Introduction

The recharge component of the water budget is generally the most significant variable influencing the groundwater availability of the system. Recharge from precipitation is commonly categorized as diffused or focused. Diffused recharge includes the precipitation that infiltrates the ground and percolates through the unsaturated zone, eventually contributing to the aquifer. Focused recharge includes precipitation that infiltrates the ground via karst features, e.g., sink, swallet, solution enhanced fractures, etc., often in the streambed of rivers. Focused recharge generally allows for precipitation to contribute to the aquifer much quicker than diffused.

Recharge to the Trinity Aquifer will vary over time, the variance being dependent and sensitive to precipitation and evapotranspiration, which can cause large swings in the amount of recharge due to wet and dry or hot and cold cycles. Recharge will also vary spatially due to geology, soil type, vegetation, wind, and land surface slope; geology often being a significant factor. Another influence is urbanization, affecting recharge in either a positive or negative way, depending on the characteristics of the system (Sharp, 2010).

The focus of this review will be on the influence of geology on the recharge to the Middle Trinity Aquifer within the Hays Trinity Groundwater Conservation District (HTGCD or District) boundary. Recharge zones are delineated following watershed boundary lines. The Onion Creek and Blanco River watersheds were each separated into upper and lower segments to capture the differing recharge mechanisms (Figure 1).

Geology

The Lower Cretaceous, Trinity Aquifer is separated into the Lower, Middle, and Upper Trinity Aquifers. Most water wells within HTGCD produce from the Middle Trinity, which consists of the Cow Creek, Hensel, and Lower Glen Rose Formations. The underlying Hammett Formation acts as a regional confining unit between the Middle Trinity and Lower Trinity (Figure 1: Stratigraphic Column).

Throughout most of the District, the Upper Glen Rose is exposed at the surface with remnants of the Edwards Formation on hilltops (Figure 1). The Upper Glen Rose is composed of 8 units of alternating beds of shales, marls, and limestones; the shale and marl beds often acting as
confining units, impeding flow from reaching the Middle Trinity (Stricklin et al., 1971). The alternating non-resistant and resistant to weathering units gives the Upper Glen Rose a stair-step topography. Unit 3 of the Upper Glen Rose is generally considered the lower confining interval, but where eroded, may allow recharge to the Middle Trinity as units 1 and 2 are generally permeable (Muller, 1990).

The Lower Glen Rose Formation outcrops throughout the Blanco River, Pedernales River, and Cypress Creek watersheds where rivers and tributaries have sufficiently eroded the Upper Glen Rose sediments. Throughout the Cypress Creek and Blanco River watershed, the predominantly carbonate Lower Glen Rose contains faults and fractures that help form karst features that allow water to transmit through impermeable units (Wierman et al., 2008). In much of the area, the Lower Glen Rose contains an upper and lower porous patch reef which can significantly increase groundwater storage and production.

In Blanco County and parts of western Hays County, the Hensel acts less like a semi-confining unit and more like a permeable unit, allowing for recharge to the Cow Creek where the Lower Glen Rose Formation is outcropping (Wierman et al., 2010; Broun et al., 2020). The Cow Creek formation is the primary producing interval of the Middle Trinity Aquifer. The porous limestone and dolomite unit rests conformably over the fine clastic, argillaceous Hammett Formation which acts as a bottom seal.

The Balcones Fault Zone is the major structural feature within the study area and consists of a series of north-easterly striking en echelon normal faults. The major faults, such as the Tom Creek and Wimberley faults, vary in throw along strike, approaching 0 to greater than 200-feet north-east of Wimberley. Where the faults have completely offset the hydro-stratigraphic units, the boundary generally acts as a low-flow barrier (Hunt et al., 2015).

Regional recharge to the Middle Trinity in Hays County is generally from precipitation in areas where the formations are exposed at the surface in Blanco and Gillespie County (Wierman et al., 2010). Regional flow is generally described with two regimes (1) across Hays County and northeasterly toward the Colorado River in Travis County and (2) southeast towards the Tom Creek Fault zone discharging through major springs like Jacob’s Well or Pleasant Valley Springs, or continuing downdip to deeper portions of the Middle Trinity (Wierman et al., 2010; Hunt et al., 2019).
Figure 1. Recharge Zones with surface geology and faults (BEG, 2018). Blue arrows represent the general regional groundwater flow path.
Description of Recharge by Watershed

Pedernales River

The Pedernales River meanders into the very northern portion of the District. The headwaters of the Pedernales’ tributaries are predominantly Upper Glen Rose but closer to the river, the Lower Glen Rose, Hensel, and Cow Creek are exposed to the surface due to the incision of the creeks (Figure 2). Middle Trinity recharge will occur where these units are exposed to the surface.

Water quality data near the watershed divide with Barton Creek generally shows total dissolved solids (TDS) concentrations greater than 1,000 mg/L (TWDB, 2020) with one under 1,000 mg/L, which may be due to the well construction insufficiently separating the Middle Trinity water from the Upper Trinity.

Potentiometric surface maps indicate water recharging the Middle Trinity in this area flows towards the north-east into Travis County towards the Colorado River (Hunt et al., 2019; Hunt et al., 2020) (Figure 2). Where the Pedernales’ tributaries have incised the Cow Creek, the Middle Trinity has very low production and generally only provides baseflow to the tributaries (Wierman et al., 2017).

Figure 2. The Pedernales River watershed with Middle Trinity water quality data (TWDB, 2020). Blue arrows represent the general regional groundwater flow path.
Barton Creek

The Barton Creek watershed within HTGCD predominately consists of Upper Glen Rose with some outcropping Edwards remnants on hilltops close to the watershed divide (Figure 3). The Upper Glen Rose consists of alternating carbonates, shales, and marls. The shale and marl can act as confining units and impede groundwater from percolating to the Middle Trinity. Groundwater then accumulates and develops shallow perched systems that generally have a horizontal flow, potentially discharging as seep springs where the confining units are exposed on hillsides (Ashworth, 1983; Muller, 1990). These seep springs are often a source of baseflow to Barton Creek.

There are areas where Barton Creek has partially or fully incised Unit 3 (Upper Glen Rose). The erosion of Unit 3 throughout the Onion Creek watershed was determined to be a significant factor in allowing recharge to the Middle Trinity Aquifer as Unit 3 is considered an impermeable unit. This may also be occurring throughout the Barton Creek watershed, if so, at a smaller scale.

Water quality data is very sparse, but total dissolved solids (TDS) is generally greater than 1,000 mg/L in Middle Trinity sampled wells (TWDB, 2020).

Figure 3. Barton Creek watershed with Middle Trinity water quality data (TWDB, 2020). Blue arrows represent the general regional groundwater flow path.
Most wells east of Highway 12 produce from the Lower Trinity as the Middle Trinity water is of poor quality and the availability is unreliable.

Groundwater in the Barton Creek watershed flows from the regional source in Blanco County where the Middle Trinity units are exposed at the surface. Potentiometric maps indicate some contribution from the Onion Creek watershed but is difficult to determine as the Middle Trinity data in Barton Creek is sparse (Figure 3).

The Barton Creek recharge zone most likely has minimal amounts of diffused Middle Trinity recharge but may have recharge where Unit 3 is incised in Barton Creek. It should be noted that the precipitation that does infiltrate the ground may discharge as seep springs that provide baseflow to Barton Creek which contributes to Edwards Aquifer further downstream.

**Upper Onion Creek Segment**

The Upper Onion Creek recharge zone predominately has the Upper Glen Rose Formation on the surface (Figure 4). Similar to other recharge zones, the Upper Glen Rose consists of alternating carbonates, shales, and marls which can impede water from percolating to the Middle Trinity and instead may act as shallow perched systems, often discharging where the impeding unit is exposed on hillsides (Ashworth, 1983; Muller, 1990).

Flow studies of the Onion, South Onion, and Gatlin Creeks indicate several losing segments, combined with the identification of karst features in the creeks, it was concluded that these segments may be contributing to the Middle Trinity Aquifer (Hunt et al., 2016). Some of this loss will reappear in springs down gradient but will also contribute to the aquifer. Watson et al. (2018) mapped Unit 3 of the Upper Glen Rose and showed a correlation between where Unit 3 was eroded and losing segments of the Onion and South Onion Creeks. The quantity of recharge to the Middle Trinity from diffused or focused karst features has not been quantified. Seep springs from the Upper Glen Rose shallow perched system provides baseflow to Onion Creek tributaries which may end up contributing to the Middle Trinity through one of the creek’s losing segments.

The well field for the Dripping Springs Water Supply Corporation (DSWSC) is just upstream of the confluence of Onion and South Onion Creeks. Geochemical analysis of the DSWSC #3 well indicated a freshwater source but is most likely a combination of local freshwater sources and older water from regional flow from the west. Water level responses to precipitation events also show connectivity to a surface water source (Hunt et al., 2016).

Since the surface geology is predominantly Upper Glen Rose, contribution to the Middle Trinity via diffused recharge is most likely minimal. The focused recharge of the Onion and South Onion Creeks with the regional flow can be shown with regional potentiometric surface maps and water quality data. A hydraulic head high is found southwest of Dripping Springs throughout the Onion Creek watershed, which may indicate a source providing a significant amount of recharge to the Middle Trinity Aquifer (Hunt et
al., 2019). Total dissolved solids (TDS) concentrations exceed 1,000 mg/L in most Middle Trinity wells upgradient of the Onion and South Onion Creeks’ losing segments, indicating groundwater from this area is most likely upgradient regional flow from Blanco County.

**Bear Creek**

The Bear Creek watershed is predominately Upper Glen Rose outcrop with Edwards on the downdip block of the Tom Creek Fault zone (Figure 5). The Upper Glen Rose is generally greater than 200-feet thick throughout Bear Creek. The Upper Glen Rose consists of alternating carbonates, shales, and marls units. The shale and marl can act as confining units and impede groundwater from percolating to the Middle Trinity. Groundwater then accumulates and develops shallow perched systems that generally have a horizontal flow, potentially discharging as seep springs where the confining units are exposed on hillsides (Ashworth, 1983; Muller, 1990). These seep springs are often the source of baseflow to Bear Creek.
Fresh groundwater (TDS less than 1,000 mg/L) is observed around the Tom Creek Fault zone, which may indicate recharge to the Middle Trinity from a fresher source via cross-formational flow along faults and fractures or the surface. The potential cross-formational flow warrants further investigation on its recharge implications to the Middle Trinity from either the Upper Glen Rose, Edwards, or surface.

Most wells east of Nutty Brown Road produce from the Lower Trinity, indicating the Lower Trinity water availability is more reliable than the Middle Trinity.

Potentiometric maps suggest groundwater in the Bear Creek watershed is most likely flowing from the regional source in Blanco County with contributions from the losing South Onion and Onion Creek segments (Hunt et al., 2019; Hunt et al., 2020).

The Bear Creek recharge zone may have some amounts of diffused or focused recharge reaching the Middle Trinity, but it should be noted that the precipitation that does infiltrate the ground may discharge as seep springs that provide baseflow to Bear Creek.

Figure 5. Bear Creek watershed with Middle Trinity water quality data (TWDB, 2020). Blue arrows represent the general regional groundwater flow path.
**Lower Onion Creek Segment**

The Lower Onion Creek Segment is predominately Upper Glen Rose updip of the Tom Creek Fault zone and Edwards on the downdip block (Figure 6). Unit 3 of the Upper Glen Rose is eroded in parts of the updip block which may allow diffused recharge into the Middle Trinity.

The Onion Creek segment of this zone is considered gaining. Downstream, Onion Creek contributes to the Edwards Aquifer via Crippled Crawfish Cave (Hunt et al., 2017).

Water quality data shows young groundwater on the updip block of the Tom Creek Fault zone and older groundwater on the downdip block indicating the fault zone may act as a semi-barrier to flow (TWDB, 2020).

Potentiometric surface mapping indicates water contributing to this area is a combination of the regional flow from the west and surface water from the Onion Creek watershed (Hunt et al., 2019).

In this area, other than the potential for diffused recharge contributing to the Middle Trinity where the Upper Glen Rose is thin, a minimal amount of recharge contributes to the aquifer.

![Figure 6. Lower Onion Creek watershed with Middle Trinity water quality data (TWDB, 2020). Blue arrows represent the general regional groundwater flow path.](image-url)
Lower Blanco River Segment

The Lower Segment of the Blanco River within HTGCD predominately has Edwards and Upper Glen Rose on the surface (Figure 7). The recharge zone consists of the down thrown block of the Tom Creek and Wimberley Fault zone, which is about 400-feet from the surface to the top of the Lower Glen Rose.

Flow studies of the Blanco River indicate the segment that crosses this region is gaining (Hunt et al., 2017). Water quality relative to the updip portions of the Cypress Creek and Blanco Zones indicates a much higher TDS concentration, typically greater than 1,000 mg/L (TWDB, 2020).

Most of the Middle Trinity in this region presumably receives its water from the Upper Blanco Segment and Cypress Creek watershed, as groundwater that did not discharge as springs but instead continued downdip. Groundwater from these areas would have flowed across the Tom Creek and Wimberley Fault zones but the throw of these faults is much smaller compared to further northeast where throws can be greater than 200-feet. The fault zones most likely create a low-flow boundary rather than a no-flow boundary.

The Lower Blanco River Segment recharge zone most likely has minimal amounts of diffused or focused recharge reaching the Middle Trinity, but it should be noted that the precipitation that does infiltrate the ground may discharge as seep springs that provide baseflow to Blanco River and contribute to the Edwards Aquifer downstream.

Figure 7. Lower Blanco watershed with Middle Trinity water quality data (TWDB, 2020). Blue arrows represent the general regional groundwater flow path.
**Upper Blanco River Segment**

The Upper Blanco River recharge zone predominately has Lower Glen Rose on the surface with Upper Glen Rose close to the watershed divides (Figure 8). The Upper Glen Rose consists of alternating carbonates, shales, and marls. The shale and marl can act as confining units and impede groundwater from percolating to the Middle Trinity. Groundwater then accumulates and develops shallow perched systems that generally have a horizontal flow, potentially discharging as seep springs where the confining units are exposed on hillsides (Ashworth, 1983; Muller, 1990). These seep springs often provide baseflow to the Blanco River.

Downdip of the Tom Creek Fault zone is predominately Upper Glen Rose at the surface (Figure 8). Other than close to the watershed divide, the Upper Glen Rose is less than 100-feet thick. Since the basal units of the Upper Glen Rose are generally permeable, infiltrating precipitation may contribute diffused recharge to the Middle Trinity.

Flow studies of the Blanco River indicated a losing segment where the Hensel and Cow Creek are exposed. Karst features have also been identified in the riverbeds (Hunt et al., 2017). Some of this loss will reappear as discharge via Park or Pleasant Valley Springs, while the remaining continue downdip to the deeper portions of the Middle Trinity (Watson et al., 2014; Hunt et al., 2017; Hunt et al., 2019).

Throughout the Upper Blanco River Segment, the Middle Trinity water quality data indicate a young freshwater source with TDS less than 1,000 mg/L (TWDB, 2020).

Water levels can be observed to react within days of rain events, indicating a quick recharge via focused and/or diffused recharge.

There are also many seep springs along the Upper and Lower Glen Rose contact that provide baseflow to the Blanco River. Even if this water does not make its way to the Middle Trinity, during severe droughts, the Blanco River is the only continuous surface source of recharge to the Edwards Aquifer (Gary et al., 2020).

The Upper Blanco River recharge segment is most likely has both diffused and focused recharge contributing to the Middle Trinity. Regional flow is also most likely contributing to this area.

**Cypress Creek**

The Cypress Creek watershed has the Upper and Lower Glen Rose Formations exposed at the surface with a sliver of Edwards remnants exposed downdip of the Tom Creek Fault Zone on the watershed divide (Figure 8). Focused recharge is most likely contributing to the aquifer via the Lower Glen Rose, which has been documented as having many recharging karstic features (Schumacher and Saller, 2008; Wierman et al., 2008). The significance of focused recharge can be readily observed during precipitation events by comparing Jacob’s Well flow and Lower Glen Rose monitoring wells (Wierman and Hunt, 2018).
The Upper Glen Rose has alternating units of carbonates and shales, which can impede and drive groundwater movement horizontally, discharging as springs where these confining units are exposed on hillsides (Wierman et al., 2008). Due to this, seep springs can be seen on hillsides where impermeable units are outcropping. The contact between the Upper and Lower Glen Rose is a common example of where these seep springs are observed (Ashworth, 1983; White, 2019).

Cypress Creek between Jacob’s Well and RR12 in Wimberley has shown no quantifiable streamflow loss. This may be due to more competent surface geology and the absence of recharging karst features in the Upper Glen Rose (Dedden, 2006).

Gary et al. (2019) developed a water budget analysis to estimate effective recharge and delineate the springshed area for Jacob’s Well. Using multiple water budget approaches, the study estimated an effective recharge of 10- to 25-percent for the Dry Cypress Creek watershed.

The Tom Creek Fault Zone, an *en echelon* normal fault zone, trends northeast through the watershed. The downthrown block is predominately Upper Glen Rose with many recharging karsts features; water levels,
therefore, react in a lagged fashion to precipitation compared to the upthrown block (Wierman and Hunt, 2018). Due to the structural stress of the area, faults perpendicular to the Tom Creek Fault zone have been documented with many joints and fractures, especially in the competent Lower Glen Rose units. These features when intercepting the surface can act as recharge or discharge points and have been observed to fully penetrate through shale units allowing groundwater to cross otherwise impermeable units (Schumacher and Saller, 2008).

District Recharge Summary

Throughout Blanco County, diffused recharge occurs where the Middle Trinity units are exposed to the surface, providing the aquifer with regional flow. Potentiometric surface maps suggest the aquifer has two main flow regimes (1) eastern direction across Hays County and towards the Colorado River in Travis County and (2) southeast across Hays County towards the Balcones Fault Zone.

The surface geology of the District is predominantly Upper Glen Rose except in the river basins of the Blanco, Cypress Creek, and Pedernales. Diffused recharge to the Middle Trinity Aquifer is minimal where the Upper Glen Rose is exposed to the surface due to its impermeable units. Many seep springs that provide baseflow to creeks and streams of the District are discharging from the Upper Glen Rose. Water infiltrates the Upper Glen Rose and is directed horizontally when encountering an impermeable unit, often discharging as a seep spring on hillsides where the impeding unit is exposed to the surface.

The surface geology throughout the Blanco River, Cypress Creek, and Pedernales River watersheds all have outcropping Middle Trinity units, allowing infiltration to the aquifer units. Throughout the Blanco and Cypress Creek watersheds, the Lower Glen Rose is heavily fractured with common karstic features, often allowing for water to infiltrate and percolate through impermeable units. With the semi-confining nature of the Hensel, where the Lower Glen Rose is on the surface, surface water may infiltrate and contribute to the Cow Creek. To a lesser degree fractures throughout the Upper Onion Creek have also been shown to allow water to recharge the Middle Trinity.

Streamflow measurements can indicate where creeks are losing or gaining flow, combined with dye trace studies, water quality data, and water level data, surface water within the Blanco River, Dry Cypress Creek, and Onion Creek were determined to be recharging Middle Trinity.

Future Studies

1. Investigating surface water and groundwater interactions of the Onion Creek watershed have shown where and how recharge is contributing to the Middle Trinity Aquifer. Unit 3 is incised by Gatlin Creek but with limited flow data, it is currently considered a gaining stream, a more detailed flow study will allow for a more definitive conclusion. Future studies may also look to quantifying the amount of recharge during different flow conditions and continue dye trace studies to build a database to better understand the flow regimes of the karst recharging features.
2. The Barton Creek watershed has limited data to evaluate whether water from Barton Creek is contributing to the Middle Trinity Aquifer; in several creek segments, it appears that the lower confining unit of the Upper Glen Rose, Unit 3, may be eroded. An approach similar to the Onion Creek studies, undertaken on Barton Creek will help to further understand the influence of Unit 3 on recharge.

3. Bear Creek has multiple Middle Trinity water quality data points indicating a fresher source in wells around the Tom Creek Fault Zone. With this area having an Upper Glen Rose section that appears to be too thick to allow diffused recharge, this freshwater may be due to cross-formation flow via faults or fractures.

References


Dedden, J.E., 2008, The hydrology and biology of Cypress Creek (Hays County), a subtropical karstic stream in south central Texas, Thesis, Texas State University, San Marcos, Department of Biology, 51 p.


Schumacher, W., Saller, S., 2008, Cypress Creek project-structural analysis: Characteristics of the Glen Rose formation in and around the Cypress Creek watershed and their implication on groundwater flow, HTGCD, 34 p.


Wierman, D.A., Hunt, B.B., 2018, Groundwater level monitoring results for HTGCD transducer wells and Wimberley Valley Public Water Supply wells, Hays County, Central Texas, prepared as part of the Cypress Creek Watershed Protection Project, Meadows Center for Water and Environment, Texas State University at San Marcos, TX, 14 p.

White, K., 2019, Results of a karst terrain feature survey for the proposed Permian Highway Pipeline Project, Central Texas, prepared for Permian Highway Pipeline LLC, Houston, TX, 213 p.