Pecos Amphipod
(*Gammarus pecos*)

5-Year Review:
Summary and Evaluation

U.S. Fish and Wildlife Service
Austin Ecological Services Field Office
Austin, Texas

5-YEAR REVIEW
Pecos Amphipod (*Gammarus pecos*)

1.0 GENERAL INFORMATION

1.1 Reviewers

Lead Regional or Headquarters Office:
Southwest Regional Office, Region 2

Lead Field Office:
Austin Ecological Services Field Office
Michael Warriner, Branch Chief, Listing and Recovery Branch, 512-490-0057 ext. 236

1.2 Methodology used to complete the review:

The U.S. Fish and Wildlife Service (Service) conducts status reviews of species on the List of Endangered and Threatened Wildlife and Plants (50 CFR 17.12) as required by section 4(c)(2)(A) of the Endangered Species Act (16 U.S.C. 1531 et seq.). The Service provides notice of status reviews via the Federal Register and requests new information on the status of the species (e.g., life history, habitat conditions, and threats). Data for this status review were solicited from interested parties through a Federal Register notice announcing this review on July 26, 2019 (84 FR 36113). The Austin Ecological Services Field Office conducted this review and considered both new and previously existing information from federal and state agencies, municipal and county governments, non-governmental organizations, academia, and the public. The primary source of information used in this analysis was the July 9, 2013 final listing and critical habitat rules (78 FR 41227; 78 FR 40970), peer-reviewed literature, unpublished reports, publicly accessible databases, and personal communications.

1.3 Background:

The purpose of this 5-year review is to ensure the Pecos amphipod (*Gammarus pecos*) has the appropriate level of protection under the Endangered Species Act. The review documents a determination by the Service whether the status of this species has changed since the time of its listing. The review also provides updated information on the current threats, ongoing conservation efforts, and needs for future conservation actions.

The Pecos amphipod is a freshwater crusteacean (Crustacea: Amphipoda) that is restricted to a small, isolated desert spring and ciénega (i.e., marsh) system in the Chihuahuan Desert of western Texas. The primary threat to the species' persistence is the degradation and loss of aquatic habitat (i.e., flowing water from spring outlets) due to the decline of groundwater levels in the aquifer(s) that support spring flows. The Service listed the Pecos amphipod as endangered on July 9, 2013.

1.3.1 FR Notice citation announcing initiation of this review:

84 FR 36113

1.3.2 Listing history

Original Listing
FR notice: 78 FR 41227
Date listed: July 9, 2013
Entity listed: Species, *Gammarus pecos*
Classification: Endangered

1.3.3 Associated rulemakings:

A final rule designating critical habitat for the Pecos amphipod was published in the Federal Register on July 9, 2013 (78 FR 40970).

1.3.4 Review History:

The Service identified the Pecos amphipod as a candidate for listing in the May 22, 1984, Endangered or Threatened Wildlife and Plants, Annual Notice of Review (49 FR 21664). The species was a Category 2 candidate, indicating the Service had some indication that listing as threatened or endangered might be warranted, but there was insufficient data available to justify a proposal to list the species. The Pecos amphipod remained a Category 2 candidate in subsequent annual Candidate Notices of Review (54 FR 554; 56 FR 58804; 59 FR 58982). In the February 28, 1996 Notice (61 FR 7596), the Service discontinued the designation of Category 2 species as candidates, which removed the Pecos amphipod from the candidate list. The Pecos amphipod was not included in other candidate notices due to taxonomic uncertainties; whether the species range actually restricted to the Diamond Y Spring system. Genetic research confirmed that the species is indeed endemic to Diamond Y Spring.

The Pecos amphipod was included in a June 25, 2007 petition by WildEarth Guardians to the Service. On January 6, 2009, we published a partial 90-day finding of the petition which included a finding that the petition did not present substantial scientific or commercial information indicating that the listing of the Pecos amphipod may be warranted (74 FR 419). During a review of species endemic to the Diamond Y Spring system, the Service assessed the status of the Pecos amphipod. Based on that assessment, the Service published a proposed rule on August 16, 2012 to list the Pecos amphipod as endangered (77 FR 49601). On July 9, 2013, the Service published a final rule to list the Pecos amphipod as endangered due to threats from habitat loss and degradation of aquatic resources, particularly the current and ongoing decline in spring flows that support the habitat of all the species, and the potential for future water contamination at the Diamond Y Spring system and other natural or manmade factors, including the presence of nonnative snails and the small, reduced ranges of the species (78 FY 41227). This is the first 5-year review for the species since its listing as endangered in 2013.

1.3.5 Species' Recovery Priority Number at start of 5-year review:

A recovery priority number was not previously assigned to this species.

1.3.6 Recovery Plan or Outline:

The Service does not have a recovery plan for the Pecos amphipod.

2.0 REVIEW ANALYSIS

2.1 Application of the 1996 Distinct Population Segment (DPS) policy

2.1.1 Is the species under review a vertebrate?

No, the Pecos amphipod is a freshwater crustacean and the DPS policy does not apply.

2.2 Recovery Criteria

2.2.1 Does the species have a final, approved recovery plan1 containing objective, measurable criteria?

No, the Service has not completed a recovery plan for the Pecos amphipod.

2.3 Updated Information and Current Species Status

2.3.1 Biology and Habitat

The Pecos amphipod inhabits the Diamond Y Spring system, a complex of isolated, desert freshwater springs, seeps, and associated ciénegas (i.e., desert wetland), in the Chihuahuan Basin and Playas ecoregion of western Texas (Taylor 1987, pp. 41-42; Veni 1991, pp. 15-17; Boghici 1997, pp. 3-4, 49-53; Griffith et al. 2004; Van Auken et al. 2007, pp. 140-144). This spring-ciénega system hosts a number of other endemic, federally-listed

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[1] Although the guidance generally directs the reviewer to consider criteria from final approved recovery plans, criteria in published draft recovery plans may be considered at the reviewer's discretion.

species including Diamond tryonia (*Pseudotryonia adamantina*), Gonzales tryronia (Tryonia circumstriata), Leon Springs pupfish (*Cyprinodon bovinus*), Pecso assiminea (*Assiminea pecos*), and Pecos sunflower (*Helianthus paradoxus*). Bell et al. (2014, p. 30) considered the Diamond Y Spring system as among the most highly threatened aquatic systems in the Chihuahuan Desert of Texas.

The Pecos amphipod may have also occurred in other area springs, to include Comanche and Leon Springs in Pecos County. No relict specimens have been collected from those sites, but remains of other Diamond Y Spring system species (i.e., Diamond and Gonzales tryonia) have been noted at Comanche Springs (78 FR 41237). That spring, along with its spring run and ciénega, were altered by irrigation efforts in the late 1800s and transformed into a recreational swimming pool facility in the late 1930s (Brune 1975, pp. 30, 57-58; Small and Ozuna 1993, p. 25; Jensen et al. 2006, pp. 14-15). Perennial flow at Comanche Springs ceased in the early 1960s due to decades of heavy groundwater pumping for irrigation (Brune 1981, pp. 357-358; Small and Ozuna 1993, pp. 24-29).

The Diamond Y Spring system is within the tributary drainage of Diamond Y Draw/Leon Creek that drains northeast to the Pecos River (Figures 1). The spring system is located about 12 kilometers (km) [8 miles (mi)] north of the City of Fort Stockton in Pecos County. The Nature Conservancy owns and manages the Diamond Y Spring Preserve, which encompasses the spring and ciénega system (Figure 2; Karges 2003, pp. 143-145). The preserve consists of 1,603 hectares (ha) [3,962 acres (ac)] of contiguous land around Diamond Y Draw (Karges 2003, p. 143).

Pecos County is situated in a warm and arid region of Texas with average annual precipitation of 33 centimeters (cm) [13 inches (in)], average maximum temperature of 26.7°Celsius (°C) [80.1°Fahrenheit (°F)], and evapotranspiration rates of 0.24-0.40 meters/year (m/yr) [0.8-1.3 feet/year (ft/yr)] (Sankarasubramanian and Vogel 2003, p. 16-3; Reitz et al. 2017; Duniway et al. 2019, p. 3; Prism Climate Group 2019). Vegetation within a 10 km (6.2 miles (mi) radius of the Diamond Y Spring system consists of creosotebush scrub, mesquite-creosotebush shrubland, desert wash shrubland, and a mix of grasslands (Elliott 2014, pp. 58, 80, 84-85, 126-127, 179; Texas Parks and Wildlife Department 2019). Vegetation directly adjacent to spring openings and runs is ciénega, an herbaceous plant community that develops and persists on drainages fed by perennial freshwater springs (Hendrickson and Minckley 1984, p. 168; Elliott 2014, pp. 163-164; Cole and Cole 2015, pp. 28, 31-32).

Grazing dominates human land use (1,060,773 ha [2,621,228 ac] or 86%) in Pecos County followed by a small amount of cropland (Texas Land Trends 2019). As of 2017, there were 309 farms in Pecos County with an average farm size of 3,766 ha (9,281 ac) [U.S. Department of Agriculture 2017, p. 1)]. Irrigated cropland has declines since the mid-1960s from 48,284 ha (119,313 ac) in 1964 to 11,113 ha (27,460 ac) in 2000 (Texas Water Development Board 2001, p. 61; Texas Water Development Board 2019).

Petroleum extraction, transportation, and processing infrastructure are a ubiquitous feature of the landscape close to Diamond Y Spring system and Pecos County. Over 200 active oil and natural gas wells, 175 plugged wells, and 27 injection wells occur within a 4 km (2.5 mi) radius of Diamond Y Spring Preserve (Railroad Commission of Texas 2019). A natural gas refinery is 0.8 km (0.5 mi) to the south of Diamond Y Spring. Several natural gas pipelines traverse the preserve (Pipeline and Hazardous Materials Safety Administration 2019).

Figure 1. Diamond Y Spring system in Pecos County, Texas. Map adapted from Echelle et al. (2002, p. 38).

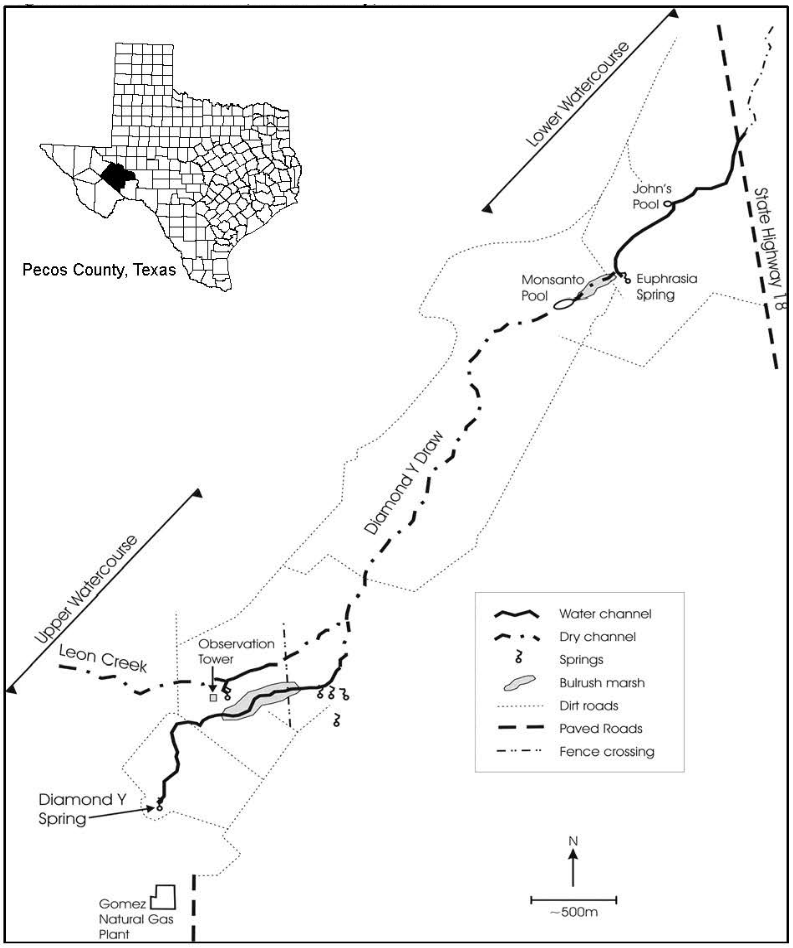
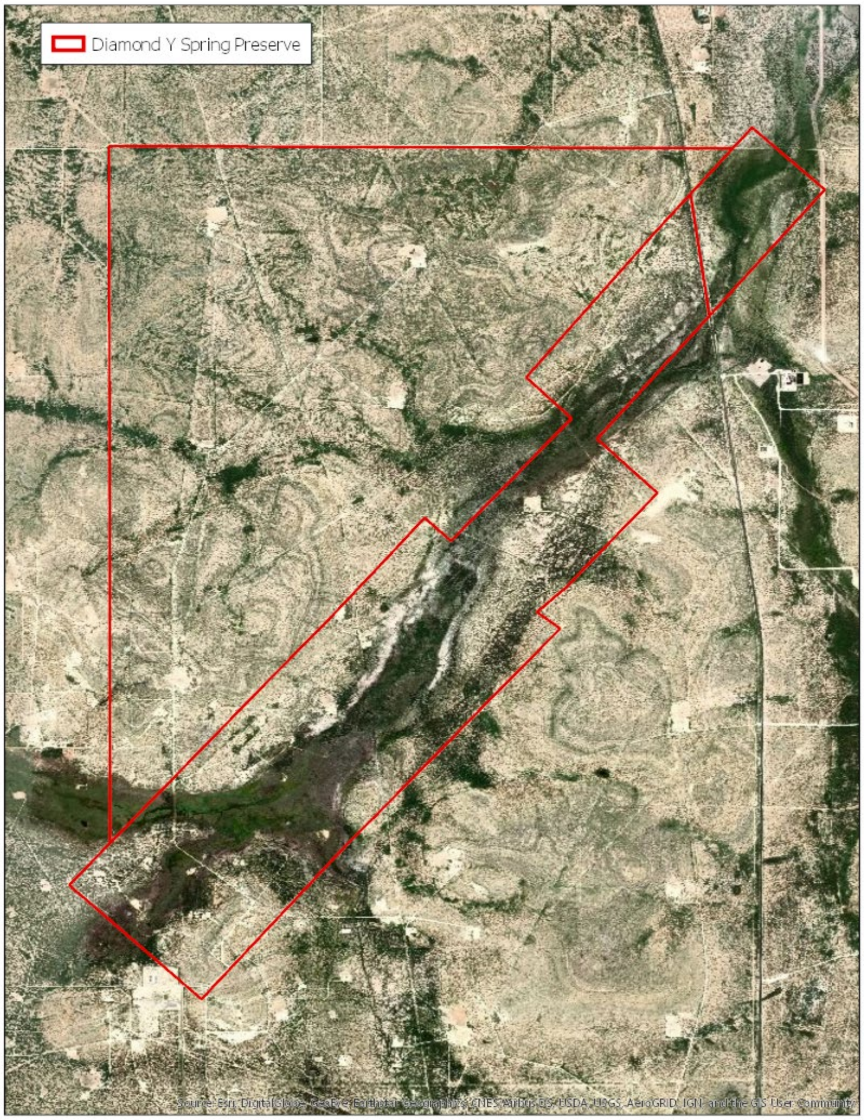


Figure 2. Diamond Y Spring Preserve in Pecos County, Texas.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Pecos County, along with portions of Culberson, Loving, Reeves, Ward, and Winkler counties, overlay an area of intensive oil and natural gas extraction, the Delaware Basin (Scanlon et al. 2017a, pp. 10904-10905). The Delaware Basin is the western subbasin of the overarching Permian Basin that extends from southwestern New Mexico into western Texas (Dutton et al. 2005, p. 555). The Permian Basin is a major oil- and natural gas-producing region that consists of over 30 individual petroleum plays (Dutton et al. 2005, pp. 558-558). A petroleum play, per the U.S. Energy Information Administration (2019b), is “a set of known or postulated oil and gas accumulations sharing similar geologic, geographic, and temporal properties, such as source rock, migration pathway, timing, trapping mechanism, and hydrocarbon type.”

In 2017, the Permian Basin accounted for 20% of total U.S. crude oil production and 9% of natural gas production (U.S. Energy Information Administration 2018a, p. 2). Petroleum extraction here primarily consists of vertically drilled wells and horizontal drilling combined with hydraulic fracturing (Nicot et al. 2012, pp. 13-14; Scanlon et al. 2017a, p. 10904). A recent assessment of the Delaware Basin, specifically the Wolfcamp Shale and Bone Spring Formation therein, indicates that it contains among the largest deposits of recoverable oil and natural gas resources in the Permian Basin (U.S. Geological Survey 2018, pp. 2-4). The Wolfcamp Shale and Bone Spring Formation were among the largest U.S. oil- and natural gas-producing plays in 2017 (U.S. Energy Information Administration 2018b, pp. 1, 3-4, 11, 15, 20).

The Pecos amphipod was first collected in 1964 from Diamond Y Spring and was described by Cole and Bousfield (1970, p. 89). Cole (1985, p. 101) analyzed morphological characteristics of the *Gammarus pecos* species complex and suggested the *Gammarus* amphipod from San Solomon Spring should also be included as Pecos amphipod. However, updated genetic analyses based on allozymes (Gervasio et al. 2004, p. 526) and mitochondrial DNA (Seidel et al. 2009, p. 2309) have shown that Pecos amphipods are limited in distribution to the Diamond Y Spring system. In addition, Gervasio et al. (2004, pp. 523, 526) evaluated amphipods from three different locations within the Diamond Y Spring system and found no significant differences in genetic variation, indicating they all represented a single species.

The Pecos amphipod belongs to the family Gammaridae, a group of small freshwater inland crustaceans. Gammarids commonly inhabit shallow, cool, well-oxygenated waters of streams, ponds, ditches, sloughs, and springs (Smith 2001, p. 574). These bottom-dwelling amphipods feed on algae, submergent vegetation, and decaying organic matter (Smith 2001, p. 572). Amphipod eggs are held within a marsupium (brood pouch) within the female’s exoskeleton (Smith 2001, p. 573). Most amphipods complete their life cycle in 1 year and breed from February to October, depending on water temperature (Smith 2001, p. 572). Amphipods form breeding pairs that remain attached for 1 to 7 days at or near the substrate while continuing to feed and swim (Bousfield 1989, p. 1721). They can produce from 15 to 50 offspring, forming a ‘‘brood.’’ Most amphipods produce one brood, but some species produce a series of broods during the breeding season (Smith 2001, p. 573).

The Pecos amphipod is grouped with a related set of amphipods collectively referred to as the *Gammarus pecos* species complex, that are restricted to desert spring systems from the Pecos River Basin in southeast New Mexico and west Texas (Cole 1985, p. 93; Lang et al. 2003, p. 47; Gervasio *et al*. 2004, p. 521). Similar to desert springsnails, these freshwater amphipods are thought to have derived from a widespread ancestral marine amphipod that was isolated inland during the recession of the Late Cretaceous sea, about 66 million years ago (Holsinger 1967, pp. 125–133; Lang et al. 2003, p. 47). They likely evolved into distinct species during recent dry periods (since the Late Pleistocene, about 100,000 years ago) through allopatric speciation (that is, speciation by geographic separation) following separation and isolation in the remnant aquatic habitats associated with springs (Gervasio *et al*. 2004, p. 528).

Amphipods in the *Gammarus pecos* species complex occur only in desert spring outflow channels on substrates, often within interstitial spaces on and underneath rocks and within gravels (Lang et al. 2003, p. 49) and are most commonly found in microhabitats with flowing water. They are also commonly found in dense stands of submerged vegetation (Cole 1976, p. 80). Because of their affinity for constant water temperatures, they are most common in the immediate spring outflow channels, usually only a few hundred meters downstream of spring outlets

The Pecos amphipod is generally found in all the flowing water habitats associated with the outflows of springs and seeps in the Diamond Y Spring system (Echelle et al. 2001, p. 20; Lang et al. 2003, p. 51; Allan 2011, p. 2; Lang 2011, entire). The species is often locally abundant, with reported mean densities ranging from 2,208 individuals meters^2 (m^2) [205 per feet^2 (ft^2); ±1,585 m^2, ±147 ft^2) to 8,042 individuals per m^2 (748 ft^2; ±7,229 m^2, ±672 ft^2] (Lang et al. 2003, p. 51).

2.3.1.1 New information on the species' biology and life history:

No new information.

2.3.1.2 Abundance, population trends (e.g. increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or demographic trends:

Systematic surveys or monitoring efforts for the Pecos amphipod have not been conducted since 2003 (Lang et al. 2003, p. 51).

2.3.1.3 Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):

No new information.

2.3.1.4 Taxonomic classification or changes in nomenclature:

No new information.

2.3.1.5 Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, etc.), or historic range

(e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.):

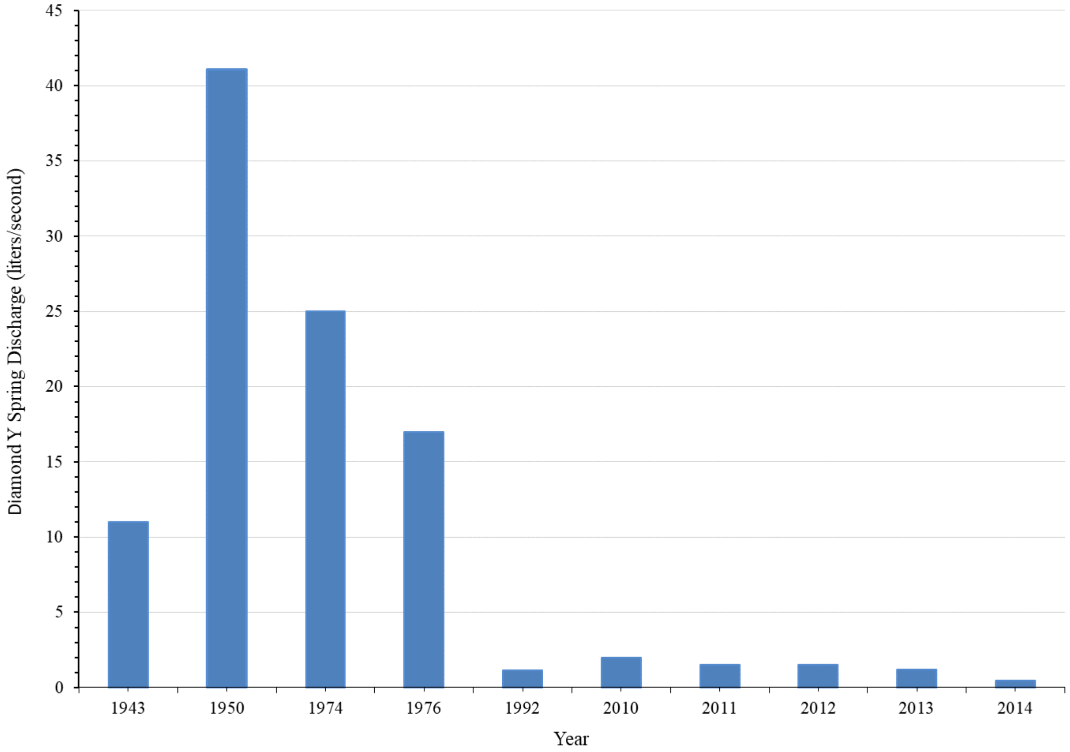
Systematic surveys or monitoring efforts for the Pecos amphipod have not been conducted since 2003 (Lang et al. 2003, p. 51).

2.3.1.6 Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):

Water Quantity

The Diamond Y Spring system contains the last major springs that still flow in Pecos County (Brune 1981, p. 360; Veni 1991, p. 2). Discharge data for this spring is sparse (Figure 3), with only sporadic measurement made since the 1940s (Veni 1991, pp. 18-20; Boghici 1997, p. 53). Diamond Y Springs discharge is slightly to moderately brackish with total dissolved solid concentrations of 4,000 milligrams/liter (mg/l) [4,007 parts per million (ppm)] to 8,000 mg/l [8,014 ppm] (Boghici, 1997, pp. 56-57, 77). The little monitoring data that does exist depicts a significant decline in springflow from the 1950s to the mid-2010s (Kiner 2002, pp. 20-21).

Figure 3. Diamond Y Spring discharge: 1943-2014.



In August 2018, staff with The Nature Conservancy noted an atypically severe decline in flow at Diamond Y Spring (Ryan Smith, personal communication, August 16, 2018). Pool level at Diamond Y Spring continued to drop that month and was reported as being 23 cm (9 in) lower than in March 2017. Flow out of the pool had ceased and remained dry for approximately 200-300 m (656-984 ft) downstream. Spring flow declined or ceased completely in several smaller springs in the upper watercourse near the confluence with Leon Creek and in the lower watercourse. Rainfall in September 2018 raised pool level and resulted in a return of flow to the downstream draw. The exact cause of the August 2018 spring-flow declines is unknown but warrants investigation and underscores the sensitive nature of this spring system and its dependent species.

Depths for both Diamond Y and Euphrasia Springs were monitored by the Middle Pecos Groundwater Conservation District (2018, pp. 19, 22) from 2017-2018. In 2018, the Bureau of Economic Geology installed monitoring stations at Diamond Y and Euphrasia Springs (Figures 4 and 5).

Figure 4. Spring depth and precipitation at Diamond Y Spring: August 2018-August 2020 (Bureau of Economic Geology 2019).

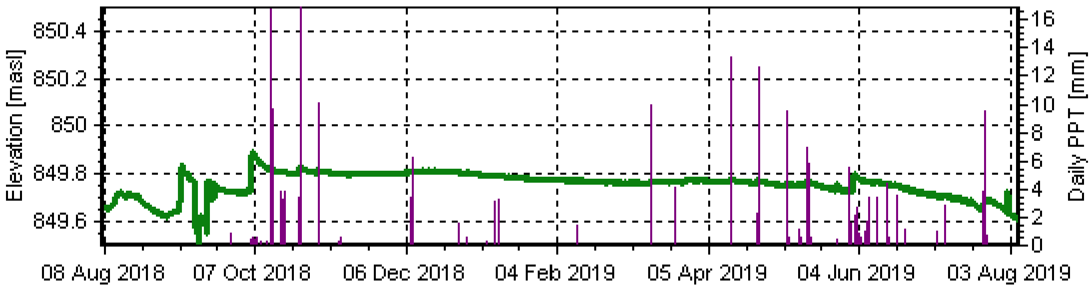
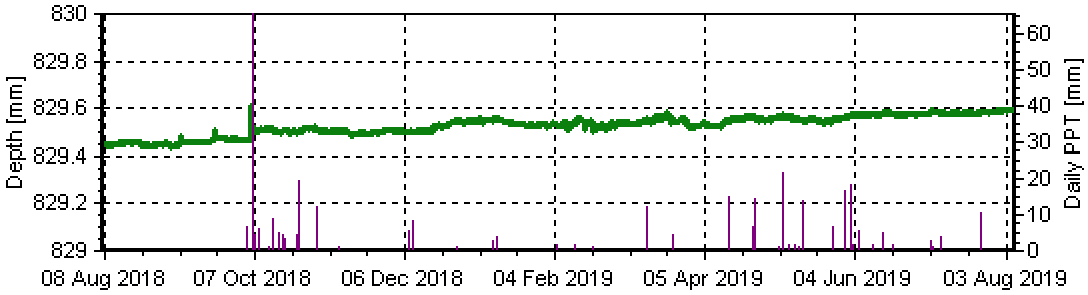
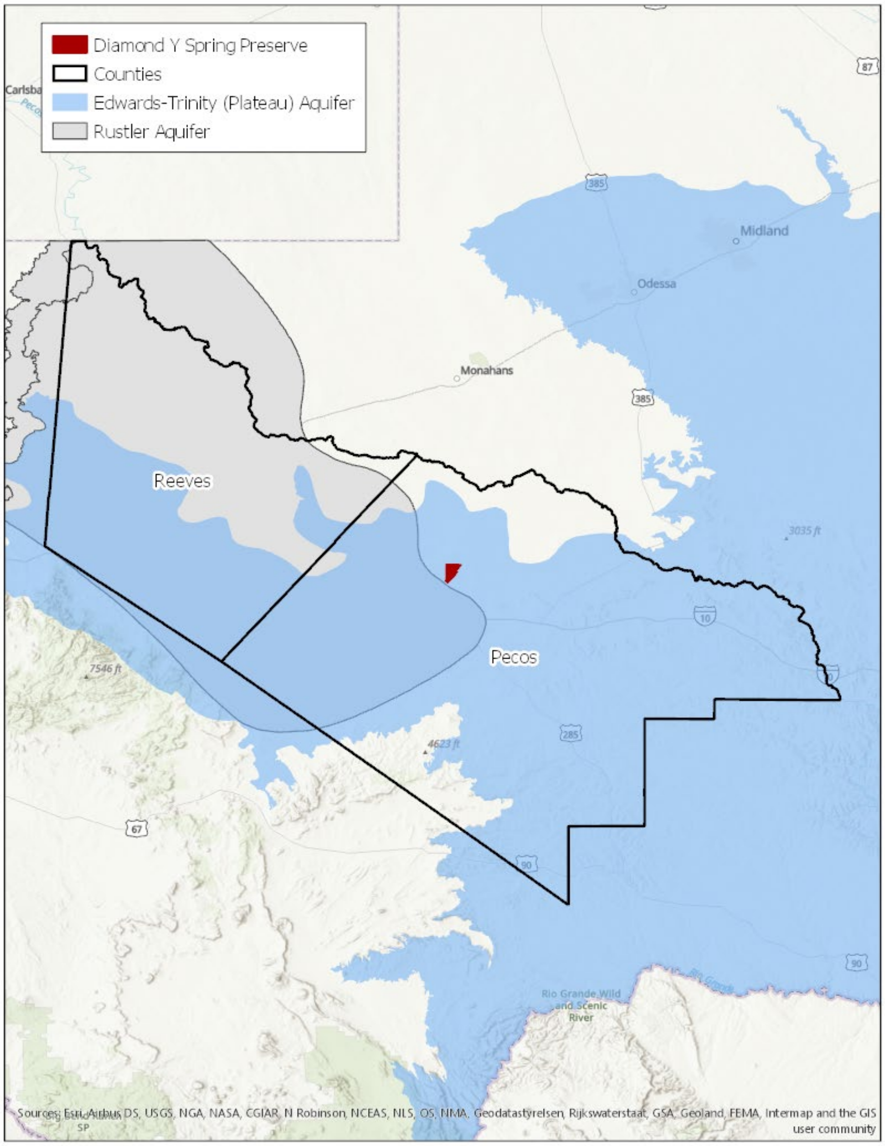


Figure 5. Spring depth and precipitation at Euphrasia Spring: August 2018-August 2020 (Bureau of Economic Geology 2019).



The Diamond Y Spring system is potentially the eastern extent of a regional groundwater flow system in the Trans-Pecos region of western Texas (Figure 6). Specifically, the spring system may receive flow through the Salt Basin-Toyah Basin-Pecos River system that supports the San Solomon Spring system to the west in Reeves County (Sharp 2001, pp. 42, 45-46, 47-49; Sharp et al. 2003 pp. 5-8; Uliana et al. 2007 pp. 341). Research suggests that Diamond Y Spring system flows originate from some combination of groundwater from the Rustler and Edwards–Trinity (Plateau) Aquifers (Figure 7; Boghici 1997, pp. 79-86, 107-108; Sharp et al. 2003, pp. 7-8; Bumgarner 2012, p. 46; Ewing et al. 2012, pp. 3-3-3-4, 4-35, 4-86-4-87).

Figure 7. Rustler and Edwards-Trinity (Plateau) Aquifers: Pecos and Reeves counties, Texas.



Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community

Groundwater Pumping: Non-exempt Wells

An important determinant in the persistence of flow at the Diamond Y Spring system is the degree to which supporting aquifers have been subject to groundwater withdrawals. Data on estimated historical groundwater pumping from the Rustler and Edwards-Trinity (Plateau) Aquifers in Pecos and Reeves counties were obtained from Ewing et al. (2012, pp. 4-127-4-136) and the Texas Water Development Board (2001, pp. 61, 64; 2019b; 2019c).

Volumes of pumped groundwater from those information sources are not a complete depiction of pumpage totals, however. The Texas Water Development Board uses annual surveys of industrial and municipal users along with usage estimates derived from a number of sources including annual livestock numbers, area of irrigated agriculture, and weather data, among others to estimate groundwater withdrawals (Texas Water Development Board 2019b; 2019c). Data regarding groundwater pumping is mostly limited to groundwater wells that are non-exempt from permitting requirements under Texas Water Code Chapter 36. Comparable data from groundwater wells exempt from permitting requirements are unavailable. Lack of data from non-exempt wells may lead to underestimates of groundwater use and confound planning efforts (Lashmet and Miller 2015, p. 259; Backstrom 2018, p. 4). The differences in exempt and non-exempt groundwater wells lies in Texas' approach to regulation of groundwater.

The English common law rule of absolute ownership forms the basis of Texas groundwater governance and enables private landowners, in the absence of trespassing, negligence, malice, or willful waste, to withdraw unlimited amounts of groundwater from their property (Todd 1992, pp. 249-255; Kaiser and Skillern 2001, pp. 263-264; Opiela 2002, pp. 97-105; Cook et al. 2015, p. 50; Eoh 2015, pp. 1233-1236; Welles 2015, pp. 486-491; Closas and Molle 2018, p. 513). The State's groundwater does receive some degree of local regulation through the formation and administration of groundwater conservation districts. Groundwater conservation districts are voluntarily established legal entities, authorized by the Texas Legislature, to protect and manage groundwater resources within their jurisdictions (Welles 2015, pp. 491-494; Closas and Molle 2018, p. 513). Districts can regulate groundwater withdrawals to an extent through permitting of groundwater wells, reporting of groundwater production, and limits on withdrawals (Fipps 1998, pp. 4-7; Closas and Molle 2018, p. 513-515).

Groundwater wells regulated by groundwater conservation districts are non-exempt from permitting and other district requirements. Conversely, under Texas Water Code Chapter 36.117, groundwater wells for the following uses are considered exempt from groundwater conservation district permits:

- Drilling or operating a well used solely for domestic use or for providing water for livestock or poultry if the well is located or to be located on a tract of land larger than 10 acres [4 ha]; and drilled, completed, or equipped so that it is incapable of producing more than 25,000 gallons [95 m^3] of groundwater a day.
- Drilling a water well used solely to supply water for a rig that is actively engaged in drilling or exploration operations for an oil or gas well permitted by the Railroad Commission of Texas.
- Drilling a water well authorized under a permit issued by the Railroad Commission of Texas or for production from the well to the extent the withdrawals are required for mining activities regardless of any subsequent use of the water.

Groundwater wells to support the water needs of oil and natural gas drilling or exploration are often exempt from reporting pumped volumes, identifying source aquifer(s) of pumped groundwater, and restrictions on withdrawal volumes (Bracken 2010, pp. 182-183; Rahm 2011, p. 2979; Galant 2012, pp. 828-832, 835; Freyman 2014, pp. 34, 56; Lashmet and Miller 2015, p. 252-253; Backstrom 2018, p. 4). Groundwater conservation districts, however, can require that exempts wells be registered with the district and adhere to rules regarding well spacing, casing, and reporting (Galant 2012, pp. 832-834; Cook et al. 2015, p. 52). There is level of uncertainty as to whether groundwater wells drilled to support hydraulic fracturing operations are exempt from groundwater conservation district permitting requirements (Lashmet and Miller 2015, pp. 253-258). Some groundwater conservation districts require permits for wells drilled to support that activity while others do not (Cook et al. 2015, p. 50-52; Lashmet and Miller 2015, pp. 254-255).

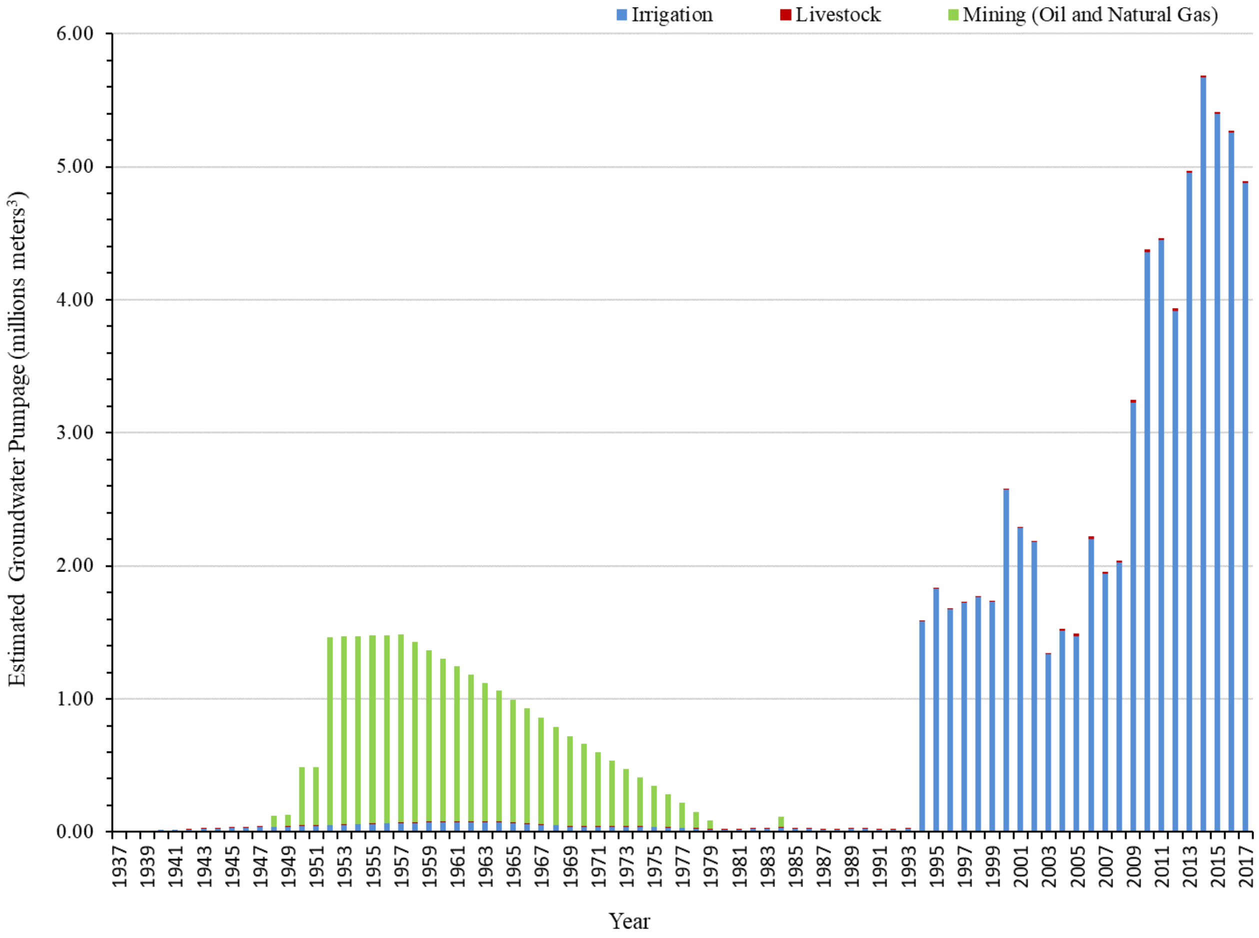
The following groundwater pumpage volumes from the Rustler and Edwards-Trinity (Plateau) Aquifers in Pecos and Reeves counties are estimated withdrawals from exempt groundwater wells. Comparably detailed data for groundwater pumped by exempt wells are unavailable (Nicot and Scanlon 2012, pp. 3581, 3583; Cook et al. 2015, p. 51). Groundwater pumpage values reported below are likely underestimates of pumped volumes.

The Rustler Aquifer occurs mostly within Pecos and Reeves counties with smaller portions extending into Culberson, Loving, and Ward counties (Boghici and Van Broekhoven 2001, pp. 209–210; Ewing et al. 2012, pp. 2-7-2-8). Recharge to the aquifer comes from precipitation in the Rustler Hills in Culberson County, with additional recharge contributed by cross-formational flows from deeper aquifer formations (Boghici and Van

Broekhoven 2001, pp. 218–219; Ewing et a. 2012, pp. 4-74-4-77). Hutchison et al. (2016, p. 11; 2017a, p. 9) estimates that annual recharge, from lateral flow from other counties and precipitation, in Pecos and Reeves counties is 3,593,127 meters^3 (m^3) [2,913 acre-feet (af)]. Rustler aquifer water is fresh to moderately brackish with total dissolved solids concentration of 1,000 mg/l to 5,000 mg/l (George et al. 2011, p. 145; Ewing et al. 2012, pp. 4-148, 4-157; Lupton et al. 2016, pp. 2, 44-57, 94-100). Lupton et al. (2016, pp. 97-98) estimated that the Pecos portion of the Rustler Aquifer contained 5,896,034,400 m^3 (4,780,000 af) of brackish groundwater, while the Reeves County portion of that aquifer contained 11,040,879,480 m^3 (8,951,000 af) of brackish groundwater.

Records of groundwater pumping from the Rustler Aquifer in Pecos County date from 1937 at a reported 2,467 m^3 (2 af) [Ewing et al. 2012, pp. 4-127-4-136]. From 1937 to 2017, a total of 97,602,805 m^3 (79,128 af) of groundwater is estimated as being removed from the Rustler Aquifer in Pecos County (Figure 8; Ewing et al. 2012, pp. 4-127-4-136; Texas Water Development Board 2019c). Irrigation was the primary use of groundwater from 1937-1947 (Ewing et al. 2012, pp. 4-127-4-128). Available records indicate that pumping to support oil extraction, was the primary use from 1948-1979 with an annual average use of 781,717 m3 (634 af) [Ewing et al. 2012, pp. 4-126, 4-133-4-134, 4-141].

Figure 8. Estimated groundwater pumpage from the Rustler Aquifer in Pecos County, Texas: 1937-2017 (Ewing et al. 2012, pp. 4-127-4-136; Texas Water Development Board 2019c).



After 1980, irrigation again became the primary use for groundwater pumped from the Rustler Aquifer in Pecos County. Pumping from the aquifer, to support irrigation, increased to unprecedented volumes after 1994 with the most dramatic increases seen after 2010. From 2010-2017, estimated groundwater pumping from the Rustler Aquifer in Pecos County totaled 38,866,954 m^3 (31,510 af) [Texas Water Development Board 2019c]. In comparison, estimated pumping for irrigation for the 73-year period from 1937-2009 totaled 33,105,369 m^3 (26,839 af), with the greatest volumes removed from 1994-2009 (31,035,590 m^3 [25,161 af]). The annual average rate of withdrawal during the 8-year period from 2010-2017 (4,858, 369 m^3 [3,939 af]) is over ten-times the average amount pumped annually from 1937-2009 (453,498 m3 [368 af]).

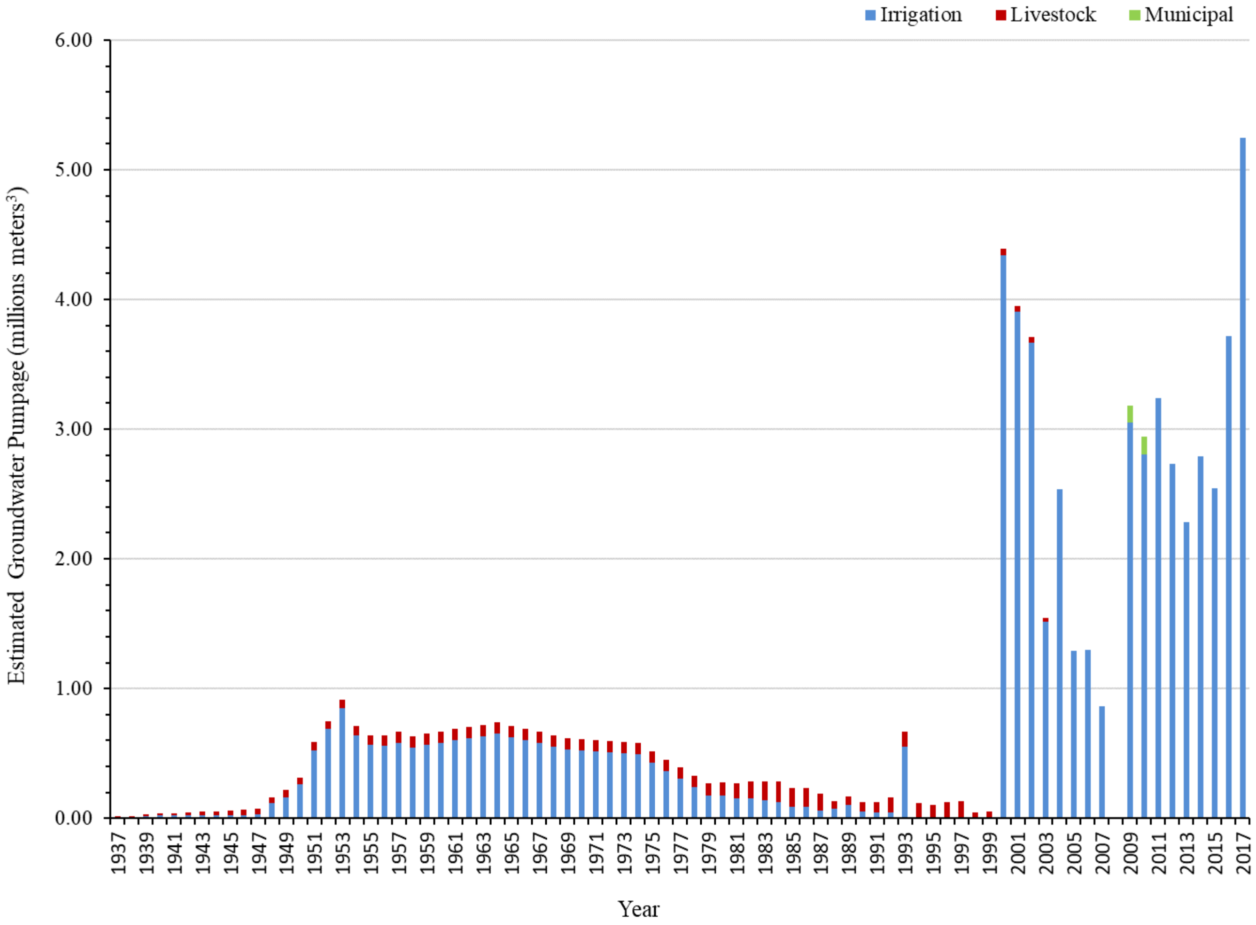
In Reeves County, 8,634 m^3 (7 af) of groundwater was pumped from the Rustler Aquifer for irrigation and livestock uses in 1937 (Ewing et al. 2012, pp. 4-127-4-136). From 1937 to 2017, a total of 71,224,835 m^3

(57,743 af) of groundwater is reported as being removed from the Rustler Aquifer in Reeves County (Figure 9; Ewing et al. 2012, pp. 4-127-4-136; Texas Water Development Board 2019). Irrigation has been the primary use of groundwater from 1937-2017, followed by livestock use (Ewing et al. 2012, pp. 4-127-4-128). As in Pecos County, use of Rustler Aquifer groundwater for irrigation has been at historically unprecedented volumes since 2000. Missing values from Texas Water Development Board data during the years of 1994-1999 and 2008 account for the drops in pumping for those years.

From 2000-2017, estimated groundwater pumping for irrigation from the aquifer totaled 47,782,548 m^3 (37,738 af) [Texas Water Development Board 2019c]. By comparison, estimated pumping for irrigation for the 63-year period from 1937-1999 in Reeves County totaled 18,014,975 m^3 (14,605 af). The annual average rate of withdrawal over the 18-year period from 2000-2017 (2,654,586 m^3 [2,152 af]) is over nine-times the average amount pumped from 1937-1999 (285,952 m3 [231 af]).

The Edwards–Trinity (Plateau) Aquifer underlies 9,064,958 ha (22,400,000 ac) of west-central Texas, extending westward from Travis County to Brewster County (Anaya and Jones 2009, pp. 3-4). The Western Edwards Plateau, or Trans-Pecos, portion of this aquifer occurs under much of Pecos and Reeves counties, reaching its westward extent in Culberson and Jeff Davis counties (Anaya and Jones 2009, pp. 25, 32-34; George et al. 2011, pp. 35, 38). Recharge to the aquifer is a combination of precipitation, input from stream losses, and runoff into sinkholes (Anaya and Jones 2009, p. 47).

Figure 9. Estimated groundwater pumpage from the Rustler Aquifer in Reeves County, Texas: 1937-2017 (Ewing et al. 2012, pp. 4-127-4-136; Texas Water Development Board 2019c).



Groundwater declines due to irrigation have caused some induced recharge from the Pecos River, in the form of moderately to highly brackish waters, to the aquifer (Barker et al. 1994, pp. 42-43). Muller and Price (1979, p. 72) estimated an annual effective recharge for the Western Edwards Plateau component of the Edwards-Trinity (Plateau) Aquifer of 215,488,956 m^3 (174,700 af). Groundwater in this portion of the aquifer is fresh to moderately brackish with total dissolved solid concentrations of 500 mg/l to 5,000 mg/l (Rees and Buckner 1980, pp. 1, 15-22; Anaya and Jones 2009, p. 50; George et al. 2011, pp. 35).

Available data regarding groundwater pumping from the Western Edwards Plateau portion of the Edwards-Trinity (Plateau) Aquifer in Pecos and Reeves counties dates to 1958 but is incomplete with data absent for several spans of time (Texas Water Development Board 2019b). Specifically, data is lacking for periods prior to 1958, 1959-1963, 1965-1968, 1970-1973, 1975-1978, and 1980-1983. Irrigation volumes are only readily available for 1958, 1964, 1969, and 1979 and reflect data captured every five years during the Texas Water Development Board's (2001, entire) Surveys of Irrigation in Texas. Based on available data, from 1958-2017, 4,052,884,707 m^3 (3,285,732 af) of groundwater was pumped from the Pecos County portion of this aquifer, with the majority of that volume used for irrigation (3,778,293,557 m^3 [3,063,117 af]).

The individual irrigation pumping survey years of 1958, 1964, 1969, 1974, and 1979 saw the greatest annual removals of groundwater from the Edwards-Trinity (Plateau) Aquifer in Pecos County to date (Figure 10). Volume of groundwater pumped for those five years averaged 294,209,650 m^3 (238,520 af) per year. In comparison, average groundwater withdrawals for the 34-year period from1984-2017 averaged 65,932,517 m^3 (53,542 af) per year. Given lack of data from the 1940s to 1957, and limited data from 1958-1979, the total amount of groundwater pumped from the aquifer in Pecos County is likely far greater than available information indicate.

Groundwater pumping in Pecos County had been occurring since the late 19th century and increased significantly beginning in the 1940s (Armstrong and McMillon 1972, pp. 43-44, 58, 61-62; Barker et al. 1994, p. 43). Heavy pumping for irrigation from the 1940s into the 1960s coincides with the decline and/or failure of perennial flow at Comanche, Leon, San Pedro, and Santa Rosa Springs among other freshwater springs in Pecos County (Audsley 1956, pp. 14-15; Armstrong and McMillon 1961, pp. 44; Brune 1981, pp. 356-363; Small and Ozuna 1993, p. 26). Groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Pecos County declined from the late 1960s through the late 2000s. Groundwater pumping increased in 2010, reaching levels comparable to volumes pumped in the late 1970s.

Volumes pumped from the aquifer for irrigation in Reeves County, prior to 1984, are available for the years 1958, 1964, 1969, 1974, 1979, and 1980 with average annual pumping of 32,345,0732 m^3 (262,226 af) for those six individual years. Amounts pumped for irrigation in Reeves County during those years are significant and similar to the historic amounts withdrawn from the Pecos County portion of the aquifer (Figure 11). Pumped volumes drop sharply from 1969 onwards with average annual withdrawals from 1984-2008 of 1,816,837 m^3 per year (1,473 af per year) primarily for irrigation. From 2009-2017, average annual groundwater pumping values have increased to 2,428,194 m^3 (1,968 af) [Figure 12].

Figure 10. Estimated groundwater pumpage from the Edwards-Trinity (Plateau) Aquifer in Pecos County, Texas: 1958-2017 (Texas Water Development Board 2019b; 2019c).

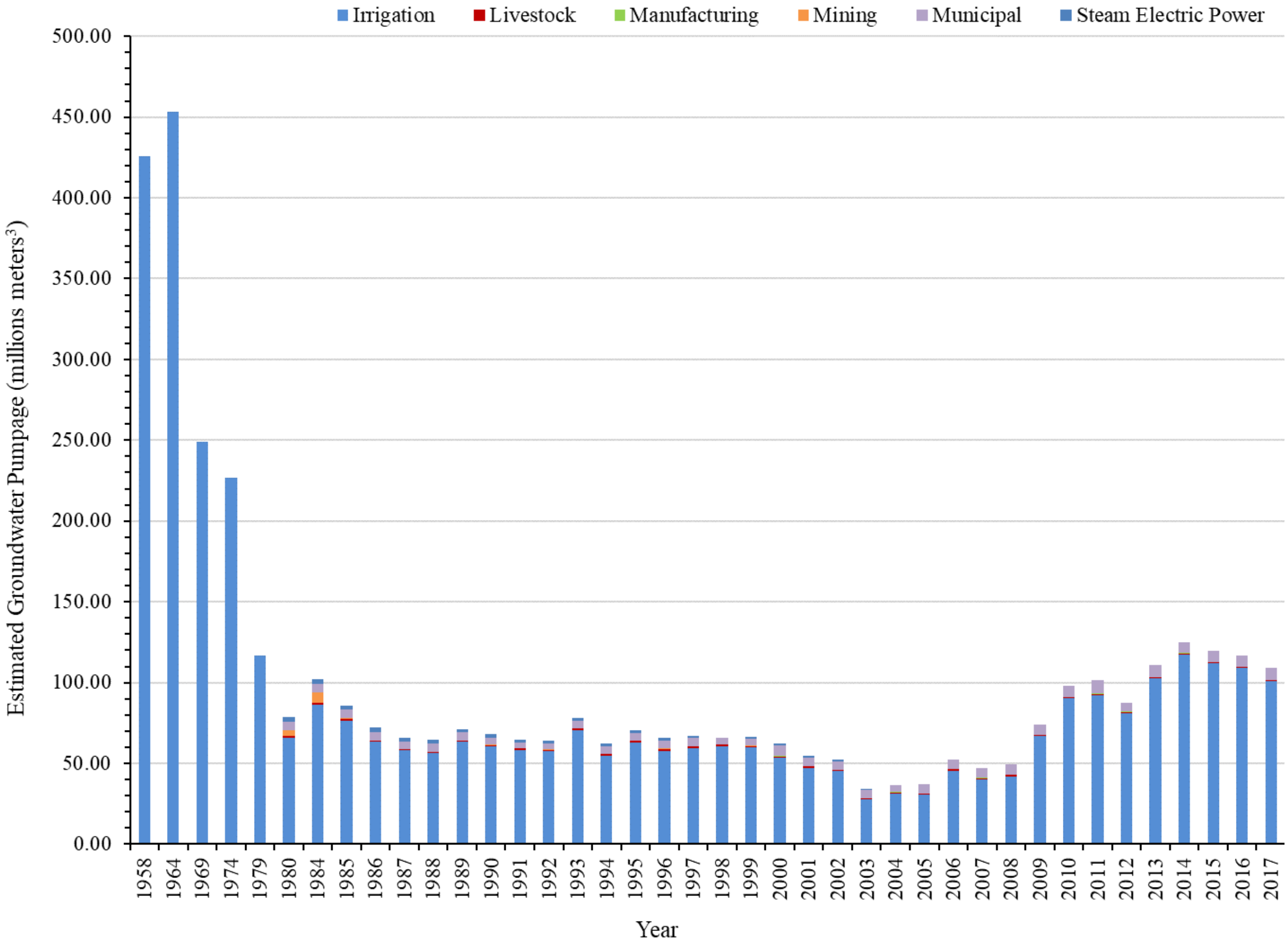
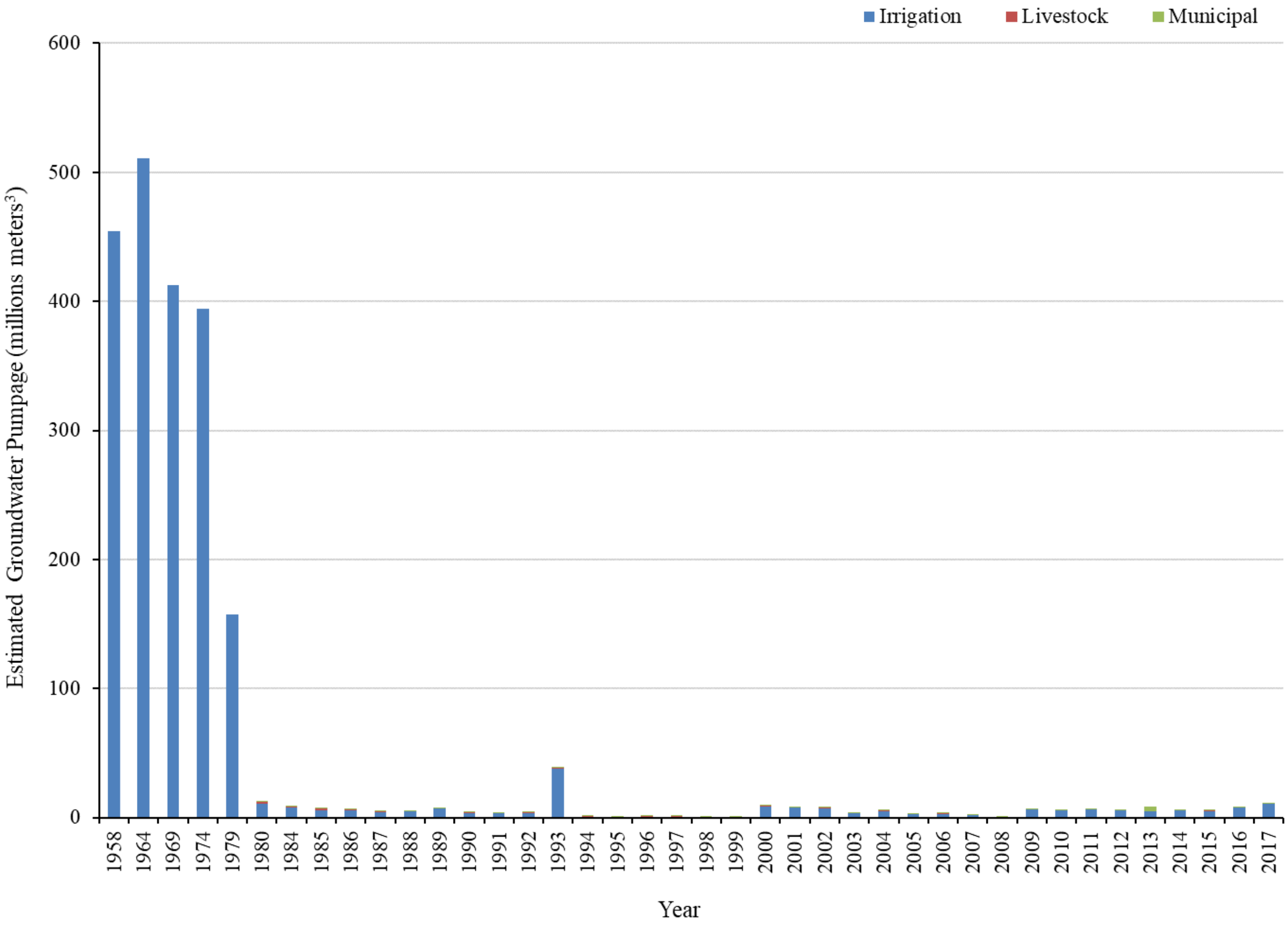


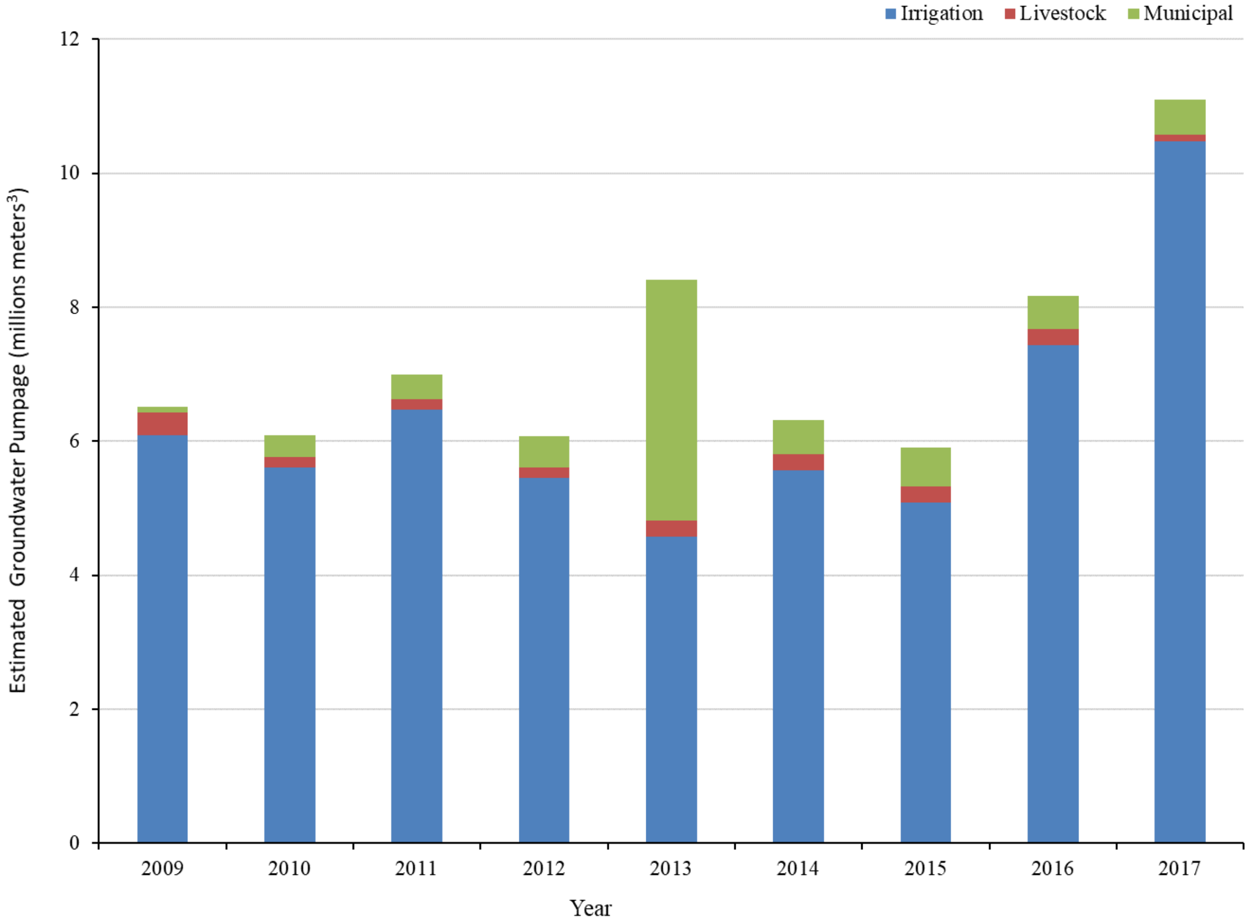
Figure 11. Estimated groundwater pumpage from the Edwards-Trinity (Plateau) Aquifer in Reeves County, Texas: 1958-2017 (Texas Water Development Board 2019b; 2019c).



Groundwater Pumping: Exempt Wells (Oil and Natural Gas)

Although relatively detailed data exist on groundwater pumping from exempt wells, lack of information on non-exempt wells, specifically those that support oil and natural gas extraction, limits understanding of potential threats to continued springflow. Oil and natural gas production in the Permian Basin began in the 1920s with the drilling of vertical wells into moderate to high permeability reservoirs where oil and natural gas readily flows to wellbores, termed conventional production (Scanlon et al. 2017a, p. 10905). Conventional production in the Permian Basin has declined since the 1970s and, since the late 2000s, been largely supplanted by directionally or horizontally drilled wells combined with hydraulic fracturing (U.S. Environmental Protection Agency 2016, pp. ES-6-ES7, 3-4; Scanlon et al. 2017a, pp. 10905-10906; Scanlon et al. 2017b, pp. S46-S48).

Figure 12. Estimated groundwater pumpage from the Edwards-Trinity (Plateau) Aquifer in Reeves County, Texas: 2009-2017 (Texas Water Development Board 2019c).

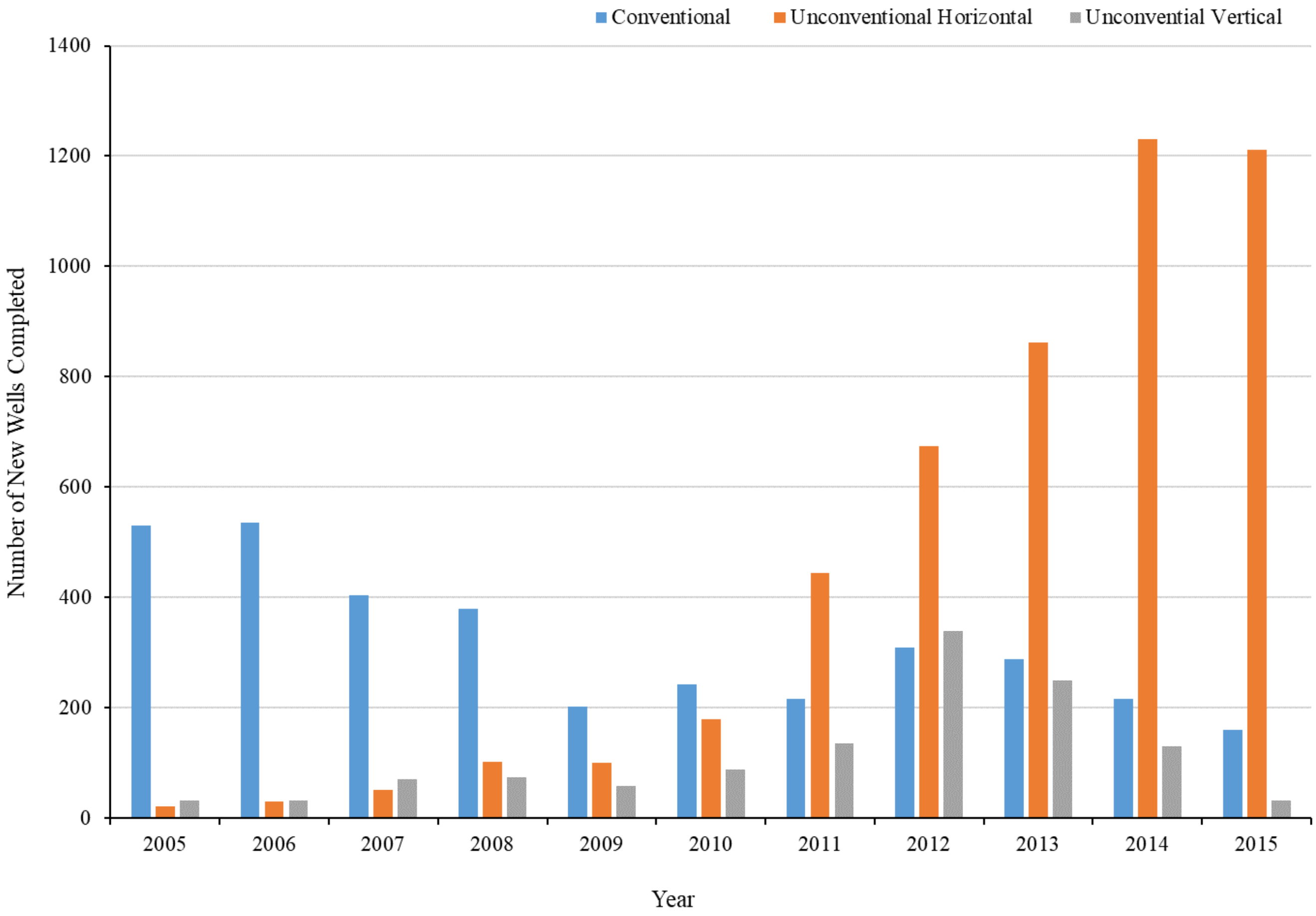


Hydraulic fracturing is a process in which a mixture of water, chemicals, and proppant (e.g., sand) are injected into an oil and natural gas reservoir under pressure to fracture the reservoir rock and increase flow of those resources to the wellbore (Cook et al. 2015, p. 47; U.S. Environmental Protection Agency 2016, p. 3-3). Directional or horizontal drilling exposes more of an oil or natural gas-bearing rock formation to production wells (Ma et al. 2016, pp. 368-369). Hydraulic fracturing and directional drilling have made extraction of oil and natural gas from low permeability reservoirs (i.e., unconventional reservoirs), where those materials do not move as freely, economically viable (U.S. Environmental Protection Agency 2016, pp. 3-5-3.7).

Conventional drilling dominated the Delaware Basin through 2010 (Figure 13; Scanlon et al. 2017b, p. S48). Hydraulically fractured horizontal wells, or unconventional drilling, increased significantly from 2011 to 2015 across the basin, largely replacing conventionally drilled wells. We obtained data on oil and natural gas wells within the footprints of the

Rustler and Edwards-Trinity (Plateau) Aquifers from Railroad Commission of Texas records compiled by the commercial IHS database (IHS Markit 2019).

Figure 13. Number of new conventional and unconventional oil and gas wells completed in the Delaware Basin: 2005-2017 (Scanlon et al. 2017b, p. S46).

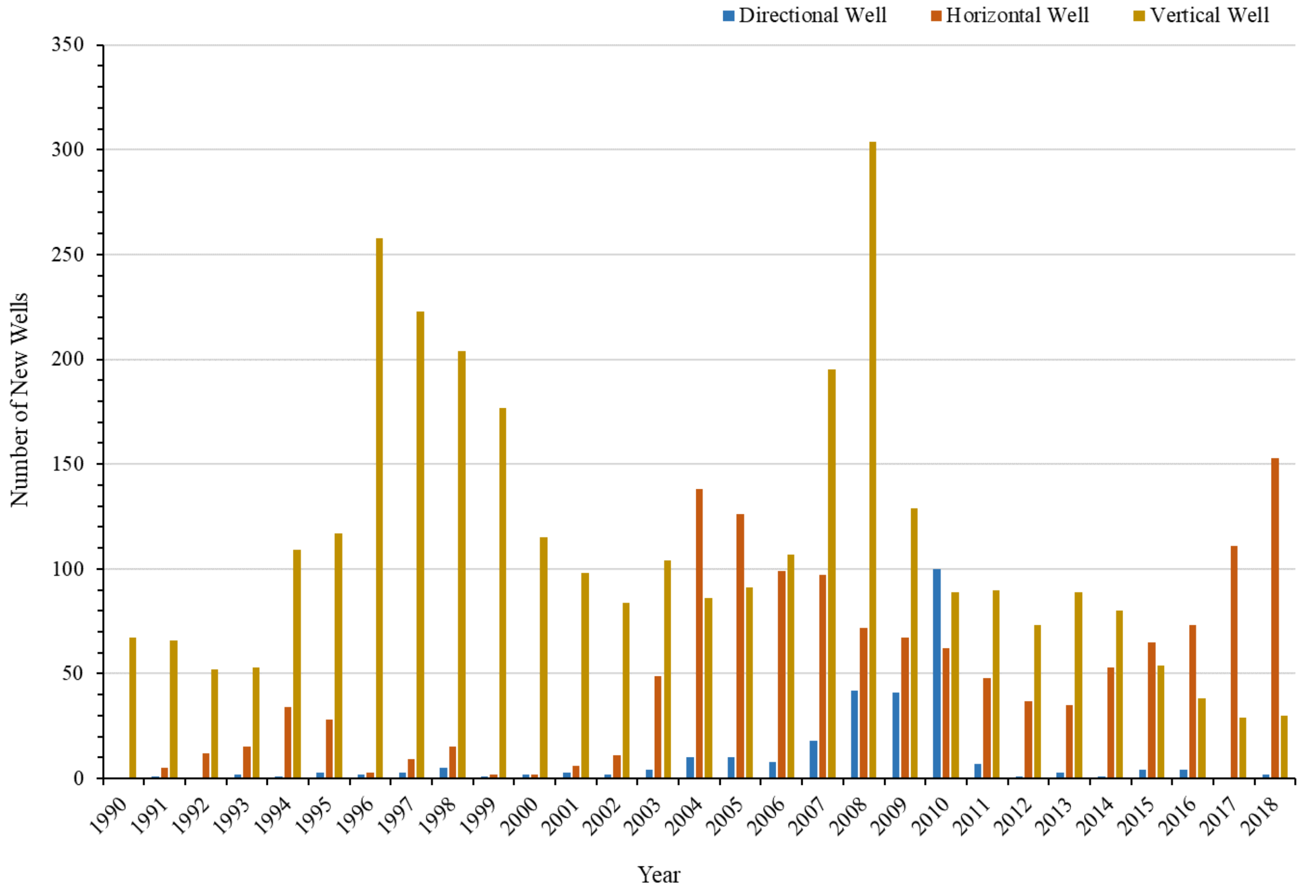


Since 2014 to 2015, horizontal wells are the most frequently established well type in Pecos (Figure 14) and Reeves (Figure 15) counties, with the latter county seeing especially sharp increases since 2017. In 2018, horizontal wells were 83% of the new wells drilled in Pecos County and 99% of the new wells drilled in Reeves County. Increases drilling activity in that county is likely in response to Apache Corporation's 2016 announcement of a new oil and natural gas play, the Alpine High, in Reeves County (Olson and Ailworth 2016; Texas Parks and Wildlife Department 2018, p. 8).

Conventional and unconventional wells require some volume of water for well establishment and extraction of oil or natural gas (Mielke et al. 2010, pp. 13-14, 16-19; Scanlon et al. 2014a, p. 12392; Gallegos et al. 2015a, p.

5842; U.S. Environmental Protection Agency 2016, pp. 4-4-4-13). While no data are available for exempt groundwater wells regarding pumped volumes or source aquifers, information does exist on the volumes of water used to hydraulically fracture wells in Texas. In 2012, the Railroad Commission of Texas required oil and natural gas operators to report water volumes and chemicals used in hydraulic fracturing to the online chemical registry, FracFocus (www.fracfocus.org) [Konschnik et al 2013, pp. 3-6; Dundon et al. 2015, p. 497-498].

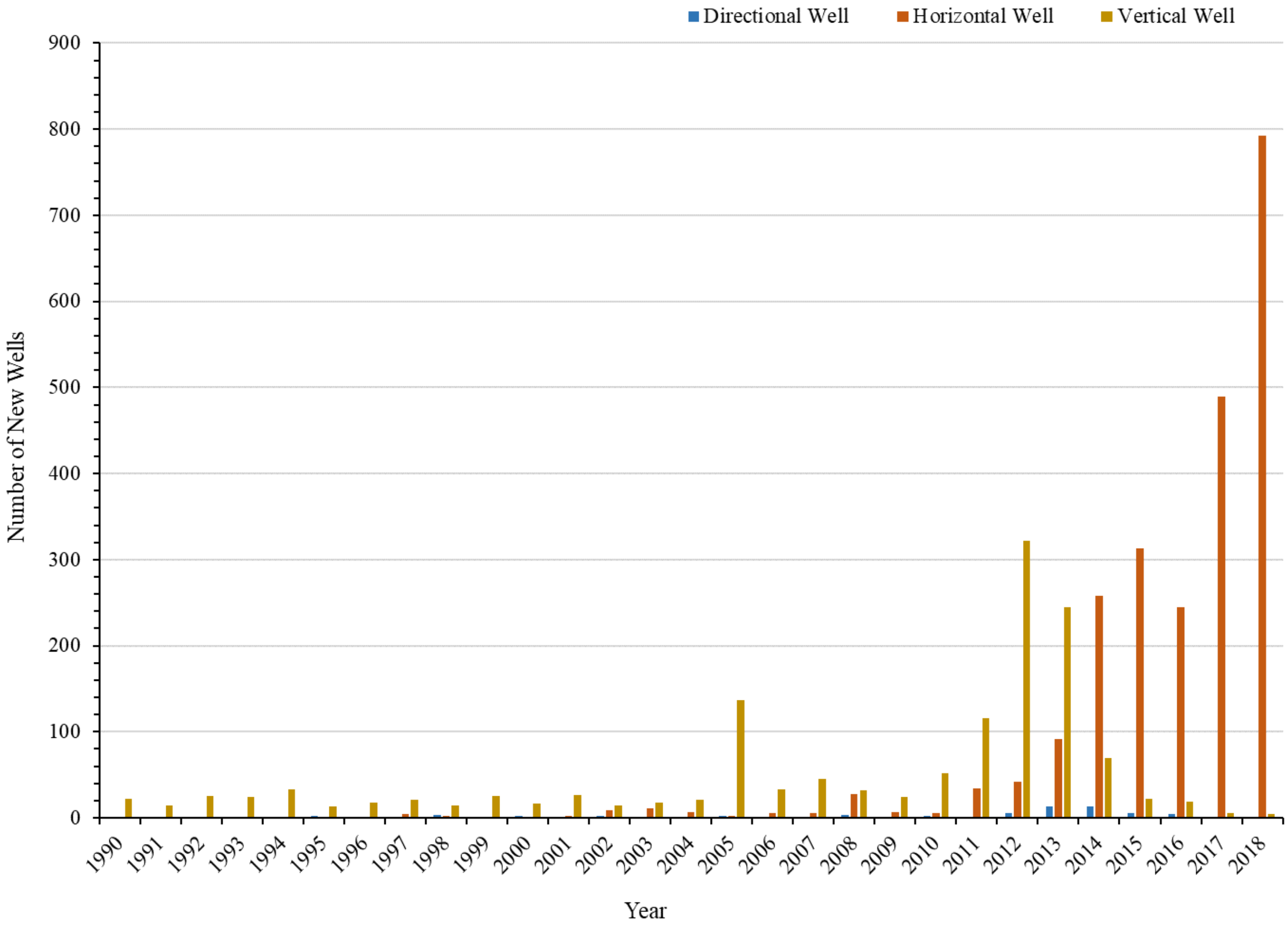
Figure 14. Number of new conventional and unconventional oil and gas wells completed in Pecos County, Texas: 1990-2018 (IHS Markit 2019).



Groundwater is the sole source of water for oil and natural gas extraction activities in the Permian Basin (Nicot et al. 2012, pp. 54, 56). Use of groundwater can vary dramatically among well types (i.e., vertical or horizontal). Scanlon et al. (2017a, p. 10905) estimated that conventional wells use approximately 1,600 m^3 (1.3 af) per well. Unconventional horizontal wells are the most frequently established well type in Pecos and Reeves counties and across the Delaware Basin. Nicot et al. (2012, pp. 54, 68) estimated that brackish groundwater accounted for 80% of the groundwater used for hydraulic fracturing in the western Permian Basin.

Brackish groundwater is increasingly viewed as a source of water for that water-intensive drilling method given the presence of several brackish groundwater aquifers in the region (Scanlon 2014a, pp. 11-12). Scanlon et al. (2017b, p. S52) reported that horizontal wells in the Delaware Basin used a median water volume of 23,250 m^3 (19 af) per well in 2015. Kondash et al. (2018, p. 2) found that per well water use in the Permian Basin increased from 4,900 m^3 (4.0 af) in 2011 to 42,500 m^3 (34.5 af) in 2016.

Figure 15. Number of new conventional and unconventional oil and gas wells completed in Reeves County, Texas: 1990-2018 (IHS Markit 2019).

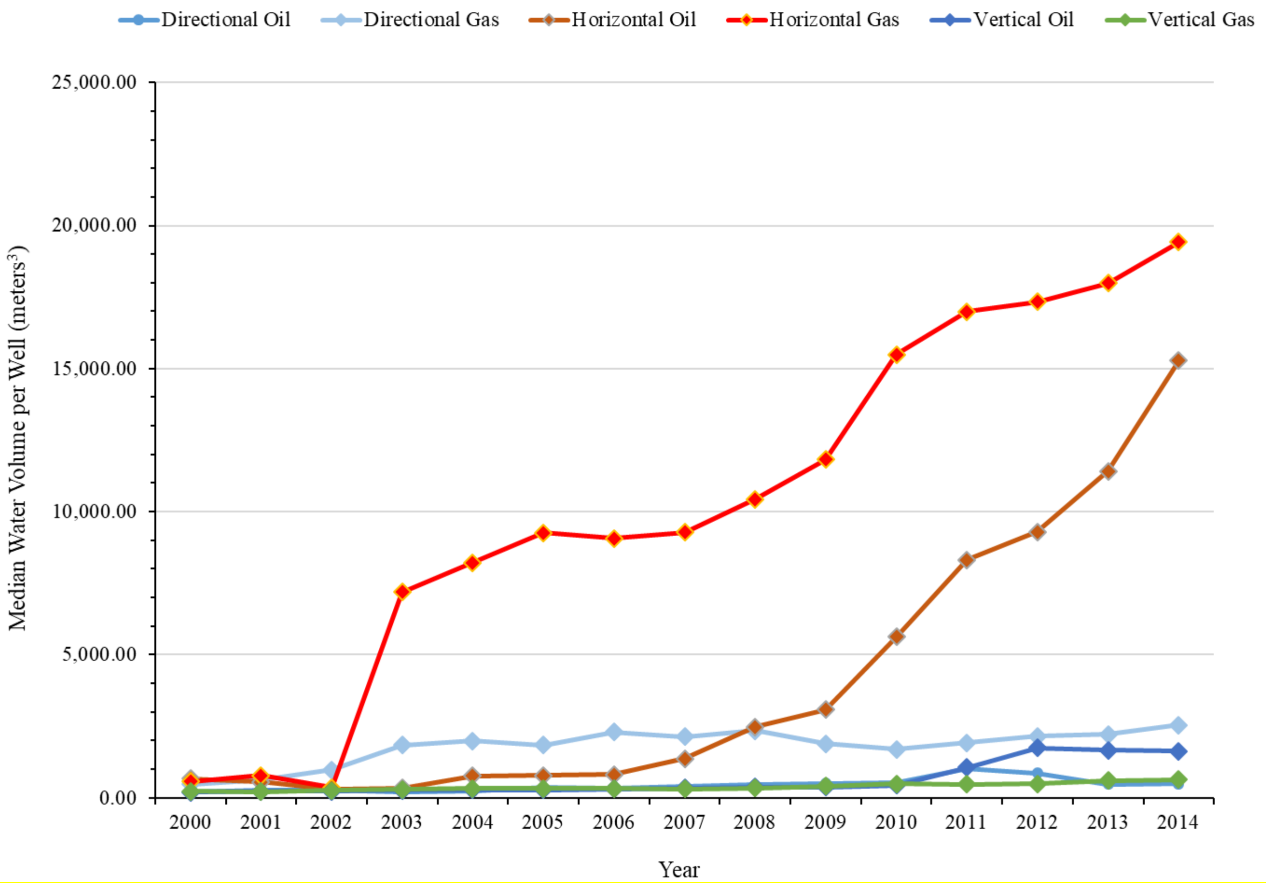


Gallegos et al. (2015a, p. 5842) demonstrated that median annual water volume demand for horizontal oil and natural gas wells nationally far out-paced water use by directional and vertical wells for the period between 2000-2014 (Figure 16). Increased lengths of horizontal wells drive an increased demand for larger volumes of hydraulic fracturing fluid (Nicot and Scanlon 2012, p. 3582; Nicot et al. 2012, pp. 13-14; Gallegos et al. 2015, p. 5840-5841). In the Permian Basin, Kondash et al. (2018a, pp. 2-4) noted that water use per meter of horizontal well length increased from

4.4 m^3 (0.004 af) in 2011 to 29 m^3 (0.023 af) in 2016 for natural gas wells and from 3.9 m^3 (0.003 af) in 2011 to 19 m^3 (0.015 af) in 2016 for oil wells.

Horizontal wells became the most frequently established oil and natural gas wells in both Pecos and Reeves counties in 2015 and 2014, respectively. Applying the 2015 median per well water volume of 23,250 m^3 (19 af) from Scanlon et al. (2017b, S52) for Delaware Basin horizontal wells, a very coarse estimate of potential water use for 2015 can be derived for Pecos and Reeves counties. That value, multiplied by the 53 horizontal wells drilled in Pecos County that year, yields a total of 1,232,250 m^3 (999 af) of water. Total estimated groundwater pumpage from all aquifers in Pecos County in 2015 was 196,078,915 m^3 (158,964 af) [Texas Water Development Board 2019b; 2019c]. If all groundwater for horizontal wells were pumped from wells in that county, then usage would account for approximately 0.6% of total pumpage. For the 313 horizontal wells drilled in Reeves County, 7,277,250 m^3 (5,900 af) of water would have been required. Total estimated groundwater pumpage from all aquifers in Reeves County in 2015 was 53,509,596 m^3 (43,381 af) [Texas Water Development Board 2019b; 2019c]. If all groundwater for horizontal wells were pumped from Reeves County well, that use would account for approximately 14% of total pumpage.

Figure 16. Median water volume used per hydraulically fractured well nationally from 2000-2014 (Gallegos et al. 2016b, p. 22).



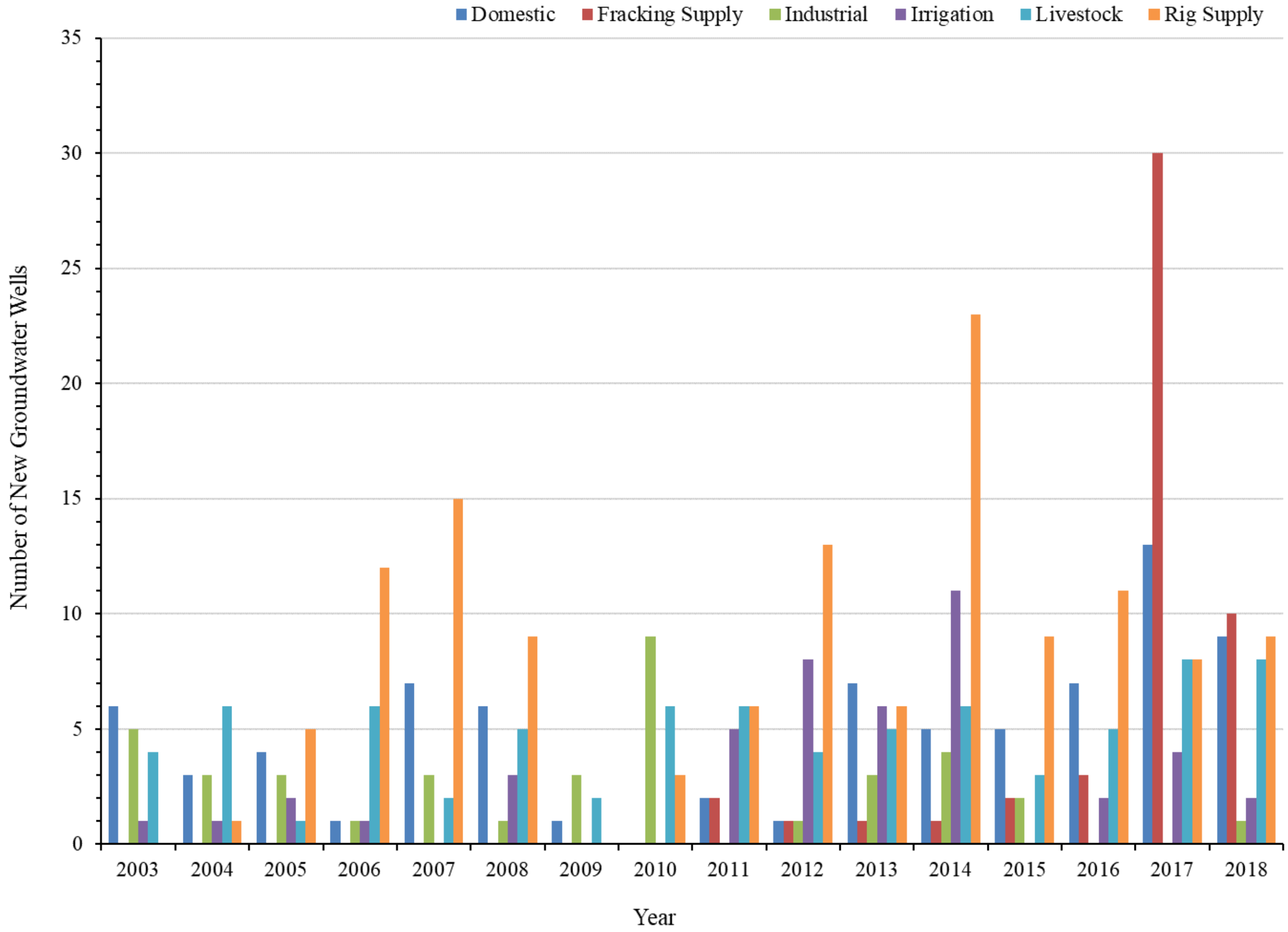
In 2014, water use for hydraulic fracturing was 2.7% of total uses in the Permian Basin (Scanlon et al. 2017a, pp. 10909-10910; 2017b, p. S62). In the Delaware Basin, for that same year, percentage water use was substantially higher at 16.7% of total uses (Scanlon et al. 2017b, p. S62). Water demands for hydraulic fracturing and horizontal drilling can represent higher percentages of total water use at the county level (Freyman 2014, pp. 29, 51-52). For example, in the Eagle Ford Shale Play of southern Texas, hydraulic fracturing water use in 2011 and 2012 was 30% or more compared to total water use in 2010 for Dimmitt (44.0%), Irion (30.8%), Karnes (56.7%), La Salle (52.1%), and McMullen (113.5%) counties (U.S. Environmental Protection Agency 2016, pp. 4-16, 4-24).

Groundwater wells drilled to meet the water needs of hydraulically fractured wells have increased in number in both Pecos and Reeves counties. In Texas, licensed water-well drillers that complete new wells must submit a well log to the Texas Department of Licensing and Regulation that includes completion date, proposed use, along with other information (Anderson and Gunn 2015, pp. 10-11). This information is retrievable through the Submitted Drillers Reports Database (Texas Water Development Board 2019d).

In Pecos and Reeves counties, new groundwater wells drilled to supply hydraulic fracturing activity (i.e., fracking supply) were first reported in 2011 (Figures 17 and 18). From 2011-2018, 50 fracking supply groundwater wells were drilled in Pecos County while 323 of those wells were drilled in Reeves County. The majority of fracking supply wells were drilled from 2017-2018. Rig supply groundwater wells are those wells drilled to supply water to an oil or gas drilling site.

New groundwater wells to meet oil and natural gas extraction needs from 2003-2018, fracking and rig supply wells combined, comprise 43% of the new wells drilled in Pecos County and 75% of the new wells in Reeves County. Data on the amount of groundwater pumped from those wells and from which aquifer water is withdrawn are not available as these groundwater wells are generally exempt from reporting requirements.

Figure 17. New groundwater wells drilled in Pecos County: 2003-2018 (Texas Water Development Board 2019d).



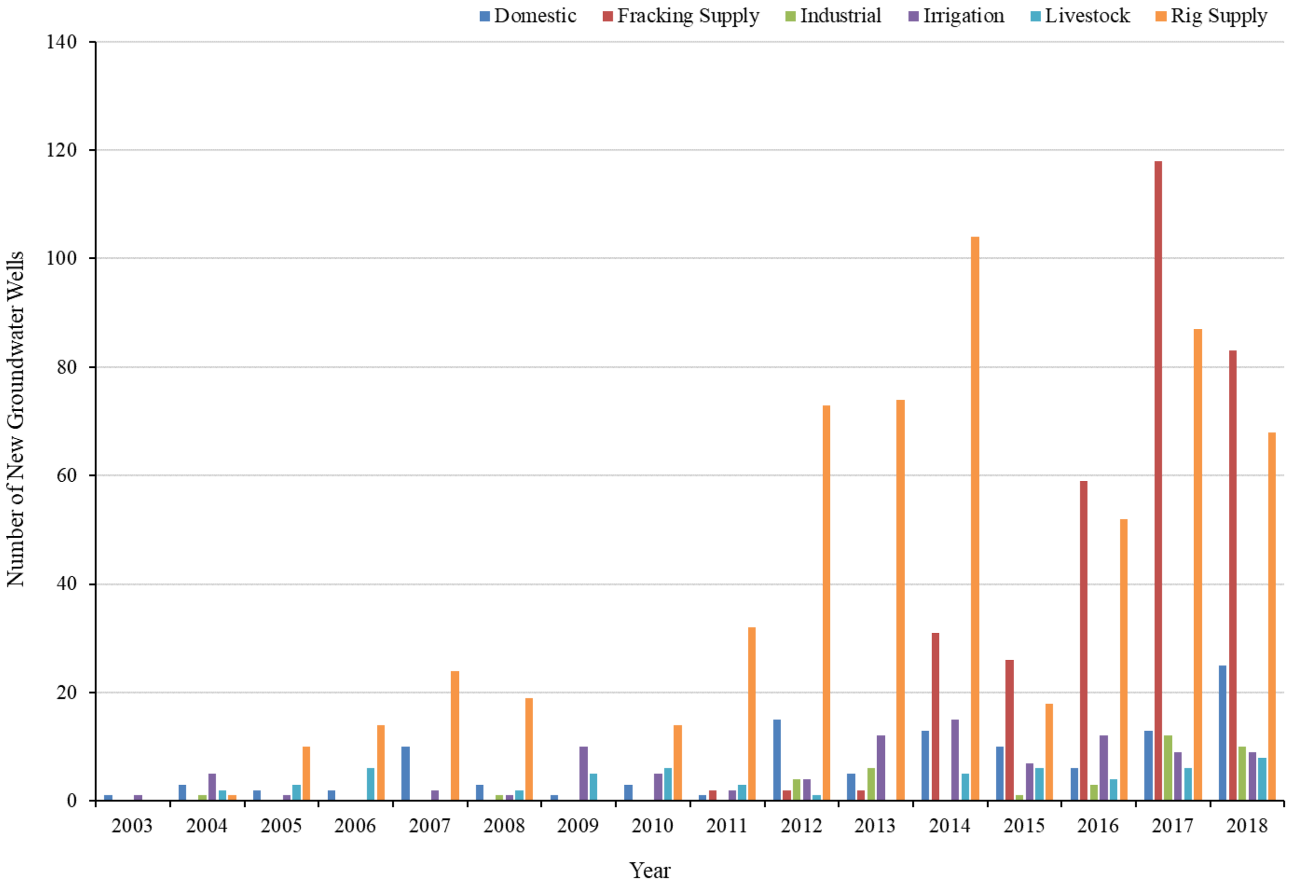
<u>Groundwater Pumping: Groundwater Marketing</u>

Aquifers in Texas that contain brackish groundwater, such as the Rustler and Edwards-Trinity (Plateau) Aquifers, may become more even more important sources of groundwater into the future. The State of Texas is making a concerted effort to assess brackish groundwater aquifers as an alternative water source to reduce use of fresh groundwater resources. In 2015, the Texas Legislature passed House Bill 30 (Texas Legislature 2019) that states:

> "(b) Brackish groundwater is a potential new source of water for municipal, industrial, and other purposes. This state has an estimated 880 trillion gallons of brackish groundwater, much of which is untapped. For many years this water was considered largely useless for most purposes, but advances in technology and pressures on other supplies have revealed that brackish

> groundwater is in fact a vital resource. In addition to providing potentially vast new supplies, the development of brackish groundwater can reduce pressures on the use of fresh groundwater."

Figure 18. New groundwater wells drilled in Reeves County: 2003-2018 (Texas Water Development Board 2019d).



Texas House Bill 30 directed the Texas Water Development Board to identify, assess, and designate brackish groundwater production zones (Texas Legislature Online 2019). The Rustler and Edwards-Trinity (Plateau) Aquifers both contain significant volumes of brackish groundwater (Scanlon et al. 2014b, p. 46). The Rustler Aquifer is designated as a brackish groundwater production zone currently. The Edwards-Trinity (Plateau) Aquifer is under evaluation for that designation.

Several groundwater-marketing projects already exist or are planned to pump and privately sale brackish groundwater from western Texas aquifers to hydraulic fracturing operations in the region (Root 2018). The State of New Mexico's relatively more stringent regulation of groundwater is reportedly also spurring increased exports of groundwater from Texas to support hydraulic fracturing in that state (Root 2018). A recent $32,500,000 sale of a 14,973 ha (37,000 ac) private ranch (i.e., KC7 Ranch) in Jeff Davis and Reeves counties underscores current perceived groundwater marketability of a property that reportedly has the potential to produce 47,736 m^3 (38.7 af) of brackish groundwater per day from the Capitan Reef Complex Aquifer (Dickson 2019; Wethe 2019b). A 27,356 ha (67,600 ac) private ranch that extends into portions of Jeff Davis, Loving, and Reeves counties has also been marketed in terms of its underlying groundwater resources to supply hydraulic fracturing in western Texas and New Mexico (Wethe 2019a).

The Middle Pecos Groundwater District approved a permit in 2015 for private landowners to pump 12,334,800 m^3 (10,000 af) groundwater per year from the Edwards-Trinity (Plateau) Aquifer for export to oil and natural gas drilling sites (Paul 2015). In 2017, the Culberson County Groundwater Conservation District approved a private landowner's permit to pump 20,476 m^3 (16.6 af) of brackish groundwater per day from the Capitan Reef Complex aquifer that will be transported by pipeline into the Delaware Basin for sale to petroleum companies (Hunn 2017). Another groundwater marketing project in Culberson and Reeves counties is expected to install approximately 100 wells to pump brackish groundwater to meet a potential hydraulic fracturing demand of 59,620,256 m^3 (48,335 af) of groundwater per year (Blum 2017). Private interests are also pursing efforts to pump and export groundwater for municipal uses (Rocha 2014). A private landowner was granted a permit in 2017 by the Middle Pecos Groundwater Conservation District to pump 35,030,832 m^3 (28,400 af) of groundwater per year from the Edwards-Trinity (Plateau) Aquifer for potential export to the City of Odessa (Metzger 2017; Paul 2017a; 2017b).

Groundwater conservation districts in Texas cannot prohibit the export of groundwater out of their jurisdictions (Marbury and Taylor 2007, pp. 10-11). Districts, however, can require permits be approved and issued for groundwater export that consider such factors as aquifer condition, depletion, and effects on other use sectors (Leiskar et al. 2002, pp. 27-28; Marbury and Taylor 2007, p. 11). Areas without groundwater districts are vulnerable to unregulated groundwater pumping and export (Puig-Williams 2015, pp. 1-2, 5). Observations have been made in Loving County, a county with no groundwater conservation district, of allegedly unpermitted waterlines transporting groundwater from Texas across the state line to New Mexico to supply petroleum extraction operations (Root 2018). Unpermitted export of groundwater can also occur in counties with groundwater conservation districts. In 2014, the City of Fort Stockton in Pecos County was fined by the Middle Pecos Groundwater Conservation District for the unpermitted sale and export of 64,511 m^3 (52.3 af) of groundwater to a petroleum company in Reeves County (Martinez 2014).

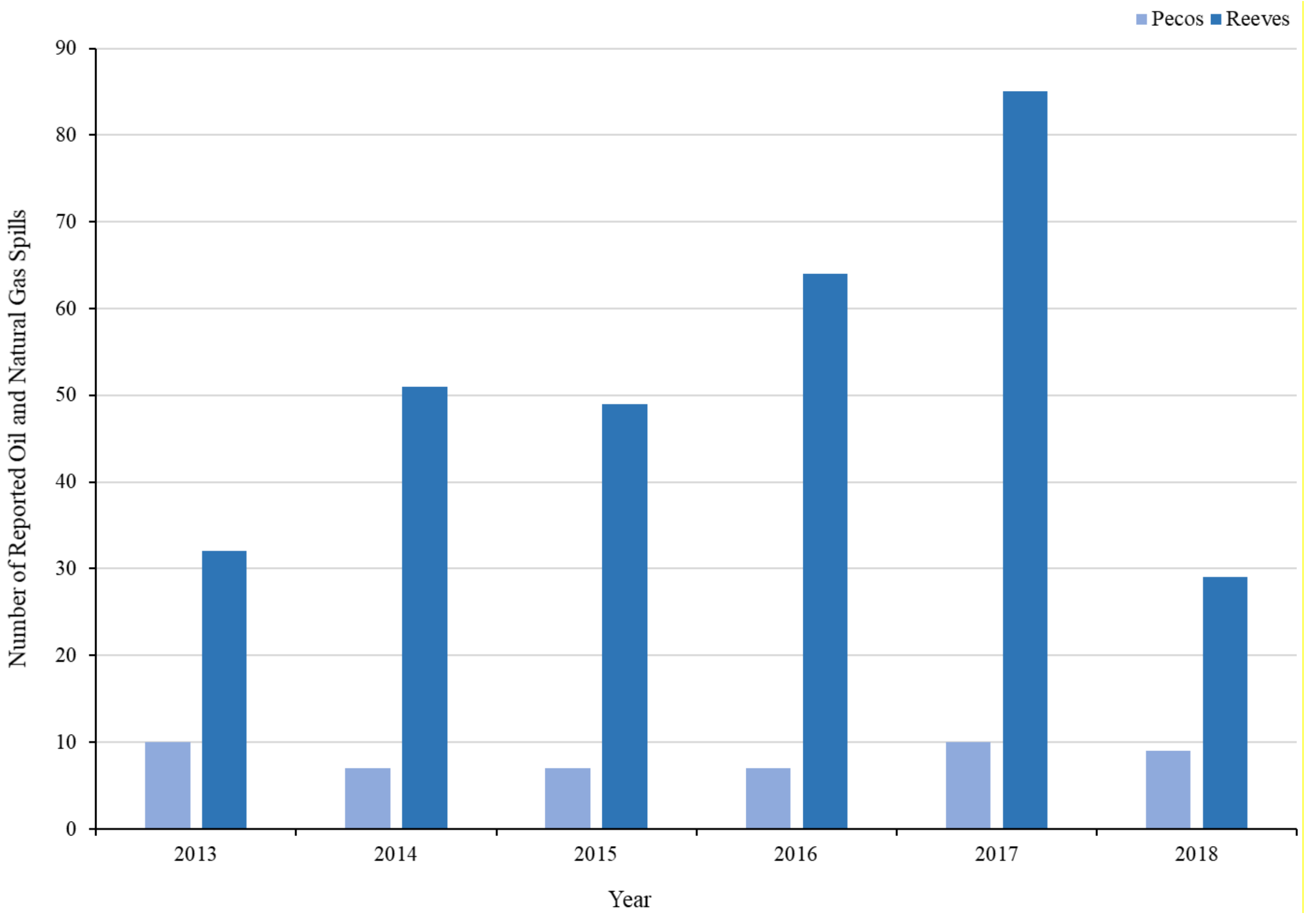
Water Quality

Groundwater, surface water, and land surface contamination are potential risks that can accompany conventional and unconventional oil and natural gas extraction, processing, storage, and transport (Collins 1971, pp. 2386-2392; Allen et al. 2011, pp. 76-82; Entrekin et al. 2011, pp. 508-509; Osborn et al. 2011, p. 8173; Vidic et al. 2013, pp. 1235009-6-1235009-8; Burton et al. 2014, pp. 1680-1685; Jackson et al. 2014, pp. 341-343; Vengosh et al. 2014, pp. 8336-8342; Zhang and Yang 2015, pp. 878-880; Cooper et al. 2016, pp. 781-784; U.S. Environmental Protection Agency 2016, pp. 9-9-9-83, Texas Parks and Wildlife Department 2018, p. 12). Intense oil and natural gas activity occurs within and adjacent to Diamond Y Spring Preserve. Over 200 active oil and natural gas wells, 175 plugged wells, and 27 injection wells occur within a 4 km (2.5 mi) radius of the preserve (Railroad Commission of Texas 2019c).

From 1990 to 2018, a total of 4,918 and 3,850 conventional and unconventional oil and natural gas wells were drilled in Pecos and Reeves counties, respectively (IHS Markit 2019). A natural gas refinery is 0.8 km (0.5 mi) south of Diamond Y Spring. A new crude oil refinery (i.e., MMEX Resources Corporation) is being constructed 32 km (20 mi) to the east of Diamond Y Preserve and will have a capacity of producing 100,000 barrels per day once completed (Fountain 2019; McEwen 2019). Operations of the refinery will include road transport of crude oil to the facility for processing and transport of refined fuel product by rail (Fountain 2019; McEwen 2019). Several natural gas pipelines also traverse Diamond Y Springs Preserve (Pipeline and Hazardous Materials Safety Administration 2019).

A pipeline rupture and natural gas processing release occurred in or near the preserve in the 1990s (Industrial Economics, Inc. 2005, pp. 4-12). As drilling activity increased from 2009-2015 in Texas, there have been accompanying increases in the number of reported crude oil spills, with an annual recovery rate of released materials of just under 60% (Clancy et al. 2018, pp. 1466-1467, 1470). County-level data were compiled from the Railroad Commission of Texas's (2019a) Crude Oil, Gas Well Liquids, or Associated Products (H-8) Loss Reports. Numbers of reported spills in Reeves County increased substantially from 2013 to 2018, while reported spills in Pecos County remained relatively low (Figure 19). Crude oil accounted for 86% and 79% of the spills in Pecos and Reeves counties, respectively. From 2013-2018, 184 m^3 (240 $yard^3$ [yd^3]) of petroleum materials are reported as being unrecovered from spill events. Over that same time-period, 1,863 m3 (2,436 yd^3) of petroleum materials are reported as unrecovered from Reeves County spills. Recovery rates for spilled oil and natural gas in Pecos and Reeves counties were 67% and 62%, respectively.

Figure 19. Number of reported oil and natural gas spills in Pecos and Reeves counties, Texas: 2013-2018 (Railroad Commission of Texas 2019a).



While the Railroad Commission of Texas tracks spills of oil and natural gas, produced water and wastewater generated by those activities appears to receive less scrutiny (U.S. General Accounting Office 1989, p. 34-35, 37; Clark and Veil 2009, p. 13; Lustgarten 2012; Soraghan 2015; Beal 2017). Produced water is any type of water that flows from the subsurface through oil and gas wells to the surface as a by-product of extraction activity (U.S. Environmental Protection Agency 2016, p. 7-4). Wastewater is produced water from hydraulically fractured oil and natural gas wells (U.S. Environmental Protection Agency 2016, p. 8-3). Produced water and wastewater can contain high amounts of salt, petroleum residues, heavy metals, hydraulic fracturing additives, and radioactive substances (Clemens and Jones 1955, pp. 99-100; Benko and Drewes 2008, pp. 240-245; Neff et al. 2011, pp. 2-16; U.S. Environmental Protection Agency 2016, pp. 7-11-7-23, 8-11-8-13; Sun et al. 2019, pp. 456-460).

Produced water may be transported by pipelines to stored containers, or surface impoundments and later reused, recycled, or transported to disposal sites (U.S. Environmental Protection Agency 2016, pp. 7-25-7-26). Wastewater is managed most frequently through injection into subsurface formations via Class IID wells (i.e., disposal wells) [U.S. Environmental Protection Agency 2016, pp. 8-14, 8-23-8-26]. This water may also be treated and re-used, injected subsurface for enhanced oil recovery (Class IIR wells), exposed to surface evaporation, used for irrigation, or discharged to land surface or surface waters (U.S. General Accounting Office 1989, pp. 19-28; U.S. Environmental Protection Agency 2016, pp. 8-14, 8-35-8-36, 8-39-8-47; Sun et al. 2019, pp. 457-458). Injection of produced water and wastewater represents a potential risk of groundwater contamination and induced seismicity (Vidic et al. 2013, 1235009-6; Jackson et al. 2014, pp. 344-346; Vengosh et al. 2014, p. 8341; Rubinstein and Mahani 2015, pp. 4-6).

In 2012, Texas oil and natural gas operations accounted for 35% of the national volumes of produced water at 11,821,746,333 m^3 (958,406 af) [Veil 2015, pp. 37]. Veil (2015, p. 99-100) reported that over 90% of that produced water was injected into wells for enhanced oil recovery or into underground disposal wells (Clark and Veil 2009, p. 16) with the remainder discharged into surface waters. In 2016, the U.S. Environmental Protection Agency (2016, p. 8-16) noted that 48% of wastewater in Texas was used for enhanced oil recovery and 37% was injected into disposal wells. In 2010, 8% (i.e., 4,024) of Class II wells in Texas were identified as failing inspection tests for significant leaks (Lustgarten and Schmidt 2012). From 1950-2018, 1,157 and 423 injection/disposal wells have been drilled in Pecos and Reeves counties, respectively (Figures 20 and 21). In Pecos County, most wells were established during the 1980s with increasing frequency of saltwater disposal wells in the 2010s. Reeves County has seen a marked increase in the drilling of new saltwater disposal wells.

Figure 20. Number of new enhanced oil recovery, injection, and saltwater disposal wells established annually in Pecos County: 1950-2018 (IHS Markit 2019).

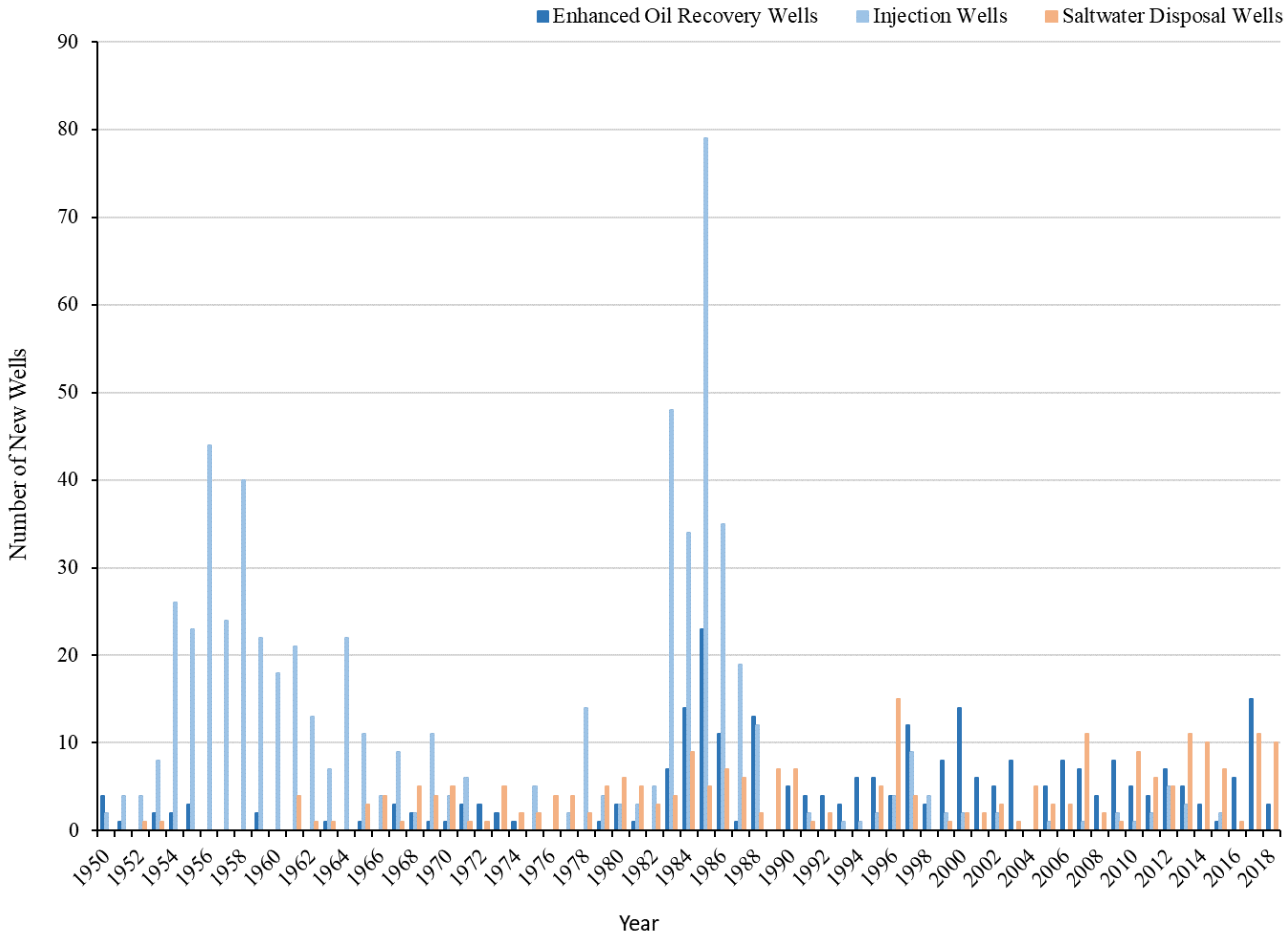
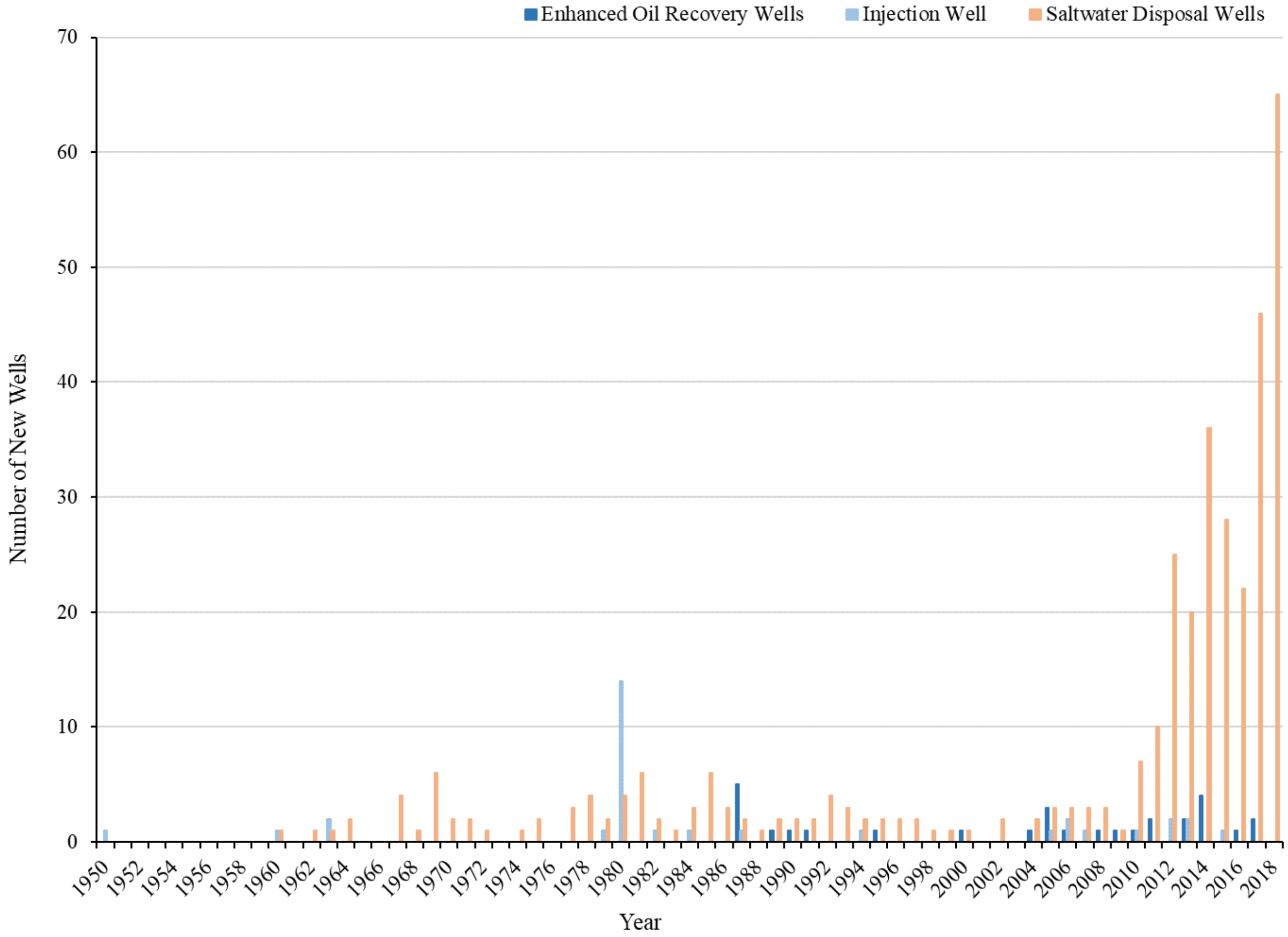


Figure 21. Number of new enhanced oil recovery, injection, and saltwater disposal wells established annually in Reeves County: 1950-2018 (IHS Markit 2019).



Produced water or wastewater may also be spilled or released into groundwater, surface water, or land surface through pipeline leaks, well blowouts, leaks from impoundments, unplugged wells, or illegal dumping (U.S. Environmental Protection Agency 2016, pp. 7-26-7-29, 7-31-7-33, 7-40-7-41). Between 2009 and 2014, Texas had 4,783 wastewater spills with total volume spilled of 234,361 m^3 (190 af) [Flesher 2015]. Flesher (2015) provides the following account of a northern Pecos County surface discharge of wastewater discovered by Middle Pecos Groundwater Conservation District staff in 2015:

> “In Fort Stockton, Texas, officials in February accused oil company Bugington Energy of illegally dumping 3 million gallons [11,348 m^3 (9.2 af)] of wastewater in pastures. Paul Weatherby, general manager of the Middle Pecos Groundwater Conservation District, said he fears contamination of the area's groundwater

> table. The district levied a $130,000 fine but the company hasn't paid, contending the district overstepped its authority."

That discharge is thought to have occurred over a two-year period with a flow rate of 11 liters (L) [3 gallons (gal)] per minute with a chloride content of 53,903 mg/l (54,000 ppm) [Middle Pecos Groundwater Conservation District 2015, p. 2]. It was estimated that the Buginton Energy wastewater discharge would reach the underlying water table at 9 m (30 ft) below land surface in 12 to 26 days (Middle Pecos Groundwater Conservation District 2015, p. 9).

Other instances of wastewater dumping onto roadways or ditches, improper handling at disposal facilities, and inadequate or failing storage infrastructure have been observed across the Permian Basin (Gregory and Hatler 2008, p. 86; Fehling 2013; Mulder 2015; Beal 2017). What impact spills or intentional dumping of wastewater is having across the Rustler and Edwards-Trinity (Platea) Aquifers in Pecos and Reeves counties is unknown.

Unplugged and improperly plugged inactive wells can also represent contamination risks (Gass et al. 1977, pp. 1, 4, 9, 13-16; Jackson et al. 2014, pp. 341U.S. Environmental Protection Agency 2016, pp. ES-32, 6-58-6-66, 6-74-6-75, 8-45-8-46, 10-18). Orphaned wells are those wells that are "not producing or injecting, has not received state approval to remain idle, and for which the operator is unknown or insolvent" (Interstate Oil and Gas Compact Commission 2008, p. 4). Unplugged or improperly plugged orphaned wells may degrade overtime and leak oil, natural gas, and/or brine into groundwater or release those contaminants onto the surface (Railroad Commission of Texas 2000, p. 2; Ho et al. 2016, pp. 5-8; American Geosciences Institute 2018, p. 1).

Railroad Commission of Texas Statewide Rule 14(b)(2) requires that "plugging operations on each dry or inactive well shall be commenced within a period of one year after drilling or operations cease and shall proceed with due diligence until completed unless the Commission or its delegate approves a plugging extension." As of January 2019, there are 214 orphaned oil wells and 41 orphaned natural gas wells in Pecos County (Railroad Commission of Texas 2019b). Average number of months inactive for all orphaned wells in Pecos County is 166 months or 14 years. In Reeves County, there are 55 orphaned oil wells and 27 orphaned natural gas wells and average number of months inactive is 194 months or 16 years (Railroad Commission of Texas 2019b).

Deteriorating, orphaned wells, along with improperly plugged abandoned wells, can also lead to localized subsidence, ground fissures, and impoundments of potentially contaminated subsurface water (Johnson 1989, pp. 85-87; Nichol and Kariyawasam 2000, pp. 7, 10-15; Gregory and Hatler 2008, pp. 86-87). Approximately 30 km (19 mi) northwest of Diamond Y Spring Preserve, brackish water flowing up through a long orphaned oil well, converted to irrigation purposes, inundated a 19-20 ha (47-49ac) area resulting in 2-3 cm (0.8-1.2 in) of surface subsidence over a 2.5-year period (Kim and Lu 2018, pp. 5-7). Formation of what has been dubbed “Boehmer Lake,” in combination with very rapid subsidence (~10 cm/yr [4 in/yr]), led to the closure of FM 1053 due to safety concerns (Malewitz 2017; Kim and Lu 2018, p. 6).

A number of other orphaned wells are known to be flowing and releasing brackish water and/or potential petroleum contaminants to the surface in Pecos County (Malewitz 2016). There are over 150 abandoned oil and natural gas wells within a 10 km (6.2 mi) radius of Diamond Y Preserve (IHS Markit 2019). That number does not include the number of orphaned oil and natural gas wells that may been converted to irrigation wells (Gregory and Hatler 2008, p. 88-89). Completion dates for known orphaned wells range from 1944 to 1998. Numbers of orphaned wells will likely increase into the future given the unprecedented numbers of hydraulically fractured, horizontal oil and natural gas wells drilled across Pecos and Reeves counties.

Electrical conductivity and temperature for both Diamond Y and Euphrasia Springs was monitored by the Middle Pecos Groundwater Conservation District (2018, pp. 20-21, 23-24) from 2017 to 2018. In 2018, the Bureau of Economic Geology installed monitoring stations at Diamond Y and Euphrasia Springs to collect data on water temperature and electrical conductivity (Figures 22 and 23).

Figure 22. Water temperature and electrical conductivity at Diamond Y Spring: August 2018-August 2020 (Bureau of Economic Geology 2019).

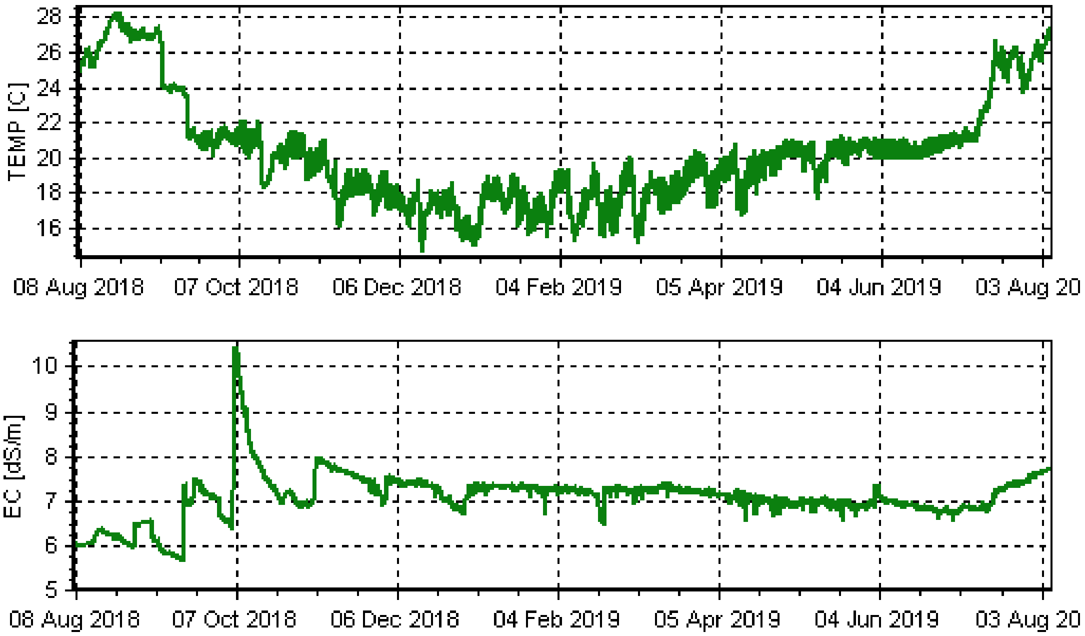
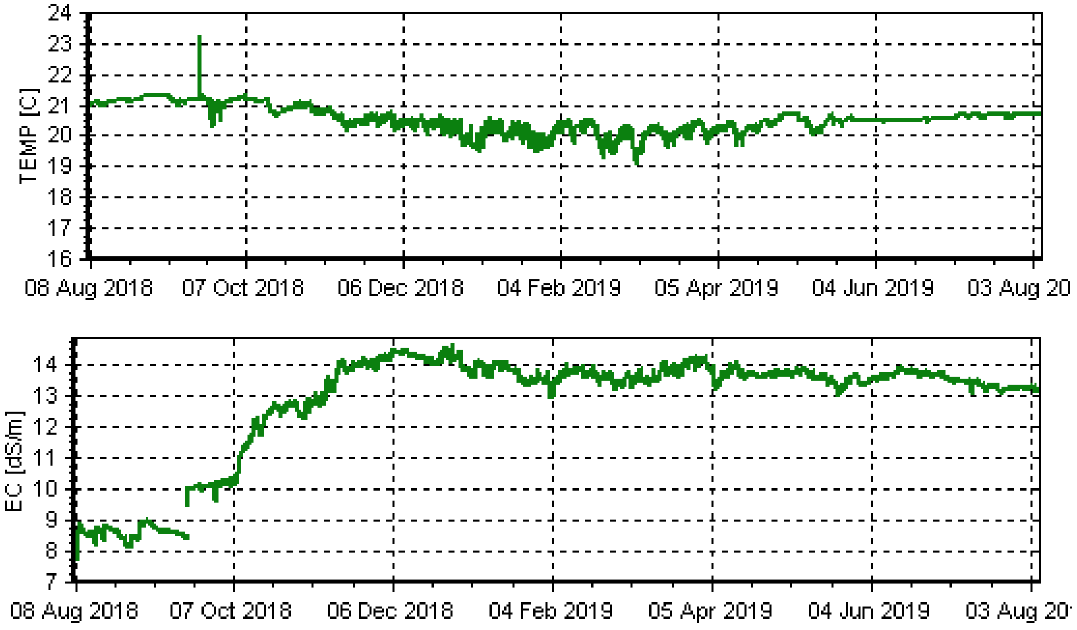


Figure 23. Water temperature and electrical conductivity at Euphrasia Spring: August 2018-August 2020 (Bureau of Economic Geology 2019).



Climate Change

Anthropogenic climate change has the potential to impact quantity and quality of groundwater the Pecos amphipod depends upon for survival (Green et al. 2011, pp. 538-546; Kløve et al. 2014, pp. 252-253; U.S. Global Climate Change Research Program 2017, p. 14). In the U.S., annual average air temperature increased by 1.0°C (1.8°F) between 1901 and 2016 with temperatures expected to rise by 1.4°C (2.5°F) between 2021 and 2050 (U.S. Global Change Research Program 2017, p. 17). Much greater temperature increases are projected for 2017-2100 (U.S. Global Change Research Program 2017, p. 17).

Annual average air temperatures in the southern Great Plains, including Texas, are projected to increase by 2.0-2.8°C (3.6-5.1°F) by the mid-21st century (Kloesel et al. 2018, p. 995). Periods of extreme heat are expected to be more frequent, with number of days exceeding 38°C (100°F) increasing by an additional 30-60 days per year by the end of the 21st century (National Oceanic and Atmospheric Administration 2016, pp. 1, 3; Kloesel et. al. 2018, pp. 990, 996).

Downscaled climate projections for Pecos County were obtained from the U.S. Climate Resilience Toolkit (U.S. Federal Government, 2018). For the period 2020-2099, projections indicate that average daily maximum temperature will increase in that county from 27.2°C (81°F) in 2020 to 32.0°C (90°F) by 2099 under high emissions (Representative Concentration Pathway [RCP] 8.5) [Figure 24]. Under low emissions (RCP 4.5), average daily temperature will increase from 27.5°C (81.5°F) in 2020 to 29.0°C (84.2°F) by 2099.

Number of days per year above 40.5°C (105°F) in Pecos County are projected to increase from 5.9 days in 2020 to 63.4 days in 2099 with high emissions and from 5.3 days in 2020 to 19.8 days under low emissions (Figure 25). Average annual precipitation and number of dry days per year are not projected to change as markedly as air temperature over the period of 2020 to 2099 in Pecos County under high or low emission scenarios (Figures 26 and 27).

Accompanying higher temperatures is the potential for more frequent drought and increasing aridity for Texas and the southwestern U.S. (Seager et al. 2007, pp. 1181, 1183; National Oceanic and Atmospheric Administration 2016, p. 3; Park et al. 2017, pp. 71-72; Wendt et al. 2018, p. 587; Marvel et al. 2019, p. 64). Severe droughts in Texas are now much more probable than they were 40 to 50 years ago (Rupp et al. 2012, pp. 1053–1054). In 2011, Texas experienced the worst annual drought since record-keeping began in 1895 (National Oceanic and Atmospheric Administration 2012, p. 4; Nielsen-Gammon 2012, pp. 61-94).

Climate change-driven aridity in western Texas may affect aquifer recharge and spur municipal and industry (i.e., agriculture and petroleum interests) demands for increased groundwater pumping volumes, potentially affecting springflows (Mace and Wade 2008, pp. 657-658; Taylor et al. 2012, p. 3). The Edwards-Trinity (Plateau) Aquifer is potentially susceptible to increased withdrawals if municipalities increase pumping of that aquifer to meet their needs (Mace and Ward 2008, p. 659). Increases in air temperature, and other climate-change driven variables, could impact surface water quality of spring pools and runs by decreasing dissolved oxygen levels and increasing metal toxicity (Murdoch et al. 2000, pp. 349-353).

Springflows and aquatic habitat at the Diamond Y Spring system have declined substantially since the mid-1900s (Figure 3; Kennedy 1977, p. 93; Veni 1991, pp. 18-20; Boghici 1997, p. 53). Increasing aridity, coupled with increased demands for groundwater pumping, has the potential to reduce both spingflow and extent of aquatic and associated ciénega habitat (Patten et al. 2008, pp. 403-405, 409-410; Cole and Cole 2015, pp. 32-33). The Pecos amphipod, like other desert-spring invertebrates, is vulnerable to extinction through climate change-driven deterioration of the groundwater-dependent ecosystem they require for survival (Davis et al. 2013, pp. 1980-1981; Cole and Cole 2015, pp. 28-29, 33; Springer et al. 2015, p. 14525; Stanislawczyk 2018, p. 951).

Figure 24. Average annual daily maximum temperature projected under low (RCP 4.5) and high (RCP 8.5) emission scenarios for Pecos County: 2020-2099. Blue line (average) and blue shaded region (maximum and minimum): low emissions. Red line (average) and shaded region (maximum and minimum): high emissions. Graph courtesy of the U.S. Climate Resilience Toolkit Climate Explorer (U.S. Federal Government, 2018).

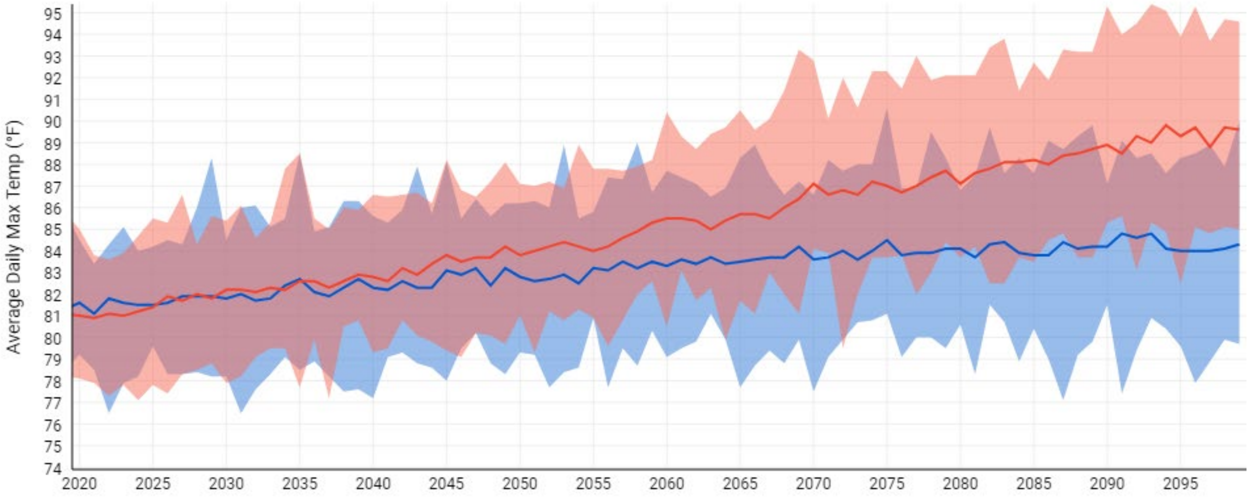


Figure 25. Number of days per year above 105°F (40.5°C) projected under low (RCP 4.5) and high (RCP 8.5) emission scenarios for Pecos County: 2020-2099. Blue line (average) and blue shaded region (maximum and minimum): low emissions. Red line (average) and shaded region (maximum and minimum): high emissions. Graph courtesy of the U.S. Climate Resilience Toolkit Climate Explorer (U.S. Federal Government, 2018).

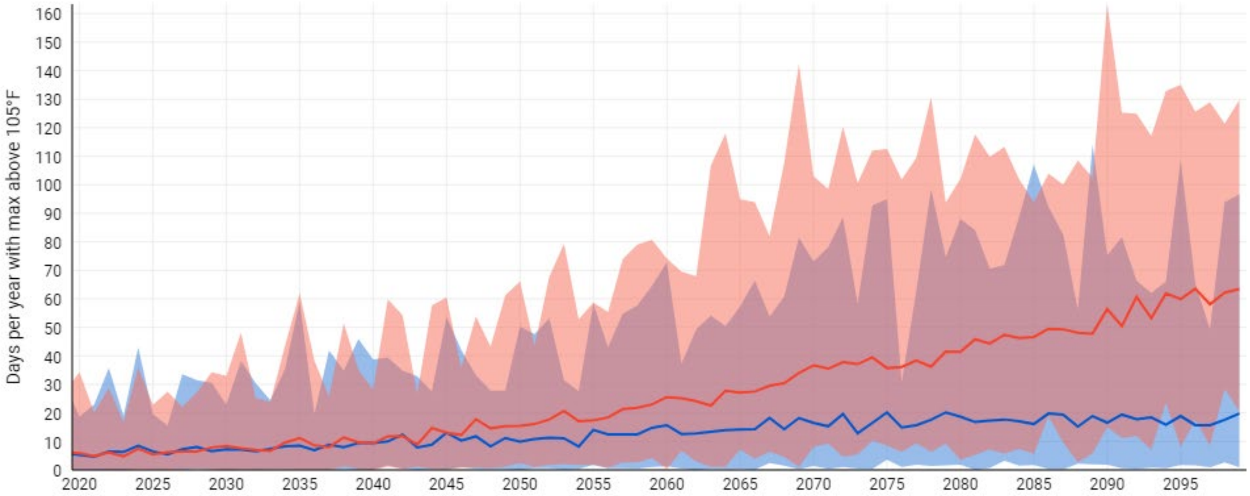


Figure 26. Annual precipitation projected under low (RCP 4.5) and high (RCP 8.5) emission scenarios for Pecos County: 2020-2099. Blue line (average) and blue shaded region (maximum and minimum): low emissions. Red line (average) and shaded region (maximum and minimum): high emissions. Graph courtesy of the U.S. Climate Resilience Toolkit Climate Explorer (U.S. Federal Government, 2018).

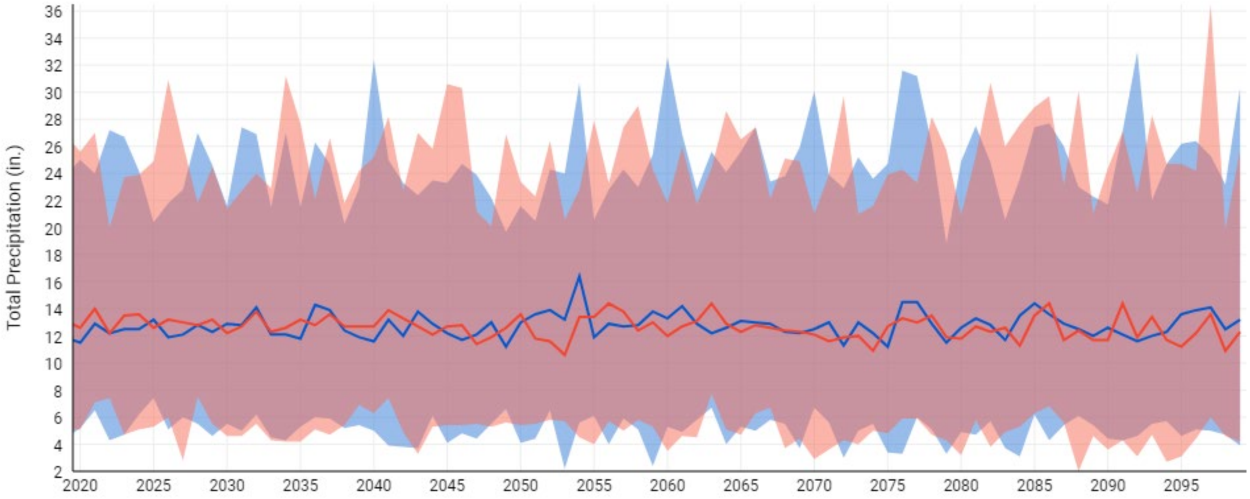
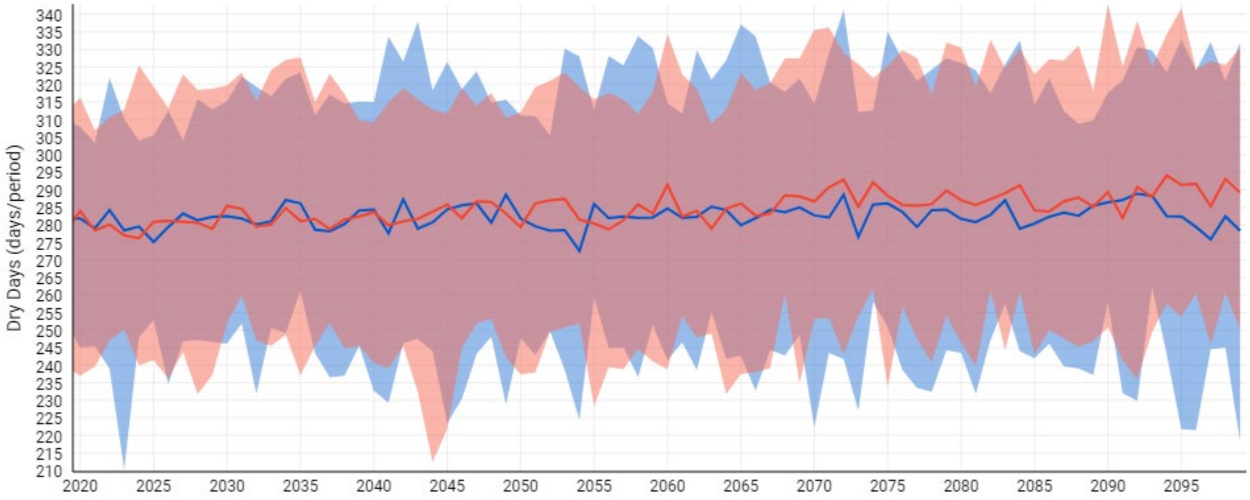


Figure 27. Annual number of dry days projected under low (RCP 4.5) and high (RCP 8.5) emission scenarios for Pecos County: 2020-2099. Blue line (average) and blue shaded region (maximum and minimum): low emissions. Red line (average) and shaded region (maximum and minimum): high emissions. Graph courtesy of the U.S. Climate Resilience Toolkit Climate Explorer (U.S. Federal Government, 2018).



2.3.1.7 Other:

No new information.

2.3.2 Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

2.3.2.1 Present or threatened destruction, modification or curtailment of its habitat or range:

Water Quantity

Degradation and loss of aquatic habitat is a major threat to the persistence of the Pecos amphipod, and other desert spring-dependent species, due to decline of groundwater levels in the aquifers that support springflow (Mehlhop and Vaughn 1994, p. 70; Lybeard et al. 2004, p. 326; Hershler et al. 2011, pp. 8, 24, 26; Hershler et al. 2014a, p. 395; Hershler et al. 2014b, pp. 51, 53, 56, 58, 59, 63). Pumping of the regional aquifer system for agricultural production of crops has resulted in severe declines in flow or complete loss of flow for at least 14 springs in Pecos County including such major springs as Comanche (1.9 meters^3/second (m^3/s) [67.1 feet^3/second (ft^3/s)]) in 1899 to 0 m^3/s (0 ft^3/s) in 1972) and Leon Springs (0.65 m^3/s (23 ft^3/s) in 1920 to 0 m^3/s (0 ft^3/s) in 1962) [Audsley 1956, pp. 7,9, 14-15: Brune 1975, pp. 56-59; Brune 1981, pp. 38, 356-363; Veni 1991, pp. 8-13].

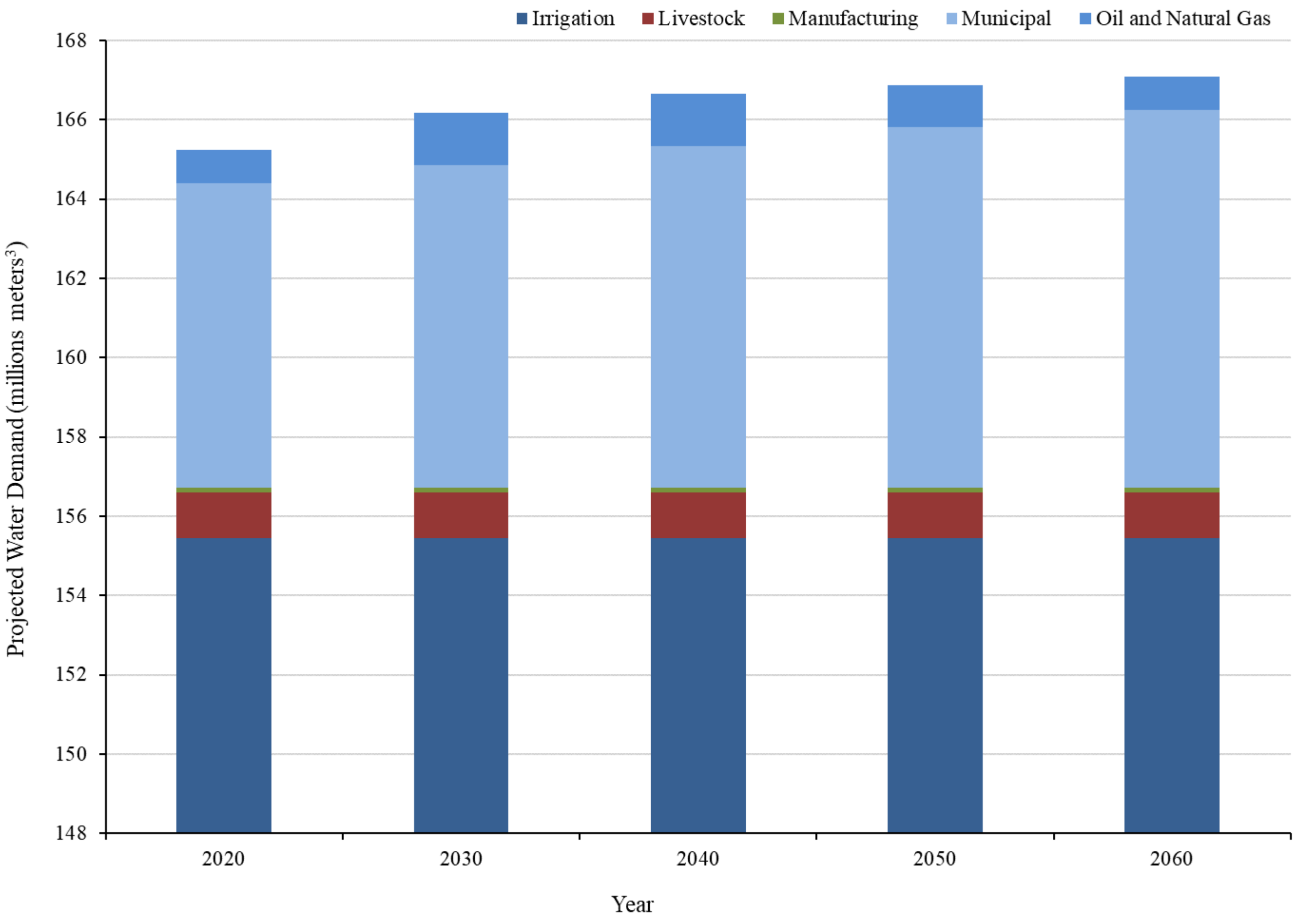
Across the Chihuahuan Desert of Texas and Mexico, groundwater pumping has led to the loss or diminishment of spring habitat resulting in the extinction of the following desert springsnails, *Juturnia brunei* from Reeves County, Texas and *T. santarosae* and *T. shikueii* from Chihuahua, Mexico (Hershler et al. 2014b, pp. 51, 53, 60-63. An undescribed amphipod species reported in the 1980s from Phantomn Lake Spring in Reeves County is thought to be extinct (Gervasio et al. 2004, p. 521). Groundwater pumping, combined with human disturbance of desert springs, has reduced amphipod and springsnail habitat and, in some cases, led to localized extirpations (Cole 1985, p. 27; Hershler et al. 2014b, pp. 56, 58, 59).

Since the early 2000s, the Rustler Aquifer in both Pecos and Reeves counties has experienced historically unprecedented groundwater pumping (Figures 8 and 9). Significant use of this aquifer in those counties, primarily for irrigation, is a relatively new phenomenon. The long-term impacts of such large withdrawals on spring flow at Diamond Y Spring system is unknown. While groundwater pumping of the Edwards-Trinity (Plateau) Aquifer has declined since the mid- to late 1970s, over 100,000,000 m^3 (81,071 af) has been pumped from the Pecos County portion of that aquifer annually since 2013.

Endeavors to extract, sale, and export brackish groundwater from regional aquifers are likely to increase into the future in concert with projected increases in hydraulic fracturing for oil and natural gas in the Permian Basin.

The 2017 Texas State Water Plan (Texas Water Development Board 2017a) provides projected water demands for Pecos and Reeves counties by use-sector from 2020 to 2060 (Figures 28 and 29). Projections do not incorporate the potential for increasing aridity, driven by anthropogenic climate change, and the likelihood of increased groundwater demands, however. In Pecos County, water demands are projected to increase from 2020 through 2060 with increased usage from municipal and petroleum extraction users. Conversely, water demand in Reeves County is projected to decline over that forty-year period. Increases from manufacturing, municipal, and petroleum extraction uses blunt declines in irrigation use in that county.

Figure 28. Projected water demand for Pecos County: 2020-2060 (Texas Water Development Board 2017a).

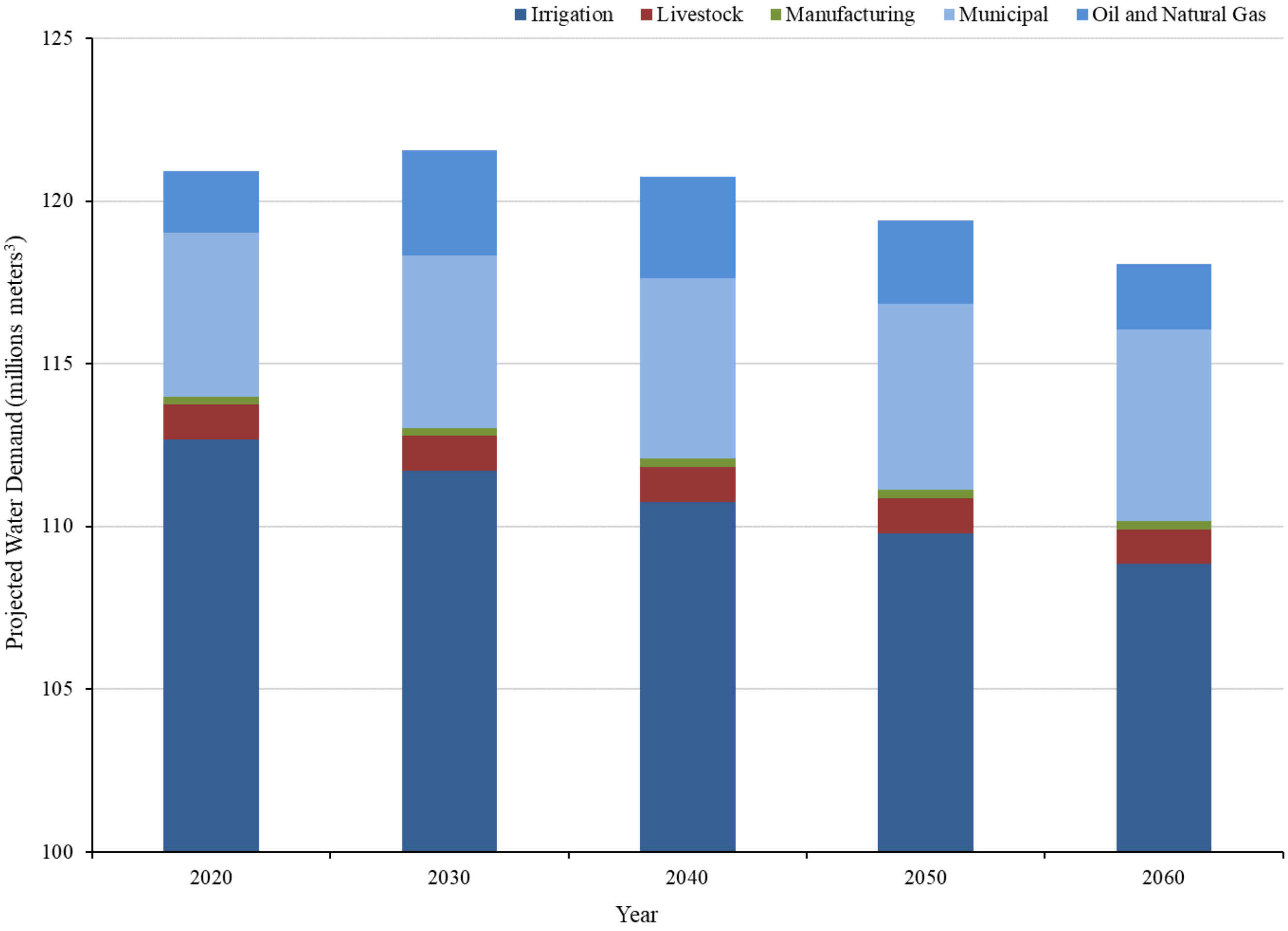


Irrigation is the primary use of groundwater extracted from the Rustler and Edwards-Trinity (Plateau) Aquifers in Pecos and Reeves Counties. Surface water is very limited with both counties relying primarily on groundwater for irrigation (Freese and Nichols, Inc. and LBG-Guyton Associates 2016, pp. 1-25, 3-34, 3-38, 5E-67, 5E-71). In 2017, a combined 106,026,240 m^3 (85,957 af) is estimated to have been pumped from those aquifers in Pecos County for irrigation. Other aquifers in that county were also pumped for irrigation in 2017 with 63,371,268 m^3 (51,376 af) withdrawn from the Capitan Reef Complex and Pecos Valley

Aquifers (Texas Water Development Board 2019b) for a total of 169,397,508 m^3 (137,333 af). The 2017 Texas State Water Plan (Texas Water Development Board 2017a) projects that Pecos County will have an annual average irrigation demand from 2020-2060 of 155,446,850 m^3 (126,023 af), 13,950,658 m^3 (11,310 af) less than 2017 estimated use.

Reeves County groundwater use from the Rustler and Edwards-Trinity (Plateau) Aquifers in 2017 for irrigation was 109,976,768 m^3 (89,160 af). The Igneous and Pecos Valley Aquifers were also utilized for irrigation that year with 78,564,042 m^3 (63,693 af) withdrawn for a total of 188,540,810 m^3 (155,853af). Reeves County projected annual average irrigation demand from 2020-2060 is 110,763,050 m^3 (89,797 af), 77,777,081m^3 (63,055 af) less than 2017 estimated use.

Figure 29. Projected water demand for Reeves County: 2020-2060 (Texas Water Development Board 2017a).



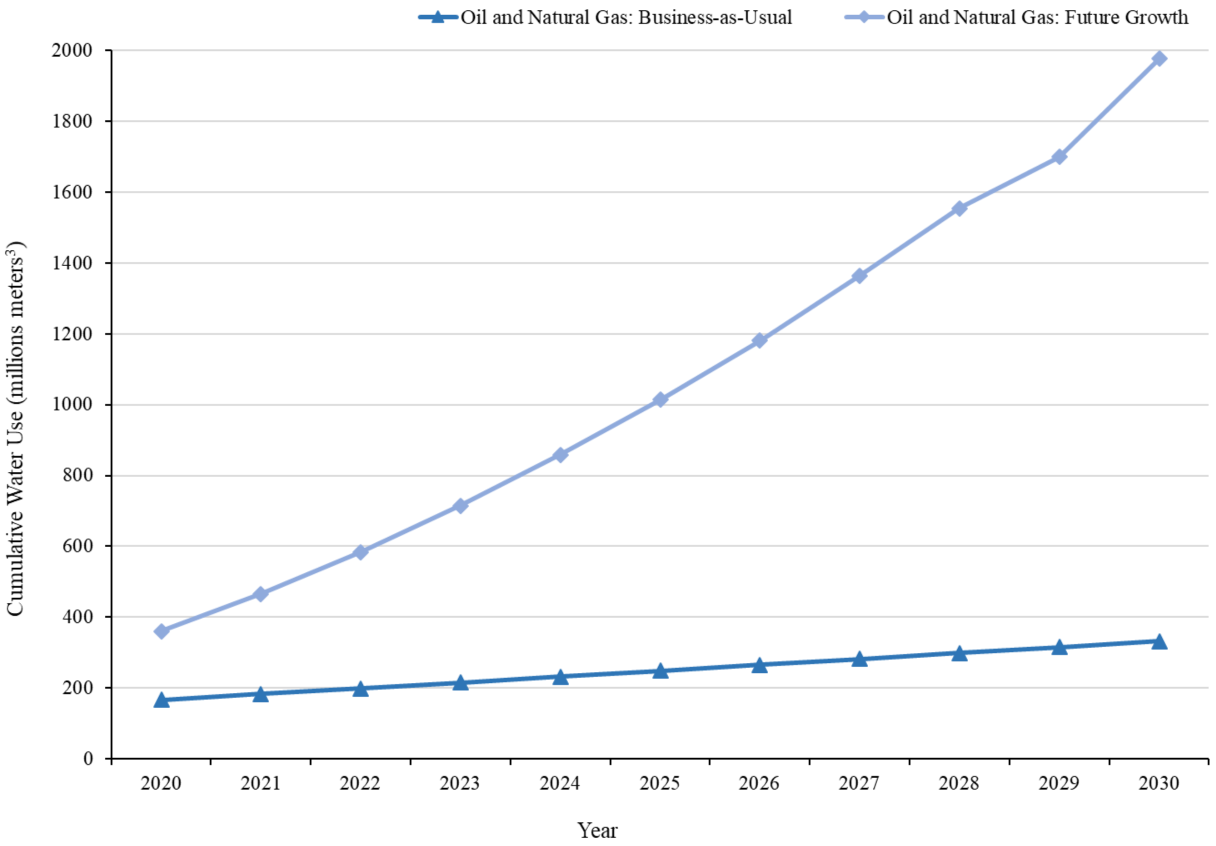
The 2017 Texas State Water Plan proposes several measures for water conservation and management strategies to either reduce water use or develop new groundwater and surface water sources through 2060 (Freese and Nichols, Inc. and LBG-Guyton Associates 2016, pp. 5A-1-5A-12, 5B-1-5B-20; Texas Water Development Board 2017b, pp. 87-103). The plan's measures are largely voluntary, require varying regulatory approvals, and may be cost-prohibitive (Freese and Nichols, Inc. and LBG-Guyton Associates 2016, p. 5B-11; Texas Water Development Board 2017b, p. 100). Whether groundwater conservation districts and use-sectors adopt water conservation measures and actual savings realized is highly uncertain (Closas and Molle 2018, pp. 520-528). Pecos and Reeves counties would need to see dramatic reductions in water for irrigation use from 2017 estimated levels, 13,950,658 m^3 (11,310 af) and 77,777,081m^3 (63,055 af) respectively, to meet projected annual demands starting in 2020.

Pecos and Reeves counties have seen dramatic increases in unconventional horizontal drilling combined with water-intensive hydraulic fracturing (Figures 14 and 15). To meet the needs of hydraulically fractured wells, both counties have seen striking increases in groundwater wells drilled solely to supply water for this drilling practice (Figures 17 and 18). Brackish groundwater makes up a significant portion of groundwater used in hydraulic fracturing in this region of the Permian Basin (Nicot et al. 2012, p. 54). From 2011 to 2016, water use for hydraulic fracturing in the Permian Basin increased from a median of 4,900 m^3 (3.97 af) per well to 42,500 m^3 (34.45 af) per well in 2016 (Kondash et al. 2018a, pp. 2-4). Kondash et al. (2018a, pp. 5-7; 2018b, pp. 5, 8-9) forecasted future cumulative hydraulic fracturing water use for the Permian Basin in two scenarios:

- Business-as-usual: Number of new wells drilled each year remained constant from 2018 to 2030 and was equal to the number of new wells drilled in 2016 (i.e., lower oil prices 2014-2015). Average price of West Texas Intermediate crude oil in 2015 was $48.69 per barrel (EIA 2019).
- Future Growth: A return to previously high drilling rates (i.e., high oil prices). From 2011-2013, West Texas Intermediate crude oil averaged $95.80 per barrel (EIA 2019).

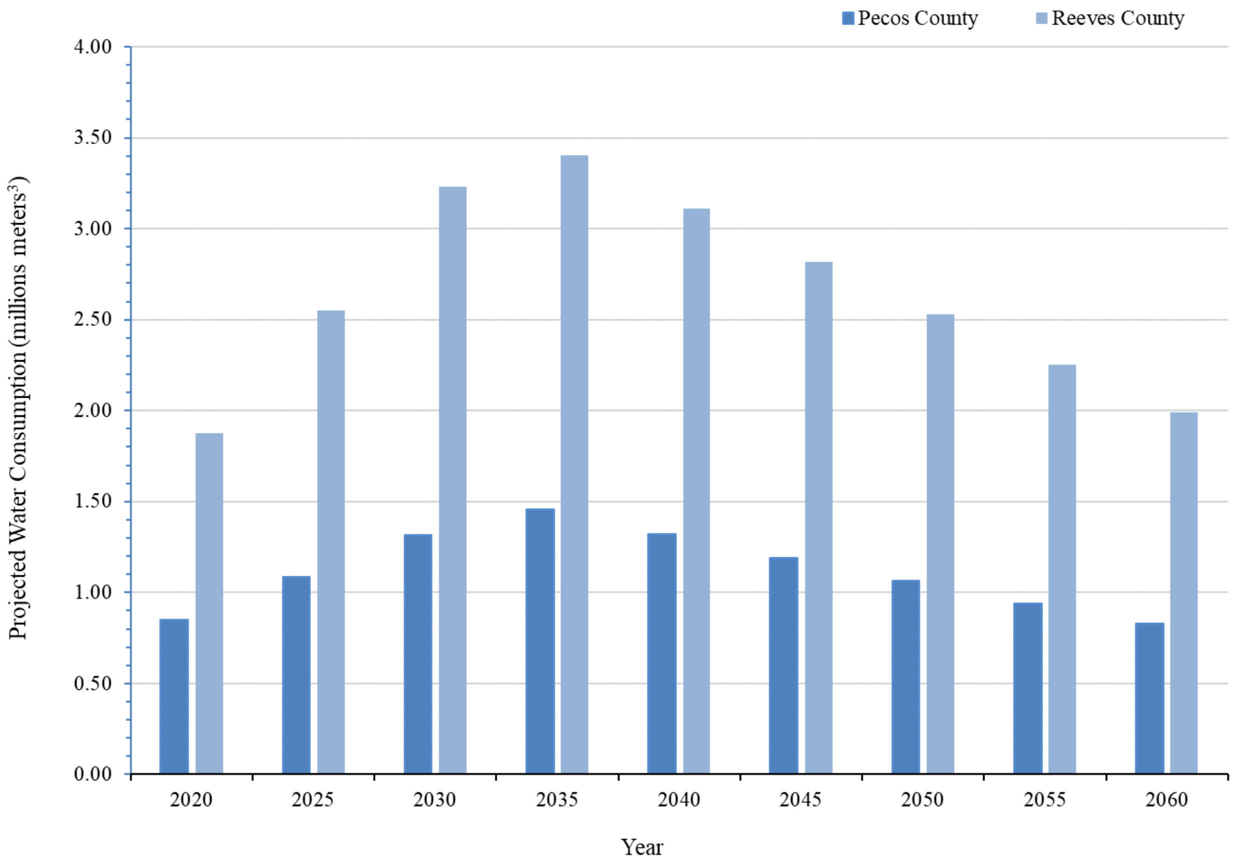
Under a business-as-usual scenario, cumulative water use in the Permian Basin increases moderately from 2020 to 2030 (Figure 30). However, a return to high oil prices of 2011-2013 would see a far more rapid increase in water use. The average price of West Texas Intermediate crude oil for January-July 2019 is $57.31 per barrel (EIA 2019). With higher oil prices, it is likely that hydraulic fracturing water use in the Permian Basin will increase over the next 10 years requiring commensurate groundwater withdrawals.

Figure 30. Cumulative water use projections for hydraulic fracturing in the Permian Basin: 2020-2030 (Kondash et al. 2018b, pp. 8-9).



Nicot et al. (2012, pp. 7, 65-68) developed more fine-grained projections for all oil and natural gas water use, including hydraulic fracturing, in Texas through 2060. For Pecos and Reeves counties, those researchers project an increase in oil and natural gas water use through 2035 with declining use through 2060 (Figure 31). The decline after 2035 is partially attributable to an anticipated increased use of reused or recycled drilling water by operators (Nicot et al. 2012, p. 65). Projections by Kondash et al. (2018a, pp 5-7; 2018b pp. 5, 8-9) and Nicot et al. (2012, pp. 65-68, 74) suggest that groundwater withdrawals in Pecos and Reeves counties are likely to increase in the coming decades and only return to lower 2020 levels sometime beyond 2060.

Figure 31. Projected oil and natural gas water use in Pecos and Reeves counties: 2020-2060 (Nicot et al. 2012, p. 79).



The new crude oil refinery slated for completion in Pecos County will require a source of water to refine fuel products (Jacobs Consultancy 2016, pp. 6-7; Sun et al. 2018, pp. 543-544). Groundwater from local aquifers is the most likely source given the near-complete absence of surface water in that county. Refinery processes require significant amounts of water (IPIECA 2010, pp. 2-3, 18-19). Wu et al. (2009, p. 992) estimated that U.S. refineries may consume an average of 1.53 L (0.4 gal) of water to process 1 L (0.3 gal) of crude oil. More recent estimates from Sun et al. (2018, pp. 549-551) range from an average of 0.34 L (0.09 gal) to 0.47 L (0.12 gal) per 1 L (0.3 gal) of fuel and diesel products. A crude oil refinery capable of producing 100,000 barrels (1,589,873 L [420,000 gal]) of refined product per day may require 540,526 L (142,792 gal) to 747,240 L (197,400 gal), or 540 m^3 (0.4 af) to 747 m^3 (0.6 af) daily.

The Energy Information Administration (2019a, pp. 16) projects that production of U.S. crude oil and natural gas plant liquids will continue to increase through 2025. Production of large volumes of natural gas are also expected from oil formations, particularly the Bone Spring and Wolfcamp formations of the Delaware Basin, through 2030-2040 (Energy Information Administration 2019a, pp. 18, 58). IHS Markit (2019) projects Permian Basin oil production to increase by 3 million barrels per day, more than doubling current production, by 2023.

Past and current use of the Rustler and Edwards-Trinity (Plateau) Aquifers in Pecos and Reeves counties has been substantial. Heavy groundwater pumping lead to the loss of several perennial flowing springs across the region. Flow at Diamond Y Spring system has declined since the 1970s and there have been recent observations of short interruptions or steep declines in Diamond Y Spring flow. Projections of future water demand suggest that the aquifers that support spring flow at Diamond Y Spring system are likely to be under increasing withdrawal pressures for several decades to come. The level of drawdown supporting aquifers can sustain, and still support adequate perennial flow, at Diamond Y Spring system is unknown. The system has already experienced flow declines and extent of aquatic habitat has receded. Decline in water quantity is an imminent threat to the persistence of the Pecos amphipod.

Water Quality

Water quality of the aquifers that support flow at Diamond Y Spring system continue to face contamination threats from intense oil and natural gas activities occurring across Pecos and Reeves counties. Oil and natural gas extraction, processing, and transport are a significant threat to the Pecos amphipod given the potential for contamination of groundwater, surface water, or land surface (Veni 1991, p. 83; Fullington 1991, p. 6). The region that overlays the Rustler and Edwards-Trinity (Plateau) Aquifers that support Diamond Y Spring system spring flow have seen historically unprecedented unconventional oil and natural gas well drilling since the early 2000s (Figures 14 and 15). Over that same period, numbers of reported oil and natural gas spills have also increased significantly in Reeves counties; a county that has seen especially sharp spikes in horizontal well drilling activity since 2017 (Figures 15 and 19). If projections of increasing oil and natural gas activity in Pecos and Reeves counties are accurate (Nicot et al. 2012, pp. 65-68, 74; Kondash et al. 2018a, pp 5-7; 2018b pp. 5, 8-9; Energy Information Administration 2019a, pp. 16, 18, 58), spill events may also increase over time and threaten Diamond Y Spring system water quality.

Handling of wastewater generated by oil and natural gas drilling activities is also a water quality concern. Large numbers of Class II injection wells have been established in Pecos and Reeves counties since the 1950s for disposal of wastewater or enhanced oil recovery (Figure 20). In 2010, 8% of Class II wells in Texas exhibited significant leaks (Lustgarten and Schmidt 2012). From 2009-2014, there have been 4,783 wastewater spills or unauthorized releases in Texas, with documented occurrences of illegal wastewater dumping in Pecos County (Flesher 2015). Pecos and Reeves counties contain 256 and 82 orphaned oil and natural gas wells, respectively (Railroad Commission of Texas 2019b).

Recently, a long unplugged well in Pecos County released large volumes of brackish water to the surface leading to localized surface subsidence (Kim and

Liu 2018, pp. 5-7). Orphaned wells releasing potential petroleum contaminants, along brackish water, to the surface have been observed in Pecos County (Malewitz 2016). Like oil and natural gas spills, increased drilling activity into the near future will potentially increase spills, unauthorized discharges, and numbers of orphaned wells that can threaten groundwater and surface water quality (Collins 1971, pp. 2386-2392; Brittingham et al. 2014, pp. 110356, 11038-11039; Farag and Harper 2014, pp. 158-160; Pichtel 2016, pp. 6-10).

The crude oil refinery nearing completion in Pecos County will generate wastewater during the course of processing refined petroleum products. Coelho et al. (2006, pp. 181-182) suggest that the volume of wastewater generated by a refinery is 0.4-1.6 times the amount of crude oil processed. A refinery capable of producing 100,000 barrels (1,589,873 L [420,000 gal]) of refined petroleum products per day may generate wastewater volumes of 636 m^3 (0.5 af) to 2,544 m^3 (2.1 af) per day. Generated volumes of wastewater will need to be handled and disposed of which will carry some potential for release or spill contamination events (Wake 2005, pp. 132-139).

Some conservation measures were implemented at Diamond Y Spring Preserve in the past to reduce the potential for a contamination event. In the 1970s, the U.S. Department of Agriculture and Natural Resources Conservation Service constructed a small berm encompassing the south side of Diamond Y Spring to prevent a surface spill from the Gomez Gas Plant from reaching the springhead. After The Nature Conservancy acquired Diamond Y Springs Preserve in 1990, oil and natural gas companies took steps to minimize the potential for contamination of the aquatic habitats. These measures included decommissioning buried corrodible metal pipelines and replacing them with synthetic surface lines, installing emergency shut-off valves, building berms around oil pad sites, and removing abandoned oil pad sites and their access roads that had been impeding surface water flow (Karges 2003, p. 144).

We currently have no evidence of habitat destruction or modification due to groundwater, surface water, or land surface contamination from petroleum leaks or spills. However, the potential for future adverse effects from a catastrophic event is an ongoing threat of high severity.

Modification of Spring Channels

Spring outflow channels in the Diamond Y Spring system have remained mostly intact. Past cattle-grazing, road construction, and well pad installation resulted in some changes to the spring system. After The Nature Conservancy assumed ownership in 1990, cattle-grazing was discontinued and some infrastructure removed. Several caliche (i.e., hard calcium carbonate material) roads still traverse spring outflows with small culverts used to pass the restricted flows.

Some concern exists regarding encroachment of bulrush (*Schoenoplectus* *americanus*) into the spring channels. Bulrush is an emergent plant that grows in dense stands along the margins of spring channels. When flow levels decline, reducing water depths and velocities, bulrush can become very dense and dominate the wetted channel. In 1998, bulrush made up 39% of the plant species in the wetted marsh areas of the Diamond Y Draw (Van Auken et al. 2007, p. 54). Observations by Itzkowitz (2008, p. 5; 2010, pp. 13–14) found that bulrush was increasing in density at several locations within the upper and lower watercourses in Diamond Y Draw resulting in the loss of open water habitats. Itzkowitz (2010, pp. 13–14) also noted a positive response by bulrush following a controlled fire for grassland management.

Dense bulrush stands may alter habitat in several ways. Bulrush grows to a height of about 0.7 m (2 ft) tall in very dense stands. Dense bulrush thickets will result in increased shading of the water surface, which is likely to reduce the algae and other food sources for the invertebrates. In addition, the stems will slow the water velocity, and the root masses will collect sediments and alter the substrates in the stream. These small changes in habitat conditions may result in proportionally large areas of the spring outflow channels being unsuitable for use by aquatic invertebrates.

Another impact to spring channels comes from disturbance by feral hogs *(Sus scrofa)*. The area around Diamond Y Spring has not previously been reported as within their distribution (Mapston 2005, p. 5), but they have been confirmed there (Allan 2011, p. 2). Feral hogs prefer wet and marshy areas and damage spring channels by creating wallows, muddy depressions they use to keep cool and coat themselves with mud (Mapston 2005, p. 15). Alterations in the spring channels caused by the wallows make the affected area uninhabitable for the Diamond tyronia. The effects of feral hog wallows are limited to small areas but act as another stressor on the very limited habitat of these three Diamond Y Spring species.

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes:

We know of no commercial or recreational uses of the Pecos amphipod. For that reason, we conclude that overutilization for commercial, recreational, scientific, or educational purposes are not a threat to this species, and we have no indication that these factors will affect the species in the future. The only collections of the Pecos amphipod may occur for scientific purposes and are regulated by the Service pursuant to section 10(a)(1)(A) of the Act and by Texas Parks and Wildlife Department (TPWD, Title 31, Part 2, Chapter 69, subchapter J).

2.3.2.3 Disease or predation:

Disease or predation are not known to affect the Pecos amphipod. This species is likely natural prey for fishes that occur in occupied habitats. Non-native predatory fishes do not occur within their spring habitats, but there are crayfish, which are predators of snails (Hershler 1998, p. 14; Dillon 2000, pp. 293–294). Ladd and Rogowski (2012, p. 289) suggested that the non-native red-rim melania (*Melanoides tuberculata*) may prey upon different species of native snail eggs. However, evidence of such predation is limited, and the extent to which predation might affect native amphipods is unknown.

2.3.2.4 Inadequacy of existing regulatory mechanisms:

Texas Parks and Wildlife Department

On March 23, 2015, Texas Parks and Wildlife Department designated the Pecos amphipod as a State endangered species (40 Texas Register 1711). Parks and Wildlife Code (Chapter 68 Sec. 68.004) directs that any "fish or wildlife" species listed as federally endangered be listed as State endangered. In Texas, no person may "take, possess, propagate, transport, export, sell or offer for sale, or ship any species of fish or wildlife listed by the department as endangered (31 Texas Administrative Code §65.171)." These State regulations provide no protections for the species' habitat (e.g., maintaining spring flow). The Nature Conservancy continues to hold ownership of the Diamond Y Spring Preserve, which provides protection to spring outflow channels and the surrounding surface habitat. However, conservation ownership is unable to provide the groundwater protections needed to ensure adequate spring flow quantity and quality.

Groundwater Conservation Districts

Groundwater conservation districts are the State of Texas' preferred instrument for groundwater management (Lehman 2004, pp. 103-104, 107-109; Freese and Nichols, Inc. and LBG-Guyton Associates 2016, pp. 3-2-3-3). A groundwater conservation district is a voluntarily established legal entity, authorized by the Texas Legislature, to protect and manage groundwater resources within their jurisdiction (Welles 2015, pp. 491-494; Closas and Molle 2018, p. 513). Districts can regulate groundwater withdrawals to an extent through permitting of groundwater wells, reporting of groundwater production, and limits on withdrawals (Fipps 1998, pp. 4-7; Closas and Molle 2018, p. 513-515). As of July 2019, Texas contained 97 confirmed groundwater conservation districts (TWDB 2019 map). Most districts do not coincide with aquifer boundaries but instead follow county political boundaries (Lehman 2004, pp. 121-122; Closas and Molle 2018, pp. 513, 516). Areas of Texas without groundwater conservation districts are vulnerable to unrestricted groundwater pumping which may affect local communities, species, and their habitats (Puig-Williams 2014, pp. 11-12; Puig-Williams 2016, Clearwater Underground Water Conservation District 2018, pp. 89-92; pp. 3-4; Closas and Molle 2018, pp. 517-518; Keester 2018, pp. 3-4; Hargrove 2019).

In 2001, the Texas Legislature created groundwater management areas, which are planning areas based around aquifer or hydrogeological boundaries rather than political boundaries (Fipps 1998, pp. 2-3). A primary objective of groundwater management areas is to coordinate planning among groundwater conservation districts on an aquifer-wide basis (Mace et al. 2008, p. 2; Foster 2009, pp. 392). In groundwater management areas, groundwater conservation districts with jurisdiction over included aquifers develop desired future conditions for those aquifers (Mace et al. 2008, pp. 3-4; Closas and Molle 2018, p. 517).

Texas Administrative Code (Title 31, Part 10, Chapter 36) defines desired future conditions as “the desired, quantified condition of groundwater resources (such as water levels, spring flows, or volumes) within a management area at one or more specified future times as defined by participating groundwater conservation districts within a groundwater management area as part of the joint planning process.” Under Texas Water Code Chapter 36, groundwater conservation district can consider a set of nine factors when developing desired future conditions, including aquifer uses, water supply needs, hydrological conditions (e.g., average annual recharge), environmental impacts (e.g., springflow), and impacts on private property rights. As a result, developed conditions can be a complicated amalgam of economic, scientific, and political considerations.

Developed desired future conditions are quantifiable conditions (e.g., level of aquifer drawdown, storage volume, or springflow volume) for how groundwater conservation districts will manage an aquifer to some target date in the future (i.e., 50 years) [Mace et al. 2008, p. 3; Closas and Molle 2018, p. 516]. Water users can legally challenge (i.e., petition and appeal) desired future conditions viewed as too stringent and potentially lead to the establishment of more permissive groundwater pumping (Closas and Molle 2018, p. 518-519, 522-523).

Groundwater management areas submit developed aquifer-specific desired future conditions to the Texas Water Development Board, which conducts analyses (e.g., groundwater availability modelling) to assess the amount of groundwater available for production in the aquifer, termed modeled available groundwater (Nelsoney 2015, pp. 206-207; Puig-Williams 2016, pp. 88-89). Modelled available groundwater is the amount of annual amount of groundwater that can be withdrawn from an aquifer to meet desired future conditions (Mace 2016, pp. 19-20). Groundwater conservation districts are to incorporate modeled available groundwater in their management plans and used as a factor in permitting groundwater withdrawals (Mace et al. 2008, pp. 4-5; Foster 2009, pp. 381-382; Closas and Molle 2018, pp. 514-515).

Two groundwater conservation districts manage groundwater in Pecos and Reeves counties, the Middle Pecos and Reeves County Groundwater Conservation Districts, respectively. The Middle Pecos Groundwater Conservation District is included within Groundwater Management Areas 3 and 7, while the Reeves County Groundwater Conservation District is within Groundwater Management Area 3. Desired future conditions for the Rustler and Edwards-Trinity (Plateau) Aquifers in Groundwater Management Areas 3 and 7 call for drawing down those aquifers by varying amounts into 2070 (Tables 1 and 2).

The modeled available groundwater for the Rustler Aquifer in Pecos County totals 8,687,399 m^3 (7,042 af) [Tables 3 and 4]. Estimated groundwater pumpage in 2017 was 4,890,748 m^3 (3,965 af). Modeled available groundwater for that aquifer in Reeves County is 2,944,317 m^3 (2,387 af). Estimated groundwater pumpage in 2017 was 5,242,290 m^3 (4,250 af) which exceeds the modeled available groundwater by 2,297,973 m^3 (1,863 af). Modeled available groundwater for the Edwards-Trinity (Plateau) Aquifer in Pecos County totals 296,291,764 m^3 (240,208 af). In 2017, estimated groundwater pumpage was 109,132,143 m^3 (88,475 af). Modeled available groundwater for that aquifer in Reeves County totals 110,697,429 m^3 (89,744 af). Estimated groundwater pumpage in 2017 was 11,100,222 m^3 (8,999 af).

Table 1. Desired future conditions for the Rustler and Edwards-Trinity (Plateau) Aquifers in Groundwater Management Area 3 (Texas Water Development Board 2016).

Aquifer	County	Desired Future Condition
Edwards-Trinity (Plateau)	Pecos	Total net drawdown not to exceed 14 feet in 2070, as compared with aquifer levels in 2010
Edwards-Trinity (Plateau	Reeves	Total net drawdown not to exceed 8 feet in 2070, as compared with aquifer levels in 2010
Rustler	Pecos	Total net drawdown not to exceed 69 feet in 2070, as compared with aquifer levels in 2009
Rustler	Reeves	Total net drawdown not to exceed 40 feet in 2070, as compared with aquifer levels in 2009

Table 2. Desired future conditions for the Rustler and Edwards-Trinity (Plateau) Aquifers in Groundwater Management Area 7 (Texas Water Development Board 2016).

Aquifer	County	Desired Future Condition
Edwards-Trinity (Plateau)	Pecos	Average drawdown not to exceed 14 feet of drawdown from 2010 to 2070
Edwards-Trinity (Plateau	Reeves	Average drawdown not to exceed 14 feet of drawdown from 2010 to 2070
Rustler	Pecos	Total new drawdown of the Rustler Aquifer in Pecos County (Middle Pecos GCD) in 2070 not to exceed 94 feet as compared with 2009 aquifer levels.

Table 3. Annual modeled available groundwater for the Rustler and Edwards-Trinity (Plateau) Aquifers in Groundwater Management Area 3: 2020-2070 (Texas Water Development Board 2016).

Aquifer	**County**	**Modeled Available Groundwater: 2020-2070 Meters^3 (Acre-feet) per Year**
Edwards-Trinity (Plateau)	Pecos	151,593,459 (122,899)
Edwards-Trinity (Plateau	Reeves	110,697,429 (89,744)
Rustler	Pecos	3,700 (3)
Rustler	Reeves	2,944,317 (2,387)

Table 4. Annual modeled Available Groundwater for the Rustler and Edwards-Trinity (Plateau) Aquifers in Groundwater Management Area 7: 2020-2070 (Texas Water Development Board 2016).

Aquifer	**County**	**Modeled Available Groundwater: 2020-2070 Meters^3 (Acre-feet) per Year**
Edwards-Trinity (Plateau)	Pecos	144,698,305 (117,309)
Rustler	Pecos	8,683,699 (7,040)

The Middle Pecos Groundwater Conservation District was established in 1999 with its first management plan adopted in 2004 (Middle Pecos Groundwater Conservation District 2015, p. 5). The Reeves County Groundwater Conservation District was formed in 2013 and its first management plan was adopted in 2018 (Reeves County Groundwater Conservation District 2018, p. 2). Desired future conditions for both groundwater conservation districts allow for managed drawdowns of the Rustler and Edwards-Trinity (Plateau) Aquifers that exceed recharge.

Annual recharge of the Rustler Aquifer in Pecos and Reeves counties has been estimated at 3,593,127 m^3 (2,913 af) [Hutchison et al. 2016, p. 11; 2017a, p. 9]. Total annual modeled available groundwater for the Rustler Aquifer in those counties is 11,631,716 m^3 (9,430 af). Estimated annual recharge for the Western Edwards Plateau component of the Edwards-Trinity (Plateau) Aquifer is 215,488,956 m^3 (174,700 af) [Muller and Price (1979, p. 72]. Total modeled available groundwater for the portions of that aquifer in Pecos and Reeves counties is 406,989,193 m^3 (329,952 af).

Texas Water Code Chapter 36 states that groundwater conservation districts, before voting on proposed desired future conditions, shall consider "other environmental impacts, including impacts on spring flow." Consideration of springflow is not mandatory, however. Desired future conditions for the Middle Pecos and Reeves County Groundwater Conservation Districts do not include mechanisms to regulate groundwater pumping in order to maintain springflow of any local springs, including the Diamond Y Spring system. Only three of Texas's 97 groundwater conservation districts (i.e., Barton Springs/Edwards Aquifer, Clearwater, and Kinney County Groundwater Conservation Districts) incorporate springflow as a component of desired future conditions.

The aquifers that support flow at Diamond Y Spring system are projected to be drawdown over the next 50 years. Whether low recharge aquifers, like the Rustler and Western Edwards portion of the Edwards-Trinity (Plateau) Aquifers, can provide the necessary flow for dependent spring systems is uncertain. Modelled available groundwater volumes may not sufficiently account for increasing oil and natural gas activity, to include increased water demands for hydraulic fracturing and water needs of a planned crude oil refinery in Pecos County. Desired future conditions and modeled available groundwater volumes also do not incorporate the potential for increased groundwater demands due to climate-change driven aridity across western Texas.

Texas is the only U.S. state that applies the principle of absolute ownership to groundwater (Foster 2009, pp. 382-383; Burchi 2018, p. 120). A decentralized approach to groundwater management is preferred in Texas through the voluntary creation of groundwater conservation districts. Foster (2009, pp. 387-391) evaluated the effectiveness of these districts in preventing groundwater depletion. Based on a subset of statistically sufficient districts, that researcher noted a set of groundwater conservation districts that increased groundwater depletion and another set that lowered depletion (Foster 2009, pp. 391-392, 394-396).

As groundwater conservation districts typically operate at the county-level, different management approaches (i.e., less to more restrictive) may influence groundwater management across an aquifer (Brock and Sanger 2003, pp. 11-13; Kaiser 2006, pp. 477, 481-482; Closas and Molle 2018, pp. 519-520). Groundwater conservation districts can also vary in their financial status, with the management goals of less well-funded districts hampered by insufficient budgets (Brock and Sanger 2003, pp. 8-10; Closas and Molle 2018, pp. 514, 516). While there are groundwater conservation districts that manage aquifers within their jurisdiction sustainably, Texas' decentralized approach to groundwater management may not provide sufficient protection for an entire aquifer. Consequently, regulatory mechanisms directing future groundwater withdrawals from the aquifers that support flow at Diamond Y Spring system are inadequate to protect the Pecos amphipod against future habitat loss or degradation.

Texas Regulations for Oil and Gas Activities

The Railroad Commission of Texas regulates many activities of the oil and natural gas industry to minimize the opportunity for the release of contaminants into groundwater or surface water in Texas (Texas Administrative Code, Title 16. Economic Regulation, Part 1). While these regulations may potentially reduce the risk of contaminant releases, they cannot remove the threat of a catastrophic event that could lead to the extinction of the Pecos amphipod. Given the inherent risks associated with oil and natural gas activities in proximity to the habitat of the Pecos amphipod, Railroad Commission of Texas regulations cannot remove or alleviate threats associated with water contamination from a petroleum, produced water, and/or wastewater leak, spill, or release.

2.3.2.5 Other natural or manmade factors affecting its continued existence:

Nonnative Fish Management

Chemical eradication of nonnative fishes at the Diamond Y Spring system is a potential threat to the Pecos amphipod. In the mid-1970s, another species endemic to the spring system, the Leon Springs pupfish, was threatened by hybridization with introduced, nonnative sheepshead minnows (*Cyprinodon variegatus*) [Kiner 2002, pp. 35-37]. Over the past 40 years, two documented efforts (i.e., 1970s and 1990s) occurred to eradicate the nonnative minnow, using fish toxicants to remove all fish species, and restock Diamond Y Spring system with pure Leon Springs pupfish.

In 1976, Texas Parks and Wildlife Department, in collaboration with researchers from Oklahoma State University and the University of Texas at Austin, treated the site with the fish toxicant, rotenone (Hubbs et al. 1978, pp. 489-490). No monitoring efforts were made for the invertebrate community pre- or post-treatment (Hubbs et al. 1978, pp. 489–490). In 1998, researchers from Oklahoma State University, through a traditional Section 6 grant awarded by Texas Parks and Wildlife Department, attempted a second eradication using the fish toxicant Antimycin A (Echelle et al. 2001, pp. 9–10; Kiner 2002, pp. 41-43).

During the 1990s effort, researchers took steps to preserve spring-associated invertebrates (i.e., holding them in tanks) and implemented a pre- and post-monitoring effort (Echelle et al. 2001, p. 14). Monitoring results suggested that the Antimycin A had an immediate and dramatic negative effect on Pecos amphipods; however, that species' abundance returned to pretreatment levels seven months post-treatment (Echelle et al. 2002, p. 23; Kiner 2002, pp. 47-48, 51, 54). Gonzales tryonia exhibited a decline in abundance that persisted during the single year of monitoring following the treatment at both treated and untreated sites (Echelle et al. 2002, pp. 23, 51; Kiner 2002, pp. 48-49, 55).

No information is available on the impacts of the 1976 rotenone treatment, but application of that chemical likely had some short-term impacts on spring-associated invertebrates (Mangum and Madrigal 1999, pp. 130-133; Melaas et al. 2001, pp. 183-185; Vinson et al. 2010, pp. 62-67). Both Antimycin A and rotenone kill fish and other gill-breathing animals by inhibiting their use of oxygen at the cellular level (Vinson et al. 2010, p. 62). The long-term effects of these chemicals are uncertain, but the available information indicates that the Gonzales tryonia may have responded negatively over at least one year. This action was limited to the upper watercourse populations, and the effects were likely short-term in nature.

The use of fish toxicants represents a past stressor that is no longer directly affecting the species but may have some lasting consequences to the distribution and abundance of Pecos amphipod. If sheepshead minnow were to invade the Diamond Y Spring system again, no entity should conduct chemical eradication efforts for fish given their impact on the listed spring-associated invertebrates. We consider this threat relatively insignificant as it was not severe in its impact and it is not likely to occur again in the future.

Nonnative Snails

The non-native red-rim melania became established in Diamond Y Spring in the mid-1990s (Echelle et al. 2002, p. 15; McDermott 2000, p. 15). As of the early 2010s, this invasive snail was the most abundant aquatic snail in the Diamond Y Spring system (Ladd 2010, p. 18). Effects of the red-rim melania on Pecos amphipod have not been studied directly. Because the snail occurs in relatively high densities, the potential for inter-specific competition for food and habitat resources exists. Rader et al. (2003, pp. 651–655) reviewed the biology and possible impacts of red-rim melania and suggested that the species had displaced some native spring-snails in spring systems of the Bonneville Basin of Utah.

The potential impacts of the red-rim melania on the Pecos amphipod are largely unknown, but the species is presumed to have some negative consequences to co-occurring native aquatic snails through competition for space and resources. Considering the best available information, we conclude that the presence of this nonnative snail represents a moderate threat to the Pecos amphipod.

Other Nonnative Species

A potential future threat to these species comes from the possible introduction of additional nonnative animal species into their habitat. In general, introduced species are a serious threat to native aquatic animal species (Lodge et al. 2000, p. 7). Limited public access to the Diamond Y Spring Preserve, through The Nature Conservancy stewardship, aids in minimizing inadvertent or intentional introductions. However, limited public access did not prevent the introduction of the nonnative sheepshead minnow to the spring system (Echelle et al. 2002, p. 4). Biologists conducting studies in multiple spring sites could introduce nonnative or even non-resident native aquatic invertebrates to the system (Echelle et al. 2002, p. 26). Researchers should take steps to thoroughly inspect and clean equipment and clothing when conducting work across multiple spring sites. While the introduction of any future nonnative species could represent a threat to the aquatic invertebrates, the likelihood of this happening is relatively low because it is only a future possibility.

Small, Reduced Range

An important contributor to the high risk of extinction of the Pecos amphipod is its very limited distribution that has likely experienced reduction though past destruction of previously occupied spring habitat (i.e., Comanche Springs). Within Diamond Y Spring system, the species' distribution has experienced further reductions as flows from small springs and seeps have declined and reduced the amount of wetted areas in the spring outflow. As a minute crustacean, the species has very limited mobility and is entirely dependent upon a very rare desert spring habitat making it unlikely that it will expand beyond its current known range. The geographically restricted range of the Pecos amphipod increases the risk of extinction from any effects associated with other threats or stochastic events. When species are limited to small, isolated habitats, they are more likely to become extinct due to a local event that negatively affects populations (Shepard 1993, pp. 354–357; McKinney 1997, p. 497). While a small, reduced range does not represent an independent threat to these species, it does substantially increase the risk of extinction from the effects of other threats, including those addressed in this analysis, and those that could occur in the future.

2.4 Synthesis

The Pecos amphipod is a freshwater crustacean that is restricted to a small, isolated desert spring and ciénega system in the Chihuahuan Desert of western Texas. Several large springs in the region have experienced severe declines in flow or complete loss of perennial flow due to heavy groundwater pumping for irrigation. Flow at Diamond Y Spring system has declined significantly since the 1970s. This phenomenon, coupled with human alteration and disturbance of spring habitats (i.e., springhead, run, and ciénega), has led to the extirpation or extinction of desert amphipods and springsnails across the Chihuahuan Desert.

The aquifers that support flow of the Diamond Y Spring system are under increasing pressure from groundwater pumping in Pecos and Reeves counties. The Rustler Aquifer has experienced historically unprecedented groundwater withdrawals over the last 19 years. Withdrawals from the Edwards-Plateau (Trinity) Plateau Aquifer have also increased over the last 10 years, reaching pumped volumes comparable to the 1980s. The majority of pumped groundwater from both aquifers is for irrigation.

The 2017 Texas State Water Plan projects future annual water demands for Pecos and Reeves counties from 2020 through 2060. Groundwater will likely be the primary source for future needs as both counties have little surface water resources. Annual projections for irrigation, the largest water-user, are well below estimated groundwater volumes pumped from local aquifers in 2017. In the absence of stringent or pro-active water conservation measures, it is uncertain whether the lower projected volumes can be realized. A complicator for Texas water plan projections is the lack of consideration of climate change driven impacts on future water demands. Anthropogenic climate change is projected to lead to warmer and more arid conditions across western Texas, conditions that could precipitate increased demands for groundwater from use-sectors.

Diamond Y Spring system is situated in the Delaware Basin, one the most active regions for oil and natural gas extraction activities nationally. Hydraulically fractured wells have increased to never-before-seen numbers across the region spurring increased groundwater withdrawals from local aquifers to meet drilling needs. Increased oil and natural gas drilling, production, transportation, and processing will potentially increase the risk of petroleum and/or wastewater contaminant discharges, spills, and releases.

The Pecos amphipod requires adequate volumes of suitable quality groundwater to persist within the Diamond Y Spring system. Springflow there has already decline markedly over the last 40 years. Threats to groundwater quantity and quality continue to be imminent and likely to continue into the future. Irrigation use of supporting aquifers is already substantial and may increase, along with other human needs (i.e., municipal water source), into the future with climate-change driven aridity. Oil and natural gas activity is likewise significant and projected to increase into the near-future furthering demands for groundwater withdrawals. These threats, along with others (e.g., invasive species, small range), continue to endanger the continued persistence of the Pecos amphipod. At this time, we do not recommend a change in listing status for the Pecos amphipod.

3.0 RESULTS

3.1 Recommended Classification:

____ Downlist to Threatened
____ Uplist to Endangered
____ **Delist** (Indicate reasons for delisting per 50 CFR 424.11):
    ____ *Extinction*
    ____ *Recovery*
    ____ *Original data for classification in error*
__X_ **No change is needed**

3.2 New Recovery Priority Number: 5C

Brief Rationale: The Pecos amphipod faces a high degree of threat related to adequate water quantity and quality. Intensive management is needed to alleviate those threats. Given the species limited range of occurrence and imminence of threats, recovery potential is low. Threats to the Pecos amphipod are primarily related to groundwater pumping to support a range of economic activity (e.g., irrigation and petroleum extraction) that may conflict with persistence of the species.

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

I. Develop a species status assessment and recovery plan that contains measurable objectives and criteria for the Pecos amphipod.

II. Define the specific aquifer source(s) of springflow in the Diamond Y Spring system.

III. Define current distribution of the Pecos amphipod within the Diamond Y Spring system and develop a systematic monitoring effort for the species.

IV. Use defined distribution of the Pecos amphipod to examine ramifications of declining or interrupted springflow.

V. Assess compatibility of listed fish species management at Diamond Y Spring system with persistence of Pecos amphipod.

VI. Investigate the feasibility of establishing a refugia population of the Pecos amphipod.

VII. Develop an emergency contingency plan for the Pecos amphipod in the event of a catastrophic event or precipitous decline in springflow at Diamond Y Spring system.

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U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW of the Pecos amphipod (*Gammarus pecos*)

Current Classification:

Recommendation resulting from the 5-Year Review:

____ Downlist to Threatened
____ Uplist to Endangered
____ Delist
__X_ No change needed

Appropriate Listing/Reclassification Priority Number, if applicable: Not applicable

Review Conducted By: Michael Warriner, Austin Ecological Services Field Office, Austin, Texas

FIELD OFFICE APPROVAL:

Lead Field Supervisor, Fish and Wildlife Service

Approve ______________________________ Date 9/23/19