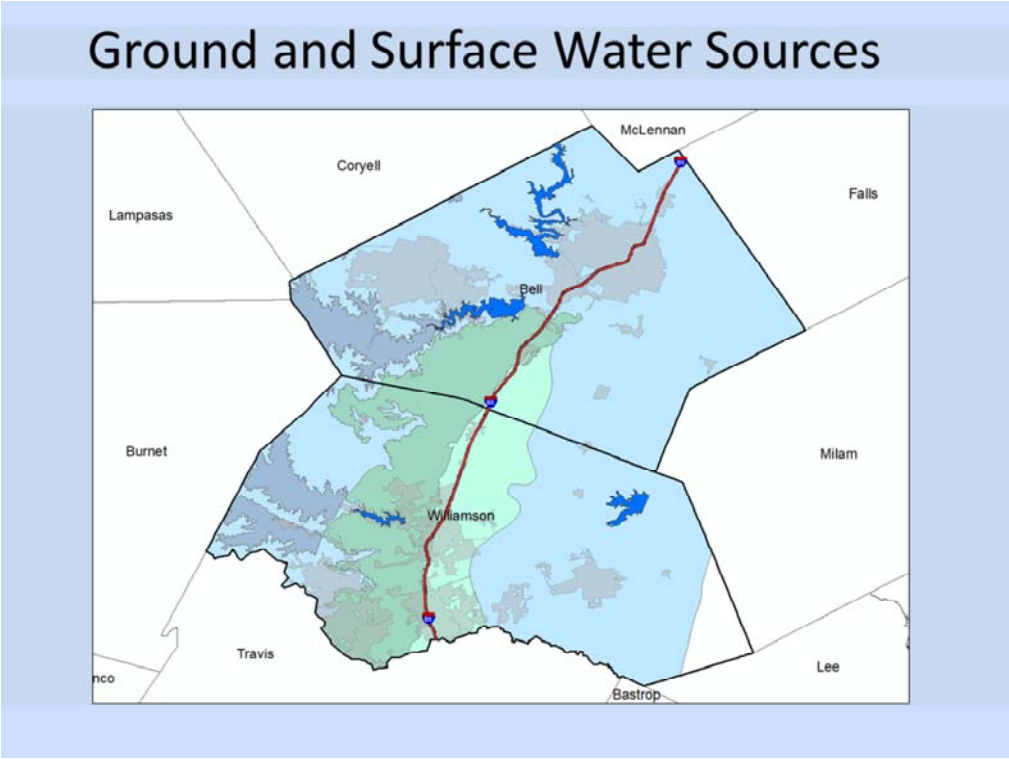
Forty years ago when I came to Texas with my parents, Highway 190 was two lane, one coming, one going.
Killeen had just the downtown area and almost no businesses along 190. As kids we used to play in the fields and pastures where Lowes and Walmart now stand.
Stillhouse Lake where I spent most of my youth there were few houses. Today things look very different.
This photo shows the urban growth, a residential neighborhood, of Georgetown to the south in Williamson County.

The population of Belton was a mere 4000, near Today it is over 18,000 which represents an annual growth rate of about 2%.



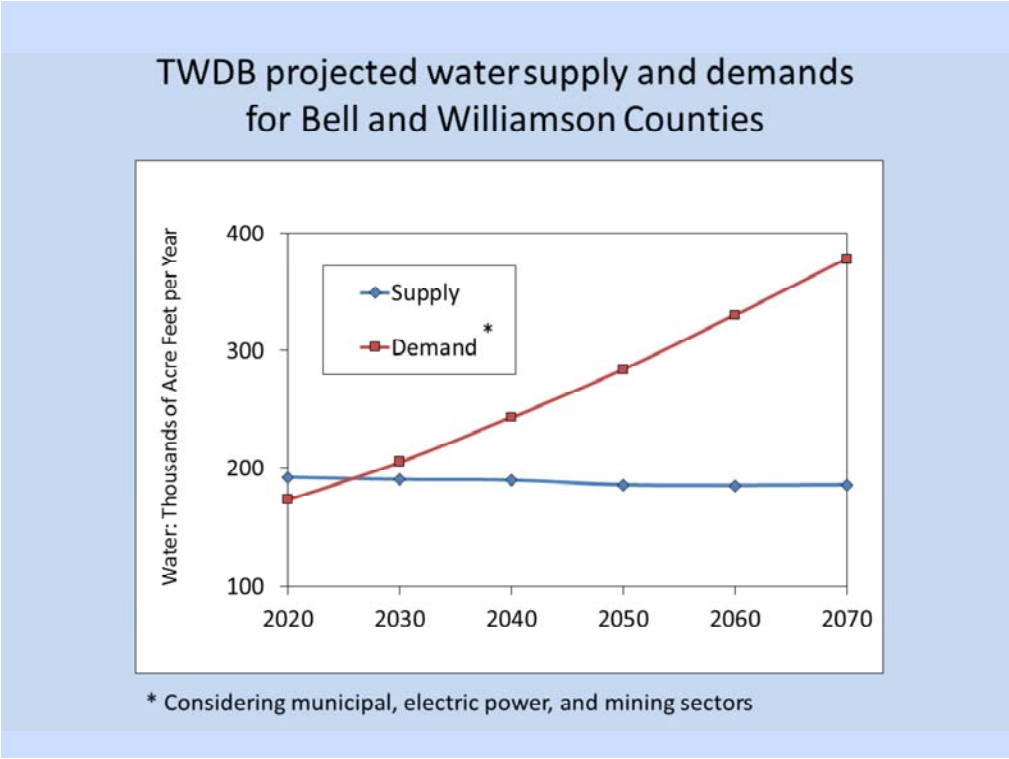
The highest urban growth in the nation is occurring in Georgetown, Texas which expanded 7.8 percent from 2014 to 2015.
At the current rate, Williamson County alone is projected to grow to more than 1.5 million people by 2070.

Bell County's population is, as already noted, experiencing rapid growth and expected to increase 46% by 2070; from 371,000 to 688,000 people
The combined growth of Bell and Williamson counties represents a potential population of nearly 2.25 million by 2070.



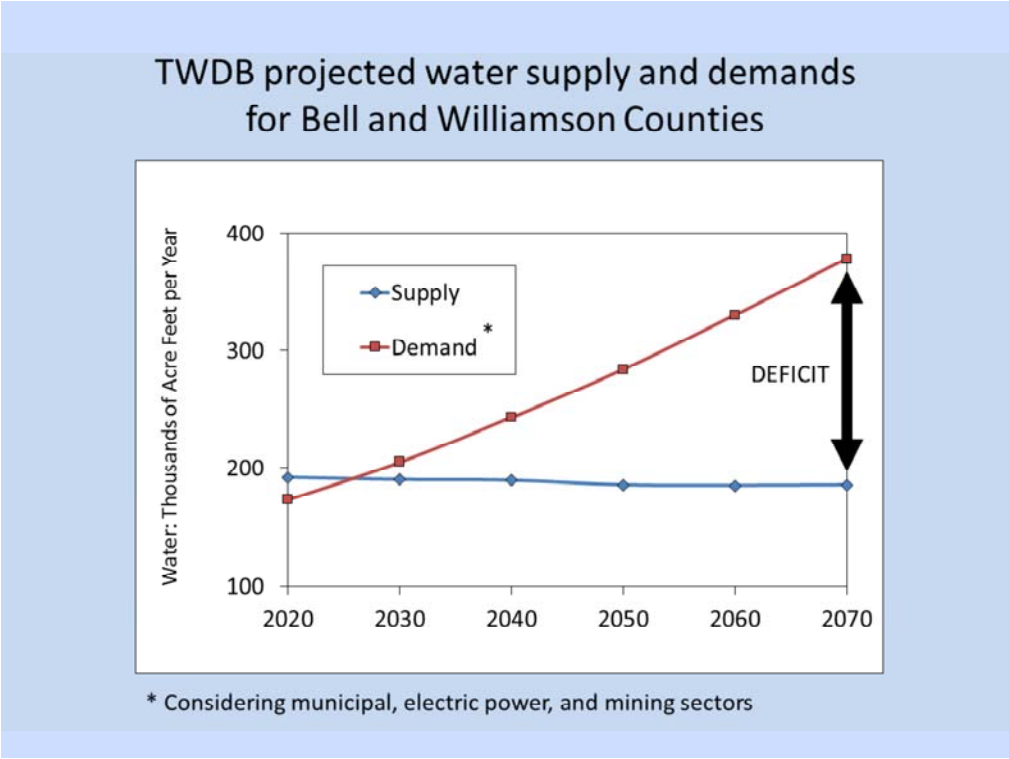
What does this growth mean for our local water sources?
Bell and Williamson Counties are water rich with 4 surface reservoirs and 4 major aquifers to draw from.

A 2011 TWDB report notes that Bell County uses approximately 80% surface and 20% groundwater.
Williamson County utilizes between 60-70% surface and 30-40 % ground, which suggests an overdependence upon ground resources.



Even with generous resources, the TWDB is projecting the state's existing surface water supply to decrease 8% by 2060, primarily from existing reservoir sedimentation.
Meanwhile, groundwater levels have experienced a median decline of almost 22 meters (77feet) since the 1930's due to agricultural irrigation and urban sprawl.

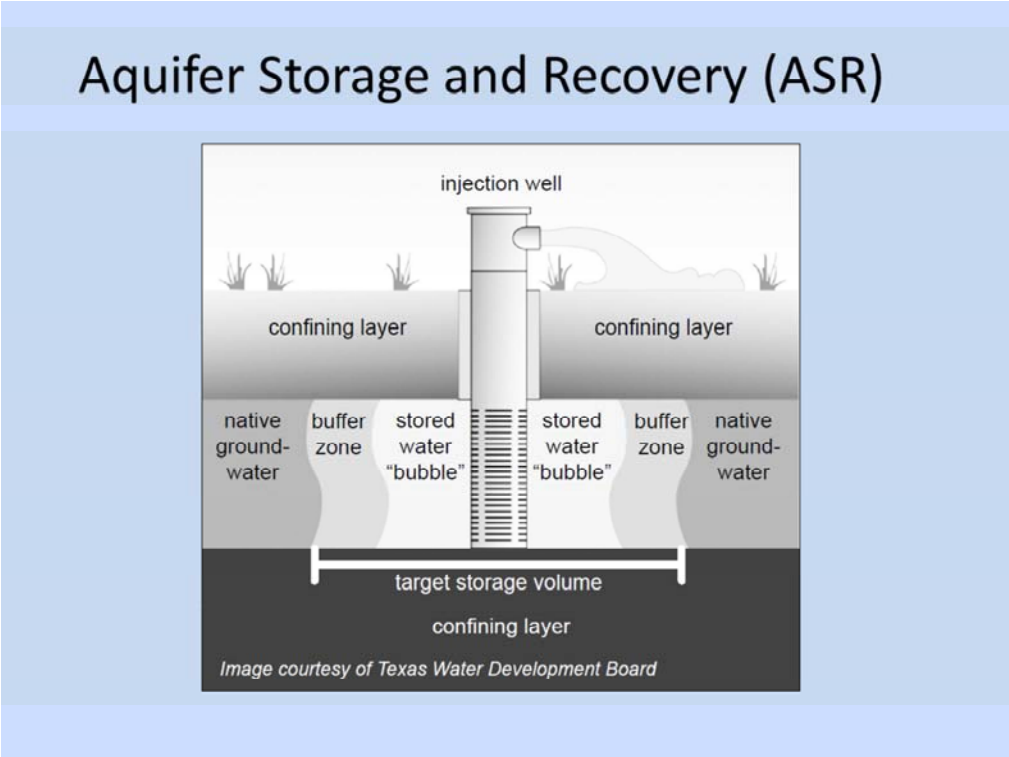
Considering data confined to Bell and Williamson counties, for municipal, electric, and mining sectors, there is a growing deficit.



The difference between projected water supplies and water demand shows deficit of approximately 193 thousand acre feet per year by 2070.

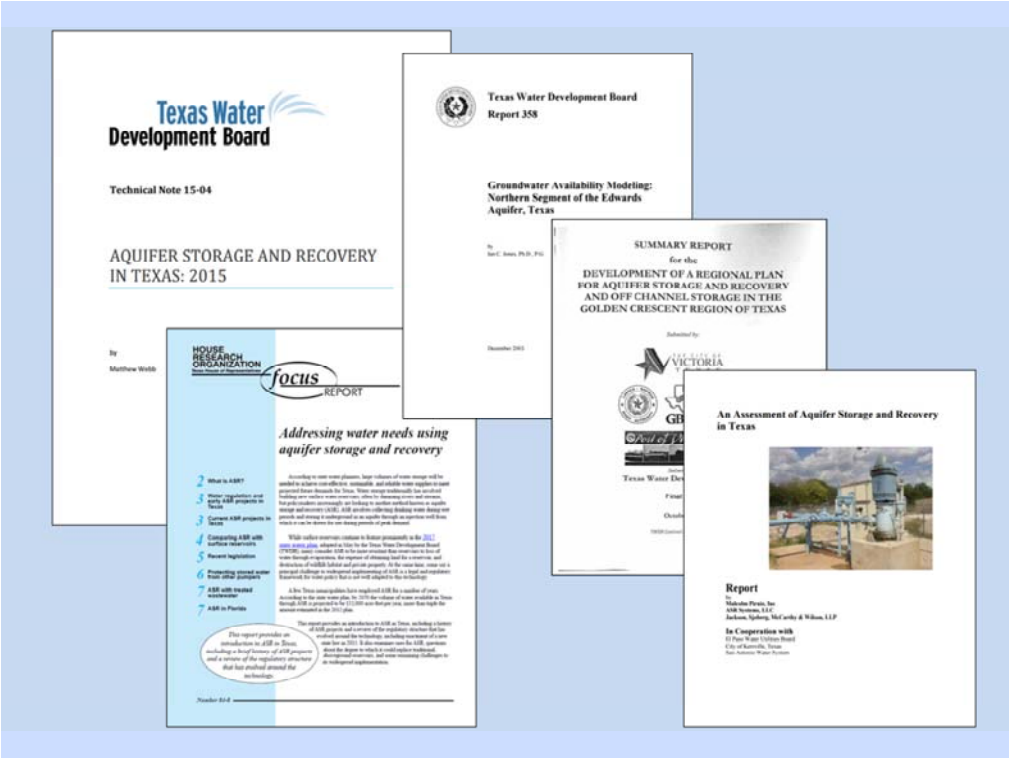
How can Bell County prepare for, meet, and exceed this projected deficit?

Additionally, how can Bell County prepare for unexpected weather extremes, on top of this? Think about drought!



The Texas Water Development Board, in conjunction with state Groundwater Management Areas and local conservation districts have all cooperated to develop extensive plans and solutions appropriate to meeting local needs.

Aquifer Storage and Recovery (ASR) is a recognized method and is recommended for many areas in the 2017 Texas Water Plan.
It has two big advantages including a small footprint as land is not required for inundation (i.e., reservoir area) and a reduction of evaporative loss (as much as 20% of all reservoir water evaporates every year).
There are disadvantages as well that must be considered.



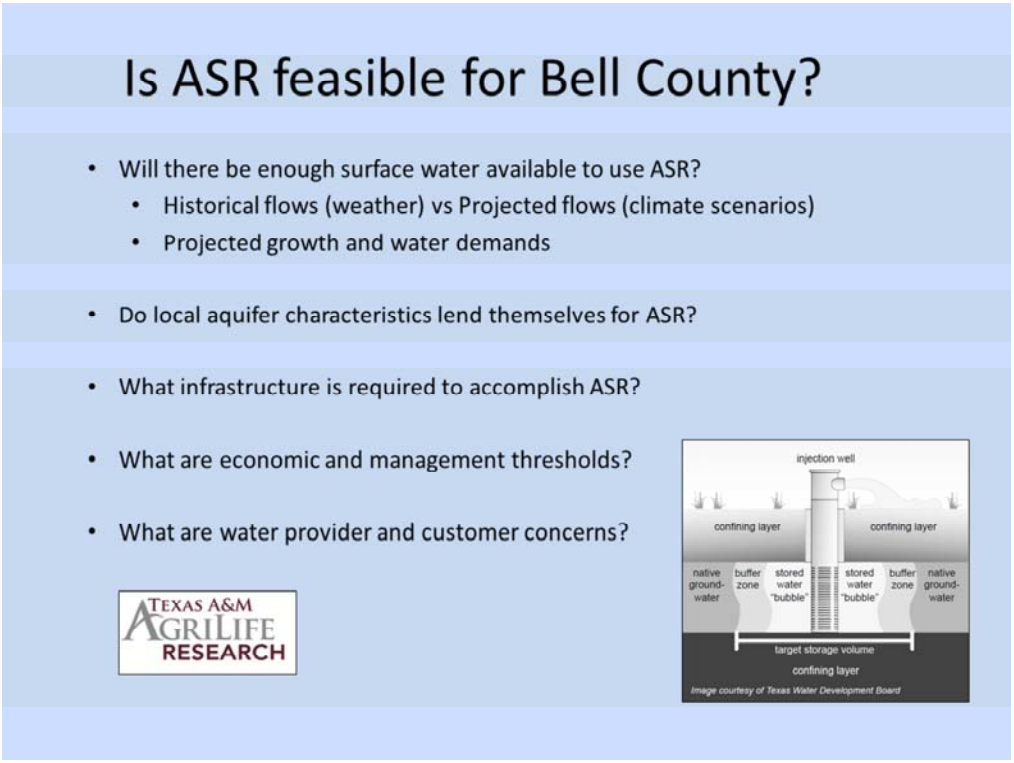
As noted earlier presentations, the method has been and is being utilized all over Texas. Numerous reports have been published by state agencies, local authorities, and consulting firms.

Two of the most informative about ASR include:
Aquifer Storage and Recovery in Texas: 2015 by Matthew Webb (presenting today) and,
Addressing water needs using aquifer storage and recovery: Texas House Research Organization

ASR is not new in Texas.

It has been utilized at least 8 times in the past with 3 facilities continuing operation; El Paso, San Antonio, Kerrville.
Each instance has adopted different methodologies. Most notably, the source water for each facility: reuse water, groundwater, and surface water.

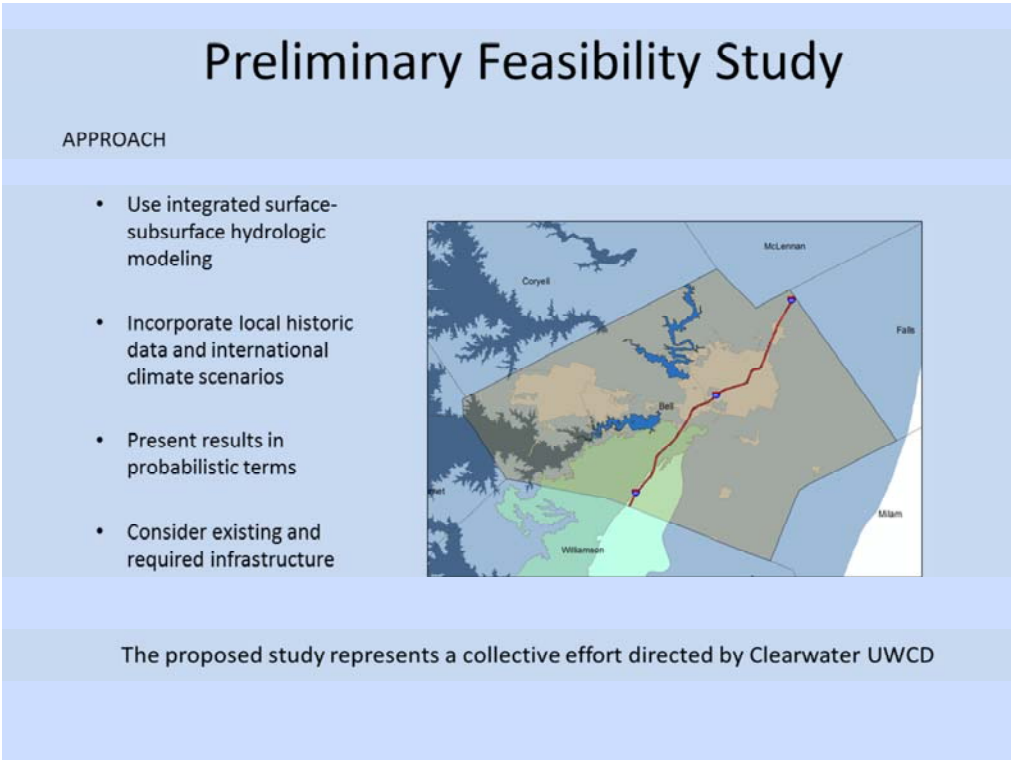
Eighteen studies have been initiated or completed that will apply the technology all over the state.



BREC is considering, at the request of Clearwater Underground Water Conservation District, the implementation of a preliminary evaluation of ASR feasibility for Bell County.

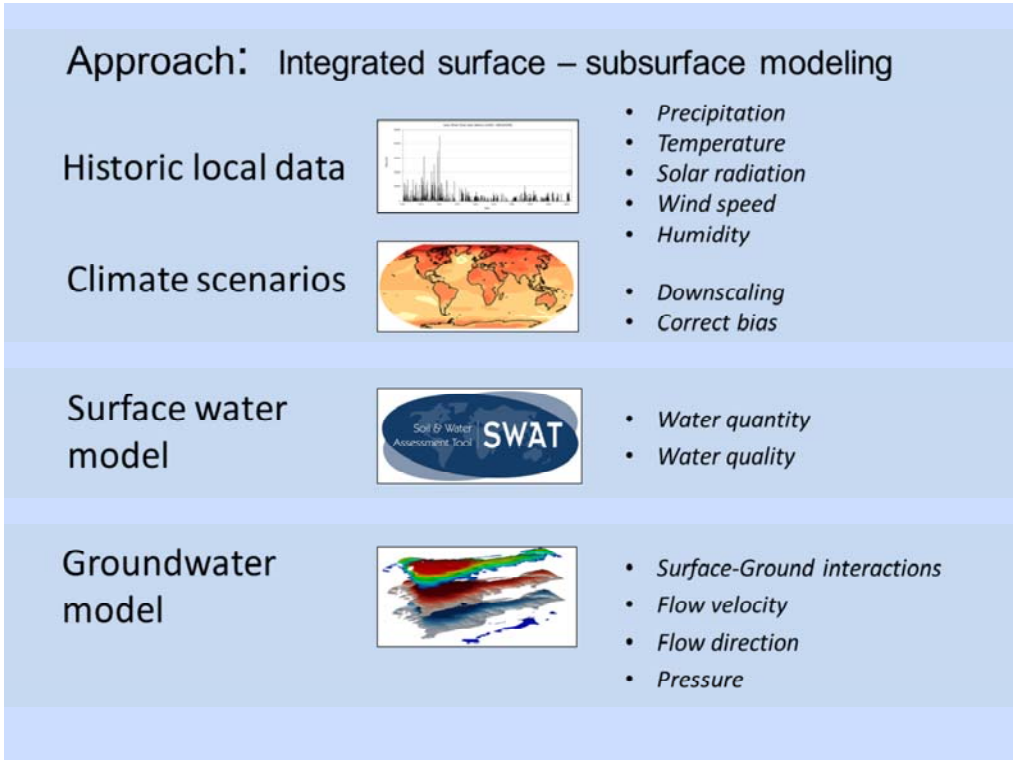
Questions under consideration include:

Will there be enough future surface flows available for ASR?
Are local aquifers appropriate for ASR?
What infrastructure is required for ASR?
What are the local economic costs and benefits of ASR?
What do the stakeholders think about ASR?



Preliminary evaluation: Indicates that a purveyor is contemplating aquifer storage and recovery and has considered basic concepts such as source water, target storage aquifer, type of beneficial use, and cost.
Texas A&M AgriLife – Blackland scientists have suggested an integrated surface-subsurface modeling approach considering climate uncertainty (long term weather forcasts).
No public entity has utilized this approach. Although state has appropriated funds for studies in the past, this study represents a collective effort directed by Clearwater.

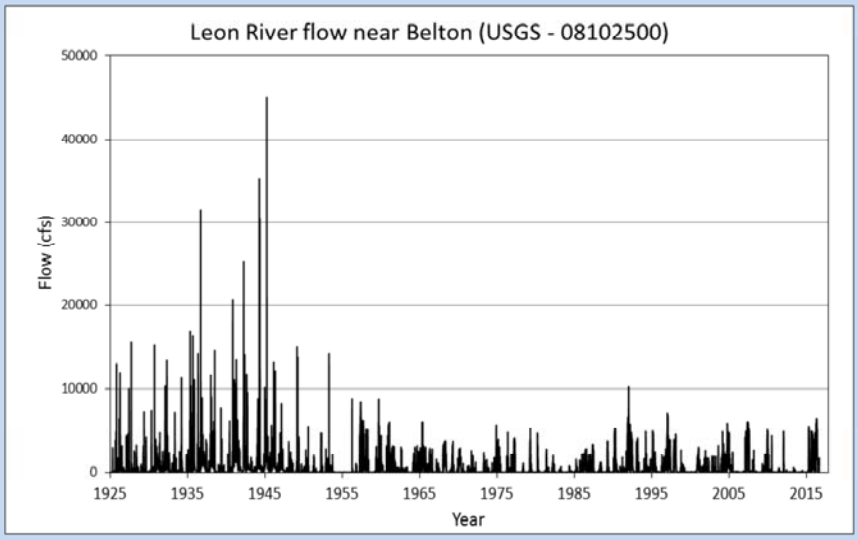
Historic local data (precipitation, temperature, etc.) utilized to calibrate a surface water model
International climate scenarios (i.e., long-term weather forecasting) would be downscaled and imposed upon SWAT predictions to predict future surface water availability
The surface water model would be linked to a groundwater model to determine locations and infrastructure required to store water in a local aquifer



A few details of the approach suggested by the BREC Team:

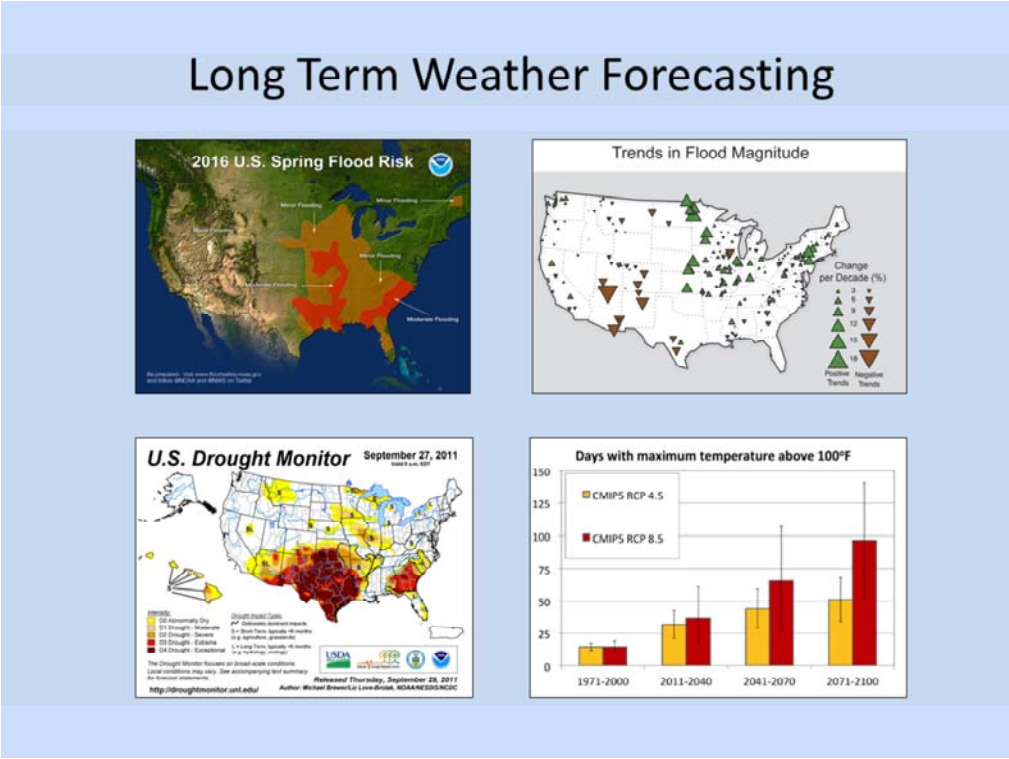
1) the use of historical stream flow data to calibrate the SWAT watershed simulation model,
2) the incorporation of climate data from GCMs,
3) the use of the SWAT hydrologic model to calculate hydro-dynamic responses of watershed components (i.e., vegetation, evapotranspiration, runoff, etc.) to changing climate conditions and predict future water availability,
4) the use of the MODFLOW model for aquifer storage and groundwater retrieval for consumption, and
5) the assessment of infrastructure, environmental, and economic costs.

Local historic data



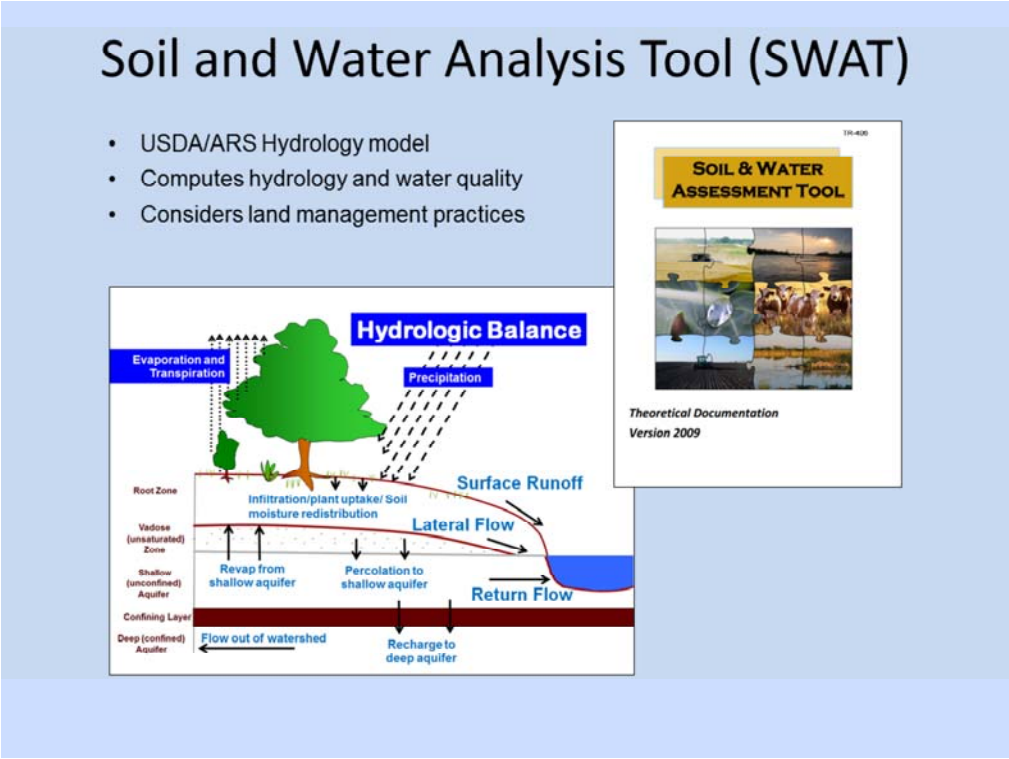
Our local watersheds are rich in available historic data required to calibrate the models. There are more than 10 USGS streamflow gauges collecting precipitation and streamflow data
More than 6 local airports, and several agricultural research facilities, including BREC, collecting additional weather data

This chart is an example of river flow data available from USGS at the Belton gauge. Note the construction of Belton Dam and subsidence of large floods.
Additionally, and perhaps more important to understanding future flows, note the large amount of variation in the flow, even when controlled by reservoir managers (Corp of Engineers).



Predicting. Estimating. How about Understanding what our future weather conditions in Texas may be like?

Governments around the world are watching climate and weather patterns closely as it holds the potential to affect some many things in our lives.
The US DoD is particularly interested and carefully examining long term weather forecasting as related to national security.
Here are a couple of topics that may affect many of us here today, flood prediction (fast events) and drought prediction (slowly developing disasters).
The top two charts predict flooding location and magnitude, based on climate models run by the National Oceanic and Atmospheric Administration.
The bottom two show the 2011 Texas drought and PREDICTED days exceeding 100 f (Austin study). Note the averages are increasing, BUT, also note vertical lines with each bar.
These represent uncertainty, what we don't know. The values not absolute but averages of a range of values. Keep this in mind as it will be important in a moment.



A little primer on the Soil and Water Analysis Tool, more commonly known as SWAT.

SWAT was developed to simulate the affects of land use management practices on hydrology and water quality processes. Ultimately it is a program that solves the water balance equation:
The model simulates hydrological processes at multiple spatial scales based upon available input data and variable definitions.

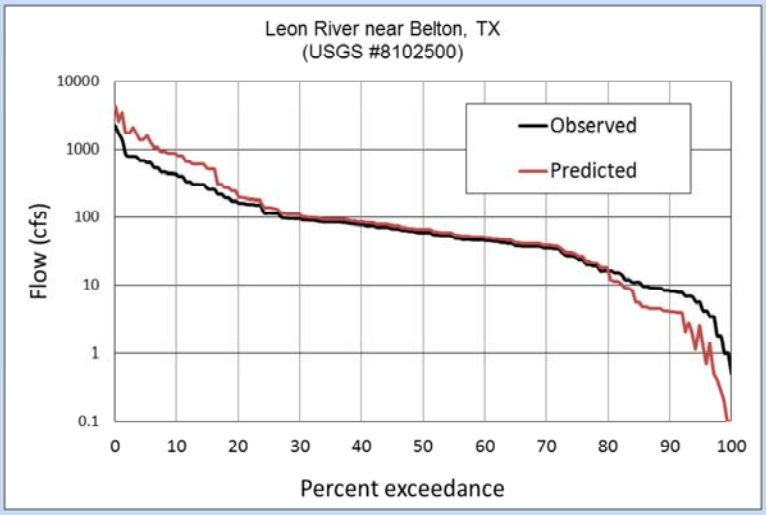
Required inputs

- Precipitation
- Temperature
  - High
  - Low
- Solar Radiation
- Wind Speed

- Relative Humidity

SWAT outputs

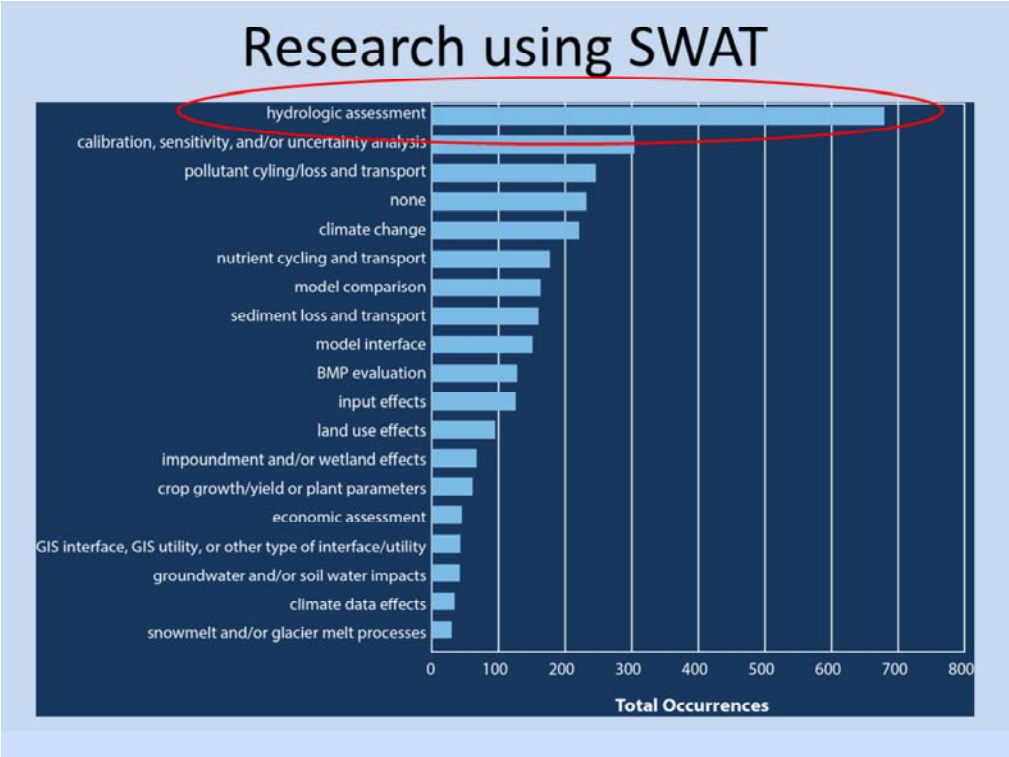
- Water quantity and quality



It is very important to note that SWAT provides output in probabilistic terms, for example a flow duration curve.
This explains past (observed) and future (predicted) in terms of probability of exceedance.

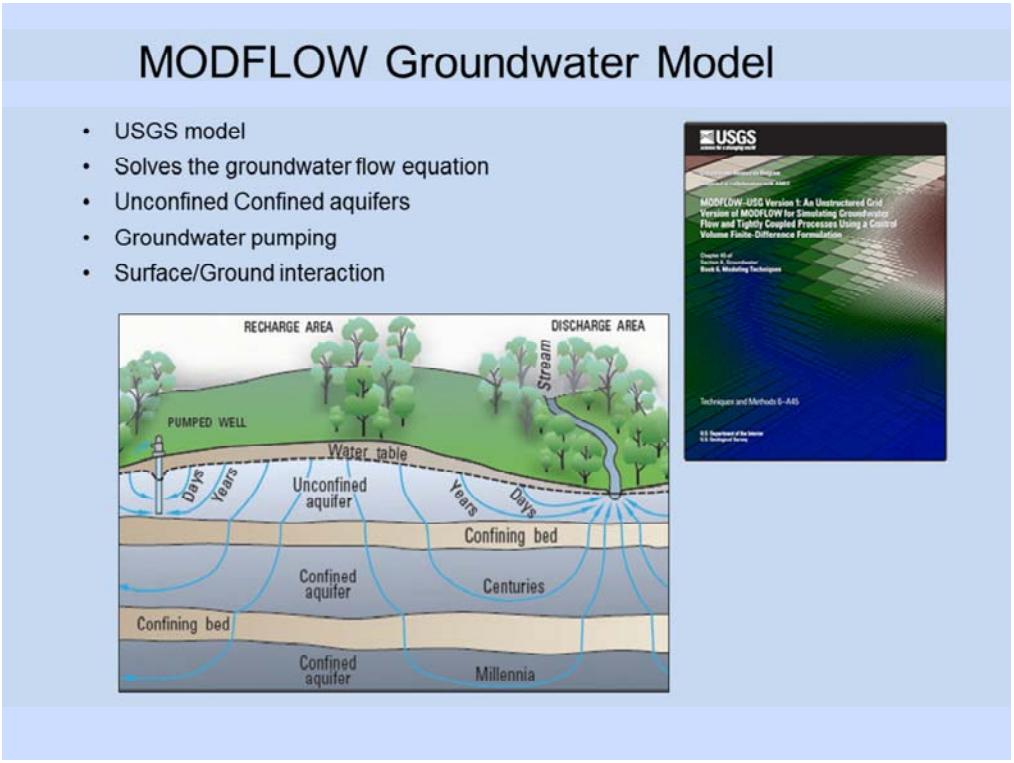
For example, thirty percent of the time, river flow is 100 cfs, or higher. This can be used to compare risk rather than relying on a single value.

Another example is hurricane forecasting. Recall that when forecasters predict landfall, they give a number of possibilities, each with an associated probability or increasing chance, usually expressed as %.
Presenting results in probabilistic terms is critical to public officials when trying to determine whether or not to issue evacuation orders; a very costly decision.



SWAT's watershed hydrologic computation has been extensively developed, tested, and used to assess changes in land use and climate upon watershed hydrology and water quality.
In our case, BREC scientists intend to use global climate scenarios to adjust SWAT inputs to produce future runoff estimates.

Note that SWAT has been utilized for numerous assessments and that hydrological assessment (i.e., determining surface water volumes) is most common.
More than 2800 formal articles have been published describing SWAT application and results.

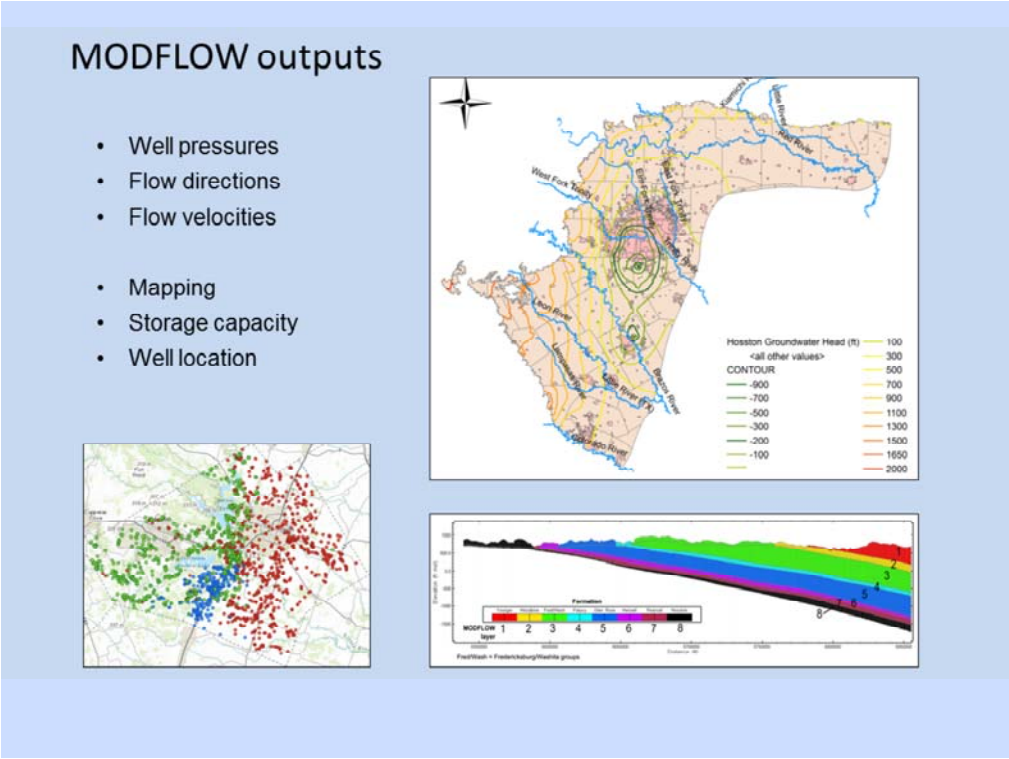


Linking the SWAT model to the MODFLOW model provides a coupled surface-subsurface hydrologic model.
MODFLOW is called as a subroutine within SWAT and replaces the standard SWAT groundwater subroutines.

The Modular Groundwater Flow Model, or MODFLOW, was created by the U.S. Geological Survey in the early 1980s.
It is a modular finite-difference flow model, essentially computer code that solves the groundwater flow equation.
The program is used by hydrogeologists to simulate the flow of groundwater through aquifers.
MODFLOW is now considered to be the *de facto* standard code for aquifer simulation.
Dr. Ryan Bailey, part of our research team, from Colorado State University has developed the SWAT-MODFLOW linkage code with Dr. Jaehak Jeong from AgriLife-Blackland.

MODFLOW outputs are used to create watershed maps describing:
Groundwater hydraulic head, flow velocity, and travel time.

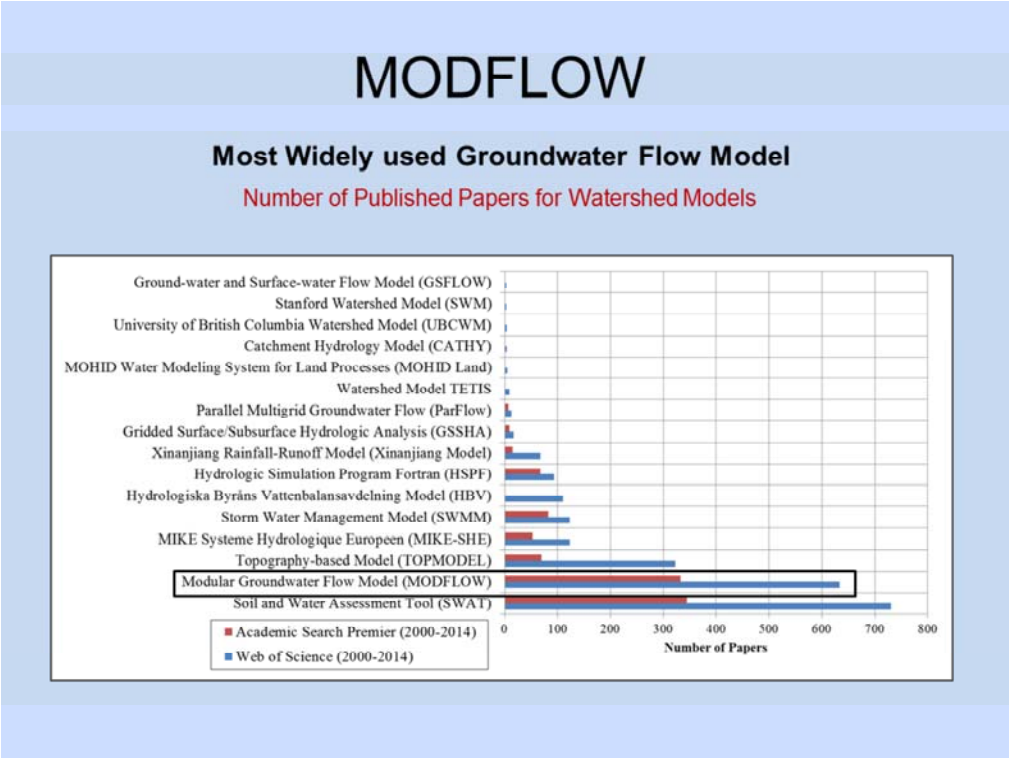
This information be used to locate and design wells.



MODFLOW calculates groundwater flow direction, flow velocity and pressure.

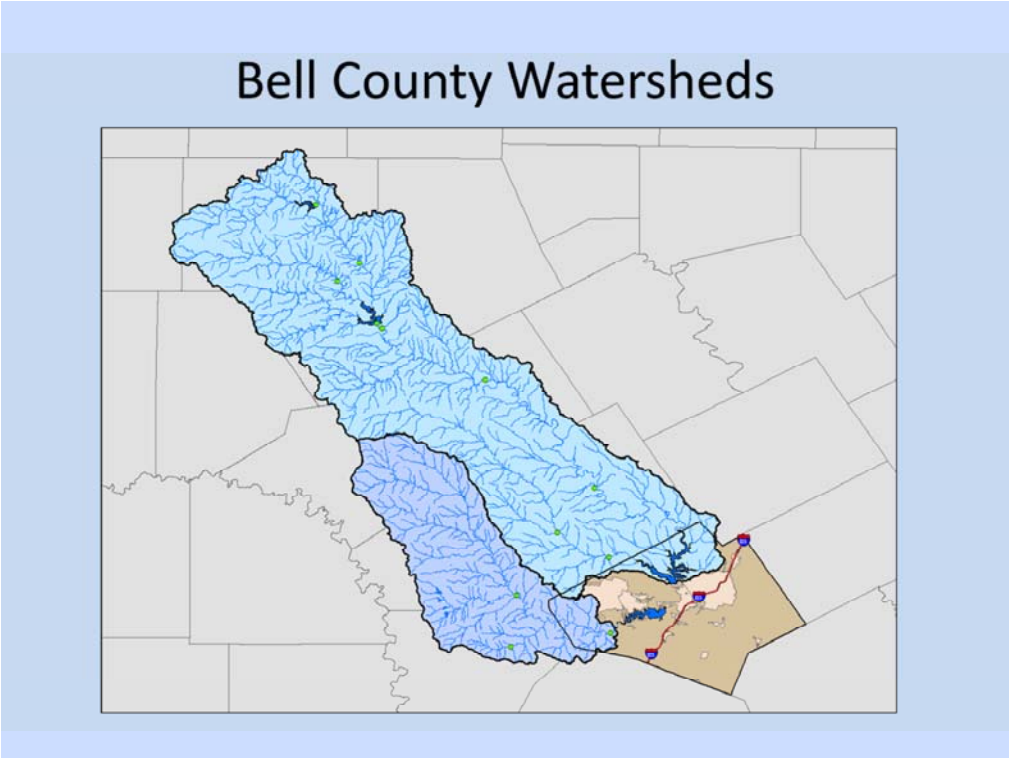
Which can be used to generate maps to determine aquifer storage capacity and determine location.
The charts to the right are plotted model results for the Trinity-Woodbine aquifer showing pressure “contours”, note diminished pressures around the DFW metro-plex where withdrawal is high.

The chart at the lower right is from Clearwater’s on-line tool showing well locations.
MODFLOW can be used to estimate future well pressures and availability based upon input data such as pumping rates.
As with surface modeling, groundwater modeling requires good, local, historic data to accurately estimate future trends.
Clearwater’s monitoring , analysis, and data management of Bell County underground water resources represents a high level of sophistication and is unique in the state.
This is particularly important to local stakeholders. Clearwater is looking out for them.



Like SWAT for surface water evaluations, it is equally important to note that MODFLOW has been extensively utilized for groundwater assessments, with more than 1000 published articles.

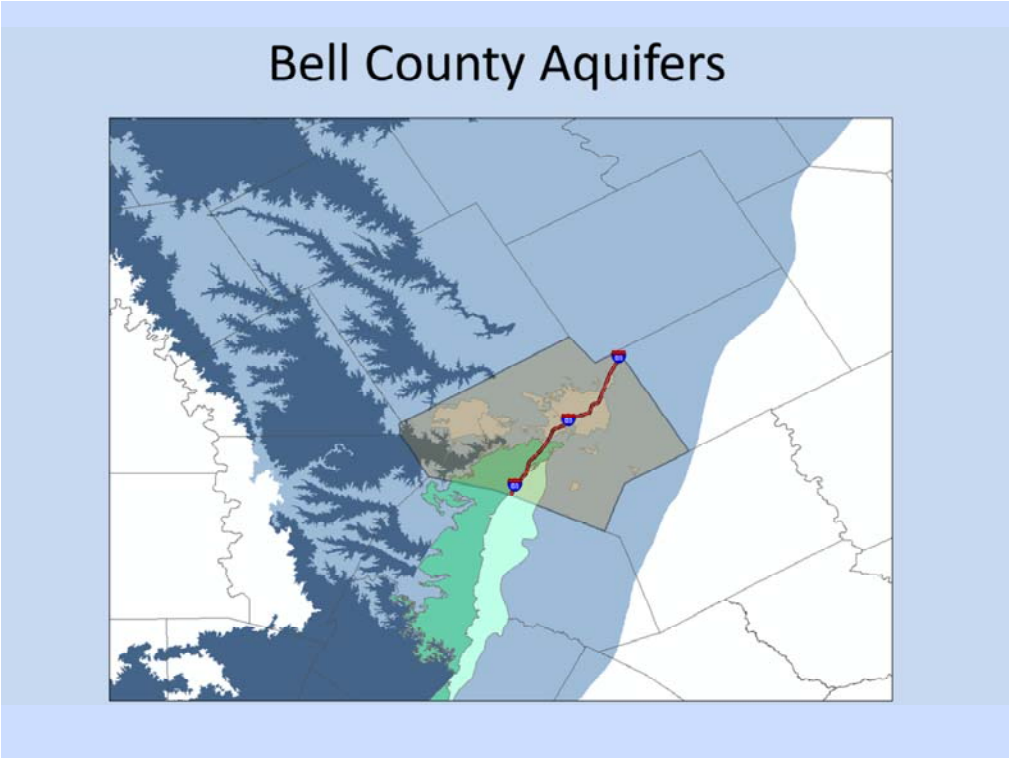
In fact, note the two highest utilized water flow models in use are SWAT and MODFLOW (see bottom of chart), based upon citation in academic journal databases.



So, what are our water sources that we can consider for ASR? Surface water.

Bell County has two large watersheds feeding two large reservoirs; Lake Belton and Lake Stillhouse.
These reservoirs are considered regional supplies and are not restricted to Bell County use alone.

When estimating our future water availabilities, from surface water modeling via SWAT, we need to consider future weather patterns, the effect upon vegetation, current water right holders, environmental flow, many things.
Allocations already purchased may be stored using ASR technology and used to meet future demands and mitigate long dry periods or drought.



There are two major aquifers under Bell County that could be considered for ASR.

The Trinity/Woodbine (in blue) and the Edwards (in green). Darker colors indicate the outcrop (shallow recharge area) while lighter colors indicate the down dip (deeper area). Both of these currently provide groundwater and are carefully monitored by Clearwater.

Again, I want to note that Texas A&M AgriLife Research and scientists at Blackland Research and Extension Center work for you and hold your interests and wellbeing in the greatest regard.
We have at the request of Clearwater Underground Water Conservation District management assembled this team proposing a unique and scientifically sound preliminary ASR study for Bell County.

Thank you and if there are any questions, please see me or other AgriLife scientists here today or contact me directly. All the best.