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The role of groundwater production alternative on water productivity in the southern high plains region of Texas, USA

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Abstract
Texas ranks third in the United States in both agricultural acres irrigated and irrigation water applied. Significant advances have been made in irrigation efficiency and water productivity.; however, some challenges remain. The agricultural sector responds to change, and farmers and ranchers have demonstrated resiliency by adapting to the changes in water supply, cost, and regulations. Projections in the 1970s suggested that the Ogallala Aquifer would be exhausted by the early 2000s, but the farmers responded by using newly developed efficient technologies, and the projection did not come true. Opportunities remain for continued improvements in water use efficiency, including: 1) Improving irrigation scheduling, 2) Adopting drought tolerant crop varieties, 3) Developing Improved Irrigation Water Management Technologies, 4) Continued Adoption of Conservation Practices and 5) Improving Irrigation Conveyance Systems. The sustainability of the Southern High Plains (SHP) region in Texas is heavily dependent on the groundwater production from Ogallala Aquifer for crop production. The case study presented here illuminates the existing potential for alternative groundwater sourcing from brackish form. The major aquifer, Ogallala Formation, overlies the minor Dockum Hydrostratigraphic Unit (Dockum-HSU) in much of the Texas Panhandle and West Texas. The brackish groundwater resources from Dockum-HSU can serve as an important alternative source of water to the rapidly depleting Ogallala aquifer. However, water quality and the aquifer physical properties can limit the direct use from the deep Dockum-HSU.

Keywords: Groundwater; Irrigation Water Management, Texas; Water Productivity; Water Use Efficiency

INTRODUCTION

Although both surface water and groundwater are used for agricultural irrigation, the source of most agricultural irrigation water is groundwater (TWRI, 2012). In 2000, 86% of the irrigated acres in the state used groundwater, 11.6% used surface water, and the remaining 2.4% used a mix of groundwater and surface water (TWDB, 2001). Groundwater is the sole source of irrigation water in the Texas High Plains, while the Rio Grande Basin and upper portions of the Gulf Coast rely heavily on surface water. Combinations of sources provide irrigation water for the Winter Garden (predominantly groundwater) and middle Gulf Coast (predominantly surface water) regions (TWDB, 2011).

Much of the agricultural irrigation in Texas is concentrated in areas far from urban growth. The state's irrigated acres are concentrated in those areas having both productive soils and available water. As

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shown in Figure 1, most agricultural irrigation in West and South Texas are located far from the State's major urban centers in Central, North, and Southeast Texas. Annual estimated water use in Texas totaled 16.2 million acre-feet in 2009, with about 57% used for agricultural irrigation (TWDB, 2012). Total annual irrigation water use has remained steady, averaging approximately 9.5 million acre-feet, since the late 1970s (Figure 2). While statewide agricultural irrigation application rates have stayed relatively constant since the mid 1970s (TWDB, 2001.2011), agricultural yields have increased significantly as improvements in irrigation technology and management, crop management, and crop genetics have been developed and implemented. For example, Figure 3 shows that average per-acre corn yields have increased by 62% since 1975 while cotton yields have more than doubled (USDA-NASS, 2008).

Rapid development and expansion of urban areas are decreasing the amount of land available for irrigated agriculture, and this is especially noticeable in Regions M and E (TWRI, 2012). Many of these acres are being converted to residential areas with significant quantities of irrigated urban landscapes. Further, surface water supplies available for agricultural irrigation are decreasing as water demands for municipal, industrial, and energy sectors increase (Figure 1). In Regions C, K, and M, municipal demand increases of more than 90% are expected by 2060 (Table 1).

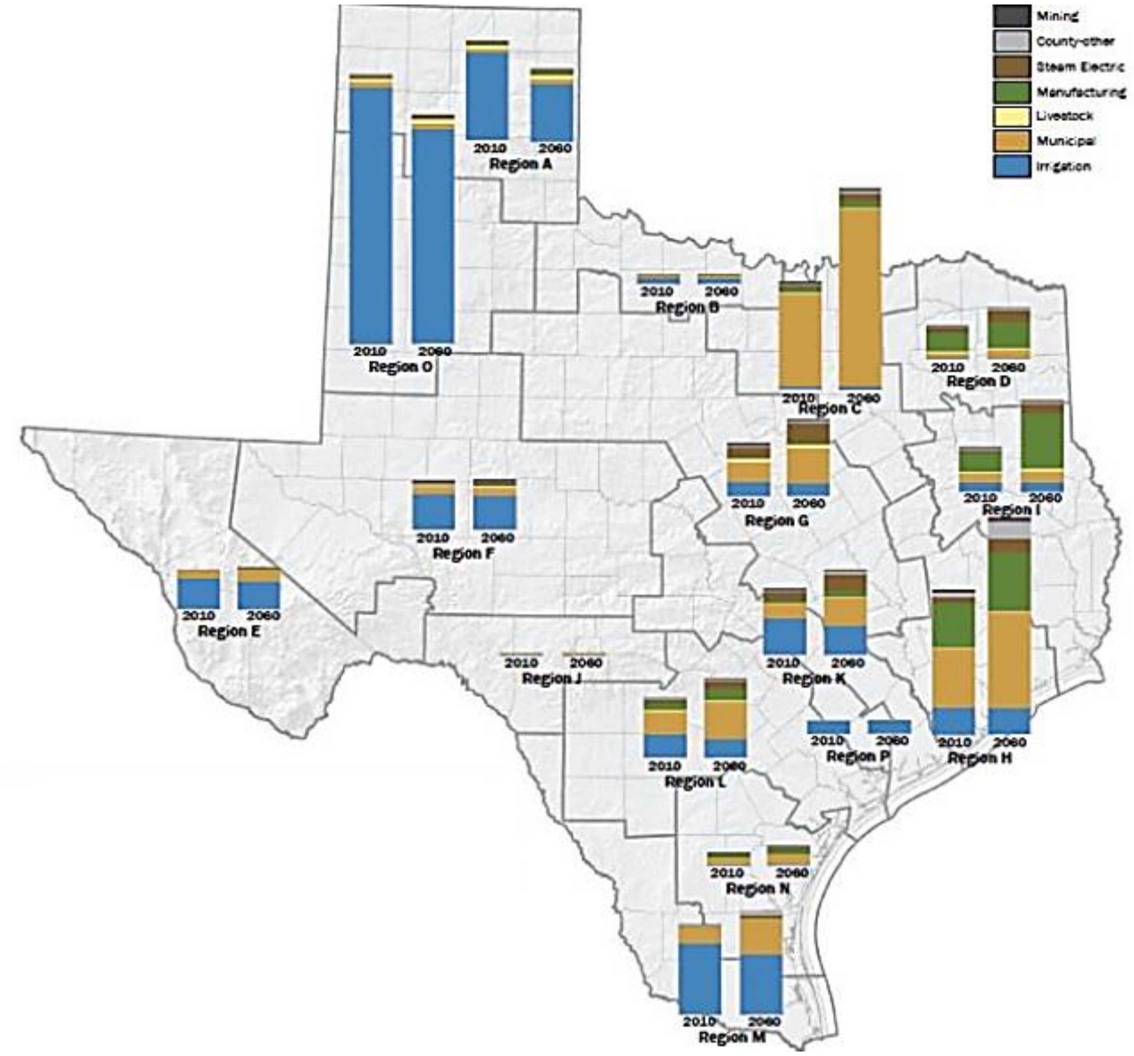


Fig. 1. Existing (as of 2010) and future (2060) water demands for each water use category in each water planning region (TWDB, 2012)

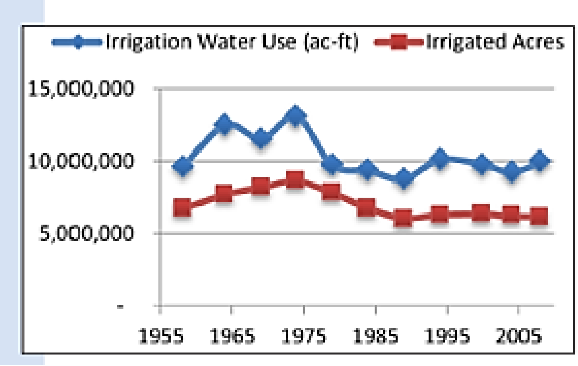


Fig. 2. Irrigated acres and irrigation water use in Texas, 1958 – 2008 (TWDB, 2001.2011)

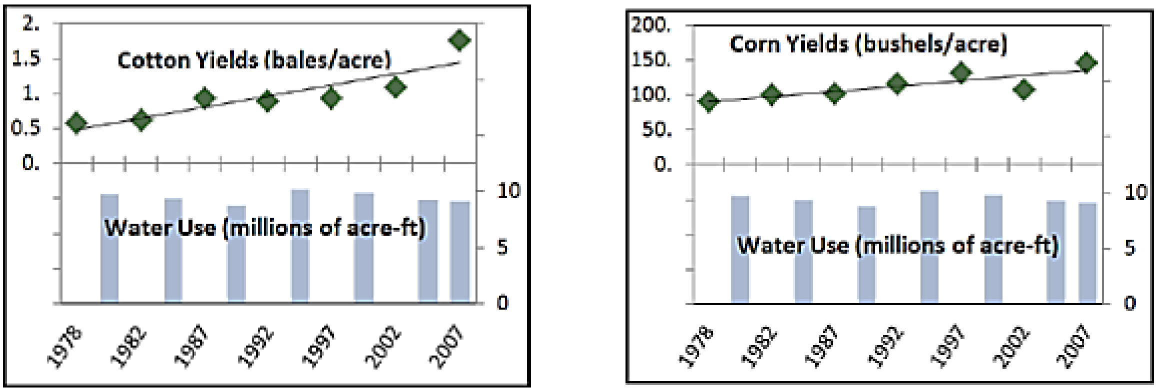
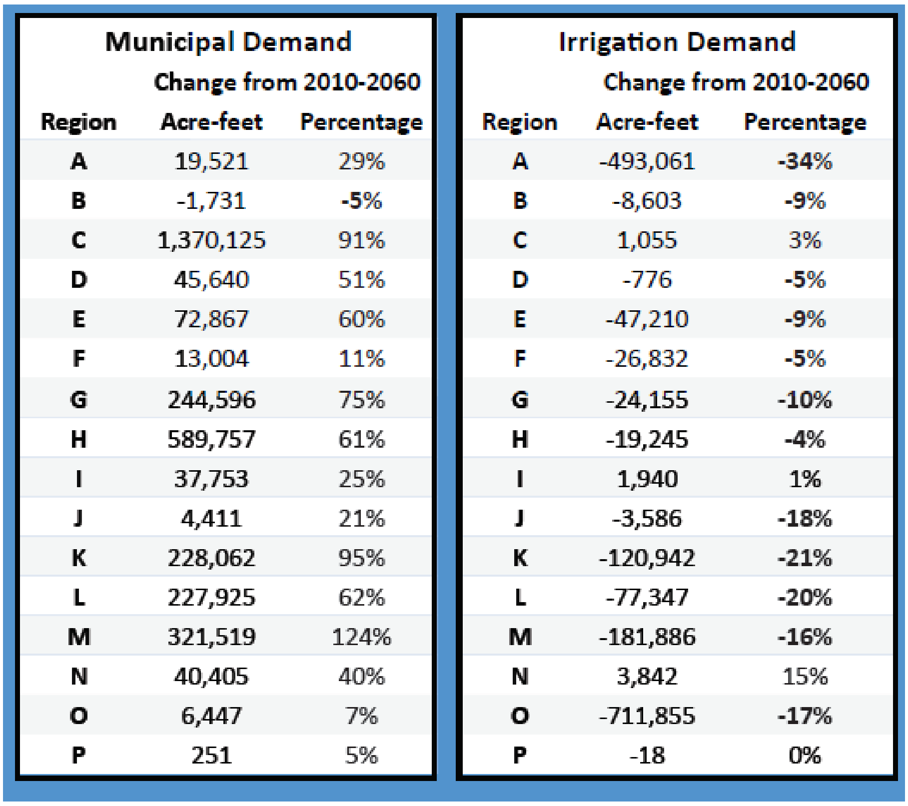


Fig. 3. Increases in cotton and corn yields (USDA-NASS, 2008) in comparison to statewide agricultural irrigation use in Texas (TWDB, 2001.2011)

Table 1. Changes in existing (as of 2010) and future (2060) water demands, for municipal and irrigation needs, in each water planning regon (IWMI, 2012)



Municipal Demand			Irrigation Demand		
	Change from 2010-2060			Change from 2010-2060	
Region	Acre-feet	Percentage	Region	Acre-feet	Percentage
A	19,521	29%	A	-493,061	-34%
B	-1,731	-5%	B	-8,603	-9%
C	1,370,125	91%	C	1,055	3%
D	45,640	51%	D	-776	-5%
E	72,867	60%	E	-47,210	-9%
F	13,004	11%	F	-26,832	-5%
G	244,596	75%	G	-24,155	-10%
H	589,757	61%	H	-19,245	-4%
I	37,753	25%	I	1,940	1%
J	4,411	21%	J	-3,586	-18%
K	228,062	95%	K	-120,942	-21%
L	227,925	62%	L	-77,347	-20%
M	321,519	124%	M	-181,886	-16%
N	40,405	40%	N	3,842	15%
O	6,447	7%	O	-711,855	-17%
P	251	5%	P	-18	0%

The tremendous pressure from urban growth is forcing many areas to look to obtain the water from other regions. With the projected doubling of the population of Texas over the next 50 years, sustaining irrigated agriculture will become ever more challenging because of the competing interests generated by this growth. It will also become more important with the increasing food demands of this population and need for a secure food supply (TWRI, 2012).

MATERIALS AND METHODS

Case Study Area

The sustainability of the Southern High Plains (SHP) region in Texas is heavily dependent on the groundwater production from Ogallala Aquifer for crop production (Uddameri *et al*., 2017a). The SHP is located at the northwestern part of Texas and is a part of the North American Great Plains. Cotton (60% of Texas and 40% of US), corn (27% of Texas), sorghum (27% of Texas and 14% of US), peanuts (83% of Texas and 6.5% of US) and winter wheat (22% of Texas and 7% of US) are the five major planted crops in this region (USDA-NASS, 2017). Figure 4 shows the amount of areas these crops are planted in the SHP region and in the entire Texas state. The SHP region also supports almost 25% of the cattle on feed in the nation (Allen *et al*., 2007). There is a continuous population growth in the major metro areas in this region- Lubbock, Amarillo, Odessa and Midland which will increase the domestic water demand (Carlson and Glasrud, 2014). This region is otherwise rural. Deposition of the Ogallala formation occurred during the Neogene geologic period and covered by eolian sediments later (Nativ and Smith, 1987). The semi-arid SHP gets a low annual rainfall of approximately 24 inches and high evaporation of around 67 inches (Hudak, 2016).

RESULTS AND DISCUSSION

Groundwater Use Practice

The total fresh groundwater withdrawal in the SHP area is mainly used for irrigation. In the year 2015, the total extraction was 3.80 Million Acre-ft (Dieter et al. 2018). The other sectors that use fresh groundwater are public (1.92%), domestic (0.38%), industrial (0.49%), livestock (2.10%) and thermoelectric uses (0.37%). Figure 5 shows the county level total fresh groundwater withdrawal in the SHP region where more than 200 thousand Acre-feet extractions were made in Dallam, Hartley, Sherman, Castro, Hales and Gaines counties in the year 2015.

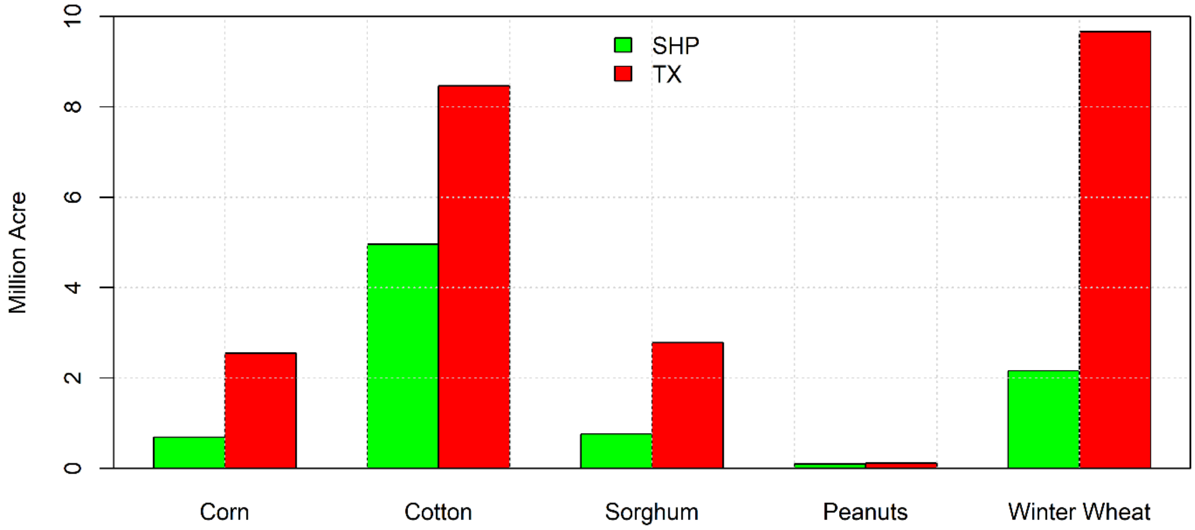


Fig. 4. Major Crop Productions in the SHP and Texas (based on data from (USDA-NASS, 2017))

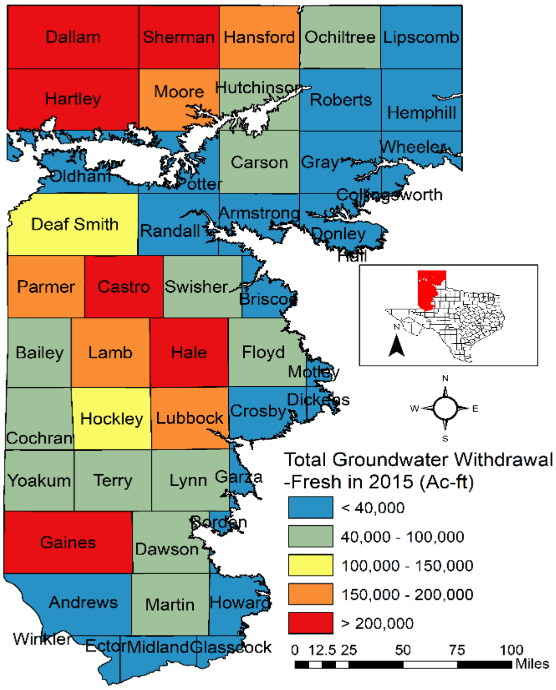


Fig. 5. County-level Total Fresh Groundwater Withdrawal in the Southern High Plains Region in Texas in 2015 (based on data from (Dieter *et al.*, 2018))

Groundwater Depletion Problem

Water level in Ogallala aquifer is declining steadily because of much faster withdrawal rate than recharge in this semi-arid region due to limited amount of precipitation (Rajan *et al.*, 2015). According to the current depletion rate, irrigation may not be possible on 35% of the southern High Plains region in the next 30 years (Scanlon *et al.*, 2012). There will be a significant water demand for agricultural, industrial and municipal uses due to the rapid urbanization rate in this region and future climate change (Al-Gamal, 2020). The Groundwater Management Areas (GMAs) in the High Plains region has adopted a 50/50 rule which is at least 50% of the saturated thickness must be preserved in the next 50 years as the Desired Future Condition (DFC) of the aquifer (Uddameri *et al.*, 2017b). Majority portion of the Ogallala aquifer in the SHP region is facing the problem of low saturated thickness. Figure 6 shows the distribution of calculated saturated thickness values in the different counties of the SHP region (average of the years 2010 to 2020) based on the data from Texas Water Development Board Groundwater Database (TWDB GWDB). Saturated thickness (Sat TH) is calculated using the land surface datum (LSD), water level below LSD ($\mathrm{WL}_{\text{below LSD}}$) and aquifer bottom elevation ($\mathrm{Aquifer}_{\text{bottom}}$) as follows

$$\mathrm{Sat\ TH} = \mathrm{LSD} - \mathrm{WL}_{\text{below LSD}} - \mathrm{Aquifer}_{\text{bottom}} \quad (1)$$

Few counties in the Northern parts have comparatively higher saturated thickness values (> 200 ft): Potter, Roberts, Lipscomb and others. The counties mostly in the southern parts including Yoakum, Terry, Lynn, Garza, Borden and others have low saturated thickness values of below 50 ft and sustainable production of groundwater could be difficult during such low values (Uddameri et al., 2017b). These estimation of saturated thickness values match well with other studies done by McGuire *et al.*, (2012) and McGuire (2014) in this region. It has now become important for the policy makers to look for alternative ways to prolong the life of the Ogallala aquifer to ensure a future uninterrupted economic growth in this region by not obstructing the current water requirements for food and energy productions.

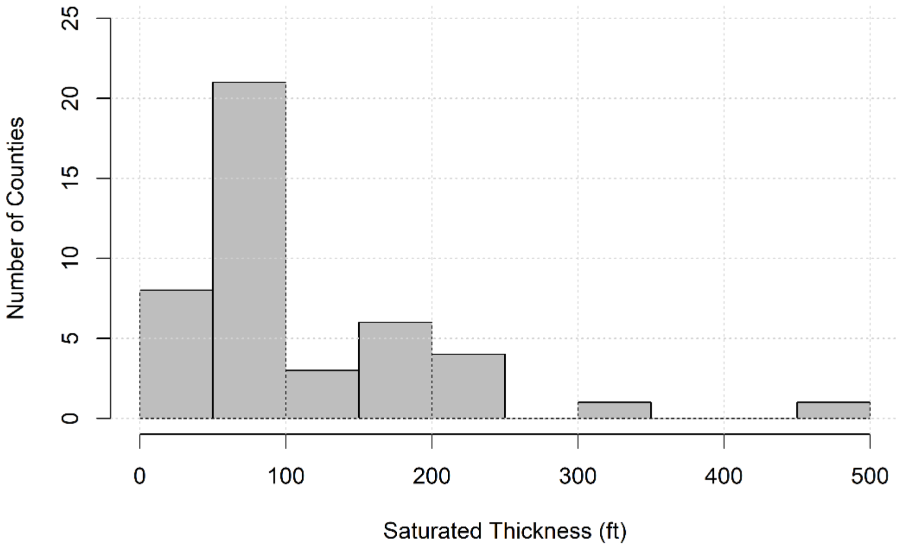


Fig. 6. County-level Average Saturated Thickness Distribution in the Southern High Plains Region in Texas from 2010 to 2020 (based on data from TWDB GWDB)

Alternative Groundwater Resources

The major aquifer Ogallala Formation overlies the minor Dockum Hydrostratigraphic Unit (Dockum-HSU) in much of the Texas Panhandle and West Texas. The brackish groundwater resources from Dockum-HSU can serve as an important alternative source of water to the rapidly depleting Ogallala aquifer (Bradley and Kalaswad, 2003). However, water quality and the aquifer physical properties can limit the direct use from the deep Dockum-HSU. In recent days, there have been a lot of efforts in identifying and mapping the major concerning water quality constituents in the groundwater of Dockum-HSU and its compatibility for different uses: hydraulic fracturing, municipal and crop production. Also, there are several works that provide guidelines for possible treatment options and blending of brackish Dockum HSU water with much better-quality Ogallala groundwater in the SHP region. The physical properties of the aquifer, aquitard and production wells are well discussed in literature with explanation on the freshwater-saltwater upconing problem that impacts the production from the deep Dockum-HSU (Karim *et al.*, 2020; Karim 2018; Uddameri and Reible, 2018; Hernandez and Uddameri, 2015).

CONCLUSION

On the high plains of the Texas Panhandle, farmers owe their livelihoods to a marvel of geology: the cool, gravely waters of the country's largest aquifer, the Ogallala. Stretching across eight states, the amount of water is so vast that, according to one writer, it could fill Lake Erie nine times over. Within Texas, the Ogallala accounts for about 40 percent of all water use (Galbraith, 2010). The aquifer's levels have declined sharply here. During a dry growing season of 2009, the High Plains Water District, which includes all or part of 15 Panhandle counties, recorded an average drop of 1.5 feet, the most since 1997. The rains returned, but the 2007 state water plan had projected that the Ogallala's volume will fall a staggering 52 percent between 2010 and 2060, as corn and cotton growers continue to draw from its depths.

The brackish groundwater resources from Dockum-HSU can serve as an important alternative source of water. The opportune moment is now to set water quality DFC (Desired Future Conditions) goals to assess the viability of Dockum-HSU aquifer water use.

In the meantime, the Panhandle Groundwater District’s core principle since its inception of conserving groundwater is noteworthy for improving water productivity (PGCD, 2020). The district is continuously working to take positive and prompt action to identify and address all reported wasteful practices and instances of water waste. In addition, the district has implemented a number of programs that are designed to support the constituents in the district with drought conditions. The district maintains a link on their website to the National Oceanic and Atmospheric Administration (NOAA) drought monitor indices. The District's effort to control and prevent groundwater contamination extends to an annual sampling program within its Water Quality Network.

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