Comanche Springs Pupfish
(Cyprinodon elegans)

5-Year Review:
Summary and Evaluation

U.S. Fish and Wildlife Service
Austin Ecological Services Field Office
Austin, TX
August 2013

5-YEAR REVIEW

Species reviewed: Comanche Springs pupfish (*Cyprinodon elegans*)

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5-YEAR REVIEW
Comanche Springs Pupfish (*Cyprinodon elegans*)

1.0 GENERAL INFORMATION

1.1 Reviewers

Lead Regional or Headquarters Office: Southwest Regional Office, Region 2
Susan Jacobsen, Chief, Threatened and Endangered Species, (505) 248-6641
Wendy Brown, Recovery Coordinator, (504) 248-6664
Jennifer Smith-Castro, Recovery Biologist, (505) 248-6663

Lead Field Office: Austin Ecological Services Field Office, Region 2
Adam Zerrenner, Field Supervisor, (512) 490-0057 x 248.
Alisa Shull, Chief, Recovery & Conservation Branch, (512) 490-0057 x236
Joshua Booker, Biologist, Recovery & Candidate Conservation Branch, (512) 490-0057 x238

Cooperating Field Offices: Texas Fish & Wildlife Conservation Office, Region 2
Mike Montagne, Project Leader, (512) 353-0011 x 236

Southwestern Native Aquatic Resources and Recovery Center, Region 2
Manuel E. Ulibarri, Center Director, (575) 734-5910

Uvalde National Fish Hatchery, Region 2
Grant Webber, Project Leader, (830) 278-2419 x 101

1.2 Purpose of 5-Year Reviews:

The U.S. Fish and Wildlife Service (Service or USFWS) is required by section 4(c)(2) of the Endangered Species Act (Act) to conduct a status review of each listed species once every 5 years. The purpose of a 5-year review is to evaluate whether or not the species' status has changed since it was listed (or since the most recent 5-year review). Based on the 5-year review, we recommend whether the species should be removed from the list of endangered and threatened species, be changed in status from endangered to threatened, or be changed in status from threatened to endangered. Our original listing as endangered or threatened is based on the species' status considering the five threat factors described in section 4(a)(1) of the Act. These same five factors are considered in any subsequent reclassification or delisting decisions. In the 5-year review, we consider the best available scientific and commercial data on the species, and focus on new information available since the species was listed or last reviewed. To make any recommended change in listing status, we must propose to do so through a separate rule-making process including public review and comment. The review also provides updated information on the current threats to the Comanche Springs pupfish, ongoing conservation efforts, and the priority needs for future conservation actions.

1.3 Methodology Used To Complete the Review

Public notice for this review was published in the Federal Register on February 11, 2009 (74 FR 6917 6919). This review was conducted by Austin Ecological Services Field Office and Texas Fish & Wildlife Conservation Office staff using information from the 1981 Comanche Springs Pupfish Recovery Plan (USFWS 1981), peer-reviewed articles, agency reports, and other documents available in the Austin ES Field Office files.

1.4 Background

1.4.1 FR Notice citation announcing initiation of this review:

February 11, 2009 (74 FR 6917 6919), 5-year Reviews of 23 Southwestern Species.

1.4.2 Listing history

<u>Original Listing</u>
FR notice: 32 FR 4001
Date listed: March 11, 1967
Entity listed: Species, *Cyprinodon elegans*
Classification: Endangered

1.4.3 Associated rulemakings: None.

1.4.4 Review History:

The Comanche Springs pupfish was originally listed as an endangered species on March 11, 1967, following establishment of the Endangered Species Preservation Act on October 15, 1966 and is currently listed as endangered under the Endangered Species Act of 1973, as amended. No previous 5-year review has been conducted for this species. Other review documents include: a recovery plan (USFWS 1981), biological opinions for habitat restoration projects at Phantom Lake

Spring (USFWS 1992, 2000) and San Solomon Spring (USFWS 2009a), a biological opinion for irrigation canal maintenance (USFWS 2004), and a habitat conservation plan for a habitat restoration project at San Solomon Spring (TPWD 2008).

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

The Recovery Priority Number at the start of this 5-year review was 2, meaning a high degree of threat, the recovery potential is high, and the listed entity is a species.

1.4.6 Recovery Plan or Outline

Name of plan or outline: Recovery Plan for the Comanche Springs Pupfish
Date issued: September 2, 1981
Dates of previous revisions, if applicable: N/A

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? Yes.

2.1.2 Is the species under review listed as a DPS? No.

2.1.3 Is there relevant new information for this species regarding the application of the DPS policy? No.

2.2 Recovery Criteria

2.2.1 Does the species have a final, approved recovery plan? Yes.

2.2.1.1 Does the recovery plan contain objective, measurable criteria? No. The 1981 Recovery Plan for the Comanche Springs Pupfish does not list formal recovery criteria. It instead lists three objectives and a more detailed four-point "step-down outline" (USFWS, 1981, pp. 9-10). The objectives are as follows:

(1) To assure perpetuation of the species in its natural habitat.
(2) To assure genetic diversity of Comanche Springs pupfish by improving the quality of presently occupied habitats, by increasing the quantity of suitable habitat, and by establishing a sound, continuing program of management and public information.
(3) To downlist the species from endangered to threatened status.
The restricted area of natural occurrence of the species and declining flow from the springs probably preclude eventual delisting of the species.

2.3 Updated Information and Current Species Status

2.3.1 Biology and Habitat

2.3.1.1 New information on the species' biology and life history

Comanche Springs pupfish spawning occurs in stenothermal (narrow temperature range) spring outflows and in small, eurythermal (wide temperature range) pools of standing water (Itzkowitz 1969, p. 229). Large numbers of adults are capable of spawning year-round (Echelle 1991, p. 152) once female sexual maturity is reached at about five months (Cokendolpher 1978, p. 8). Males orient and maintain position upstream from their territories until a female enters the territory and positions herself near the algal mat substrate (Itzkowitz 1969, pp. 229-230). These territories are variable in size (averaging about 1.5 square feet or 0.14 square meters) and most often over algal mats in swift water (Itzkowitz 1969, p. 229) or large rocks in calm water (Leiser and Itzkowitz 2003, p. 119). Brannan et al. (2003, pp. 87-88) found that males identify territories using visual landmarks. Eggs are laid singly onto the algal mat substrates of the male's territory (Itzkowitz 1969, p. 230). In captivity, females can lay 30 eggs per day, which then hatch in five days at 68 ºF (20 ºC; Cokendolpher 1978, p. 8). Larger adult Comanche Springs pupfish tend to produce more eggs, similar to the Pecos River pupfish (*C. pecosensis*; Garrett and Price 1993, p. 9). The males guard eggs until hatching and they aggressively defend their territories against intruders (Itzkowitz 1969, p. 230).

Comanche Springs pupfish males exhibit three different mating techniques based on male size: territorial defense (largest males compete for direct access to mates), satellite positioning (average-sized males occupy the periphery of large male territories), and sneak spawning (smallest males retain the coloration of a female to mate without detection from large males; Leiser and Itzkowitz 2002, p. 68; Leiser and Itzkowitz 2003, pp. 120-121). Because male breeding success depends upon territories, habitat size is an important metric of Comanche Springs pupfish population growth (Robinson and Wilson 2012, p. 9). As habitat size increases, the number of territories increases, allowing more males to breed. Male territories are variable in size, ranging from an average of 0.14 m^2 (Itzkowitz 1969, p. 229) in stream-like conditions (that is, concrete canals) to an average of 0.225 m^2 in pool habitats (Leiser and Itzkowitz 2003, p. 120).

Comanche Springs pupfish are relatively short-lived fish with most individuals living about one year (USFWS 2009a, p. 5). This aspect, coupled with their reproductive biology, causes large fluctuations in population numbers (USFWS 1981, p. 11; Winemiller and Anderson 1997, p. 210).

Gut analysis of 20 specimens by Winemiller and Anderson (1997, p. 209) revealed Comanche Springs pupfish eat mostly filamentous algae and some snails (*Cochliopa texana*). Lab experiments suggest that Comanche Springs pupfish prefer water temperatures between 68-86 ºF (20-30 ºC), and their critical thermal maximum (temperature at which death is likely) is about 105 ºF (40.5 ºC; Gehlbach et al. 1978, pp. 100-101).

2.3.1.2 Abundance, population trends (for example, increasing, decreasing, stable), demographic features (for example, age structure, sex ratio, family size, birth rate, age at mortality, and mortality rate), or demographic trends:

Comanche Springs pupfish are currently found in three springs and one creek: Phantom Lake Spring (located in easternmost Jeff Davis County, Texas), San Solomon Spring, Giffin Spring, and Toyah Creek near Balmorhea, Reeves County, Texas (Garrett 2003, p. 152).

Based on sampling efforts made in 1972, Echelle estimated an adult population of about 1,000 or more in San Solomon Spring and several thousand in the nearby irrigation canals (Echelle 1975, p. 530). During a two-year sampling study in the early 1990s, population size in the park canal was estimated to be as low as 968 (May 1990) and as high as 6,480 (September 1990) (Garrett 2003, p. 153). The proportion of males in relation to females in the canal population averaged 0.41 during the study (Garrett and Price 1993, p. 7). Garrett and Price (1993, p. 7) collected about 1.36 adults for every juvenile over the course of the study, although this ratio fluctuated between 0.26 and 3.36. Many more adults were present in May of both years (Garrett and Price 1993, p. 7).

In 1996, a wetland named San Solomon Ciénega was created in Balmorhea State Park to replicate the original ciénega (which was destroyed by the park swimming pool) and provide high quality habitat for Comanche Springs pupfish (TPWD 2008, p. 4; Garrett 2003, p. 154). The number of pupfish in the San Solomon Spring outflow greatly increased as a result of the increased habitat availability. From 1999 to 2001, the population in San Solomon Ciénega in Balmorhea State Park averaged 270,000 in summer to about 18,000 in winter (Garrett 2003, p. 154). A second wetland area was created in 2009, and the Comanche Springs pupfish population here was estimated to be an average of 8,516 individuals between December 2009 and August 2012 (Hargrave 2012, p. 9). The pupfish population within the older San Solomon Ciénega averaged 561 individuals during the same time period (Hargrave 2012, p. 6).

Similarly, habitat restoration at Phantom Lake Spring in 1993 in the form of a 361 ft (110 m) long channel resulted in an increase in local abundance, with an estimated average density of 14.7 pupfish / m^2 (Winemiller and Anderson 1997, p. 210). However, more recent declines in springflow from Phantom Lake Spring resulted in the complete drying of the canal and downstream irrigation ditches by 1999 (USGS 2011a). There were less than 100 estimated Comanche Springs pupfish at Phantom Lake Spring in September 2010 (Lewis et al. unpublished data, p. 5). Abundance of Comanche Springs pupfish in Toyah Creek and Giffin

Spring has also been low, ranging from 128 to 0 individuals (Echelle 1975, p. 530, Garrett and Price 1993, pp. 3-4), but recent population estimates are lacking.

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

Genetically, the Comanche Springs pupfish is markedly divergent from all other species of *Cyprinodon* in the American Southwest (Echelle and Echelle 1998, p. 855). The species appears most closely related to a complex of three species (*C. eximius*, *C. pachycephalus*, and *C. macrolepis*) in the Rio Conchos basin of northern Mexico and tributaries of the middle Rio Grande in Texas (Echelle and Echelle 1998, p. 855).

A protein electrophoretic survey indicated that about 3% of total genetic diversity of Comanche Spring pupfish is variation among the four major populations (Phantom Lake, San Solomon, Giffin Spring, and Toyah Creek; Echelle et al. 1987, p. 678). A high amount of variation occurred between sites within populations, indicating some restriction of upstream gene flow due to sluice gates in the irrigation canals (Echelle et al. 1987, p. 679). A previous study also found differences in several morphological features from specimens taken 40 years ago from the now extirpated Comanche Springs population (Fort Stockton, Texas) (Echelle 1975, p. 532). Among existing populations, specimens from Phantom Lake Spring and Toyah Creek differ from each other in degree of belly scalation and number of dorsal and caudal fin rays (Echelle 1975, pp. 532-534). The Giffin and San Solomon springs populations are intermediate for these characters (Echelle 1975, p. 535).

It is difficult to determine the original extent of isolation of Phantom Lake Spring from the other area springs because of more than 100 years of alteration by irrigation practices (Echelle et al. 1987, p. 680). However, some degree of isolation is indicated by the observation that, for both morphologic and genetic data, a significant amount of the variation is a result of divergence of the Phantom Lake Spring group (Echelle et al. 1987, pp. 679-680). Gene flow is unidirectional from Phantom Lake Spring to San Solomon to Giffin Spring to Toyah Creek and/or Lake Balmorhea due to the structure of the irrigation canal system (Echelle et al. 1987, p. 669). In general, Comanche Springs pupfish in springhead areas have lower genetic diversity than pupfish in downstream areas (Echelle et al. 1987, p. 680).

2.3.1.4 Taxonomic classification or changes in nomenclature:

The Comanche Springs pupfish was discovered and formally described in 1853 (Baird and Girard 1853). It is in the family Cyprinodontidae. The taxonomy and nomenclature of the Comanche Springs pupfish has not changed or been questioned since its original description.

2.3.1.5 Spatial distribution, trends in spatial distribution (for example increasingly fragmented, increased numbers of corridors, etc.), or historic range (for example corrections to the historical range, change in distribution of the species' within its historic range, etc.):

Comanche Springs pupfish historically occurred in two isolated spring systems 56 mi (90 km) apart in the Pecos River drainage of western Texas: Comanche Springs and the Balmorhea area springs (Garrett 2003, p. 152; Figure 1). Comanche Springs, located within the present city limits of Fort Stockton, Pecos County, Texas, has been dry since the 1950s (Brune 1981, pp. 357-358). The existing populations are restricted to a series of springs, their outflows, and a system of irrigation canals historically interconnecting Phantom Lake Spring (located in easternmost Jeff Davis County, Texas), San Solomon Spring, Giffin Spring, and Toyah Creek near Balmorhea, Reeves County, Texas (Garrett 2003, p. 152; Figure 2).

Garrett and Price (1993) documented Comanche Springs pupfish in seven localities in the Balmorhea area: Phantom Lake Spring outflow canal, Phantom Lake Spring Canal downstream, Balmorhea State Park canal below San Solomon Spring, canal below Giffin Spring, two main canal sites between the State Park and Balmorhea, and Toyah Creek near the IH-10 bridge. Toyah Creek is an intermittent tributary (that is, flowing only after intense rainfall) of the Pecos River (USFWS 2004, p. 16), so pupfish habitat is only occasionally present. In 2001, a small number of Comanche Springs pupfish were also found immediately downstream of East Sandia Spring, where the spring outflow enters the irrigation canal (Echelle et al. 2002, p. 2). One Comanche Springs pupfish was collected previously from East Sandia Spring in October 1998 by Clark Hubbs (Hubbs 1998, p. 1). West Sandia Spring and Saragosa Spring, which are also within the Balmorhea spring complex, have virtually ceased flowing in recent times and the contemporary presence of Comanche Springs pupfish is considered unlikely (Brune 1981, p. 386, Karges 2003, p. 145, USFWS 2004, p. 16). These two gravity-fed springs probably supported the species prior to human alteration in the area (USFWS 1981, p. 2).

2.3.1.6 Habitat or ecosystem conditions (for example, amount, distribution, and suitability of the habitat or ecosystem):

The amount of quality habitat for Comanche Springs pupfish is determined primarily by spring flow. The relationships of the supporting aquifers for the springs are not fully defined. The base flows from the Balmorhea area springs are likely discharge points of a regional flow system from aquifers that are part of the West Texas Bolsons (the northern Salt Basin Aquifer, west of the Delaware Mountains, and Wildhorse Flat, west of the Apache Mountains) in Culberson County to the northwest (Sharp 2001, p. 42; Sharp et al. 2003, pp. 8-9; Texas Water Development Board 2005, p. 106; Uliana et al. 2007, p. 345) (Figure 3).

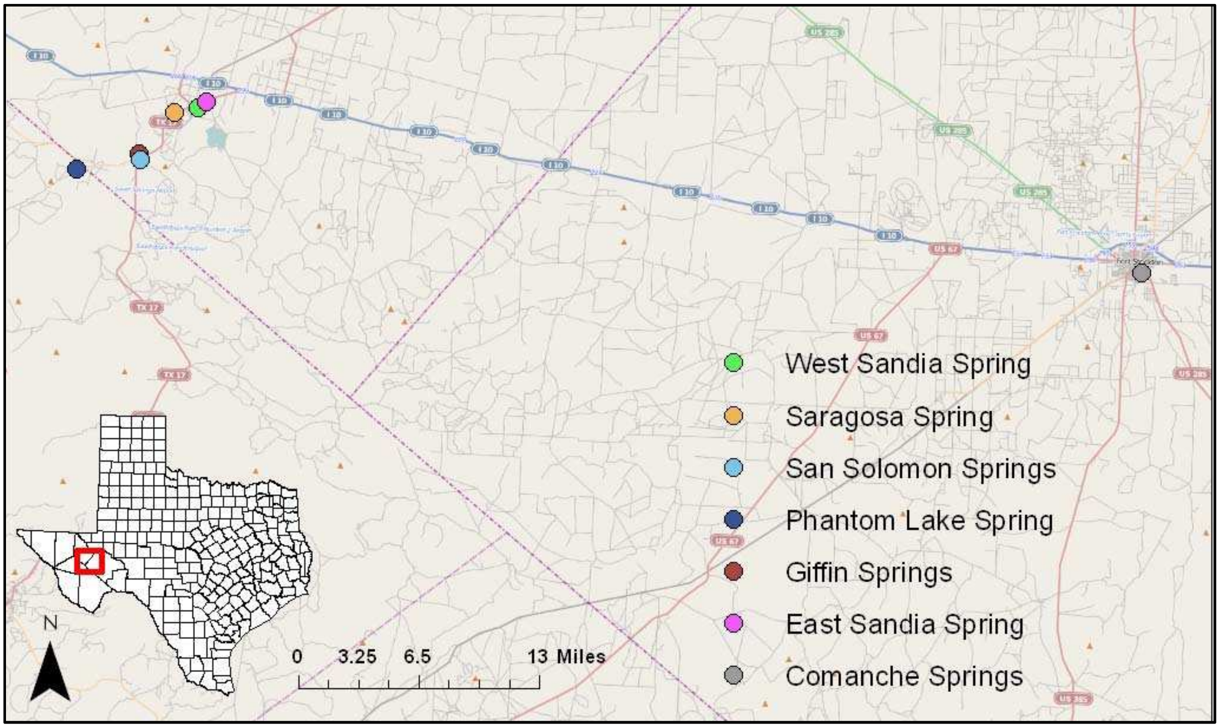

Figure 1: Historic Range of Comanche Springs pupfish.

Figure 2: Location of springs near Balmorhea, Texas. Confirmed Comanche Springs pupfish populations are currently only present at San Solomon Spring, Phantom Lake Spring, Giffin Spring, Toyah Creek, and the associated irrigation canal system.

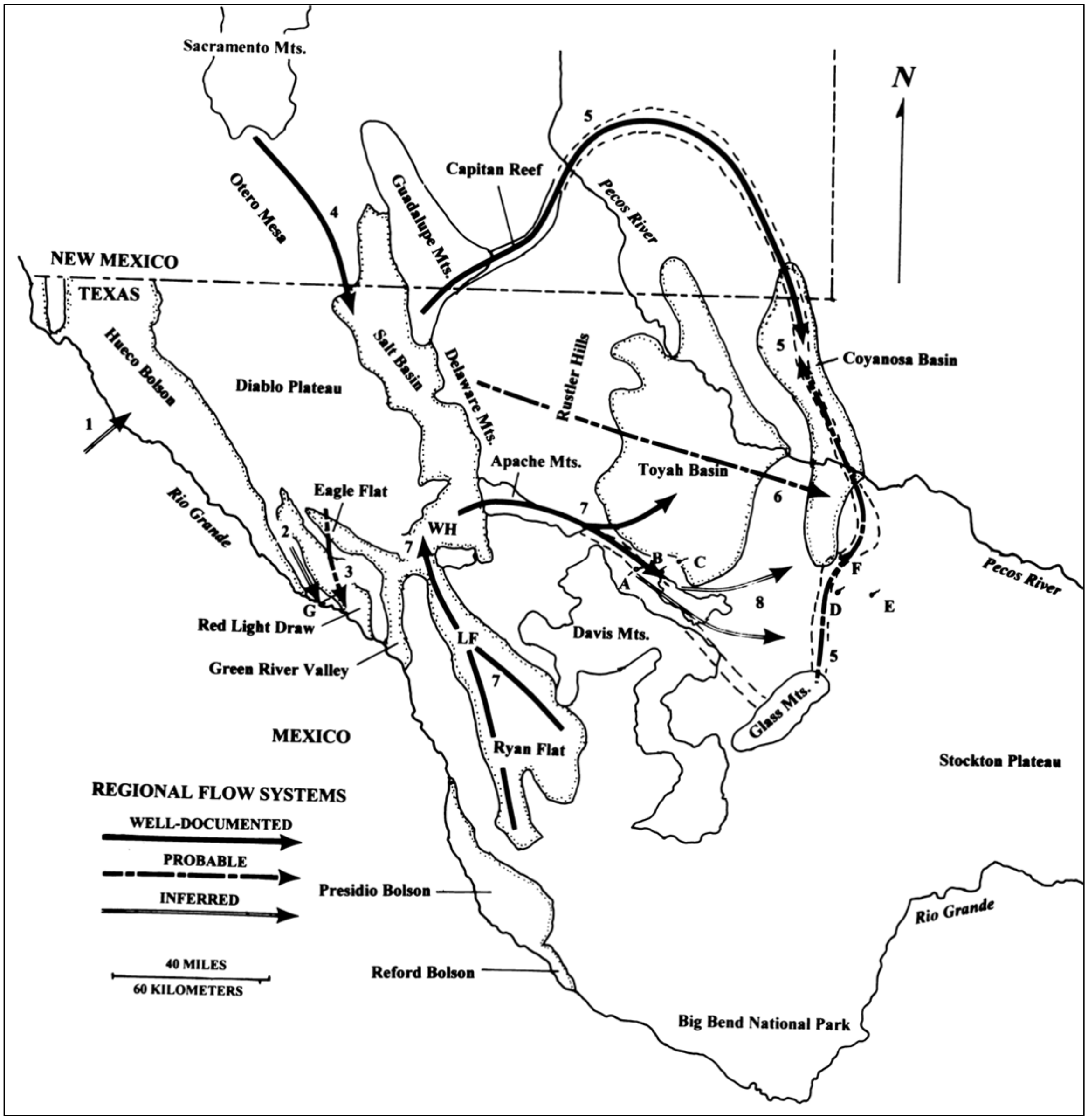

Figure 3: Regional flow systems of West Texas. WH and LF denote Wild Horse Flat and Lobo Flat, respectively, of the West Texas Bolsons. Springs are denoted by letters—A, Phantom Lake Spring; B, San Solomon and Giffin Springs; C, East and West Sandia Springs; D, Leon Springs; E, Comanche Springs; F, Diamond-Y Springs; and G, Indian Hot Springs. The regional flow systems are numbered—1 and 2, the inferred flow systems discharging at the Fabens artesian zone and Indian Hot Springs (G), respectively; 3, Eagle Flat–Red Light Draw flow system; 4, Sacramento Mountains-Dell City flow system; 5, flow systems in the Capitan Reef; 6, eastward flow in the Delaware Basin, perhaps discharging at Diamond-Y Springs (F); 7, the Salt Basin-Toyah Basin-Pecos River system that also feeds Balmorhea Springs (A, B, and C); and 8, speculative eastward extensions of this last flow system (from Sharp 2001, p. 42).

In addition, other studies (LaFave and Sharp 1987, p. 9; Schuster 1997, p. 97; Sharp et al. 1999, pp. 2-4; Bumgarner et al. 2012, p. 45) indicate that base flow comes from the underlying Edwards-Trinity regional groundwater system (Cretaceous limestone), while the springs also respond to runoff from the Davis Mountains that recharges the overlying, local alluvial aquifers, sometimes resulting in spring flow spikes following rainfall events. Similar water chemistry, water age, and near constant temperatures of about 79 ^{o}F (26 ^{o}C) among three of the area springs (Phantom Lake, San Solomon, and Giffin) indicate that their waters likely originate from the same source of Cretaceous limestone (Schuster 1997, pp. 43-44). East Sandia waters are likely a result of shallower, local groundwater sources (Schuster 1997, pp. 92-93). Significant recharge events in the Davis Mountains lower the total dissolved solids (TDS) content of these springs over a period of a few days, with a return to high TDS levels over a period of weeks to months. This pattern indicates rapid recharge to the Edwards-Trinity Aquifer along the eastern edge of the mountains accompanied by considerable storage in the lower permeable layers, which then discharge slowly into the Edwards-Trinity Aquifer (Hart 1992, pp. 76-94). Thus, the quantity and quality of pupfish habitat in the Balmorhea area varies with recharge events in the northeastern portion of the Davis Mountains.

Irrigation canal system: Comanche Springs pupfish habitat has been markedly altered into a 60 mi (97 km) long irrigation network of concrete-lined canals operated by the Reeves County Water Improvement District No. 1 (RCWID). The area has been highly modified repeatedly over the past century for the benefit of irrigation agriculture (Bogener 1993, pp. 2-3). The aquatic habitat in the canals is swiftly flowing, highly impacted, ephemeral, and very dependent upon local irrigation practices and other water-use patterns. For the most part, the irrigation canals provide little suitable habitat for Comanche Springs pupfish (USFWS 1981, p. 4). In addition, to repair or re-dredge canals, flows are sometimes diverted by the RCWID, causing mortalities of Comanche Springs pupfish (Davis 1979, p. 53). In 2004, the Natural Resources Conservation Service (NRCS) and RCWID consulted with the Service and received incidental take coverage for a 10-year period on canal maintenance activities, allowing “take” of up to 100 percent of the fishes inhabiting the irrigation canals (USFWS 2004, p. 27). The Service concluded that these activities would not jeopardize the continued existence of the Comanche Springs pupfish (USFWS 2004, p. 26). To minimize impacts to the pupfish, the incidental take permit requires NRCS to educate landowners on several potential protective measures, including preventing the movement of fish from upstream to downstream locations and reducing the extent and duration of dewatering canals for maintenance (USFWS 2004, pp. 27-28). The canals currently serve as connections between larger spring populations.

San Solomon Spring: San Solomon Spring, in Reeves County, is by far the largest spring in the Balmorhea area (Brune 1981, p. 384). It provides the water for the swimming pool at Balmorhea State Park and most of the irrigation water for the RCWID. Balmorhea State Park encompasses about 45.9 ac (18.6 ha) southwest of Balmorhea in Reeves County. The park is owned and managed by Texas Parks and Wildlife Department (TPWD). Park facilities were built by the Civilian Conservation Corps in the early 1930s and were opened as a state park in 1968. The entire spring head was converted into a concrete-lined swimming pool, destroying a natural ciénega (a desert spring-fed wetland) in the process (TPWD 2008, p. 4). The outflow from the pool is completely contained in concrete irrigation channels. A canal encircling the historic motel was built in 1974 to create habitat for the Comanche Springs pupfish and the endangered Pecos gambusia (*Gambusia nobilis*). Vegetation, substrate depth, water flow, and chemical contamination in the canal are controlled by Balmorhea State Park to optimize habitat for the pupfish (TPWD 1999, pp. 47-49). Pool and canal maintenance activities are covered under an incidental take permit (USFWS 2009b, entire).

In cooperation with local residents, farmers, and RCWID, the construction of a 2.5 acre (1 ha) ciénega was completed in 1996 (Garrett 2003, pp. 151-155). This wetland is situated within the boundaries of the original, natural ciénega on Balmorhea State Park land and was designed to resemble and function like the original ciénega. The RCWID and the local community it represents agreed to provide the essential water needed to create a secure environment for the two endangered fishes (Garrett 2003, p. 153). The main purpose of this restoration project was to recreate vital habitat, not only for the two endangered fishes, but for other aquatic, terrestrial, and wetland-adapted organisms as well (Garrett 2003, pp. 151-160). As a result, the native fish fauna, including Comanche Springs pupfish, has flourished. This location now contains the largest known concentration of Comanche Springs pupfish.

Additional pupfish habitat was created on the State Park in 2010. The concrete canal encircling the historic motel was deteriorating and causing problems with the foundation of the motel. In 2009 and 2010, TPWD constructed a second small ciénega habitat just north of the existing canal, with funding assistance from the Service and in consultation with the Service (USFWS 2009a, p. 2, Lockwood 2010, entire; Figure 4). By relocating the canal and providing a new ciénega, the aquatic habitat available for the native fishes and invertebrates at the park was enhanced and increased in size (USFWS 2009, p. 3, Lockwood 2010, p. 8).

Phantom Lake Spring: Once the largest spring in Jeff Davis County (Schuster 1997, p. 83), waters from Phantom Lake Spring issued from a cave and originally formed a ciénega that drained back into the cave. The first few meters inside the mouth of the cave and the surface spring system provide habitat for two endangered fishes (Comanche Springs pupfish and Pecos gambusia) and three endangered invertebrates [Phantom tryonia (*Tryonia cheatumi*), Phantom springsnail (*Pyrgulopsis texana*), and diminutive amphipod (*Gammarus hyalleloides*)].

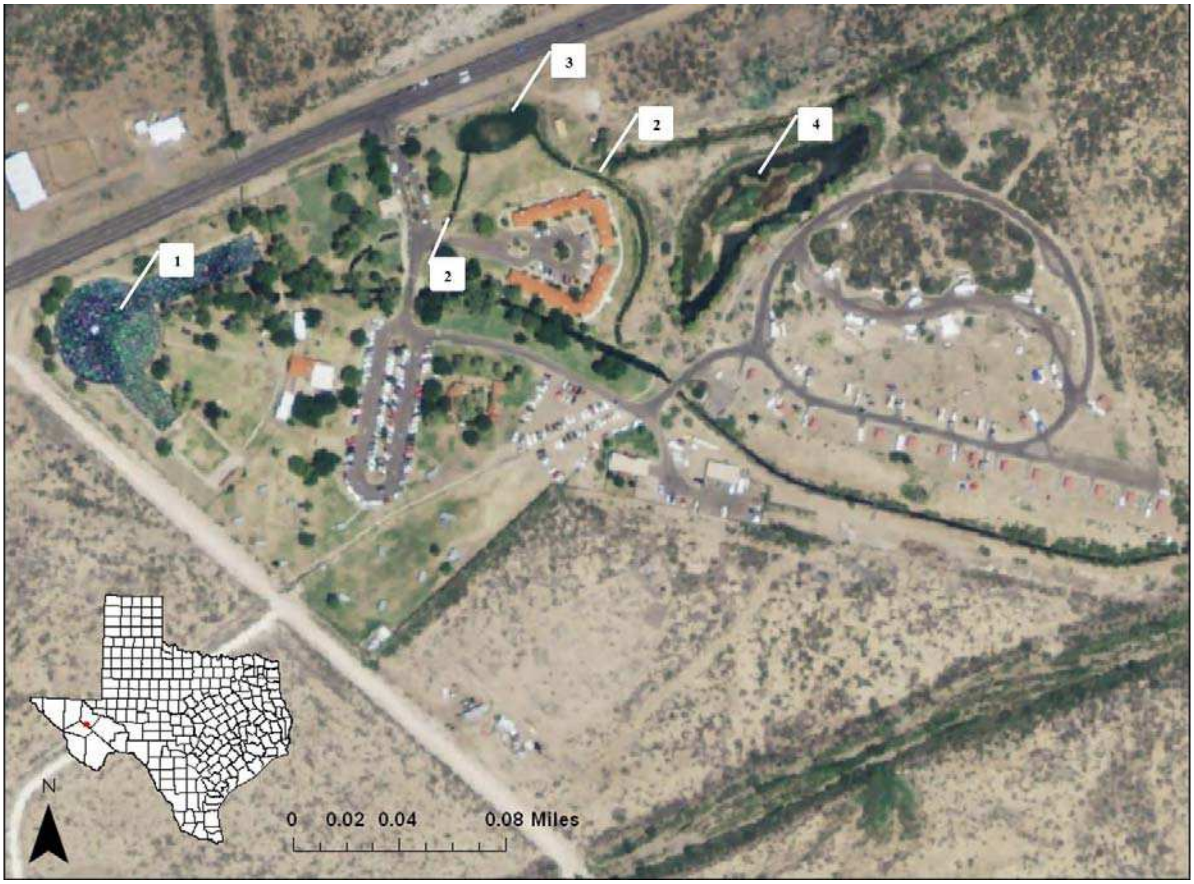

Figure 4: Overhead map of Balmorhea State Park showing the San Solomon spring origin and pool (1), relocated canal (2), new 2010 ciénega (3), and the 1996 ciénega (4) (Aerial photo taken in 2012).

In the 1940s, water was captured in a concrete irrigation canal as it emanated from the cave. Outflow from Phantom Lake Spring has been declining since U.S. Geological Survey has been making regular measurements in 1948 (Schuster 1997, pp. 80-84; USGS 2011a; Figure 5). With the combination of reduced outflow discharge and the habitat modifications to channelize the flows into agricultural ditches, quality habitat for the pupfish became extremely limited by 1990. Construction of a more natural, earthen canal in 1993 at Phantom Lake Spring (Figure 6) provided additional quality habitat in the form of multiple water depths, flow conditions, cover, and abundant food sources (USFWS 1992, p. 1). To supplement the wild population, 110 sub-adult pupfish from a captive population at Uvalde National Fish Hatchery were initially stocked into this canal (USFWS 2002, p. 2). Local abundance of pupfish increased to carrying capacity and eventually evened out at an estimated average density of 14.7 pupfish / m^2 (Winemiller and Anderson 1997, p. 210). Subsequent declines in springflow from Phantom Lake Spring resulted in the complete drying of the canal and downstream irrigation ditches by 1999 (Figure 7). This left only the small cave mouth area where Phantom Lake Spring previously discharged as remnant pupfish habitat, which has been maintained artificially with a pumping system since 2001 (USFWS 2000, p. 3). The pump system has failed several times, resulting in stagnant pools and near drying conditions (BOR 2011, p. 35). Occasional flooding supplied water to the irrigation ditches and canal.

In cooperation with the U.S. Bureau of Reclamation and the Texas Parks and Wildlife Department, the U.S. Fish and Wildlife Service recently secured the current cave pool, filled in the 1993 canal, and rebuilt a larger, more natural ciénega (USFWS 2012a, p. 4; BOR 2011, pp. 1-5). A more reliable pumping system was constructed, complete with a backup power supply, remote monitoring system (via satellite link communication), and alarm system to reduce response time to system failures. A more natural ciénega was created to the south of the current pool, adjacent to the cave wall (Figure 8), where it was lined and covered over with natural substrate (for example*,* gravel, boulders from the surrounding area). Invasive salt cedar (*Tamarisk* spp.) was removed mechanically and chemically to prevent impact to the area's hydrology and promote native vegetation. The old canal was filled in and bare areas were reseeded with native vegetation.

Giffin Spring: Giffin Spring is located less than 1.0 mi (1.6 km) west, across State Highway 17, from Balmorhea State Park. Access is limited because the spring is on private property. In recent decades, Giffin Spring has maintained a near constant 3 to 4 cfs (cubic feet per second) [0.08 to 0.11 cms (cubic meters per second)] outflow (Ashworth et al. 1997, p. 6). The outflow channel has been modified (dammed and channelized) to accommodate irrigation for downstream canals.

Saragosa Spring: Saragosa Spring is located about two miles northeast of Giffin Springs. This small spring went dry in the 1970s (Brune 1981, p. 386). It is believed to have supported Comanche Springs pupfish populations in the past (Echelle 1975, p. 530; USFWS 1981, p. 2), but we are not aware of any direct observations of the species at this location.

Toyah Creek: Toyah Creek is primarily fed by Giffin Spring and several smaller springs along the stream bed (Echelle 1975, p. 530). The Comanche Springs pupfish have rarely been found in Toyah Creek, although Echelle (1975, p. 530) counted as many as 128 pupfish on one visit. On six separate visits, Garrett and Price (1993, p. 3-4) encountered Comanche Springs pupfish twice and counted as many as eight individuals on a single visit. Echelle (1975, p. 536) attributes the low abundance to competition and predation by the more abundant green sunfish (*Lepomis cyanellus*). Water quality at Toyah Creek may be degraded, as Garrett and Price (1993, p. 1, 3) reported higher TDS and conductivity compared to other Balmorhea area habitat. Furthermore, Toyah Creek is an intermittent stream that only flows after large storm events (USFWS 2004, p. 16), making the pupfish habitat unreliable.

East Sandia Spring: East Sandia Spring is located about 2 mi (3.2 km) east of Balmorhea near the community of Brogado. The spring is included in a 240 ac (97 ha) preserve owned and managed by The Nature Conservancy (Karges 2003, pp. 145-146). A significant sacaton grassland (coarse grass) is associated with the habitat. The small outflow channel from East Sandia Spring flows into the RCWID irrigation system about 328 to 656 ft (100 to 200 m) after surfacing. Comanche Springs pupfish were historically found here (Karges 2003, p. 145), but they have not been documented since 1998 (Hubbs 1998, p. 1), possibly indicating that the habitat has become degraded in some way. Surveys conducted in 1999 indicated that one portion of the spring had severe bank degradation and possible water quality degradation due to cattle and sheep disturbance (McDermott 2000, p. 20). Invasive salt cedar management is a critical issue for this spring due to the tree's ability to deplete shallow groundwater reserves (Karges 2003, p. 145-146). In 2005, the Nature Conservancy began actively managing this invasive vegetation (Allan 2005, p. 1). In addition, sheepshead minnow became abundant in East Sandia Spring due to human activity sometime between 1979 and 1988 (Echelle and Echelle 1994, p. 596). This invasive species may have outcompeted or genetically swamped the Comanche Springs pupfish through hybridization at this location.

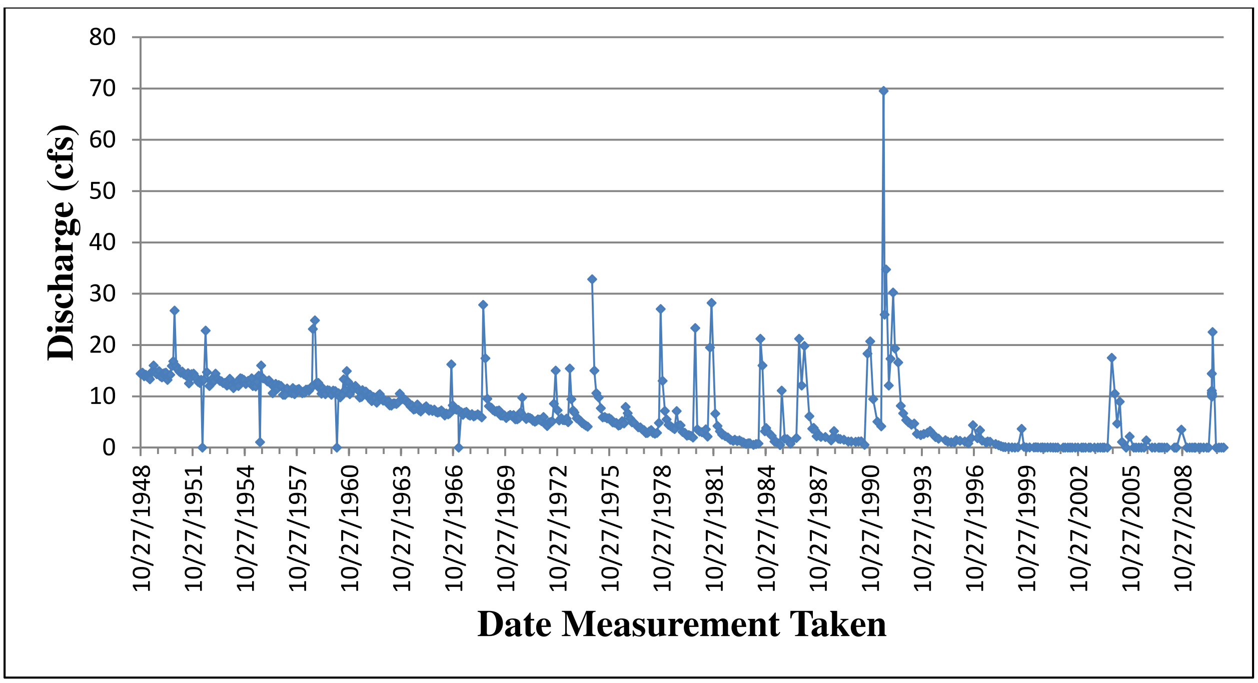

Figure 5: Phantom Lake Spring Discharge from 1948-2011 (USGS 2011a)

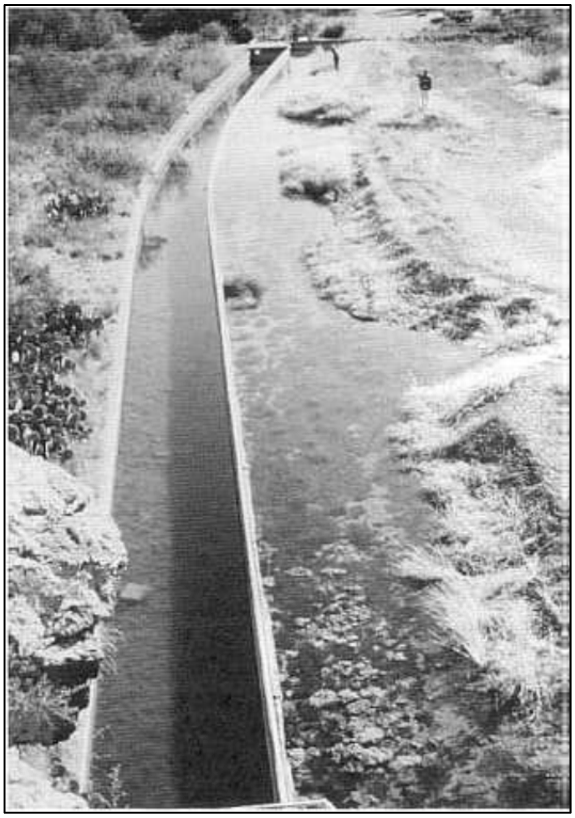

Figure 6: Looking downstream, Phantom Lake Spring irrigation canal (left) and adjacent restored canal habitat (right) in November 1993 (Winemiller and Anderson 1997, p. 205).

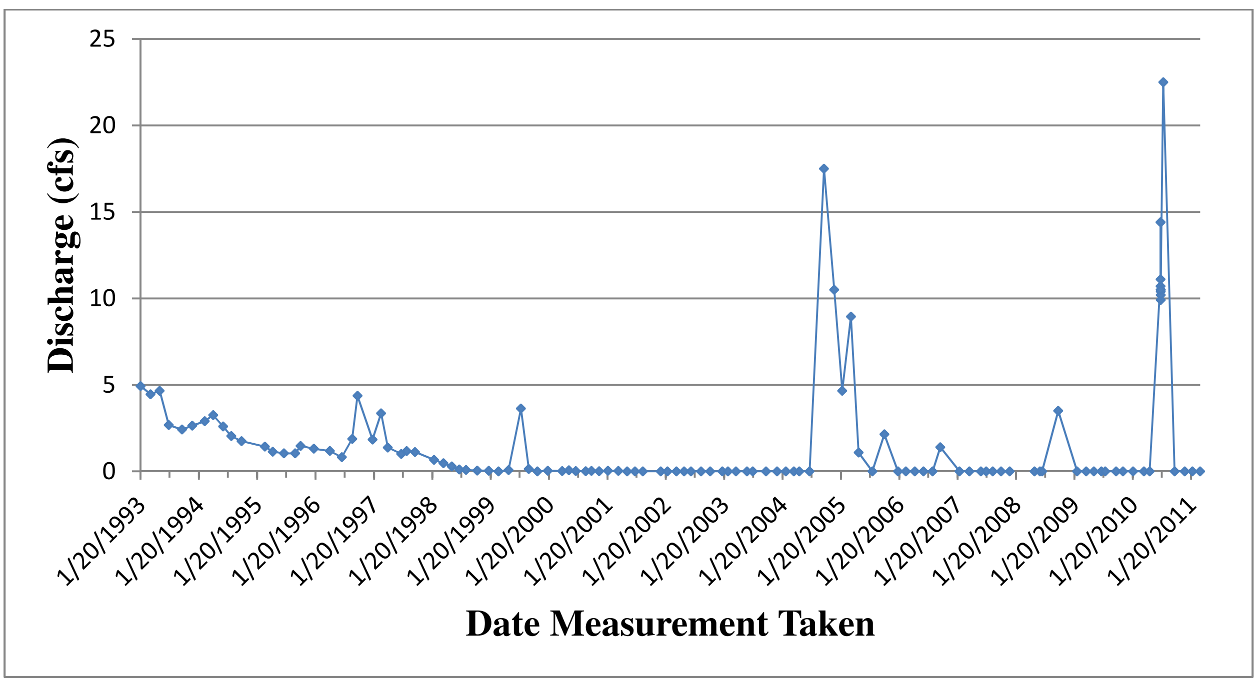

Figure 7: Phantom Lake Spring Discharge from 1993-2011 (USGS 2011a)

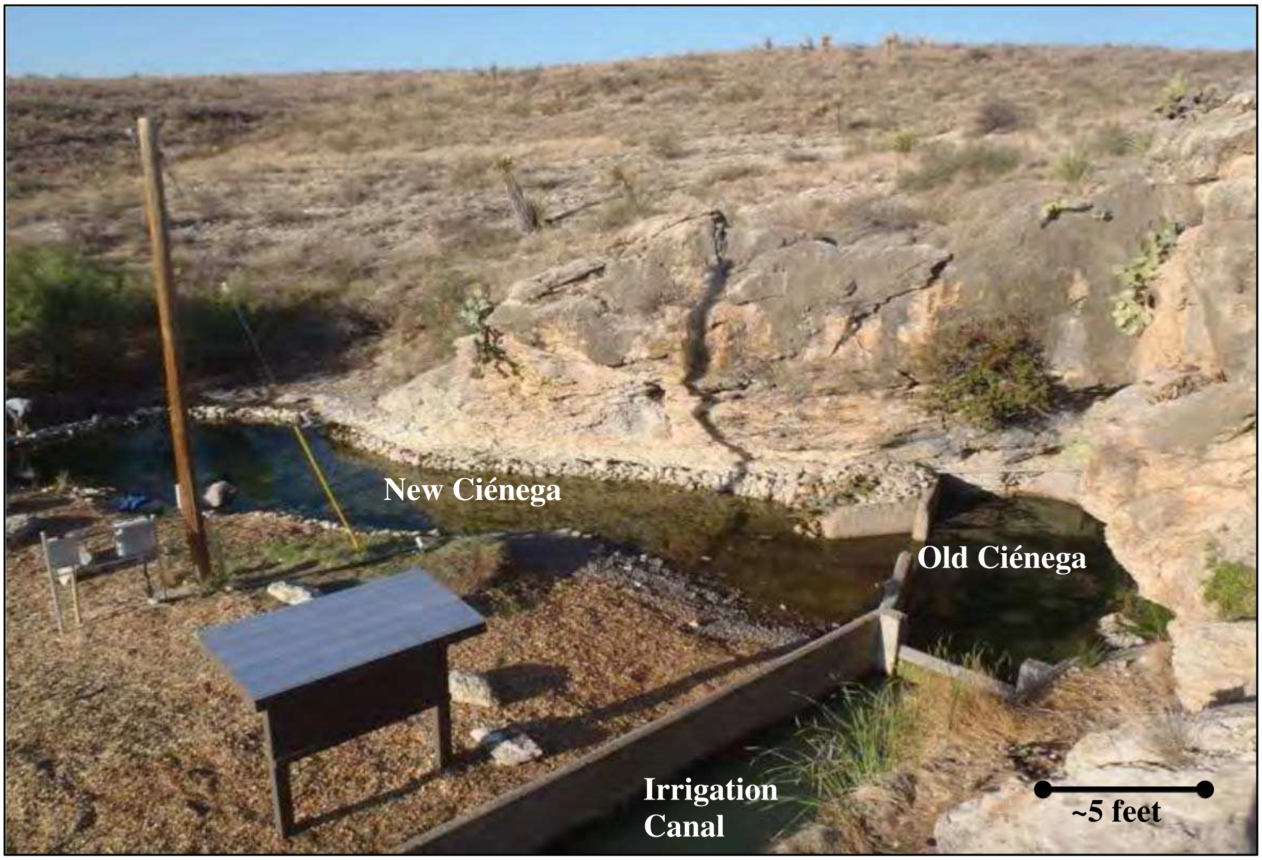

Figure 8: Completed restoration work at Phantom Lake Spring (photo taken in September 2011).

2.3.1.7 Other:

Captive Brood Stocks

The Service is maintaining captive stocks of Comanche Springs pupfish at the Southwestern Native Aquatic Resources and Recovery Center (SNARRC) (formerly Dexter National Fish Hatchery and Technology Center) in Dexter, New Mexico and the Uvalde National Fish Hatchery in Uvalde County, Texas. The Uvalde population originated from 73 individuals collected from the distinctive subpopulation at Phantom Lake Spring in 1990 (USFWS 2002, p. 2). This captive population was used to supplement the wild Phantom Lake Spring population in 1993 (USFWS 2002, p. 2). The captive stock was an estimated 3,000 to 5,000 individuals in 2011 (Karin Eldridge, Uvalde NFH, pers. comm., 2011), but a recent die-off in one pond reduced the population to 700 individuals (Robinson and Wilson 2012, p. 5). On March 13, 2013, 3,500 individual pupfish were transferred from SNARRC to Uvalde to supplement the declining population and to maintain genetic diversity (Grant Webber, Uvalde NFH, pers. comm., 2013; Manuel Ulibarri, SNARRC, pers. comm., 2013). As of July 2013, the population is estimated at 10,000 individuals (Grant Webber, Uvalde NFH, pers. comm., 2013).

The current SNARRC population came from 400 individuals taken from the Uvalde stock in 2003 following a genetic evaluation of the stock (Echelle et al. 2002, entire; Robinson and Wilson 2012, p. 4). The captive population at SNARRC is estimated at 7,500 individuals (Manuel Ulibarri, SNARRC, pers. comm., 2013). Both captive stocks receive annual inspections for pathogens. The fish at SNARRC are currently free of any pathogens of concern and there have not been any disease infections or parasite problems with this captive stock (Manuel Ulibarri, SNARRC, pers. comm., 2011; USFWS 2012b, p. 1). Both the Uvalde and SNARRC captive stocks were shown to have greater diversity than the wild Phantom Lake Spring population, indicating that the captive rearing capacity is adequate at preserving genetic diversity, including rare alleles (Robinson and Wilson 2012, p. 10).

2.3.2 Five-Factor Analysis (threats and conservation measures)

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

Habitat for Comanche Springs pupfish is entirely dependent on flows from springs in the Balmorhea area. In the extreme case, if the flow from a spring ceased, then all of the species' habitat downstream of that spring would be lost. Leon Springs, located about 40 mi (64 km) east of Balmorhea in Pecos County, was measured at 18 cfs (0.5 cms) in the 1930s and was also known to contain rare fish, but ceased flowing in the 1950s following significant irrigation pumping (Brune 1981, p. 359). This also occurred in Comanche Springs in Fort Stockton, the type locality of the Comanche Springs pupfish, in 1961 (Brune 1981, p. 358). Several other springs in the Toyah basin (Alamo Springs, Irving Springs, Buck Springs, Hoban Springs, Weinacht Springs, Santa Isabel Springs, Splittgarber Springs) went dry around the same time period (Brune 1981, pp. 383-386, Schuster 1997, p. 61). Springs in this area are clearly vulnerable to desiccation.

Waters from Phantom Lake Spring emerge at a higher elevation than other springs in the Balmorhea system, resulting in Phantom Lake Spring being the first to be impacted by declining groundwater levels (Brune 1981, p. 259). Since regular measurements began in 1948, discharge from Phantom Lake Spring declined until it reached 0 cfs (0 cms) in 1999 (Figure 1, 2). Today, there is no natural outflow from Phantom Lake Spring and spring flow is maintained artificially with pumps. Although long-term data are scarce, San Solomon Spring flows have declined somewhat over the history of record, but not as much as Phantom Lake Spring (Schuster 1997, p. 82, Sharp et al. 1999, p. 4-5, Figure 9). San Solomon Spring discharges are usually in the 25 to 30 cfs (0.7 to 0.8 cms) range (Schuster 1997, p. 82, Sharp et al. 1999, p. 5) and are consistent with the theory that the water bypassing under Phantom Lake are later discharged at the San Solomon Spring. Additionally, Brune (1981, pp. 384-385; 1975, pp. 61-62) reported declining discharges from Giffin, West Sandia, East Sandia, and Saragosa springs. In recent decades, Giffin Spring has maintained a near constant 3 to 4 cfs (0.08 to 0.11 cms) outflow (Ashworth et al. 1997, p. 6), while West Sandia Spring has ceased flowing over long periods of time (Schuster 1997, p. 93). East Sandia had measured discharges in 1995 and 1996 ranging from 0.45 to 4.07 cfs (0.01 to 0.12 cms) (Schuster 1997, p. 94). Saragosa Spring failed in the late 1970s (Brune 1981, p. 386) and currently provides no habitat for Comanche Springs pupfish (USFWS 2004, p. 16).

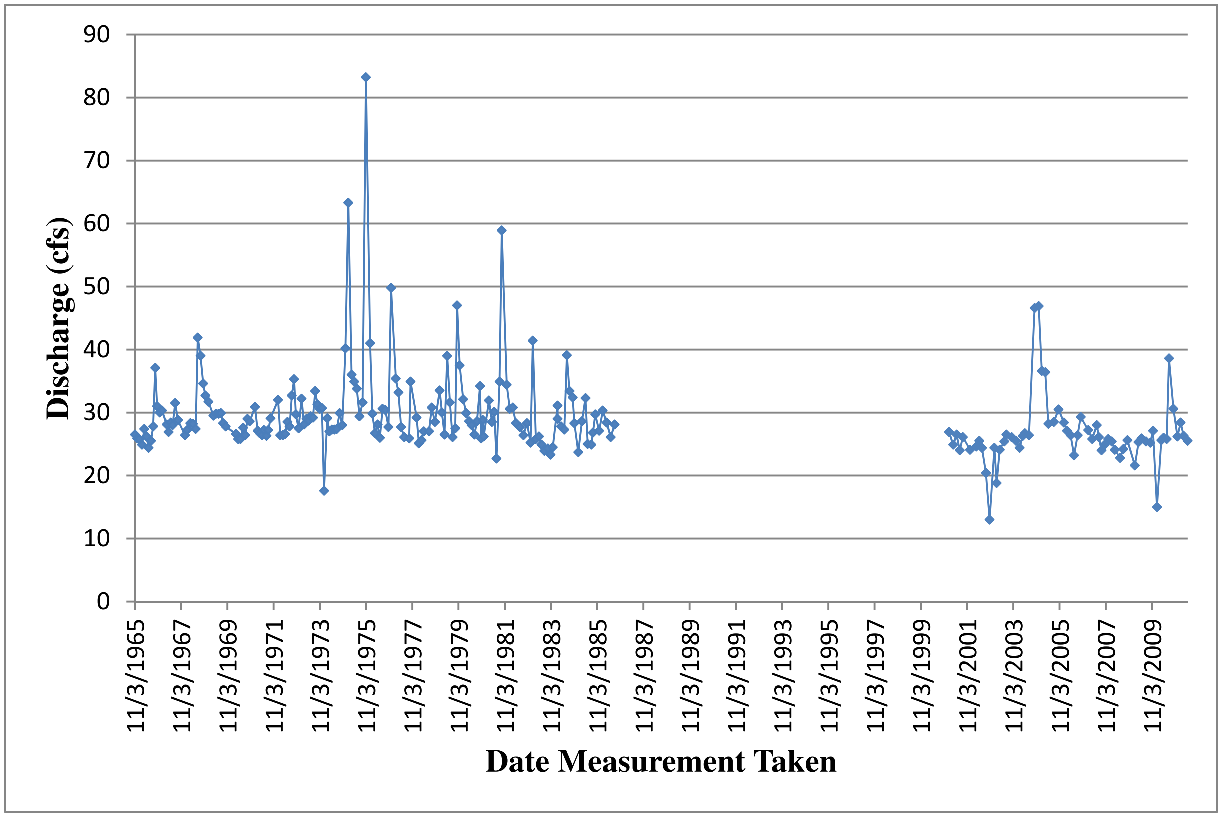

Figure 9: San Solomon Spring Discharge from 1965 to 2011 (USGS 2011b). Measurements were not taken from 1986 to 2001.

The exact cause or causes for this decline in spring flow are unclear. Some of the most likely reasons are groundwater pumping of the supporting aquifer and decreased recharge of the aquifer from drought. Ashworth et al. (1997, pp. 1-13) provided a brief study to examine the cause of declining spring flows in the Toyah Basin. This study suggested that recent declines in spring flows are more likely to be the result of diminished recharge due to the extended dry period rather than from groundwater pumping (Ashworth et al. 1997, p. 5). Although certainly a factor, drought is unlikely the only reason for the declines because the drought of record in the 1950s had no effect on the overall flow trend (Allan 2000, p. 51; Sharp 2001, p. 49). Sharp et al. (1999) further proposed that the decline in flows is most likely the result of groundwater pumping in this region.

An assessment of the springs near Balmorhea by Sharp (2001, p. 49) concluded: "The effects of humans on the Toyah Basin aquifer have been significant. Irrigation pumpage increased rapidly after 1945. Many springs in the area have since ceased to flow (Brune 1981, pp. 382-383). Irrigation pumpage from the Toyah Basin lowered water-table elevations and created a cone of depression (that is a lowering of the groundwater elevation around pumping areas). Thus, pumpage totals altered the regional-flow-system discharge zone from the Pecos River to irrigation wells within the Toyah Basin (Boghici 1997, pp. 100-108; Schuster 1997, pp. 16-19). Recent declines of pumpage for irrigation because of economic conditions have allowed partial recovery of water levels, but it seems doubtful that predevelopment conditions will be achieved."

The Texas Water Development Board (2005, pp. 1-120) provided a thorough review of the hydrogeology and the regional flow system for the springs that support the Comanche Springs pupfish. The complexity of the aquifer system and the limited availability of data result in a high level of uncertainty about the cause of spring flow declines. However, the report concluded that, "…if most of the base flow to the springs consists of ancient groundwater that accumulated long ago, any extraction of this water from the system anywhere along the flow path may adversely affect water levels" (Texas Water Development Board 2005, p. 108). Management and conservation of these aquifers is the key for ensuring the continued survival of rare species in the spring habitats (Bowles and Arsuffi 1993, p. 327).

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

Overutilization is not known to be a factor threatening the Comanche Springs pupfish. The only collections of the fish occur rarely 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:

An additional factor potentially affecting the Comanche Springs pupfish is the introduced *Melanoides tuberculatus* snail and its associated gill parasite (*Centrocestus formosanus*). This exotic trematode from Asia is known to infect the gills of fish in large numbers, causing inflammation and gill tissue destruction (Mitchell et al. 2005, pp. 12-15). Surveys conducted in 1999 found *M. tuberculatus* at Phantom Lake Spring and San Solomon Spring, but not East Sandia Spring (McDermott 2000, pp. 14-15). Thirty-six percent of the Comanche Springs pupfish collected at San Solomon Spring in May 1999 were infected with the gill parasite, while 89 percent of the pupfish at Phantom Lake Spring were infected (McDermott 2000, p. 39). By October of the same year, the proportion of infected pupfish at Phantom had decreased to 28 percent

(McDermott 2000, p. 39). The number of cysts on the gills caused by the parasite ranged from 0 to 47 in both populations and gill health appeared good (that is, not bloody or swollen), indicating that the parasite loads were not negatively affecting respiration (McDermott 2000, pp. 26, 39). Parasite load was negatively related to survivorship of Comanche Springs pupfish in lab experiments, but there was large variability among individuals in their reactions to the parasite (McDermott 2000, pp. 21, 48).

Melanoides tuberculatus also feeds on fish eggs (Phillips et al. 2010, p. 116), but it is unknown if they are impacting Comanche Springs pupfish egg production.

2.3.2.4 Inadequacy of existing regulatory mechanisms:

<u>State Listing</u>
The State of Texas lists the Comanche Springs pupfish as endangered under Title 31 Part 2 of Texas Administrative Code. TPWD regulations prohibit the taking, possession, transportation, or sale of any animal species designated by State law as endangered or threatened without the issuance of a permit. There is no protection by State law for habitat or minimum spring flows for State-listed species, therefore, only minimal protections are afforded the Comanche Springs pupfish by the State of Texas and these protections do not address threats to the species.

<u>Groundwater management</u>
In Texas, groundwater is generally managed through local groundwater conservation districts, which have the authority to regulate the spacing of water wells and the production from water wells. Although the range of Comanche Springs pupfish spans over Jeff Davis and Reeves Counties, the occupied spring flow falls under the management of only one groundwater conservation district: the Jeff Davis County Underground Water Conservation District. Reeves County, the location of San Solomon Spring, Giffin Spring, East Sandia Spring, and Toyah Creek, does not currently have a groundwater district.

There are currently four local groundwater districts in the area west of the springs (see Figure 10; Texas Water Development Board 2011, p. 1) that could possibly manage groundwater to protect spring flows in the Balmorhea spring system. The Culberson County Groundwater Conservation District covers the southwestern portion of Culberson County and was confirmed (established by the Texas legislature and approved by local voters) in 1998. The Jeff Davis County Underground Water Conservation District covers all of Jeff Davis County and was confirmed in 1993. The Presidio County Underground Water Conservation District covers all of Presidio County and was confirmed in 1999. The Hudspeth County Underground Water District No. 1 covers the northwest portion of Hudspeth County and was confirmed in 1957. This area of Hudspeth County manages the Bone Spring-Victoria Peak aquifer (Hudspeth County Underground Water District No. 1 2007, p. 1), which is not known to contribute water to the regional flow that supplies the San Solomon Spring system (Ashworth 2001, pp. 143–144). Therefore, we will not further consider that groundwater district.

In 2010, the Groundwater Management Area 4 established "desired future conditions" for the aquifers occurring within a five-county area of west Texas (Adams 2010, entire; TWDB 2012a, entire). These projected conditions are important because they guide the plans for use of groundwater within groundwater conservation districts to attain the desired future condition of each aquifer they manage (TWDB 2012b, p. 23). In the following discussion we review the plans and desired future conditions for the groundwater conservation districts in Culberson, Jeff Davis, and Presidio Counties relative to the potential regulation of groundwater for maintaining spring flows and abating future declines in the San Solomon Spring system.

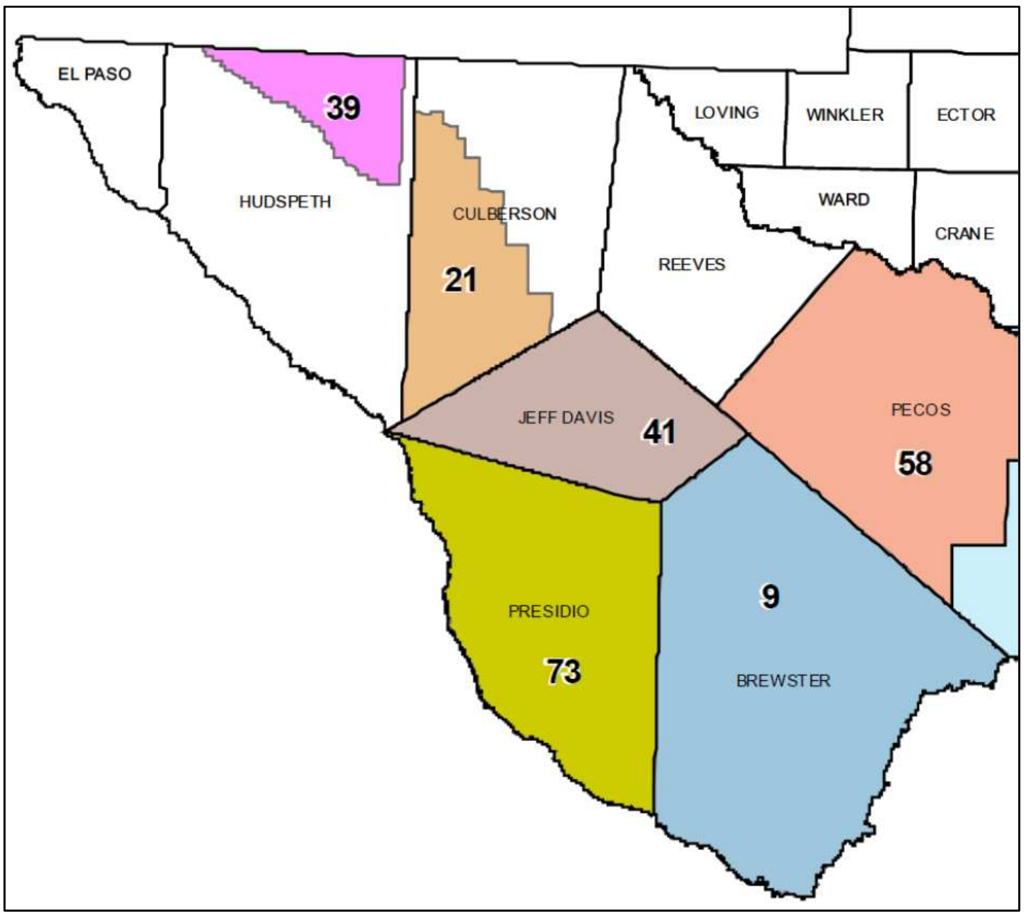

Figure 10: Confirmed Groundwater Conservation Districts in West Texas. 39 - Hudspeth County Groundwater Conservation District, 21 - Culberson County Groundwater Conservation District, 41 – Jeff Davis County Groundwater Conservation District, 73 - Presidio County Groundwater Conservation District, Pecos County Groundwater Conservation District, and 9 - Brewster County Groundwater Conservation District.

The Culberson County Groundwater Conservation District seeks to implement water management strategies to "prevent the extreme decline of water levels for the benefit of all water right owners, the economy, our citizens, and the environment of the territory inside the district" (Culberson County Groundwater Conservation District 2007, p. 1). The missions of Jeff Davis County Underground Water District and Presidio County Underground Water Conservation District are to "strive to develop, promote, and implement water conservation and management strategies to protect water resources for the benefit of the citizens, economy, and environment of the District" (Jeff Davis County Underground Water Conservation District 2008, p. 1; Presidio County Underground Water Conservation District 2009, p. 1). However, all three management plans specifically exclude addressing natural resources issues as a goal because, "The District has no documented occurrences of endangered or threatened species dependent upon groundwater resources" (Culberson County Groundwater Conservation District 2007, p. 10; Jeff Davis County Underground Water Conservation District 2008, p. 19; Presidio County Underground Water Conservation District 2009, p. 14). This lack of acknowledgement of the relationship of the groundwater resources under the Districts' management to the conservation of the spring flow habitat at the Balmorhea area spring system prevents any direct benefits of their management plans for the Comanche Springs pupfish.

We also considered the desired future condition of the regional aquifers that support Balmorhea area spring system flows. The Culberson County Groundwater Conservation District manages the groundwater where the bulk of groundwater pumping occurs in the Salt Basin Bolson aquifer (northern part of the West Texas Bolson and the source of the water for the San Solomon Spring system) (Oliver 2010, p. 7). The desired future condition for aquifers within the Culberson County Groundwater Conservation District area includes a 24-m (78-ft) drawdown for the Salt Basin Bolson aquifer to accommodate an average annual groundwater pumping of 46 million cm (cubic meters) [38,000 af (acre-feet)] (Adams 2010, p. 2; Oliver 2010, p. 7). The desired future condition for the West Texas Bolsons for Jeff Davis County Underground Water Conservation District includes a 72-ft (22-m) drawdown over the next 50 years to accommodate an average annual groundwater pumping of 10 million cm (8,075 af) (Adams 2010, p. 2; Oliver 2010, p. 7). The desired future condition for the West Texas Bolsons for Presidio County Underground Water District also includes a 72-ft (22-m) drawdown over the next 50 years to accommodate an average annual groundwater pumping of 12 million cm (9,793 af) (Adams 2010, p. 2; Oliver 2010, p. 7). These drawdowns are based on analysis using groundwater availability models developed for TWDB (Beach et al. 2004, pp. 10-6–10-8; Oliver 2010, entire). We expect that these groundwater districts will use their district rules to regulate water withdrawals in such a way as to implement these desired future conditions.

We are not aware of any information or studies that have assessed the impacts on spring flows associated with the drawdowns from the desired future conditions. However, the drawdown levels could be substantial compared to the available groundwater, which receives little natural recharge beyond regional flow. So although it is impossible to determine precisely, we anticipate the planned level of groundwater drawdown will likely result in continued future declines in flow rates of springs occupied by the Comanche Springs pupfish. Therefore, we expect that continued drawdown of the aquifers as identified in the desired future conditions will contribute to ongoing and future spring flow declines.

2.3.2.5 Other natural or manmade factors affecting its continued existence:

Hybridization

Whole populations of fish species can be quickly lost due to hybridization with an introduced, non-native, related species [for examples, see Pecos pupfish in the Pecos River (Echelle and Connor 1989, pp. 725-726) and Leon Springs pupfish in Diamond Y Spring (Echelle and Echelle 1997, pp. 159-160)]. Comanche Springs pupfish exhibits little premating reproductive isolation when artificially brought into contact with introduced pupfishes (Stevenson and Buchanan 1973, p. 683). Nearby sources of non-native pupfish that could potentially hybridize with Comanche Springs pupfish include Leon Springs pupfish (*C. bovinus)* and Pecos River pupfish (*C. pecosensis*). However, the biggest threat to the Comanche Springs pupfish is the locally abundant sheepshead minnow (*C. variegatus*).

Sheepshead minnow is a pupfish species native to the Gulf of Mexico, Caribbean, and Atlantic coast of North America. It was introduced to Lake Balmorhea in the 1960s and has been found to hybridize with Comanche Springs pupfish at the intersection of the lake and irrigation canals (Stevenson and Buchanan 1973, p. 683, 688). Twenty years later, a protein electrophoretic survey indicated only meager evidence of introgression (gene flow from one species to another) in the lake population of sheepshead minnow outside the area of contact between the two species (Echelle and Echelle 1994, p. 595). There was no evidence of genetic contamination of Comanche springs pupfish outside the lake, probably because of a barrier to upstream dispersal--a 1.6 ft (0.5 m) vertical drop at the terminus of the concrete canal.

One study found a high level of postzygotic reproductive isolation between Comanche Springs pupfish and the exotic sheepshead minnow (Tech 2006, p. 1836), which appears to limit genetic introgression (Echelle and Echelle 1994, p. 595). However, the same study found greater fitness losses in Comanche Springs pupfish backcrosses. In other words, when hybrids of Comanche Springs pupfish and sheepshead minnows reproduce with Comanche Springs pupfish, the fitness of those offspring is low compared to the offspring of hybrids that breed with sheepshead minnows. This finding suggests that Comanche Springs pupfish may be vulnerable to extinction through hybridization. Sheepshead minnow is abundant in East Sandia Spring and Lake Balmorhea (Echelle and Echelle 1994, p. 596) and has the potential to spread into the nearby San Solomon and Phantom

Lake Spring. Previous attempts at removing sheepshead minnow from an ecosystem have failed (Garrett 2003, p. 155), highlighting the need to protect other Comanche Springs pupfish habitat from introduction. More study is needed on the patterns of introgression within the area of contact between the two species to fully evaluate the impact of sheepshead minnow on the genetic purity of Comanche Springs pupfish (Tech 2006, p. 1836). There is also a lack of knowledge on the specific ecological interactions (that is, competition) between these two species.

Climate change

Our analyses under the Endangered Species Act include consideration of ongoing and projected changes in climate. The terms "climate" and "climate change" are defined by the Intergovernmental Panel on Climate Change (IPCC). The term "climate" refers to the mean and variability of different types of weather conditions over time, with 30 years being a typical period for such measurements, although shorter or longer periods also may be used (IPCC 2007a, p. 78). The term "climate change" thus refers to a change in the mean or variability of one or more measures of climate (for example, temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (IPCC 2007a, p. 78).

According to the IPCC (2007b, p. 1), "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level." Average Northern Hemisphere temperatures during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in at least the past 1,300 years (IPCC 2007b, p. 1). It is very likely that over the past 50 years cold days, cold nights, and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent (IPCC 2007b, p. 1). It is likely that heat waves have become more frequent over most land areas, and the frequency of heavy precipitation events has increased over most areas (IPCC 2007b, p. 1).

The IPCC (2007b, p. 6) predicts that changes in the global climate system during the 21st century are very likely to be larger than those observed during the 20th century. For the next two decades a warming of about 0.2°C (0.4°F) per decade is projected (IPCC 2007b, p. 6). Afterwards, temperature projections increasingly depend on specific emission scenarios (IPCC 2007b, p. 6). Various emissions scenarios suggest that by the end of the 21st century, average global temperatures are expected to increase 0.6°C to 4.0°C (1.1°F to 7.2°F) with the greatest warming expected over land (IPCC 2007b, pp. 6-8).

Global climate projections are informative, and, in some cases, the only or the best scientific information available for us to use. However, projected changes in climate and related impacts can vary substantially across and within different regions of the world (for example, IPCC 2007b, p. 9). Therefore, we use "downscaled" projections when they are available and have been developed through appropriate scientific procedures, because such projections provide higher resolution information that is more relevant to spatial scales used for analyses of a given species (see Glick et al. 2011, pp. 58–61, for a discussion of downscaling). With regard to our analysis for the Comanche Springs pupfish, downscaled projections are available.

Localized projections suggest the southwest may experience the greatest temperature increase of any area in the lower 48 States (IPCC 2007b, p. 8). Temperature in Texas is expected to increase by up to 4.8°C (8.6°F) by the end of 2100 (Jiang and Yang 2012, p. 235). The IPCC also predicts that hot extremes and heat waves will increase in frequency and that many semi-arid areas like the western United States will suffer a decrease in water resources due to climate change (IPCC 2007b, p. 8). Model projections of future climate in southwestern North America show a transition to a more arid climate that began in the late 20th and early 21st centuries (Seager et al. 2007, p. 1183). Based on downscaling global models of climate change, Texas is expected to receive up to 20 percent less precipitation in winters and up to 10 percent more precipitation in summers (Jiang and Yang 2012, p. 238). However, most regions in Texas are predicted to become drier as temperatures increase (Jiang and Yang 2012, pp. 240-242).

An increased risk of drought in Texas could occur if evaporation exceeds precipitation levels in a particular region due to increased greenhouse gases in the atmosphere (CH2M HILL 2007, p. 18). A reduction of recharge to aquifers and a greater likelihood for more extreme droughts, such as the droughts of 2008 to 2009 and 2011, were identified as potential climate change-related impacts to water resources (CH2M HILL 2007, p. 23). Extreme droughts in Texas are now much more probable than they were 40 to 50 years ago (Rupp et al. 2012, pp. 1053–1054).

Expected future warming from climate change could decrease overall availability of water recharging to aquifers in western Texas. If this were to occur, then, in addition to declines that have already occurred at Phantom Lake Spring, flows at other springs supporting Comanche Springs pupfish populations could decline. These declines would be directly due to decreases in recharge from declining precipitation, because the aquifer is dependent on rainfall precipitation for recharge (Anaya and Jones 2009, p. 47). Mace and Wade (2008, p. 659) also expected the Edwards-Trinity Aquifer to be susceptible directly to climate change because the karstic nature (porous rocks) of the aquifers provides quick recharge from precipitation events. In other words, rainfall entering the Edwards-Trinity Aquifer spends little time in storage underground, providing spring flows with very little supply buffer during extended periods of drought.

Although local precipitation models vary substantially, with some even predicting increased annual precipitation, a consensus is emerging that evaporation rates in central and western Texas are likely to increase significantly (Jackson 2008, p. 21). As a result of more precipitation occurring in the wet seasons, more extended dry periods, and overall higher evaporation rates from increased temperatures and dry winds, many models are predicting that seasonal variability in flow rates is likely to increase (Jackson 2008, p. 19; Mace and Wade 2008, p. 656).

Indirectly, any declines in precipitation or increases in evaporation rates from climate change could result in increases in groundwater pumpage. Climate has a significant effect on the amount of groundwater pumpage from the Edwards-Trinity Aquifer because of increased irrigation pumpage during drought times (Anaya and Jones 2009, p. 48). Mace and Wade (2008, p. 664) also concluded that increasing pumping rates may be one of the indirect effects of climate change on aquifers in Texas.

Other direct effects of climate change on the physical and biological environment of the Comanche Springs pupfish are possible, but difficult to predict as no formal vulnerability assessment has been completed. The Comanche Springs pupfish may be sensitive to the effects of climate change because its habitat is closely dependent on stable flows. The spring habitat of the fish is dependent on groundwater levels that are directly influenced by precipitation patterns which could be altered as a result of climate change. Water temperature probably is a less important aspect of Comanche Springs pupfish habitat due to its broad temperature tolerance and high critical thermal maximum, but it is unknown what role water temperature plays in reproductive success.

Other indirect climate change effects to water quality, non-native species, disease susceptibility, or other factors are possible. Warmer water and poor water quality (that is, low dissolved oxygen) tend to increase breathing rates in fish, making them more vulnerable to gill parasite infection (McDermott 2000, p. 19). In addition, *Melanoides tuberculatus* (the invasive snail species that harbors the gill parasite) is more tolerant of warmer temperatures compared to native snail species (Weir and Salice 2012, p. 390).

While it appears reasonable to assume that Comanche Springs pupfish may be affected by climate change, we lack sufficient certainty to know specifically how climate change will affect the species.

<u>Small Population Size and Stochastic Events</u>

The genetically isolated Phantom Lake Spring population of Comanche Springs pupfish may be susceptible to threats associated with small population size and impacts from stochastic events. The risk of extinction for any species is known to be highly indirectly correlated with population size (O'Grady et al. 2004, pp. 516, 518; Pimm et al. 1988, pp. 774-775). In other words, the smaller the population the greater the overall risk of extinction. There were less than 100 estimated Comanche Springs pupfish at Phantom Lake Spring in September 2010 (Lewis et al. unpublished data, p. 5). Stochastic events from either environmental factors (random events such as severe weather) or demographic factors (random causes of births and deaths of individuals) are also heightened threats to the Comanche Springs pupfish because of the small population size (Melbourne and Hastings 2008, p. 100).

2.4 Synthesis

The best available scientific information indicates that the primary threats to the Comanche Springs pupfish are: 1) habitat loss from the loss of spring flow due to a decline in groundwater levels, and 2) hybridization or competition with sheepshead minnow due to further introductions into Comanche Springs pupfish populations.

The information reviewed indicates that impacts to spring flows from significant increase in groundwater use or declines in recharge are likely to occur in the upcoming decades. Many springs in the area with similar groundwater sources have failed in the past 50 years, and most of the remaining springs have shown declining trends in outflow. One spring habitat with genetically unique pupfish (Phantom Lake Spring) has gone dry since the 1981 Recovery Plan and is currently being maintained artificially with pumping. The magnitude of impact on Comanche Springs pupfish from the loss of spring flow is extremely high. Because the range of the species is limited to a few small locations, habitat modification due to a decline in spring flows could result in additional local extirpations and eventual extinction. Although there have been recent conservation efforts at Phantom Lake Spring and San Solomon Spring that have improved Comanche Springs pupfish habitat, these efforts would be all for naught if spring flow continued to decline. In addition, the established captive brood stocks at Uvalde and SNARRC are not beneficial if there is no spring habitat in which to re-establish the populations.

The threats associated with hybridization and competition are due to the presence of sheepshead minnow in East Sandia Spring, Lake Balmorhea, and the hybridization zone at the mouth of the canal system. Genetic introgression appears to be limited to Lake Balmorhea thus far. However, if this species were introduced into the San Solomon or Phantom Lake ciénegas, the Comanche Springs pupfish populations there could be lost, similar to the outcome of Pecos pupfish and Leon Springs pupfish populations when they encountered sheepshead minnow introductions. Removal of sheepshead minnow is very difficult. Therefore, the magnitude of the impact of this threat on the species is considered high.

Secondary threats include habitat modification from water quality degradation, local habitat changes, lack of regulatory mechanisms, and increased susceptibility to the gill parasite. None of these concerns acting alone in otherwise robust populations are likely to result in substantial threats to the species, but together or in small populations, any of these could negatively impact the Comanche Springs pupfish.

All of these threats, both primary and secondary, have either stayed constant or increased since the listing of the Comanche Springs pupfish and development of its recovery plan in 1981.

Some of the threats (specifically, increased susceptibility to the gill parasite and climate change) are novel threats that have emerged since the recovery plan. Although the creation of additional habitat has increased the abundance of pupfish in some populations, the species as a whole remains vulnerable. Besides East Sandia Spring, no other waters in the natural range of the species may be suitable for relocation or establishment. Survival of the species depends entirely on its success in the Balmorhea area, an area which is under threats of decreasing spring flows and sheepshead minnow invasion. Therefore, we recommend that the Comanche Springs pupfish remain classified as endangered.

3.0 RESULTS

3.1 Recommended Classification

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

3.2 New Recovery Priority Number

This species is re-assigned a Recovery Priority Number of 11.

Brief Rationale: The degree of threat is moderate, meaning the Comanche Springs pupfish will not face extinction in the immediate future if recovery is temporarily held off, due to the relatively stable and protected population at San Solomon Spring. Although other populations of the pupfish are vulnerable to extirpation, the San Solomon population is not in immediate danger of extirpation due to the robust population size, habitat monitoring by TPWD, and large spring flows that have only declined slightly in the past 40 years. The recovery potential is considered low due to threats, particularly declining spring flow and hybridization with sheepshead minnow, that are pervasive and difficult to alleviate. The taxonomy of the Comanche Springs pupfish is a species.

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

The following recommendations are based on the Comanche Springs pupfish recovery plan (USFWS 1981, pp. 11-15) and subsequent discussions with the Rio Grande Fishes Recovery Team and other experts.

4.1 Monitor populations.

The reproductive biology of Comanche Springs pupfish, along with its relatively short life span, combine to cause relatively large fluctuations in population numbers. For this reason, it is important to monitor the populations frequently. Monitoring should be done in several areas representative of the variety of habitats typically occupied by the species. Dates of sampling should be representative of periods of maximum and minimum temperatures and water usage for irrigation. Monitoring should also cover areas that are lacking in recent abundance estimates (for example, Giffin Spring, Toyah Creek, East Sandia Spring) and have had recent habitat restoration (Phantom Lake Spring and the newly created San Solomon Ciénega). Monitoring personnel should obtain appropriate permission from landowners and scientific permits from the Service and TPWD before monitoring begins. [Recovery Task 1.1 (USFWS 1981, p. 11)]

4.2 Monitor habitat.

Coincident with monitoring the populations, the monitoring personnel should record such things as rate of water flow and chemistry, abundance and type of aquatic vegetation, changes in shoreline vegetation, and any other indicators of change in habitat quality. Relative abundance of other fish species should also be noted. Monitoring personnel also should be charged with the responsibility of noting and compiling published water flow records (for example, USGS publications on the springs). Special attention should be made to monitor pump system integrity and function at Phantom Lake Spring. [Recovery Task 1.2 (USFWS 1981, p. 11)]

4.3 Enhance existing habitats.

The existing habitat should be improved when opportunities arise, only after evaluating the impacts on other endangered species in the area. This includes monitoring current restoration efforts at Phantom Lake Spring and East Sandia Spring, and focusing on improving habitat at Giffin Spring and Toyah Creek. Abundance estimates of Comanche Springs pupfish should be taken before and after restoration projects to evaluate success. [Recovery Task 1.4 (USFWS 1981, p. 12)]

4.4 Control sheepshead minnow throughout the Comanche Springs pupfish range.

Monitor canals for the presence of pupfish with characteristics of sheepshead minnows. Where feasible, eliminate sheepshead minnow. Modify canals to serve as fish barriers to help prevent upstream contamination of Comanche Springs pupfish.

4.5 Monitor genetic status of Comanche Springs pupfish populations.

Periodically verify genetic purity of existing Comanche Springs pupfish stocks and maintain purity at Balmorhea State Park (canal and San Solomon ciénegas) and Phantom Lake Spring. Population sizes should be maintained at levels sufficient to avoid loss of genetic diversity. [Recovery Task 2.0 (USFWS 1981, p. 15)]

4.6 Monitor for effects of the gill parasite.

Comanche Spring pupfish should be routinely inspected for presence of gill parasites in all populations. The host snail and parasites should be counted to determine trends in parasite load and host snail abundances through time. Any observations of adverse effects of the gill parasites on individual pupfish should be recorded.

4.7 Research sources of Balmorhea area spring flow.

Use hydrogeologic techniques to delineate recharge areas for the springs occupied by Comanche Springs pupfish. Determine groundwater flow rates and recharge rates of the aquifers that contribute to surface discharge.

4.8 If necessary, supplement captive breeding stock with additional genetic diversity.

Previous research indicates that Comanche Springs pupfish in springhead areas have lower genetic diversity than pupfish in downstream areas (Echelle et al. 1987, p. 680). The current captive breeding stocks of Comanche Springs pupfish originate from the isolated Phantom Lake Spring and may not include the genetic diversity found in downstream populations. Additional research should be conducted to investigate if the wild populations of pupfish at Giffin Spring, East Sandia, San Solomon Spring, and Toyah Creek contain unique alleles not present in the captive stocks. If these wild populations are demonstrated to have greater genetic diversity, this diversity should be preserved in captive breeding stocks in case these populations are lost.

4.9 Update the recovery plan.

The recovery plan should be updated to include objective and measurable criteria that take into consideration all of the threats to the species, including climate change. This is currently considered the lowest priority action because other conservation actions described in this 5-year review should be conducted first to accomplish tangible benefits for conservation of the species.

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U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW OF COMANCHE SPRINGS PUPFISH
(*Cyprinodon elegans*)

Current Classification: Endangered

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: N/A

Review Conducted By: Joshua Booker, Austin Ecological Services Field Office, Austin, Texas

FIELD OFFICE APPROVAL:

Lead Field Supervisor, Fish and Wildlife Service, Austin Ecological Services Field Office, Austin, Texas

Approve ________________ Date 8/14/13

REGIONAL OFFICE APPROVAL:

Acting, **Assistant Regional Director, Ecological Services, U.S. Fish and Wildlife Service, Region 2**

Approve Susan Jacobsen Date Aug 23, 2013