Impacts of Recharge and Discharge on Sustainability of the Trinity Aquifers of Central Texas

B. A. Smith, B. B. Hunt, J. Watson, and J. Camp

Abstract

The karstic Trinity Aquifers of central Texas provide baseflow to streams and are used extensively as water supplies for domestic, municipal, agricultural, and industrial purposes. Rapid increases in population in the area are placing significant demands on the aquifers in an area that has very limited surface water supplies and is prone to significant droughts. Droughts occur frequently in this area and current levels of pumping in the Trinity Aquifer have resulted in both the capture of springflow in karstic areas, resulting in a major spring ceasing flow during drought and groundwater mining in other less karstic areas of the Trinity. The most significant historical drought in central Texas occurred in the 1950s and lasted for up to 10 years. Tree-ring data show that even more significant droughts have occurred over the past thousand years. Predictions for changes to precipitation due to climate change are for more extensive flooding and more severe drought. Long-term trends in water levels are downward with only limited recovery during very wet periods. An understanding of how these aquifer systems function is key to proper aquifer management which is likely to involve limits to pumping during average conditions and more severe reductions during periods of drought and incorporating alternative water supplies such as rainwater harvesting, aquifer storage and recovery, and perhaps importation of water from distant sources.

Keywords

Karst • Trinity Aquifer • Drought • Sustainability

B. A. Smith (✉) · J. Watson · J. Camp
Barton Springs/Edwards Aquifer Conservation District, 1124 Regal Row, Austin, TX, USA
e-mail: brians@bseacd.org

B. B. Hunt
Bureau of Economic Geology, University of Texas, Austin, TX 78704, USA

1 Introduction

The Trinity Aquifers of central Texas have been used as a source of water for many years, and water discharging from springs provides base flow to streams in the area. Base flows in streams that are fed by the Trinity Aquifers provide recharge to downgradient portions of the Trinity Aquifers and to the Edwards Aquifer. Rapid population growth in recent years has significantly increased the demand for groundwater in the area. Hays County, which is at the center of the study area, has been the fastest growing county in the USA from 2010 to 2020 (U.S. Census Bureau 2021). The certain increase in demand for groundwater coupled with severe drought will likely cause significant reductions in springflow and decreases in water levels. This will cause many water-supply wells to cease the ability to yield water and negative ecological impacts along spring-fed streams, both of which will lead to serious economic consequences for the area. Furthermore, reduction of Trinity Aquifer springflow will reduce recharge to the Edwards Aquifer that hosts a variety of endangered aquatic species at Barton and San Marcos Springs.

Studies are being conducted to better understand the aquifers of central Texas so that proper management of these aquifers will allow for sufficient groundwater of good quality to be available for human and ecological purposes.

2 Hydrogeology

The geologic units that make up the Trinity Aquifers in the study area (Fig. 1) are largely limestones and dolomites of Early Cretaceous age (Fig. 2). These sediments were deposited on a broad shelf that separated the deeper water of the Gulf of Mexico to the southeast and land of the Llano Uplift to the northwest. Some of the depositional environments in which these sediments were deposited are coastal plains, tidal flats, shorelines, and a variety of shallow-water

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environments (Hunt et al. 2020). These units are nearly flat lying with a gentle dip to the east and southeast (Wierman et al. 2010). Major faulting occurred during the early Miocene along the Balcones Fault Zone. The strikes of these faults are generally north-northeast, and most of the faults occur in central and eastern Hays County and in adjacent counties to the north and south (Fig. 1). The Balcones Fault Zone consists of a series of en-echelon normal faults, down-to-the southeast. Fracturing associated with the faulting shattered the brittle carbonate rocks, providing pathways for groundwater movement and the development of solution conduits.

The eastern portion of the study area contains the Edwards Group at and near the surface. Stratigraphically beneath the Edwards Group is the Trinity Group that is exposed in the western portion of the study area. In the western side of the study area, the outcrops are dominated by the Lower Glen Rose Member within the river valleys, with the Upper Glen Rose Member making up the areas of higher elevation.

The Upper Glen Rose Member (Fig. 2) is 108 m (355 ft) thick in the upper reaches of the Onion Creek watershed and thickens to about 137 m (450 ft) in the eastern portion of the study area. In outcrop, the Upper Glen Rose Member is subdivided into eight informal lithologic units, which correlate to the classic work of Stricklin et al. (1971). These units generally consist of stacked and alternating limestones, dolomites, mudstones, and marls.

The Lower Glen Rose Member (Fig. 2), about 76 m (250 ft) thick, is characterized by fossiliferous limestone units with well-developed rudistid reef mounds and biostromes often found near the top and base of the unit. The shaley and dolomitic Hensel, about 10 m (33 ft) thick, is also exposed in the incised river valleys and locally provides semi-confining aquifer properties. The Cow Creek Limestone is about 23 m (75 ft) thick. The upper portion of the

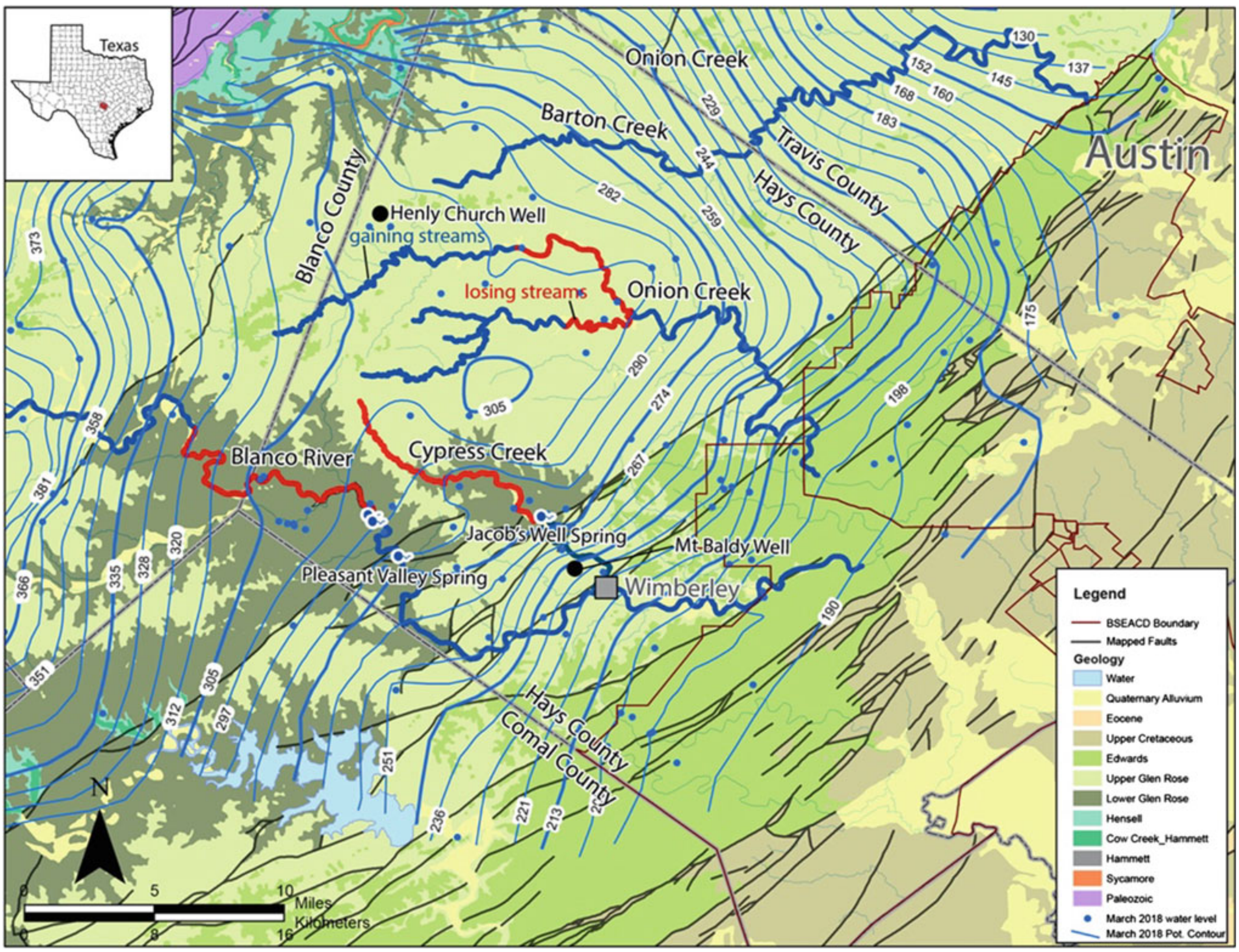

Fig. 1 Geologic map of study area including county boundaries, major surface streams, locations of wells for water-level measurements, and potentiometric contours. The Barton Springs/Edwards Aquifer Conservation District (BSEACD) boundary is represented by dark red lines in eastern Hays County. The Hays Trinity Groundwater Conservation District (HTGCD) makes up the remainder of Hays County west of BSEACD. Potentiometric contours are in meters

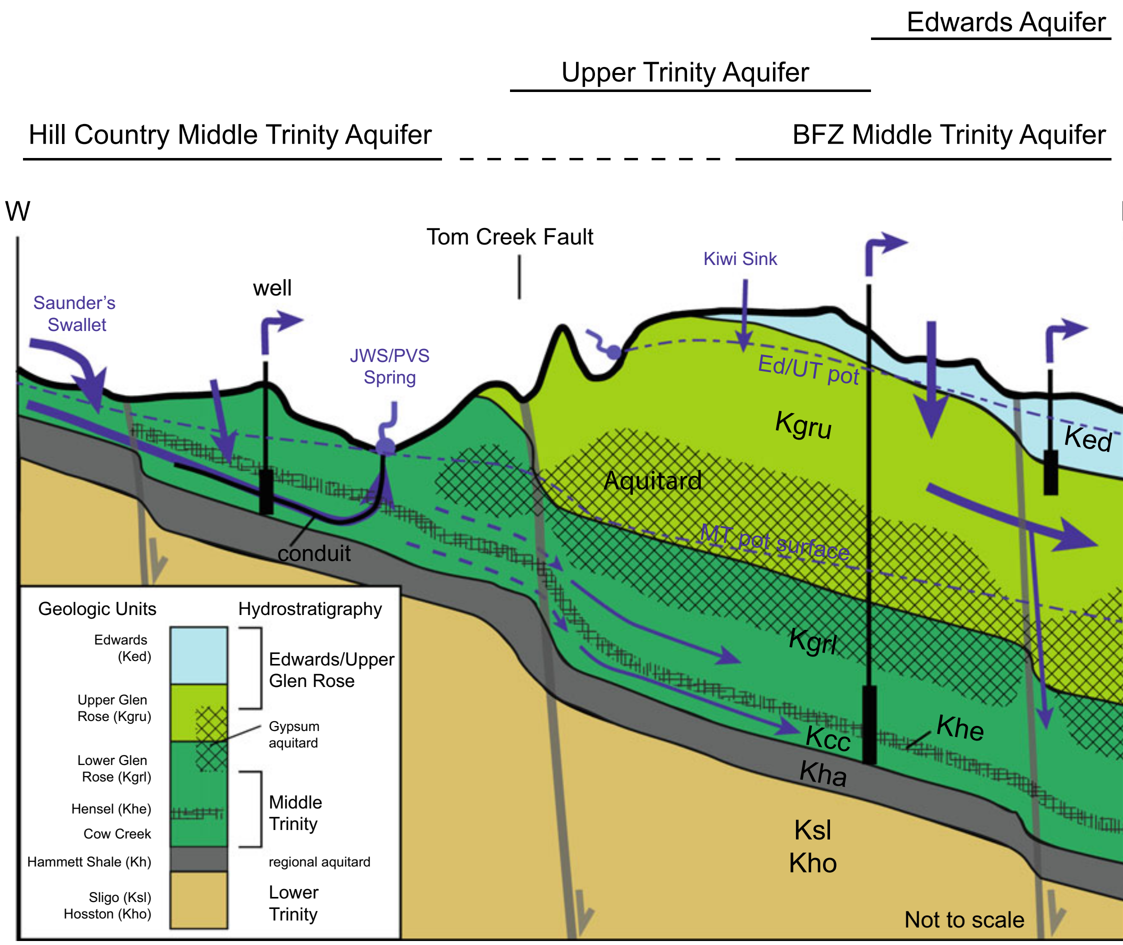

Fig. 2 Schematic cross-section of the aquifers and formations that are the subjects of this paper and arrows showing generalized directions of flow (Smith et al. 2018)

Cow Creek Limestone is a cross-bedded grainstone unit that is often limestone but can also be dolomite. The lower portion of the Cow Creek Limestone becomes more dolomitic and silty with depth grading into the underlying Hammett Shale. The Hammett Shale serves as a confining unit between the Middle and Lower Trinity Aquifers.

These carbonate units have undergone varying degrees of karstification by hypogenetic processes and by later eogenetic processes. Groundwater flow in these aquifers is a combination of flow through the primary porosity matrix of the rocks, flow through localized pores that have developed by dissolution of the rock, and through conduits that have developed by dissolution along faults, fractures, and bedding planes. Little is known about the distribution of these porosity types within the aquifers because of the lack of accessibility to the deeper portions of these aquifers. Observations of structural and karst features at the surface provide some clues to the nature of the deeper karst. Solution voids, such as caves and sinkholes, are common throughout the study area where these limestones and dolomites are exposed at the surface.

3 Recharge

Recharge to the Trinity Aquifers has not been well quantified and the distribution of recharge across geographic locations has not been determined in detail. However, numerical modeling efforts that are underway are evaluating rainfall, streamflow, and water-level data to gain a better understanding of recharge in the study area. Part of these efforts will be to determine how much recharge is taking place along streams and how much is taking place in the uplands.

Recent studies (Smith et al. 2015; Hunt et al. 2017) indicate significant recharge to the Upper and Middle Trinity Aquifers occurs from losing streams, such as the Blanco River, Cypress Creek, Onion Creek, and Barton Creek (Fig. 1). The losing reaches of the Blanco River and Cypress Creek sustain Pleasant Valley Spring and Jacob's Well Spring, respectively. Any water in the Cow Creek that does not exit the aquifer at the springs provides flow to the deeper part of the Middle Trinity Aquifer to the east.

Another source of recharge to the Middle Trinity is vertical leakage from the overlying Upper Glen Rose (Jones et al. 2011). Recharge to the Middle Trinity Aquifer in central Hays County is primarily from lateral flows from the updip recharge areas to the west (Smith et al. 2015). However, there is some indication of a hydrologic connection (vertical leakage) from the Upper Glen Rose into the Middle Trinity either due to significant head gradients from recharge in the Upper Glen Rose or drawdown from pumping from the Middle Trinity Aquifer (BSEACD 2017). Much of the recharge to the Upper Trinity Aquifer is from direct precipitation and infiltration in upland areas where the Upper Trinity geologic units are exposed at the surface (Wierman et al. 2010).

Recharge from Barton Creek to the Trinity Aquifers has not been delineated in detail, but flow measurements and dye-trace studies have shown that recharge to the Trinity Aquifers is taking place along some segments of Barton Creek. At one location on Barton Creek, about 7 km (4.3 miles) above the Hays–Travis County boundary, a dye-trace study was conducted in which dye was injected into swallets in the bed of Onion Creek where the Upper Glen Rose Member outcrops. The dyes were detected in several Middle Trinity water-supply wells as much as 5.3 km (3.3 miles) downgradient of the injection points.

4 Potentiometric Map

Some of the tools being used to characterize these aquifers are a network of pressure transducers in monitor wells, synoptic water-level measurements, streamflow measurements for gain/loss studies, geochemical analyses of groundwater and surface water, aquifer testing, dye-trace studies, and analytical and numerical modeling. Water-level measurements collected in March 2018 from more than 110 wells were used to construct the potentiometric map for the Middle Trinity Aquifer (Fig. 1). The map shows that groundwater flows generally from the west to the east over the western and central portions of the study area. Near the center of Hays County, groundwater flow diverges with flow to the northeast and to the southeast. Further east in the study area, the geologic units are faulted deeper into the subsurface where there are no wells.

5 Hydrographs

Hydrographs from two Middle Trinity monitor wells and from a flow gage at Jacob's Well Spring show the impacts of drought and pumping on water levels and spring discharge (Fig. 3). Water levels in the Henly Church well in the far

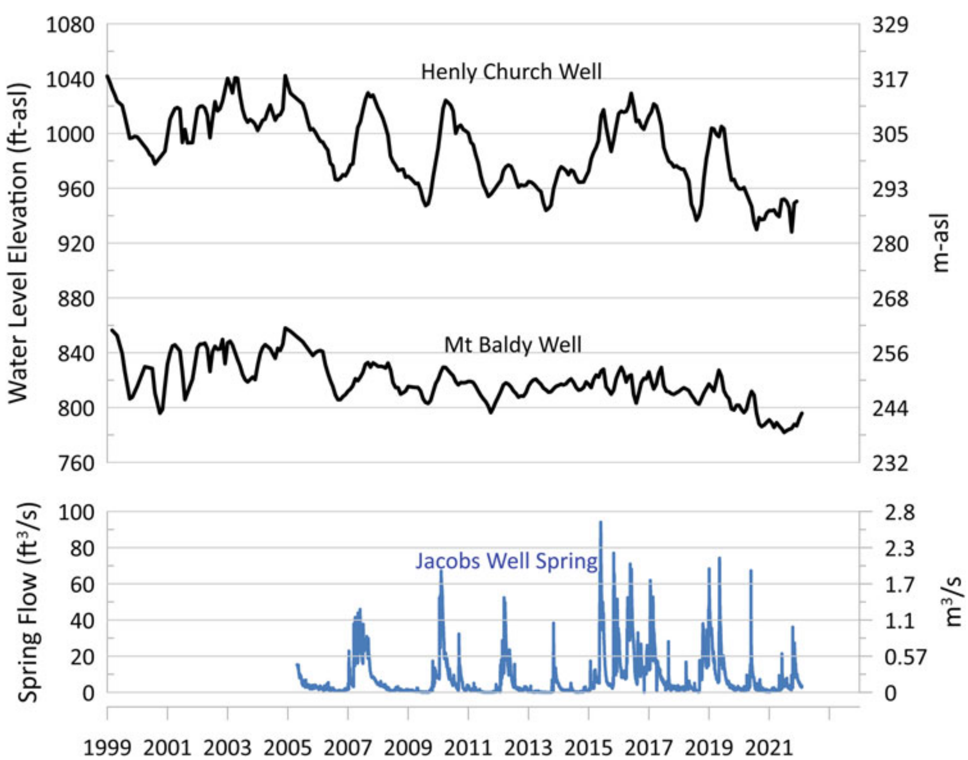

Fig. 3 Hydrographs of water levels in Henly Church and Mt. Baldy wells and flow from Jacob's Well Spring

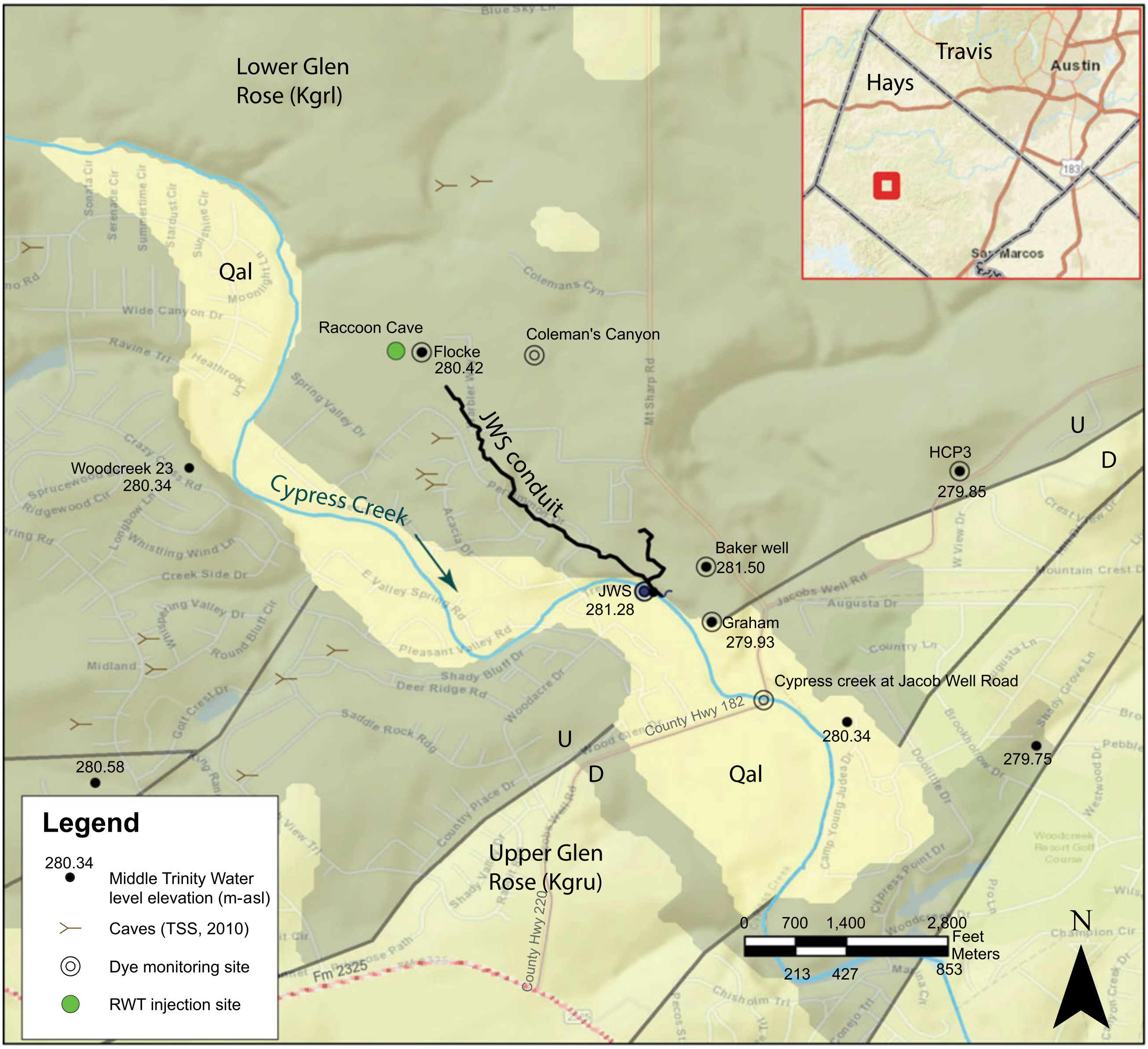

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Fig. 4 Geologic map of the area around Cypress Creek including Jacob's Well Spring (JWS) and the underwater cave passage shown with heavy black line

western portion of Hays County (Fig. 1) show an overall decline from 1999 with distinct highs and lows representing wet and dry conditions, respectively. Water levels in the Mt. Baldy well northwest of Wimberley (Fig. 1) show more moderate highs and lows, but the overall trend shows a more moderate decrease from 1999 until 2019 when water levels make a steeper drop.

Flow from Jacob's Well Spring is the primary source of flow in Cypress Creek which feeds into the Blanco River in the town of Wimberley (Figs. 1, 4, and 5). A large conduit, accessible by cave divers, is the main pathway for water to discharge from Jacob's Well Spring. This cave has been mapped to a length of 1723 m (5655 ft) with the main conduit having a length of 1323 m (4341 ft) and a northwest-southeast strike. The main conduit is situated in the Cow Creek and Hensel formations.

Continuous flow measurements from Jacob's Well Spring began in 2005 (Fig. 3). Long-term average discharge from Jacob's Well Spring is about 0.5 m^3/s (17 ft^3/s-cfs). Reports from residents indicate that during the drought-of-record of

Fig. 5 Jacob's Well Spring on Cypress Creek, central Hays County

the 1950s, Jacob's Well Spring never ceased flowing. Flow from Jacob's Well Spring ceased altogether during four periods of drought between 2005 and 2014. Since 2014, there have only been moderate droughts in the study area as reflected in the hydrograph for Jacob's Well Spring (Fig. 3). However, with above average rainfall, including record-setting rains in 2015, the Henly Church and Mt. Baldy monitor wells show water levels in 2020 and 2021 were lower than any time since 1999 when water-level measurements were first made with continuously recording instruments. And the water-level highs from 2015 to 2017 were lower than the highs in 2002 and 2004 when rainfall amounts were considerably less. The most likely explanation for this discrepancy is the increases in groundwater extraction that have been taking place in recent years.

6 Population Increases and Groundwater Extraction

There is very little firm data for the number of water-supply wells in the area and even less for the amount of extraction from these wells. Most of the wells that extract groundwater from the Trinity Aquifers are low-production domestic wells for which there are no meters to record production. Wells that supply water to housing developments or to commercial entities are permitted by the groundwater districts and in recent years, there are records for this extraction. Groundwater districts in the study area are collecting more information about new wells being installed and learning more about wells that were installed in the past. But any estimates for groundwater extraction is very approximate. Better estimates of increases in groundwater extraction can be made from population records. Considering that there is very little surface water available in the study area, increases in groundwater extraction should coincide with changes in population. According to the U.S. Census Bureau (2021), Hays County is the fastest growing county in the United States for counties with populations greater than 100,000 for the census period 2011–2020. The population of Hays County increased by 53% since 2010 to 241,067 people. These trends in population growth and groundwater extraction suggest that unreasonable impacts to the Trinity Aquifers are likely to happen in the not-too-distant future. Recent studies have shown that in portions of southwest Travis County, the Middle Trinity Aquifer is depleted of groundwater such that new wells are being completed into the Lower Trinity Aquifer (Hunt et al. 2020).

7 Groundwater Management

Groundwater management in Texas is conducted largely by groundwater conservation districts that are authorized by the State of Texas to regulate the production of groundwater. Groundwater conservation districts cover less than two thirds of the state, and the districts have varying authority to regulate groundwater. Groundwater production in other parts of the state is not regulated. Within the study area (Fig. 1), which consists of the western two thirds of Hays County, two groundwater districts regulate the use of groundwater, the Barton Springs/Edwards Aquifer Conservation District (BSEACD), and the Hays Trinity Groundwater Conservation District. BSEACD manages the aquifers within the district by assessing the sustainable yield of the aquifers. This involves regulating the aquifers in a manner to avoid unreasonable impacts to the aquifers and related water resources. Unreasonable impacts are considered by BSEACD to be loss of yield of groundwater to existing wells, degradation of water quality, depletion of groundwater over a long-term basis, significant decreases in springflow, and ecological impacts to surface waters. Avoidance of unreasonable impacts to the aquifers is achieved by conducting scientific studies and promulgating rules in a process that involves various stakeholders in the development of groundwater management policy.

8 Conclusions

Increases in population in the study area are bringing about a significant increase in groundwater extraction. Multiple sources of data indicate that water levels and springflow are decreasing even as rainfall is increasing. Recent data suggest that groundwater in the study area is being depleted to varying degrees. Some areas have already lost the ability to extract groundwater from some portion of the aquifers and must now drill deeper or look for other sources of water such as rainwater harvesting, aquifer storage and recovery, desalination of saline groundwater, and importing water by pipelines from distant sources.

Because of the lack of groundwater data from the most intense droughts in central Texas, collecting data from numerous monitoring points is critical to this process. This involves developing more monitoring wells with a broad geographic distribution. Measuring flow in the streams that contribute water to the aquifers and that receive flow from springs must be conducted under various flow conditions. Only limited tracer tests have been conducted in the study area, so more tracer testing needs to be conducted to better understand groundwater flow paths and velocities of flow. Numerical modeling of these aquifers will be a critical tool in understanding these aquifers and making predictions about future groundwater availability under various pumping and drought scenarios. A better understanding of population growth and groundwater extraction is needed. Proper management of the aquifers will provide long-term use of the aquifers for groundwater users and protection for the various ecologic resources associated with these aquifers.

The keys to effective management of the Trinity Aquifers will be conducting a high level of scientific studies and involving an advisory team of groundwater scientists with involvement of a diverse group of stakeholders to advise the process and promulgation of rules that meet the legal and societal requirements for groundwater management.

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